TWAP
TRANSBOUNDARY WATERS ASSESSMENT PROGRAMME

Transboundary River Basins

Status and Trends

VOLUME 3: RIVER BASINS

UNEP

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UNEP-DHI PARTNERSHIP
Centre on Water and Environment

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VOLUME 3 RIVER BASINS

Transboundary River Basins

Status and Trends

UNEP-DHI PARTNERSHIP
Centre on Water and Environment
UNEP DHI

DeltAlliance

Center for International Earth Science Information Network
EARTH INSTITUTE | COLUMBIA UNIVERSITY

GLOBAL IGBP CHANGE International Geosphere-Biosphere Programme

SIWI

CESR Center for Environmental Systems Research

CUNY The City University of New York

IUCN

FORMIN.FINLAND.FI
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OSU Oregon State University

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Dr. Pierre-Philippe Mathieu	European Space Agency (ESA), European Space Research Institute (ESRIN)	Data Portal and Website
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Administrative Boundaries

Source of administrative boundaries used throughout the assessment: The Global Administrative Unit Layers (GAUL) dataset, implemented by FAO within the CountrySTAT and Agricultural Market Information System (AMIS) projects.

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Preface

The Global Environment Facility (GEF) approved a Full Size Project (FSP), "A Transboundary Waters Assessment Programme: Aquifers, Lake/Reservoir Basins, River Basins, Large Marine Ecosystems, and Open Ocean to catalyze sound environmental management", in December 2012, following the completion of the Medium Size Project (MSP) "Development of the Methodology and Arrangements for the GEF Transboundary Waters Assessment Programme" in 2011. The TWAP FSP started in 2013, focusing on two major objectives: (1) to carry out the first global-scale assessment of transboundary water systems that will assist the GEF and other international organizations to improve the setting of priorities for funding; and (2) to formalise the partnership with key institutions to ensure that transboundary considerations are incorporated in regular assessment programmes to provide continuing insights on the status and trends of transboundary water systems.

The TWAP FSP was implemented by UNEP as Implementing Agency, UNEP's Division of Early Warning and Assessment (DEWA) as Executing Agency, and the following lead agencies for each of the water system categories: the International Hydrological Programme (IHP) of the United Nations Educational, Scientific and Cultural Organization (UNESCO) for transboundary aquifers including groundwater systems in small island developing states (SIDS); the International Lake Environment Committee Foundation (ILEC) for lake and reservoir basins; the UNEP-DHI Partnership – Centre on Water and Environment (UNEP-DHI) for river basins; and the Intergovernmental Oceanographic Commission (IOC) of UNESCO for large marine ecosystems (LMEs) and the open ocean.

The five water-category specific assessments cover 199 transboundary aquifers and groundwater systems in 43 small island developing states, 206 transboundary lakes and reservoirs, 286 transboundary river basins; 66 large marine ecosystems; and the open ocean, a total of 758 international water systems. The assessment results are organized into five technical reports and a sixth volume that provides a cross-category analysis of status and trends:

- Volume 1 – ***Transboundary Aquifers and Groundwater Systems of Small Island Developing States: Status and Trends***
- Volume 2 – ***Transboundary Lakes and Reservoirs: Status and Trends***
- Volume 3 – ***Transboundary River Basins: Status and Trends***
- Volume 4 – ***Large Marine Ecosystems: Status and Trends***
- Volume 5 – ***The Open Ocean: Status and Trends***
- Volume 6 – ***Transboundary Water Systems: Crosscutting Status and Trends***

A ***Summary for Policy Makers*** accompanies each volume.

Volume 3 presents the results of the first global assessment of transboundary river basins, prepared in partnership with UNEP-DHI (lead), the International Union for the Conservation of Nature, the Stockholm International Water Institute, Oregon State University, The City University of New York Environmental CrossRoads Initiative, the International Geosphere-Biosphere Programme, Columbia University Center for International Earth Science Information Network, the Delta Alliance, and the University of Kassel Center for Environmental Systems Research.

Acronyms

ANBO	African Network for Basin Organizations
AWS	Agricultural Water Stress
BCU	Basin Country Unit
BOD	Biological Oxygen Demand
CBD	Convention on Biological Diversity
CESR	Centre for Environmental Systems Research
CIESIN	Center for International Earth Science Information Network
CESR	Centre for Environmental Systems Research
CUNY	City University of New York
CV	Coefficient of Variation
DA	Delta Alliance
DIN	Dissolved Inorganic Nitrogen
DIP	Dissolved Inorganic Phosphorous
DPSIR	Driver-Pressure-State-Impact-Response
EPI	Environmental Performance Index
EWS	Environmental Water Stress
FAO	Food and Agriculture Organization
GAR	Global Assessment Report
GDP	Gross Domestic Product
GEF	Global Environment Facility
GLWD	Global Lakes and Wetlands Database
GNI	Gross National Income
GPW	Gridded Population of the World
GRUMP	Global Rural-Urban Mapping Project
HDI	Human Development Index
HWS	Human Water Stress
IFTD	International Freshwater Treaties Database
IGBP	International Geosphere-Biosphere Programme
IMR	Infant Mortality Rate

INBO	International Network of Basin Organizations
IUCN	International Union for Conservation of Nature
JMP	Joint Monitoring Programme (on water supply & sanitation)
LME	Large Marine Ecosystem
MAR	Mean Annual Runoff
MMR	Mean Monthly Runoff
NEWS	Nutrient Export from WaterSheds Model
NASA	National Aeronautics and Space Administration
NP	Nutrient Pollution
NTL	Night-time Lights
OECD	Organisation for Economic Co-operation and Development
OO	Open Ocean
OSU	Oregon State University
PCA	Principal Component Analysis
PWCMT	Program in Water Conflict Management and Transformation
RBO	River Basin Organization
RIPP	Riparian Position database
RIS	Ramsar Information Sheets
RLSR	Relative Sea Level Rise
SIWI	Stockholm International Water Institute
TB	Transboundary
TFDD	Transboundary Freshwater Disputes Database
TWAP	Transboundary Waters Assessment Programme
TWAP RB	TWAP River Basins Component
UN	United Nations
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
UNEP-DHI	UNEP-DHI Partnership: Centre on Water and Environment
UNESCO	United Nations Educational, Scientific and Cultural Organization
WaterGAP	Water Global Analysis and Prognosis
WB	World Bank
WBM	Water Balance (& Transport) Model
WHO	World Health Organization
WWDR	World Water Development Report
WWF	World Wildlife Fund

Glossary

Basin Country Units (BCUs) – a basin country unit (BCU) is the portion of a country within a river basin shared by two or more countries. There are 796 BCUs identified within the 286 transboundary river basins included in this project.

Core basins – the set of basins for which results have been calculated for the full set of indicators. These 156 basins include 80% of the total area and population of all 286 basins.

High/low confidence results – lower confidence results for a number of indicators are associated with modelling limitations relating to the size of the basins/BCUs (e.g. less than 10 grid cells) or other factors that may affect the reliability of the calculated scores. These basin scores are presented, but marked as having a 'lower confidence' in the results download sheets. All other scores are treated as results of high confidence. The specific limitations relating to the lower confidence results are marked and explained in the metadata sheets of the individual indicators.

Indicator-based assessment – 15 core indicators are used to represent a broad spectrum of issues that are likely to be of relevance to humans and ecosystems in the majority of transboundary river basins around the world. In order to have a comparable set of indicators, some issues with relevance to particular basins may have been omitted from this global analysis.

Integrated indicator analysis – the analysis of all indicators in a combined fashion, using a number of statistical tools.

Relative risk categories – the categorization approach used to identify transboundary basins which are at higher or lower 'risk' from a variety of stressors (based on indicator assessment results). Five categories are used (1 – very low to 5 – very high) based on the principle of relative risk; rather than a detailed basin by basin study, the assessment is overarching and looks at a direct comparison of the situation between basins.

Thematic group – groups of indicators which together give an overall snapshot of a thematic area. In this assessment there are five thematic groups: water quantity, water quality, ecosystems, governance and socioeconomics. Each of the 15 core indicators fall into one of these groups.

Transboundary river basins – rivers for which the hydrological boundaries cross an international border, even by a relatively small amount (a total of 286 transboundary river basins identified in this project).

TWAP Full-Sized Project (TWAP FSP) – Transboundary Waters Assessment Programme global assessment, consisting of five independent indicator-based assessments (for five transboundary water system categories - aquifers, lakes, rivers, large marine ecosystems and open oceans).

TWAP RB – Transboundary Waters Assessment Programme River Basins component.

Technical Summary

The world's 286 transboundary river basins span 151 countries, including more than 40% of the Earth's population and land area (*Figure 1*). They support the socioeconomic development and wellbeing of humanity and are home to a high proportion of the world's biodiversity.

These river systems cross borders, and through human dependence on their water, link countries in a complex web of environmental, political, economic and security-related interdependencies. Transboundary water management is challenging since the water-management regime, priorities and cultures usually differ between countries. It therefore requires coordination across different political, legal, institutional and technical settings.

The Transboundary Waters Assessment Programme (TWAP) was initiated by the Global Environment Facility (GEF) to create the first baseline assessment of *all* the planet's transboundary water resources. The purpose of this is to provide benchmarks of the current state of water systems to inform policy, encourage knowledge exchange, identify and classify water bodies at risk and increase awareness of the importance and state of transboundary waters. The *Transboundary River Basins Assessment* is one of five assessments of transboundary water systems (see http://www.geftwap.org).

This assessment aims to be of use to a broad variety of stakeholders, including transboundary institutions of specific water systems (e.g. river-basin organizations, bi-national and inter-State Commissions), national institutions and governments, regional and international agencies and donors. The report is released following the entry into force of the UN International Watercourses Convention (2014), providing a solid baseline for this Convention and for international and regional institutions with an interest in water and food security. It is also designed to be relevant to groups of countries managing shared resources, and to individual countries to broaden their understanding of the current situation and future outlook.

Throughout the report, the authors have sought to identify needs for further research and methods to complement those applied to this study of transboundary river basins[1]. However, gaps in data should not be an excuse for inaction. The world has entered a phase of risk management, where risks of environmental degradation, water scarcity and climate change are increasingly real. Here, the precautionary principle must be invoked. Failure to manage transboundary river basins may result in significant human suffering and economic losses.

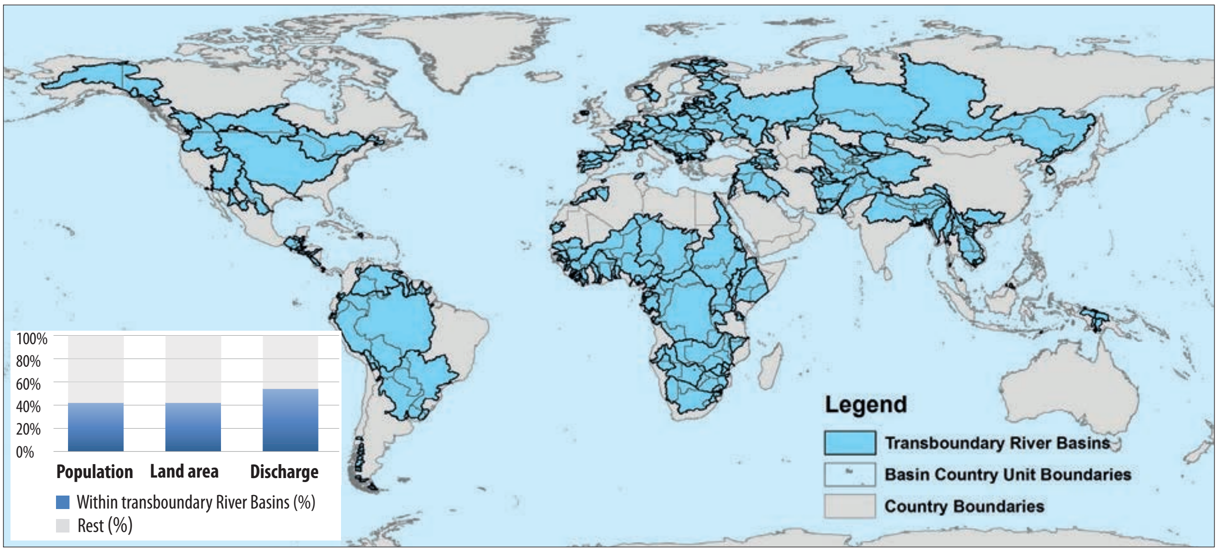
Box 1. How to use the online TWAP River Basins Data Portal

If you want to learn about your country, a particular transboundary river basin or issue such as water scarcity, you can conduct your own data searches online — click the Data Portal button on http://twap-rivers.org/

The site allows you to select any number of indicators (e.g. Nutrient Pollution, Threat to Fish or Legal Framework), a river basin (e.g. Nile), and also see which transboundary river basins your country is in.
You can then create your own selections of data and analyses of relative risk for the basins, countries and issues that interest you.

1 See Chapter 6, *Transboundary River Basins Report*

Figure 1. Transboundary rivers that link countries in a common future. 151 countries and 2.8 billion people share 286 transboundary river basins.



Introduction to the assessment

This Technical Summary describes the global assessment of transboundary river basins, as detailed in the Transboundary River Basins Report (available on http://twap-rivers.org/).

This is the first truly global and comprehensive assessment of the world's 286 transboundary river basins covering a broad spectrum of issues (natural and social sciences) and scales (from large to very small basins and Basin Country Units (BCUs)). It is the work of a consortium of nine partners, coordinated by the UNEP-DHI Partnership, Denmark. Partners include: Center for Environmental Systems Research, University of Kassel, Germany; Center for International Earth Science Information Network, Columbia University, USA; City University of New York, Environmental CrossRoads Initiative, USA; International Union for the Conservation of Nature; International Geosphere-Biosphere Program; Oregon State University, USA; Stockholm International Water Institute, Sweden, and Delta Alliance (primarily Alterra Wageningen and Deltares). Each partner contributed expertise, datasets, models and assessment tools to undertake this broad global assessment.

The aims of the TWAP River Basins component are to:

i) undertake a baseline comparative assessment of all of the world's transboundary river basins, and a selection of deltas, which will enable the identification of priority issues and hotspots at risk from a variety of stressors;
ii) establish a sustainable institutional framework to undertake the baseline assessment as well as periodic assessments to track changes over time.

The assessment uses indicators of 'stressors' which are listed in *Table 1* below. They fall under five key themes (water quantity, water quality, ecosystems, governance and socioeconomics) to provide a comprehensive picture of the state of transboundary river basins today. Using the same five thematic groups, the report also provides projections for 2030 and 2050, providing some estimates of the state of transboundary river systems for us and the next generation. The assessment strives to address both human and ecosystem vulnerability to stresses since these are closely linked. The baseline and global nature of the assessment limits the extent to which specific causal links between human-ecosystem interactions can be established, since these vary from basin to basin and in most cases warrant detailed case investigations.

Table 1. Overview of TWAP River Basins Assessment Thematic Groups and Indicators. *There are five thematic groups, and 15 core indicators. Five indicators are projected for 2030 and 2050.*

THEMATIC GROUP	INDICATORS	
	Baseline (2010)	Projected (2030/2050)
Water Quantity	1. Environmental water stress 2. Human water stress 3. Agricultural water stress	Environmental water stress Human water stress
Water Quality	4. Nutrient pollution 5. Wastewater pollution	Nutrient pollution
Ecosystems	6. Wetland disconnectivity 7. Ecosystem impacts from dams 8. Threat to fish 9. Extinction risk	[Environmental water stress]
Governance	10. Legal framework 11. Hydropolitical tension 12. Enabling environment	Exacerbating factors to hydropolitical tension
Socioeconomics	13. Economic dependence on water resources 14. Societal well-being 15. Exposure to floods and droughts	Change in population density

Water Systems Links	
Lakes	Lake influence
Deltas	1. Relative sea level rise 2. Wetland ecological threat 3. Population pressure 4. Delta governance

Dams provide various services for humans, but usually have negative impacts on freshwater ecosystems and deltas. Mitigating impacts can be particularly challenging in transboundary river basins.

Box 2. The concept of relative risk and its use in this report

As this is a global assessment, it is not intended to be a detailed 'state-of-the-environment' assessment for each of the transboundary river basins. The objective is to complete a *relative* analysis between basins based on relative risks to societies and ecosystems.

Thus, this assessment uses a concept of relative risk to present indicator results, adopting five categories ranging from 'very low' to 'very high'. These relative risks are represented in the maps using following colours:

1 – Very Low	1 – Low	3 – Moderate	4 – High	5 – Very High	No data

The state of water resources in any location depends on a complex array of natural circumstances, stressors and management responses. Measuring differences within each basin involves assessment of the transboundary nature of the issues and links between locations. In this assessment, the transboundary nature of basins has been highlighted through the use of Basin Country Units (BCUs) – the portions of each basin belonging to the respective country – and for deltas through delta country units (DCUs).

Using BCUs (and DCUs) helps to show how each country contributes to the overall picture of risk in a given basin. It also illustrates that basin-wide problems and solutions in transboundary basins are often directly linked to individual countries. Thus, this BCU approach contributes to identifying countries that may need to be proactive or may need more assistance to solve problems that have transboundary implications.

For both individual indicators and for combinations of indicators, this assessment provides a global perspective of the magnitudes of risk, a framework for comparative analysis of risks among basins, and identification of basins most and least at risk. Overall, this provides a context for policy responses at global and regional levels but also at the basin and country levels, and facilitates inter-basin learning. TWAP River Basin results can also be used in combination with detailed studies on individual basins.

The assessment paints a complex picture. There are serious risks to many basins in different parts of the world, with differing levels of development, for all of the assessed stressors. There is no single most important issue, and there are no basins with either 'very low' or 'very high' risk for the full range of issues. Thus, the issues (indicators) are presented in the full report separately and together[2] in a series of linked analyses which drill down into the results from a number of different perspectives.

Results

The key findings for each thematic group are given below, with maps illustrating one of the indicators from that group. Taken together, the maps illustrate the diversity of results between the thematic groups and hence the challenges to identifying overall hotspots.[3]

2 Indicators are presented separately in Chapter 3, and together in Chapter 4 of the *TWAP River Basins Report*

3 For more detailed indicator-by-indicator analysis, see Chapter 3 of the *TWAP River Basins Report*.

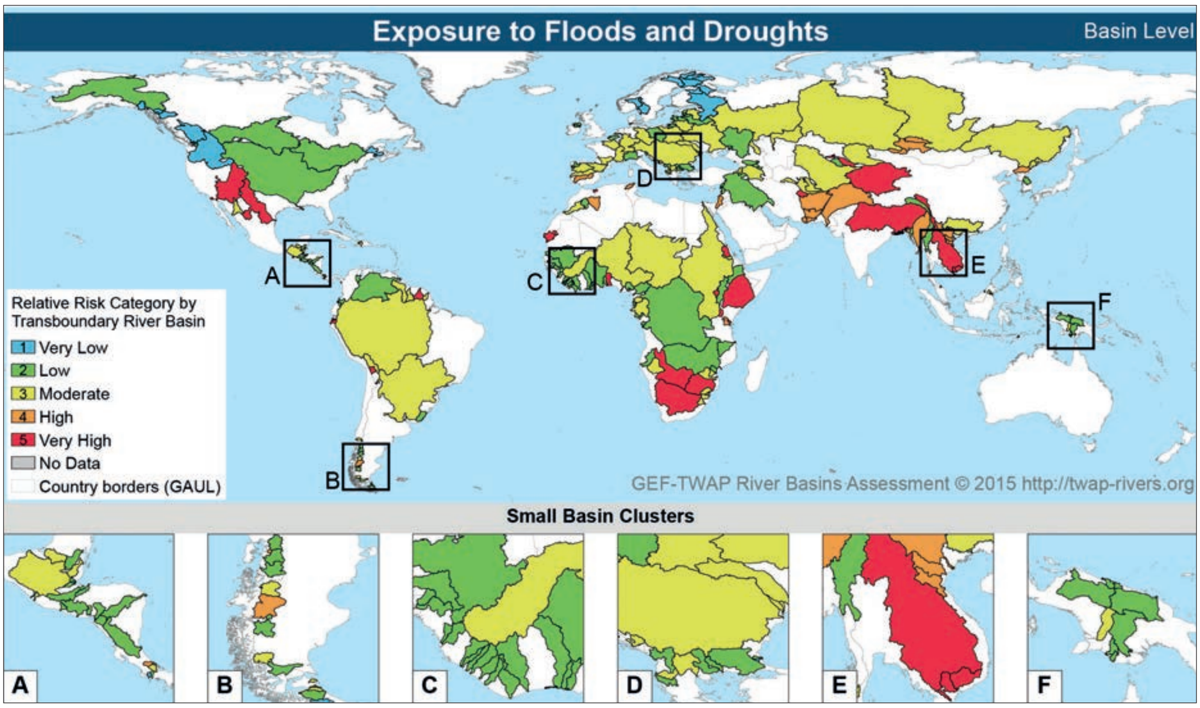
Socioeconomics

The socioeconomics thematic group has three indicators: economic dependence on water resources (proportion of countries' economic activity within the basin), societal wellbeing (human development indicators such as infant mortality) and exposure to floods and droughts (in terms of economic loss and population affected).

Key findings

1. **Climate-related risk is linked to economic dependence and low wellbeing:** Basins with high economic dependence, low levels of societal wellbeing and high exposure to floods and droughts have the highest climate-related risks. These basins are found mostly in Africa and south and southeast Asia. They include, at the highest levels of vulnerability, the Limpopo, the Ganges and the Mekong.
2. **Wellbeing and governance capacity to address disasters are linked:** In basins where societal wellbeing is low, governance capacity to address vulnerability to floods and droughts is also likely to be low. Women, children and people with disabilities are groups particularly vulnerable to floods and droughts. Attention might be warranted to assess governance needs and increase capacity in these countries and basins.
3. **Larger basins have larger economic dependence:** Larger basins tend to have higher levels of economic dependence on basin water resources, due mainly to the fact that larger basins are likely to include greater portions of the populations and areas of the countries. The 14 basins with the highest levels of economic dependence collectively comprise a population that is almost 50% of all transboundary basins (almost 1.4 billion people). These larger basins may be harder to manage from a transboundary point of view because of the number of countries and diversity of priorities. Management becomes even more critical to safeguard socioeconomic wellbeing in these countries.

Figure 2. Exposure to Floods and Droughts by Transboundary River Basin. The map illustrates relative risk levels from floods and droughts. The red regions are those with highest relative risk from either floods or droughts. Moderate and high risks are widespread across the globe.



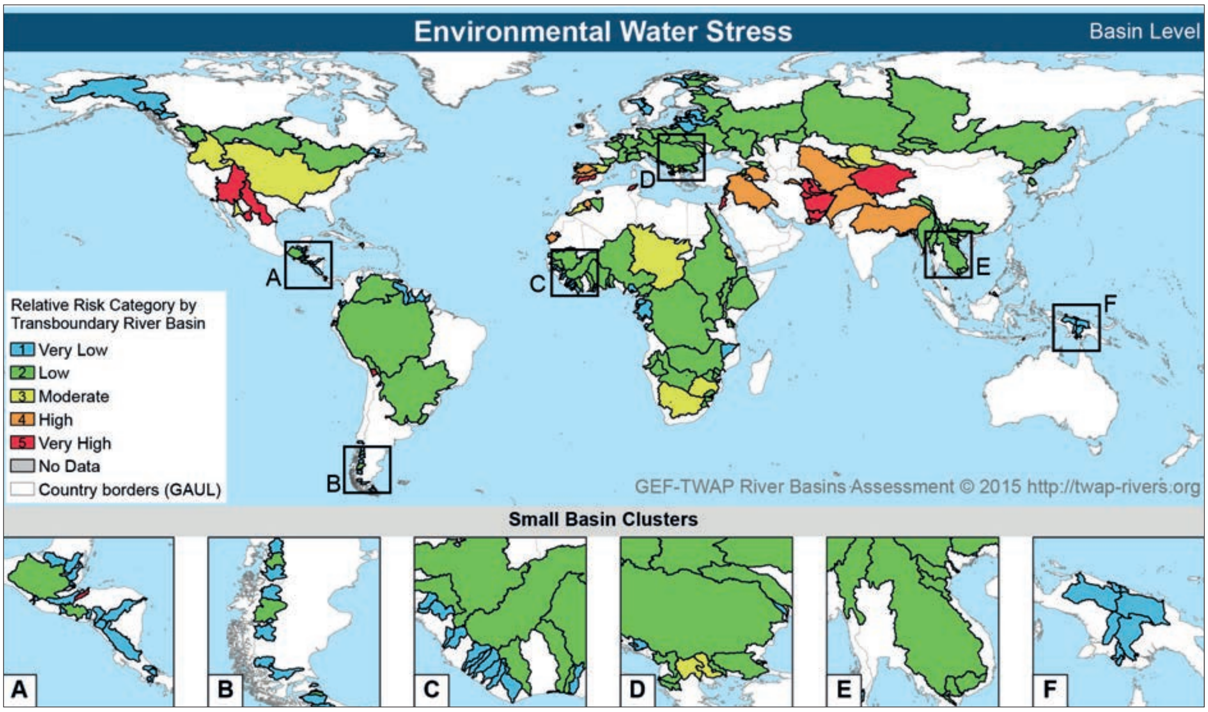
Water Quantity

Agriculture is the largest user of water globally, so understanding areas of agricultural water stress is important for future food security. The water quantity thematic group has three indicators: environmental water stress (the alteration of flow regimes from natural flow conditions), human water stress (water availability per capita and water use compared to availability), and agricultural water stress (the imbalance between water use and availability). These three indicators provide a composite picture of water stress in terms of quantity for transboundary river basins and BCUs.

Key findings

1. **Action to address agricultural water stress must not increase environmental water stress:** Hotspots of environmental water stress are highly correlated with those of agricultural water stress. Addressing agricultural water stress (for example through increasing large-scale water storage) should be done with careful consideration of environmental water requirements.
2. **Human water stress needs to be addressed to mitigate projected environmental and agricultural stress:** Actions to counter human water stress should be expedited in river basins that are already prone to water stress to mitigate the increasing stress projected for most of these regions.

Figure 3. Environmental Water Stress by Transboundary River Basin. The map illustrates relative risk levels of risk to ecosystems based on the alteration of flow regimes from natural conditions, due to withdrawals and dam operations. The red regions are those with highest relative risk, mostly in Middle East/Central Asia and North America.



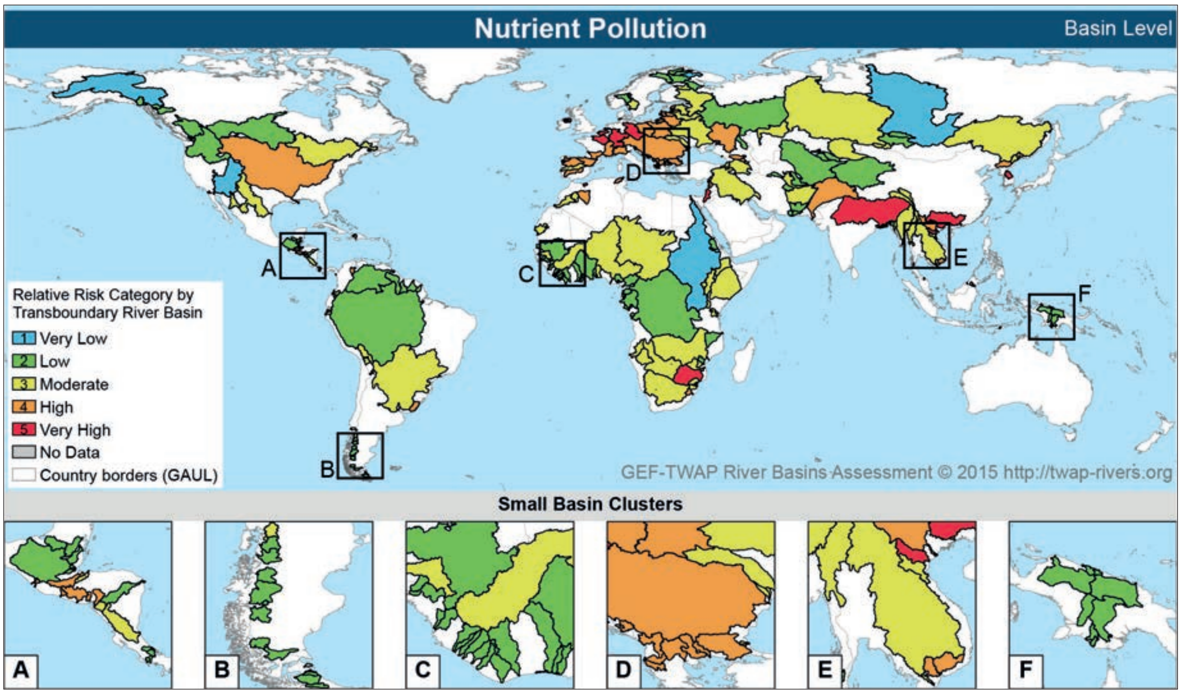
Water Quality

Poor water quality can lead to loss of vital ecosystem services, livelihoods and ill health. The water quality thematic group has two indicators: nutrient pollution and wastewater pollution. The nutrient pollution indicator mainly addresses nutrient (nitrogen and phosphorus) over-enrichment (eutrophication). The wastewater pollution indicator mainly addresses risks of pathogens (found in untreated human waste). Together, these two indicators give an overall snapshot of the risk to human populations and ecosystems from pollution.

Key findings

1. **Water quality risks are high in many transboundary river basins:** Water quality is severely affected in more than 80% of the basins, either by nutrient over-enrichment (typically in developed regions e.g. North America and Europe) or by pathogens (generally in developing regions, e.g. South America, Africa, and in northern Asian basins with Russia), or in both (e.g. emerging economies in southern and eastern Asia).
2. **Water quality risks are projected to increase:** The projected scenario for nutrient pollution suggests that the relative risk will increase in around 30% of basins between 2000 and 2030, with the risk in two basins increasing by three categories. Between 2030 and 2050 nutrient pollution risk is projected to increase further in 21 basins, while in six basins the risk decreases by one category[4]. The effects of nutrient pollution are also likely to exacerbate risks across other indicators and water systems (e.g. ecosystem health, coastal areas and aquifers).
3. **Mitigation measures are needed in all river basins to reduce risks:** In basins with a risk of nutrient and wastewater pollution, improvements to wastewater treatment may help to reduce both risks. Improved nutrient management in agriculture (e.g. crop and livestock) will likely be needed to reduce current risks of nutrient pollution in many basins. Even in basins with relatively low risk, both strategies are likely to become more important as the global population continues to rise, which is likely to increase risks of nutrient and wastewater pollution unless adequate mitigation measures are in place.

Figure 4. Nutrient Pollution by Transboundary River Basin. The map illustrates relative risk levels from nutrient pollution. The red regions are those with highest relative risk. Moderate and high risks are widespread across the globe.



4 High confidence results only. See glossary and Chapter 3.3 of the *TWAP River Basins Report*.

Ecosystems

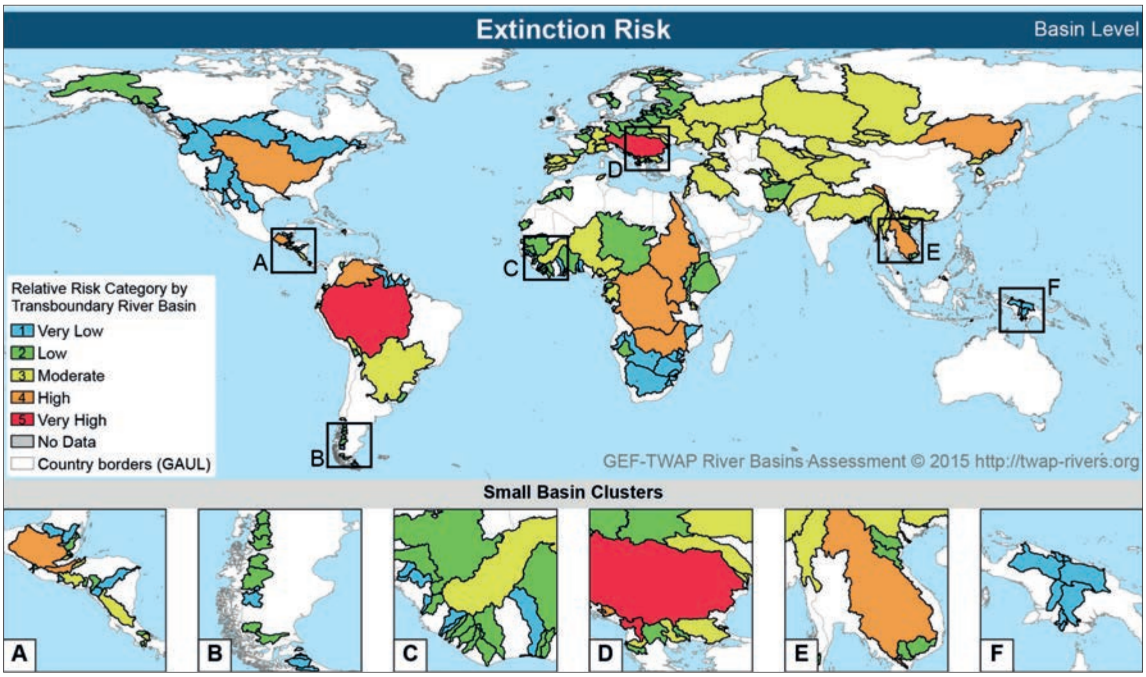
The ecosystems thematic group has four indicators: ecosystem impacts from dams (dam density and river flow disruption), threats to fish (fishing pressure and non-native species), extinction risk (risk of extinction of species) and wetland disconnectivity. The last of these encapsulates the impacts of wetland disturbance and loss, such as draining of wetlands, levee construction and altering river courses, and the resulting losses of ecosystem functionality.

Taken together, the ecosystem indicators show that the majority of basins are at risk from one or more of the issues assessed, with a fairly even geographic distribution. For example, while the ecosystem impacts from dams indicator tends to highlight basins at risk in more industrialized regions, the wetland disconnectivity indicator highlights basins in developing regions where encroachment of agriculture and urban areas on wetlands is a current threat – this calls for improved policy and management strategies.

Key findings

1. **Local-level, tailored solutions are needed to address species extinction risks:** Analysis at the BCU level gives a more detailed picture of extinction risks than analysis at the basin level, reflecting higher levels of endemic species or threats in some areas of a river basin such as the upper reaches or in large lake systems. This suggests that responses, too, should be at a more detailed level than basin-wide to address extinction risks. There is therefore an urgent need to continue to identify hotspots from transboundary impacts through basin-specific assessments (including, for example, GEF Transboundary Diagnostic Analyses (TDAs)). Conservation strategies should be focussed on ecological importance, not necessarily on scale.
2. **Decisions about dam sites and dam design are key to minimising negative ecosystem impacts:** Dam density is often a key driver of impacts on ecosystems, with impacts on flow and fragmentation of river systems. Recognizing the benefits of dams to human development, ongoing commitments are needed to improve guidelines for siting new dams, designing dams for multiple purposes and optimising the operation of dams to maximise human benefits and minimise negative ecosystem impacts. This is particularly important in a transboundary context, where dams are typically located in upstream countries.

Figure 5. Extinction Risk by Transboundary River Basin. The map illustrates relative risk levels of extinction considering vulnerability, irreplaceability and richness of species. The orange and red regions are those with highest relative risk, widely distributed throughout the world.



Governance

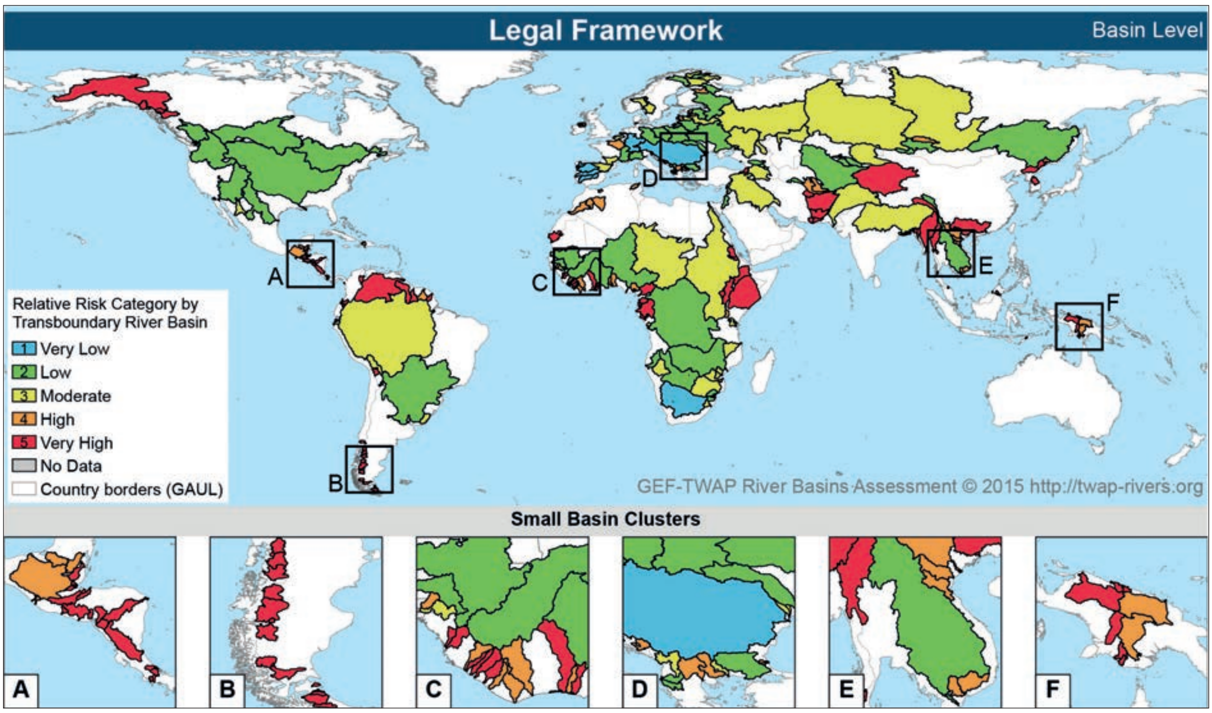
The governance thematic group has three indicators: legal framework (e.g. existence and substance of basin treaties), enabling environment (water governance capacity at the national level) and hydropolitical tension (potential sources of political tension in the basin relating to water and institutional capacity to diffuse such tension).

Governance indicators show a concentration of transboundary basins with good formal institutional capacity, both transboundary and national, in Northern America and Europe, with other positive examples spread through the remaining regions. Many regions still lack formal frameworks for cooperation, which can reduce tensions when basins are under pressure. In parallel with developing instruments for cooperation, renewed efforts are needed to ensure that formal arrangements translate into action and fair cooperation between countries.

Key findings

1. **More effort is needed on transboundary agreements:** The adoption of international principles associated with the shift of water paradigms toward more sustainable development has been faster in domestic water governance arrangements than in international treaties. Focus is needed on renegotiating and implementing transboundary agreements to incorporate more integrated approaches into basin-level management.
2. **Construction of water infrastructure needs a cooperative context:** The construction of new water infrastructure is in progress or planned in many transboundary basins, including in areas where international water cooperation instruments are still absent or limited in scope. In such areas, a formal institutional framework for transboundary dialogue could help to assuage potential disputes stemming from unilateral basin development.

Figure 6. Legal Framework by Transboundary River Basin. The map illustrates relative risk levels relating to the existence of key principles of contemporary water governance in international agreements, as well as the ratification of one of the two global international freshwater conventions. It does not measure the performance or implementation of the agreements. The red regions are those with highest relative risk.



3. **Capacity building is required within countries to meet transboundary objectives:** There have been advances in the development of transboundary institutional capacity to deal with transboundary tensions and the application of integrated approaches to national water management, but capacity building is still work-in-progress in most countries.

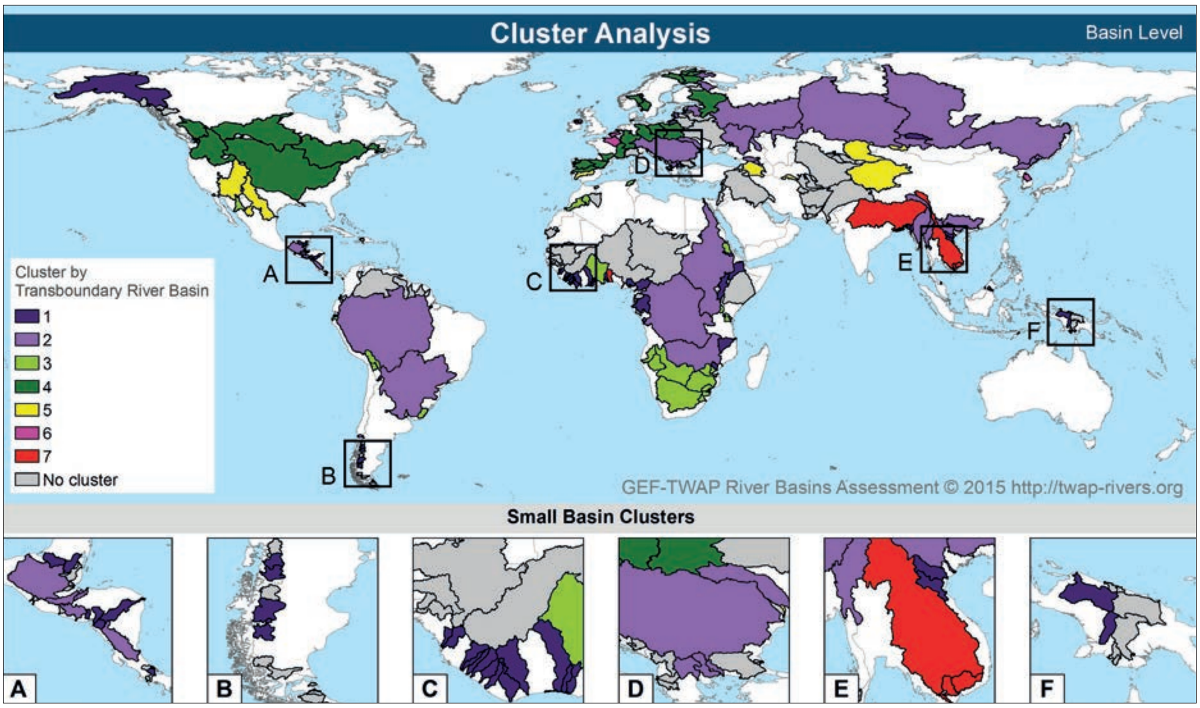
Looking deeper: integrated analysis across themes

Taken together, the results of this assessment reveal complex links, which can be clarified by further analysis. An integrated analysis of the indicators has therefore been undertaken, using a number of statistical techniques to examine the relationships among the indicators and identify key patterns across thematic groups.[5]
A selection of broad findings from the integrated analysis follows.

Basins with similar risk profiles

While each basin has unique challenges and opportunities, understanding similarities between them can facilitate inter-basin learning and further the development of broad management strategies that may be applicable to multiple basins with similar risk profiles. A cluster analysis was undertaken to identify such basin groups (*Figure 7*).

Figure 7. Cluster analysis showing seven groups of basins with similar risk profiles, numbered 1-7. Common risk profiles can facilitate inter-basin learning and shared approaches to management.



5 See Chapter 4, *TWAP River Basins Report*.

Key findings

1. **Cluster group 1: Undeveloped basins with low pressures on water resources:** 45 basins (covering a population of roughly 90 million) that have generally low risk for most indicators. These tend to be either small basins in various parts of Africa, presumably with little water resource development, or isolated basins in temperate and polar regions, presumably with low pressures on water resources. This group represents basins that are largely undeveloped and may therefore offer opportunities for sustainable development.
2. **Cluster group 2: Inadequate governance, high ecosystem risk despite low development of water resources:** 39 basins (870 million people) appear to have inadequate governance which manifests in high risks to ecosystems, despite relatively low levels of development of water resources. These basins present a challenge for sustainable development and the management of risk, particularly given the moderate to high levels of exposure to droughts and floods respectively. Assessing governance needs in these basins would appear to be a priority.
3. **Cluster group 3: Poor governance, high risk, high water use:** 25 basins (80 million) have generally poor governance and generally high risks across the socioeconomics indicators, and appear to be utilizing relatively high portions of their available water resources and have high economic dependence on them. Transboundary inter-sectoral allocation mechanisms may be useful management tools in these basins.
4. **Cluster group 4: High human wellbeing, good governance, high risk for ecosystems and human water stress:** 25 basins (280 million) tend to have high levels of societal well-being, and good governance, but also high risk to ecosystems and of human water stress and moderate risk of environmental water stress. Low risks of agricultural water stress but high risks from ecosystem impacts from dams implies that storage capacity has been developed to mitigate agricultural water stress, but at the expense of the environment.

The remaining cluster groups, 5–7, have relatively few basins, so characteristics are more likely to be driven by the circumstances in a few of the basins rather than broad similarities. Nevertheless, possible interpretations of these groups are included in the *Transboundary River Basins Report*.

Correlations between indicators across thematic groups

Determining correlations between indicators across thematic groups can help to identify the strength of the statistical relationships of the links in the conceptual model that underpins this work. The results indicate how the human dimension of transboundary rivers, gauged by socioeconomic and governance indicators, is related to the physical dimension represented by water quality and quantity and ecosystem impacts. For example:

- wastewater pollution, societal well-being and enabling environment (governance at the country level) are strongly related, suggesting that addressing wastewater pollution should occur in parallel with improvements in societal well-being and national governance;
- environmental, human and agricultural water stress, and exposure to drought, which are usually worse in basins with high inter-annual variability of water flows, are strongly correlated. This confirms that in the past dams have been built to address water flow variability to meet high human and agricultural demands, with negative impacts on environmental water flows;
- there is a negative correlation (although weak) between governance and societal well-being indicators, and ecosystem impacts from dams and threats to fish. This would imply that basins which have been developed to support high levels of societal wellbeing may have done so at the expense of the environment.

Upstream and downstream relationships and transboundary cooperation

The relationships between upstream and downstream areas within each basin are arguably one of the most important features of in-basin dynamics. Upstream actions can impact downstream BCUs. It is therefore key to observe how risks at the source of a river relate to risks further downstream and at the mouth of the river.

The average risk for all indicators for BCUs located at the mouth of a transboundary basin is marginally higher than their respective BCUs at the source. Almost twice as many BCUs at the river mouth have higher risk than their respective BCUs at the source, although the differences are generally not large.

The disparity of levels of risk among countries can act as a catalyst or as an obstacle for transboundary cooperation and have different effects on the overall status of the basin. However, there is no clear correlation between the level of general risk disparity and the overall level of risk in basins. This needs to be evaluated on a case-by-case basis, since the web of causal relationships is too complex to be captured in a global baseline study.

Without adequate benefit-sharing agreements and cooperative approaches to integrated water resource management, economically-dependent downstream countries may be negatively impacted. Unilateral appropriation of water resources often leads to tensions between countries. However, even with the best of intentions, it may become increasingly challenging to develop policies, laws and management arrangements for transboundary benefits during prolonged water scarcity or when there are tensions between national priorities and transboundary considerations. This is illustrated by complicated transboundary cooperation surrounding dam building in upland areas such as the upper reaches of the Mekong, the Blue Nile, and the Indus rivers.

So, while establishing mechanisms to facilitate transboundary cooperation is an important starting point, successful outcomes will only be achieved through a mixture of political will, adequate resources and technical capacity at both national and transboundary levels.

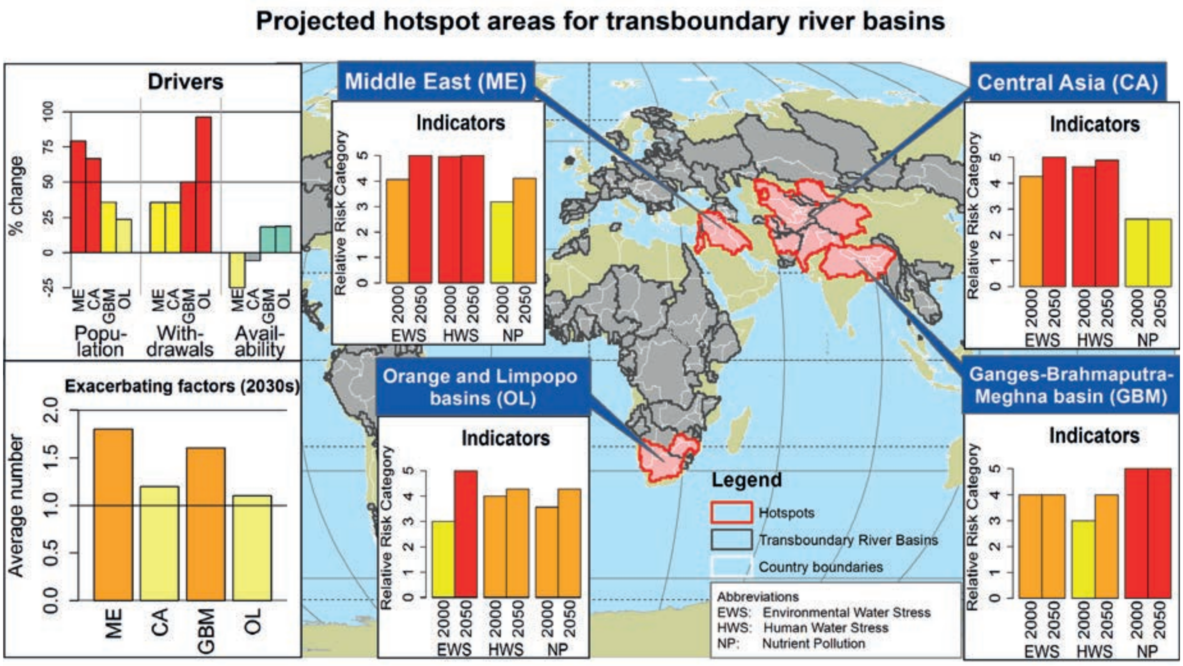
Risk projections

Simulated projections for 2030 and 2050 were generated based on a 'business-as-usual' socio-economic scenario with associated high greenhouse gas (GHG) emissions. These affect future temperature and rainfall patterns, which in turn affect water availability, reliability and variability. The following indicators were considered: environmental stress induced by flow regime alteration, human water stress, nutrient pollution, potential exacerbating factors to hydropolitical tension, and change in population density.

Four future risk hotspots for transboundary river systems were identified (see Figure 8). Environmental and human (E&H) water stress is anticipated to increase in all four:

- **Orange and Limpopo basins, Southern Africa:** increased Environment and Human (E&H) water stress due mainly to increasing water withdrawals, and nutrient pollution due mainly to increased human sewage. Countries affected: Botswana, Lesotho, Mozambique, Namibia, South Africa, Zimbabwe.
- **Selected Central Asia basins:** range of factors differing between basins, including increased E&H water stress due to combination of projected increases and decreases in water availability, increasing water withdrawal and population density, increased nutrient pollution and hydropolitical tensions. Basins: Tarim, Indus, Aral Sea, Helmand, Murgab, Hari, Talas, Shu and Ili. Countries affected: Afghanistan, China, India, Iran, Kazakhstan, Kyrgyzstan, Nepal, Pakistan, Tajikistan, Turkmenistan, Uzbekistan.
- **Ganges-Brahmaputra-Meghna basin:** increased E&H water stress due mainly to increased (>50%) water demand driven by population growth. Nutrient pollution remains high, with agriculture sources (fertilizer and animal manure) being major contributors and sewage becoming increasingly important, and there is increased risk of hydropolitical tension associated with new water infrastructure. Countries affected: Bangladesh, Bhutan, China, India, Myanmar, Nepal.
- **Selected Middle East basins:** continuing high to very high risk of E&H water stress due to decrease in renewable freshwater resources and higher water demand from increased population and irrigation. Nutrient pollution increases or remains in the highest risk category; increased risk of hydropolitical tension due to political context. Basins: Orontes, Jordan River, Euphrates and Tigris. Countries affected: Egypt, Iraq, Iran, Israel, Jordan, Lebanon, Palestine, Saudi Arabia, Syria, Turkey.

Figure 8. Four future risk hotspots for transboundary river basins. The figure shows the percentage change in three key drivers (population, water withdrawals, and water availability) from 2010 to 2050.



In addition to the four hotspots, the within-basin differences between countries – illustrated by certain indicators – are expected to increase in many other basins (e.g. the Nile, Northern Africa).

Delta vulnerability in transboundary river basins

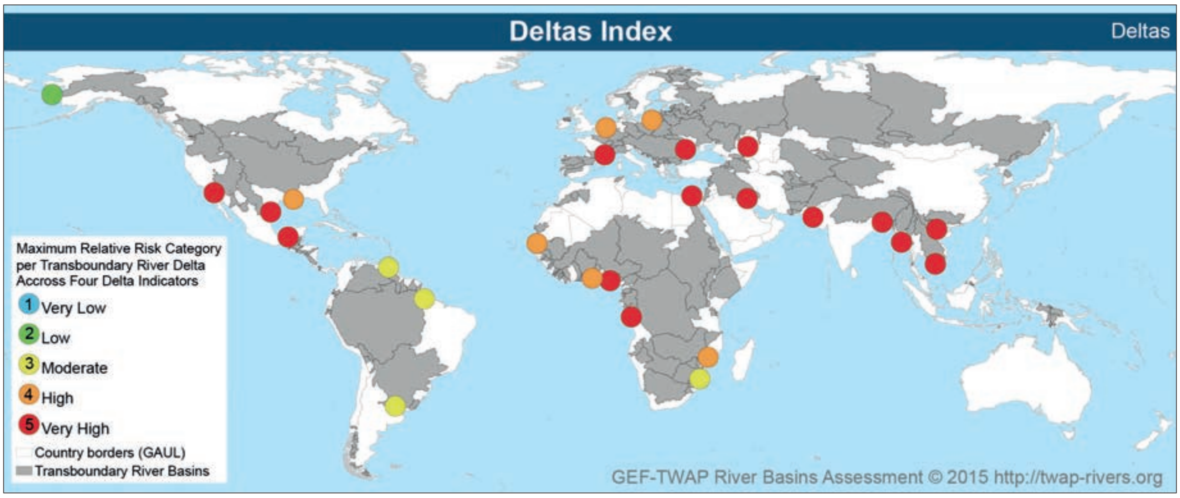
The assessment of 26 deltas was undertaken as an initial attempt to investigate the interface between river basins and coastal areas, which have been assessed in full within the Large Marine Ecosystem (LME) component of the TWAP (www.geftwap.org). This deltas assessment has four indicators, which broadly reflect the thematic groups used in the analysis of river basins: relative sea-level rise, wetland ecological threat, population pressure and delta governance.[6]

Key findings

1. **The vulnerability of deltas differs across the world:** The results show a geographical spread of vulnerability depending on the indicator. The Ganges-Brahmaputra-Meghna delta appears to be the most vulnerable, followed by the Niger and Volta deltas. The Amazon, Orinoco and Yukon deltas appear to have low to moderate vulnerability.
2. **Deltas in Asia are most at risk:** In general the deltas in Asia seem to have the most serious challenges in terms of human vulnerability caused by a combination of relative sea level rise and population pressures (and sometimes poor delta governance).

6 See Chapter 5, *TWAP River Basins Report*.

Figure 9. Vulnerability of 26 deltas which are part of transboundary river basins (maximum relative risk category of relative sea level rise, wetland ecological threat, population pressure and delta governance).



As well as investigating deltas, the relative influence of man-made and natural lakes on river basins was assessed. The lakes influence indicator measures the buffering and storage capacity of lakes in a river basin, giving an indication of how the basin might react to certain threats, and how some of the risks may be mitigated in basins with a high proportion of reservoirs, where water flows can to some extent be controlled.

Some policy and management response options

Some of the issues raised in this assessment are closely linked to the natural levels of water availability and population density, which exert inherent pressures on water resources, as well as historic actions (e.g. dam building), which may be difficult to address through policy measures. However, all the indicators provide information that can be incorporated into policy development and management planning. For example, understanding the relative level of ecosystem impacts from dams provides impetus to further develop policies to protect the remaining ecosystems in the basin (e.g. through protected areas), or to improve dam operation to ensure environmental flow allocations and management of sediment load to the river mouth and coastal areas.

Governance capacity at basin and national levels underpins the ability to respond to risks identified in this assessment. The governance thematic group of indicators can help to identify transboundary basins and countries where more detailed assessments of governance/capacity needs may be warranted, particularly where other risks are also high. Basins in cluster groups 2, 3 and 7 (*Figure 7*)[7] may require the most urgent attention in this case.

A closer examination of the individual indicators would be required to identify specific basins and BCUs that would benefit from targeted policy development. Assessment of capacity needs could for example be implemented through GEF Transboundary Diagnostic Analysis (TDA) and Strategic Action Plans (SAP) which could enhance the connectivity and relevance of capacity needs assessments to wider economic and infrastructure planning decision-making processes.

In addition to governance considerations, classes of response options to address risks identified in this assessment, and achieve human and natural system water security, include:

7 See Section 4.2, *TWAP River Basins Report*.

- **Infrastructure:** either constructed or natural, for addressing risks associated with water scarcity (water quantity thematic group), water pollution (water quality thematic group), societal wellbeing (water supply and sanitation) and exposure to floods and droughts. Many win-win options are available through environmental protection measures for direct human gain (e.g. 'green infrastructure' for improvements to water quality and flood and drought mitigation) and optimization of infrastructure solutions (e.g. multipurpose dams).
- **Improved technical and institutional capacity:** (particularly related to the enabling environment and other governance indicators) for addressing a wide range of risks through increasing levels of knowledge to better guide policy development, planning and management.
- **Economic incentives / investments:** cost-recovery measures (e.g. for addressing water scarcity or water quality). Options include progressive tariff structures for all water uses, subsidies for improving water efficiency, and charges (e.g. pollution charges).
- **Environmental protection / rehabilitation:** basins in cluster group 2 may be particularly relevant here, with generally high species-extinction risk, moderate risks across all thematic groups and high risk of hydropolitical tension, suggesting impending construction of water infrastructure with a lack of adequate governance. Cluster group 4 also has high risks in the ecosystems thematic group, but generally good governance, implying that these risks may already be being addressed.

The implementation of any of the above classes of policy responses is dependent on governance and economic capacity. Thus, basins with weaker capacity may have a much larger set of issues to address in parallel with more specific responses such as infrastructure development for improvements to societal wellbeing. In these basins, it is particularly important to have an integrated approach to management.

Special attention should also be paid to the impact of upstream interventions on the most vulnerable deltas (e.g. reduction of sediment load by the construction of dams, changed hydrodynamics of rivers, pollution, and increased risk of salinity intrusion).

Good management is key to protecting water resources for humans and ecosystems.

The cluster groups identified show that some basins face similar challenges. Appropriate partnerships should therefore be developed, with exchange of knowledge and experience (best practices) and working together on similar issues for joint outcomes. These are likely to include greater private sector engagement and ultimately investment in delivering joint objectives with government and international organizations and development partners.

The private sector is an important but often overlooked stakeholder in water resource management. It is heavily involved in investment and construction of infrastructure projects, and industry is also an increasingly significant user and potential polluter of water. The involvement of the private sector provides great opportunities but also poses some challenges to governance of water resources, particularly at the transboundary level.

Focus should be not only on high-risk basins but also on low- and moderate-risk basins (e.g. cluster group 1) where sustainable development and management may ensure that they remain at relatively low risk. Interventions in the short term may present opportunities for significant savings in the long term if the situation worsens.

Conclusion – understanding our river basins now and into the future

There are several worldwide initiatives that could benefit from the elaborate methodology and indicators that have been developed for this global assessment (see TWAP River Basins Sustaining Mechanisms document for more detail). Other mechanisms adopting this methodology, partly or fully, would also assist in fully realizing the potential value of TWAP results by keeping the datasets alive, and contribute to periodic assessments.

For example, there is considerable opportunity to make use of the *Transboundary River Basins Assessment* methods and indicators to support the two global international watercourse conventions (United Nations Economic Commission for Europe (UNECE) and UN) considering the current lack of monitoring mechanisms that make indicator-based comparisons between basins over time possible. Furthermore, the timing of the TWAP assessment coincides with the entry into force of the UN International Watercourses Convention, providing a solid baseline for this Convention. The TWAP assessment can also support monitoring of the proposed Sustainable Development Goals (SDGs). All targets under the proposed water goal (and some under other goals) are relevant to transboundary basins. The indicators in this assessment can support, or be modified to support, a number of these targets, including those related to water quantity, water quality, sustainable use of water resources, and protection of ecosystems. Target 6.5 explicitly mentions transboundary cooperation: "by 2030 implement integrated water resources management at all levels, including through transboundary cooperation as appropriate". All three governance indicators will be able to support this target, particularly the legal framework and enabling environment indicators.

It is important that, in relation to the SDGs and other global assessments, the TWAP methodology is not confined to transboundary basins. The majority of datasets are global, gridded data that can be aggregated to the desirable unit (e.g. region, country, and local area).

The assessment framework and indicators developed in this assessment may also be useful as a platform for river-basin organisations seeking to establish monitoring and evaluation systems. This basin-level information could feed back into future global analyses. It can also be used to develop the GEF Transboundary Diagnostic Analyses (TDAs) into a more science-driven, robust and comparable process.

Other organizations that could benefit from the *Transboundary River Basins Assessment* methodology and results as a complement to qualitative country/basin reports include Regional Economic Commissions, transboundary institutions and bi/tri-lateral commissions, intergovernmental organizations and roundtables, development agencies, investment framework agencies, the International Network of Basin Organizations (INBO) and regional basin umbrella organisations, the World Water Assessment Programme (WWAP), Global Water Partnership (GWP), Delta Alliance and other regional institutions with a mandate for monitoring and assessing transboundary waters. Some

Read More Online

On the assessment site http://twap-rivers.org/ you will find a short *Summary for Policy Makers*, the full *TWAP River Basins Report* and *Technical Annexes*, the TWAP *River Basins Sustaining Mechanisms Report*, River Basins Factsheets and you can search the TWAP River Basins Data Portal.

of the ways in which the results and conclusions of this and future assessments can benefit such institutions are: priority setting, work programming and investment targeting, informing negotiations, and collaborative economic and environmental ventures.

Most importantly, the TWAP has fostered a willing partnership of institutions with the capacity to work with other interested parties to either reproduce the assessment in full or to adapt and improve aspects of the assessment to be fit for a number of purposes at many different levels. The TWAP data portal provides an entry point to further information and provides users with the opportunity to explore the data (http://www.geftwap.org/).

Chapter 1 Introduction

Andrew Piazza/flickr

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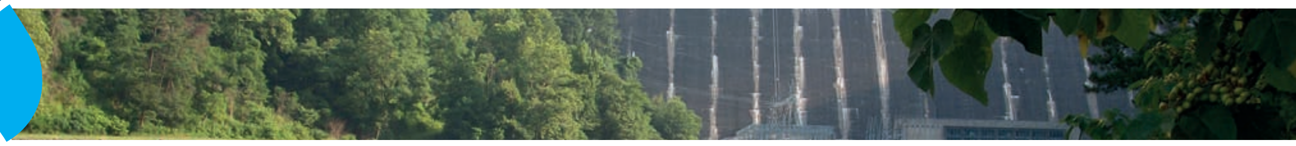
1 Introduction



1.1 TWAP Background and Goals

The water systems of the world – aquifers, lakes, rivers, large marine ecosystems, and open oceans - support the socioeconomic development and wellbeing of humanity and are home to a high proportion of the world's biodiversity. Many of these systems are shared by two or more nations and these transboundary resources are linked by a complex web of environmental, political, economic and security interdependencies.

The Transboundary Waters Assessment Programme (TWAP) was initiated by the Global Environment Facility (GEF) to create the first baseline assessment of *all* the planet's transboundary water resources. This will serve a number of purposes, including benchmarking and knowledge exchange, identification and classification of water bodies at risk, and increased awareness of the importance and state of transboundary waters. It is hoped that the TWAP will be of use to a broad variety of stakeholders, including transboundary institutions for specific water systems (e.g. river basin organizations), national institutions and governments, international agencies and donors, to obtain an overview of global issues threatening human populations and ecosystems through the water system. Thus the long-term goal of the TWAP is to promote investment in management and development of transboundary water systems through strong stakeholder engagement.

The aim of the current phase of the TWAP (2013-2016) is to establish a sustainable institutional framework and undertake a baseline assessment of transboundary water systems. Potential future assessments will allow the tracking of changes over time based on an understanding of baseline environmental and water resource conditions.

The TWAP contains one component for each of the five water systems: (i) Groundwater, (ii) Lake Basins, (iii) River Basins, (iv) Large Marine Ecosystems (LMEs), and (v) Open Ocean. This report describes the assessment work of the River Basins component.

1.2 Transboundary River Basins (RB) Component: aims and objectives

The aims of the transboundary River Basins (RB) component are to:

- undertake a baseline comparative assessment of the majority of the world's transboundary river basins (286) and a selection of deltas, which will enable the identification of priority issues and hotspots 'at risk' from a variety of stressors;
- establish a sustainable institutional framework to undertake the baseline assessment as well as periodic assessments to track changes over time.

The assessment is global in scope and indicator-based and is not intended to be a detailed 'state of the environment' assessment of each transboundary river basin. The objective is therefore to carry out a relative analysis of basins based on relative risks to societies and ecosystems.

1.3 The Big Picture: why transboundary and what have we learnt?

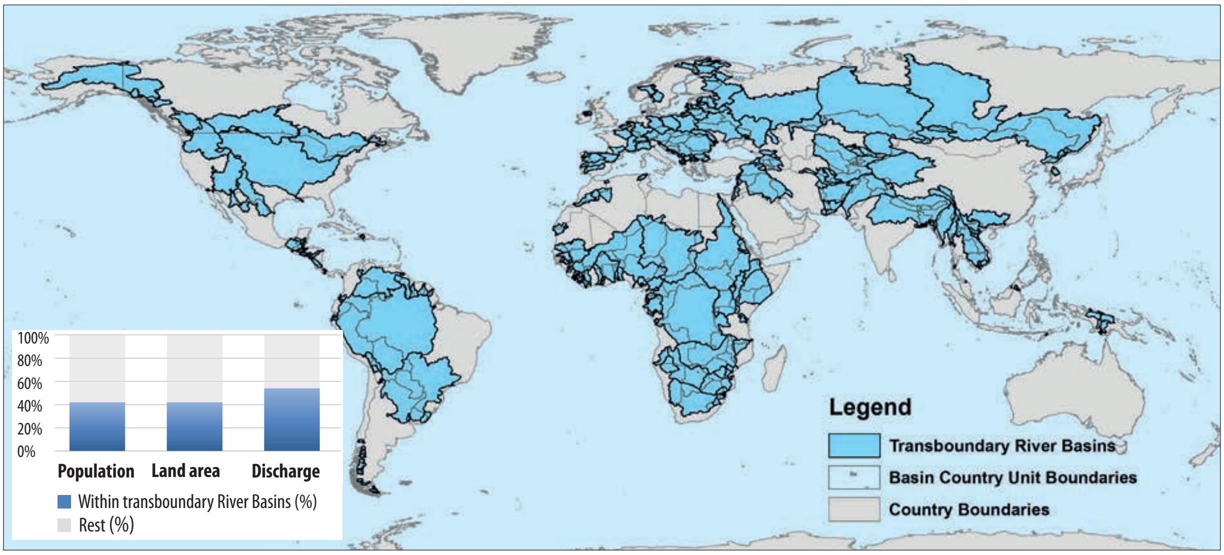
The world's 286 transboundary river basins span 151 countries, include more than 2.8 billion people (around 42 % of the world's population), cover 62 million km^2 (42 % of the total land area of the Earth), and produce around 22 000 km^3 of river discharge each year (roughly 54 % of the global river discharge) (Figure 1.1).[1] [2] The countries which are part of each transboundary river basin are naturally linked through the joint use of common water resources. Transboundary water management is likely to be more complex than that at the national level since the water management regime, priorities and cultures usually differ more between than within countries. Transboundary management of water resources therefore requires coordination across different political, legal, institutional and technical settings.

This assessment categorizes relative levels of risk to transboundary basins across a range of issues, including water stress (over-exploited and degraded water resources) and threats to ecosystems, and considers the socio-economic and governance capacity to address these risks.

The assessment results portray a complex picture – there are serious risks to a wide geographic and developmental spread of basins for all of these issues. There is no single issue which is the most important, and there are no basins with either 'very low' or 'very high' risk for the full range of issues. Thus, the issues (indicators) are presented separately (chapter 3) and together (chapter 4) in a series of separate but linked analyses which drill down into the results from a number of different perspectives.

The challenges faced by basins and deltas include a mixture of threats which can be mitigated to some degree, but also unique geophysical, climatic and socioeconomic parameters which set the bounds for applying management responses. Ultimately, successful outcomes will only be achieved with a mixture of political will, resources and adequate governance capacity at both national and transboundary scales.

Figure 1.1. The world's 286 transboundary river basins span 151 countries and include more than 40% of the Earth's total land area and population (updated 2014).



Sources: Country boundaries - Global Administrative Unit Layers (GAUL) (FAO 2013); Population GPW v.3 2010 estimates (CIESIN 2005); Discharge WaterGAP2.2 estimates (Müller Schmied et al. 2014).

1 A table of transboundary river basins and their member countries is given at the end of this report.

2 Population estimates of people that live in basins using Gridded Population of the World v.3 2010 estimates (CIESIN 2005). Land area estimates derived from HydroBASINS (Lehner and Grill 2013) and FAO GAUL (FAO 2013), including lakes, and excluding the Caspian Sea. Discharge data derived from WaterGAP2.2 estimates (Müller Schmied et al. 2014).

1.4 River Basins Assessment Partnership

Over recent decades a number of global assessments have been undertaken related to various aspects of water resources and their management. Through these assessments, significant institutional knowledge and expertise, data, and assessment tools have been developed. Rather than starting from scratch, the aim of the TWAP River Basins assessment has been to build on this tremendous body of work to maximise the effectiveness and accuracy of such a global assessment. During the design phase of this project (2009-2011, UNEP-DHI 2011), a large number of potential partners were identified who could contribute significant expertise, data and assessment tools. The final list of partners was selected based on the following criteria:

- their combined ability to assess various aspects relating to water;
- their leading position within their field;
- their ability to contribute their own resources to the assessment;
- their commitment to being part of future assessments.

The River Basins working group is made up of the following nine partners. For a description of the indicators see section 2.1.

- **UNEP-DHI Partnership: Centre on Water and Environment** (component coordinator). UNEP-DHI draws on more than three decades of experience in water resource management, policy and modelling and has been involved in a number of global, regional and local assessments for the UN and other bodies (e.g. UN-Water World Water Development Reports (WWDRs), UNEP Global Environment Outlooks (GEOs)). UNEP-DHI is familiar with GEF and UNEP processes and has a broad network including river basin organizations, private companies, research institutions and UN organizations, and is therefore well placed to coordinate the River Basins component. It is also responsible for the Wastewater Pollution and Enabling Environment indicators.
- **Stockholm International Water Institute (SIWI).** Transboundary Water Management is one of SIWI's main work areas and SIWI expertise in water governance and socioeconomic aspects of water is an essential component of TWAP. Within the TWAP RB, SIWI is responsible for the Legal Framework Indicator, the cross-cutting governance assessment, and supporting component coordination. SIWI also contributes to the sustainability aspects of the assessment.
- **International Union for the Conservation of Nature (IUCN).** IUCN is a leading provider of biodiversity knowledge, and its products (e.g. Red List Index) have already contributed to valuable global assessments and reporting (e.g. Millennium Ecosystem Assessment, Convention on Biological Diversity (CBD) Aichi Targets). IUCN also has experience in defining ways to improve livelihoods and enhance human wellbeing while conserving the integrity and health of water ecosystems and their services. IUCN is responsible for supporting component coordination including harmonization of the adopted basin delineation layer and review of reporting on ecosystem indicators, and the Extinction Risk Indicator.
- **CUNY Environmental CrossRoads Initiative,** City College of New York, is an internationally recognized centre for environmental research, and a unique meeting ground for science and policy experts. CUNY CrossRoads employs regional to global scale hydrology models (WBM_{plus}) to assess how humans are embedded into the basic character of the water cycle through water abstraction and flow diversion, land-cover change, pollution, destruction of aquatic biodiversity, and climate change. Within TWAP RB, CUNY is responsible for the following indicators: Human Water Stress (baseline and projected), Wetland Disconnectivity, Ecosystem Impacts from Dams, and Threat to Fish.
- **Centre for Environmental Systems Research (CESR),** University of Kassel, with the WaterGAP (Water - Global Analysis and Prognosis) model, has broad experience in modelling and assessing global water resources, i.e. current and future water availability and sectoral water uses. CESR supports the TWAP by providing its latest datasets and modelling capability and is responsible for the following indicators: Environmental Water Stress (baseline and projected), Agricultural Water Stress, and Lake Influence.

- **Oregon State University (OSU)**, Program in Water Conflict Management and Transformation (PWCMT). The PWCMT creates and hosts the largest online database on international freshwater treaties and has undertaken a large number of projects to analyse the performance of transboundary institutions under diverse stressors. It also serves as a training, resource and information hub for students, citizens, officials, and business leaders across the United States and internationally, facilitating dialogue on critical water issues across diverse values and perspectives. It is responsible for the indicator Risk of Potential Hydropolitical Tensions due to Basin Development in Absence of Adequate Institutional Capacity (Hydropolitical Tensions Indicator - baseline and projected).

- **International Geosphere-Biosphere Programme (IGBP).** IGBP projects develop comprehensive science plans through a process of discussion and consultation with the global scientific community, involving hundreds of scientists from all continents. This ensures the development of truly international research frameworks and fosters international and interdisciplinary networks within national and regional research efforts. IGBP, with its Global Nutrient Export from WaterSheds 2 (Global NEWS 2), is responsible for the Nutrient Pollution Indicator (baseline and projected).

- **Center for International Earth Science Information Network (CIESIN),** Columbia University, works at the intersection of the social, natural, and information sciences, and specializes in on-line data and information management, spatial data integration and training, and interdisciplinary research related to human interactions in the environment. Within TWAP RB, CIESIN contributes significant experience and data with respect to global population datasets, and is responsible for the indicators for Economic Dependence on Water Resources, Societal Wellbeing, Exposure to Floods and Droughts, and projected Change in Population Density, as well as contributing the global population datasets for the whole of the TWAP.

- **Delta Alliance (DA)** (primarily Alterra and Deltares, Netherlands) is an international knowledge-driven network organization with the mission of improving the resilience of the world's deltas. Under TWAP RB, DA is responsible for the Delta Vulnerability indicators for a selection of significant transboundary deltas, drawing on methodologies developed for projects previously realized by the DA.

Transboundary river basins have a wide variety of uses and pressures on them, and a global assessment requires a range of data, modelling and expertise.

During the assessment, the TWAP RB partnership reached out to a variety of additional stakeholders, including River Basin Organizations, academics, global and regional organizations, and water conventions. These have been involved in the development of the methodology, as well as the review of assessment results. Some of these stakeholders can be found in the Acknowledgements section of this report.

1.5 Scope of Assessment and Limitations

The primary aim of the assessment is to undertake a global baseline comparative assessment of all transboundary river basins, which has the following implications for the interpretation of results:

- **Global:** the assessment must be based on data that is available for the vast majority of basins. When it comes to publicly available data, there is significant variation between basins. Because of the decreasing availability of physical data points and monitoring, it was deemed necessary during the design of the assessment to use existing global models to simulate hydrology and water impacts for the majority of the indicators. The current resolution of the majority of these models is 0.5 x 0.5 degrees (about 2 500 km^2 at the equator), although the population datasets are generally at a much higher resolution of 30 arc seconds (about 1 km^2 at the equator). This scale of modelling has implications for the level of confidence in the results for a number of smaller basins (see section 2.3.3).

- **Baseline:** As this is the first time such a comprehensive assessment has been attempted, it is not within its scope to try to determine causality between issues. For example, if a basin has high pollution risk but good governance, it is not possible to infer from the results with certainty whether the pollution risk would have been higher without the good governance, whether the governance is effective in mitigating the pollution levels, or whether governance arrangements were put in place to address the water quality issues. While every attempt has been made to understand the links between the indicators, and possible interpretations are often offered, understanding causality can only really be achieved through more detailed studies for each individual basin.

- **Comparative:** given the broad scope and global range of the assessment, it is not intended to be a detailed 'state of the environment' assessment for every transboundary river basin. The results should therefore mainly be understood in comparative terms rather than as absolute values for any one issue. Furthermore, the assessment uses a broad range of indicators to represent various issues. The indicator results should therefore be seen as representative of a given issue, without providing a detailed understanding of the issue in its entirety.

Given the above scope and limitations, it is recognized that some basins will have more detailed and potentially more accurate information than this global analysis can offer. The identification of any discrepancies between local assessments and this assessment will be welcomed as a means of strengthening the assessment.

1.6 Report Structure

The remaining sections of this report are structured as follows:

Chapter 2 provides information on the overall methodological approach of the assessment. This includes information on the considerations and criteria behind the choice of indicators and explanation on the main assessment units (in this case basins and Basin Country Units). Chapter 2 also briefly introduces spatial resolution of the main datasets, and the aggregation methods used to calculate basin and BCU risk categories. The categorization approach is also described here.

Chapter 3 presents assessment results for all river basin indicators across the five thematic groups – Socioeconomics, Water Quantity, Water Quality, Ecosystems and Governance. Indicator result sections include brief descriptions of the indicator, calculation steps, the main findings and a brief interpretation of the results. Both baseline and projected indicators are included where relevant, as well as some reflections on the possible correlations of results within the thematic groups.

Chapter 4 presents an integrated analysis of the indicator results, looking at the results across the thematic groups. The analysis dissects emerging results correlations, groups of basins that have similar risk profiles, and basins that appear to represent relative 'success stories'. The chapter is structured around a number of relevant questions that the results of this assessment can help to answer.

Chapter 5 presents results for indicators that tie the transboundary river basins analysis to other water systems. In this assessment, the water systems links are underpinned by the analysis of Lake Influence and a suite of indicators assessing Delta Vulnerability[3].

Chapter 6 summarizes the key messages and main findings of the assessment, adding the perspective of policy relevance and ideas for further development and future use of the assessment.

A table of transboundary river basins and their member countries is given at the end of this report.

3 Additional water system links are discussed in the TWAP cross-cutting perspectives report, examining the trends and links emerging from the assessment results across of all five water system components of TWAP, including TWAP RB. Available at www.geftwap.org

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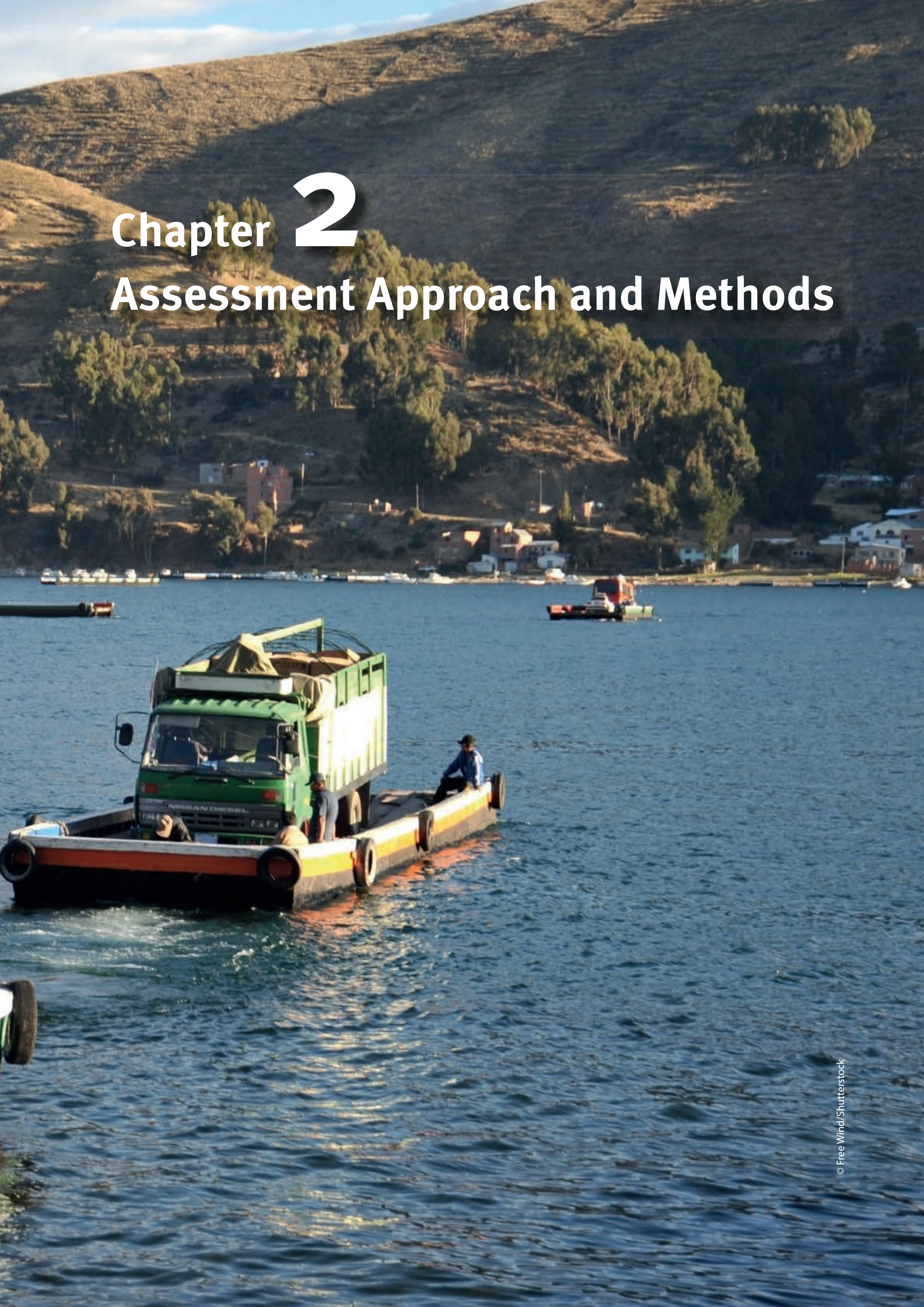
Chapter 2
Assessment Approach and Methods



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Assessment Approach and Methods

2.1 Selection of Indicators and Data Sources

This assessment aims to address both human and ecosystem vulnerability to stresses on their respective but closely-linked systems. The baseline and global nature of the assessment limits the extent to which specific causal links between human-ecosystem interactions can be established, as these vary from basin to basin and in most cases require detailed case investigations. On the 'human' side, it is recognized that in many parts of the world the primary focus of river basin management is on socio-economic needs, and on how livelihoods are affected by basin stresses and management responses. Ecosystem services have been considered either implicitly or explicitly within the indicators. However it is difficult to quantify ecosystem services, both direct and indirect, in practice. This is especially true for ecosystem services other than provisioning (e.g. food, water, fibre, fuel), which is still a challenge at the local, let alone the global level.

The conceptual framework of this assessment (Figure 2.1) therefore combines elements of the widely-recognized DPSIR (Drivers-Pressures-States-Impacts-Responses) and MA (Millennium Ecosystem Assessment) approaches into an issue-based conceptual framework.

The assessment is intended to be as broad as possible in scope. 'Issues' that affect both human wellbeing and ecosystems have been classified into five thematic groups:

- water quantity;
- water quality;
- ecosystems;
- governance;
- socioeconomics.

Indicators were selected to asses these thematic groups on the basis of the following criteria (UNEP-DHI 2011):

1. capturing human and ecosystem vulnerability;
2. the four 'A's (IGA WG 2009):
   - availability – data availability at the global scale, fit for the purposes of TWAP and which are cost-effective to acquire (either through data or modelling);
   - acceptability – perceived likelihood of stakeholder 'ownership' of indicators;
   - applicability – relevance to transboundary issues at the global scale in the context of TWAP river basins, including being relevant to other transboundary water systems where possible;
   - aggregation – the potential to aggregate data at the river-basin level and comparability between basins;
3. relevance to identification of GEF priority issues, emerging issues and links to other water systems;
4. easy to understand and interpret, and without excessive overlap between indicators.

A long list of indicators was refined through several iterations and the involvement of stakeholders, peers, and the GEF to become a 'short list' of 15 core indicators[4], as shown in Table 2.1.

4 For a more detailed description of the development of the assessment framework and the indicators, see Part 1 and Annex 6 in the Methodology for the Assessment of Transboundary River Basins (UNEP-DHI 2011).

Figure 2.1. TWAP River Basins conceptual assessment framework, showing the interdependencies between human wellbeing and ecosystem function.

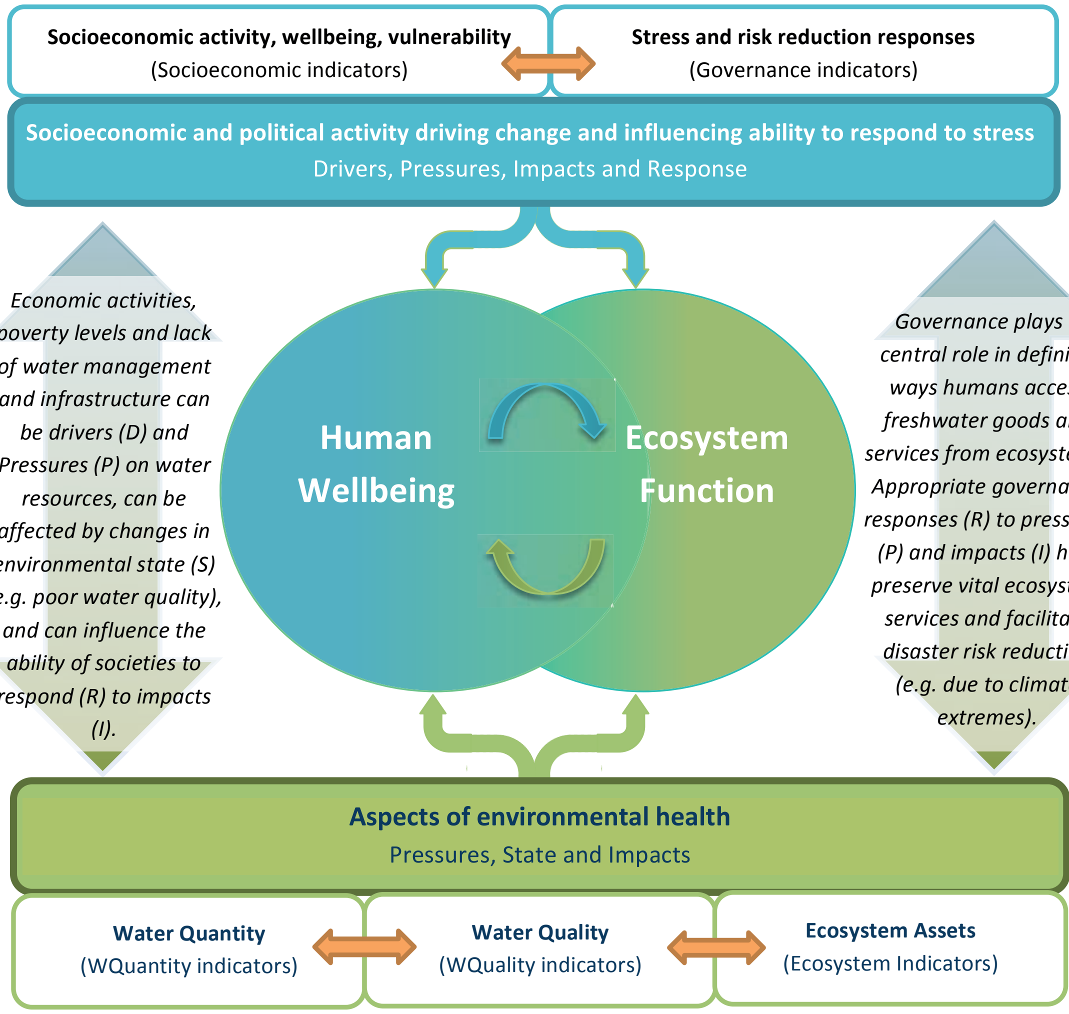


Table 2.1. Overview of TWAP River Basins Assessment Thematic Groups and Indicators

THEMATIC GROUP	INDICATORS	
	Baseline (2010)	Projected (2030/2050)
Water Quantity	1. Environmental water stress 2. Human water stress 3. Agricultural water stress	1. Environmental water stress 2. Human water stress
Water Quality	4. Nutrient pollution 5. Wastewater pollution	3. Nutrient pollution
Ecosystems	6. Wetland disconnectivity 7. Ecosystem impacts from dams 8. Threat to fish 9. Extinction risk	[Environmental water stress]
Governance	10. Legal framework 11. Hydropolitical tension 12. Enabling environment	4. Exacerbating factors to hydropolitical tension
Socioeconomics	13. Economic dependence on water resources 14. Societal wellbeing 15. Exposure to floods and droughts	5. Change in population density

Water Systems Links	
Lakes	1. Lake influence
Deltas	1. Relative sea level rise 2. Wetland ecological threat 3. Population pressure 4. Delta governance

Considerable efforts were made to keep the number of indicators to a minimum, for ease of understanding and use. So while the indicator set cannot capture all issues that may be relevant to any particular basin, the indicators cover a wide range of issues that are broadly relevant in a global context. Furthermore, an attempt has been made to remove redundancies in indicators that may cover similar issues and show similar patterns of global risk. As there is no 'perfect' indicator, sometimes a combination of indicators is necessary to achieve the required overall robustness for assessment of a particular issue. The indicators in each thematic group have therefore been chosen to complement each other by addressing different aspects of that group. Taken together, they give a more robust picture of the thematic group.

The inclusion of governance and socioeconomics indicators is an important aspect of this assessment, though they are both areas that are challenging to assess with indicators. The governance indicators consider governance capacity at both the basin and national levels, as well as the risk of tension between countries due to basin development in the absence of adequate institutional capacity. The socioeconomic indicators give some idea of the vulnerability of societies within basins, but also the likely level of pressures societies are exerting on their shared water resources.

It is therefore considered that the selected number of 15 baseline indicators covers an appropriate range of global issues, and that the end result will be simple enough to understand by a wide range of users.

The five projected indicators were chosen to cover the five thematic groups. While it is not really possible to project how governance will develop in the future, the 'exacerbating factors to hydropolitical tension' include six current factors that may be expected to affect governance in the next 10-15 years. This indicator is therefore relevant to the 2030 time period. The 'change in population density' is a key driver for the use and potential pollution of water resources, and has been selected as the projected indicator to cover the Socioeconomics thematic group.

Although there are clear links between river basins and the other water systems assessed in other TWAP components (e.g. lakes and reservoirs, aquifers, and coastal areas), one of the project requirements was to consider some of the links with lakes, and to assess deltas as an important interface between river basins and coastal areas. The Lake Influence Indicator considers the storage volume in lakes and reservoirs relative to the water available in a river basin. This gives some insight into how a basin will respond to 'shocks' such as pollution, floods, or droughts. The delta indicators broadly match the five thematic groups from the assessment of river basins, and can be compared with those indicators from the respective groups.

More detailed descriptions of indicators can be found in Chapter 3 and in Annex IX (Indicator Metadata Sheets). Note that aspects of the vulnerability of human populations are also captured in the transboundary river basin fact sheets, introduced in section 2.5.

It is important that the primary focus of the TWAP is a *global* baseline assessment, though with potential for periodic repetitions to identify impacts of intervention, or changing situations without intervention. The indicators have therefore been designed to enable both a *baseline* assessment, and subsequent assessments measuring *change*. The baseline assessment is, as far as possible, based on the year 2010. Those indicators which did not have data to allow for a 2010 baseline generally had a baseline between 2000 and 2010. If a common baseline was required for all indicators, the baseline would have been set at the year 2000, given the data and resources available to the assessment. While not ideal in terms of comparisons between indicators, it was deemed preferable to use data as close as possible to 2010 to give more up-to-date results to facilitate comparison between basins. Updates to all datasets are expected in future assessments.

2.2 Assessment Units

This assessment is carried out mainly at two scales:

1. Transboundary river basins:
These are the main focus of the assessment, and most indicators are derived by calculating an average score for each of the 286 basins. The aim of this project is to assess as many of these as feasible. This assessment has tried to be as comprehensive as possible in the following ways:

- Inclusion of all transboundary river basins: if the hydrological boundaries of a river basin cross an international border, even by a relatively small amount, that basin is included. While the extent to which some of these basins are relevant for a transboundary assessment may be debated, it was deemed appropriate for this baseline assessment to include all of them. Furthermore, defining which basins are 'significantly' transboundary is likely to involve considerable subjectivity and vary from basin to basin.

- For each indicator, all basins for which it is possible to generate a value are included in the assessment. Thus, each indicator assesses a different number of basins (Chapter 3). Only for the integrated analysis involving all indicators (Chapter 4) is a core set of 156 basins used which have values for all indicators. These 156 basins cover 80% of the total area and population of all 286 basins.

2. Basin Country Units (BCUs): a BCU is the portion of a country within a particular basin. There are currently 796 BCUs identified within the 286 river basins, based on the overlay of the basin and country layers. An analysis of BCUs gets to the heart of the transboundary nature of the problem, by understanding the differences between BCUs within a transboundary basin.

An example of a transboundary river basin and the corresponding BCUs is shown in Figure 2-2. The codes identify the different country areas within a basin.

Figure 2.2. Akpa river basin and corresponding basin country units (BCUs) (Nigeria and Cameroon).

One of the outcomes of this project was an update to the former transboundary river basins dataset (maintained within the Transboundary Freshwater Disputes Database (TFDD) by Oregon State University (OSU 2015)). The improvements are described briefly below and in more detail in Annex IV.

Basin outlines were adapted from the HydroBASINS dataset, which is an update of HydroSHEDS (Lehner and Grill 2013). HydroBASINS is believed to be the most accurate global delineation of basins, based on a 90m Digital Elevation Model (DEM), which is the highest resolution currently globally available. This led to an update of the basin delineations previously stored in the TFDD, which were derived from Hydro 1k (dated about 1997).

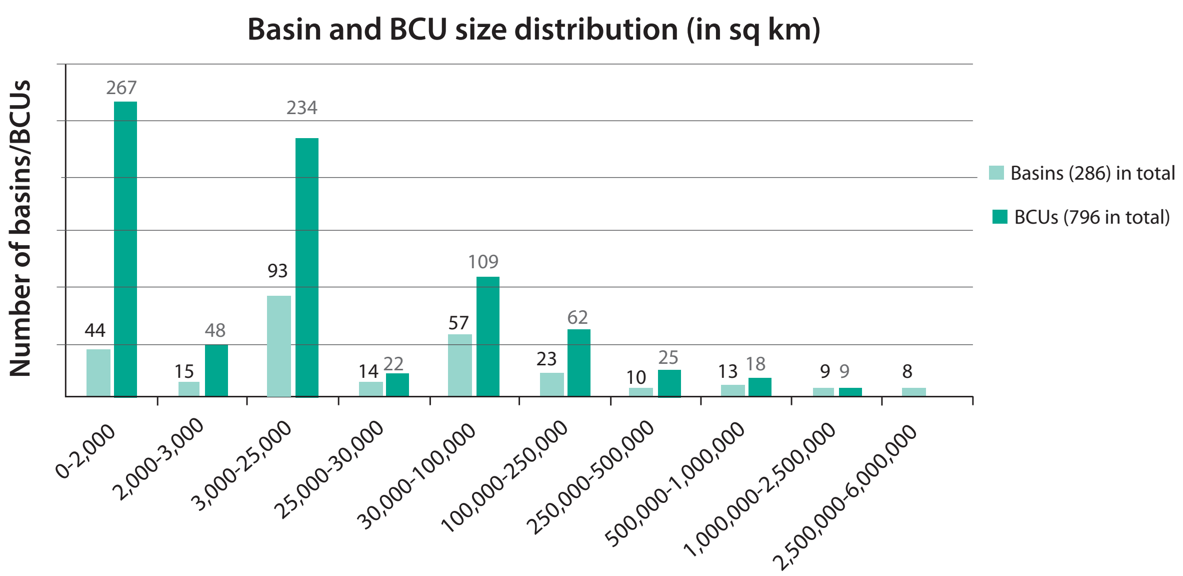
Country borders and delineation of BCUs were derived from the FAO GAUL dataset (FAO 2013)[5].

Transboundary basins were identified using the HydroBASINS output, the previous TFDD basin outlines, and the GAUL country borders, with some manual corrections for basins where there were large discrepancies from the previous version. The improved dataset resulted in an additional ten transboundary river basins that were not included in previous versions of the TFDD, for a new total of 286 transboundary basins, and corresponding 796 BCUs.

The size distribution of the basins and BCUs can be seen in Figure 2.3.

The maps and full list of all basins by continent and the unique basin IDs assigned to them can be found in Annexes II and III. Annex III-2 identifies the basins smaller than 30 000 km^2, which generally have lower levels of confidence in the results. Further details of the process and methodology used for the identification and creation of transboundary basin and basin country units (BCUs) can be found in Annex IV.

Figure 2.3. Basin and BCU Distribution by Size (in sq km).



5 Global Administrative Unit Layers (GAUL) (FAO 2013), maintained by the United Nations Food and Agriculture Organisation (FAO), uses the latest country boundaries from the UN Cartographic Unit (UNCS) and includes disputed territories. GAUL includes these areas in a way that preserves the national integrity for all disputing countries – an approach also taken by the RB component by assigning all country codes to the corresponding disputed BCU. Disputed BCU areas are treated as distinct areas in this analysis.

2.3 Aggregating Data to Basin and BCU Scales

The underlying data and results fall mainly into two categories which need to be aggregated to the basin and Basin Country Unit (BCU):

- country-level data: national values are usually assigned to the BCU where appropriate, then BCU values are typically aggregated to the basin level by a weighted average (e.g. by the average portion of population and area in that BCU compared to the basin total);
- gridded data: grid cells are assigned to basins and BCUs using GIS spatial information tools.

The underlying data for the Extinction Risk Indicator is calculated at the basin level compatible with the transboundary basin delineations used in this assessment (extracted from Level 08 HydroBASINS).

The Nutrient Pollution Indicator also generates modelled results at the basin level, although using slightly different basin delineations. A weighted average is applied to transfer the results to the TWAP basins.

For more information see individual indicator descriptions in Chapter 3 and the respective metadata sheets in Annex IX.

2.3.1 Country-level Data

This applies mainly to indicators Wastewater Pollution (#5), Hydropolitical Tension (#11), Enabling Environment (#12), and Societal Wellbeing (#14). For indicators #11 and #12, the national values from each BCU were aggregated to the basin level by the relative weighting of the average of population and area in each BCU compared to the basin.[6] Population estimates were derived from the Gridded Population of the World version 3 (GPW v.3) (CIESIN 2005), 2010 estimates. Area estimates were derived from BCU delineations described in section 2.2.

For indicator #14, national level socioeconomic data was aggregated to each BCU on the basis of the Global Rural-Urban Mapping Project (GRUMP v1, CIESIN *et al*. 2011) dataset at 30 arc second resolution (differentiating between urban and rural populations where relevant for the particular sub-indicator). The BCU values were then aggregated to the basin level as above.

2.3.2 Gridded (raster) Data

This applies to the majority of the remaining indicators, most of which are biophysical rather than governance or socioeconomic. Most of the modelled indicators use a 0.5 x 0.5 degree grid (about 50 x 50 km or 2 500 km^2 at the equator, smaller towards to the poles). Both global hydrological models (WaterGAP and WBM) use the same land mask (CRU world map) and the same allocation of grid cells to the associated river basin/BCU. Standard GIS tools are used to aggregate grid values to basin and BCU areas.

2.3.3 Data Sources

Table 2.2 gives a brief overview of the main approaches used to calculate results for the TWAP RB indicators. Further information is provided in the respective indicator sections in chapters 3 and 5.

6 Initially discharge and runoff datasets were included, but given the small size of many BCUs, accurate datasets could not be identified. Population and area are therefore used as proxy measures for the relative 'significance' of each BCU within the basin.

Table 2.2. Summary of parameters by indicator: data source, spatial coverage of data, number of basins and BCUs assessed

		Data			Results			
Thematic Group	**Indicator**	**Primary assessment tool / data source**	**Underlying Data Spatial resolution**	**Baseline year**	**Nr. basins assessed**	**Nr. basins with higher confidence results***	**Nr. BCUs assessed**	**Nr BCUs with higher confidence results***
Baseline Transboundary Status (2010)								
Water Quantity	1. Environmental Water Stress	Modelling (WaterGAP 2.2)	0.5° grid	2010 (climate 1971-2000)	270	163	635	292
	2. Human Water Stress	Modelling (WBM_{plus})	0.5° grid	2010 (climate 1971-2000)	247	135	578	252
	3. Agricultural Water Stress	Modelling (WaterGAP 2.2)	0.5° grid	2010 (climate 1971-2000)	270	163	635	292
Water Quality	4. Nutrient Pollution	Modelling (GlobalNEWS 2)	Basin	2000	280	133	-	-
	5. Wastewater Pollution	Literature (EPI data)	BCU	2010 (1990 – 2013)	284	280	776	776
Ecosystems	6. Wetland Disconnectivity	Modelling (WBM_{plus})	0.5° grid	2000	205	126	542	327
	7. Ecosystem Impacts from Dams	Modelling (WBM_{plus})	0.5° grid	2000	238	132	551	243
	8. Threat to Fish	Modelling (WBM_{plus})	0.5° grid	2000	224	132	520	240
	9. Extinction Risk	IUCN Red List	HydroBASINS level 8	2010 (2003 (est.) – 2014)	282	147	785	453
Governance	10.Legal Framework	Literature (OSU TFDD treaty database)	Basin	2007 (1820 – 2007)	286	277	792	780
	11.Hydropolitical Tension	Literature	BCU	2010	286	286	796	796
	12.Enabling Environment	Questionnaire (IWRM 2012 Status Report)	National to BCU	2010 (2012)	230	212	674	674

		Data			Results			
Thematic Group	**Indicator**	**Primary assessment tool / data source**	**Underlying Data Spatial resolution**	**Baseline year**	**Nr. basins assessed**	**Nr. basins with higher confidence results***	**Nr. BCUs assessed**	**Nr BCUs with higher confidence results***
Socioeconomics	13.Economic Dependence on Water Resources	Satellite (DMSP-OLS) & Modelling (WaterGAP 2.2)	30 arc secs & 0.5° grid	2010 (climate 1971-2000)	286	286	796	453
	14.Societal Wellbeing	Literature (Various, see section 3.1.2)	National to BCU	2010 (2000 – 2012 depending on sub-indicator)	286	286	796	796
	15.Exposure to Floods and Droughts	Modelling (WaterGAP 2.2)	0.5° grid	1971-2000 and 2011	286	179	785	442
Projected Transboundary Stress (2030/2050)								
Projected stress	1. Environmental Water Stress	Modelling (WaterGAP 2.2)	0.5° grid	n/a	270	163	635	292
	2. Human Water Stress	Modelling (WBM_{plus})	0.5° grid		247	135	578	252
	3. Nutrient Pollution	Modelling (GlobalNEWS 2)	0.5° grid		283	133	-	-
	4. Population Density	Modelling (ISI-MIP)	0.5° grid		239	139	548	548
	5. Hydropolitical Tension	Literature	BCU		286	286	796	406
Water Systems Links								
Lakes	1. Lake Influence	Lakes and Wetlands Database Level 1 (GLWD1) + WaterGAP2.2	0.5° grid	2000	270	163	-	-
Deltas	2. Delta Vulnerability Indicators	Literature (Various – see section 5.2)	Deltas	2000 (2000 – 2012 depending on indicator)	Assessment of 26 deltas			

** Assessment results cover basins for which results have been calculated with varying levels of confidence. The levels of confidence in assessment results can be associated with the resolution of data (e.g. lower confidence in results for very small basins), or other factors such as missing data. The details of levels of confidence are described in the individual indicator sections in chapter 3 and their respective metadata sheets in Annex IX. Annex III-2 identifies the basins smaller than 30 000 km², which generally have lower levels of confidence in the results.*

2.4 Categorization

Basins and BCUs are grouped into five relative risk categories for each indicator, for the following main reasons:

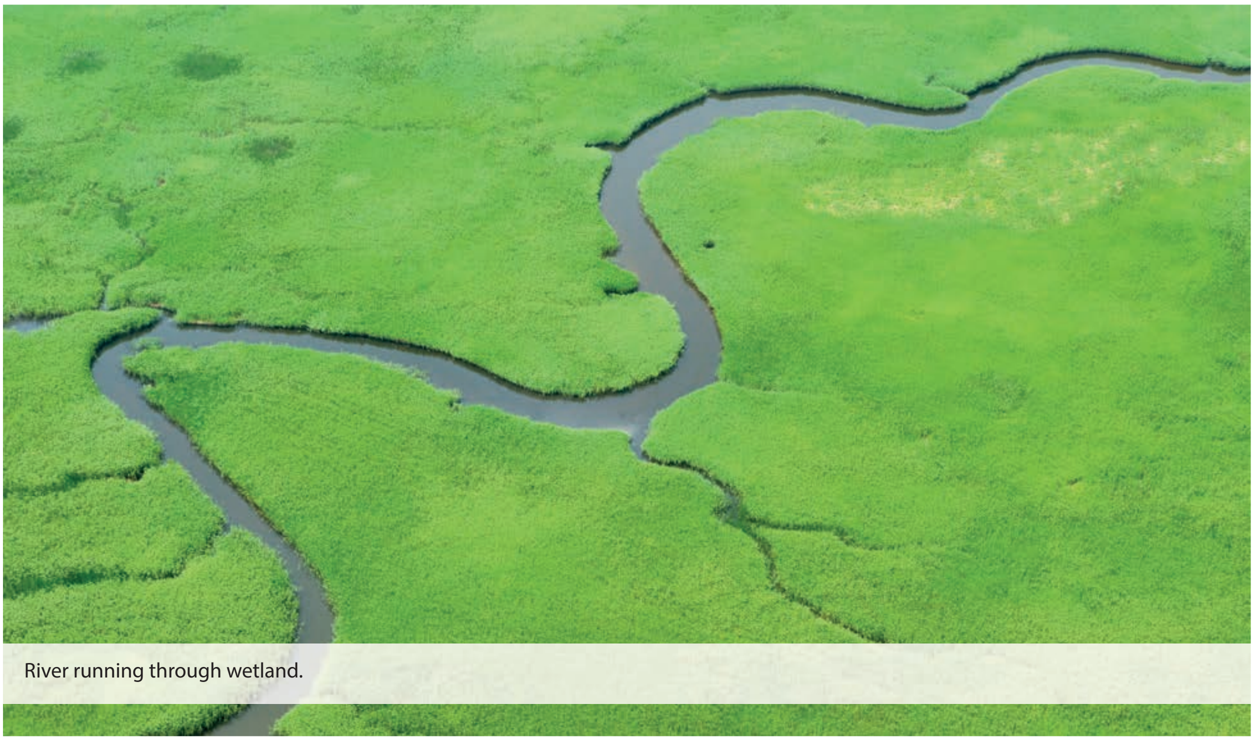
- given the large number of basins and BCUs, a common categorization approach allows the dataset to be simplified to facilitate the identification of basins and BCUs with similar results profiles, without delving into the details of exact indicator scores;
- given the global nature of the assessment, it may not be possible to place a particular basin exactly within a ranked list with a high degree of confidence; rather, basins may be said to be comparable with other basins with similar scores (i.e. in the same category);
- by using a common risk categorization narrative for all indicators, the results profile of a basin can be analysed across the full suite of indicators.

The assessment has defined categories of relative risk to be applied to all indicators as follows:

Table 2.3 Risk Categorization Approach

Relative Risk Category
1 - Very low
2 - Low
3 - Moderate
4 - High
5 - Very high

The principle of *relative* risk is used here since the assessment is intended to be not a detailed basin-by-basin study but an overarching assessment which allows for the direct comparison of the situation between basins. Risk here refers to the risk to either humans or ecosystems for the particular issue the indicator represents within the transboundary basin context.



River running through wetland.

The relative risk categories were assigned using thresholds defined on an indicator-by-indicator basis, using science-based thresholds where available and statistical categorization approaches where no such thresholds could be identified. The individual approaches to assigning these thresholds are discussed in the indicator descriptions in chapter 3 and in detail in the metadata sheets for each of the indicators in Annex IX.

2.5 Data and Information Management

In addition to the information in this report, all data and results can be found through the TWAP RB website and data portal (http://twap-rivers.org/). Data and results may be viewed in a number of different ways, including at the basin and BCU levels, and indicator maps, results sheets and indicator description sheets can be downloaded. River-basin factsheets can also be downloaded for each basin. These contain the background information relevant to each basin, as well as an overview of the results (see example factsheet in Annex V).

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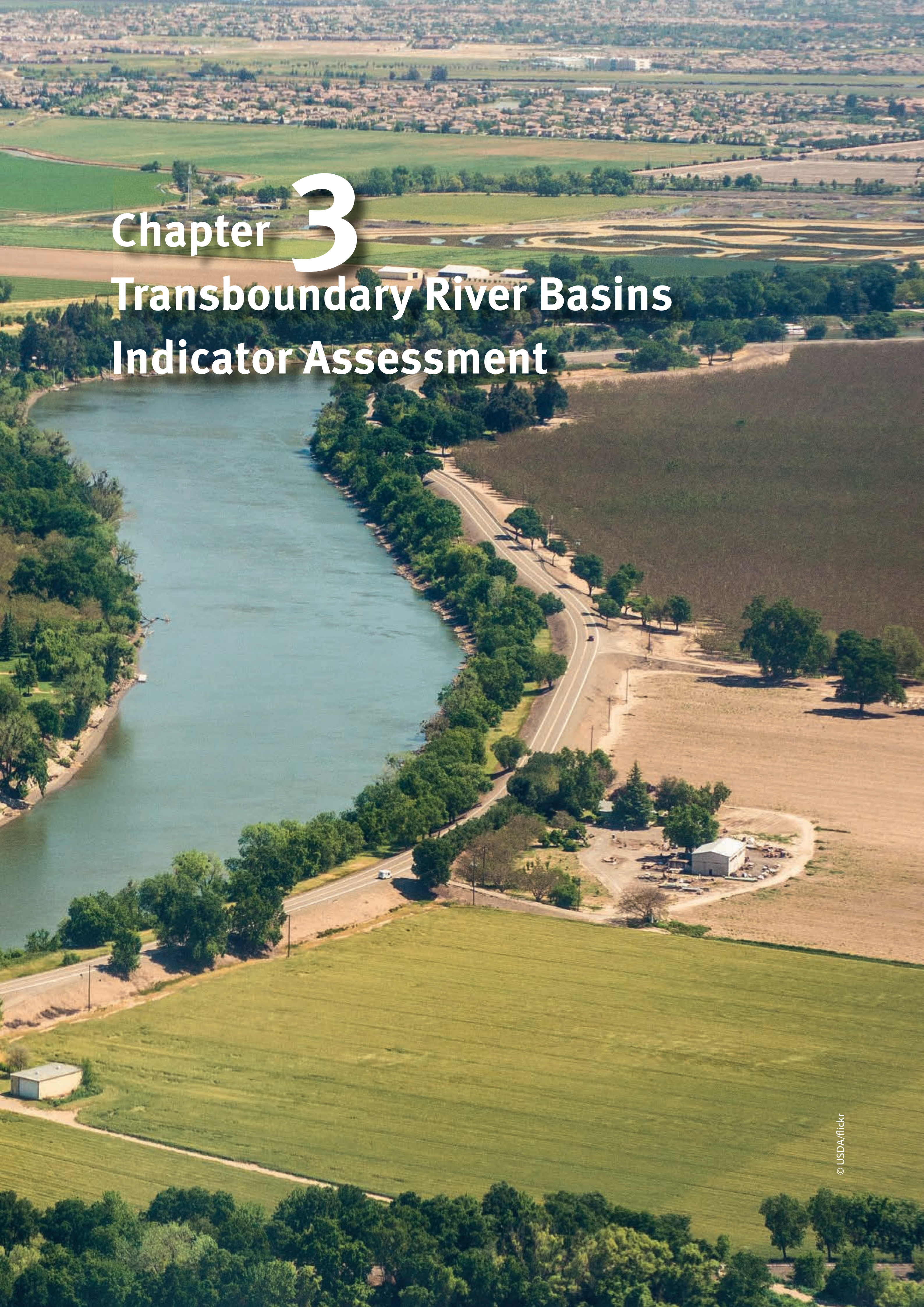

Chapter 3
Transboundary River Basins Indicator Assessment

Chapter 3.1 Socioeconomics

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Chapter 3.4 Ecosystems

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Chapter 3.5 Governance

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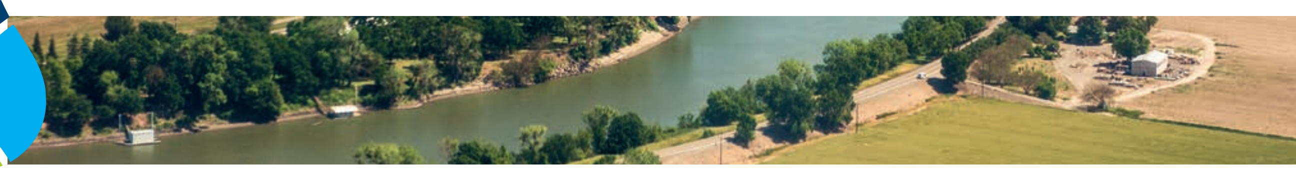
Transboundary River Basins Indicator Assessment



This chapter presents the results of the TWAP RB indicator assessment, giving the findings of the indicator calculations for all baseline and projected river basin indicators.

It is structured according to the five thematic groups (sections 3.1 to 3.5). Each thematic section describes the indicators for the respective thematic group, summarizes key thematic findings, and examines the correlations between indicators within same thematic group. Each thematic section includes results for the baseline indicators and projected results for a selection of indicators. Projected transboundary stress was calculated for five indicators, roughly covering all five indicator thematic groups, to give an insight into possible future risk scenarios in the basins. Results of the projected indicators are included in the respective thematic group chapters, along with the baseline results.

Figure 3.1 gives an overview of the structure of the chapter, broken down into five sections (thematic groups) and sub-sections (indicators). The socio-economics thematic group is discussed first as this sets the context for several of the physical parameters. The governance indicators illustrate the capacity of basins and countries to respond to challenges highlighted by the other indicators.

Figure 3.1. River Basin Indicator Overview by Section and Sub-section.

TWAP River Basins Indicators: Assessment Results

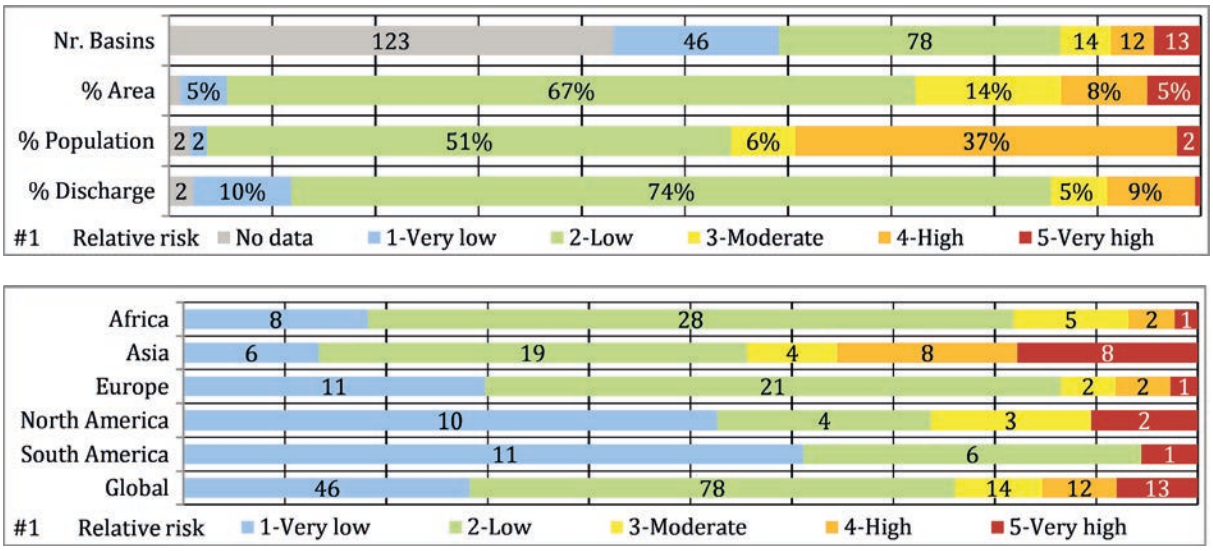
3.1 Socioeconomics	3.2 Water Quantity	3.3 Water Quality	3.4 Ecosystems	3.5 Governance
3.1.1 Economic Dependence on Water Resources	3.2.1 Environmental Water Stress – Baseline	3.3.1 Nutrient Pollution – Baseline and Projected for 2030 and 2050	3.4.1 Wetland Disconnectivity	3.5.1 Legal Framework
3.1.2 Societal Wellbeing	3.2.2 Environmental Water Stress – Projected 2030 and 2050	3.3.2 Wastewater Pollution	3.4.2 Ecosystem Impacts from Dams	3.5.2 Hydropolitical Tension – Baseline
3.1.3 Exposure to Floods and Droughts	3.2.3 Human Water Stress – Baseline	**Water Quality Thematic Summary**	3.4.3 Threat to Fish	3.5.3 Hydropolitical Tension – Projected
3.1.4 Projected Changes in Population Density	3.2.4 Human Water Stress – Projected 2030 and 2050		3.4.4 Extinction Risk	3.5.4 Enabling Environment
Socioeconomics Thematic Summary	3.2.5 Agricultural Water Stress		**Ecosystems Thematic Summary**	**Governance Thematic Summary**
	Water Quantity Thematic Summary			

Each thematic section begins with an overview of the indicators in the group, and the overarching key findings from the group of indicators. The thematic group sections conclude with a summary of results for that thematic group, considering the indicators as a group rather than individually.

Each indicator sub-section begins with the key findings for that indicator, and then describes the rationale, computation, results, interpretation of results, and limitations and potential for future development.

The individual indicator results sections contain global results maps of relative risk at the basin and basin country unit (BCU) level. The maps provide a global overview of results, with six windows underneath zooming in on areas of smaller basins and BCUs. The results for these basins and BCUs are likely to have lower confidence results for the majority of the modelled indicators. Basins with lower levels of confidence (as described in the 'limitations' section for each indicator), are marked by hatching on the results sheets and basin factsheets downloadable from the portal (http://twap-rivers.org). The results sections also contain 'banner' diagrams summarizing the spread of indicator categories from a global perspective, but also in terms of the distribution of risks by continent, area, population, and discharge of transboundary river basins. All banner diagrams accounting for indicator results are based on data with a relatively high degree of confidence in the results, unless otherwise indicated. The calculated results for lower confidence basins therefore fall under the category 'no data', since the calculated risk cannot be presented with high scientific confidence. The global maps, however, give a visual snapshot of *all* results.

Figure 3.2. Example of 'banner diagrams' used for each indicator, showing relative risk categories by: number of basins, global transboundary basin % for area, population and discharge (top) and number of basins by region (bottom).



An example of a banner diagram is provided above. It shows, for example, that even though 123 basins either had no results or lower confidence results for this indicator, these basins account for only about 1% of the total area and 2% of the total population and discharge for all transboundary river basins. Thus, interpretation of results at the global level may be considered appropriate, even though the results for a large number of smaller basins (as shown on the global maps) are only indicative and cannot be assigned a credible level of scientific confidence. The banner diagram also shows that population appears to be a driver for this indicator, since a much greater proportion of the population, rather than of the area, falls in the moderate to very high relative risk categories (3 – 5). For visual clarity, all labels of 1% have been removed from the diagrams, and labels of 2% and 3% have had the '%' symbol removed.

3.1 Socioeconomics

This section addresses results from the socioeconomic analysis, focusing on three components: economic dependence on water resources, societal wellbeing, and exposure to climate-related natural hazards (floods and droughts). These components represent key aspects of the coupled human-environment system: the economy, human wellbeing, and disaster risk.

The Economic Dependence on Water Resources Indicator (#13) is a measure of the degree to which economies are dependent on the water resources of transboundary basins. This is assessed through a weighted average of the economic activity of each BCU compared to the rest of the country within which it lies. A complete evaluation of ecosystem services represented by the water resources in all basins included in this assessment is not possible, but this indicator is a useful proxy.

The Societal Wellbeing Indicator (#14) is a measure of the degree to which societies in the basins are vulnerable to changes in the quality and quantity of water resources flowing in those basins. The sub-indicators here track closely those used in the Millennium Development Goals. Societies with lower levels of economic development are expected to be more vulnerable to economic shocks that result from perturbations in water availability, and to natural disasters.

The Exposure to Floods and Droughts Indicator (#15) is a measure of the degree to which economies and populations are at risk from climate extremes. Natural disasters can deal a severe blow to economies, shaving off significant portions of GDP and slowing development trajectories. In an ideal world we would be able to measure the degree to which disaster risk reduction policies and programmes are in place, and this is partly captured in the governance and institutional components of the TWAP assessment.

Our understanding of risk is informed by the Intergovernmental Panel on Climate Change, where risk has three aspects, as defined below (IPCC 2014):

- **Hazard:** The potential occurrence of an event that may adversely impact people, economies or ecosystems.
- **Vulnerability:** The propensity or predisposition to be adversely affected by a hazard. Vulnerability encompasses a variety of concepts including sensitivity to harm and lack of capacity to cope and adapt.
- **Exposure:** The presence of people, economic assets and services, or ecosystems that could be adversely affected by a hazard.

Water in transboundary river basins is a key component of economic development, including as a coolant in power plants

Risk is often understood as 'likelihood' (i.e. considering the hazard) multiplied by 'consequence' (i.e. considering vulnerability and exposure). Given the above framework, the Economic Dependence Indicator (#13) mainly includes aspects of exposure, but also considers vulnerability. The Societal Wellbeing Indicator (#14) mainly includes aspects of vulnerability. The Exposure to Floods and Droughts Indicator (#15) combines aspects of hazard and exposure. Together, the indicators give an overall picture of risk to societies.

This thematic group builds on understanding gleaned from the Millennium Ecosystem Assessment and the Millennium Development Goals, among others. Although the chosen metrics are imperfect, they aim to illuminate the coupled human-environment system in ways that the environmental stress and human water stress metrics on their own do not.

Thematic group key findings

1. **Climate-related risk is linked to economic dependence and low wellbeing:** Basins with high economic dependence, low levels of societal wellbeing and high exposure to floods and droughts have the highest climate-related risks. These basins are found mostly in Africa and south and southeast Asia. They include, at the highest levels of vulnerability, the Limpopo, the Ganges and the Mekong.
2. **Wellbeing and governance capacity to address disasters are linked:** In basins where societal wellbeing is low, governance capacity to address vulnerability to floods and droughts is also likely to be low. Women, children and people with disabilities are groups particularly vulnerable to floods and droughts. Attention might be warranted to assess governance needs and increase capacity in these countries and basins.
3. **Larger basins have larger economic dependence:** Larger basins tend to have higher levels of economic dependence on basin water resources, due mainly to the fact that larger basins are likely to include greater portions of the populations and areas of the countries. The 14 basins with the highest levels of economic dependence collectively comprise a population that is almost 50% of all transboundary basins (almost 1.4 billion people). These larger basins may be harder to manage from a transboundary point of view because of the number of countries and diversity of priorities. Management becomes even more critical to safeguard socioeconomic wellbeing in these countries.

3.1.1 Economic Dependence on Water Resources

Key findings

1. **Many countries have high dependence on transboundary rivers:** There are several basins in Africa, Europe, and Asia that have high levels of economic dependence on transboundary water resources – including the highly populated Nile, Danube, and Ganges basins.
2. **Benefit sharing is key for basins with high economic activity:** Sharing benefits is most critical for basins which have high economic dependence on transboundary waters and high absolute levels of economic activity. The states that share them therefore have a strong incentive to negotiate benefit-sharing agreements and implement integrated river basin management. These basins include the La Plata, Danube, Tigris, Ganges, Indus, and Mekong.

Rationale

Withdrawal from water systems is often related to human activities aimed at supporting production activities to sustain economic growth. For example freshwater is often abstracted to provide for irrigated agriculture as well as domestic and industrial needs. Understanding the degree to which a country's economic activity is concentrated in given portions of transboundary basins (BCUs), and therefore the level of dependence on freshwater resources in those basins, will help to illuminate the risk to economies sharing a basin should water supplies be altered substantially. This same metric can also help to assess the level of human pressure on water resources.
This indicator is composed of the following sub-indicators:

- urban activity fraction - a measure of urban economic activity, including domestic, commercial and industrial;
- agricultural activity fraction - a measure of irrigation activity.

Computation

For the urban activity fraction sub-indicator, we used night-time lights (NTL) data from the Defence Meteorological Satellite Program-Optical Line Scanner (DMSP-OLS). These data are commonly used for identifying human settlements and economic activity (at least urban and industrial activity). Night-time lights radiance data were summed by BCU and by country, and the BCU total was divided by the country total to get an urban activity fraction per BCU. The BCU results were then aggregated to the basin level by taking the weighted average of the BCUs, with weights based on an average of the proportional share of population and land area in each BCU, compared to the basin total. This is a measure of the urban economic dependence of the countries that share a basin on the water resources within that basin.

For the agricultural activity fraction sub-indicator, we used water withdrawal for irrigation data from the WaterGAP 2.2 model (Müller Schmied et al. 2014). We applied an identical process to the urban activity fraction, calculating the fraction of irrigation water withdrawal for each BCU compared to the respective country totals, and then calculating the weighted average of BCU scores to develop a basin score. Because of WaterGAP grid cell resolution, 158 BCUs out of 796 did not have the agricultural activity fraction sub-indicator.

The urban and agricultural activity fractions were somewhat correlated (Pearson's r =0.36, p<001), so we averaged the two to create an overall economic dependency measure. BCUs without the agricultural activity fraction are based entirely on the urban activity fraction. Fractions were then converted to the five risk categories based on expert opinion as shown in Table 3.1. At the high end, we consider basins that contain more than 60% of the riparian countries' economic activity to be at very high relative risk, in the sense that water resources in these basins are more needed in order to maintain industrial and agricultural activities. Any decline in these resources, therefore, is likely to result in significant negative impacts on the countries' economies. We consider basins containing 40-60% of economic activity to be at high relative risk, and those with 20-40% to be at moderate relative risk. Basins with only marginal percentages of riparian countries' economic activity, 0-20%, are at very low to low relative risk.

Table 3.1 Economic Dependence on Water Resources Relative Risk Categorization

Relative risk categories	Average of Economic Activity and Agriculture Activity Fractions
1 - Very low	0-0.1
2 - Low	0.1-0.2
3 - Moderate	0.2-0.4
4 - High	0.4-0.6
5 - Very high	0.60-1.0

Metadata on each of these sub-indicators can be found in Annex IX.

Results

Figure 3.3 shows the results of the indicator by risk category. Several basins in Africa – the Nile, Congo, and Zambezi – demonstrate very high levels of economic dependence. Other basins with very high dependence include La Plata (S. America), Danube and Po (Europe), Ganges (South Asia), Jordan and Tigris (Middle East), and the Aral Sea (Central Asia).

Moderately high risk basins in Figure 3.3 often show up with one or more highly dependent BCUs in Figure 3.4. Examples include the dependence of Mali and Niger's economies on the Niger River, Macedonia's dependence on the Vardar, Belarus' dependence on the Dnieper, Pakistan's dependence on the Indus, and Laos and Cambodia's dependence on the Mekong.

Figure 3.3. Economic Dependence on Water Resources by Transboundary River Basin. Based on urban and agricultural activities, there are a number of basins which are of very high economic importance to the countries in them, and where benefit sharing and adequate transboundary institutions are critical.

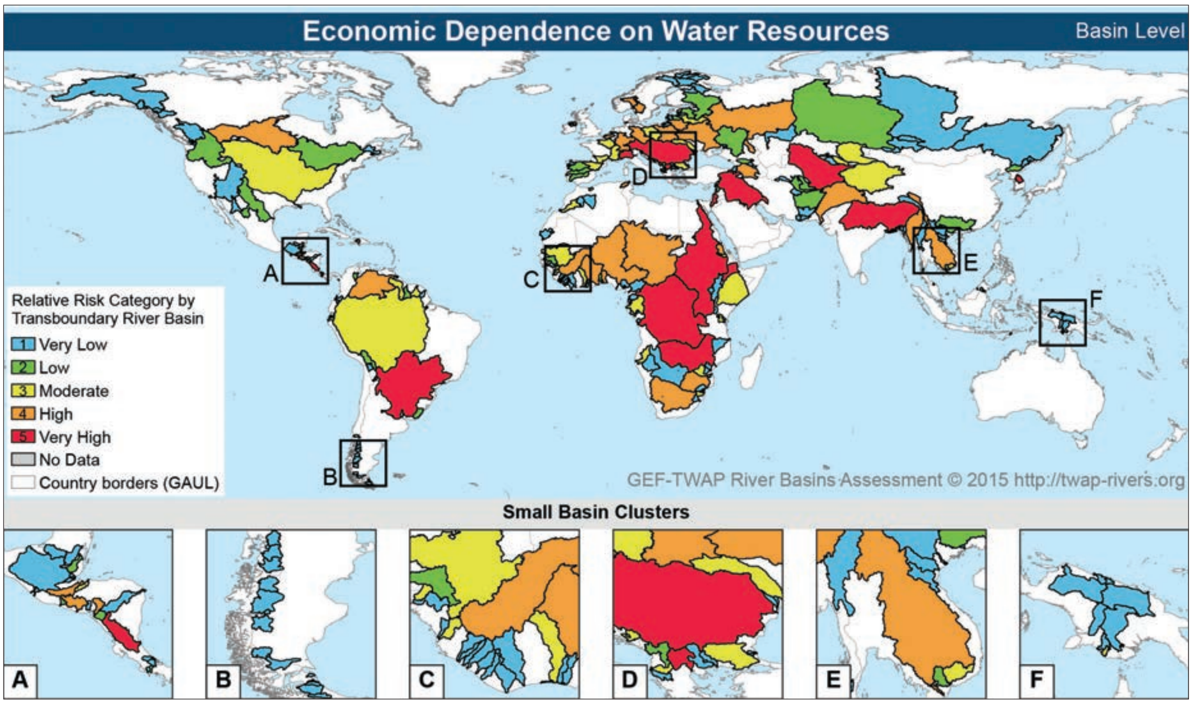


Figure 3.4. Economic Dependence on Water Resources by Basin Country Unit (BCU), based on urban and agricultural activities. Countries that have high economic dependence may have a strong incentive to negotiate benefit-sharing agreements and implement integrated river basin management.

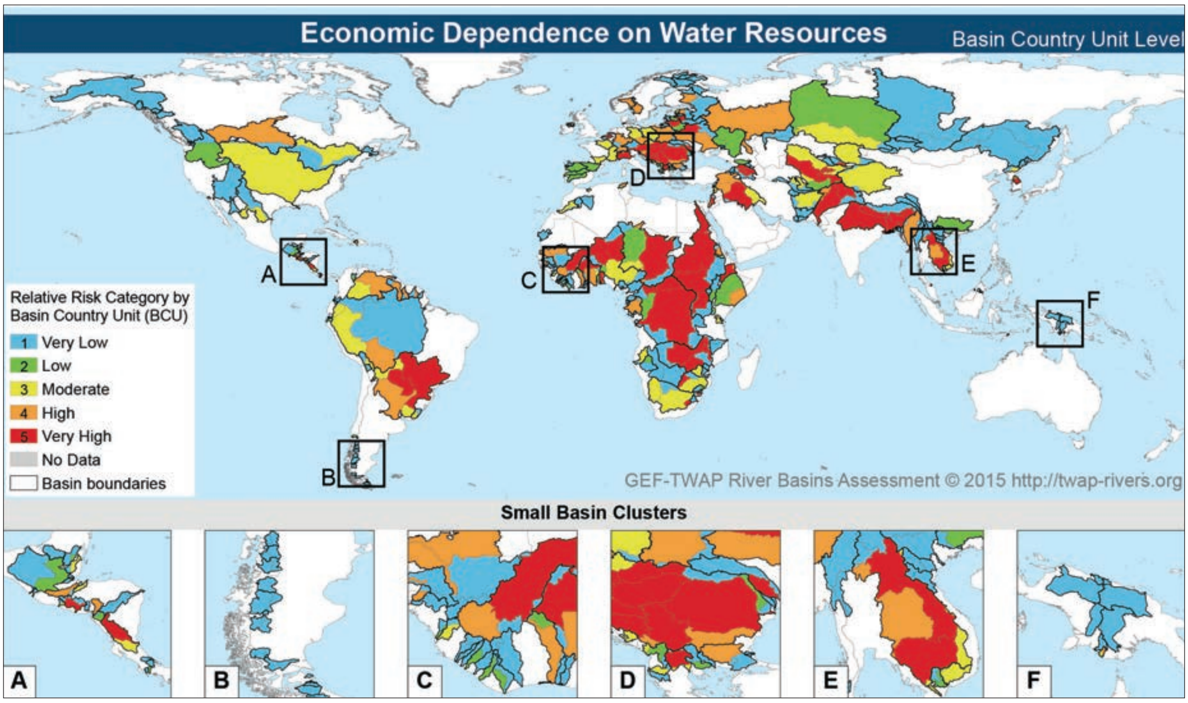
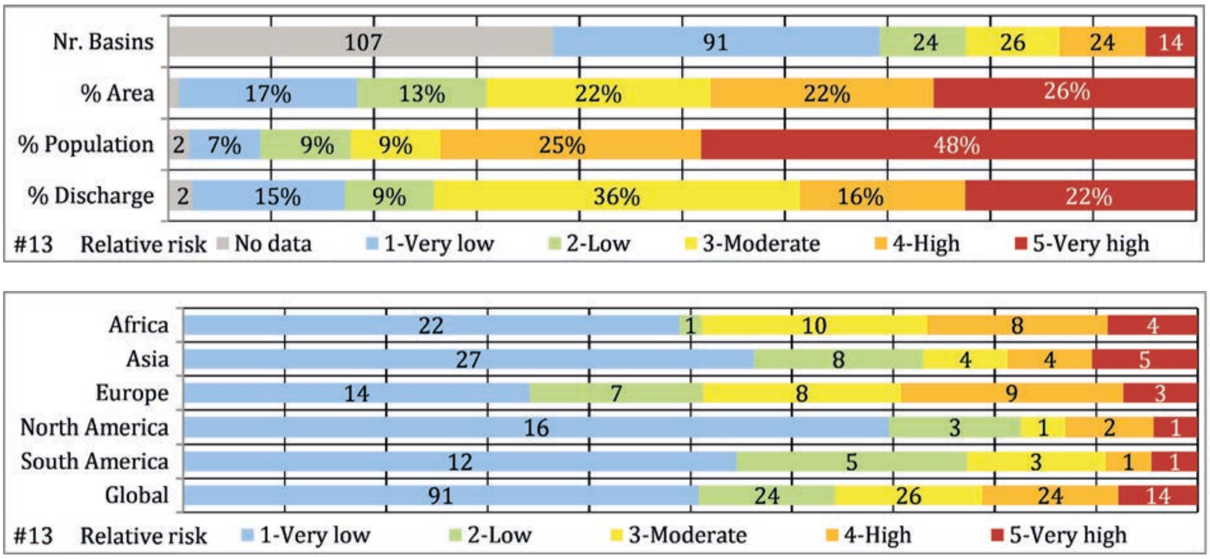


Figure 3.5. Economic Dependence on Water Resources Relative Risk Categories[7] by: number of basins, global TB basin % for area, population and discharge (top) and number of basins by region, 'no data' basins excluded (bottom). Nearly 50% of the people that live in transboundary basins do so in basins with very high economic dependence.



Interpretation of results

In general, results at the basin level show that several basins are of very high economic importance to riparian countries, with a particular concentration of basins in Africa (Nile and Congo), Europe (Danube and Po), Asia (Tigris, Aral and Ganges), and South America (La Plata). The BCU level analysis reveals some additional basins in which countries have high levels of economic dependence but which overall have only moderate to high economic dependence scores.

All other things being equal, larger basins tend to have higher levels of dependence than smaller ones. If the basin covers a large proportion of a country's territory, it is more likely that there will be a high fraction of economic activity within that basin, and the water resources within that basin will assume a greater importance in sustaining industrial and agricultural activities. Figure 3.5 shows that although there are only 14 very high risk basins, collectively they comprise nearly half the population found in all basins. Exceptions include the Mississippi, Amazon, and large basins with low population density in north-central Asia (the Ob and Yenisey).

Probably the most important from a benefit-sharing perspective are the La Plata, Danube, Tigris, Ganges, Indus, and Mekong basins. These have high absolute levels of economic activity and the states that share them therefore have a strong incentive to develop benefit-sharing strategies and improve integrated river basin management.

Limitations and potential for future development

A total of 158 BCUs (out of 796) did not have an agricultural activity fraction sub-indicator. In these cases the BCU score was based entirely on the urban activity fraction sub-indicator. This is because the grid cell resolution of the WaterGAP 2.2 data (0.5°) prevented the reporting of results for the smallest BCUs (i.e. those which could not have a 0.5° grid cell assigned to them in the hydrological model). A further 343 BCUs are assigned between one and nine grid cells, and hence are considered to have a lower degree of scientific confidence than those with ten or more. However, these 501 BCUs account for about 1% of total BCU area, thus the overall interpretation of results at the global level is valid.

7 All banner diagrams are based on data which have a relatively high degree of confidence in results, unless otherwise indicated.

For the economic activity fraction sub-indicator, the analysis is limited mainly by the assumptions regarding the relationship between night-time lights, economic activity, and water withdrawals. It is assumed that this indicator most closely tracks the domestic and industrial withdrawals indicators. Statistical analyses showed that this indicator was highly correlated with results processed in an analogous manner for energy withdrawals and industrial withdrawals based on the WaterGAP 2.2 model. There thus appear to be moderate levels of confidence in these results.
Societal Wellbeing

3.1.2 Societal Wellbeing

Key findings

1. **Highest levels of vulnerability to climate shocks are found in Africa:** When combined with assessments of basins exposed to floods and droughts (see next indicator), one can identify basins with high levels of exposure and potential vulnerability to climate shocks, thereby gaining an overall understanding of risk. These include the Oueme, Okavango, Limpopo, Lake Natron, and Cancoso/Lauca basins.
2. **As expected, the basins of Sub-Saharan Africa have the lowest levels of societal wellbeing.**

Rationale

This indicator includes a number of sub-indicators common to the Human Development Index and the Millennium Development Goals. Basins with very low levels of societal wellbeing will be more vulnerable to substantial changes to hydrological regimes or climatic shocks to the system because the populations in these basins are generally more directly dependent on water resources for their livelihoods, and have fewer assets to enable them to cope with bad years.

The sub-indicators capture a broad range of issues relevant to societal wellbeing and levels of economic development, including:

a) access to improved drinking-water supply (WHO/UNICEF 2014);
b) access to improved sanitation (WHO/UNICEF 2014);
c) adult literacy (UNESCO 2012);
d) infant mortality rate (CIESIN 2010);
e) Gini coefficient (economic inequality) (World Bank 2013).

We considered basins with low levels of access to water and sanitation and adult literacy and high infant mortality and economic inequality to be more ‘at risk’, in the sense that any shocks or changes to current river basin flows could have significant adverse effects on the populations of these basins.

Computation

Sub-indicators *a* and *b*, access to improved drinking water supply and improved sanitation, are available at the country level with urban/rural percentage breakdowns. We therefore used the Global Rural Urban Mapping Project (GRUMP), v1 (CIESIN *et al*. 2011) data product to calculate the urban population and rural population per BCU, then multiplied these totals by the percentage coverage for urban and rural populations, respectively. The result is the total urban population and rural population with access to improved services in each BCU. The urban and rural totals were added to give the total population with access to improved services in each BCU. Finally, this was divided by the total population in the BCU to arrive at a percentage of the BCU population covered by improved water supplies and sanitation. We then calculated basin-level percentage coverage based on a weighted average of the BCU percentages, based on the relative area and population in each BCU compared to the basin total.

Sub-indicators *c* and *e* – adult literacy and Gini coefficient – were only available at the country level. Thus, basin values are a weighted average of the country values, based on the population/land area in each BCU.

For sub-indicator *d*, infant mortality rate (IMR) data were available on a global grid. The rates were multiplied by population for each grid cell in a BCU, then divided by total BCU population to arrive at a population-weighted IMR for the BCU. Again, we calculated basin IMR values based on a weighted average of BCU IMRs.

Conversion to category scores for each sub-indicator was performed as follows, with thresholds shown in Table 3.2. Sub-indicators *a*, *b*, and *c* are all percentages with theoretical minima of 0 and maxima of 100, in which higher scores are good. We created an average of the three sub-indicators (ignoring missing values), then used the average to establish one category score for the three sub-indicators. The thresholds are based on an examination of the distribution of the sub-indicator scores.

The thresholds for sub-indicator *d*, infant mortality rates, are based on Redford *et al*. (2008).

The thresholds for sub -indicator *e*, the Gini coefficient, are based on an examination of the distribution of the sub-indicator scores.

The category score for the overall indicator was based on an average of three components, the category score for indicators *a-b-c*, the category score for indicator *d*, and the category for indicator *e*. The resulting average was then converted to a new overall Societal Wellbeing Indicator category using the thresholds below.

Table 3.2. Societal Wellbeing Risk Categorization

Relative risk categories		Average of sub-indicators a, b, and c (%)	Sub-indicator d. IMR	e. Gini Coefficient	Average of sub-indicator *a-b-c*, *d*, and *e* category scores
1	Very low	>=95	<=15	<=25	0-1.5
2	Low	80-95	15-32	25-30	1.5-2.5
3	Moderate	60-80	32-65	30-35	2.5-3.3
4	High	40-60	65-100	35-40	3.3-4.0
5	Very high	<40	>=100	>=40	>4.0

Metadata on each of these sub-indicators can be found in Annex IX. The first four indicators are highly correlated (Pearson's r coefficients >0.55, p>.001). The Gini coefficient, which is a measure of economic inequality, was largely uncorrelated with the other sub-indicators. Thus, the aggregate results are more heavily driven by the first four sub-indicators.


Hanging latrines on a river bank - an example of poor sanitation.

Figure 3.6. Societal Wellbeing by Transboundary River Basin (top) and Basin Country Unit (BCU) (bottom), based on factors common to the Human Development Index and Millennium Development Goals. As expected, basins in sub-Saharan Africa have the lowest levels of societal wellbeing, and are therefore more vulnerable to water stress, poor water quality, and climatic extremes such as floods and droughts.

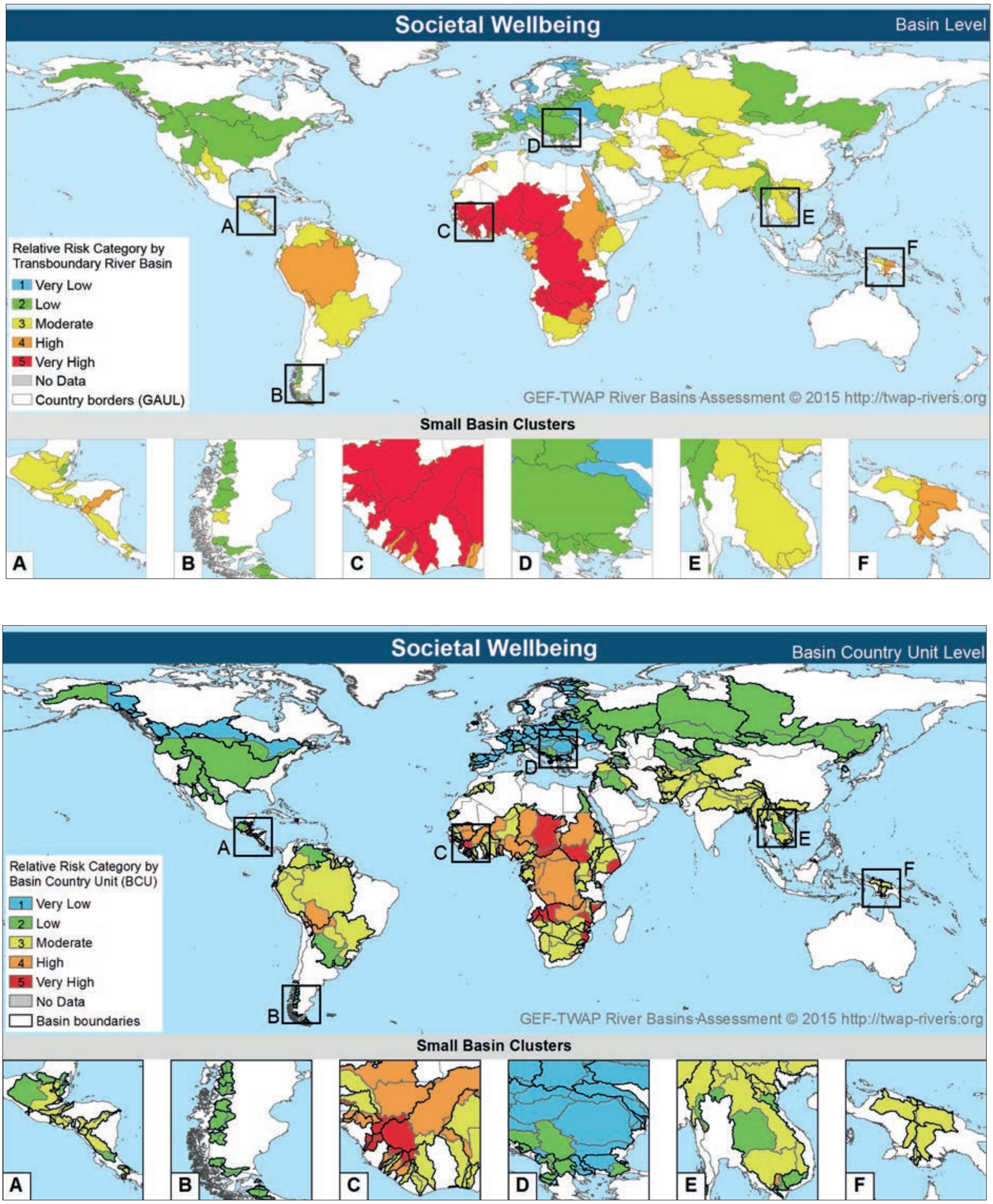
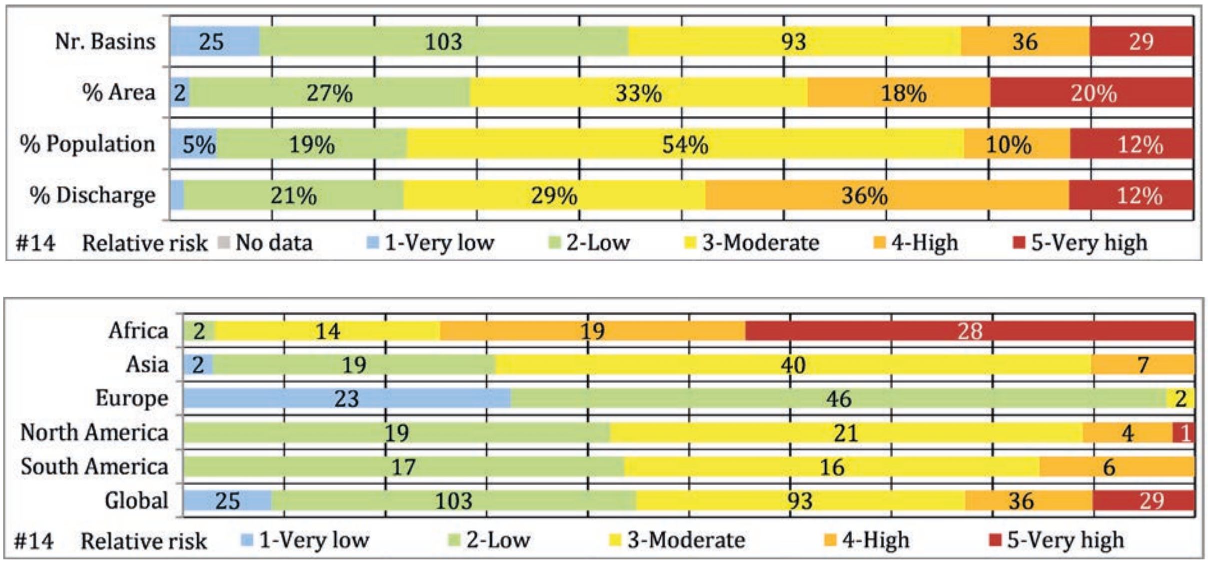


Figure 3.7. Societal Wellbeing Relative Risk Categories by: number of basins, global TB basin % for area, population and discharge (top); and number of basins by region, 'no data' basins excluded (bottom). 47 of the Africa's 63 basins are at high or very high risk.



Results

Sub-Saharan African basins are at the highest risk in terms of societal wellbeing, with very high to moderately high risk owing to low levels of economic development. A few other basins are at high risk including the Hari (shared by Afghanistan, Iran and Turkmenistan), the Sepik (shared by Papua New Guinea and Indonesia), and the Amazon.

In terms of BCUs, the break-points for categories are the same, but the underlying distribution of scores is slightly different, so their results are not completely consistent with the basin categories. Results are basically similar, but they highlight some BCUs with particularly low levels of societal wellbeing, including BCUs for Chad, South Sudan, and Angola.

Interpretation of results

Low societal wellbeing generally goes hand in hand with poor governance, including limited institutional capacity to manage transboundary water resources, and limited resilience to climate shocks, a topic we address in the next section. This is borne out by the integrated statistical analysis, which found that the first four sub-indicators are highly correlated ($r>0.5$, $p<0.05$) with the indicator on enabling environment. Both of these indicators are based mainly on national-level data, which would further explain the strong correlation. The Gini coefficient is not as highly correlated.

Limitations and potential for future development

The categorization system at both the sub-indicator and indicator levels requires some judgment because of the limited literature available on the basis of which science-based thresholds can be set. However, overall the results reflect those of related assessments (such as MDG and HDI assessments) reasonably well and are therefore considered to be reasonably robust. There is thus a relatively high level of confidence in these results.

3.1.3 Exposure to Floods and Droughts

Key findings

1. **Semi-arid areas are most exposed to disasters:** Populations and economies in semi-arid areas are most at risk from flood and drought.
2. **Exposure to floods and droughts, economic dependency and wellbeing encapsulate vulnerability:** The results for this indicator, when viewed in combination with the results for the economic dependence and societal wellbeing indicators, both of which represent the propensity to be affected by shocks, produce an overall picture of risk.
3. **Most high risk basins are in Africa and Asia:** Examples of basins with relatively high risk when considering hazard, exposure and vulnerability include the Nile, Limpopo and Juba-Shibeli basins in Africa, and the Ganges and Indus in Asia.

Rationale

This indicator analyses the risks to the populations and economies in BCUs and basins from climate-related natural disasters. Two types of natural disasters, floods and droughts, cause the greatest loss of life and economic losses of all natural disasters each year, and the likelihood and severity of floods and droughts is likely to increase with climate change. Impacts of floods and droughts are felt by humans and ecosystems, and include impacts on food security, damage to infrastructure, and displacement of people, as well as loss of lives. Hydrological variability induced by climate change will affect flow patterns in river systems. The risk of droughts and floods will typically increase, affecting both the quantity and quality of water being transported through water systems. Efforts to mitigate the impacts of flow variability brought about by climate change, for example through infrastructure construction (dams, dykes, canals), will have variable impacts on downstream areas depending on the hydrological system and the kind of infrastructure.

This indicator is based on two sub-indicators:

- Exposure to floods: potential economic costs (in US dollars) of floods, divided by GDP;
- Exposure to droughts: the population-weighted coefficient of variation of inter-annual river flows (1971-2000).

Economic exposure to floods is a measure of the likelihood of floods (hazard) and consequence (costs) in BCUs and basins relative to GDP. Because drought metrics are more difficult to standardize and therefore economic exposure is more difficult to calculate, we used an alternative metric of the population-weighted coefficient of variation (CV) of inter-annual river flows during the period 1971-2000 as a proxy for population exposure to drought (Hall *et al*. 2014; Gassert *et al*. 2013). Higher CVs equate to higher inter-annual variability of flow and therefore lower reliability, and potentially greater drought impacts. This sub-indicator could also capture high peak flows and floods, but because it captures annual flows rather than extremes that last a few days or weeks, it is more properly interpreted as a gross measure of flow variability and drought exposure. We considered basins with high economic exposure as a fraction of GDP and high inter-annual standard deviations in river flows during low flow periods to be more at risk, in the sense that they are more exposed to climatic shocks.

Computation

The first sub-indicator is based on data for estimated economic exposure to floods from the UNEP Global Assessment Report (GAR) for 2013. Economic exposure values were aggregated to the BCU level, then divided by BCU GDP based on gridded data from the same source. The result is the fraction of GDP that is exposed per BCU. BCU-level statistics were then aggregated to basin level using the standard method described above.

The second sub-indicator is calculated from annual water year (October through September) discharge data of the climate normal period (1971-2000) using the WaterGAP 2.2 model (Müller Schmied *et al*. 2014). For each grid cell the coefficient of variation (CV), defined as the ratio of the standard deviation to the mean, was calculated for the annual flows over the thirty year period. The results were population weighted, so that the contribution each grid cell makes to the overall BCU score is based on its proportion of population within the BCU. This ensures that the indicator reflects population exposure. For example, high inter-annual variability in sparsely populated arid or semi-arid portions of a BCU is not counted as much as lower inter-annual variability in portions of a BCU that have higher population density. BCU-level statistics were then aggregated to the basin level using the standard method described above.

Conversion to category scores for each sub-indicator was performed as follows, with thresholds shown in Table 3.3. For the economic exposure to flood hazards, the thresholds were based on expert opinion to give a reasonable distribution of results to suit this analysis. Note that in some BCUs the percentages exceed 100% because multiple floods in a given year can occur, and therefore flood exposure is a multiple of the GDP in the BCU.

For the CV of inter-annual flow from 1971-2000, a CV of >1 is considered to be at high risk since this means that the standard deviation is greater than the mean. The other break points represent more or less equal intervals.

Table 3.3. Exposure to Floods and Droughts Risk Categorization

Relative risk categories		Flood Economic Exposure as % of GDP	CV of Inter-Annual Flow
1	Very low	<=1	<=0.4
2	Low	1-10	0.5-0.6
3	Moderate	10-30	0.6-0.8
4	High	30-80	0.8-1.0
5	Very high	>=80	>=1.0

To assess the overall degree of exposure to floods and droughts, we took the worst of the two sub-indicator category scores as the overall category score for the indicator. We chose this approach because being highly exposed to either flood or drought can result in significant economic losses and impacts on societal wellbeing.

Further information on these sub-indicators is provided in the metadata sheets in Annex IX.

Results

At the basin level, semi-arid regions tend to have the highest exposures to floods and droughts. The Rio Grande and Colorado in the US, the Orange and Limpopo in southern Africa, and the Ganges, Tarim, and Mekong in Asia are examples of basins which are highly exposed to floods and droughts. The Indus and Dasht are examples of basins at the next highest levels of exposure.

At the BCU level, parts of the Niger, Lake Chad and Nile Basins are highly exposed, as are parts of the La Plata and Amazon basins.

Interpretation of results

Nearly one-third of the population of all basins live in very high exposure basins, and another 10% in high exposure basins. Asia has the highest percentage of basins in these two categories. Europe and North America generally have very few basins at high to very high exposure. This is somewhat counter-intuitive when viewed from the perspective of total flood economic losses, for example, but here we are considering losses relative to total basin GDP and other regions clearly have a higher proportion of assets exposed. Apart from the U.S. Southwest, these temperate climates also do not have large variations in rainfall that would result in major inter-annual swings in river flows.

Figure 3.8. Exposure to Floods and Droughts by Transboundary River Basin, based on the higher risk category of floods or droughts. Semi-arid areas tend to be at highest risk, as well as those exposed to monsoonal climate patterns.

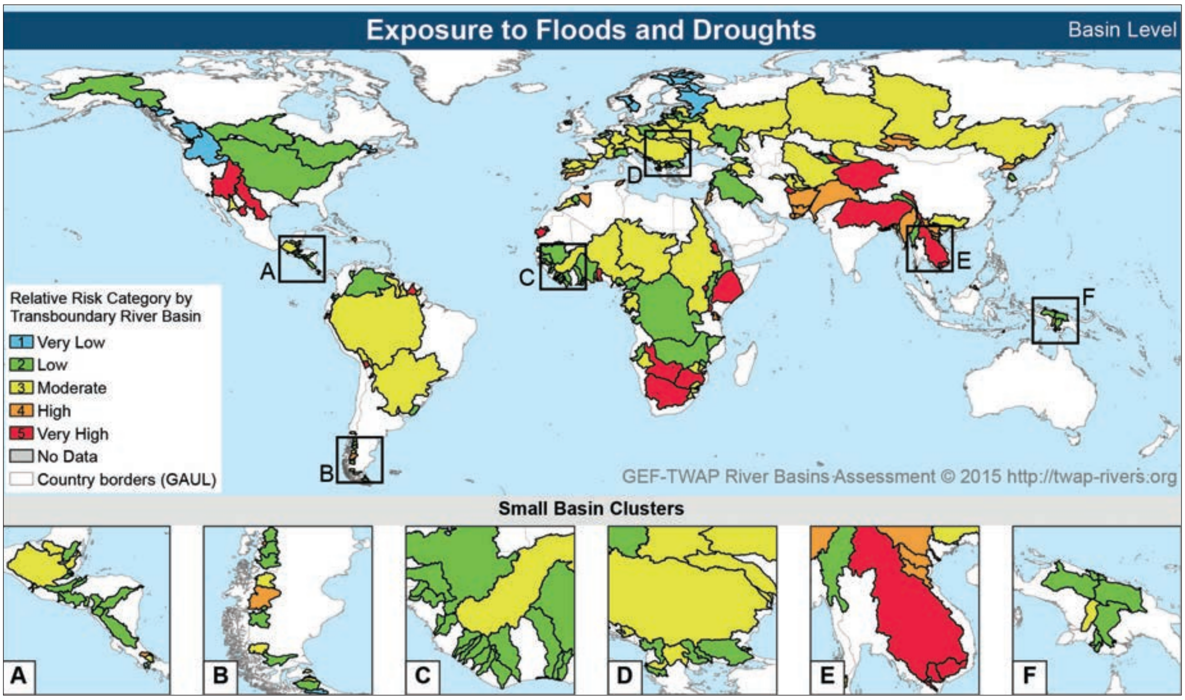


Figure 3.9. Exposure to Floods and Droughts by Basin Country Unit (BCU), based on the higher risk category of floods or droughts. Semi-arid areas tend to be at highest risk, as well as those exposed to monsoonal climate patterns.

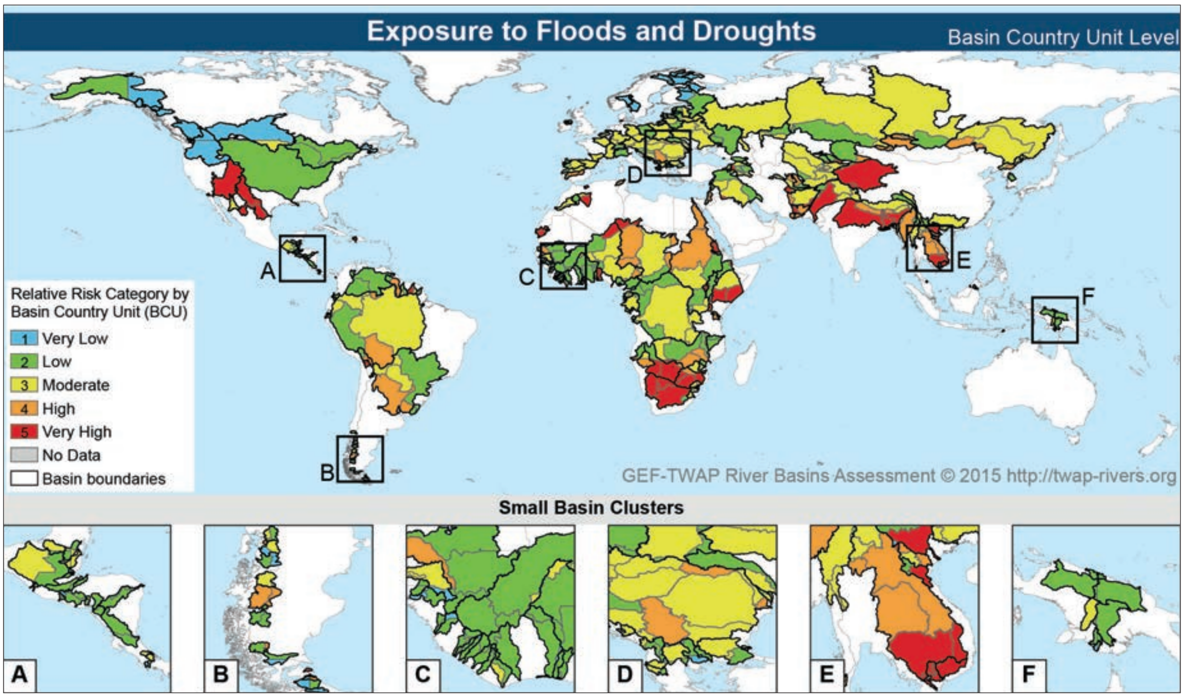
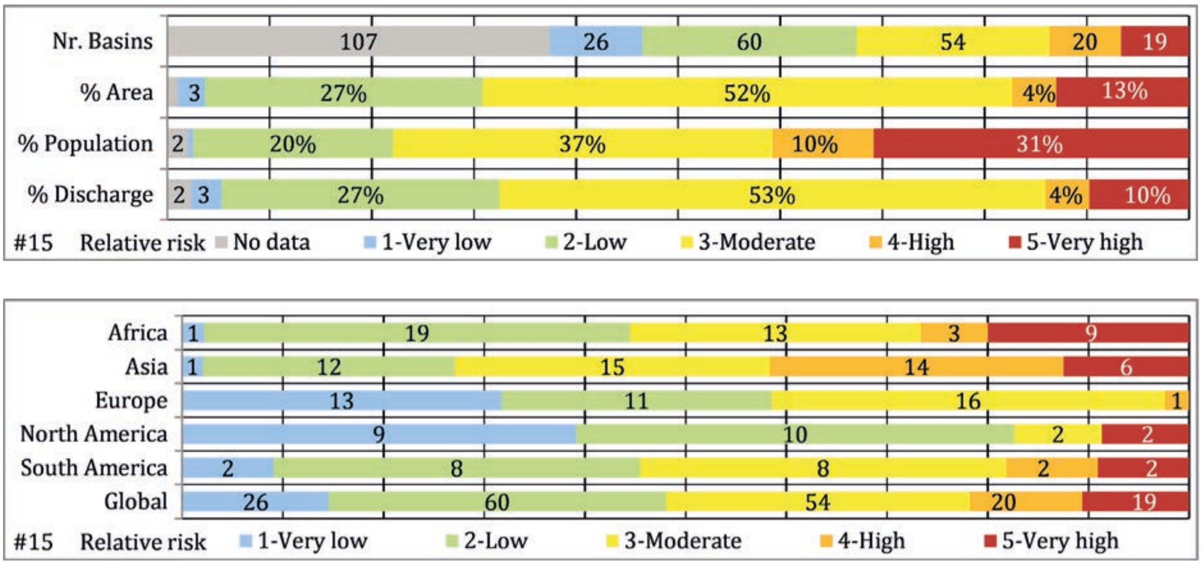


Figure 3.10. Exposure to Floods and Droughts Relative Risk Categories by: number of basins, global TB basin % for area, population and discharge (top); and number of basins by region, 'no data' basins excluded (bottom).



Limitations and potential for future development

More developed countries obviously have higher absolute GDP exposure to flood, and hence would show up as more at risk if total rather than proportional GDP exposure were chosen as the metric. Following standard practice, we normalize the results by overall GDP in order to make the indicator comparable across basins. But one could consider a metric of total GDP exposure that would underscore the absolute potential (and real) economic losses suffered by developed countries in areas such as the Mississippi and Rhine basins and their tributaries. The overall level of confidence in results is moderate.

A total of 158 BCUs (out of 796) did not have the exposure to droughts sub-indicator. This is due to the grid cell resolution of the WaterGAP 2.2 data (0.5°), which prevented reporting of results for the smallest BCUs (i.e. those which could not have a 0.5° grid cell assigned to them in the hydrological model). A further 343 BCUs are assigned between 1 and 9 grid cells, and hence are considered to have a lower degree of scientific confidence than those with 10 or more. However, these 501 BCUs account for about 1% of total BCU area, thus the overall interpretation of results at the global level is valid.

3.1.4 Projected Changes in Population Density

Key findings

1. **Population growth is linked to water stress and governance needs:** Population growth is a key driver of water use. Taken together with climate change and land-cover changes, water systems in transboundary basins will be increasingly under stress, increasing their need for good governance.
2. **Population density is likely to increase most in Africa:** Population density is projected to increase by >200% between 2010 and 2050 in three basins in Africa, the Pangani, Umba, and Kunene.

Rationale

Population growth is one of the main drivers of water use for domestic, industrial and agricultural sectors. In many regions it is a more significant determinant of future water scarcity than changes to the hydrological system induced by climate change (Vörösmarty *et al*. 2000). While efficiency gains from water-saving technologies and demand management measures may play an important role in helping to mitigate the impacts of growing water demand, there will still be important pressures on water resources in the future, especially in low-income countries with rapid population growth. This indicator has been chosen as a proxy future-oriented indicator for the socioeconomics thematic group because it is challenging to project changes in economic development or societal wellbeing. Population change is also a pragmatic way of assessing likely changes in pressures on natural resources.

Computation

For the baseline of 2010, we used the same Gridded Population of the World v3 (GPWv3) 2010 future estimates data set as that used for other parts of this assessment. These data represent projections from the year 2000 census-based population distribution, using UN country-level projections to project the population. For the projections to 2030 and 2050, we used data developed by IIASA for the Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP) in which current population densities were projected using country-level population projections for those years. The projections assume constant population distribution based on year 2000 census data. While this assumption is obviously incorrect owing to different sub-national rates of natural increase and net migration (de Sherbinin *et al*. 2012), creating alternative distributions would have required multiple scenarios which was beyond the scope of this assessment.

The gridded data representing population per grid cell for 2010, 2030, and 2050 were aggregated using BCU and basin boundaries, and then divided by land area to yield population density estimates for each time slice. Percentage change in population density was then calculated for 2010-2030 and 2010-2050. Risk category thresholds were developed based on an analysis of the distribution of the data and expert opinion, as shown in Table 3.4. Anything above 100% reflects a more than doubling of population density. No basins approach that level for 2010-2030, but some exceed it during the period 2010-2050.

Table 3.4. Projected Changes in Population Density relative risk categorization

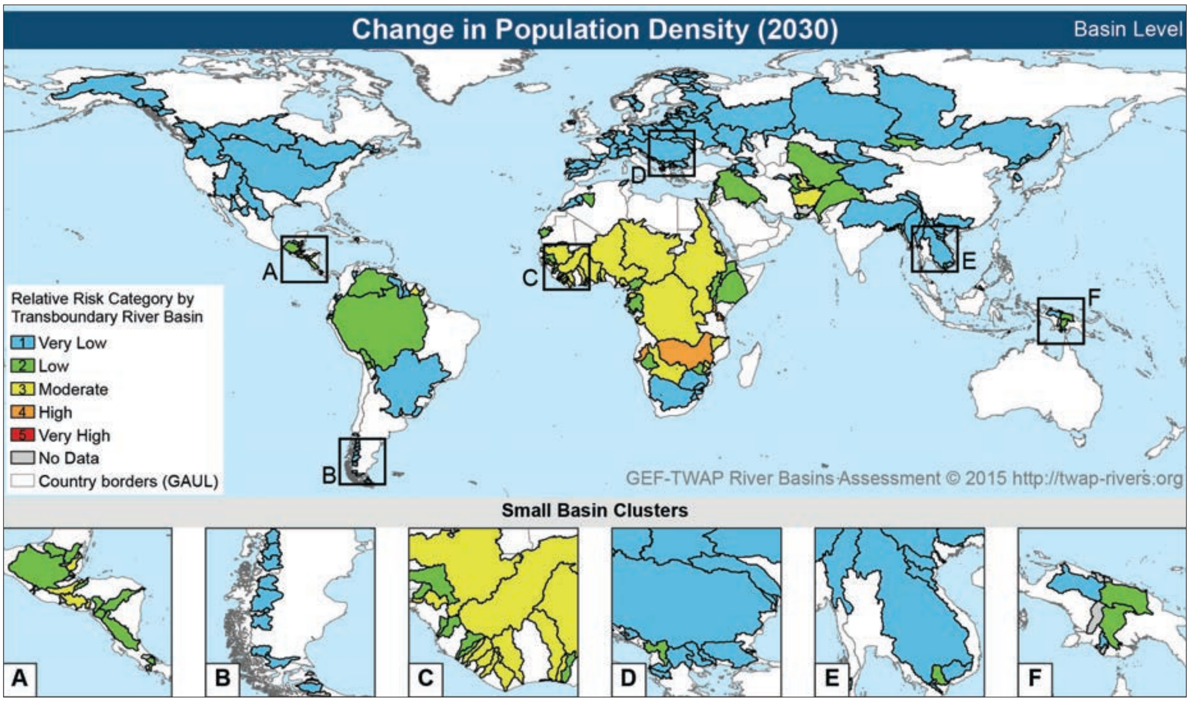
Relative risk categories	Percentage Increase in Population Density
1 - Very low	0-25%
2 - Low	25-50%
3 - Moderate	50-75%
4 - High	75%-100%
5 - Very high	>100%

Results

Figure 3.11 shows the results for the indicator at the basin level by risk category for 2010-2030 and 2010-2050. Many basins in Africa, and two in West Asia, will see a more than doubling of population density (risk category 5) by 2050. Basins in Europe, Eastern Europe, and the former Soviet Union all have very low percentage changes in population density.

Figure 3.12 shows the results for the indicator at the BCU level by risk category for 2010-2030 and 2010-2050. The spatial distribution of population growth rates (which affect population density) within basins can vary greatly. For example, while population density in the Nile and Tigris-Euphrates/Shatt al Arab basins is expected to increase by more than 100 per cent (very high relative risk) by 2050, the density in the Egyptian and Turkish BCUs of these basins is only expected to increase by 25-50% (low relative risk).

Figure 3.11. Projected Change in Population Density by Transboundary River Basin to 2030 (top) and 2050 (bottom). Population growth is linked to water stress and governance needs. By 2050, population density is expected to increase by more than 100% in most basins in Africa.



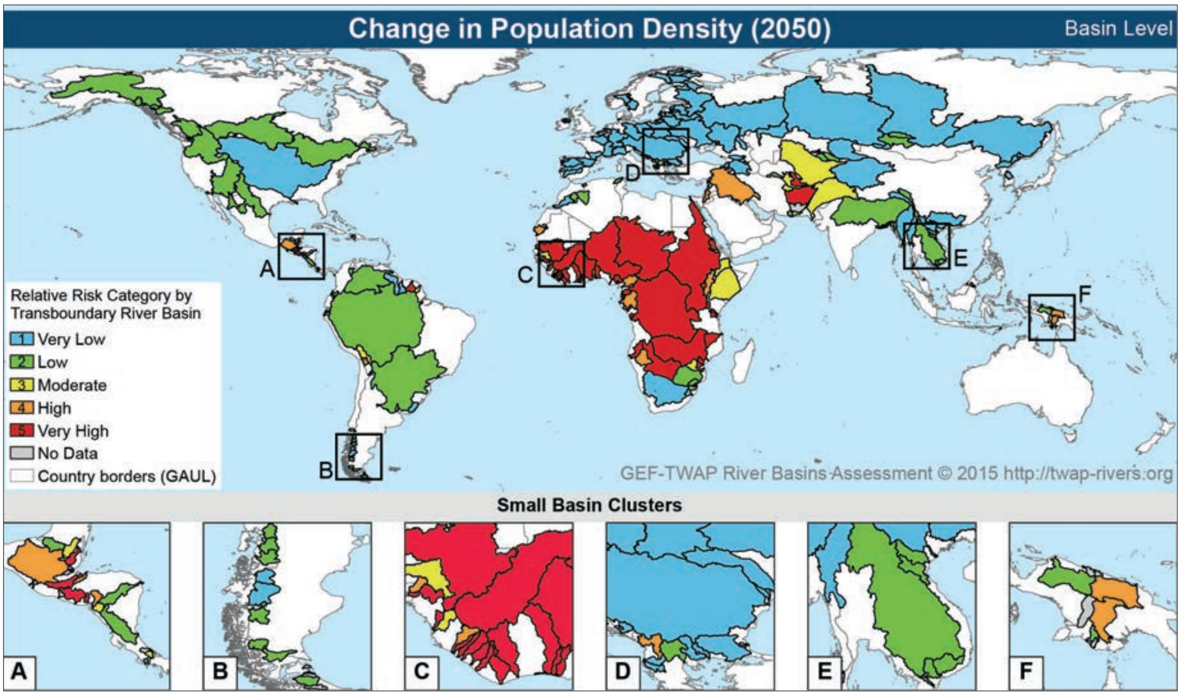


Figure 3.12. Projected Change in Population Density by BCU to 2030 (top) and 2050 (bottom). Population growth is linked to water stress and governance needs. By 2030, population density is expected to increase by 75-100% in a number of BCUs in Africa.

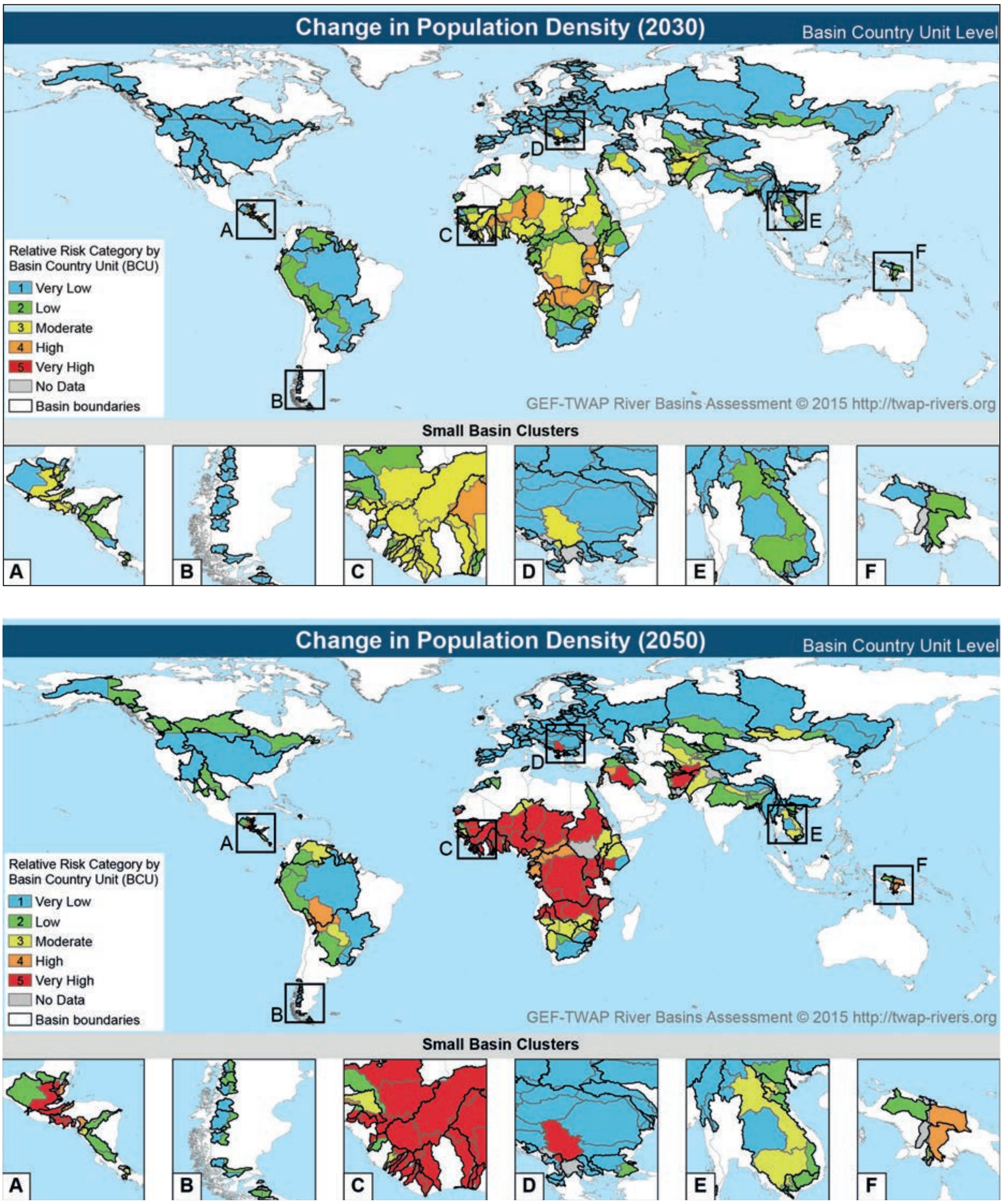


Figure 3.13. Projected Change in Population Density for 2030 risk categories by: number of basins, global TB basin % for area, population and discharge (top); and number of basins by region, 'no data' basins excluded (bottom).

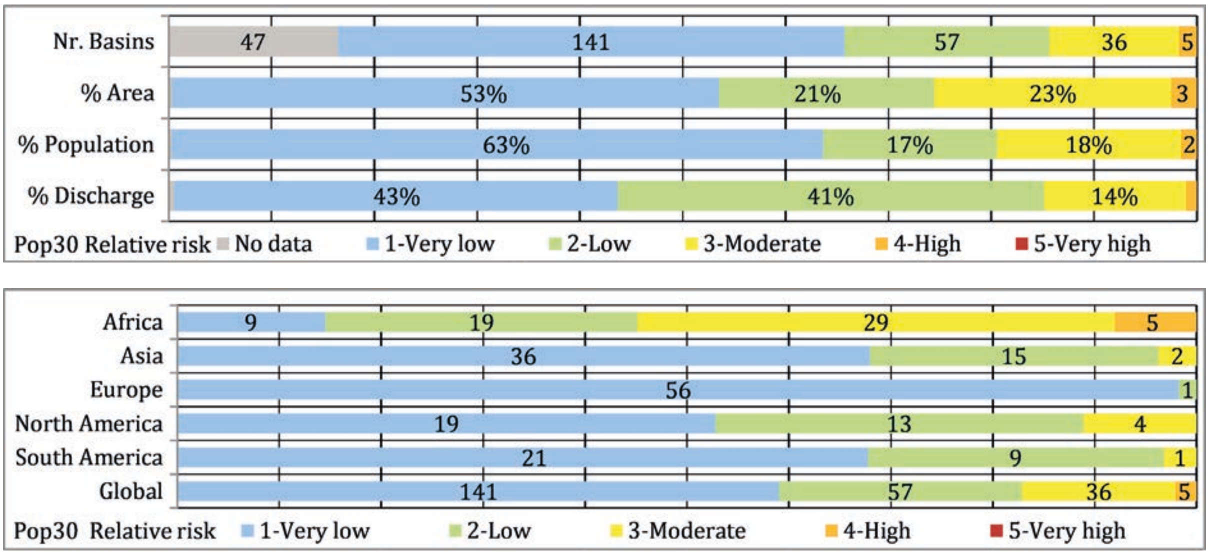
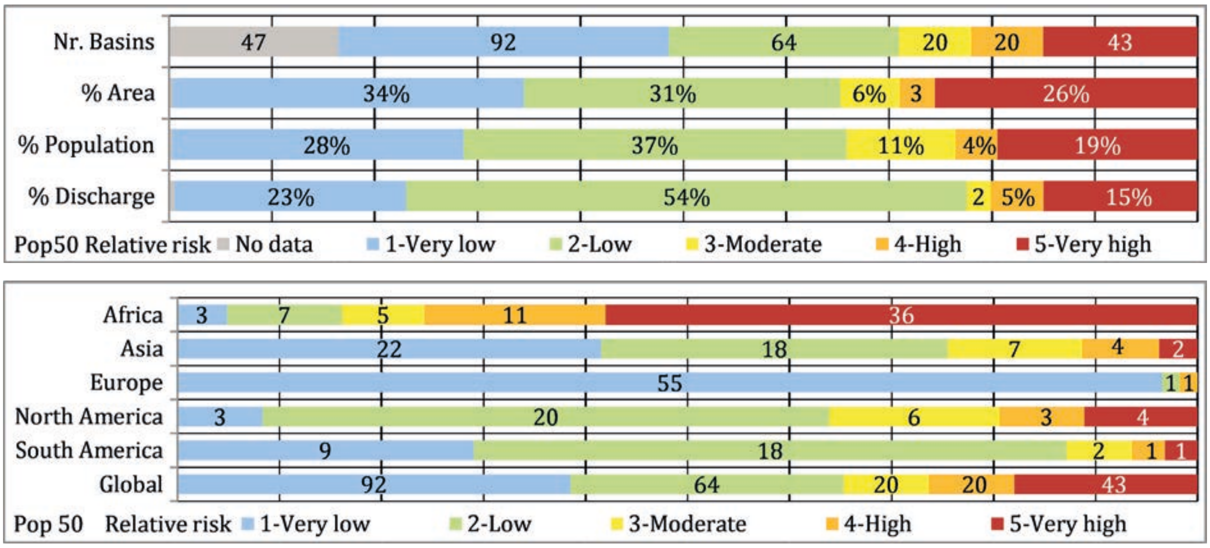


Figure 3.14. Projected Change in Population Density for 2050 risk categories by: number of basins, global TB basin % for area, population and discharge (top); and number of basins by region, 'no data' basins excluded (bottom).



Interpretation of results

The percentage change in population density is expected to be particularly high in sub-Saharan Africa (except for example the Orange Basin in southern Africa) and West Asia, probably putting additional pressures on water resources in these countries over the coming decades. As stated earlier, it will be important to institute water-saving policies and more water-efficient technologies in these regions, as well as in regions with lower population growth but which are already water-scarce. Increases in population density are likely to increase the risks discussed in the socioeconomics thematic group, unless mitigation measures are put in place. For example, understanding the economic dependence on water resources in a given basin may help address the risks of increasing population pressures. Improvements in societal wellbeing may reduce pressures on the resources in some ways (e.g. pollution), but is often also associated with increased water withdrawals (particularly urban). Increased population densities may also expose greater numbers of people to floods and droughts, depending on expected changes to the hydrological cycle due to climate change. Hence this indicator should be considered in conjunction with the other projections indicators, including governance, which will be critical to mitigating some of the increased pressures.

In addition to the relative changes in population density, it is important to consider the current levels of population density and location of large urban areas. This information is provided in Annex XI-1.

Limitations and potential for future development

More spatially-explicit global population projections would have been beneficial for this assessment. Such projections have been undertaken using the Shared Socioeconomic Pathways (SSPs) associated with the Representative Concentration Pathways (RCPs) of the IPCC, but were not available in time for use in this assessment.

3.1.5 Socioeconomics Thematic Group Summary

The key findings for the thematic group are given in the introduction to section 0. The three indicators assessed in this group are:

1. Economic Dependence on Water Resources;
2. Societal Wellbeing;
3. Exposure to Floods and Droughts.

Together, the results show interesting overall patterns of risk as a result of combinations of high economic dependency, low societal wellbeing, and high flood and drought exposure. Table 3.5 lists the basins that are in very high risk categories for each of the three indicators, and which are also at high or very high risk for one or more of the other indicators. Of the 20 basins listed at least once, all but five are in Africa.

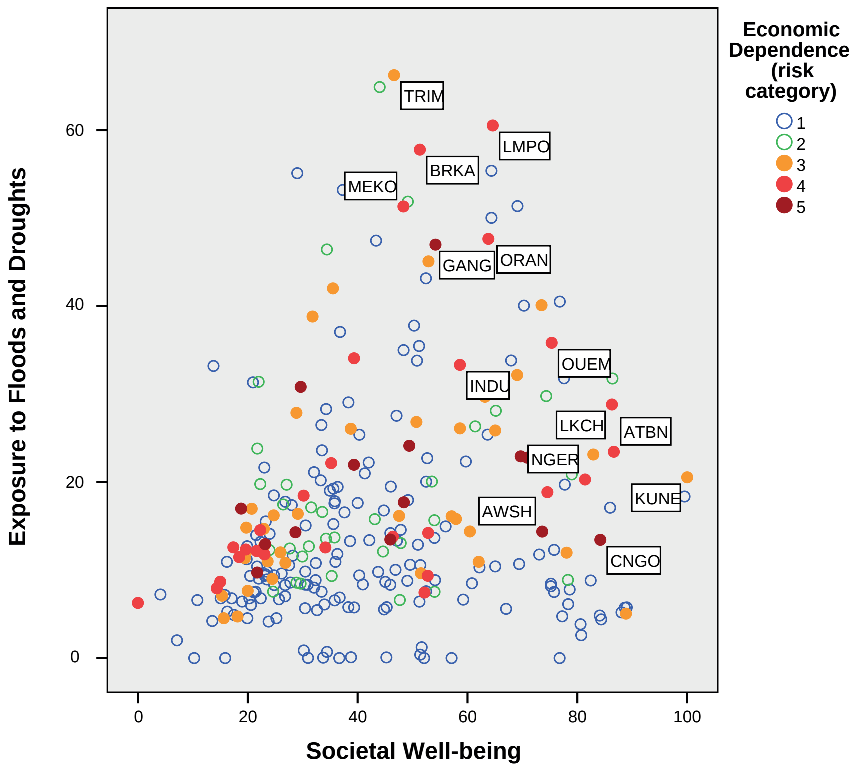
Table 3.5 Highest Risk Basins across the three Socioeconomic Indicators. Basins with high economic dependency, low societal wellbeing, and high flood and drought exposure are at higher risk. Of the 20 basins listed at least once, all but five are in Africa.

Basins with very high risk of economic dependency and…	Basins with very high risk to societal wellbeing and…	Basins with very high risk of exposure to flood and drought and…
High to very high risk to societal wellbeing	**High to very high risk of economic dependency**	**High to very high risk of economic dependency**
Awash	Zambezi	Ganges-Brahmaputra-Meghna
Congo/Zaire	Congo/Zaire	Oueme
Nile	Lake Chad	Limpopo
Zambezi	Artibonite	Orange
	Niger	Mekong
	Oueme	Baraka
	Volta	
High to very high risk of exposure to flood and drought	**High to very high risk of exposure to flood and drought**	**High to very high risk to societal wellbeing**
Ganges-Brahmaputra-Meghna	Oueme	Oueme
Jordan	Okavango	Okavango
		Limpopo
		Cancoso/Lauca
		Lake Natron

Figure 3.15 shows a scatter plot of indicators for Societal Wellbeing (x-axis) and Exposure to Floods and Droughts (y-axis) using a transformed index, in which 0 is low risk and 100 is high risk. The dots are coloured according to the categorized Economic Dependence on Water Resources Indicator. We have omitted two outliers for flood and drought (the Atui Basin in Mauritania/Western Sahara and the Song Vam Co Dong in Vietnam/Cambodia), both with moderate societal wellbeing and low Economic dependency, in order to better show the distribution of the other basins. We have labelled a number of basins that have moderate to very high levels of economic dependency and are also at risk along one of the other dimensions. These include the Tarim, Mekong, Ganges, Baraka, Orange and Limpopo basins, all with high risk of flood and drought and moderate levels of societal wellbeing (top centre in Figure 3.15), and the Oueme, Indus, Lake Chad, Atibonite, Niger, Awash, Kunene, and Congo basins, all with very low societal wellbeing.

Finally, the transformed Societal Wellbeing and Exposure to Flood and Drought indicators are weakly but significantly correlated with one another, with each other, with Pearson's r's of 0.2 ($p<0.05$). While correlation does not necessarily mean causation, and this is hardly a strong correlation, it does suggest that there might be a relationship between river flow variability and societal wellbeing. Indeed research by Hall *et al*. (2014) suggests that there are links between the coefficient of variation of river flows, water storage, institutional capacity, and economic development levels. In Figure 3.15 it can be seen that most basins cluster in the bottom left corner of the graph, indicating high societal wellbeing and low relative exposure to flood and drought. However, basins with low societal wellbeing are also likely to have limited governance capacity to address climate vulnerabilities (particularly for the country-level Enabling Environment Indicator (#12)), so particular attention might be warranted to assess governance needs and increase capacity in these countries and basins.

Figure 3.15. Societal Wellbeing versus Exposure to Flood and Drought, where 0 is low and 100 is high risk. Darker colours show higher Economic Dependence on Water Resources. The labelled basins to the top and right of the figure have higher risks for a combination of the indicators.



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3.2 Water Quantity

This section presents the results on the water quantity aspects of water stress in transboundary river basins and BCUs, considered from three different perspectives: environmental, human, and agricultural water stress. Investigating environmental and human water stress allows us to understand potential trade-offs and overlaps between these two demands on water resources. Agriculture is the largest user of water globally, and identifying areas of agricultural water stress is important to safeguard food supplies into the future. In this analysis, water stress can result from (i) changes in flow regimes from natural flow conditions (Environmental Water Stress Indicator (#1)), (ii) reduction in available water supply per capita (Human Water Stress Indicator (#2)), and (iii) an imbalance between water abstraction and water availability (Human Water Stress (#2) and/or Agricultural Water Stress (#3)). These three indicators of water stress provide a comprehensive view of water stress in terms of water quantity for transboundary basins.

However, to gain a more complete understanding of water stress, water quantity must be considered together with water quality (section 3.3). The use of water and the discharge of return flows into surface water bodies usually affect water quality and often lead to a significant degradation of water resources. Water availability plays a major role in terms of dilution potential and therefore pollutant concentration reduction, and, further, the emission of pollutants is potentially higher in regions where water resources and land are intensively used.

This section also includes projections for environmental and human water stress for 2030 and 2050, considering changes both to demand (e.g. socio-economic changes and climate change) and to supply (e.g. as affected by climate change). These changes are likely to put additional pressures and further increase the complexity of transboundary water management. Any change in the supply and use of water results in a departure from natural conditions at one point in a river catchment which will affect the availability and quality of water resources for other (downstream) users within a basin.

Transboundary river basins have a number of demands on their water resources, including urban, agricultural, and environmental.

As climate change alters the hydrological cycle (water supply) and water demand (e.g. crop water requirements), new transboundary challenges and opportunities will emerge. Socio-economic developments lead to increasing water use in the domestic and industrial sectors and put additional pressures on freshwater resources in addition to the climate-change impacts. In particular, downstream countries might suffer more, as they could face more/new water scarcity caused by upstream countries, and increased flood risks due to depletion of ecosystems in the upstream part of the river or water pollution. Water-dependant sectors in the downstream parts of a river will become more vulnerable to upstream activities. If, due to a changing climate, upstream countries need to increase water abstraction, allowing less water for downstream users, production patterns (agriculture, energy and industry) in downstream countries might be affected. Such problems might cause new conflicts between water-related sectors within and across transboundary basin countries. They may also create new opportunities and incentives for transboundary cooperation.

Thematic group key findings

1. **Action to address agricultural water stress must not increase environmental water stress:** Hotspots of environmental water stress are highly correlated with those of agricultural water stress. Addressing agricultural water stress (for example through increasing large-scale water storage) should be done with careful consideration of environmental water requirements.
2. **Human water stress needs to be addressed to mitigate projected environmental and agricultural stress:** Actions to counter human water stress should be expedited in river basins that are already prone to water stress to mitigate the increasing stress projected for most of these regions.
3. **Stress is influenced not just by quantity but by quality of water:** Overall water stress should be assessed by considering both water quantity and quality. For example, there is moderate correlation between agricultural water stress and nutrient pollution. In basins where this is the case, return flows normally available from excess irrigation water may not be fit for downstream purposes (environmental and human), compounding the water stress situation.

3.2.1 Environmental Water Stress: Environmental Stress Induced by Flow Regime Alterations – Baseline

Key findings

1. **Water flows have been changed by dams and changes in consumption:** Flow regimes have been significantly altered by dam management and water consumption in transboundary river basins in Central Asia, the Middle East, U.S.A., Northern Mexico, Spain and Portugal.
2. **Environmental water stress is linked to agricultural and human water stress:** Hotspots of environmental water stress correlate strongly with areas experiencing agricultural and human water stress.
3. **Climate change and rise in consumption is likely to increase future stress:** Environmental water stress is expected to increase due to climate change (especially in drier regions and where snowmelt plays a crucial role) and increasing water consumption.

Rationale

Over the past few decades the value of the environment has become better understood (MA 2005). In some parts of the world, environmental systems are being restored, but, predominantly, environmental systems are coming under increasing threat from demand for water from other sectors (water quantity) and from pollution of available water (water quality). While the Nutrient Pollution Indicator (#4) and Wastewater Pollution Indicator (#5) address water quality issues, the Environmental Water Stress Indicator (#1) focuses on the water quantity aspect and considers hydrological alterations to monthly dynamics of the natural flow regime caused by anthropogenic water uses and dam operations. Finally, with this indicator, regions are identified where direct water use for human purposes and flow regulation are in conflict with environmental water requirements, and thus complements the human and agricultural water stress indicators in the thematic group.

Computation

Considering flow alteration aspects for assessing environmental flows, evaluation techniques include minimum flow thresholds, statistically-based standards and 'percentage-of-flow' approaches. The most commonly used approach is to set a minimum flow threshold that must be maintained (Richter *et al*. 2011; Acreman *et al*. 2008) but there is a growing recognition that this is not sufficient, and the limit of this threshold is highly debated. In the literature, river flow is often called a 'master' or key variable which influences other important parameters such as oxygen content, contaminant dilution, water temperature, and flow velocity. Because of the key role of flow alterations on environmental flow conditions, this indicator focuses on modifications of the river flow regime and is based on the 'natural flow paradigm'. This states that the natural flow regime, including natural fluctuations, provides the optimum conditions for a river ecosystem (Poff *et al*. 1997). Over evolutionary time-spans, and as a direct result of the natural flow regime, native biota has developed different morphological, physiological and behavioural traits, as described by Lytle and Poff (2004). As long as habitats are exploited, all ecological niches are occupied and the natural range of flows can be tolerated by the endemic biota. Hence, for this global study, modified flow regimes are compared to natural flow conditions by considering mean monthly flow magnitudes and monthly flow variations between years (12 monthly sub-indicators for each aspect). In addition, it is assumed that the greater the deviation from the natural flow, the more severe the impact on the river ecosystem. Based on the Sustainability Boundary Approach (Richter 2009), which involves restricting hydrologic alterations to within a percentage-based range around natural flow conditions, Richter *et al*. (2011) suggest that, for most river alterations, a change greater than ±20% from the natural flow regime will threaten ecological integrity. Following this approach we consider ±20% as a critical threshold, but we set further thresholds at ±40%, ±60%, ±80%, and ±100%. A high environmental water stress represented by the scoring system of this approach indicates a high risk to the health of the river ecosystem. Further information on the thresholds, calculation, model, and input data is provided in Annex IX-1.

Results

The maps below show results for all 270 basins and 635 BCUs for which results were derived. However, the discussion of findings refers only to the 163 basins (and 292 BCUs) that are represented by 10 or more 0.5° grid cells (i.e. with an area roughly >25 000 km^2). Results for these basins and BCUs are considered to have a higher degree of scientific credibility. Results for the remaining basins and BCUs are indicative only.

Environmental Water Stress is measured as the monthly variation in flows from natural conditions.

Figure 3.16. Environmental Water Stress by Transboundary River Basin. Flow regimes have been significantly altered by dam management and water consumption in transboundary river basins in Central Asia, the Middle East, U.S.A., Northern Mexico, Spain and Portugal.

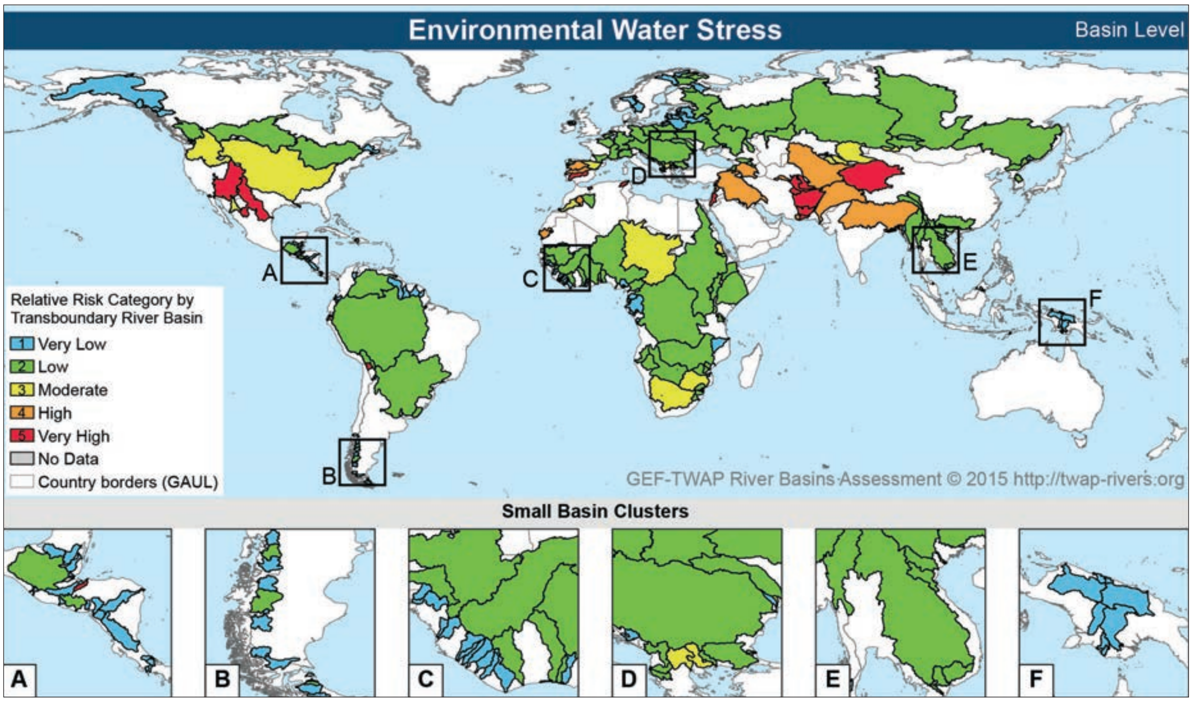
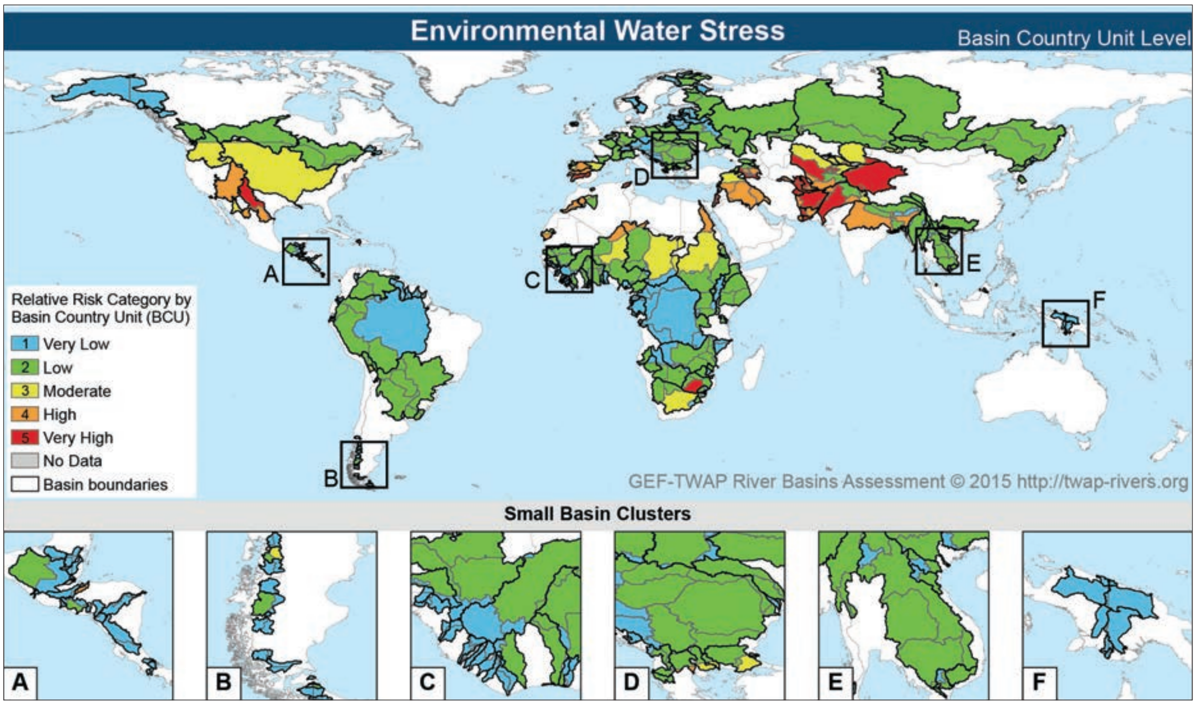


Figure 3.17. Environmental Water Stress by Basin Country Unit (BCU), measured by disruptions to the natural flow regime. BCUs where environmental water stress is highest tend to be those with significant irrigation.



Basins and BCUs with moderate to very high environmental stress (i.e., categories 3 – 5) can be found in Asia (e.g. Central Asia and the Middle East), North America (U.S.A and Northern Mexico), Europe (e.g. Spain and Portugal) and a few basins and BCUs in Africa (e.g., in the South African portion of the Limpopo basin and the Algerian portions of the Niger, Lake Chad, and Medjerda basins and in the downstream BCUs of the Nile) (Figure 3.16 and Figure 3.17). There appears to be very limited environmental stress induced by flow alterations in South America.

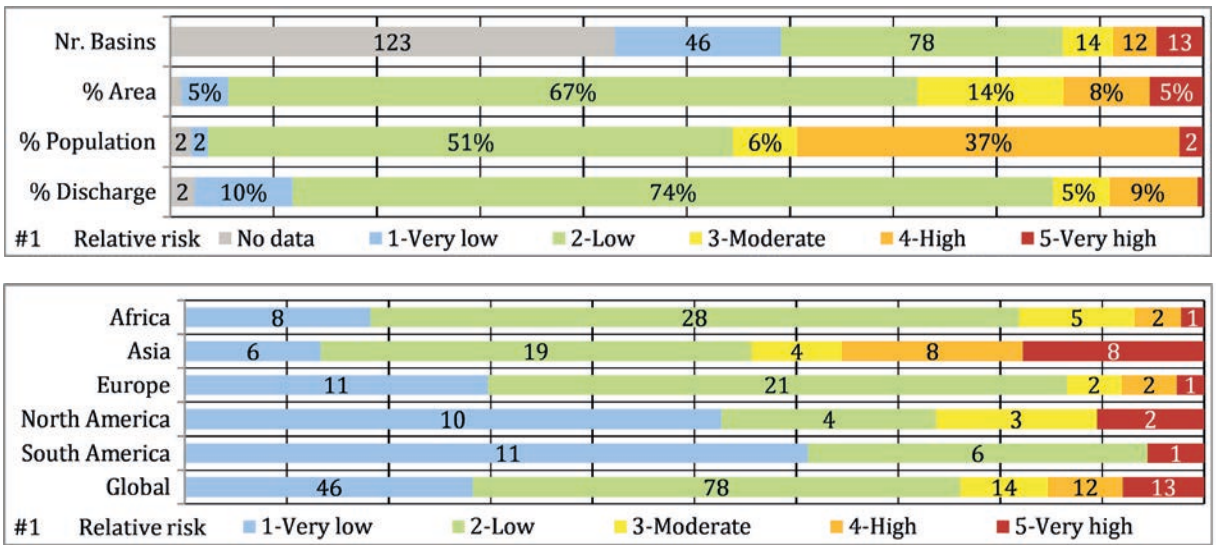
Regionally, the transboundary river basins and BCUs with the highest shares of substantial flow regime alterations (i.e. category 4 or 5) are found in Asia (36% of the basins and 40% of the BCUs) followed by North America (11% of the basins and 13% of the BCUs) (Figure 3.18). In Africa, Europe and South America, the percentage of basins with high to very high stress (category 4 or 5) is nearly the same with 8%, 7% and 6%, respectively. However, the numbers of basins that are at risk of environmental water stress are very small in South America and Africa. This analysis is based on the 163 basins with relatively high levels of confidence in results (see Limitations section). These basins cover 99% of the area and 98% of the population of transboundary river basins Figure 3.18 (top).

Interpretation of results

Increasing variations from natural flow patterns lead to increasing ecological consequences favouring invasive species at the expense of adapted endemic species (flora and fauna). Indeed, in a review of 165 papers, Poff and Zimmermann (2010) clearly demonstrated that flow alteration has many ecological consequences. In 92% of the case studies, impacts on river ecosystems were reported in response to modifications of certain flow parameters. Similar results were found in a review by Lloyd *et al*. (2004), where 86% of 65 case studies recorded ecological changes. River ecosystems are in a dynamic equilibrium, i.e. if the flow regime changes, a new equilibrium will be found, though with a potential loss in biodiversity and especially of already-threatened species.

According to the maps (Figure 3.16 and Figure 3.17) it is clear that the basins and most of the BCUs identified as environmentally water stressed are areas where irrigation plays a crucial role. This is expressed by a high correlation coefficient ($R^2 = 0.71$) between the areas of environmental and agricultural water stress (see sections 3.2.5 and 4.1). Agriculture still is the biggest water user worldwide and accounts for about 70% of total water abstraction (FAO 2012; Shiklomanov and Rodda 2003). A high population density and/or high industrial activities further increase the pressures on the existing water resources in a river basin or BCU, as identified by the percentage of population living in

Figure 3.18. Environmental Water Stress Relative Risk Categories by: number of basins, global TB basin % for area, population and discharge (top); and number of basins by region, 'no data' basins excluded (bottom). Asia has the highest portion of basins at risk of environmental water stress.



environmentally stressed areas (Figure 3.18). According to the statistical analysis, the correlation coefficient between human water-stressed areas and environmental water-stressed areas is $R^2 = 0.35$ (see section 4.1). In addition to high levels of water abstraction, dam operations contribute to modifications of the natural flow regime which is indicated by a positive correlation of $R^2 = 0.34$. Consequently, in the identified basins and BCUs under environmental water stress, it is very likely that the natural flow regime is altered due to water abstractions and dam management beyond some acceptable threshold. This is likely to increase the risk of ecosystem degradation and favour invasive species at the expense of adapted endemic species.

Limitations and potential for future development

Further research on ecological thresholds is required, particularly for larger river basins. Most environmental flow approaches used in global water scarcity assessments are pragmatic but are not based on ecological theory or informed analysis (Pahl-Wostl *et al*. 2013). For example, Richter (2009) assumes for the Sustainability Boundary Approach that alterations beyond ±20% in a river's natural flow regime increases the risk of moderate to major changes to ecosystem services and health. The exact boundary for impacts on biodiversity is clearly a matter for debate and needs further work. Assuming a simple cut-off point may be too simplistic to account for individual species life-history traits and ecological requirements, with some species potentially being impacted at a far lower level of alteration if other aspects of water flow are taken into account (e.g. velocity, temperature, dissolved oxygen (Darwall *et al*. 2011)). Other studies suggest that a value of around 30% of the catchment area under human influence may represent a threshold above which there will be a detrimental effect on freshwater ecosystems (Allan 2004). The relationships, however, are probably too complex for a single threshold to apply. Here we assume that the more river flows deviate from natural conditions, the higher the impact on the river ecosystem. We therefore consider five deviation levels: ±20%, ±40%, ±60%, ±80%, and ±100%. Each crossing of these levels is penalised with a value of 1 in the scoring system.

Hydrologic response is influenced by a number of catchment and stream characteristics, including slope, storage, conveyance and connectivity, and channel form. The TWAP assessment aims to fill the gap in consistent data on the flow regime, water use and state of aquatic ecosystems in basins that vary with respect to their socio-environmental context. Results from other indicators in the 'Ecosystem' thematic group will provide insights into the correlation between Environmental Water Stress and the state of aquatic ecosystems.

The model results were computed on a 0.5° grid and aggregated to river basin and BCU levels. Model results are available for 270 out of 286 basins and 635 out of 796 BCUs. However, 107 basins and 343 BCUs consist of less than 10 grid cells and are therefore considered to have a lower degree of scientific credibility. These results are included in the assessment, but are marked as having lower confidence in the results files and basin factsheets downloadable from the River Basins Data Portal. Analyses based on smaller grid size (e.g. 5 arc-minute grids), and hence consideration of smaller basins and BCUs, are likely to be feasible in future assessments. This would also allow a larger number of dams to be taken into account.

3.2.2 Environmental Water Stress: Environmental Stress Induced by Flow Regime Alterations – Projected Scenarios

Rationale

Climate change, in addition to dam operation and water consumption, is another factor governing flow regime alterations in the future and will interact with other anthropogenic flow modifications. To take this into account, regional and seasonal change are simulated for precipitation amounts and patterns (IPCC 2013) which will cause higher or lower runoff in the future, depending on the location and season (Alcamo *et al*. 2007). Moreover, climate change is projected to accelerate the hydrological cycle, with an increasing intensity of rainfall and frequency of extreme weather events (Milly *et al*. 2008). Higher temperatures could increase evaporation rates at surfaces and transpiration by plants, which will lead to a reduction in runoff (Frederick and Major 1997). In snow or glacier-affected

New dams and climate change are expected to have significant impacts on Environmental Water Stress.

river basins, runoff will be reduced by a decline in meltwater (Verzano and Menzel 2009). In the opposite direction, water use is likely to increase in many regions due to climatic (e.g. evapotranspiration of crops) and socio-economic changes (e.g. population growth). Many dams are built to store water for agricultural, domestic, and industrial use, or for flood management and hydropower generation. With climate change and growing electricity and water demand, new dams may be built, in particular in countries with emerging economies (Zarf *et al*. 2014). Flow regimes are therefore likely to deviate further from past natural flow conditions with consequences for flows that govern ecological functions and habitats. This indicator complements the results of the baseline period and considers future hydrological alterations from monthly dynamics of the natural flow regime caused by climate change, future water consumption and dam operations.

Computation

Based on the approach described in section 3.2.1, model simulations were carried out using the global hydrology model WaterGAP2 (Müller Schmied *et al*. 2014) to assess the future impact of climate change, water use and dam management on global river flow regimes. WaterGAP2 was driven with bias-corrected climate data from four different Global Climate Models (GCMs) for the period 1971 to 2070 (Hempel *et al*. 2013) (more details below). The aim of the hydrological modelling was to generate time-series of monthly discharge data representing the 2030s (2021–2050) and 2050s (2041–2070), as well as the natural flow regime (i.e. flow without the anthropogenic impacts of dam management and water consumption) in the baseline period (1971–2000), which sets the reference condition. In a next step, relative changes between future projection and baseline were calculated for each individual GCM and combined to an ensemble average value, which finally provided the basis for the indicator. The counting of the number of threshold exceedances followed the methodology described in section 3.2.1.

Climate projections: Irrigation water requirements and river discharges will be affected by future climate change. To account for climate change impacts in the TWAP river basins study, time-series of daily climate data from four GCMs were selected from the newly-available CMIP5 data archive (Taylor *et al*. 2012) (Table 3.6). Datasets from the archive were bias-corrected and prepared for and used within the modelling framework of the Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP, http://www.isi-mip.org/).

Table 3.6. Global Climate Model (GCM) Selection

Global Climate Model (GCM)	Institute full name
HadGEM2-ES	Met Office Hadley Centre Instituto Nacional de Pesquisas Espaciais
IPSL-CM5A-LR	Institut Pierre-Simon Laplace
MIROC-ESM-CHEM	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies
NorESM1-M	Norwegian Climate Centre

For this study, we assumed that climate drivers follow the Representative Concentration Pathway (RCP) leading to a radiative forcing (cumulative measure of human greenhouse gas emissions from all sources) value of 8.5 W/m² (RCP8.5), which depicts a high-emission 'business-as-usual' scenario (Riahi *et al*. 2011). This is in agreement with the TWAP groundwater component approach. Compared to the SRES emission scenarios, the RCP8.5 average global temperature increase would be in line with the SRES A1FI but slightly above the SRES A2 scenario at the end of the 21st century (Rogelj *et al*. 2012).

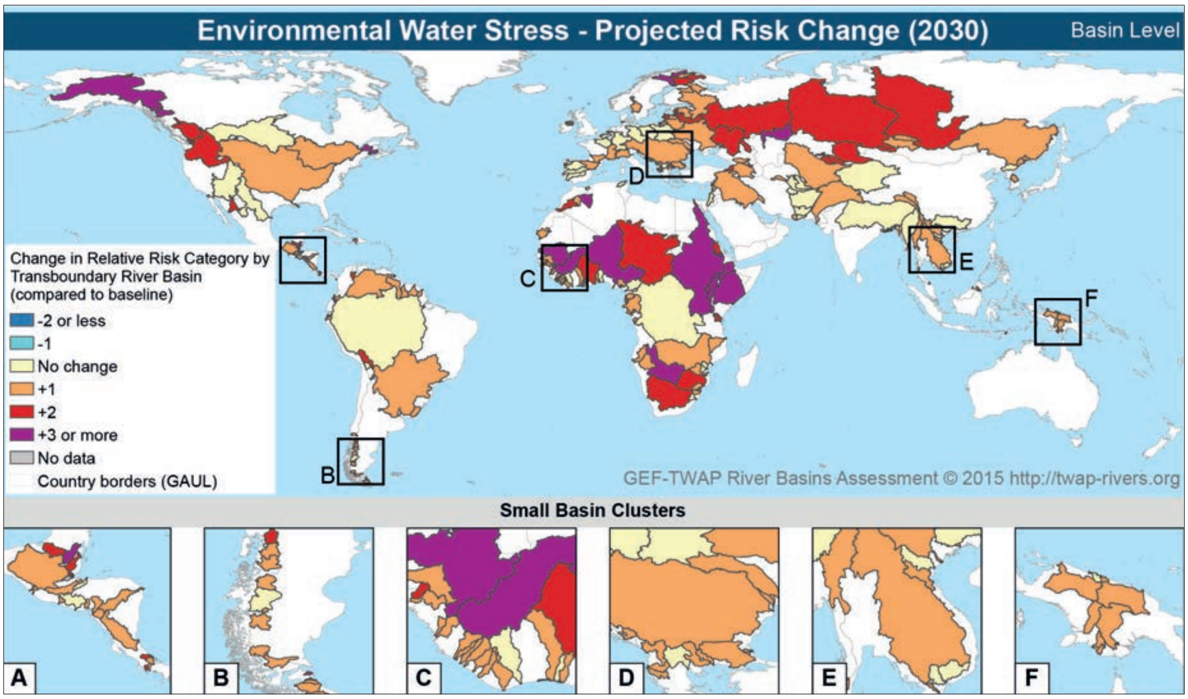
Socio-economic projection: Information on changes in future population and the economy (i.e. GDP) are required for estimating future water use, as well as for calculating the 'change in population density' and 'exacerbating factors to hydropolitical tension' indicators. In this assessment, national population and GDP datasets were used from the newly-developed Shared Socio-ecosystem Pathways (SSP) (O'Neill *et al*. 2014; SSP Database 2013). The business-as-usual scenario SSP2 (i.e., with intermediate challenges to mitigation and adaptation) was selected.

Results

Substantial river flow regime alterations can be expected due to climate change, dam management (not including the construction of new dams, which is partly addressed through the projected Hydropolitical Tensions indicator (section 3.5.3)), and the water consumption of an increasing world population. All these factors will interact in different ways in different climatic regions, leading to large geographical diversity. The resulting environmental water stress is evaluated at river basin and BCU levels for the 2030s and 2050s. The figures below show the change in relative risk category for the 2030s and 2050s, compared to the baseline: Figure 3.19 (basins) and Figure 3.20 (BCUs). For baseline relative risk category see section 3.2.1. For maps of projected relative risk categories (rather than changes) see Annex X-2.

In the 2030s, environmental water stress is expected to increase significantly (i.e. by two or more risk categories) in transboundary river basins and BCUs of north-western North America (i.e. in Alaska, Washington, Oregon, and western Canada), Northern and Eastern Europe, Russia, and in northern and southern Africa (Figure 3.19). In the 2050s, the situation is projected to exacerbate in basins and BCUs of Russia and Northern Europe with a change in relative risk category of three or more. A few basins with a change in relative risk category of two also appear in the Mediterranean Region (Figure 3.19). While in the 2030s 34% of the river basins (31% of the BCUs) are still categorised as low relative risk (i.e., category 2), this decreases to 18% (22%) in the 2050s. Further, the percentage of basins with a very high relative risk increases from 29% in the 2030s to 41% in the 2050s, and for BCUs from 33% to 40%. Basins and BCUs which are new to the very high relative risk class in the 2050s can be found in Alaska, Northern Scandinavia, Russia, Portugal and northern Spain. BCUs with a low risk remain in South America (Brazil, Paraguay, Bolivia, Columbia and Chile), Central Africa (Central African Republic, Cameroon, Congo Republic, Democratic Republic of Congo, Angola and Congo), South East Asia, and western and central Europe. This analysis refers only to the 163 transboundary river basins and 292 BCUs that have 10 or more 0.5° grid cells assigned to them (i.e. are about >25 000 km^2), and hence have a higher level of confidence in the results (see limitations section).

Figure 3.19. Projected Environmental Stress Induced by Flow Alterations: projected change in relative risk category for the 2030s (top) and 2050s (bottom) by Transboundary River Basin. Environmental water stress is expected to increase due to climate change (especially in drier regions and where snowmelt plays a crucial role) and increasing water consumption.



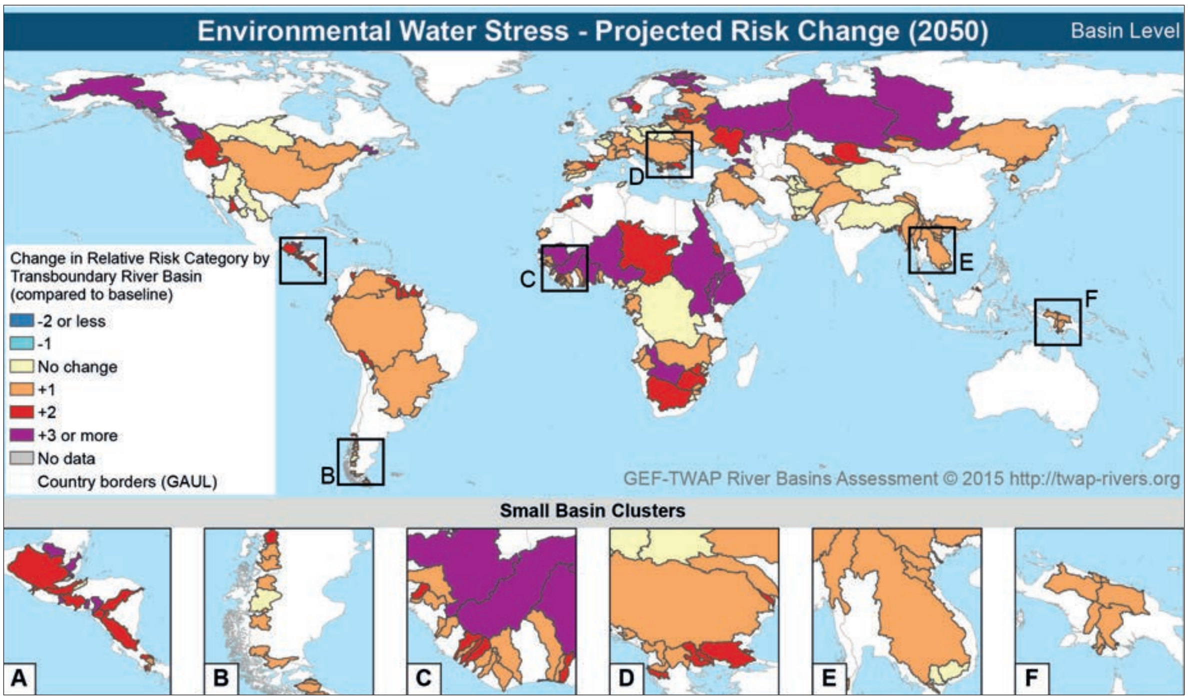
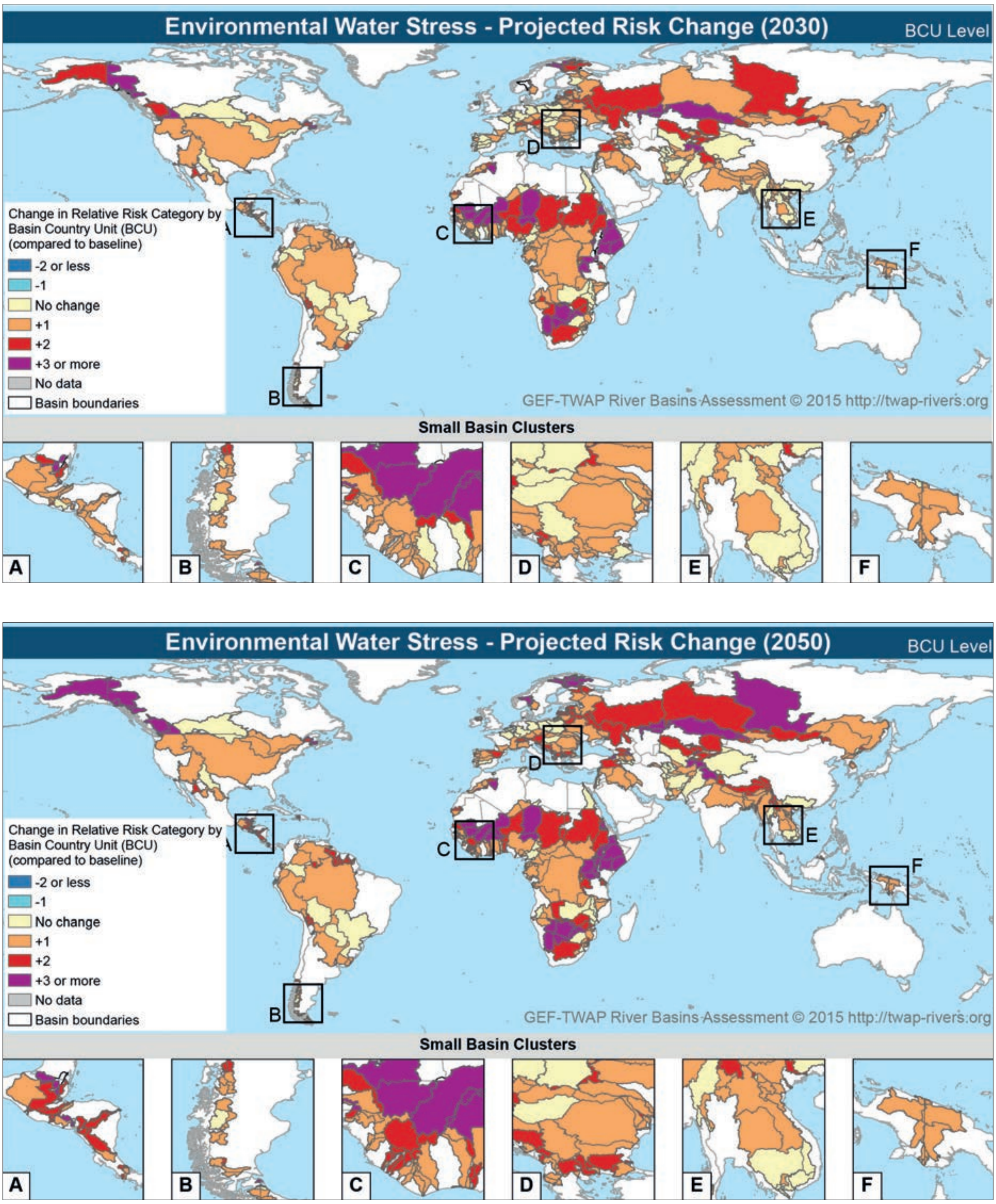


Figure 3.20. Projected Environmental Stress Induced by Flow Alterations: projected change in relative risk category for the 2030s (top) and 2050s (bottom) by Basin Country Unit (BCU). Environmental water stress is expected to increase due to climate change (especially in drier regions and where snowmelt plays a crucial role) and increasing water consumption.



Interpretation of results

In the baseline scenario, substantial flow alterations result from dam management and water consumption in transboundary river basins and BCUs of the Middle East, Central Asia, U.S.A., Northern Mexico, Spain and Portugal. While the number and location of dams are unchanged in our model simulations of the projections, the operational management will change due to changing inflow conditions and water needs. Water consumption is likely to increase in many regions of the world, characterized mainly by a high population growth rate or irrigated land. This is especially the case in Africa, Central America, and southern and eastern Asia. The projections for the 2030s and 2050s are that flow regimes will deviate further from natural conditions, particularly due to climate change which affects precipitation patterns and amounts, evapotranspiration and snow melt. For Europe, a north–south divide is expected where in general the north gets wetter and the already dry south gets even less precipitation. Reduced precipitation throughout the year, as well as the large number of dams, causes the flow modifications in the Mediterranean region (Spain and Portugal) and the Middle East (Turkey, Syria, Lebanon, Israel, Jordan, Armenia, Georgia, Armenia, Azerbaijan, Iraq and Iran). In northern Europe, in addition to the higher precipitation values, the decline in snow melt plays a crucial role (Schneider *et al*. 2013). The rising temperatures mean that snow melts earlier and precipitation is expected to fall more often as rain than snow. Thaw therefore happens earlier and less water is stored as snow pack, leading to river-flow regime changes e.g. due to advanced and lower snowmelt-induced flood peaks. These effects on snow cover and snowfall are likely to have a strong impact on flow regimes in most polar and continental climates, which are characterized by harder winters, as well as in mountainous regions. Consequently, the increases in environmental water stress are especially high in basins in Scandinavia, Russia and north-western North America. Basins with a very high relative risk may also be found in southern and northern Africa. In southern Africa, the climate projection ensemble shows relatively large changes in precipitation patterns, and the number of dams is relatively high. Countries of the Northern and Western African regions will experience flow alterations as a result of the impact of climate change and increasing water consumption. In these regions, small changes in precipitation already result in high levels of flow alteration in relative terms, labelling them with a very high relative risk in our analysis.

Finally, it is very likely that deviations from the natural flow regime will increase in the basins and BCUs currently experiencing Environmental Water Stress, as a result of climate change, water consumption and dam management beyond some admissible threshold. This is likely to increase the risk of ecosystem degradation and favour invasive species at the expense of adapted endemic species.

Limitations and potential for future development

Land-use change is another relevant parameter when developing future water-use scenarios, particularly for irrigation water requirements. An attempt was made to incorporate land-use changes into the projected scenarios, but this was not possible due to missing information from Integrated Assessment Models related to the RCP-SSP scenario development process. This is likely to be possible in future assessments, and also with regard to other SSPs and SSP-RCP combinations. Deforestation and urbanization lead to higher and faster runoff. However, compared with climate change, dam management and water use, land-use changes are expected to have a relatively small impact on freshwater resources.

The number of managed dams and reservoirs in the projected scenarios was the same as under baseline conditions. It was not feasible to estimate changes to this parameter for 2030 and 2050, but changing operational management of dams was considered in terms of changing inflow conditions and water consumption. For basins with projected increases in the number of dams, it is likely that this will lead to a larger increase in risk than has been estimated here. This may be mitigated to some extent by environmentally-sensitive dam operation. The likelihood of dam construction is partially addressed by the projected Hydropolitical Tensions indicator (section 3.5.3).

As is case for the baseline results, the model results were computed on a 0.5° grid and aggregated to river basin and BCU levels. Results are available for 270 out of 286 basins and 635 out of 796 BCUs. A total of 107 basins and 343 BCUs consist of less than 10 grid cells and are therefore considered to have a lower degree of scientific credibility.

These results are included in maps, but are marked as having lower confidence in the results files and basin factsheets downloadable from the TWAP RB data portal.

3.2.3 Human Water Stress – Baseline Scenario

Key findings

1. **The key stressors for human water stress are physical water scarcity, followed by high water demand:** The highest risk basins and BCUs are predominantly found in water-scarce regions of the world, followed by those with high demand, even where more water is available.
2. **>50% of the population using water from shared rivers is at moderate or higher risk of human water stress.**
3. **Regional patterns of climate and demand are important for projections of stress:** While an increase in human water stress is expected in many regions, some basins and particularly BCUs show a decrease, illustrating the regional differences in projected climate changes and water demand.

Rationale

Water scarcity is a, if not the, key limiting factor to development in many transboundary basins. Water stress can be caused by a combination of increasing demands from different sectors and decreasing supply due to variability related to climate change. Human water stress has been defined in a number of different ways since Falkenmark (1989) (FAO 2010; Rijsbeman 2005; Vörösmarty *et al.* 2005a,b; Yang *et al*. 2003; Ohlsson 2000; Gleick 1996). This indicator deals with water availability and water use, on the premise that the less water available per person, the greater the impact on human development and wellbeing, and the less water available for other sectors. Two sub-indicators address the aspects of water availability and water use: a) Renewable Water Supply and b) Relative Water Use.

Computation

The two sub-indicators for the Human Water Stress Indicator (#2) were developed as follows:

a) Renewable Water Supply: the available water supply divided by the total population in the basin. The available water supply is the volume of discharge generated locally within both the transboundary

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basins and the BCUs (long-term annual average runoff over years 1971-2000 from ISI-MIP Project (Warszawski *et al*. 2013). Total Population is the sum of local gridded population (GPW3) (CIESIN 2011) for 2010 in the transboundary basins and BCUs. This sub-indicator was ranked according to five relative risk categories from very low to very high, based on agreed thresholds (Vörösmarty *et al*. 2005a,b; Vörösmarty *et al*. 2000; Widstrand 1992; Falkenmark 1990; Falkenmark 1989) as noted in Table 3.7.

b) Relative water use: the mean annual withdrawal divided by the available water supply. Mean annual water withdrawal in the basin or BCU is the volume of water withdrawal per year (km3/yr) for the domestic, electricity production, manufacturing and agricultural sectors in 2010 (from ISI-MIP Project, Warszawski *et al*. 2013). Water Supply is the volume of discharge generated locally within the basins or BCUs (long-term annual average runoff from 1971 to 2000 from ISI-MIP Project (Warszawski *et al*. 2013). This sub-indicator was ranked according to five relative risk categories from very low to very high based on agreed thresholds (Vörösmarty *et al*. 2005a,b; Vörösmarty *et al*. 2000; Widstrand 1992; Falkenmark 1990; Falkenmark 1989) as noted in Table 3.7.

Table 3.7. (a) Renewable water supply and (b) Relative Water Use Risk Categorization

Relative risk category		a. Renewable water supply m^3/person/yr	b. Relative water use ratio water withdrawals/supply
1	Very low	> 1 700	< 0.1
2	Low	1 300 – 1 700	0.1-0.2
3	Moderate	1 000 – 1 300	02.-0.4
4	High	500 – 1 000	0.4-0.8
5	Very high	< 500	> 0.8

The combined Human Water Stress indicator is defined as the higher ranking category of the two sub-indicators, based on the assumption that water stress as measured by either sub-indicator may be equally serious.

Results

Basins with high and very high relative risk of human water stress are found mainly in the Middle East, Central Asia, south-western USA and southern Africa, with some smaller basins found in north-west Africa and Europe. The pattern for BCUs is similar, though there are some BCUs with high or very high risk which are found in basins with very low risk of human water stress (e.g. downstream BCUs in the Nile, the Mauritanian BCU in the Senegal, and the Algerian portions of the Lake Chad and Niger basins).

Interpretation of results

Very high and high risk basins/BCUs (categories 4 and 5) are dominated by areas of high population, high water demand, and/or low water availability or some combination of these. Low risk basins are characterized by lower population, higher water abundance and/or lower levels of industrial development to impact the water resources.

The highest risk basins (category 5) are located mainly in water-scarce regions (Figure 3.21). Basins in water-scarce regions have limited water available to support the demands of the population and are at greater risk of seasonal or inter-annual variations in water flow. In addition, impacts on water quality pose a great danger in low-flow areas as these systems lack the capacity to buffer impacts (see section 3.3).

The impacts of individual countries on the overall basin risk factor can be disaggregated through analysis of the BCUs (Figure 3.22). For example, in the Ganges Basin, the risks of human water stress are high for the basin areas in India and Bangladesh and lower for those in China and Bhutan. In the Nile Basin, risks are higher for the Egypt and Sudan portions of the basin than for areas upstream.

Figure 3.21. Human Water Stress by Transboundary River Basin. While the highest risk basins and BCUs are found mainly in water-scarce regions of the world, moderate to high risks are found in basins with high water demand relative to availability, indicating that human demands can burden even ample water resources within a basin.

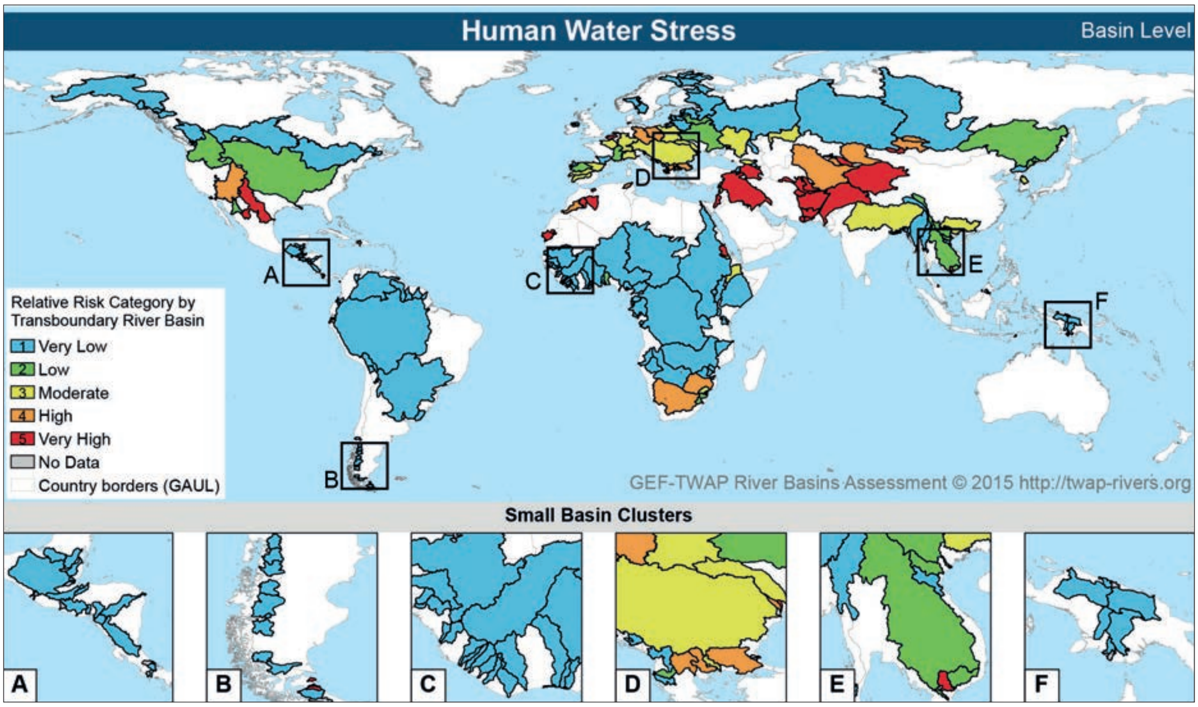


Figure 3.22. Human Water Stress by Basin Country Unit (BCU). The spatial complexity of water demand and availability within basins is evident when viewed at the BCU level; basins categorized as low risk are shown to have BCUs with low, moderate and high risk (e.g., Nile, Niger, and Ganges basins).

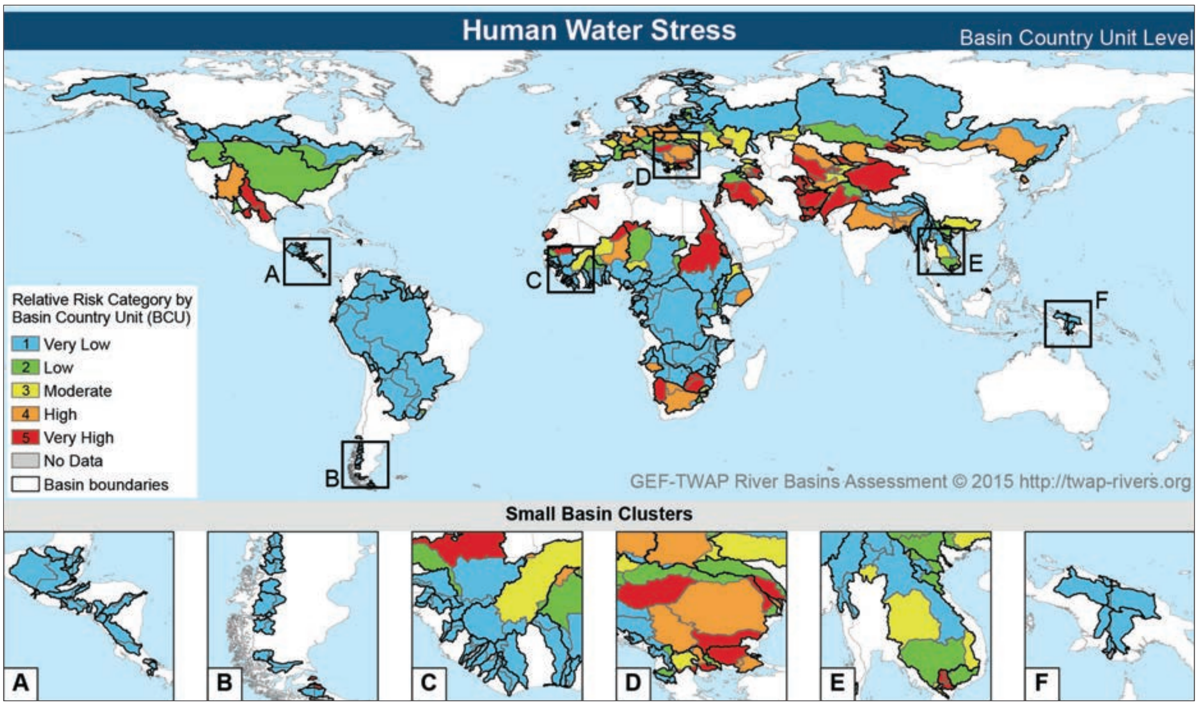
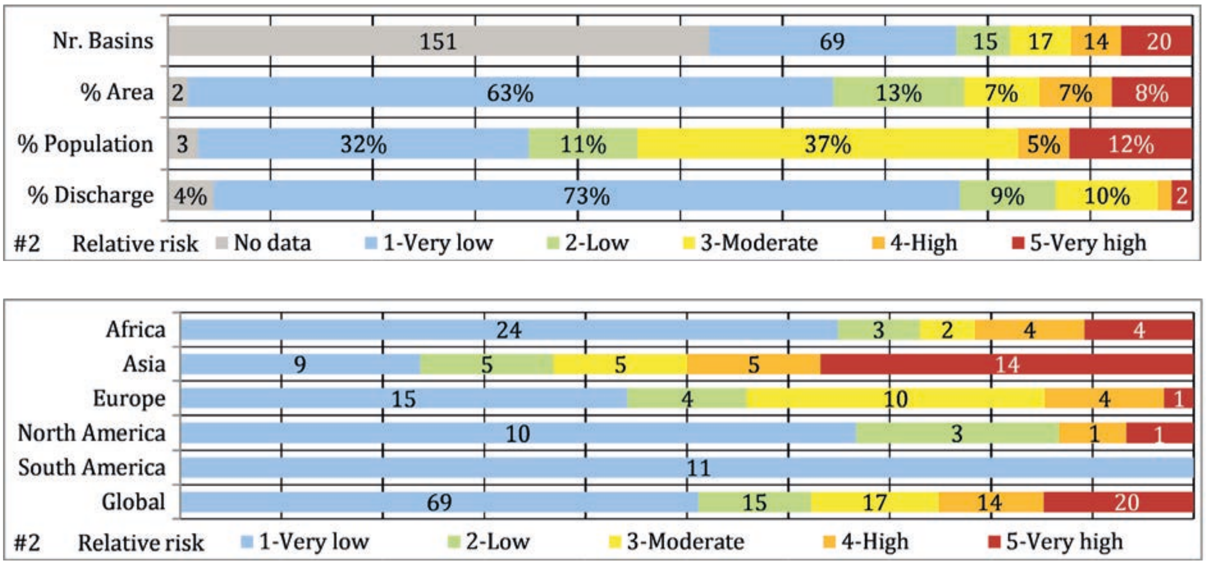


Figure 3.23. Human Water Stress Relative Risk Categories by: number of basins, global TB basin % for area, population and discharge (top); and number of basins by region, 'no data' basins excluded (bottom). More than half the population using water from shared rivers is at moderate or higher risk of human water stress.



Limitations and potential for future development

All data are computed on a 0.5° grid in the Geographic projection over the transboundary river basins and BCUs. While the maps above show all basins and BCUs for which there is a result, Figure 3.41 and the subsequent analysis is based on 135 Basins and 252 BCUs that meet the minimum spatial unit criteria at 0.5° resolution of at least 10 grid cells (~25 000km^2 area). These results have a higher degree of scientific confidence. Results for basins smaller than 25 000 – 30 000 km^2 (1 – 9 grid cells) are indicative only. These results are marked with a lower degree of confidence in the results files downloadable via the portal.

With data and technology improvements, a smaller global grid-size (e.g. 5 arc-minutes) is likely to be feasible in future assessments.

Because of differences between the TFDD basin boundaries derived from the finer scale HydroBASINS dataset and the CUNY 30- and 6-minute river basin networks, we were not able to calculate discharges within and between the BCUs. In future we would like to explore an alternative re-sample and/or downscaling using a finer resolution river network derived from HydroBASINS to achieve an estimate of discharge within and between the BCUs in each basin. The higher-resolution approach would provide much-needed capability to address the upstream/downstream dynamics within transboundary river basins.

3.2.4 Human Water Stress – Projected Scenarios

Computation of Projected Scenarios

The Human Water Stress Indicator (#2) was computed for 2030 and 2050 using the same methodology as the baseline indicator, but with projected water-supply, population and water-demand datasets. Projections were carried out using a 'business-as-usual' scenario. The TWAP River Basin team chose to use climate change projections following a radiative forcing pathway leading to 8.5 W/m^2 (i.e., RCP8.5). This is in agreement with the TWAP groundwater component approach. Compared to the SRES emission scenarios, the RCP8.5 average global temperature increase would be in line with the SRES A1FI but slightly above the SRES A2 scenario at the end of the 21st century.

The two sub-indicators that build the composite Human Water Stress Indicator for 2030 and 2050 were developed as follows:

Renewable Water Supply: the available water supply divided by the total population in the basin for 2030 and 2050. The available water supply is the volume of discharge generated locally within both the transboundary basins and the BCUs (long-term annual average runoff over 2021-2040 for 2030, and 2041-2070 for 2050 from ISI-MIP Project (Warszawski *et al*. 2013)). Total Population is the sum of local gridded population for 2030 and 2050 in the transboundary basins and BCUs produced by scaling the 2010 population (GPW3, CIESIN 2011) by country-level ISI-MIP population projections (ISI-MIP 2013).

Relative water use: the mean annual withdrawal divided by the available water supply for 2030 and 2050. Mean annual water withdrawal in the basin or BCU is the volume of water withdrawal (km^3/yr) for the domestic, electricity production, manufacturing and agricultural sectors for 2030 and 2050 (using the WaterGAP estimates for domestic and industrial water use as simulated within the ISI-MIP Project, cf. Elliot *et al*. 2014)**.** Water Supply is the volume of discharge generated locally within the basins or BCUs for 2030 and 2050 as described by the Renewable Water Supply sub-indicator.

As with the baseline analysis, the two sub-indicators were ranked according to the five relative risk categories from very low to very high based on agreed thresholds presented in the tables in section 3.2.3. The combined Human Water Stress indicator for 2030 and 2050 is defined as the higher ranking category of the two sub-indicators, based on the assumption that water stress as measured by either sub-indicator may be equally serious.

Results

Results for basins and BCUs for 2030 and 2050 show similar patterns to the baseline (2010), with generally worsening conditions. However, some countries in the Sahel region of Africa decrease in relative risk category. Like the 2010 baseline conditions, very high and high risk basins/BCUs (categories 4 and 5) in 2030 and 2050 are dominated by areas of high population, high water demand, and/or low water availability or some combination of these, while medium and low risk basins are characterized by lower population, higher water abundance and/or lower levels of industrial development to impact the water resources. The highest risk basins (category 5) in 2030 and 2050 continue to be located mainly in water-scarce regions. Figure 3.24 and Figure 3.25 show the changes in relative risk categories from baseline (2010) to 2030s and 2050s at the basin level and BCU level, respectively.

Interpretation of results

Because of projected climate variability (both drier and wetter trends) and changes in population and water demand, some regions move to higher human water stress risk categories while others move to lower risk in the projections. River basins and BCUs in South Africa, Eastern Europe and the Southern European countries of Spain and Portugal under baseline moderate and high levels of risk for 2010 change to high and very high risk in 2030 and 2050 due to drying trends in the climate resulting in lower available water supply. Although these regions show some modest increases in both population and water demand, the main driver of risk is the climate-driven decrease in available water supply. The Ganges River Basin also changes from moderate risk under baseline conditions to high risk in 2030 and 2050, driven mainly by increased population and water demand in the Indian portion of the river basin reaching into the foothills of the Himalayas in Nepal. Climate-driven water availability in these regions is indeed projected to increase, but increases in water supply are offset by projected larger numbers of users and much higher water demand, creating higher risk conditions for the river basin, particularly in India and reaching into parts of Nepal.

River basins and BCUs in Central Asia reflect the combined impact of a drier climate resulting in less water availability and higher population and water demand. River basins and BCUs in the water-scarce regions of Central Asia already at high and very high risk under baseline conditions are almost entirely at very high risk for 2030 and 2050 projections due to drier climate, diminished water supply and more users placing greater demand on that supply. The Mississippi

Figure 3.24. Projected Human Water Stress: projected change in relative risk category for the 2030s (top) and 2050s (bottom) by Transboundary River Basin. The more significant changes tend to be in basins and BCUs where there are projected increases in demand and decreases in availability.

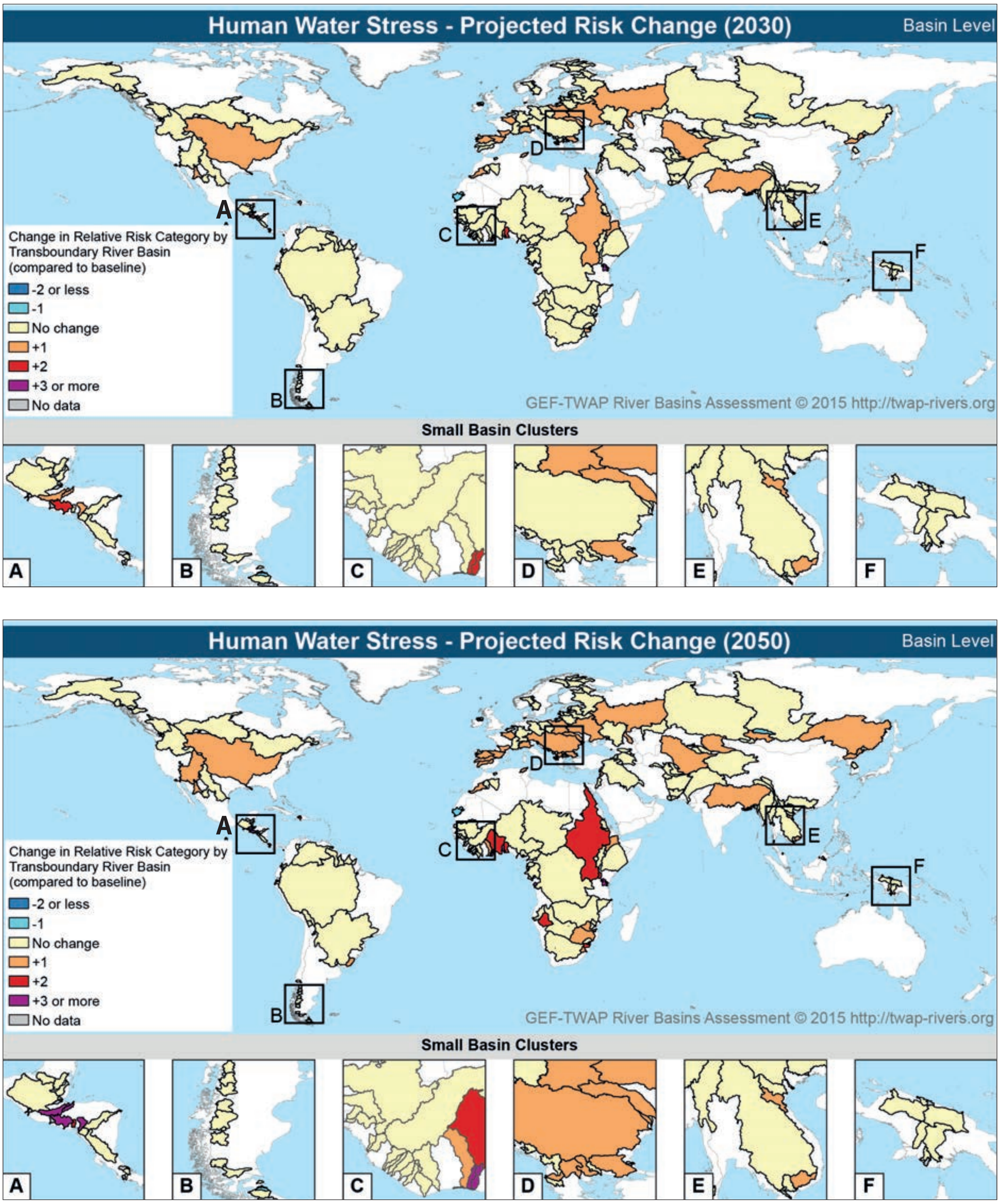
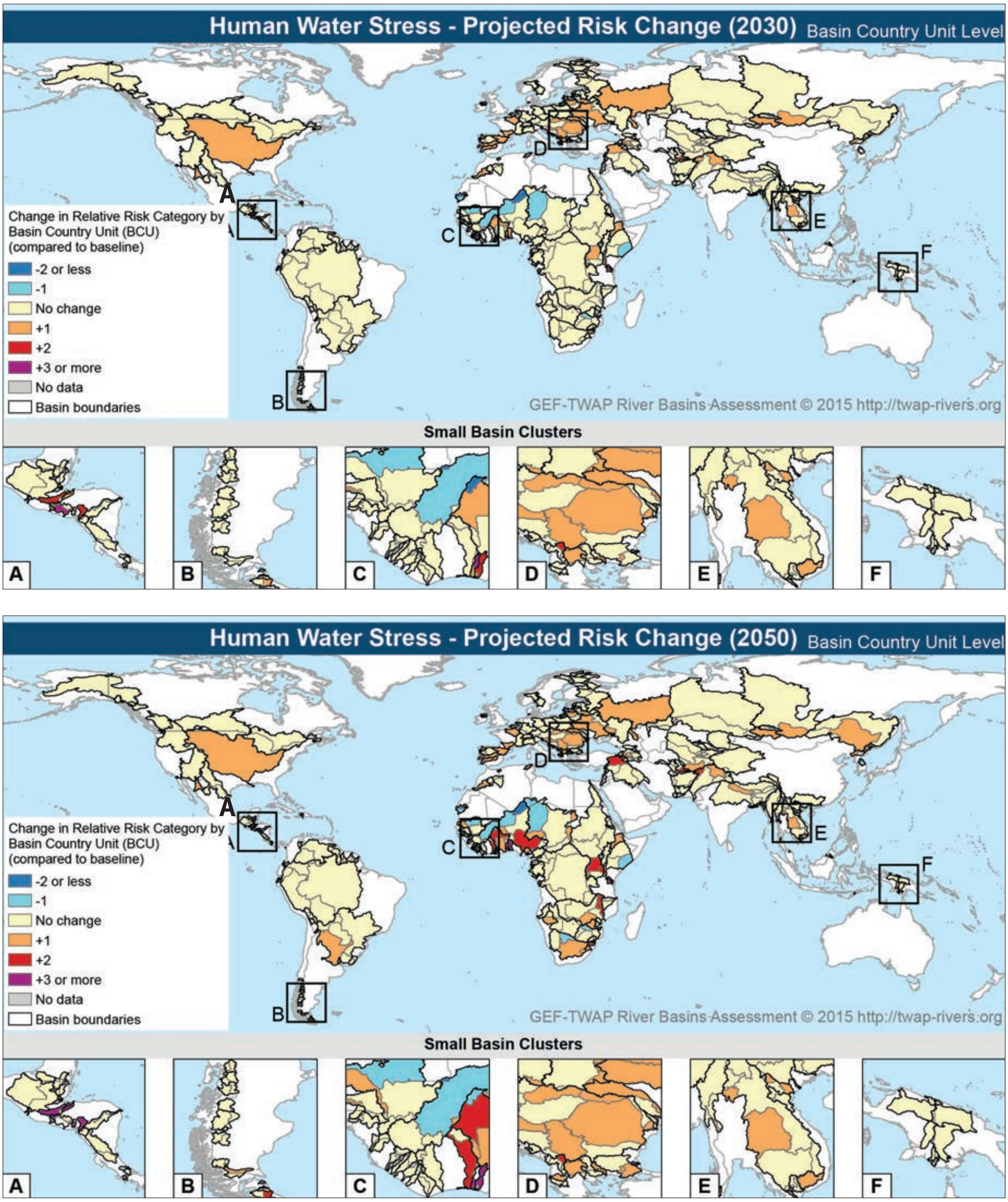


Figure 3.25. Projected Human Water Stress: projected change in relative risk category for the 2030s (top) and 2050s (bottom) by Basin Country Unit (BCU). Some BCUs in the Sahel region of western Africa are projected to have lower Human Water Stress due to climate-driven increases in availability, while other BCUs, even in the same basins, may be projected to have higher Human Water Stress, in some cases resulting in no projected change at the basin level.



and Nile Basins also increase their water stress risk due to a projected drier climate and increased water demand in parts of their basins.

BCUs in the Sahel region of Western Africa change from moderate/high to lower water stress risk due to climate-driven increase in water availability in 2030 and 2050. These regions, most notably in the drier northern part of the Niger and Lake Chad Basins in Mali and Niger, are also projected to have increases in population and water demand, but the projection of a wetter climate offsets the projected water pressure increases. IPCC and other regional models have also suggested an intensification of the monsoon and a greening of the Sahel and parts of the southern Sahara (Christensen *et al*. 2007; Brooks 2004). However, models showing projected seasonal distribution of rainfall have suggested drier conditions in these regions for July and August, offset by wetter conditions in September (Patricola and Cook 2010), reflecting a more complex seasonal pattern than is represented in the annual data used to build the risk scores. In contrast, the BCUs in the southern part of the West African monsoon-influenced areas (southern Niger and Volta Rivers) change from low to moderate levels of risk due to higher population and water demand projections which exceed the gains in water supply due to a projected wetter climate.

Limitations and potential for future development

All data are computed on a 0.5° grid in the Geographic projection over the transboundary river basins and BCUs. While the maps above show all basins and BCUs for which there is a result, the subsequent analysis is based on 135 Basins and 252 BCUs that meet the minimum spatial unit criteria at 0.5° resolution of at least 10 grid cells (~25 000km^2 area). These results have a higher degree of scientific confidence. Results for basins smaller than 25 000 – 30 000 km^2 (1 – 9 grid cells) are indicative only. These results are marked with a lower degree of confidence in the results files downloadable via the portal. Projected scenarios would benefit greatly from a higher resolution approach to the calculation of results.

3.2.5 Agricultural Water Stress

Key findings

1. **Hotspots of agricultural water stress:** These are transboundary river basins in Central Asia, the Middle East, southern U.S.A. and northern Mexico. In Europe, the Spanish parts of Guadiana and Ebro river basins are prone to agricultural water stress.
2. **One tenth of river basins have extreme agricultural pressures:** 10% of the land area of transboundary basins is under very high agricultural water stress.

Rationale

Throughout history, agriculture has been an important user of water resources. Today, agriculture accounts for about 70 per cent of all water abstraction worldwide (FAO 2012; Shiklomanov and Rodda 2003) and more than 30 per cent of global crop production is from irrigated areas (Portmann *et al*. 2011). Consequently, the impact of agriculture on global water resources is large and often the main originator of the appearance of water stress. This indicator assesses agricultural water stress due to irrigation (livestock water use is much less significant and is therefore not included), and is complementary to the indicators of human (e.g., domestic) and environmental water stress.

Computation

In order to assess agricultural water stress, the indicator ‘irrigation consumption-to-water availability’ (c_{irr}.t.a.) is introduced. Irrigation consumption refers to the part of the irrigation water that is really ‘consumed’ by the crops through evapotranspiration (net irrigation requirements), rather than the amount of water which is withdrawn, some of which may return to the system as ‘return flows’. In principle, the higher the ratio, the more intensively the water in a river basin is used. As well as the irrigation water requirements, this indicator takes into account the available water resources in each transboundary basin or BCU. More information about the computation of this indicator can be found in Annex V-1. The potential irrigation water consumption was calculated assuming the given water is freely available for optimal crop growing; no distinction was made between abstractions from groundwater and surface water resources. If the renewable water resources on their own cannot cover the demand, non-renewable water resources (e.g. fossil groundwater) are also likely to be exploited.

Results

The following discussion refers only to the 163 transboundary river basins (and 292 BCUs) with at least ten 0.5° grid cells assigned (i.e., about >25 000 km^2). Under current conditions, a large number of transboundary river basins and BCUs between latitude 10°N and 50°N are facing agricultural water stress (Figure 3.26 and Figure 3.27). Taking into account the water resources available in each basin or BCU, hotspots of very high agricultural water stress (category 5) can be identified in Central Asia, the Middle East, and North America (i.e., in the southern U.S.A. and northern Mexico). Interestingly, no high or very high agricultural water stress (category 4 and 5) occurs in Africa in the river basin map (Figure 3.26). However, when comparing the results with the BCU map (Figure 3.27), it becomes obvious that very high water stress occurs in the lower part of the Nile basin (i.e. in Egypt and Sudan). Egypt and Sudan have by far the highest water demand (especially due to irrigation and high population density), and produce some of the lowest runoff, compared to the other BCUs of the Nile river basin. These countries, in particular, depend on water from upstream areas, i.e. internal renewable freshwater resources are too small to cover agricultural requirements. Also at the BCU level, very high and high agricultural water stress occur in the Spanish parts of the Guadiana and Ebro river basin. In total, 8% of the river basins (11% of the BCUs) fall into category 5. Category 5 means that more than 30% of the available water resources are consumed by agricultural irrigation. Overall, 76% of the river basins (72% of the BCUs) are not affected by agricultural water stress (category 1 and 2), that is irrigation water consumption is less than 5% of the available water resources.

The largest shares of high and very high stressed (category 4 or higher) transboundary river basins and BCUs are found in Asia, which shows by far the highest proportion affected by agricultural water stress (Figure 3.28). In this

Figure 3.26. Agricultural Water Stress by Transboundary River Basin. Based on irrigation consumption-to-availability, hotspots are mainly in Central Asia, the Middle East, southern U.S.A. and northern Mexico.

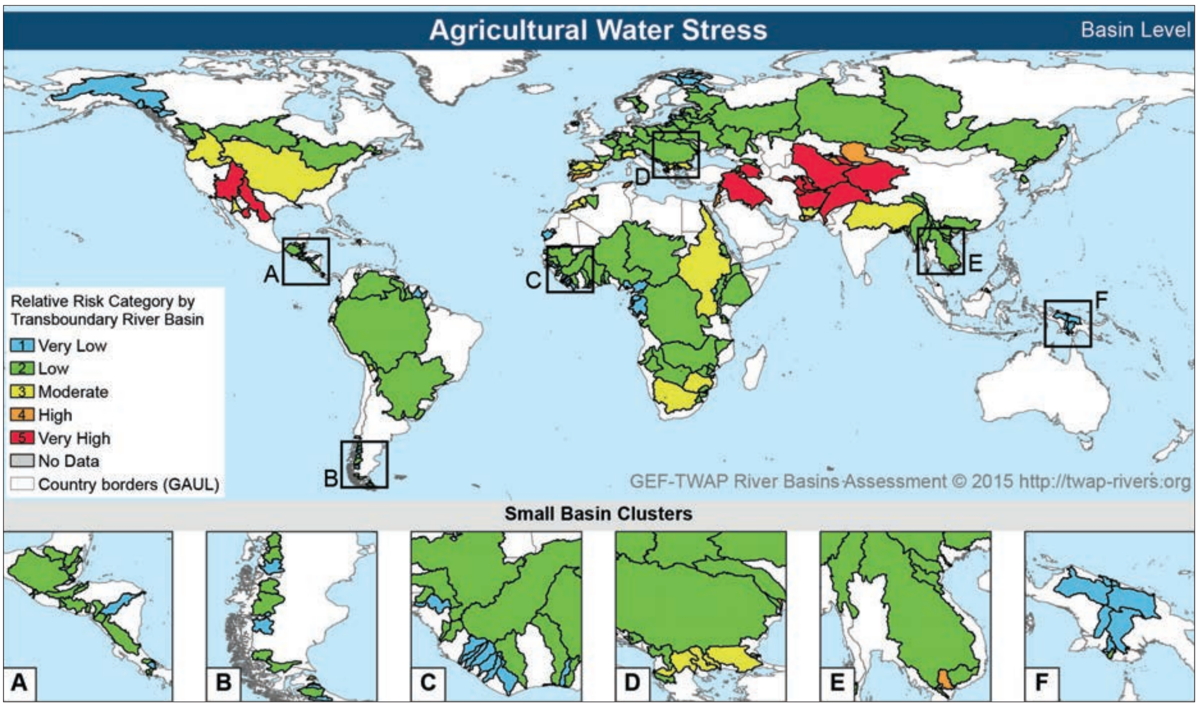


Figure 3.27. Agricultural Water Stress by Basin Country Unit (BCU). While irrigation is vital for global food supply, and accounts for the highest water abstractions worldwide, it is mainly used in drier climate zones. The vast majority of BCUs therefore have very low or low risk of agricultural water stress.

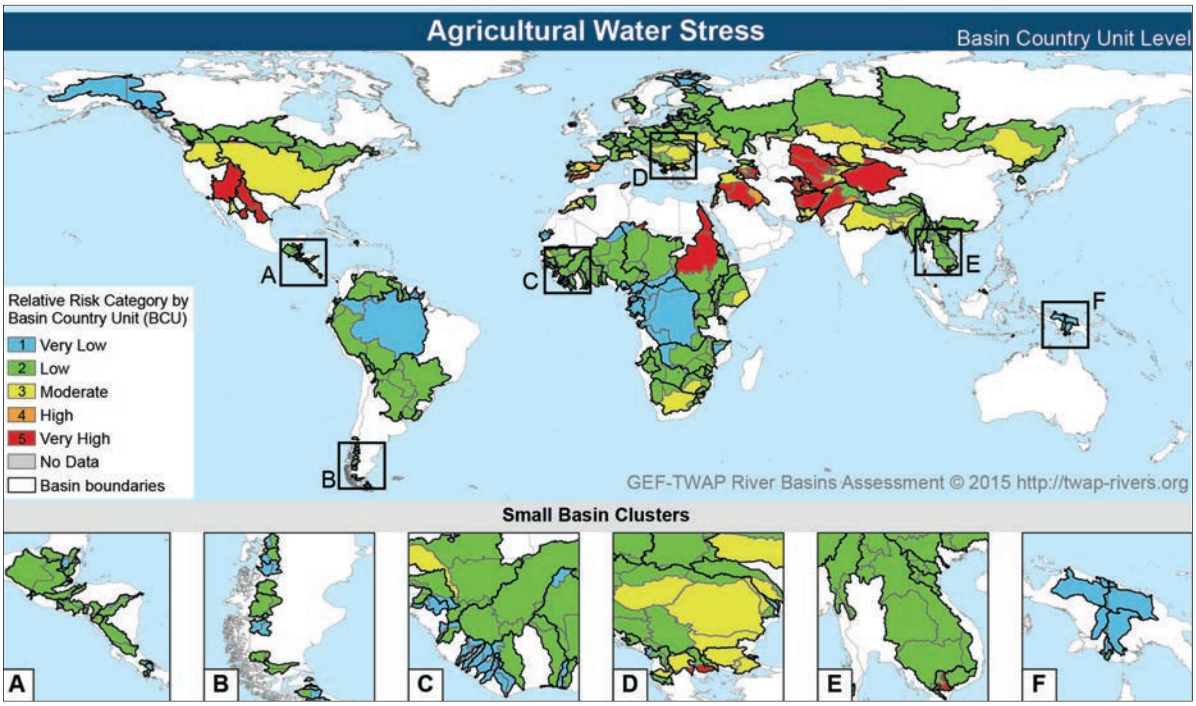
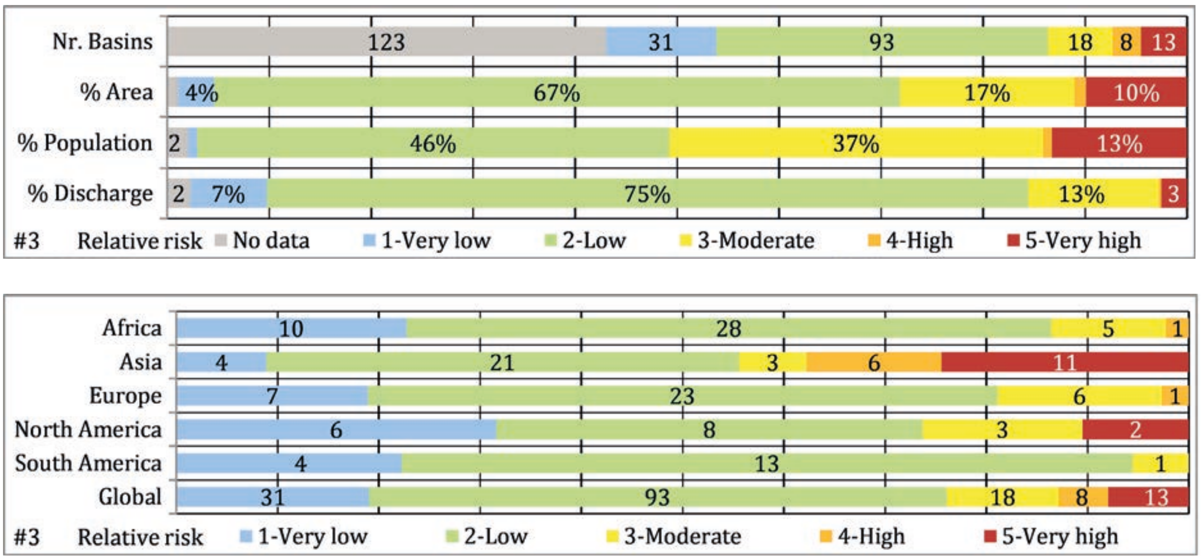


Figure 3.28. Agricultural Water Stress Relative Risk Categories by: number of basins, global TB basin % for area, population and discharge (top); and number of basins by region, 'no data' basins excluded (bottom). 10% of land area is under very high risk of agricultural water stress.



region, 38% of the transboundary river basins (36% of the BCUs) fall into categories 4 or 5. North America follows with a share of 11% (17%) covering these two risk categories. In Europe and Africa only 3% and 2% respectively of the transboundary river basins (3% and 4% of the BCUs) are under agricultural water stress. Agricultural water stress is by far the lowest in South America, where there are no river basins and BCUs with high and very high relative risk.

Interpretation of results

In BCUs that have been identified as being under agricultural water stress, irrigation is expected to be the dominant water user. In particular, areas classified as category 4 and 5 indicate less available water for other water-related sectors, and hence, potential vulnerability to climate change. Furthermore, in South and Central Asia as well as in North America, water for irrigation is often taken from non-renewable groundwater resources (Siebert *et al*. 2010). In these regions, model results indicate that water abstractions exceed the amount of renewable water resources. Agriculture is important for food security and livelihoods in many countries, and can be a key source of export income. Particularly in many developing countries, agriculture is often the most important economic sector and might be threatened in BCUs which have a high risk of agricultural water stress.

While irrigation accounts for the highest water abstractions worldwide, it is only used in drier climate zones. According to the classification applied here, 561 out of the 635 BCUs are less affected by irrigation and belong to the very low or low water stress classes.

Limitations and potential for future development

The indicator has been calculated for all TWAP river basins which could be assigned on the WaterGAP2 grid cell raster. The model results were computed on a 0.5° grid and aggregated to river basin and BCU levels. However, verified conclusions can only be drawn for transboundary basins which can be assigned ten 0.5° grid cells, roughly equivalent to > 25 000 km². In general, model results are available for 270 out of 286 basins and 635 out of 796 BCUs. 107 basins and 343 BCUs consist of less than 10 grid cells. The results for these basins and BCUs are provided, but marked as having a lower level of scientific confidence. A smaller global grid-size is likely to be feasible in a future assessment. A higher number of dams could also be taken into account.

3.2.6 Water Quantity Thematic Group Summary

The key findings for the thematic group are given in the introduction to section 3.2. The three indicators assessed in this group are:

1. Environmental Water Stress (induced by flow regime alterations);
2. Human Water Stress;
3. Agricultural Water Stress.

The three different indicators related to water quantity were developed to assess the status of freshwater resources in terms of water quantity in all the transboundary river basins of the world as well as their respective BCUs.

In order to identify transboundary basins at risk from environmental, human or agricultural water stress, we prepared a ‘water quantity index’ which highlights the hotspots (i.e. the most stressed basins) of this thematic group. The index was created by taking the maximum relative risk category of the three indicators (Figure 3.29).

The analysis identified 26 transboundary river basins (16% of all transboundary basins) in the very high risk category, covering 11% of the entire transboundary river basin area (see Figure 3.30). Note that Figure 3.30 only refers to about half of the river basins with an area greater than about 25 000 km². This is due to the limitations of the modelling approach used in this study, where reliable statements can only be made for river basins with at least ten grid cells assigned to them. However, these basins cover 99% of the total land area of the transboundary basins (or 98% of the population of these basins), meaning that only small basins are not included in the analysis, and that interpretation of results at the global level is still appropriate.

The very high risk basins (category 5) are either located in water scarce (arid) regions or characterized by large populations or high levels of human activity (resulting in high water demand). In general, the identified river basins in Central Asia are mainly under environmental, human, and agricultural water stress (as is the Rio Grande), whereas river basins in the Middle East and northern and southern Africa are subject to human and agricultural water stress

Figure 3.29. Water Quantity Index by Transboundary River Basin. Maximum relative risk category of environmental, human and agricultural water stress. The Hari, Helmand, Kowl E Namaksar, Murgab, Tarim (all in Asia) and the Rio Grande (North America) basins show very high risk categories for each of the three water stress measures, indicating high competition between different water-related sectors.

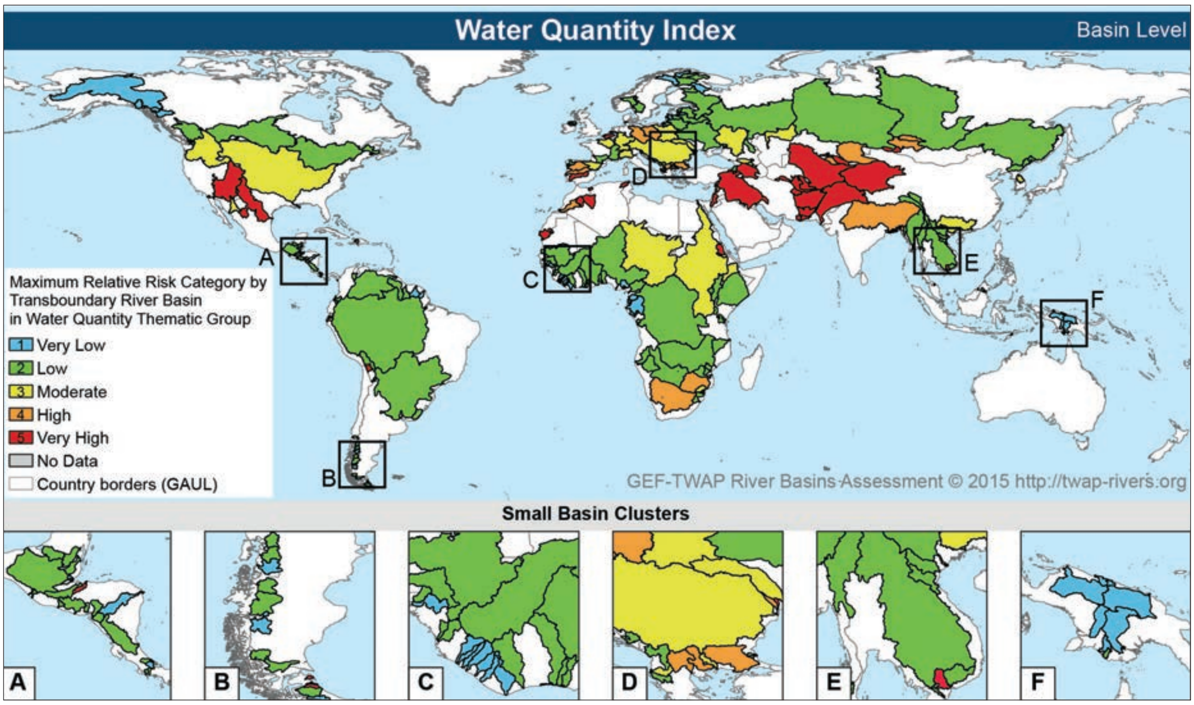
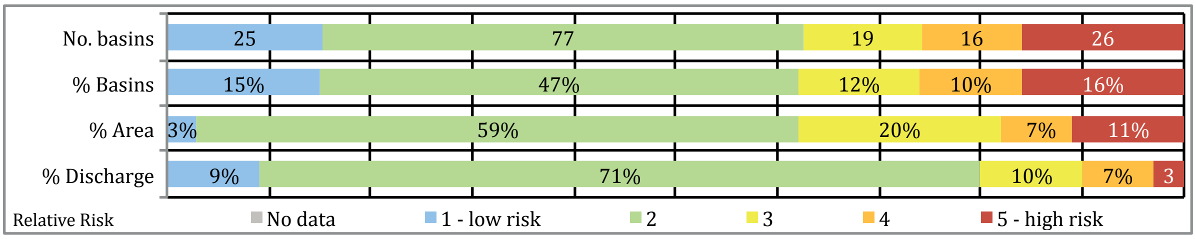


Figure 3.30. Water Quantity Index: maximum relative risk category of environmental, human and agricultural water stress. The figure shows results by: number of basins, % of basins, global TB basin % for area and discharge (basins with results for each of the three water quantity indicators and with higher degree of confidence only). The high correlation between the water stress indicators means there are relatively few basins in the very high relative risk category.



(as is the Colorado). The statistical analyses (section 4.1) of the three water quantity indicators show a high positive correlation between environmental water stress (indicator #1) and agricultural water stress (#3; Pearson's r=0.71) and a moderate correlation with human water stress (particularly sub-indicator #2b of withdrawals-to-availability ratio; Pearson's r=0.35).

The cumulative impact of human activities is highest in the following transboundary river basins: Hari, Helmand, Kowl E Namaksar, Murgab, Tarim (all in Asia) and the Rio Grande (North America). These basins show very high risk categories for each of the three water stress measures, indicating high competition between different water-related sectors (such as the environment, urban areas and agriculture), which may increase as a result of global change

Treated wastewater - or 'reclaimed water' - can be part of the solution for addressing water stress and competition between sectors.

impacts. Moreover, these river basins are subject to overexploitation of available freshwater resources, suggesting that sustainable water use will be difficult to achieve.

The statistical analyses (section 4.1) of the three water quantity indicators confirm a positive correlation with the water quality indicators, even indicating the influence of point and diffuse sources on the indicators. While the human water stress indicator (#2a) correlates with the wastewater indicator (#5; R=0.17), the agricultural water stress indicator correlates with nutrient pollution (#4; R=0.23). These correlations illustrate that a significant demand for water and its intensive use lead to more production of wastewater and fertilizer application, which again may result in negative ecosystem and human health effects. This conclusion is further supported by the positive correlation with the economic dependence measure (#13; R=0.11 to 0.13).

All water quantity indicators are also positively correlated with exposure to drought (#15b, R=0.28 to 0.61) suggesting the importance of the distribution of available water resources between water-related sectors as well as the greater risk of seasonal or inter-annual variations of water flow. Finally, negative correlation has been detected with the legal framework indicator (#10; R= -0.18 to -0.11), thus the lower the presence of key international legal principles, the higher the water stress in the respective basins. The influence is somewhat higher for environmental water stress, suggesting that environmental flow provisions are less represented in governance architectures. While the majority of the correlations described above may not be highly statistically significant, they do provide an indication of the directionality of the relationships. A more nuanced understanding may be achieved through the analysis of smaller sub-sets of basins.

When looking at the projections of the environmental and human water stress indicators, growing population, economic development and climate change are likely to increase the pressure on freshwater resources. Any change in use and natural conditions at one point in a river basin will affect the availability and quality of water resources for other (downstream) users; this, again, may increase the complexity of transboundary water management. For example, temporal, seasonal, or permanent decreases in river flow will result in a higher fraction of upstream water consumption which may endanger downstream water supply (as indicated by the statistical analysis of current conditions). Also, increasing irrigation water withdrawals due to rising temperatures may increase environmental water stress (both are strongly correlated) or water supply downstream. In particular, downstream countries might be more affected by water stress since they could face more/new water scarcity situations caused by upstream countries. As a result, water-dependent sectors in the downstream part of a river may become more vulnerable to upstream activities.

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3.3 Water Quality

Deteriorating water quality, as well as water quantity stress (section 3.2), is an increasing threat to human and environmental health in many regions. This thematic group includes two indicators that together address nutrient over-enrichment and pathogens. Nutrient (e.g., nitrogen and phosphorus) over-enrichment (eutrophication) can, for example, cause algal blooms, some of which are toxic to humans and aquatic organisms, increase turbidity, and decrease dissolved oxygen. Nutrient over-enrichment is addressed in the Nutrient Pollution Indicator (#4). Although there is considerable spatial variability, globally nutrient runoff from agriculture is the largest contributor to nitrogen in rivers, while agriculture and sewage are both important pollutant sources of phosphorus (Seitzinger *et al*. 2010). Pathogens in untreated human waste are a threat to human health, and can also contribute to nutrient over-enrichment. This is addressed by the Wastewater Pollution Indicator (#5). Thus, these two indicators are complementary, in that the first mainly addresses eutrophication and the second mainly pathogen risks.

Thematic group key findings

1. **Water quality risks are high in many transboundary river basins:** Water quality is severely affected in more than 80% of the basins, either by nutrient over-enrichment (typically in developed regions e.g. North America and Europe) or by pathogens (generally in developing regions, e.g. South America, Africa, and in northern Asian basins with Russia), or in both (e.g. emerging economies in southern and eastern Asia).
2. **Water quality risks are projected to increase:** The projected scenario for nutrient pollution suggests that the relative risk will increase in around 30% of basins between 2000 and 2030, with the risk in two basins increasing by three categories. Between 2030 and 2050 nutrient pollution risk is projected to increase further in 21 basins, while in six basins the risk decreases by one category[8]. The effects of nutrient pollution are also likely to exacerbate risks across other indicators and water systems (e.g. ecosystem health, coastal areas and aquifers).
3. **Mitigation measures are needed in all river basins to reduce risks:** In basins with a risk of nutrient and wastewater pollution, improvements to wastewater treatment may help to reduce both risks. Improved nutrient management in agriculture (e.g. crop and livestock) will likely be needed to reduce current risks of nutrient pollution in many basins. Even in basins with relatively low risk, both strategies are likely to become more important as the global population continues to rise, which is likely to increase risks of nutrient and wastewater pollution unless adequate mitigation measures are in place.

3.3.1 Nutrient Pollution – Baseline and Projected Scenarios

Key findings

1. **Half the population in basins face serious nutrient pollution risks:** For contemporary (2000) conditions, 33 (out of 133) basins have a nutrient pollution risk in the high or very high relative risk category and account for 16% of the area, 52% of the population, and 9% of river discharge. Most of these basins are in western Europe, and southern and eastern Asia, and include the Mississippi basin in North America. Basins in the moderate (52 basins), low (42 basins), and very low (6 basins) risk categories are found on all continents, although 66% of them are in Africa or Asia.
2. **Changes are projected for risks in many basins:** The projected scenario suggests that, between 2000 and 2030, 31 basins will increase by one risk category and 2 basins by three categories, and in 3 basins the risk will decrease by one category. Between 2030 and 2050 nutrient pollution risk increases in 21 basins by one category, while in 6 basins the risk decreases by one category. Understanding possible reasons for these changes would require further analysis of sources and drivers. Many of the changes to a higher risk category are in eastern and southeast Asia, but changes are projected in many basins on all continents.

8 High confidence results only

Rationale

Nutrient pollution is an increasing problem in many rivers (Dodds 2006). River nutrient pollution is caused mainly by runoff from agricultural activities (fertilizer use and wastes from livestock), sewage, and atmospheric nitrogen deposition. Contamination by nutrients (particularly forms of nitrogen and phosphorous) increases the risk of eutrophication in rivers, which can pose a threat to environmental and human health (e.g. algal blooms, decreases in dissolved oxygen, increase in toxins making water and fisheries such as shellfish unsafe for humans), affect tourism and lead to loss of livelihoods. The Nutrient Pollution Indicator (#4) considers river pollution by dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphorous (DIP), which are the nutrient forms that contribute rapidly to eutrophication and have strong anthropogenic sources.

Computation

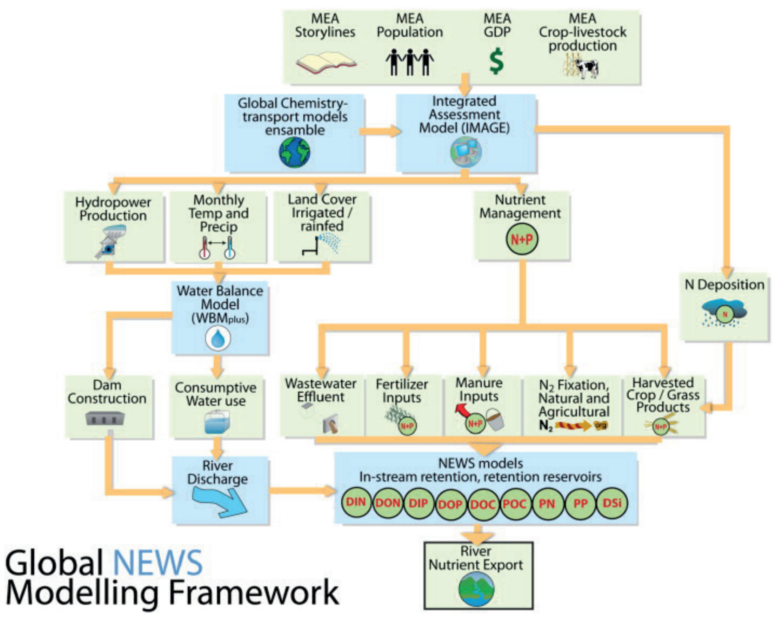
The DIN and DIP concentrations for the TWAP river basins were calculated using the Nutrient Export from Watersheds (NEWS 2) model ()[9].

The Nutrient Pollution Indicator is a combination of the DIN and DIP sub-indicators. Five risk categories for each sub-indicator were developed, based on published national river water quality criteria (see metadata sheet in Annex IX-2). A relative risk category of 1 denotes the lowest risk for eutrophication and 5 the highest.

Table 3.8. Concentration Ranges Used for Assigning Relative Risk Categories for DIN and DIP Sub-indicators

	Relative risk category	Conc. range mg N/l	Conc. range mg P/l
1	Very low	≤0.15	≤0.01
2	Low	>0.15 and ≤0.5	>0.01 and ≤0.03
3	Moderate	>0.5 and ≤1.0	>0.03 and ≤0.1
4	High	>1.0 and ≤2.0	>0.1 and ≤0.5
5	Very high	>2.0	>0.5

Figure 3.31. Conceptual Diagram of NEWS Model Construction, Sub-models and Parameters.



Source: Glibert et al. 2010 modified from Seitzinger et al. 2010

9 Extensive input data required for NEWS 2 (see Table 2 in metadata file) were not available to update the output to 2010 at the time of the assessment, but are now under development by Bouwman *et al.* (personal communication) and could be used in future assessments.

Water quality criteria consider nitrogen (N) and phosphorous (P) separately. However, it is not only N or P concentrations, but the N:P ratio that can cause negative ecosystem and human health effects. For example, high P concentrations relative to N (compared to the needs of algae) often result in N_2-fixing blue-green algal blooms in rivers that can adversely affect water quality and harm humans and ecosystems. High N concentrations alone can affect drinking water quality. High concentrations of both N and P can lead to changes in community composition, high biomass of algal and macrophytes, increase turbidity, and hypoxic/anoxic conditions, among other effects (Dodds 2006).

The risk category for the combined Nutrient Pollution Indicator for each basin was therefore calculated as the higher of the two sub-indicator categories (e.g., a DIP risk category of 4 and DIN of 2 would result in a combined Nutrient Pollution Indicator of 4 as this condition could promote blue-green (N_2-fixing) algal blooms).

For future projections (2030 and 2050), model inputs and forcings were based on the Global Orchestration (GO) scenario of the Millennium Ecosystem Assessment (MEA) (Seitzinger *et al*. 2010; Alcamo *et al*. 2009). The GO scenario is an internally-consistent, plausible global future and focuses on implications for ecosystem services. The forcing data include not only climate change, hydrology, water use, population, and GDP, but also nutrient management options for agriculture (crop and livestock) and sewage treatment (Fekete *et al*. 2010; Bouwman *et al*. 2009; Van Drecht *et al*. 2009). GO describes a globalized world with a focus on economic development with rapid economic and urbanization growth, and reactive environmental management.

The Nutrient Pollution Indicator has links with the TWAP LME component. The same river watershed model (NEWS) was used for calculating N and P for both the River Basin and LME components. Both of these components used amounts as well as nutrient ratios in the development of sub-indicators and a combined indicator, although the approaches differed due to differences in the responses of freshwater and marine ecosystems to nutrients. The base year conditions and the scenario for projections (2030 and 2050) were the same for both components.

Results

The following discussion refers only to the 133 basins that are >25 000 km^2 or meet other criteria as noted in the 'Limitations' section below and Annex IX-2 (meta-data template) (i.e., are not flagged). These 133 basins account for 96% of the total area, 95% of the population, and 95% of the river discharge in the 286 transboundary basins (Figure 3.33).

For contemporary (2000) conditions, 33 basins have a nutrient pollution risk in the high or very high relative risk category (4 or 5) and contain 16% of the area, 52% of the population and 9% of the river discharge (Figure 3.33). Most of these basins are in Western Europe, southern and eastern Asia, and include the Mississippi basin in North America (Figure 3.32). Basins in the moderate (risk 3) (52 basins), low (risk 2) (42 basins), and very low (risk 1) (6 basins) categories are found on all continents.

Based on projections from the Global Orchestration scenario for 2030 and 2050, the risk category increases (relative to 2000) for a number of basins, and in a few basins the nutrient pollution risk decreases (Figure 3.34). In particular, between 2000 and 2030, 31 basins increase by one category, 2 (Atrak and Baraka) increase by three categories, and in 3 basins the risk decreases by one category (Rhine, Ogooué and Ma). Between 2030 and 2050 nutrient pollution risk increases in 21 basins by one category, while in 6 basins the risk decreases by one category. Many of the changes to a higher risk category are in eastern and southeast Asia, but changes are projected in many basins on all continents. Figure 3.32 Nutrient Pollution by Transboundary River Basin (maximum of DIN and DIP risk categories). Most of the basins with high or very high risk of nutrient pollution are in Europe, and southern and eastern Asia.

Interpretation of results

In general basins with high and very high risk categories are in regions with large populations and/or extensive use of fertilizers in agriculture and/or high industrial animal production, based on national statistics and global databases (Bouwman *et al*. 2009; van Drecht *et al*. 2009).

Figure 3.32. Nutrient Pollution by Transboundary River Basin (maximum of DIN and DIP risk categories). Most of the basins with high or very high risk of nutrient pollution are in Europe, and southern and eastern Asia.

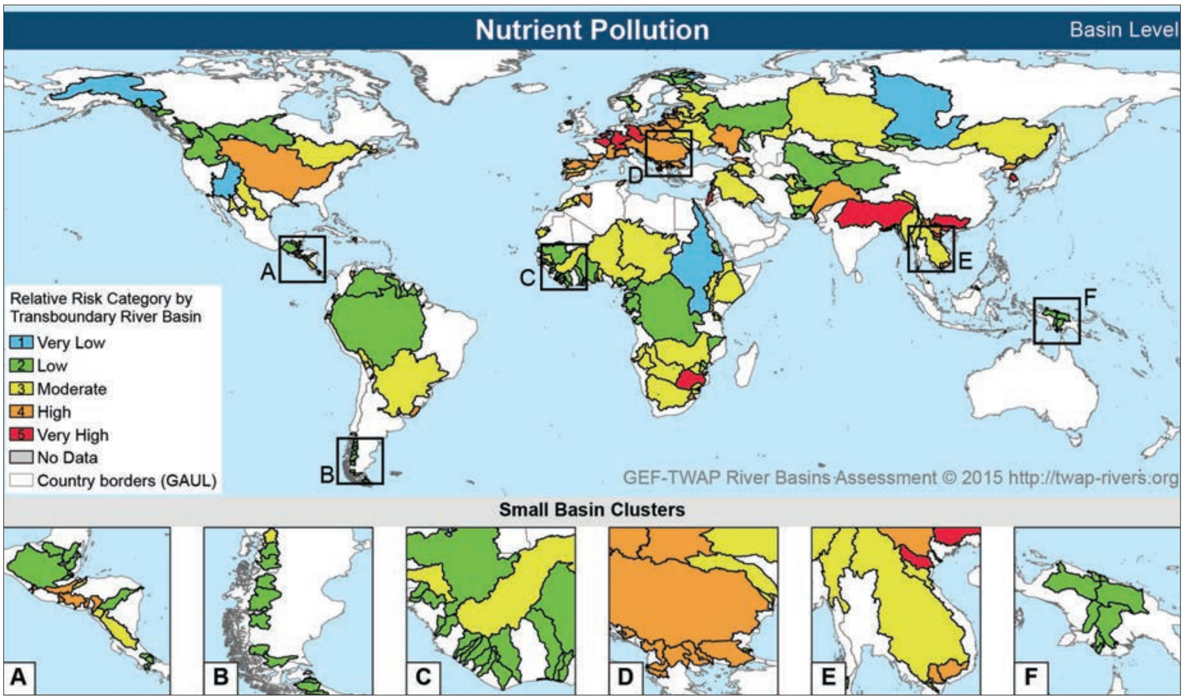


Figure 3.33 Nutrient Pollution Relative Risk Categories by: number of basins, global TB basin % for area, population and discharge (top); and number of basins by region, 'no data' basins excluded (bottom). About half the population in transboundary river basins live with high or very high risk of nutrient pollution.

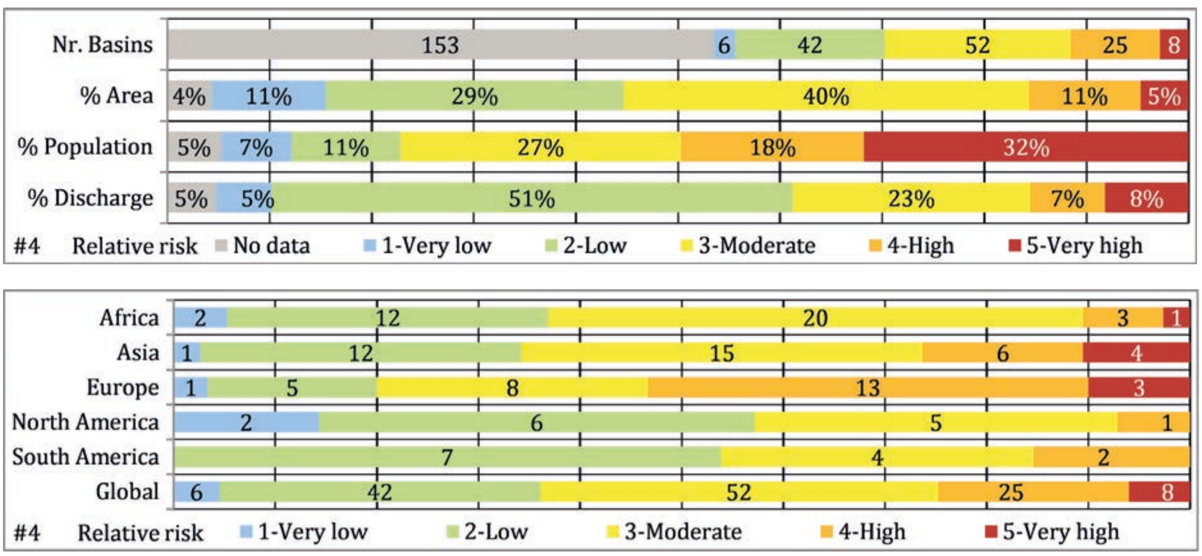
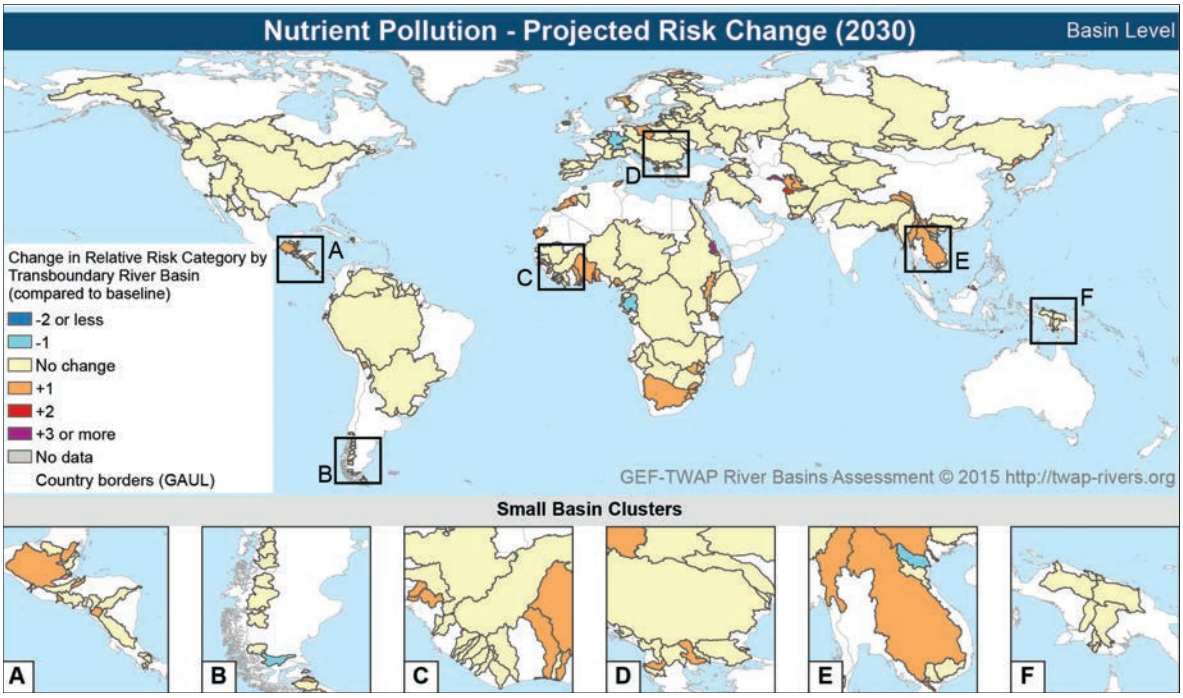
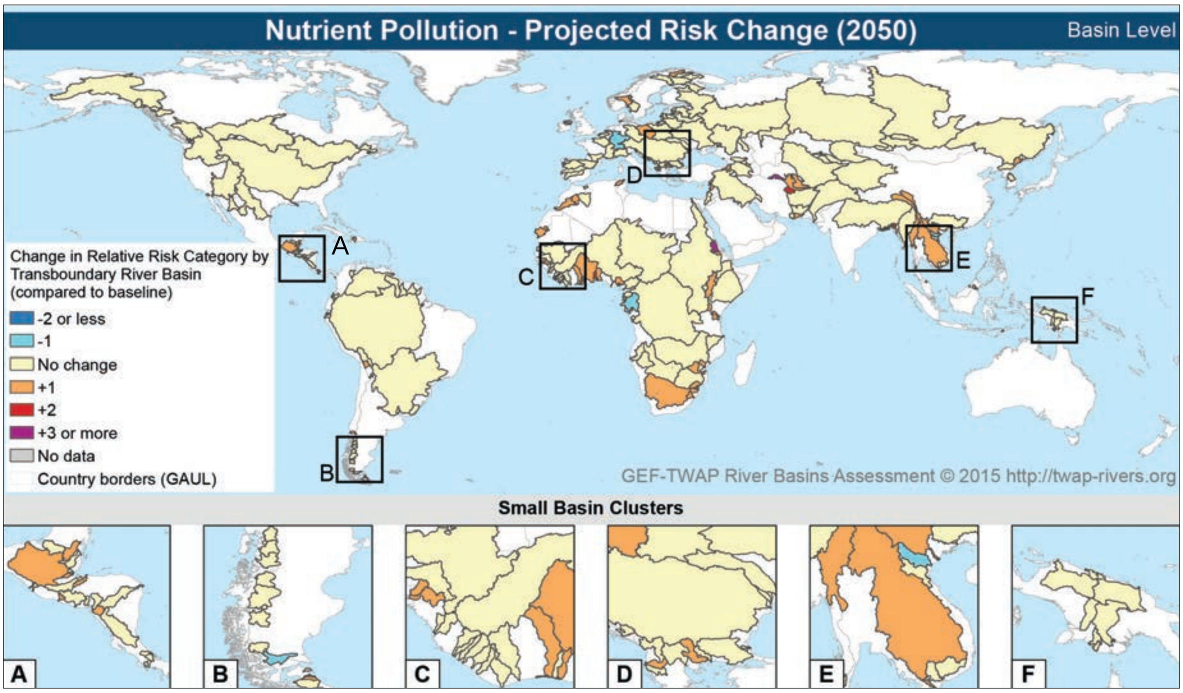


Figure 3.34. Nutrient Pollution by Transboundary River Basin (maximum of DIN and DIP risk categories): changes in relative risk category based on the MEA Global Orchestration scenario) for 2030 (top) and 2050 (bottom). Changes are expected on all continents.





Overall, the patterns of increases in pollution risk are generally consistent with projected changes in population (UN 2011), and projected increased fertilizer use and livestock production in the regions (Bouwman *et al*. 2009). The analysis presented provides information supporting the need for river nutrient water quality to receive emphasis in the Sustainable Development Goals (SDGs) , and the indicator can support the monitoring of nutrient water quality if required within the SDG monitoring framework.

Limitations and potential for future development

Although nearly all 286 transboundary river basins (280) were included in the NEWS calculations, 147 of those assessed were classified as having a lower level of confidence, and while included in the maps, they are not included in the above discussion of results.

Basins are flagged as having lower level of confidence if any of the following are true: 1) basin area <20 000 km^2, 2) basin cell count of the corresponding dominant NEWS basin <10, 3) <50% of the basin is covered (overlapped) by the corresponding dominant NEWS/STN30 basin (an assessment of the geographical coincidence between TWAP and NEWS/STN30 basins), 4) <60% of the TWAP basin is covered (overlapped) by any combination of NEWS/STN30 basins.

There is a paucity of nutrient data for most of the transboundary rivers that can be used to calculate an annual concentration for comparison with the NEWS 2 model. However, data for a wide range of rivers globally have been compared with the NEWS 2 model (Seitzinger *et al*. 2010; Yan *et al*. 2010; Mayorga *et al*. 2009). It has also been successfully applied in continental-scale studies for South America (Van der Struijk and Kroeze 2010), Africa (Yasin *et al*. 2010), China (Qu and Kroeze 2012; Qu and Kroeze 2010), and the Bay of Bengal (Sattar *et al*. 2014).

This paucity of nutrient data also dictated the use of model-based results for global consistency and coverage. Measured data from global programmes such as UNEP GEMS/Water were not readily available and, while continually being improved, suffer from inconsistent coverage. Future assessments would benefit from the availability and expansion of such data and the results of the UNEP World Water Quality Assessment that was initiated recently and is still in an early phase.

The NEWS 2 model configuration when this report was being drafted was limited to the baseline year 2000. Extensive input data required for NEWS 2 were not available to update the output to 2010 at that time, but are now under development by Bouwman *et al*. (personal communication) and could be used in future assessments. Since the NEWS 2 model output is at the scale of whole basins which can encompass substantial within-basin variability, and the scale of NEWS/STN30 basin definitions is coarser than that of TWAP basins, extrapolation or resampling to Basin Country Units (BCUs) was not defensible.

Published water quality criteria for river nitrogen and phosphorus concentrations vary considerably, so we have used the published criteria together with expert judgement to set the sub-indicator risk category thresholds.

A number of factors, not included in this analysis, can affect river ecosystem response to nutrients, for example hydrology (e.g., water depth, water discharge/flushing rate).

While sources of uncertainty and NEWS 2 model result assessments have been discussed, a quantitative approach for establishing confidence levels for the risk category sub-indicators or the combined indicator could not be readily developed. Given the various uncertainties and gaps in data noted in the text, there is medium certainty in the overall scores for river basin conditions.

An evaluation of the various nutrient sources and their distribution within each basin, and their contribution to the risk category assignments for contemporary conditions and future scenarios, would be very helpful in informing GEF and other stakeholders of various planning and investment strategies. A basin-level analysis of the contribution of nutrient sources (e.g., fertilizer use, animal production, sewage, atmospheric deposition) to river nutrient loads was conducted for the Bay of Bengal river basins using the NEWS model (Seitzinger *et al*. 2014). A similar analysis could be considered in future TWAP assessments. Within-basin analysis would also be useful for identifying upstream sources of downstream impacts on ecosystems and human health.

3.3.2 Wastewater Pollution

Key findings

1. **Two-thirds of basins have poor wastewater treatment:** At least 70% of the world's transboundary river basins suffer from inadequate wastewater treatment, with serious implications for ecosystems and downstream uses of the resource.
2. **Bring wastewater treatment up to speed with sanitation improvements:** Improvements in municipal wastewater treatment lag significantly behind improvements in water supply and sanitation – the gap needs to be closed.
3. **More attention needs to be given to wastewater treatment in rural areas:** With the majority of the world's population living in urban areas, this indicator focuses on centralised treatment systems in urban areas. However, more attention needs to be given to assessing the adequacy of non-centralised wastewater treatment in rural areas, their implications for river basin health, and addressing data gaps and uncertainties.

Rationale

While there have been great improvements in water supply and sanitation, driven by the Millennium Development Goals (MDGs), municipal wastewater treatment has not kept pace. Untreated wastewater from human activities is one of the major threats to water quality, with impacts on human health and ecosystems. After use for domestic, commercial and industrial activities, water often contains remains of the activity, e.g. pathogens, nutrients, chemical residues and other pollutants. With rapidly expanding cities, often without adequate sanitation services and regulatory frameworks to control this pollution, untreated wastewater is a significant problem in many parts of the world (UNEP 2010).

This indicator considers both the fraction of collected wastewater that is actually treated and the fraction of the population that is connected to a wastewater collection and treatment network.

The Wastewater Pollution Indicator (#5) is based directly on estimated *levels* of wastewater treatment, rather than on the absolute *volumes* of wastewater that pollute waterways. This gives an indication of the risks of pathogens which may be highly relevant to vulnerable populations at local scales, although high flows may dilute the risk of pathogens at the basin scale. So although the magnitude and exact nature of the risk to the entire basin requires more detailed investigation, this indicator identifies basins where action to improve levels of wastewater treatment is needed to reduce the levels of risk to vulnerable communities stemming from inadequate wastewater treatment.

Computation

The indicator is based on data and methodology from the Wastewater Treatment Performance indicator developed by the EPI (Environmental Performance Index) team at The Yale Center for Environmental Law and Policy (Malik *et al*. 2015). This indicator combines wastewater treatment statistics for 183 countries and was deemed to be the most comprehensive and up-to-date data source available.

The data underlying the indicator are based on a compilation of a number of different data sources: Pinsent Masons Water Yearbook (2013), United Nations Statistics Division (2011), OECD (2013), and FAO (2013). The inherent gaps at the global scale were filled using the following information (in order of priority): national-level country statistics (mainly from government reporting), subnational statistical reports for major cities (used as proxies in the absence of national data), utility-reported data, peer-reviewed academic literature.

The Wastewater Treatment Performance indicator is made up of two metrics: treatment level and connection rate (see Metadata sheet, annex IX-2).

- **Treatment level:** the percentage of wastewater treated relative to the amount of wastewater collected or produced;
- **Connection rate:** the percentage of the national population connected to municipal sewerage systems.

To calculate national wastewater treatment performance scores, the national wastewater treatment percentage was normalized by the population connected to municipal sewerage systems (i.e. 'wastewater treatment level' multiplied by 'connection rate').

To transform national data to the basin level, the national wastewater treatment performance scores were assigned to the corresponding BCUs of the transboundary basins. BCU scores were multiplied by the BCU weights to give weighted BCU scores. The BCU weights were calculated on the basis of the population in the BCU relative to the basin, given that population (as opposed to area) is the most significant driver in this dataset. Weighted BCU scores were then added to provide basin scores. To calculate the Wastewater Pollution Indicator, these scores were inverted, i.e. wastewater pollution = (1 – wastewater treatment score).

Basin and BCU results were categorized using equal quintiles (based on indicator score values), with the highest raw scores representing the highest levels of risk of wastewater pollution, thus high relative risk category and vice versa.

All basins with least 80% of the population represented by the BCUs with results were included in the assessment. Results for the four basins with between 80 and 99% of the population coverage were thus included but deemed to have a lower degree of confidence in the results. While all basins (irrespective of degree of data confidence) are included in the maps below, only those with highest degree of confidence in results (i.e. 100% of the basin population covered) are included in the numerical analyses in Figure 3.37.

Results

Figure 3.37 shows that more than 50% of basins have been classified as very high relative risk (category 5). Most of these basins and BCUs represent wastewater treatment performance scores of less than 20% (treatment level x connection rate). They are widespread, found in Africa, Asia, South and Central America, Eastern Europe, and parts of Russia (Figure 3.35).

Some additional detail to the results of this indicator emerges at the BCU level, with significant BCU differences in some basins, particularly the larger ones (Figure 3.36). Examples where BCU relative risk categories range from 1 to 5 within the same basin include the Danube and the Tigris-Euphrates/Shatt al Arab basins.

Figure 3.35 Wastewater Pollution by Transboundary River Basin. The maps show estimated levels of risks related to inadequate treatment of wastewater in the urban areas of transboundary river basins. The risks are high or very high in most of South America, Africa and Asia. While a number of high risk basins have relatively low population density and significant dilution potential from abundant water resources (e.g. the Congo and Amazon basins), inadequate wastewater treatment in urban areas may affect people and ecosystems at the local level, with the effects potentially being felt in downstream communities and countries.

Interpretation of results

The relative risk categories for the wastewater pollution indicator represent the risks that basins and BCUs may be facing as a result of inadequate wastewater treatment. This includes risks to ecosystems and human health. Since the indicator describes the estimated levels of (mainly) urban wastewater treatment, rather than absolute volumes of untreated wastewater, the results can be interpreted as relatively localised risks around urban centres. So for basins

Figure 3.35. Wastewater Pollution by Transboundary River Basin. The maps show estimated levels of risks related to inadequate treatment of wastewater in the urban areas of transboundary river basins. The risks are high or very high in most of South America, Africa and Asia. While a number of high risk basins have relatively low population density and significant dilution potential from abundant water resources (e.g. the Congo and Amazon basins), inadequate wastewater treatment in urban areas may affect people and ecosystems at the local level, with the effects potentially being felt in downstream communities and countries.

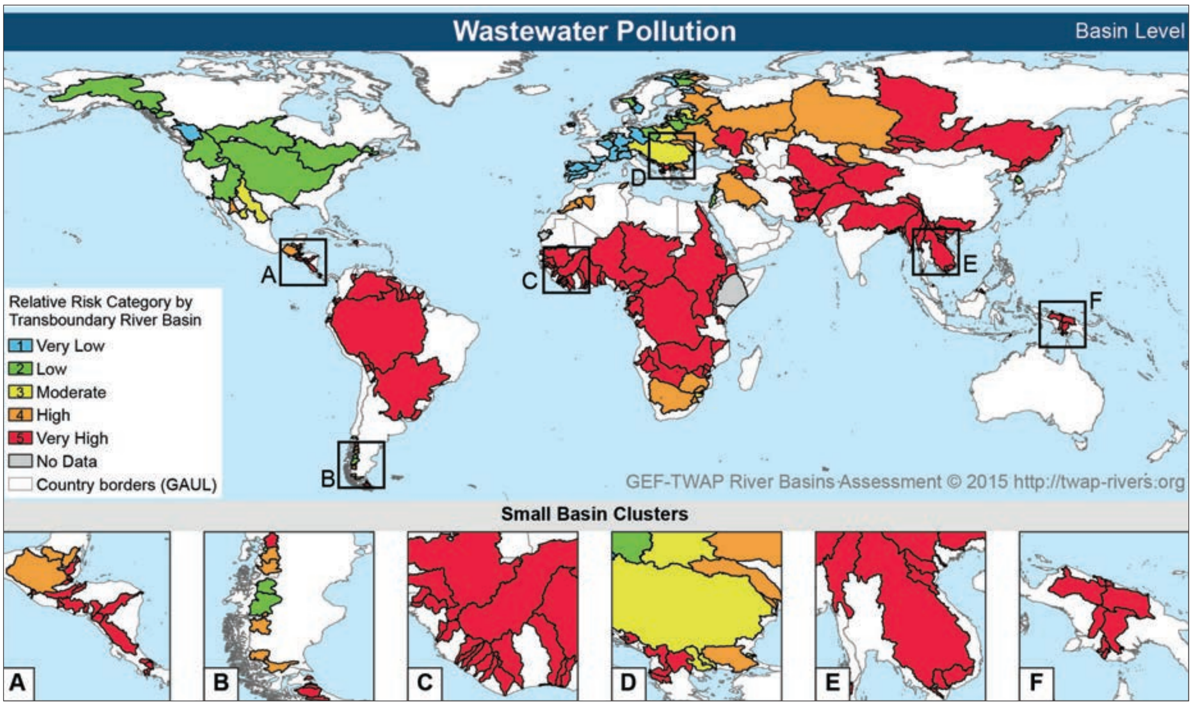


Figure 3.36 Wastewater Pollution by Basin Country Unit (BCU). Inadequate treatment of wastewater at the local level can create higher risks of pollution at the basin level, with negative impacts spreading beyond country borders. BCU level results identify basins and countries where local improvements in wastewater treatment practices could bring about basin-level benefits.

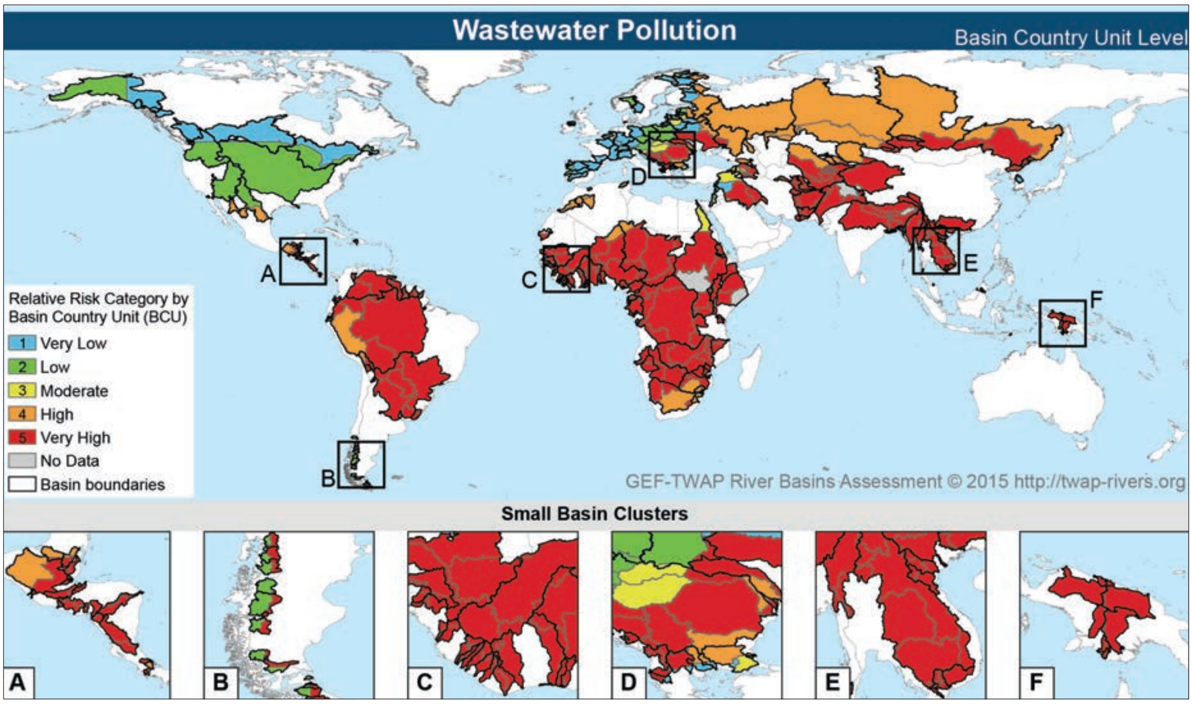
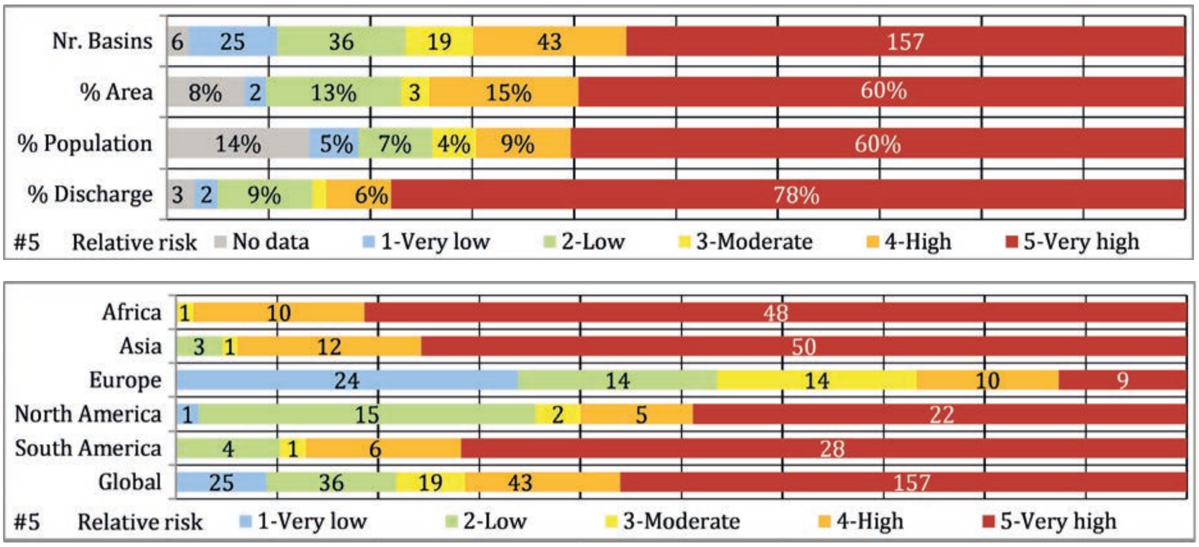


Figure 3.37. Wastewater Pollution Relative Risk Categories by: number of basins, global TB basin % for area, population and discharge (top); and number of basins by region, 'no data' basins excluded (bottom). At least 70% of the world's transboundary river basins suffer from inadequate wastewater treatment



such as the Amazon and Congo, with relatively low urban populations and high water availability, the basin-wide risks may appear rather high. The intention of the indicator is to identify basins and BCUs where attention should be given to improving urban wastewater treatment. Action may therefore be more urgently required in high to very high risk basins where rapid urbanization is occurring (see section 3.1.4 Projected Changes in Population Density and annex XI-1 on urban centres and population density).

While intuitively the results may seem to show relatively low levels of wastewater treatment, they are in agreement with assessments such as UNEP's 'Sick Water' report, which stated "90 per cent of the wastewater in developing countries discharged daily is untreated" (UNEP 2010). Looking back at the Millennium Development Goals (MDGs), it would appear that the targets established to provide improved sanitation have not been driving improvements in wastewater treatment performance to the same degree. The Sustainable Development Goals (SDGs) and the proposed Water Goal may therefore provide a global opportunity to drive improvements in wastewater collection and treatment.

At the other end of the scale, basins and BCUs with very low relative risk from wastewater pollution represent wastewater treatment performance of more than 80%. This low relative risk implies both reasonable levels of treatment of collected wastewater and reasonable connection rates. The majority of very low risk basins/BCUs are therefore, not surprisingly, in Europe, with some BCUs also in Canada, Syria, and the Republic of Korea. These basins and BCUs can be said to have well-developed infrastructure systems for wastewater collection and treatment, often accompanied by higher water quality standards (e.g. European Water Framework Directive).

Within-basin differences at the BCU level may point to areas of concern, as well as a need for in-basin dialogue and alignment of water quality and wastewater treatment standards.

Limitations and potential for future development

In the construction of this indicator, the national EPI wastewater treatment performance data are assumed to be representative of the whole country, and thus of each BCU within the basin. Consequently, there might be within-country spatial differences in wastewater treatment and collection that have not been accounted for (e.g. fewer large cities in a BCU compared to the rest of the country, larger cities, more developed areas of the same country).

The basin scores were aggregated on the basis of BCU scores. For basins where BCU data (national-level data from the EPI database) are available to cover more than 80% of basin population (but less than 99%), the basin scores are considered to have lower confidence than basins with population coverage of more than 99%. A total of four basins were therefore marked as having a lower level of confidence in results (representative of the whole basin) due to data coverage.

Connection rates are specified as the fraction of the population in the country connected to municipal sewerage systems. The indicator therefore does not consider the benefits of non-centralised sanitation systems, and may be biased against countries with significant rural or dispersed populations that are not connected to a municipal network, but which may treat effluent in other ways. One option to address this in future assessments may be to consider only the fraction of the population that is likely to use municipal sewerage systems, within the 'connection rate' metric.

The underlying EPI Wastewater Indicator data have been supported by gap-filling and some assumptions (see the indicator description sheet and Malik *et al*. 2015). For example, in some cases where national data were not available, data has been derived from major urban areas within a country. If major improvements to the underlying data are not made before the next assessment, the methodology for calculating this indicator may be further developed by considering relative levels of confidence in the underlying data. This could include application of variables relating to estimated vs. directly-reported treatment data, city-level vs. national-level data, estimated vs. directly reported year, and relatively new vs. older data sources.

Given the above limitations, the results at the basin level have relatively low to moderate levels of confidence, the major limitation being the inability to spatially disaggregate the national-level data to each respective BCU.

Regular water quality testing helps establish and monitor risks to humans and ecosystems.

Future transboundary assessments may consider the level of treatment (e.g. primary, secondary or tertiary), differentiation between urban and rural areas, consideration of sector-based sources of pollution, and non-centralized treatment systems. It may also be beneficial to consider transboundary aspects such as potential downstream impacts of the pollution. Significant improvements to the underlying datasets are also required. Global wastewater treatment data are notoriously difficult to obtain, but may be improved within the SDG process and through the revitalisation of GEMS/Water.

3.3.3 Water Quality Thematic Group Summary

The key findings for the thematic group are given in the introduction to section 3.3. The two indicators assessed in this group are:

1. Nutrient Pollution;
2. Wastewater Pollution.

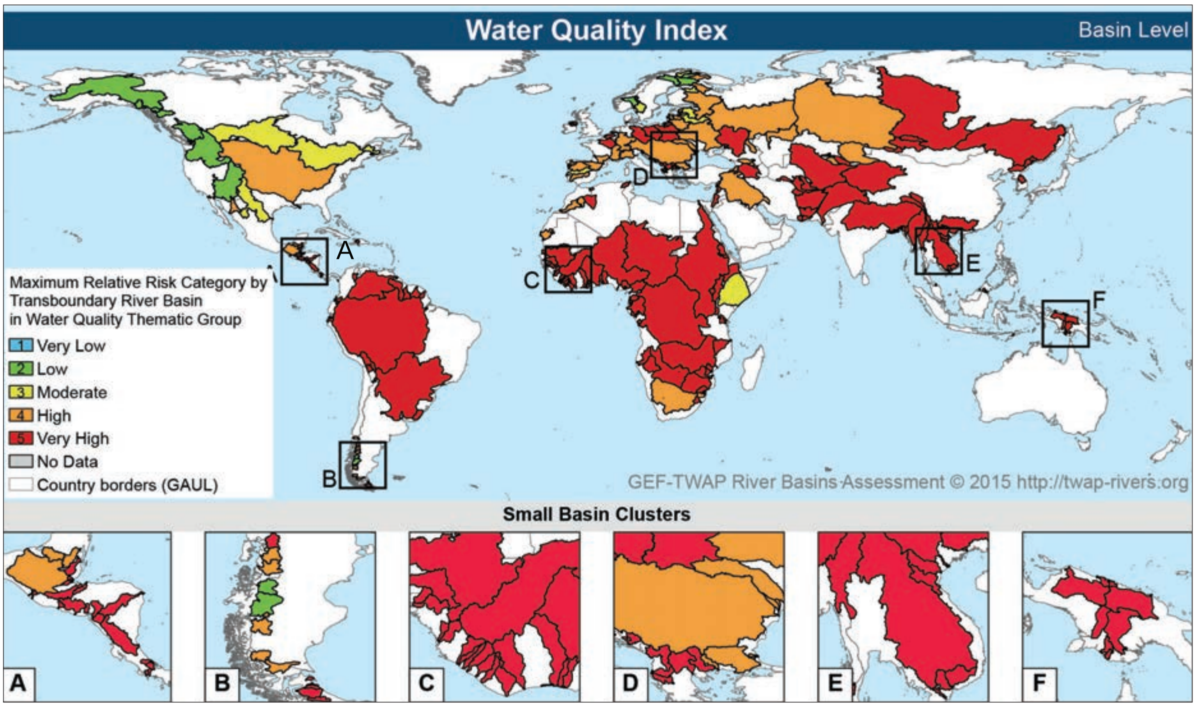
The two indicators are complementary, in that the nutrient pollution indicator primarily addresses eutrophication and the wastewater pollution indicator primarily addresses pathogen risks. Both can lead to severe degradation of water quality and ultimately to loss of livelihoods. High-risk basins for these indicators also point to possible hotspots for delta and marine pollution originating from land-based sources, where successful interventions on a basin level could yield benefits across the board.

Results of the separate indicators are shown in Figure 3.34 and Figure 3.35. When these two indicators are combined (using the maximum relative risk category of the indicators in a given basin), the global extent of threats to water quality is emphasized. The maximum relative risk category was chosen, rather than the average, since the two indicators are slightly negatively correlated and averaging indicators would therefore result in important hotspots being 'lost'. Although the nutrient pollution indicator does take urban water pollution into account, the slightly negative correlation between the two indicators may be partly explained by the geographic differences between the rural/urban sources of pollution, and because the wastewater pollution indicator is based directly on estimated levels of wastewater treatment, rather than absolute volumes of wastewater polluting the waterways, while the nutrient pollution indicator includes the absolute amount of nitrogen or phosphorous in urban wastewater.

The results of this thematic group show that water quality is severely affected in a large percentage of the transboundary rivers basins, either by nutrient over-enrichment or by pathogens, or both, based on the combined nutrient and wastewater pollution indicators (Figure 3.38). In the more developed regions of the world (e.g. North America and Europe) the very high and high risk basins are mainly related to high use of fertilizers in agriculture, high livestock production, and/or high population (treated wastewater) (Seitzinger *et al*. 2010; Bouwman *et al*. 2009). In less-developed regions of South America and Africa, and in basins shared between Russia and countries in Asia, where fertilizer use is still low, the very high and high relative risk basins are more likely to be affected by pathogens from untreated wastewater.

The wastewater indicator is based directly on estimated levels of wastewater treatment, rather than absolute volumes of wastewater polluting the waterways. This gives some indication of the risks of pathogens which may be more relevant to human populations at local scales, although high flows may dilute the risks at the basin scale. So although the magnitude of risk to the entire basin is uncertain, the indicator identifies basins where action is needed to improve wastewater treatment to reduce the risks to potentially vulnerable communities. This is why relatively sparsely populated basins such at the Congo and Amazon appear as very high risk in Figure 3.38. The very high risk in basins in southern and eastern Asia is generally due to the combination of nutrient and wastewater pollution. The use of fertilizer in many of these regions is often high, accompanied by high population and, in some areas, poor wastewater treatment.

Figure 3.38 Water Quality Index by transboundary river basin. Based on maximum relative risk category of nutrient and wastewater pollution in each basin. Water quality is severely affected in more than 80% of basins, either by nutrient over-enrichment (typically in developed regions e.g. North America and Europe) or by pathogens (generally in developing regions, e.g. South America, Africa, and in northern Asian basins with Russia), or in both (e.g. emerging economies in southern and eastern Asia).



Previous analyses have explored either nutrient pollution from all sources in global watersheds (Seitzinger *et al*. 2010) or wastewater pollution at the country level (WHO and UNICEF 2014), but rarely both together at the river-basin scale. The results of the individual indicators are broadly consistent with the previous global analyses of the individual indicators.

There are a number of opportunities for improvement or protection of water quality in transboundary basins. In all basins, development of better wastewater treatment infrastructure could be explored either to reduce risk from pathogens in basins currently at risk or to avoid future risks in currently low-risk basins. In basins at risk from nutrient pollution, implementation of better nutrient management in agriculture (crops and livestock) that increases nutrient use efficiency and reduces fertilizer use, and implementation of tertiary treatment of wastewater could be explored. In basins currently with low risk of nutrient pollution, it would be advisable to implement nutrient efficiency approaches if/when agriculture develops further. Given the large population increases projected by the end of the century (e.g. an increase of 3.1 to 5.7 billion in Africa), fertilizers will be needed to increase agricultural production, and effective wastewater treatment, which reduces both nutrients and pathogens, will be crucial.

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3.4 Ecosystems

Ecosystems are comprised of species and habitats, some of which generate goods and services for humans (TEEB 2010). Humans access goods and services from water ecosystems to build livelihoods and enhance human wellbeing while conserving – or degrading – the integrity and health of shared ecosystems. Governance has a central function in defining ways for doing this (Sanchez and Roberts, 2014) and key aspects of it will be captured by the next thematic group of indicators (section 3.5).

Appropriate measures for ecosystem health (specifically of species and their habitats) vary widely, depending on the ecosystem being considered (TEEB 2010). It is therefore important to monitor a range of indicators of habitat and species health together.

Freshwater ecosystems are threatened by a number of key pressures, including water abstraction, water pollution, destruction or degradation of habitat, flow modification, overexploitation and invasion by invasive alien species (WWF 2014; Darwall *et al*. 2008). Aspects related to water abstraction, flow modification and water pollution have been assessed in the Water Quantity and Water Quality thematic groups (sections 3.2 and 3.3 respectively). The remaining pressures have been consolidated into the Wetland Disconnectivity (#6), Ecosystem Impacts from Dams (#7), and Threat to Fish (#8) indicators, all of which have clear transboundary implications. These pressures have varying links to ecosystem service availability and biodiversity loss, which is measured by the Extinction Risk Indicator (#9).

Because of the importance of an ecosystem approach to sustainable river basin management, knowledge of current and predicted threats to species and of the areas where they are likely to be most serious is vital for informing conservation action, policy development and the development planning process (Darwall *et al*. 2008).

Comprehensive and integrated management plans are needed to address poor water quality in urban areas.

Thematic group key findings

1. **Industrialized countries currently have lower risks to wetlands, but have suffered serious wetland loss in the past:** Industrialized nations are more likely to have lower risks to wetlands, resulting from different policy and management strategies, including economic information regarding the value of wetlands for tourism, biodiversity, hydrological functions and storm protection. Based on the latest data (from 2000), there are fewer wetlands in agricultural areas in industrialised countries than in developing countries with expanding agriculture. This however masks an overall loss of wetlands in industrialized nations before 2000.
2. **Decisions about dam sites and dam design are key to minimising negative ecosystem impacts:** Dam density is often a key driver of impacts on ecosystems, with impacts on flow and fragmentation of river systems. Recognizing the benefits of dams to human development, ongoing commitments are needed to improve guidelines for siting new dams, designing dams for multiple purposes and optimising the operation of dams to maximise human benefits and minimise negative ecosystem impacts. This is particularly important in a transboundary context, where dams are typically located in upstream countries.
3. **Native fish are under multiple threats:** The most significant threats to native fish appear to be a combination of overfishing and invasive species. The potential impact of wastewater pollution on fish stocks is not clear.
4. **Local-level, tailored solutions are needed to address species extinction risks:** Analysis at the BCU level gives a more detailed picture of extinction risks than analysis at the basin level, reflecting higher levels of endemic species or threats in some areas of a river basin such as the upper reaches or in large lake systems. This suggests that responses, too, should be at a more detailed level than basin-wide to address extinction risks. There is therefore an urgent need to continue to identify hotspots from transboundary impacts through basin-specific assessments (including, for example, GEF Transboundary Diagnostic Analyses (TDAs)). Conservation strategies should be focussed on ecological importance, not necessarily on scale.

3.4.1 Wetland Disconnectivity

Key findings

1. **Agriculture in developing nations poses the highest risks to wetlands:** The highest risk basins and BCUs are found mainly in developing nations, where the largest future agricultural growth is anticipated.
2. **Industrialized nations are more likely to have lower risks to wetlands:** Different policy and management strategies, such as economic information regarding the value of wetlands for tourism, biodiversity, hydrological functions and storm protection, can help to reduce risks. Based the latest data (from 2000), there are fewer wetlands in agricultural areas in industrialized countries than in developing countries with expanding agriculture. This however masks the overall loss of wetlands from before 2000 in industrialized nations.
3. **Risks to downstream wetlands are higher:** There are many examples of downstream BCU risks to wetland habitats being higher than upstream, mainly because of agricultural expansion in the more fertile downstream areas of river basins.
4. **Over half of the population in river basins live in areas with moderate to very high wetland risks:** An estimated 1.4 billion people live in transboundary river basins with a moderate or greater risk of wetland disconnectivity.

Rationale

In most of the world's terrestrial biomes and ecoregions, habitats are being lost faster than they are being protected (Hoekstra *et al*. 2005), with freshwater habitats being significantly less represented than terrestrial habitats in current protected areas (Darwall *et al*. 2011; Roux *et al*. 2008). Wetland disturbance and loss is in many cases the result of direct drainage and destruction of wetlands for human use. In addition, levee construction and river channelization designed to protect urban areas and croplands can render floodplain areas dysfunctional by altering natural system connections (Vörösmarty *et al*. 2010). Increasing protection of wetlands is illustrative of society's recognition of the importance of ecosystems for river basins and willingness to take concrete steps to conserve these valuable resources (IUCN *et al*. 2003).

Wetland Disconnectivity is the measure of the threat imposed by severing the natural physical and biological connections between river channels and their floodplains, which can lead to distortion of flow patterns and the loss of local flood protection, water storage, habitat, nutrient processing and natural water purification. The Wetland Disconnectivity Indicator (#6) considers the proportion of existing wetlands around 2000 occupied by dense cropland or urban areas, where human occupation functions as a primary driver for impeding the functional hydrologic and biological connection between rivers and wetlands (Vörösmarty *et al*. 2010 (Driver 4)). Thus the indicator represents a measure of the loss of function in wetlands around 2000 and does not reflect an accounting of past overall loss of wetlands.

The Wetland Disconnectivity Indicator allows the identification of transboundary basins estimated to be at the highest risk of functional loss of wetland services due to human modification of the landscape and natural flow regimes. The impacts of management interventions can be monitored in the future, and, since geographic patterns of risk are not uniform, the drivers of habitat disruption need to be addressed at the basin scale.

Computation

This indicator is based on the Wetland Disconnectivity indicator from Vörösmarty *et al*. (2010), which was developed as a global gridded dataset. An area-weighted average of the underlying gridded data was computed to arrive at a single Wetland Disconnectivity value for each basin and BCU. To limit the weighting influence of a handful of small basins/BCUs comprised mainly of grid cells with high wetland disconnectivity, the highest ranking values were capped at the 97.5th percentile (see Annex IX-3 for more details). Because of the standardized nature of the original Vörösmarty *et al*. (2010) datasets, risk categories were defined as 20% equal-interval classes, with the lowest corresponding to very low risk and the highest to very high risk.

Wetlands are threatened by agricultural and urban expansion. Risks to downstream wetlands are higher.

Miwok/flickr

Figure 3.39. Wetland Disconnectivity by Transboundary River Basin. Basins in the highest risk categories are found in developing countries of Africa and Asia where an abundance of natural wetland capital is at risk from development pressures and lack of management and conservation efforts.

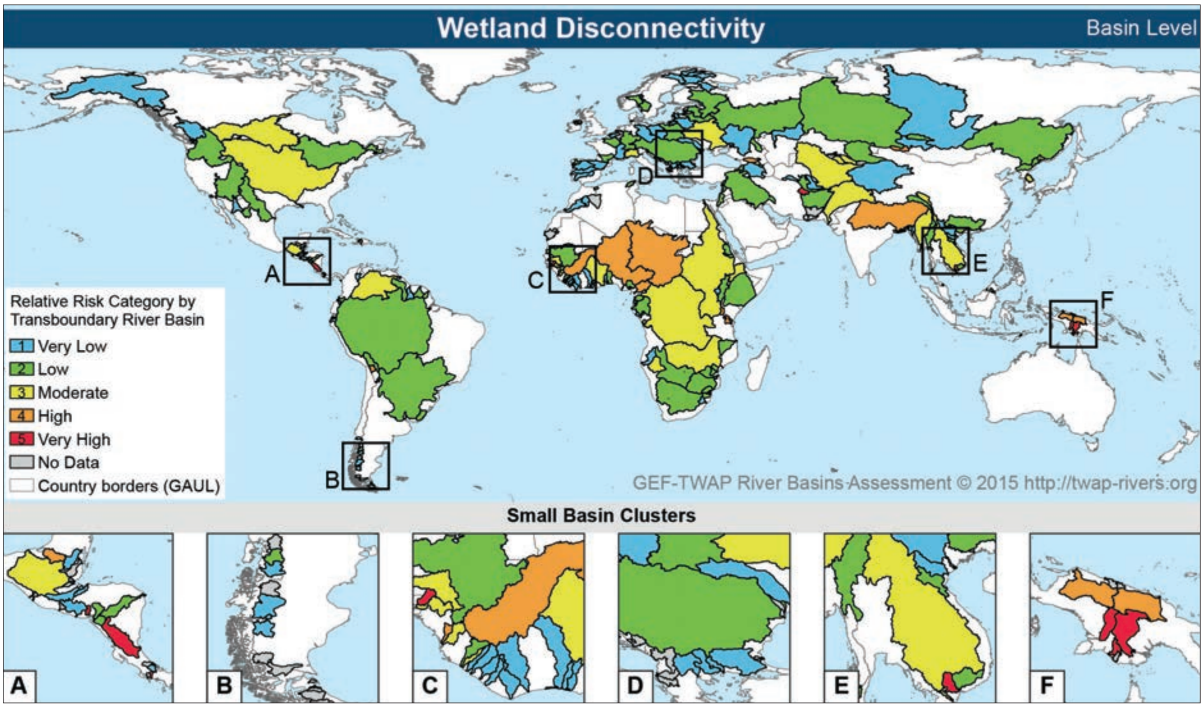


Figure 3.40. Wetland Disconnectivity by Basin Country Unit (BCU). Urgent intervention may be needed in BCUs in high relative risk categories. Downstream BCUs tend to be at greater risk, partly because of agricultural expansion in these more fertile areas.

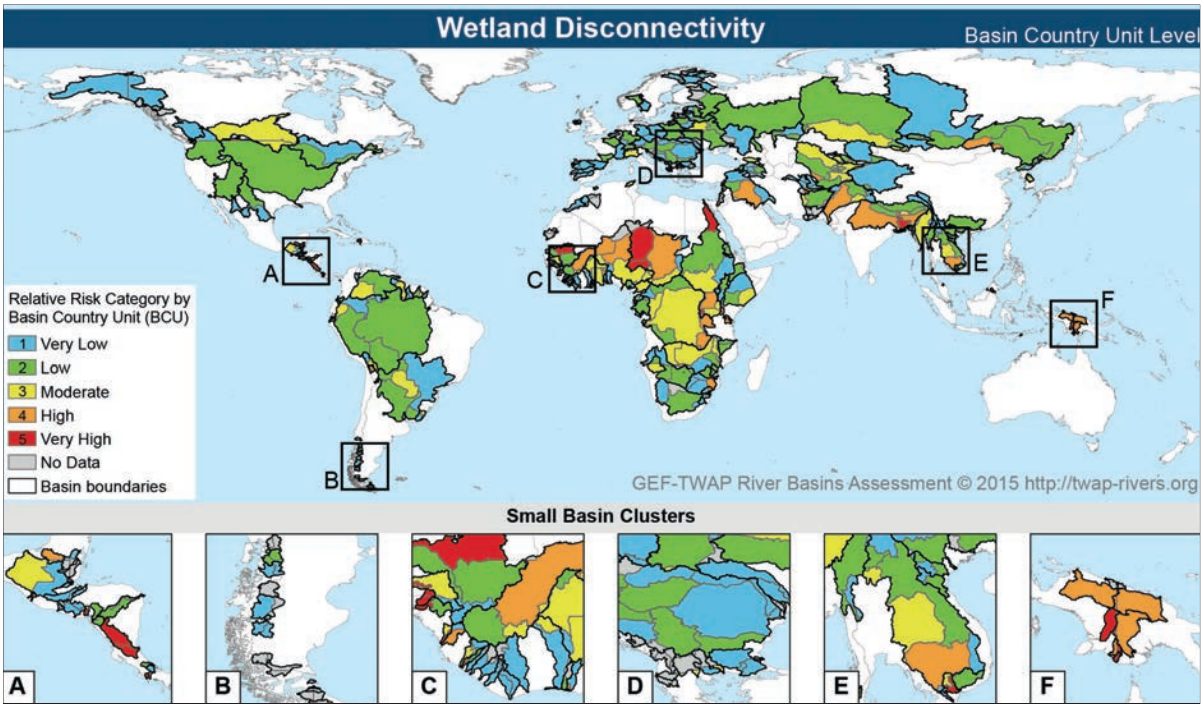
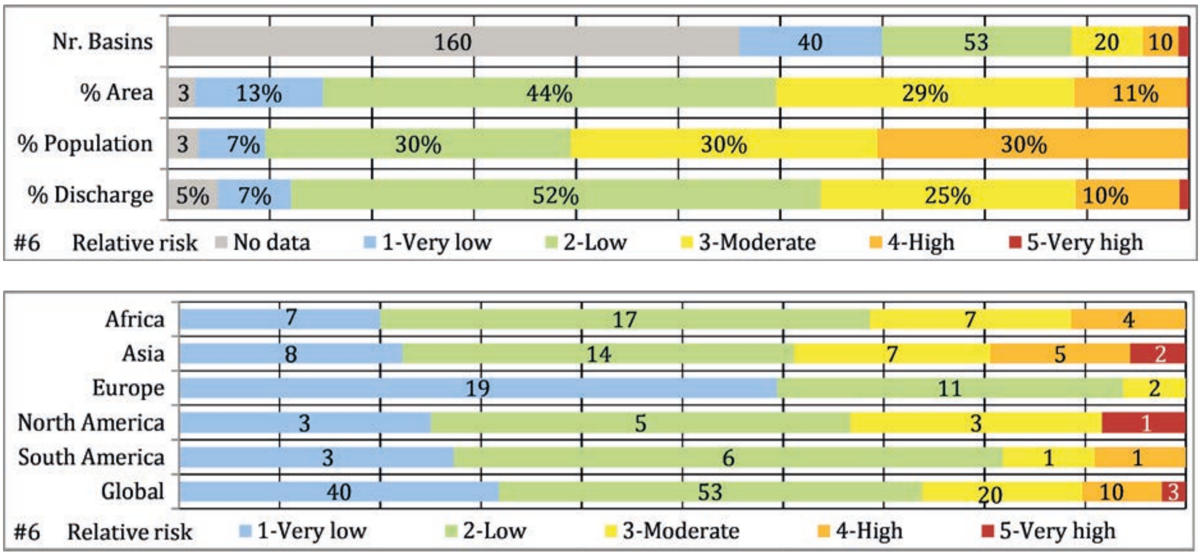


Figure 3.41 Wetland Disconnectivity Relative Risk Categories by: number of basins, global TB basin % for area, population and discharge (top); and number of basins by region, 'no data' basins excluded (bottom). About 60% of the population of transboundary basins live in basins with moderate or higher risk of wetland disconnectivity.



Results

Figure 3.39 and Figure 3.40 show the Wetland Disconnectivity relative risk category maps for transboundary basins and their respective BCUs. Basins and BCUs in the highest risk categories (4 and 5) are found in the developing nations of Africa (most notably the Sahel region basins of Lake Chad and the Niger River) and southern Asia associated with the Ganges-Brahmaputra system, Indus and Mekong Rivers.

Interpretation of results

Although industrialized nations converted or disrupted much of their natural wetlands during the 20th century (MA 2005), under current conditions most of the industrialized world shows lower risk of wetland disconnectivity of their remaining wetland resources than the rest of the world. This may be partly due to land-management policies enacted in the latter part of the 20th century which promoted wetland protection and restoration (Smardon 2009). However, since so few of the original wetlands in the industrialized world remain, continued sound management and conservation remains a concern in these areas. In contrast, the developing world retains an abundance of their natural wetland capital, but lack of management and conservation efforts, combined with pressures for increased development, threaten these valuable resources (Smardon 2009). These findings highlight areas of (mainly but not exclusively) developing countries where change is probably currently happening and where urgent intervention may be needed to mitigate further loss of wetland function. There are notable differences in upstream-downstream risk values across BCUs for several larger basins, such as the Nile, Niger, Lake Chad and the Mekong, reflecting spatially-explicit disconnectivity to wetland habitat, due mainly to agricultural expansion in the more fertile downstream areas.

Limitations and potential for future development

The lack of detailed descriptive attributes in the wetlands dataset underlying the Wetland Disconnectivity Indicator, such as names or volumes, may hamper more detailed analysis in potential future assessments; however GIS information could be derived from data sources other than remote sensing, including Ramsar site data in the Ramsar Information Sheets (RIS) format.

The gridded data for wetlands, cropland and urban extent used to derive the Wetland Disconnectivity Indicator are benchmarked to 2000. Urbanization and agriculture has continued to expand, particularly in developing nations, within the past decade or so and it is therefore conceivable that an analysis updated to 2010 might show higher disconnectivity rankings in these regions. However, a recent study by Prigent *et al*. 2012, estimating the global inundated area of land-surface open water from 1993 to 2007, showed an overall decline in global average inundated area associated with human expansion of 6% over the 15-year study period, mainly in tropical and sub-tropical South America and South Asia. Wetland disconnectivity risk updated to year 2010 may therefore not be significantly different from the 2000 data presented here.

All data are computed on a 0.5° grid in the Geographic projection over the transboundary river basins and BCUs. While the maps above show all basins and BCUs for which there is a result, Figure 3.41 and the subsequent analysis is based on 135 Basins and 252 BCUs that meet the minimum spatial unit criteria at 0.5° resolution of at least 10 grid cells (~25 000 km^2 area). These results have a higher degree of scientific confidence. Results for basins smaller than 25 000 – 30 000 km^2 (1 – 9 grid cells) are indicative only. These results are marked with a lower degree of confidence in the results files downloadable via the portal.

Smaller basins and BCUs (though still above the 10 grid cells threshold) with the majority of their basin area under high wetland disconnectivity risk dominate the highest risk category (5) and are mostly difficult to see on the maps. In potential future assessments, it may also be helpful to show a categorization based on the total area within each basin under wetland disconnectivity threat.

3.4.2 Ecosystem Impacts from Dams

Key findings

1. **High dam density leads to greater risk of ecosystem impact:** Basins and BCUs with highest relative risk have the highest concentration of dams. Dam density is often a key driver of impacts on ecosystems, resulting in larger impacts on flow and fragmentation of river systems. Over 70% of the population living in transboundary river basins live in basins with high to very high risk of ecosystem impacts from dams, although other socioeconomic benefits may be derived.
2. **Dams threaten ecosystems in industrialized nations and dry regions, but patterns are shifting:** Basins with the highest relative risk of ecosystem impacts from dams can be found in industrialized nations (due to historic, cumulative impacts of dam building) and drier regions with fewer dams but lower discharge. Ecosystems in drier areas may be more sensitive to disruption of flows. However, global patterns of dam construction are shifting to developing regions.
3. **Decisions about sites for dams and dam design are key to minimise negative ecosystem impacts:** Recognizing the benefits of dams to human development, ongoing commitments are needed to improve guidelines for siting new dams, designing dams for multiple purposes and optimising the operation of dams to maximise human benefits and minimise negative ecosystem impacts. This is particularly important in a transboundary context, where dams are typically located in upstream countries.

Rationale

While the aggregate impact of many stressors defines the state of modern river basins, dam construction and reservoir operation are typically the most important stressors on aquatic ecosystems and biodiversity (Vörösmarty *et al*. 2010). The introduction of dams can bring about a number of positive benefits to local communities (including reduced risk of floods, power generation, increased water supply reliability), but the negative impacts on ecosystems of altering waterways through river fragmentation and flow disruption by dams, water transfers and canals must be considered for managing water resources in a sustainable way. Dams also impact sediment transfer to downstream agricultural areas. It is no longer acceptable to withdraw water from nature for use in agriculture, industry, and everyday life, without taking into account the role that ecosystems play in sustaining a wide array of goods and services, including

Ecosystem impacts from dams may be felt in downstream countries.

water supply. Very large dams account for 85 per cent of registered water storage worldwide. In order to compensate for considering only the impacts of very large dams on river fragmentation and flow disruption, dam density has also been factored in. The Ecosystem Impacts from Dams Indicator (#7) is a composite of three sub-indicators addressing the various impacts dams can have on ecosystem: a) River Fragmentation, b) Flow Disruption, and c) Dam Density.

Computation

The three sub-indicators for the Ecosystem Impacts from Dams Indicator were developed as follows:

a) River Fragmentation: is a measure of the fragmentation of naturally continuous river networks. Described as the 'swimmable area' between barriers (large dams) that remains accessible to aquatic species, river fragmentation is a measure of the swimmable distance in any direction from a grid cell to the nearest barrier (Vörösmarty *et al*. 2010). It is a measure of the threat to species population size, genetic isolation and species extinction. The GWSP-GRAND data set of geo-referenced large dams was used to define swimmable areas between barriers.

b) Flow Disruption: is a measure of the change in the timing, frequency, duration and magnitude of key flow events in river systems due to large dams (Vörösmarty *et al*. 2010). Disruption to flow regimes can have significant impacts on freshwater ecosystems including changes to thermal regimes, altering wet/dry spell durations and depriving downstream reaches of essential material inputs. Flow disruption was calculated as the magnitude of flow distortion by assessing the residence time of water in large reservoirs.

c) Dam Density: is a measure of the density of medium and large dams in river systems. This sub-indicator captures the threat imposed by smaller dams not included in the River Fragmentation and Flow Disruption sub-indicators that also act as substantial barriers to the movement of water and aquatic organisms (Vörösmarty *et al*. 2010). Dam density represents the density and distribution of very large and medium to large dams mapped at the global scale.

The numerical average of the three sub-indicators was calculated at the 30-minute grid cell level then rescaled to fit a 0-1 scale using a linear transformation (X – min)/(max-min). Average Ecosystem Impacts from Dams over the BCU and basin areas was calculated as the area-weighted average of the grid cell values within each TWAP BCU

Figure 3.42. Ecosystem Impacts from Dams by Transboundary River Basin. Dams mainly threaten ecosystems in industrialised nations and dry regions (e.g. Middle East and southern Africa), but dam construction is occurring at a rapid rate in many developing countries.

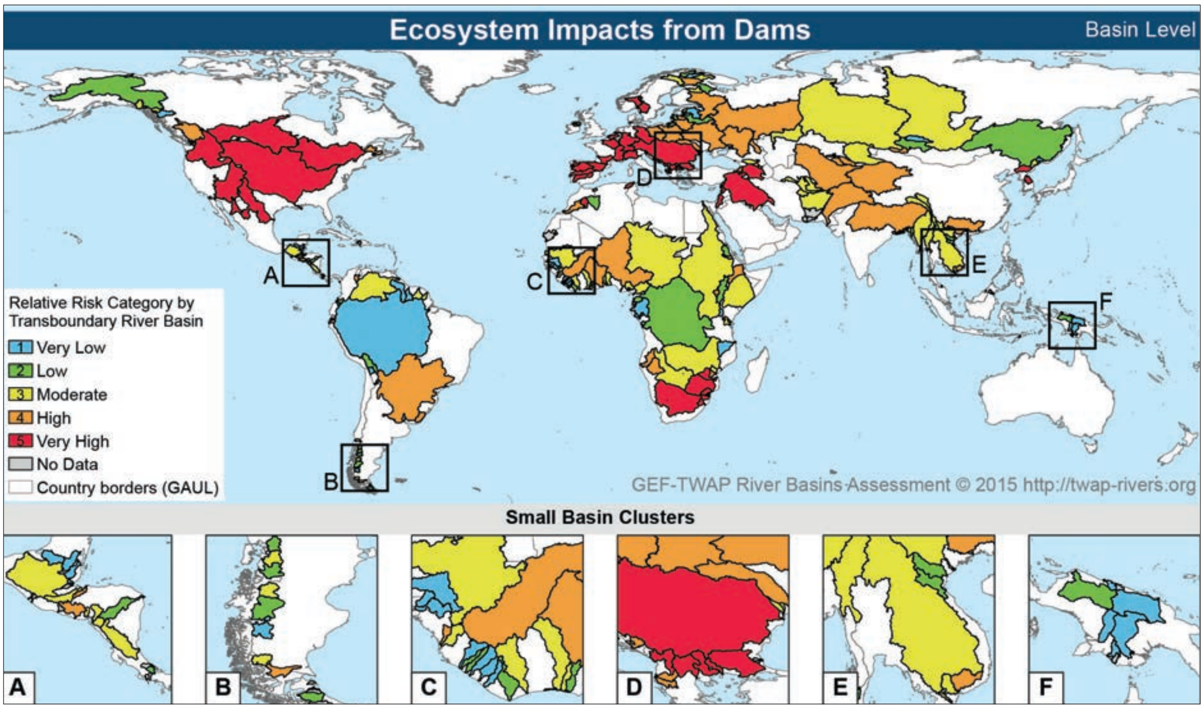


Figure 3.43. Ecosystem Impacts from Dams by Basin Country Unit (BCU). Dam construction and operation has highly significant transboundary implications.

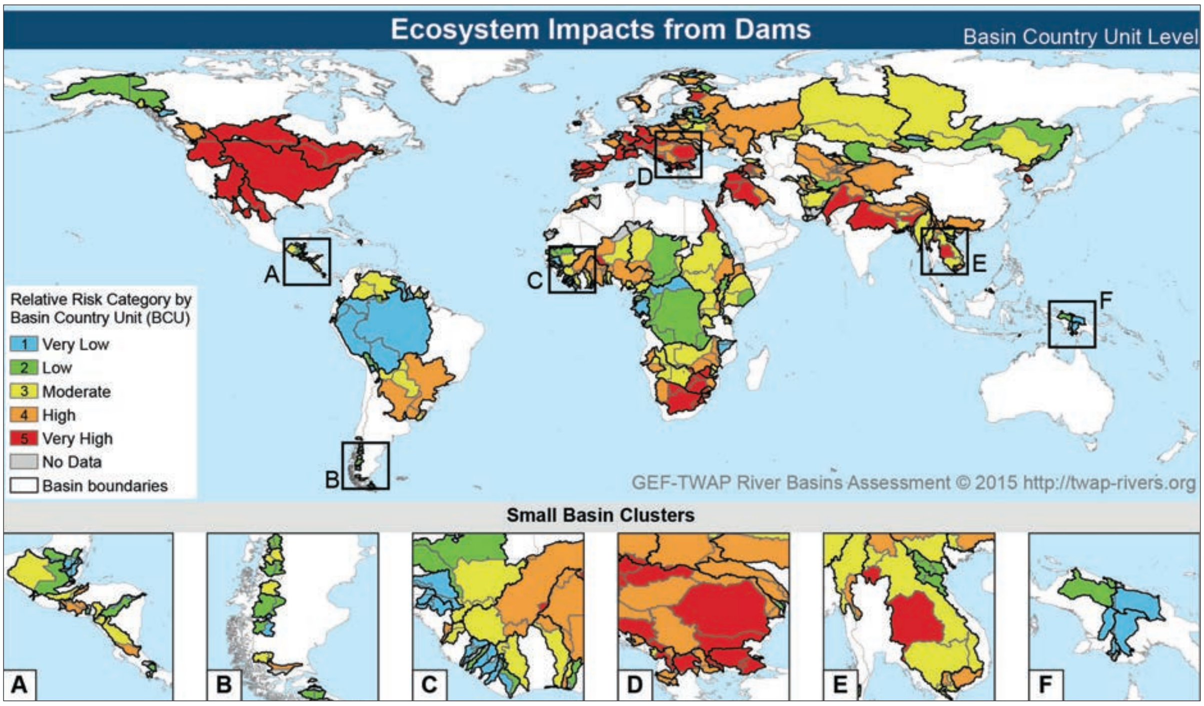
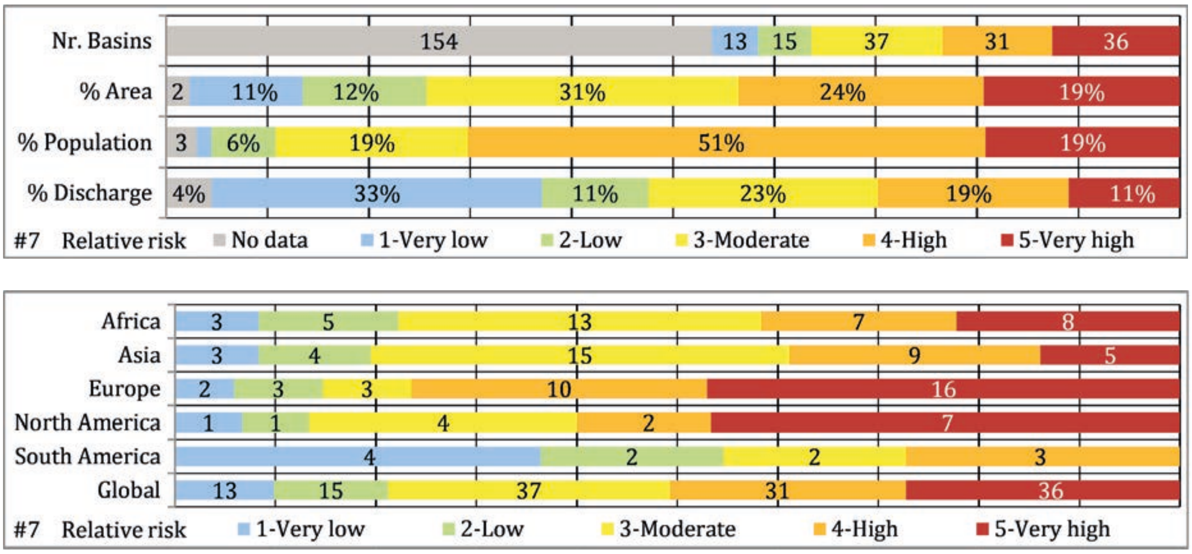


Figure 3.44. Ecosystem Impacts from Dams Relative Risk Categories by: number of basins, global TB basin % for area, population and discharge (top); and number of basins by region, 'no data' basins excluded (bottom). While many socioeconomic benefits are derived from dams, over 70% of the population living in transboundary river basins live in basins with high to very high risk of ecosystem impacts from dams.



and basin standardized to a 0-1.0 scale as above. Due to the standardized nature of the original Vörösmarty *et al*. (2010) datasets, risk categories were defined as 20% equal-interval classes with the lowest corresponding to very low relative risk and the highest to very high relative risk.

Results

Basins in the highest relative risk categories (4 and 5) for ecosystem impacts from dams are located in North America, parts of Europe, South Africa and the Middle East. The pattern for high risk BCUs (categories 4 and 5) is similar to that of the river basin risk categories with the highest risk basin occurring in countries noted for having large numbers of dams (e.g., United States, Canada, Spain, South Africa, and Turkey).

Interpretation of results

The spread of basins and BCUs in the highest relative risk categories is in agreement with the International Commission on Large Dams (ICOLD), which states that the United States, Canada, Spain, South Africa and Turkey all rank within the top 10 countries with the largest number of large dams. The higher ranking of the Tigris-Euphrates and Kura Araks basins in the Middle East reflect river systems with a smaller number of large dams (which are mainly in Turkey) relative to North America, Spain and South Africa, but also have lower discharges, resulting in high disruption to the flow regime. In the Nile basin, risks for impacts of dams are much higher for the Egyptian portion of the basin than for the upstream basin countries.

The rate of dam construction in some regions is so high that the indicator may change faster than the ability to update the reference base. For an indication of planned, proposed and under-construction dams, see Annex XI-2. This highlights that current and planned dam construction is more likely in emerging economies, hence potentially altering the patterns of risk to include emerging economies and developing countries.

Limitations and potential for future development

All data are computed on a 0.5° grid in the Geographic projection over the transboundary river basins and BCUs. While the maps above show all basins and BCUs for which there is a result, Figure 3.44 and the subsequent analysis is based on 135 Basins and 252 BCUs that meet the minimum spatial unit criteria at 0.5° resolution of at least 10 grid cells (~25 000 km^2 area). These results have a higher degree of scientific confidence. Results for basins smaller than 25 000 – 30 000 km^2 (1 – 9 grid cells) are indicative only. These results are marked with a lower degree of confidence in the results files downloadable via the portal.

Given the high rate of dam construction in some regions, particularly in emerging economies and developing countries, it may be even more pertinent to update this indicator compared to other indicators for which the situation may change more slowly. The data used for the sub-indicators was based on 2008 published data for large dams. A more recent dataset was made available in 2011. Options and implications may be investigated in future assessments.

The dam density data used should not be construed as the spatial distribution of dams, because it reflects a probabilistic estimate of spatial patterns within each country, and excludes a very large number of small dams and other structural barriers for which global data are unavailable.

The inclusion of additional dams for which no data are available may alter the relative risk classification for a given river basin. The indicator therefore represents the minimum level of risk.

3.4.3 Threat to Fish

Key findings

1. **Overfishing and invasive species threaten local fish:** The highest relative risk categories can be found in basins and BCUs that experience both fishing pressure and invasive species (non-native fish species).
2. **The majority of people in river basins live in areas where fish are under threat:** More than half of the population in transboundary basins live in river basins with a high to very high risk to fish.

Rationale

In addition to loss of fish habitat and environmental degradation (see previous indicators, e.g. Environmental Water Stress, the Water Quality indicators, and Ecosystem Impacts from Dams), the main factors that threaten inland fisheries are fishing pressure and non-native species. Overfishing is a pervasive stress in rivers worldwide due to intensive, size-selective harvesting for commerce, subsistence, and recreation (Vörösmarty *et al*. 2010). Non-native species may be introduced for hunting or biological control as well as to form part of fish catches. Invasive species can threaten native species as direct predators or competitors, as vectors of disease, by modifying the habitat, or by altering native species dynamics. The Threat to Fish Indicator (#8) is a composite of two sub-indicators addressing the various impacts on fish habitat: a) Fishing Pressure and b) Number of Non-native Fish.

Computation

Two sub-indicators for the Threat to Fish Indicator were developed as follows:

a) Fishing Pressure: a measure of the local impacts of fishing on freshwater biodiversity. This sub-indicator captures the threat due to intensive size-selective harvesting for commerce, subsistence and recreation impacting fauna community structure, population and ecosystem dynamics. Fishing pressure distribution was calculated based on a scaling relationship between country-level fish catches, net primary productivity and discharge (Vörösmarty *et al*. 2010).

b) Number of Non-native Fish: a measure of the number of fauna represented by non-native species (Vörösmarty *et al*. 2010). It captures the threat to native fauna species via competition, predation, alteration of ecosystem function and structure, and possible degradation of water quality due to invasive species. The number of non-native fish species in each river basin was taken from LePrieur *et al*. (2008)

The numerical average of the two sub-indicators was calculated at the 30-minute grid cell level then rescaled using a linear transformation (X – min)/(max-min) to fit a 0-1 scale. Average Threat to Fish over the TWAP basin and BCU regions was calculated as the area-weighted average of the grid cell values within each TWAP basin and BCU standardized to fit a 0-1 scale. Due to the standardized nature of the original Vörösmarty *et al*. (2010) datasets, risk categories were defined as 20% equal-interval classes with the lowest corresponding to very low relative risk and the highest to very high relative risk.

Results

Basins in the highest relative risk categories (4 and 5) for Threat to Fish are located mainly in Europe, North America and south and southeast Asia (most notably the Mekong Basin).

Interpretation of results

Basins in the highest relative risk categories (4 and 5) experience both fishing pressure and invasive species. Many of the mid-range risk categories (2 and 3) have higher risk for one of the two sub-indicators but not the other. For example, fishing pressure is high for the Niger, Volta and Sanaga basins in Africa but invasive species are very low, resulting in a low to moderate Threat to Fish score in these basins. Conversely, threats from invasive species are high in the Orange River in South Africa but fishing pressure is relatively low to moderate.

The pattern for high relative risk BCUs (categories 4 and 5) reflects the same high-risk categories in Europe, North America and south and southeast Asia. With the disaggregated geography of the basin country units, the difference in relative risk classes between countries in basins becomes apparent.

Overfishing and invasive species can threaten local fish.

Figure 3.45. Threat to Fish by Transboundary River Basin. A combination of overfishing and invasive species lead to the highest risk categories, particularly in Europe, North America and south and southeast Asia.

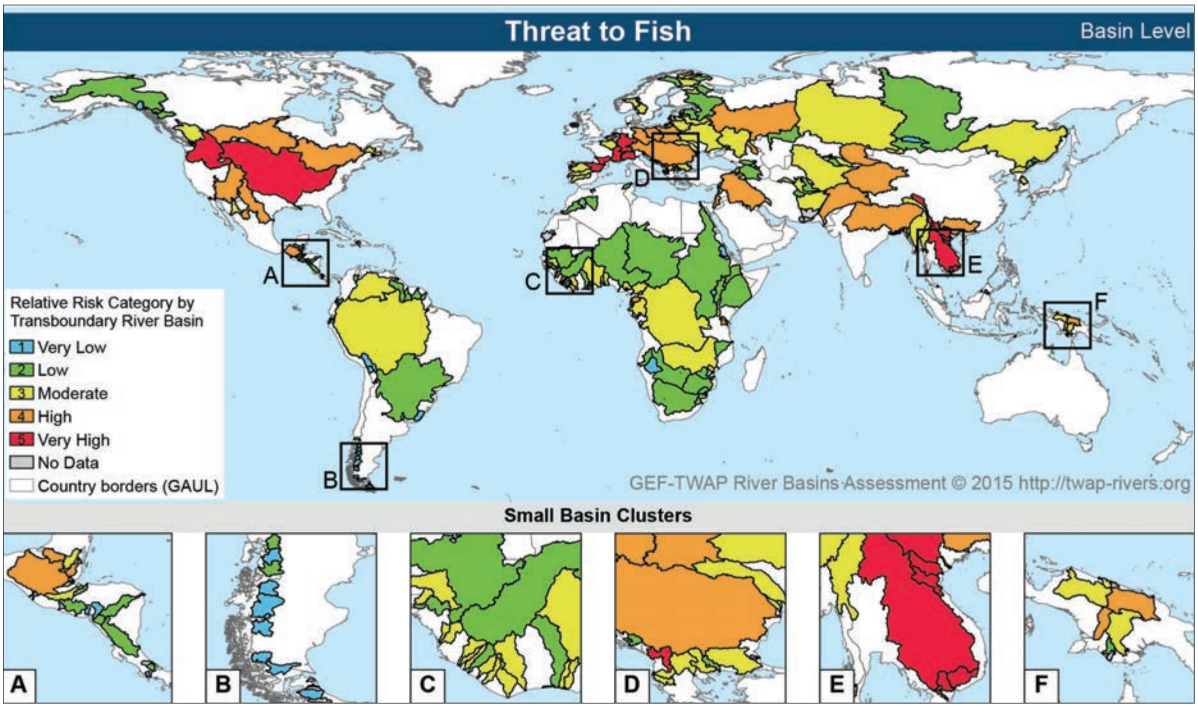


Figure 3.46. Threat to Fish by Basin Country Unit (BCU). High-risk categories for BCUs are similarly found in Europe, North America and south and southeast Asia. BCU risk classes illustrate the difference in relative risk between countries within the same basin.

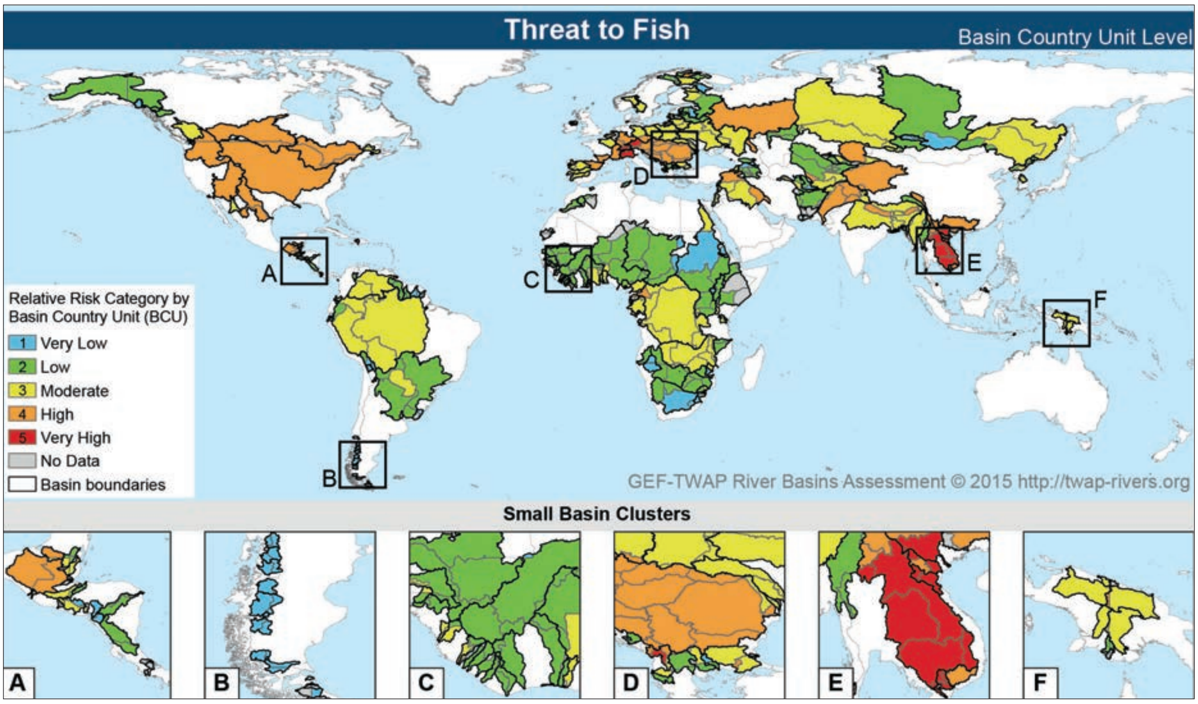
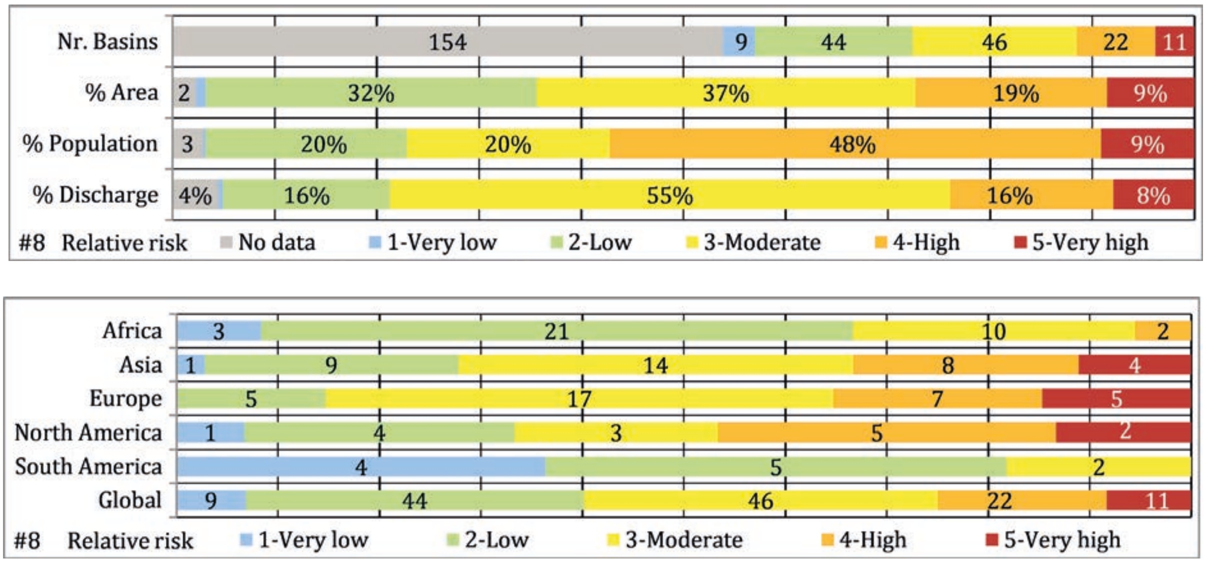


Figure 3.47. Threat to Fish Relative Risk Categories by: number of basins, global TB basin % for area, population and discharge (top); and number of basins by region, 'no data' basins excluded (bottom).



Limitations and potential for future development

All data are computed on a 0.5° grid in the Geographic projection over the transboundary river basins and BCUs. While the maps above show all basins and BCUs for which there is a result, Figure 3.47 and the subsequent analysis is based on 135 Basins and 252 BCUs that meet the minimum spatial unit criteria at 0.5° resolution of at least 10 grid cells (~25 000 km^2 area). These results have a higher degree of scientific confidence. Results for basins smaller than 25 000 – 30 000 km^2 (1 – 9 grid cells) are indicative only. These results are marked with a lower degree of confidence in the results files downloadable via the portal.

The indicator assumes that terrestrial primary productivity either directly supports fish production or serves as an adequate proxy for the aquatic primary production that supports fish. A proxy is necessary owing to the lack of sufficient observational data.

Annual catch for each grid cell is based on estimated fish catches from rivers. However, historic trends in fisheries statistics are normally available only for a few well-studied rivers, and, because of the multi-species composition of the catch in most inland water bodies, particularly in developing countries, assessments of the condition of the resources are hard to carry out.

Fishing pressure may not always be interpreted as a threat, because of the commercial or livelihood benefits. Also, the presence of fisheries may contribute positively to species conservation.

It is not clear what the potential impact of wastewater pollution is in basins with a moderate to high threat to fish. Non-native fish stocks may not react in the same way to wastewater impacts as native species.

In future work it may be possible to consider linking the non-native species indicator to the Global Invasive Species Database http://www.issg.org/database/welcome/ to identify the invasive species only for a better representation of threat.

3.4.4. Extinction Risk

Key findings

1. **The threat to freshwater biodiversity is global:** The basins in the high to very high risk categories span continents and climatic regions and have a range of population densities; they include large, medium-size, and small basins. Moderate to very high extinction risk covers over 80% of the population and 70% of the area of transboundary river basins.
2. **Local-level, tailored solutions are needed to address species extinction risks:** Analysis at the BCU level shows a more detailed picture of extinction risk than at the basin level, reflecting higher levels of endemic species or threat in certain areas of river basins such as the upper reaches or in large lake systems. This suggests that tailored responses are required for greater impact, in addition to basin-wide responses, to address extinction risks. Thus, there is an urgent need to continue to identify hotspots from transboundary impacts through, for example, GEF mechanisms such as Transboundary Diagnostic Analyses (TDAs). Conservation strategies should be focussed on ecological importance, not necessarily on scale.

Rationale

While freshwater ecosystems occupy less than one per cent of the Earth's' surface area, they are disproportionately rich in biodiversity, containing around one-third of all vertebrates (Holland *et al*. 2012; Balian *et al*. 2007), and they play a critical role in maintaining the integrity and proper functioning of freshwater and coastal ecosystems. Human population growth and socio-economic development have led to severe pressures on freshwater ecosystems globally (Vörösmarty *et al*. 2010), leading to an estimated extinction risk among freshwater species that is significantly higher than in terrestrial ecosystems (WWF 2014; Dudgeon *et al*. 2006).

As the habitat lost/protected ratio may be the same for two areas with different climates and biomes, irrespective of biodiversity status, basins can be further prioritized on the basis of the extinction risk to species. Measures of extinction risk, such as the IUCN Red List of Threatened Species, are used to identify species under threat, and can assist in monitoring the effects of management actions and the prioritization of conservation planning and decision-making. Measures of extinction risk also contribute to global objectives to prevent loss of biodiversity, for example the Aichi Targets, part of the CBD Strategic Plan for Biodiversity 2011-2020 (in particular #12 "By 2020 the extinction of known threatened species has been prevented and their conservation status, particularly of those most in decline, has been improved and sustained"). Species, and the habitats they depend on, underpin ecosystem functions and hence the goods and services provided; rates of freshwater species loss are high and increasing, compared to historic levels.

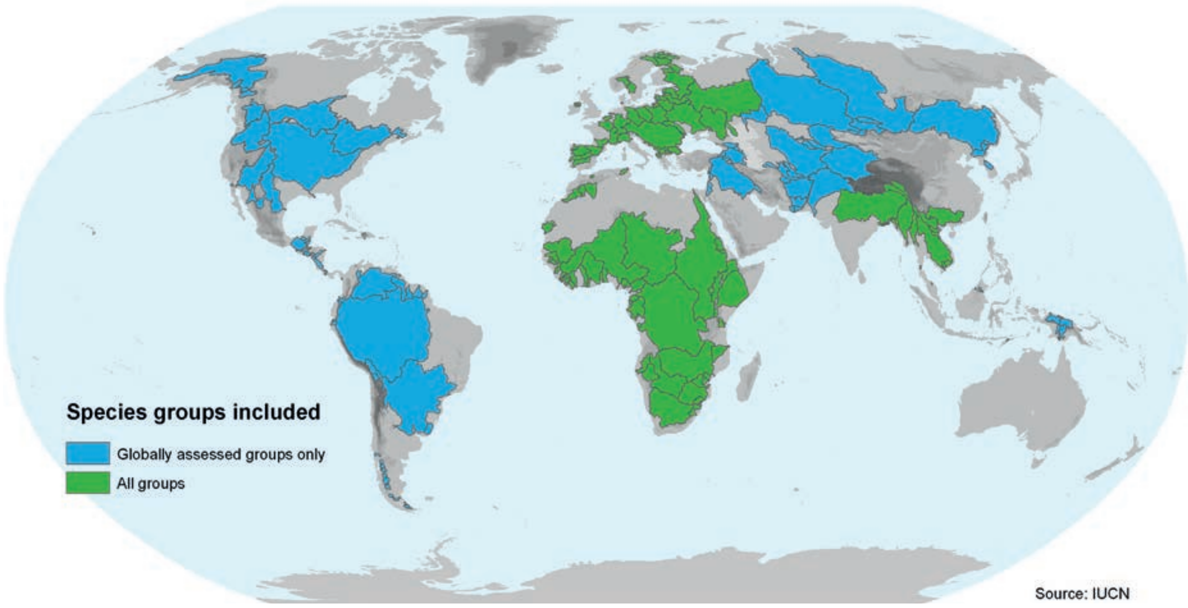
The Extinction Risk Indicator (#9) allows the identification of transboundary basins with the highest risk of species extinction. The impacts of management interventions can be monitored in the future and, since geographic patterns of risk are not uniform, the drivers of species loss need to be addressed at the basin scale.

Computation

Data

Extinction risk is based on the IUCN Red List Categories and Criteria (IUCN 2012) for selected freshwater biodiversity taxa. This was identified as the most complete biodiversity loss metric in preference to other measures of species richness (e.g., biodiversity hotspots (Myers *et al*. 2000)) or species loss (for example, the Living Planet Index (Loh *et al*. 2005)) since both under-represent freshwater biodiversity; in the case of the Living Planet Index, time-series population data are required, generally only available for a small sub-set of commercially utilized, mainly marine, fish. Research has shown that there is low correlation between different freshwater taxa, and no one group is an effective surrogate for all freshwater biodiversity (Darwall *et al*. 2011). Hence we need an index based on a broad representation of taxa.

Figure 3.48. Species Groups Included in the Extinction Risk Indicator for each basin.



Globally-assessed groups only (basins in blue) include amphibians, mammals, birds, crabs, crayfish and shrimps; All groups (basins in green) include the globally-assessed groups with the addition of fish, molluscs, dragonflies and damselflies, and plants.

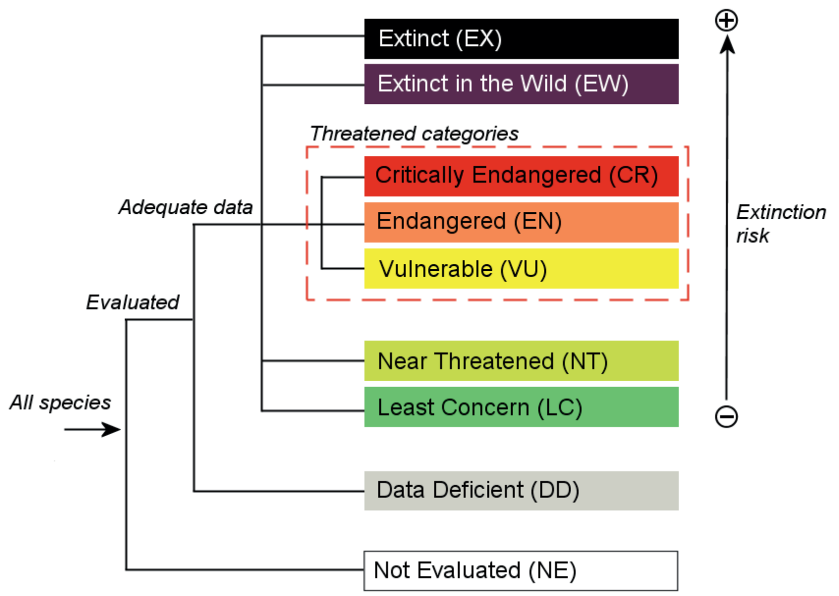
The Extinction Risk indicator uses species-level data from the IUCN Red List of Threatened species, but only includes taxonomic groups where all species have had their extinction risk assessed to avoid any bias in the results. For the basins in Africa, Europe and parts of Asia this includes freshwater fish, molluscs, dragonflies and damselflies, selected aquatic plant families, mammals, birds, amphibians, crabs, crayfish and shrimps (Figure 3.48). The basins in the other regions of the world only contain the freshwater species from the groups that have been comprehensively assessed globally (mammals, birds, amphibians, crabs, crayfish and shrimps). As no individual group of freshwater species is a good surrogate for all groups, either for total species or for threatened species (Darwall *et al.* 2011), it is important to include the groups that are not globally assessed where possible. The addition of these groups provides a much greater degree of confidence in the results for these basins since they are highly species-rich, represent a range of trophic levels, and play important roles in supporting ecosystem functioning (and services) of freshwater systems.

Metrics
This indicator incorporates the two principles of biodiversity conservation planning; *vulnerability* (i.e. threats to biodiversity leading to its loss) and *irreplaceability* (i.e. the uniqueness of the biodiversity within a site) (Brooks *et al*. 2006; Margules and Pressey 2000), as well as *species richness*.

Extinction risk is computed as: *vulnerability* weighted by a combination of *irreplaceability* and *species richness*. The metrics are described below.

To calculate *vulnerability*, freshwater species risk of extinction (according to the IUCN Red List of Threatened Species) is used. For each basin the percentage of species assessed as threatened (i.e. those assessed as Critically Endangered, Endangered and Vulnerable) was calculated (see Figure 3.49). The 'Percentage threatened species score' is calculated only for species that are not extinct, and where there is sufficient information to identify their risk of extinction, and assuming all Data Deficient species are equally threatened as Data Sufficient species i.e., Percentage threatened species score = (CR + EN + VU) / (total assessed – EX – DD).

Figure 3.49. IUCN Red List Categories.



Source: IUCN 2012

To calculate *irreplaceability*, the percentage of the species that are endemic (i.e. not found anywhere else in the world) to each basin and BCU is calculated. The total number of endemic species could not be used due to different taxonomic groups being included for different basins. This percentage of endemic species, which ranges from 0 to 37.81, was normalised to a 0-1 scale (using '(value – min)/(max-min)').

Some basins with hugely different *species richness* but with an equal proportion of threatened species (e.g. comparing 1 in 10 species to 500 in 5,000 species) would score equally. However, more importance should be given to basins where more threatened species are found. Ideally the threatened species scores would be weighted with species richness, but as different taxonomic groups are used in different basins, this figure cannot be used. River discharge is often used as a surrogate for habitat diversity and therefore species richness in a basin (Livingstone *et al*. 1982). However, as this data is not readily available for all transboundary river basins and BCUs, river length is used as a surrogate for habitat diversity and therefore species richness (as provided by the U.S. Geological Survey Digital Chart of the World Rivers layer). The lengths of the rivers by basin and BCU were calculated and normalised to a 0-1 scale (using '(value – min)/(max – min)').

To create the weighting score, the River Length normalised score is multiplied by 0.5, so greater importance is given to endemism since it represents one of the two principles of conservation planning (irreplaceability). The final weighting score that is applied to the percentage threatened species score, = Endemism $_{\text{normalised}}$ x (0.5 x River Length $_{\text{normalised}}$) /2. Extinction risk is thus: (percentage threatened species score) x (1 + average weighting score).

To present the results, the scores were placed into categories (based on the normalized scores) from 1 - 5, where 1 represents very low extinction risk and 5 very high extinction risk. The thresholds were based on a compromise between the 'natural breaks' in the results from the river basins and results from the BCUs[10]. Standardizing the thresholds between basin and BCU results allows for easier comparison between the two scales.

10 Using Jenks approach: The Jenks natural breaks classification method clusters data into classes. It determines break points that best group similar values and maximize the differences between classes.

Figure 3.50. Extinction Risk by transboundary River Basin. The basins in the high to very high risk categories span continents and climatic regions and have a range of population densities.

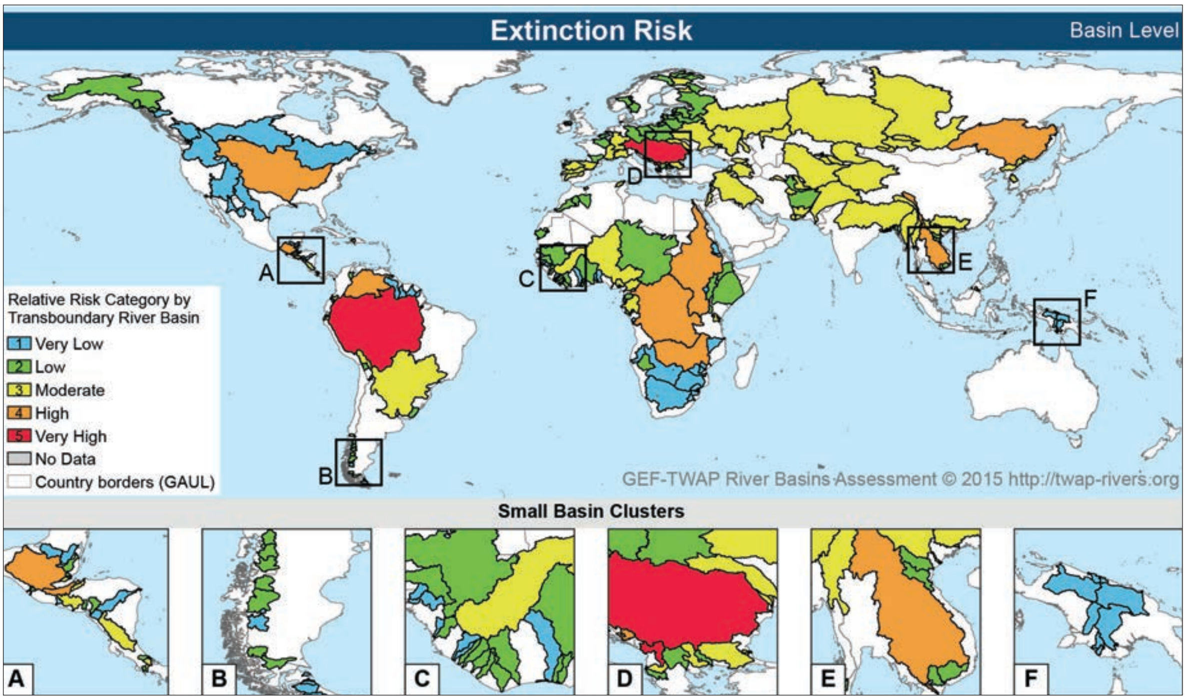


Figure 3.51. Extinction Risk by Basin Country Unit (BCU). Differences at the BCU level highlight the need for local-level, tailored solutions to address species extinction risks.

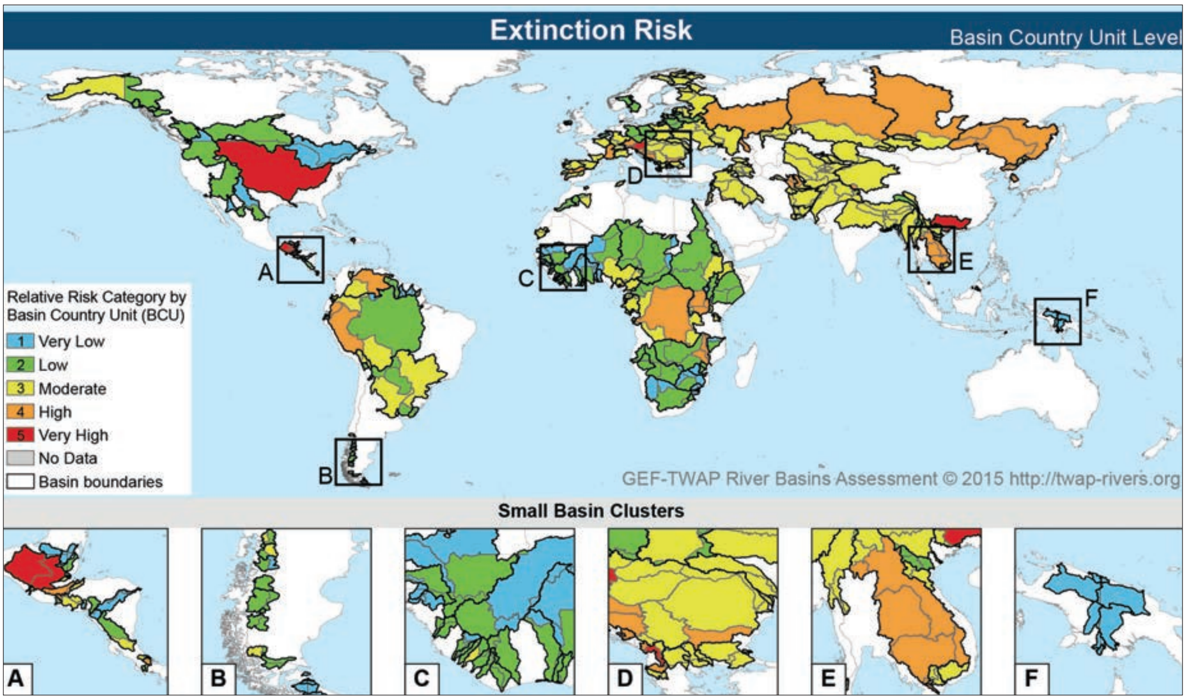
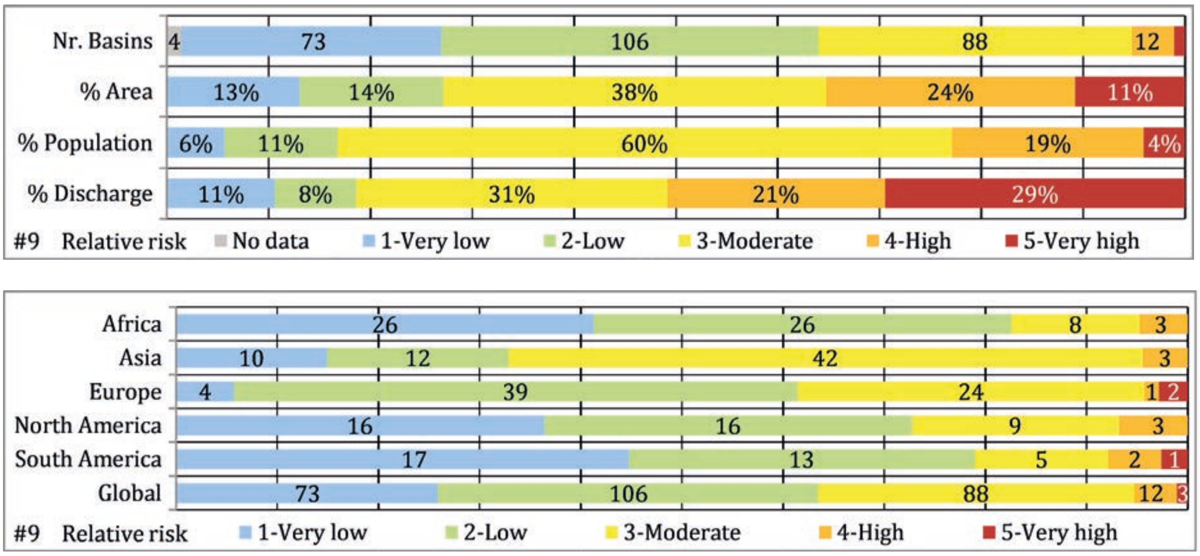


Figure 3.52. Extinction risk Relative Risk Categories by: number of basins, global TB basin % for area, population and discharge (top); and number of basins by region, 'no data' basins excluded (bottom). Banner diagram based on all results (based on high and low confidence results)



Results

Figure 3.50 and Figure 3.51 show the Extinction Risk category maps for transboundary river basins and BCUs respectively. They show that the threat to freshwater ecosystems is global, with basins and BCUs in the highest relative risk categories spanning climatic zones and with varying levels of development.

Interpretation of results

Basins or BCUs that are in the very high relative risk category are those that are most important at a global scale, in terms of conservation of freshwater biodiversity. They will probably have high proportions of threatened species, high levels of endemism and be species-rich. Those in the lower risk categories will probably have low proportions of threatened species and low levels of endemism.

There are only three basins in the highest risk category, the Danube and Drin in Eastern Europe, and the Amazon. All three have exceptionally high levels of threatened species and high levels of endemism. The basins in the second highest risk category span continents and climatic regions, and include large basins such as the Congo, Nile, Mississippi and Amur and small basins such as the Neretva and the An Nahr Al Kabir.

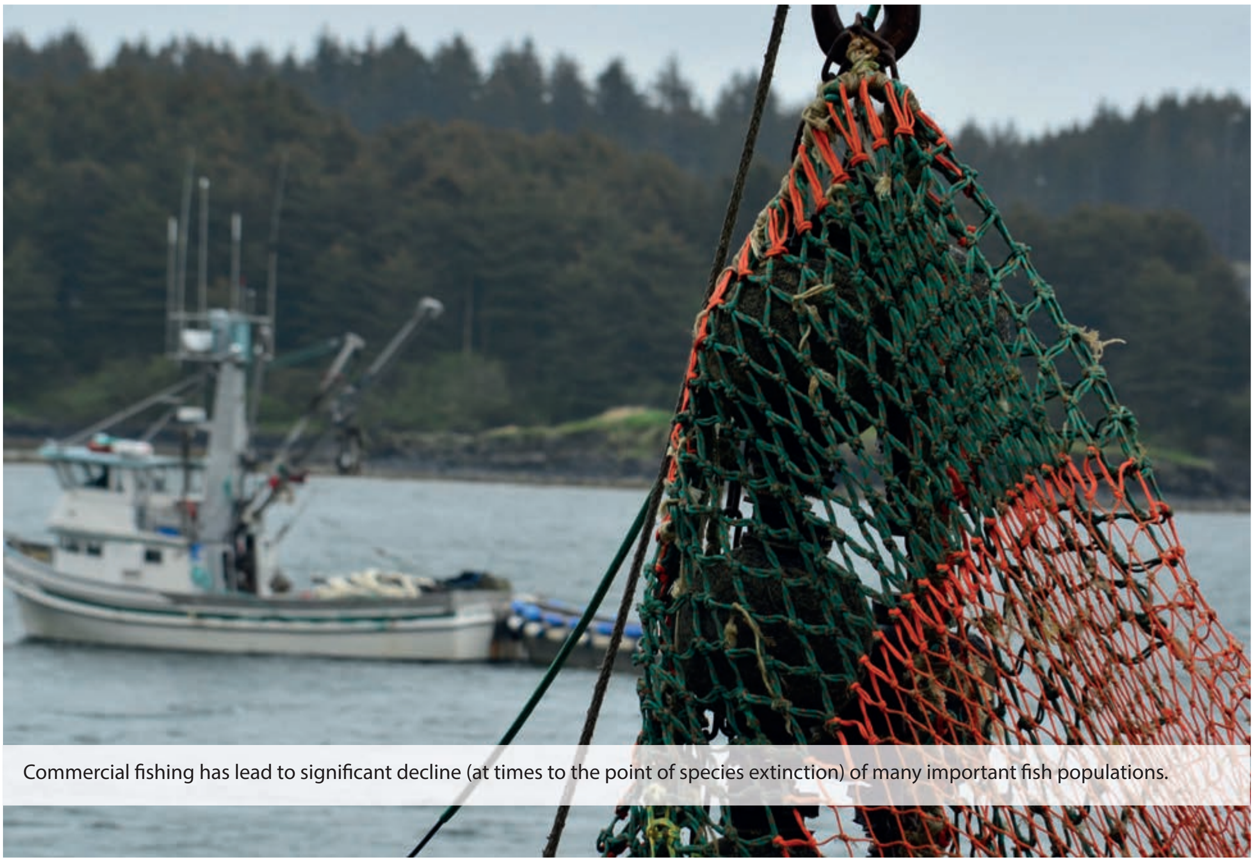
The BCUs show a more detailed picture; for example, it is the upper Amazon in the Andes (Peru and Ecuador) that is at high risk (category 4) whereas the Brazilian Amazon is at low risk (category 2), reflecting the high levels of amphibian endemism and threat in the Andes and lack of data for the Amazon basin on the additional taxonomic groups (e.g. fish). Also, it is the Great Lakes region of the Nile basin and Lake Malawi and lower Zambezi that are at high risk, which reflects the high levels of endemism and threat to the fish fauna in these areas (Darwall *et al.* 2011). The Danube also shows different levels of risk across the BCUs, with the upper parts of the basin from Austria to Bosnia and Herzegovina being in the highest risk categories. The US part of the Mississippi basin, which is almost the entire basin, is in the highest risk category because of the exceptional levels of endemism, together with a relatively high percentage of species threatened (9.3%, which is less than half that in the Danube which is the highest with 22%). However, at the basin level the relative risk category is reduced due to other rivers having equal levels of threatened species but a longer river stretch for the combined BCUs (e.g. Amazon, Nile) or many endemics in all BCUs (e.g. the Grijalva).

Limitations and potential for future development

The major limitation of this indicator is reduced confidence in the results for the 47% of basins where the indicator is based on only a subset of the species. These are the basins for which species data are available only for those taxon groups for which all known species have been assessed and mapped. In these basins the indicator is therefore based on a much reduced subset of taxon groups so is likely to be less representative of the true levels of species extinction risk. A high priority for improving the level of confidence is to fill the information gaps for this 47% of basins by completing the global coverage of IUCN Red List Assessments for fish, molluscs, dragonflies and damselflies and aquatic plants. These highly species-rich groups are important for ecosystem functioning and services (e.g. inland fisheries), are highly threatened in many cases, and should be included to provide a more comprehensive picture as an input to development and conservation planning. There is a clear need to increase investment in building adequate information sets on freshwater species for all parts of the world in order to fill these data gaps.

The river length weighting score incorporates a bias towards the temperate regions, since two basins with equal river length, one temperate and one tropical, would have the same weighting, but the tropical basin is likely to contain more species. This bias could be reduced by incorporating a latitudinal weighting to the river length score, or river discharge or water volume data could be used as a surrogate for species richness. The best solution is of course to ensure that all species are mapped and assessed globally, thus eliminating the need for the use of surrogates for species richness.

Some of the very smallest of basins (4) and BCUs (10) have no data for the Extinction Risk sub-indicator since the IUCN Red List species data is mapped to a larger resolution of basin than the basin/BCU so that species data were not associated with these basins/BCUs during the automated overlap analysis in GIS.



Commercial fishing has lead to significant decline (at times to the point of species extinction) of many important fish populations.

3.4.5 Ecosystems Thematic Group Summary

The key findings for the thematic group are given in the introduction to section 3.4. The four indicators assessed in this group are:

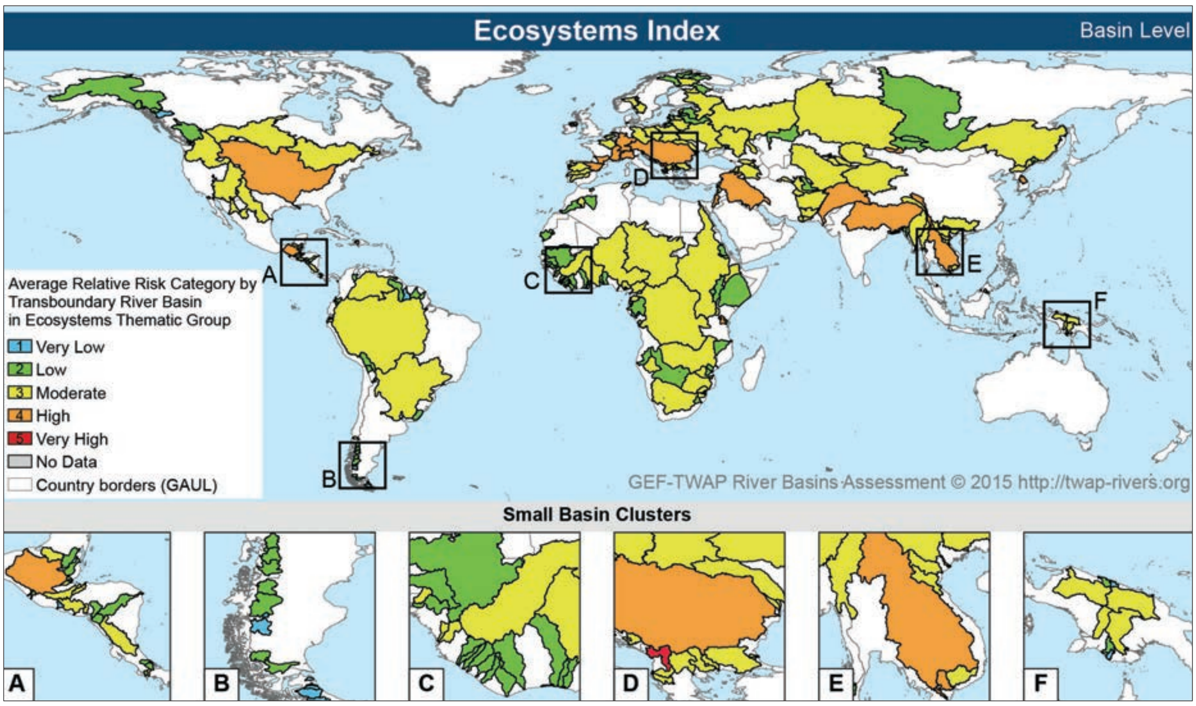
1. Wetland disconnectivity;
2. Ecosystem impacts from dams;
3. Threat to fish;
4. Extinction risk.

Taking the average relative risk category for the 195 basins with results available for the four ecosystem indicators, 25% have very low to low risk, 55% have moderate risk, and 19% have high to very high risk (Figure 3.53).

The statistical analysis (section 4.1) of the four ecosystem indicators confirms that Extinction Risk is slightly positively correlated with Threat to Fish (0.24) and Ecosystems Impacts from Dams (0.16) suggesting some level of causality between these pressures and the state of biodiversity. It is likely that the correlation with Ecosystems Impacts from Dams would be more significant if the analysis was restricted to those taxonomic groups most at risk from hydrological alterations – such as fish and molluscs. The findings are consistent with reported threats to freshwater biodiversity where overharvesting of fish for food, invasive species, habitat degradation and flow modification have been assessed as some of the most influential global drivers of threat, together with pollution and water extraction (Collen *et al*. 2014; WWF 2014; Darwall *et al*. 2011).

Wetland Disconnectivity is slightly negatively correlated with Ecosystem Impacts from Dams (-0.18), and not significantly correlated with the other two ecosystem indicators. This is not surprising given that fewer natural wetlands are currently found in regions where larger impoundment developments have taken place. In addition, larger dams are less likely to have been installed in the lower-lying terrains where wetlands, and in particular floodplains, are naturally located. A further explanation is given below:

Figure 3.53. Ecosystem Index, based on average relative risk category of each of the four ecosystem indicators, by transboundary river basin. The threat to freshwater ecosystems is global, affecting industrialised and developing countries.



The Wetland Disconnectivity indicator provides a *contemporary snapshot* (about 2000). At that time most of the wetlands in industrialized basins were already encroached on by urban areas and cropland, so they had already been ‘converted’ and were no longer registered as wetlands. In terms of threats to freshwater biodiversity in developed basins (e.g. Europe) the key threats tend to be invasive species, dams and water abstraction, and pollution (Freyhof and Brooks 2011). Large-scale loss of habitat caused by urban and agricultural expansion happened a long time ago. So this indicator mainly shows high risks in developing countries and basins where there is a current risk of wetlands being destroyed. In terms of policy relevance, it identifies areas where attention may need to be focused now to protect remaining wetlands.

In contrast, the Dams indicator measures the *cumulative* impacts of all the large dams built over the past 100 years or so. Hence, it is mainly industrialized areas, and areas where dam capacity is likely to have reached its maximum potential, which show up as having high relative risk. In terms of policy relevance, it generally identifies areas where the situation is already serious, but realistic policy response options are probably limited to improvements in dam operation. It does not necessarily highlight current high risk areas where dams are currently being constructed or planned. This aspect is addressed by the Hydropolitical Tensions indicator (#11), which captures more current (and projected) risks from water infrastructure development and hence also has a slightly negative correlation with Ecosystem Impacts from Dams (-0.16).

In terms of impacts of various threats on species, there are differences in the relative importance of threats to different taxa. For example, overexploitation of water resources appears to be a greater threat to crayfish than to fish or crabs. The type of freshwater habitat also appears to be important in determining threat levels. More species inhabiting flowing water habitats are under threat than marsh and lakes species (Collen *et al*. 2014). Riparian and aquatic communities will also be affected differently depending on the type of human pressures, with agricultural land-use expected to have a more profound impact on riparian species since fragmentation of the river structure is perhaps the most important disturbance for aquatic species (Belmar *et al*. 2014). To address river fragmentation and loss of habitat, riparian buffer zones may be considered as they have benefits for both humans and ecosystems since they serve as natural infrastructure to maintain water quality in streams and rivers and as flood protection (UNEP 2014).

Freshwater ecosystems are some of the most endangered habitats in the world, despite providing essential ecosystem services to significant share of the world's population

Species have different modes of adaptation to flow regime alteration (Lytle and Poff 2004). The sensitivity of ecosystems and therefore the services they provide to flow disturbance is expected to vary depending on local climate and hydrology. For example, Mediterranean aquatic species are adapted to high natural variation in water flows, but most cannot deal with daily sudden water releases from dams for irrigation (Belmar *et al*. 2014). Furthermore, Threat to Fish is slightly positively correlated with Ecosystem Impacts from Dams (0.24), suggesting an interaction between threat processes in basins where water infrastructure development, fishing pressure and invasive species are all high.

When looking at variation among the most at-risk basins for combined Ecosystem Impacts from Dams, Threat to Fish and Extinction Risk, the Mississippi and the Danube rank highest, followed by the Po, Rhine, Mekong, and then the Tigris-Euphrates/Shatt al Arab, followed by 20 more basins.

In contrast, the Song Vam Co Dong in Cambodia and Viet Nam represents a different case where the highest scores are associated with Wetland Disconnectivity and Threat to Fish while Ecosystem Impacts from Dams is only moderate. This is again not in conflict with the slightly negative correlation between Ecosystem Impacts from Dams and Wetland Disconnectivity. This correlation seems to confirm that, in more developed basins where dams continue to have a disruptive presence to river flows, loss of wetland function from agricultural expansion and/or urbanization has only been a moderate threat in more recent times, as described above. Furthermore, the Extinction Risk indicator does not include historic loss of species from individual basins or parts of basins (extirpated ranges). For example, if a species is lost from a basin due to dams blocking off its spawning ground (e.g. 20-50 years ago) the species would not be mapped to that basin and therefore the basin 'extinction risk' would not be as high as if it were included. This is highly relevant at the BCU level where species may be 'extirpated' (lost) from parts of a basin.

While it is important to look at cumulative impacts in order to tackle proximate threats from infrastructure development and fishery management in a coordinated fashion, attention should also be paid to BCU variations and how land-use changes upstream in river basins can also have positive (or negative) downstream impacts. For example, there are significant BCU variations in some of the basins that rank high in Threat to Fish, e.g. the Rhone and the Ebro; in Wetland Disconnectivity, e.g. the Kowl E Namakasar in Asia and the San Juan in Central America; and in Extinction Risk, e.g. the Danube and Amazon (higher risk in upstream areas). This is important for addressing the ultimate drivers of loss in highly biodiverse countries.

Human pressures also affect freshwater ecosystems at both local and basin scales, with the impacts of basin-scale disturbances being potentially greater than those at the local scale because of cumulative impacts at the basin level (Belmar *et al*. 2014). For example, pollution run-off or invasive species can be transported through an entire river basin. It is therefore important to differentiate between impacts when prioritising actions for different spatial domains.

In order to explore the links between broader human activity and their impacts on overall environmental health, we have to consider the other significant global drivers of threats to freshwater biodiversity mentioned above, i.e. pollution and water abstraction. Environmental Water Stress is positively correlated with Ecosystem Impacts from Dams (0.34) and, to a lesser extent, with Extinction Risk (0.12) (section 4.1). These correlations can be intuitively explained since the indicator represents environmental stress induced by flow regime, i.e. the water quantity aspect of considering hydrological alterations from the monthly dynamics of the natural flow regime caused by anthropogenic water uses and dam operations.

Wastewater Pollution correlates positively with Wetland Loss (0.22), and negatively with Ecosystem Impacts from Dams (-0.41) and Threat to Fish (-0.26). This could be explained by the different stages of development of the world's basins, with more industrialized basins being typically rich in dams, fishing activities and invasive species, and developing basins being more prone to losing lateral connectivity to agriculture expansion and urbanization. Threat to Fish is less strongly correlated probably because artisanal inland fisheries also make an important but often neglected and underestimated contribution to rural livelihoods in developing countries (Orr *et al*. 2012; Béné 2006; Smith *et al.* 2005).

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3.5 Governance

The governance thematic group considers the institutional capacity and management instruments currently available to deal with the water challenges highlighted by the indicator results in the other thematic groups. The governance indicators are designed to consider different scales and facets of water governance, which complement each other. The Legal Framework Indicator (#10) maps the presence of key international legal principles in transboundary treaties, providing a first overview of the set of principles underlying, at least 'on paper', transboundary water relationships across the globe. The Hydropolitical Tension Indicator (#11) narrows down the analysis to the formal provisions that exist in transboundary basins to lessen tensions arising from the construction of water infrastructure – a common source of dispute between countries – and also factors in other circumstances that could exacerbate transboundary hydropolitical tensions stemming from basin development. The Enabling Environment Indicator (#12) considers the 'enabling environment' for water resource management in each country, acknowledging that the strengths and weaknesses of governance will have implications for water resources at the basin level. This indicator considers a broad spectrum of issues including policy, planning and legal frameworks, governance and institutional frameworks, and management instruments. The three indicators together cover different aspects of water governance, looking at the same set of transboundary basins through three different but complementary lenses.

The projected Hydropolitical Tension Indicator also considers a range of political, socioeconomic and physical circumstances which could act as exacerbating factors and increase the risk of hydropolitical tensions due to basin development in the absence of institutional capacity. The indicator considers current factors that may have an impact in the next 10-15 years, and is therefore broadly comparable with the other projected indicators for the 2030 scenario.

Thematic group key findings:

1. **More effort is needed on transboundary agreements:** The adoption of international principles associated with the shift of water paradigms toward more sustainable development has been faster in domestic water governance arrangements than in international treaties. Focus is needed on renegotiating and implementing transboundary agreements to incorporate more integrated approaches into basin-level management.
2. **Construction of water infrastructure needs a cooperative context:** The construction of new water infrastructure is in progress or planned in many transboundary basins, including in areas where international water cooperation instruments are still absent or limited in scope. In such areas, a formal institutional framework for transboundary dialogue could help to assuage potential disputes stemming from unilateral basin development.
3. **Capacity building is required within countries to meet transboundary objectives:** There have been advances in the development of transboundary institutional capacity to deal with transboundary tensions and the application of integrated approaches to national water management, but capacity building is still work-in-progress in most countries.

Commercial fishing has lead to significant decline (at times to the point of species extinction) of many important fish populations.

3.5.1 Legal Framework

Key findings

1. **There is stronger consideration of key principles of international water law in large basins:** Generally, treaty arrangements for large basins tend to reflect key principles of international water law to a greater degree than those of smaller basins.
2. **Europe and North America use international law principles more:** A somewhat higher proportion of basins in Europe (35%) and North America (24%) have transboundary relationships formally guided by key principles of international water law (low and very low relative risk categories 1 and 2) than those in Asia (18%), Africa (18%) and South America (3%).
3. **Ratification of global water conventions can improve the legal framework in river basins at risk:** Most basins in the high or very high relative risk categories (4 and 5) have no treaties in place, or if there are any they do not appear to incorporate recognized principles of customary law. For such basins, ratification by countries of either of the two global water conventions can provide an improved legal framework founded on key water law principles.

Rationale

This indicator is based on the premise that the governance of a transboundary basin is guided (among other things) by the legal agreements in place and that these provide a framework for managing the shared water resources of the basin. Principles of international water law have been defined to guide dialogue among riparians for creating reasonable and equitable transboundary water resource management. This assessment maps the presence of widely recognized key international legal principles in transboundary treaties to determine the extent to which the legal framework of the basin is guided by these principles.

The overall aim is to assess the degree of correspondence/alignment of existing international freshwater treaties with the following six key legal principles: (a) equitable and reasonable utilization; (b) not causing significant harm; (c) environmental protection; (d) cooperation and information exchange; (e) notification, consultation or negotiation; (f) consultation and peaceful settlement of disputes. These principles represent important customary and general principles of international law applicable to transboundary water resource management that are accepted globally and incorporated in modern international conventions, agreements and treaties, including the Convention on the Protection and Use of Transboundary Watercourses and International Lakes (hereinafter referred to as the UNECE Water Convention) and the United Nations Convention on the Law of Non-Navigational Uses of International Watercourses (hereinafter referred to as the UN WC Convention).[11,12,13,14] Since the UNECE Water Convention and the UN WC Convention incorporate all the above-mentioned principles and both are global in scope[15], ratification by countries of these two Global Water Conventions has also been taken into consideration as part of this assessment.

11 Convention on the Protection and Use of Transboundary Watercourses and International Lakes, 17 Mar. 1992 (in force 6 Oct. 1996), *reprinted in 31* I.L.M. 1312 (1992) ("ECE Convention").

12 United Nations Convention on the Law of Non-Navigational Uses of International Watercourses, UN Doc. A/51/869, 21 May 1997, reprinted in 36 Int'l Legal Mat'ls 700.

13 Helsinki Rules on the Uses of the Waters of International Rivers, adopted by the ILA at the 52nd Conference, Helsinki, Finland, Aug. 1966, reprinted in Bogdanović, S., International Law of Water Resources – Contribution of the International Law Association (1954-2000), 89 (Kluwer Law International, The Hague 2001).

14 The Berlin Rules Report of the Seventy-First Conference of the International Law Association, Berlin 2004, http://internationalwaterlaw.org/documents/intldocs/ILA_Berlin_Rules-2004.pdf

15 The amendment to the UNECE Water Convention allowing membership from non-UNECE member states has entered into force, and became operational in 2015.

By focusing on the transboundary legal framework, this indicator complements the Hydropolitical Tension Indicator (#11) (which considers the potential for transboundary tensions over water infrastructure development) and the Enabling Environment Indicator (#12) (which considers the governance framework in place in each riparian country).

Computation

The data source for collecting information on the existence of key legal principles has been the International Freshwater Treaties Database (IFTD) which is part of the Transboundary Freshwater Dispute Database (TFDD) at Oregon State University. It includes 686 international freshwater treaties and is the most comprehensive and updated data source of transboundary freshwater treaties worldwide. Of the 686 listed international freshwater treaties, 481 were assessed. The assessment was limited to legally-binding treaties between countries concerning water as a consumable resource. Treaties listed as missing in the IFTD were also excluded from the assessment. Information on the presence of all identified key principles is readily available in the IFTD with the exception of the 'no harm principle'. This principle was therefore defined and all relevant treaties in the database (where the treaty text could be accessed) were assessed to determine its presence.

The calculation of the basin scores was undertaken in two steps, after which results were categorized.

Step 1:

- A BCU is given a score of one for each of the key principles of international water law that are present in any of the transboundary freshwater treaties the country has signed. The maximum score per BCU per principle is one, even if several treaties contain the principle in question.
- A value of zero indicates that the presence of the principle in question in any treaty signed by the BCU (country) could not be verified through the data available for this assessment.
- Each BCU (country) that has signed either of the key global water conventions (UN WC Convention or the UNECE Water Convention) receives a score of one.

Table 3.9. Calculation of the BCU Treaty Score (for each BCU)

BCU treaty score	Possible value
At least one treaty covering principle of equitable and reasonable utilization	0/1
At least one treaty covering obligation not to cause significant harm	0/1
At least one treaty covering the principle of environmental protection	0/1
At least one treaty covering the principle of cooperation and information exchange	0/1
At least one treaty covering the principle of notification, consultation or negotiation	0/1
At least one treaty covering consultation and peaceful settlement of disputes	0/1
BCU (country) has ratified UN WC Convention and/or UNECE Water Convention	0/1
BCU treaty score	0 to 7

Step 2:

Calculating a basin score required the follow steps:

- The BCU score above is weighted on the basis of an average of the relative area and population in the BCU compared with the basin;
- Each weighted BCU score is summed to a basin treaty score (from 0 to 7). The basin treaty scores are shown in Table 3.10.

Table 3.10. Calculation of the Basin Treaty Score (for each basin)

BCUs in Basin	BCU treaty score (from step 1)	BCU weight	Weighted BCU score
BCU1	0 to 7	up to 1	BCU treaty score x BCU weight = weighted BCU score
BCU2	0 to 7	up to 1	
BCU3	0 to 7	up to 1	
		Sum of each BCU weight = 1	**Basin treaty score = Sum of all weighted BCU scores (0 to 7)**

A category score was developed with scores between 1 and 5, where 1 indicates a high presence of legal principles in the governance architecture of the basin (very low relative risk), and 5 a low presence of legal principles (very high relative risk) as shown in Table 3.11 Table 3.9).

Since this is the first time such an assessment has been undertaken at the global level, the category ranges were determined to suit the particular needs of the assessment. They are defined in such a way as to highlight the basins where practically all or practically none of the principles are present in the legal framework (by defining narrow ranges for categories 1 and 5) and with a fairly even distribution between the low, moderate and high categories (2-4).

Table 3.11. Legal Framework category thresholds

Relative Risk Category	Range (basin treaty score)
1 – Very Low	6.8 - 7
2 - Low	4.5 - 6.79
3 - Moderate	2.5 - 4.49
4 - High	0.2 - 2.49
5 – Very High	0 - 0.19

Results

Basins and BCUs in the high relative risk categories for Legal Framework are found throughout the world, while those in the lowest category are concentrated in Europe and southern Africa (Figure 3.54 and Figure 3.55. Almost 40% of basins are in the highest relative risk category.

The five relative risk categories were defined as follows:

1. Very low relative risk: Nearly all assessed international principles are present in the existing basin treaties and the majority of basin countries have ratified or signed the UN WC Convention and/or the UN ECE Water Convention. The basin legal framework is guided by the key principles of international water law to a very high degree.
2. Low relative risk: The majority of the assessed international principles are present in the legal framework of the basin, which is guided by the key principles of international water law to a high degree.
3. Moderate relative risk: Some of the assessed international principles are present in the legal framework of the basin, which is guided by the key principles of international water law to a medium degree.

Figure 3.54. Legal Framework by Transboundary River Basin. Basins in the highest risk categories have very few of the key principles of international water law present in the legal framework and in several basins in the highest risk category, there is no treaty in place. Ratification of global water conventions at the country level can move basins from a high risk category to a lower one.

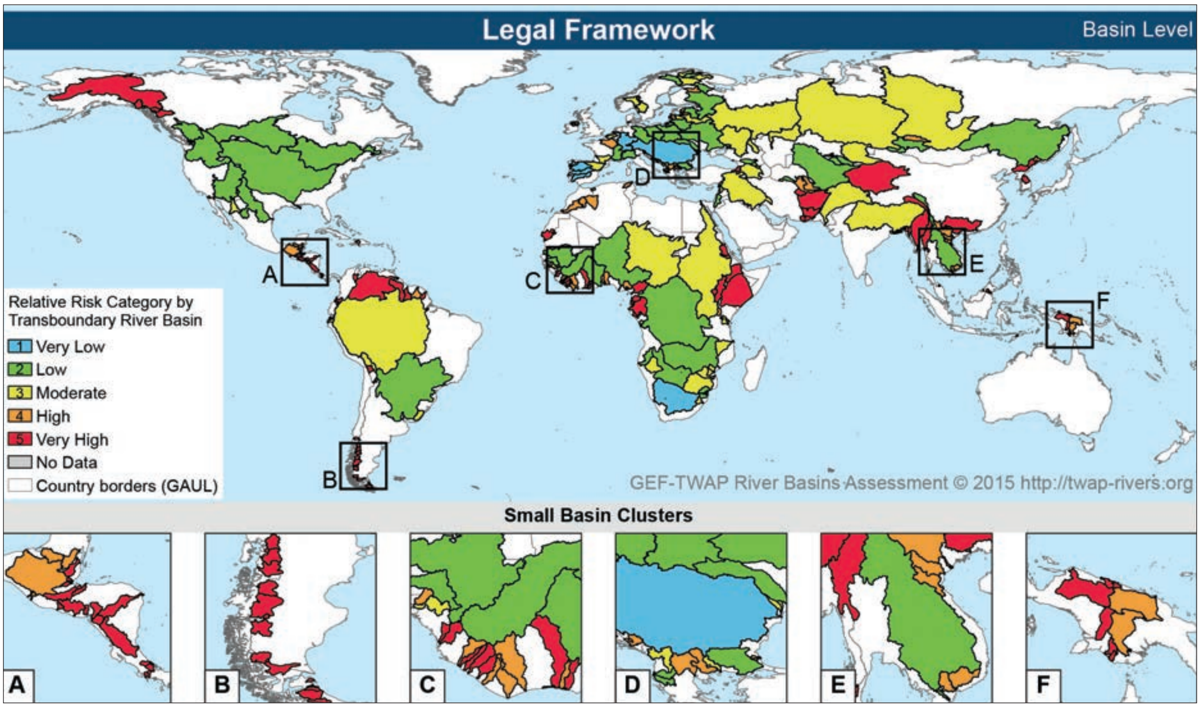


Figure 3.55. Legal Framework by Basin Country Unit (BCU). Ratification of global water conventions gives an opportunity for basin countries to improve the basin legal framework.

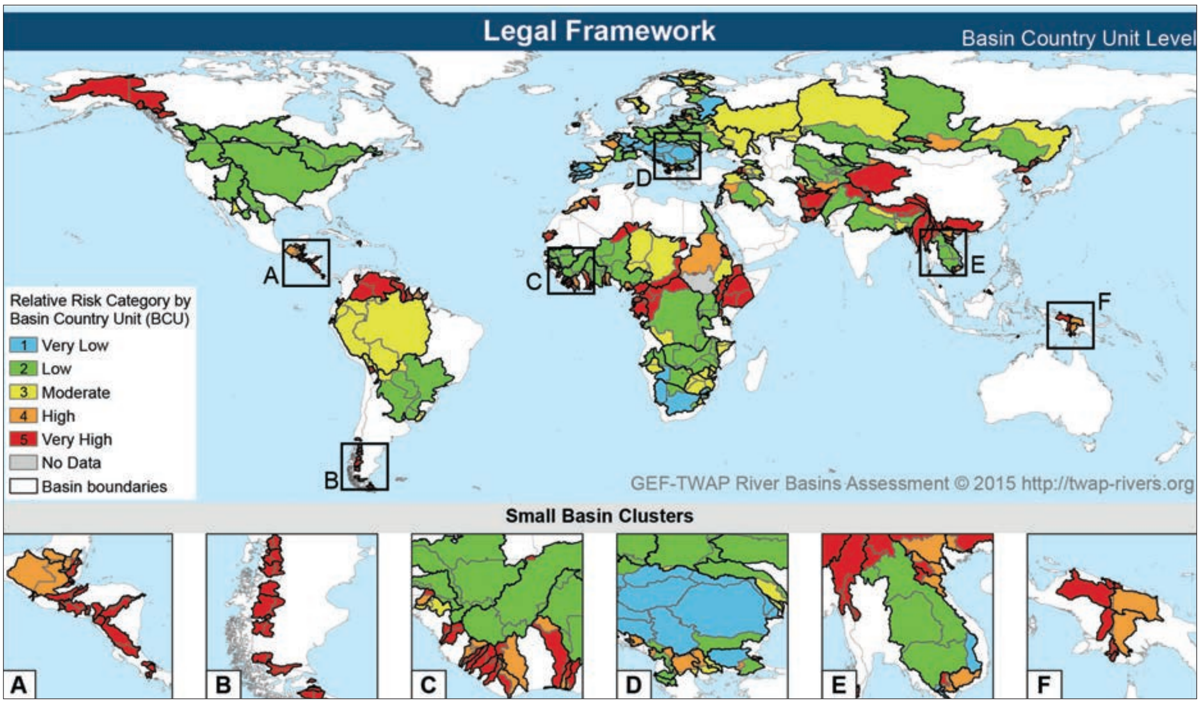
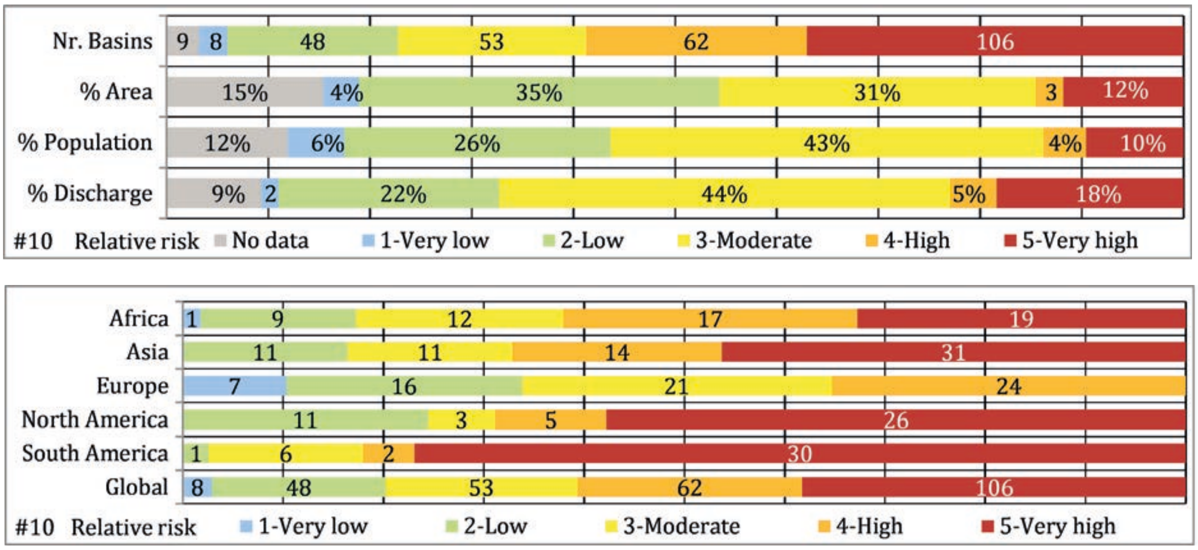


Figure 3.56. Legal Framework Relative Risk Categories by: number of basins, global TB basin % for area, population and discharge (top); and number of basins by region, 'no data' basins excluded (bottom). Treaty arrangements for large basins tend to reflect key principles of international water law to a greater degree than those of smaller basins.



4. High relative risk: A limited number of the assessed international principles are present in the legal framework of the basin, which is guided by the key principles of international water law to a limited degree.
5. Very high relative risk: Practically none of the principles are present in the legal framework of the basin, which is not guided by the key principles of international water law.

Interpretation of results

The largest share of transboundary basins worldwide (38%) fall into category 5, where practically none of the principles are present in the legal framework of the basin. In most of these basins there are no treaties in place, or if there are they do not appear to incorporate recognized principles of customary law. In addition, very few or none of the riparian states in these basins have ratified any of the global water conventions. It is important to note that falling into category 5 does not necessarily indicate a lack of cooperation in that particular basin. Countries can for example be reluctant to sign treaties and prefer to cooperate in non-legally binding, informal ways. Another aspect to take into consideration is that the recognised principles of international water law have been developing over the past 40 years or so and many river basins are guided by treaties older than that. For example, the treaty between Sweden and Finland for the Torneo basin was signed in 1971, and lacks some of the more 'modern' principles. A new treaty between the countries was signed in 2013, but was not included in this assessment, which is based on the treaties available in the IFTD (which covers 1820 to 2007).

Most basins where riparian states have decided to ratify either of the two global water conventions have, in most cases, avoided the highest risk category. For the basins where no treaties are in place, or where treaties do not appear to incorporate recognized principles of customary law, ratification by countries of either of the two global water conventions can provide an improved legal framework founded on key water law principles. However the UNECE Water Convention does require states to enter into basin arrangements in order to implement key provisions of that convention. Application of the Convention's provisions at the basin level, of bilateral and multilateral agreements, and of 'soft-law' guidance developed under the UNECE Water Convention, can also strengthen the legal framework.

The distribution between categories 2-4 is fairly even. While category 4 includes a number of basins where no treaties are in place but where riparian states have ratified either of the global water conventions, basins in the moderate and low risk categories (categories 3 and 2) have incorporated key international water law principles in relevant basin treaties.

Reaching category 1, which was narrowly defined as "nearly all assessed international principles are present in the existing basin treaties and the majority of basin countries have ratified or signed the UNWC Convention and/or the UNECE Water Convention" seems more difficult. There are only eight basins in Category 1, which makes it difficult to draw any strong conclusions, but these eight basins are in Europe (7 basins) and southern Africa (1 basin) – both regions with a long history of cooperation in transboundary water management. In southern Africa, the Southern Africa Development Community (SADC) Water Protocols can be seen as having been drivers for cooperation.

There is a fairly strong correlation between the size of the basin and the presence of the key principles within the legal frameworks (Table 3.12). Most basins larger than 500 000 km^2 have relatively low risk (categories 1 and 2 (57%)), compared to only 17% of the basins smaller than 500 000 km^2. Larger basins are generally shared by more countries than smaller basins and the economic importance of the shared water resource is likely to be of comparatively greater significance to the economies of these countries (see section 3.1.1). These factors could provide a relatively stronger incentive for large basins to sign treaties and include key principles specifying the rights and obligations between the riparian States to facilitate cooperation between the many actors.

Table 3.12. Legal Framework Indicator: Geographical Area of Basins in Different Risk Categories

Geographical area (km^2)	Cat 1-2 (%)	Cat 3-5 (%)
0 – 49 999	11%	89%
50 000 – 99 999	33%	67%
100 000 – 499 999	30%	70%
500 000 – 999 999	62%	38%
larger than 1 000 000	53%	47%

Regionally, a somewhat higher proportion of basins in Europe (34%) and North America (24%) are categories 1 and 2 than those in Africa (17%), Asia (16%) and South America (3%) (Figure 3.56). The low score of South America could have a number of reasons:

- 27 of the 39 transboundary basins in South America are relatively small (less than 25 000 km^2 (or 100 x 250 km^2);
- 17 basins have populations of less than 20 000 people;
- 31 basins are shared between only two countries, and when considering the BCU weight (i.e. the average of the population and area proportions of the BCU compared to the basin), many of these basins are mainly covered by a single country (BCU weight >85%).

So while there are many transboundary basins in South America, the relevance of creating formal transboundary treaties may be reduced (which is consistent with the findings of Lee (1995, pp 552)). Indeed there was no treaty registered in the IFTD for 30 of the basins, but for those that had a formal treaty, most were in the 'moderate' risk category.

Limitations

- Results for some of the basins/BCUs are considered to have lower levels of confidence. This is the case where: a) certain treaties are not considered valid by all basin states; b) there is no or very limited information available for a BCU (e.g. South Sudan and Palestine); and c) the presence of the key principle (not to cause significant harm) not assessed in the IFTD could not be verified for one or more BCUs in the basin because of ambiguous formulation in the treaty or difficulty in arranging translation of a treaty language not familiar to the assessment team. These 9 basins and 16 BCUs are marked as having lower level of confidence in the result sheets downloadable from the TWAP RB data portal.

- The assessment does not measure the 'performance' of the cooperation in a certain basin (the implementation of the treaties or the application of the principles in question) as this was deemed too challenging at the global level. It only provides an assessment of the legal framework in place. However, one proxy measure for the performance of governance systems is the Corruption Perception Index, and further information is provided in Annex XI-3.
- The method is designed primarily to compare the legal frameworks in place at the basin level, while still recognizing the value of any ratification of the two global water conventions by riparian states. As a result, 'basin treaties' are of higher relative importance to the final BCU or basin score (generating a score between 0-6 depending on how many key principles are included in such treaties) than the countries' ratification of the two global conventions (generating a maximum score of 1). This needs to be considered when interpreting the results.
- The assessment relies to a large extent on the information in the IFTD. However, it is outside the scope of this assessment to verify the extent of comprehensiveness or correctness of the database. Relevant treaties, or principles within treaties, may exist that have been overlooked by this assessment. For example, the IFTD was last updated in 2009 so the assessment does not take into consideration treaties that may have been signed in recent years.
- A score of zero in the methodology indicates that the presence of the principle in question could not be verified, in some cases because of a lack of information. The degree of confidence in results for the lower score/higher risk basins and BCUs is therefore lower than that of the higher score/lower risk basins and BCUs.
- While the assessment includes all treaties in the database, irrespective of whether they are broad in scope or pertaining to a specific issue (such as the construction of a dam), it is not possible to ascertain the scope of the agreement from the final results. However, this information is available in the IFTD. Where a treaty is signed only between two countries (possibly on a specific issue), the relative significance of those countries in the basin by population and area is considered in the overall basin score.
- The method does not take into consideration whether the above principles are covered by the BCUs' ratification of the same or of several different treaties.
- Taking the above limitations into consideration, this assessment provides a global overview of the existence of key principles of international water law in transboundary legal frameworks. It allows comparison on a broader scale between regions and basins. However, the information should not be interpreted in 'absolute terms' with regard to specific BCUs or basins.

Potential for future development

- A repeat assessment should also cover agreements signed after 2007;
- This assessment has considered all relevant treaties, also those of limited technical scope. Although this could be seen as providing a more comprehensive view of the legal framework in place, an assessment focusing primarily on the 'main basin treaties' may paint a slightly different picture;
- A repeat assessment could be combined with a thorough and extended analysis of the legal framework in place for selected basins in the different categories. Such an in-depth analysis should also include consideration of the implementation and effectiveness of the legal framework;
- Semi-international treaties (e.g. between states and provinces across borders, not necessarily sovereign states) could be considered. There are examples of strong transboundary cooperation at the sub-national scale;
- Consideration of the gradual strengthening of the legal and institutional framework should be considered in future assessments. This is applicable to all the governance indicators.

3.5.2 Hydropolitical Tension: Risk of Potential Hydropolitical Tensions due to Basin Development in Absence of Adequate Institutional Capacity

Key findings

1. **Infrastructure development is occurring in many regions with low institutional capacity:** Infrastructure development with limited formal institutional capacity is occurring or planned e.g. in Southeast Asia, South Asia, Central America, the northern part of the South American continent, and the southern Balkans as well as in different parts of Africa.
2. **Other conflict risk factors could affect river basin management:** In Central and Eastern Africa, the Middle East, and Central, South and South-East Asia, a combination of several factors, related to declining water availability, low levels of economic development or presence of armed conflict, could exacerbate hydropolitical tensions.

Rationale

Formal arrangements governing transboundary river basins, in the form of international water treaties and river basin organizations, can be highly instrumental in managing disputes among fellow riparians arising from the development of new water infrastructure. This indicator maps the risk of potential hydropolitical tensions that exists when basins may be ill-equipped to deal with transboundary disputes associated with the development of new water infrastructure. The calculation of the indicator is based on estimates of the level of formal institutional capacity expressed by the presence or absence of relevant treaty provisions and river basin organizations, juxtaposed with the respective basin's ongoing and planned development of water infrastructure in transboundary basins.

Computation

The computation of this indicator required several steps at the BCU level. The results were then aggregated to obtain basin scores.

Calculation of institutional resilience, which expresses the capacity of each BCU to deal with tensions associated with the development of new dams and water-diversion schemes, consists of five components (Table 3.13). Some of those (presence of a water treaty, presence of a river basin organization or existence of conflict resolution mechanisms) contribute to creating a general framework for cooperation within a transboundary basin. Others are particularly relevant for dealing with tensions that could stem from the construction of a water infrastructure: mechanisms to allocate water among riparians and provisions to manage flow variability (floods and droughts). The data for institutional capacity were obtained from De Stefano *et al*. (2012) complemented by data on additional conflict resolution mechanisms embedded in international RBOs (Schmeier, no date). One point is given to a BCU for each treaty and RBO component present for that BCU, resulting in a treaty-RBO resilience score ranging from zero to five.

Table 3.13. Hydropolitical Tension: Components of Score Calculation

Treaty-RBO component	Possible value
At least one water treaty	0/1
At least one treaty with an allocation mechanism	0/1
At least one treaty with a flow variability management mechanism	0/1
At least one treaty with a conflict resolution mechanism	0/1
At least one river basin organization	0/1
Total possible value for a basin-country unit	0 to 5

The treaty-RBO resilience scores are then grouped into three institutional vulnerability levels for each BCU, with 'low' representing a treaty-RBO score of four or five, 'medium' a score of two or three, and 'high' a score of zero or one. The estimate of potential stress on institutional structures due to new water infrastructure development considers dams exceeding 10 Megawatts in capacity and diversion projects diverting quantities greater than 100 000 m^3/yr that were planned, proposed or under construction as of July 2014 (Petersen-Perlman 2014). A number of sources were used to build the dataset: the United Nations Framework Convention on Climate Change's Clean Development Mechanisms (http://cdm.unfccc.int), International Rivers, the International Commission on Large Dams (ICOLD), and websites of other organizations known to fund dam construction (e.g. World Bank). The analysis also considered the potential downstream stress that new water infrastructure development may bring. Ultimately, the BCUs are labelled high hazard (H) if there is such development or if they are downstream of such development and low hazard (L) if there is none (Table 3.14).

Table 3.14. Hydropolitical Tension: BCU Hazard Classification due to Water Developments

Water Developments (presence of Large Dam and Water Diversion Projects)	Score (Hazard)
No presence (in the BCU or upstream of it)	1 - LOW
Presence (in the BCU or upstream of it)	3 - HIGH

The level of hazard due to the development of water infrastructure was then combined with the values of institutional vulnerability (Table 3.15).

Table 3.15. Hydropolitical Tension: Values of Institutional Vulnerability

Vuln↓/ Haz→	1 - LOW	3 – HIGH
1 (low V)	1	3
2 (med V)	2	6
3 (high V)	3	9

The resulting values were then regrouped into five relative risk categories (Table 3.16) which represent the risk of potential hydropolitical tensions due to basin development in the absence of institutional capacity at a BCU level.

Table 3.16. Hydropolitical Tension: BCU Relative Risk Categorization

Risk scores from Table 3	Relative Risk categories
1	1 Very low
2	2 Low
3	3 Moderate
6	4 High
9	5 Very High

To obtain aggregated values by basin, a weight was calculated for each BCU by taking an average of the area ratio and the population ratio of the BCU compared to the basin. The resulting basin scores were regrouped into five categories using intervals centred on the five categories used for the BCU (Table 3.17).

Table 3.17. Hydropolitical Tension: Basin Risk Categorization

Relative risk score	Relative risk category
1.00 - 1.50	1 Very low
1.51 - 2.50	2 Low
2.51 - 3.50	3 Moderate
3.51 - 4.50	4 High
4.51 - 5.00	5 Very high

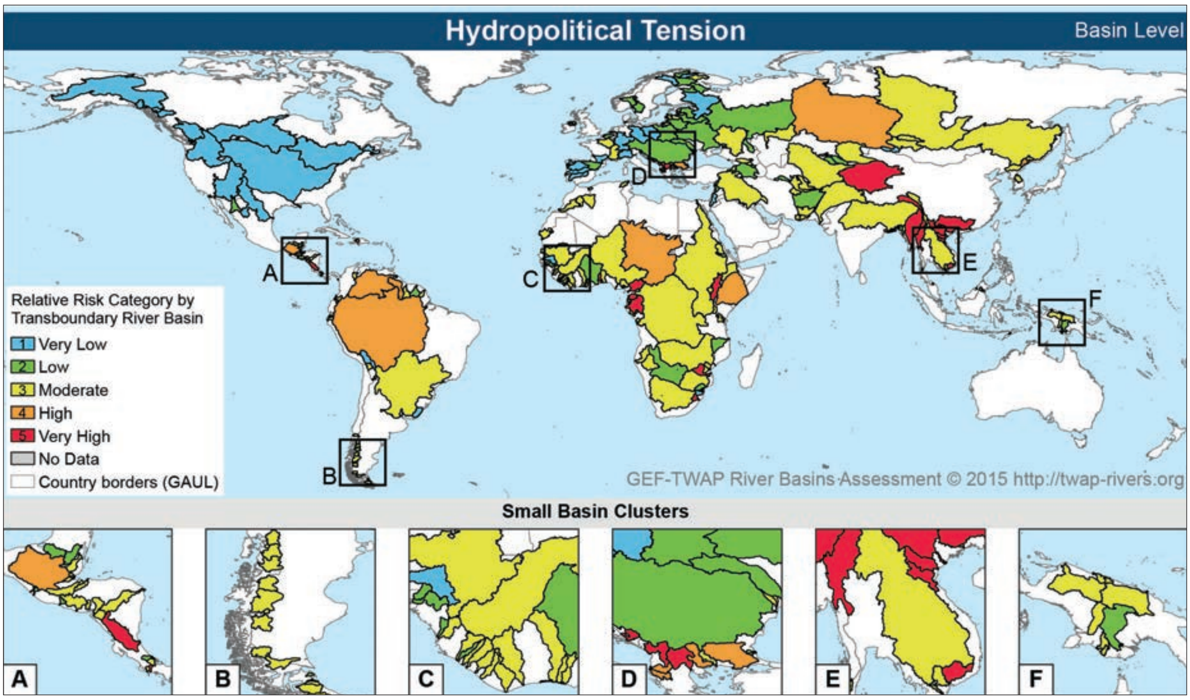
Results

More than 50% of the basins were found to fall into class 3 or 'moderate' risk, while about one-tenth are in the high or very high relative risk categories.

Interpretation of results

The distribution of new water infrastructure points to areas with high elevation and emerging or developing economies that require increased hydropower and water regulation to sustain their economic development. Many of these areas still lack well-developed instruments for transboundary cooperation. A high concentration of new dams to be built in a context of limited formal transboundary cooperation can be seen in Southeast Asia, Central America, the Amazon, South Asia, and the southern Balkans. Basins with dam development also exist in Africa, but no clear geographical patterns can be detected. Hotspots in the African continent include in Ethiopia, where there are plans for the construction of several new dams; in the area of Lake Chad basin, where diverting works are planned or

Figure 3.57. Hydropolitical Tension by Transboundary River Basin. Infrastructure development is occurring in many basins with low formal institutional capacity.



under construction; and in South Sudan, which still lacks instruments for transboundary water management. In Asia, China is a key player in water development but has so far been reluctant to engage in multilateral transboundary agreements, preferring to engage one on one with each of its neighbours. In South America, a number of dams are planned in the Orinoco basin, and the lack of institutional mechanisms could lead to transboundary tensions.

Figure 3.58. Hydropolitical Tension by Basin Country Unit (BCU). Within-basin differences at the BCU level highlight countries where there may be an urgent need for improved institutional capacity due to ongoing or planned water infrastructure construction.

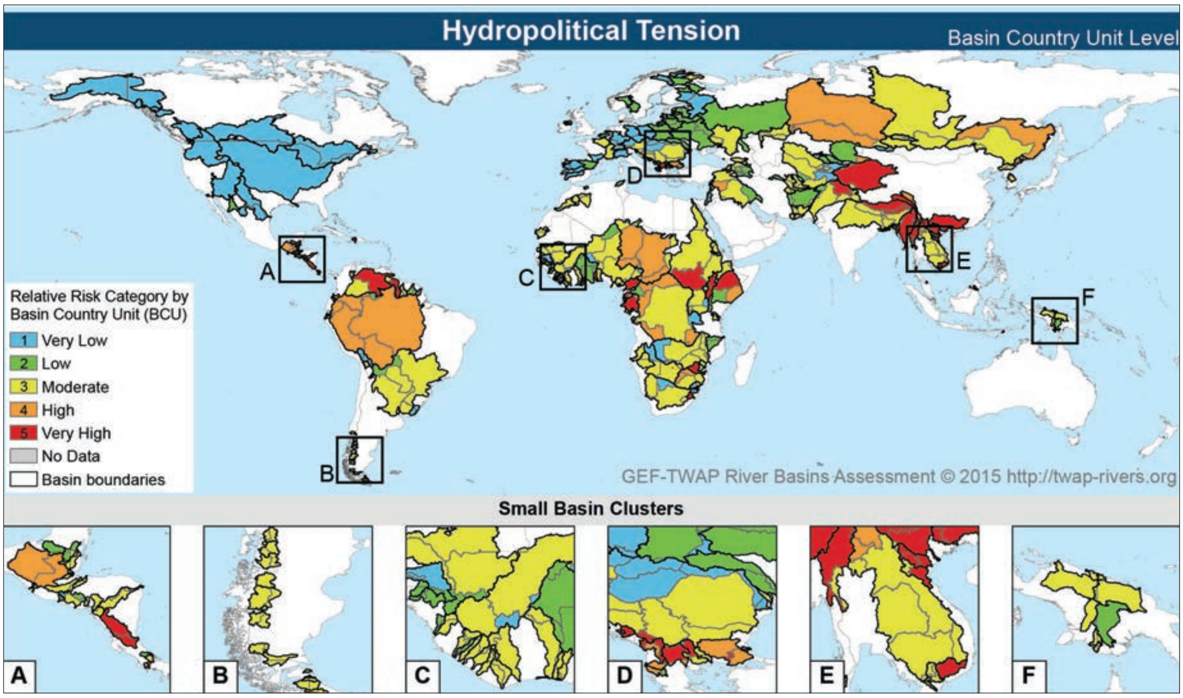
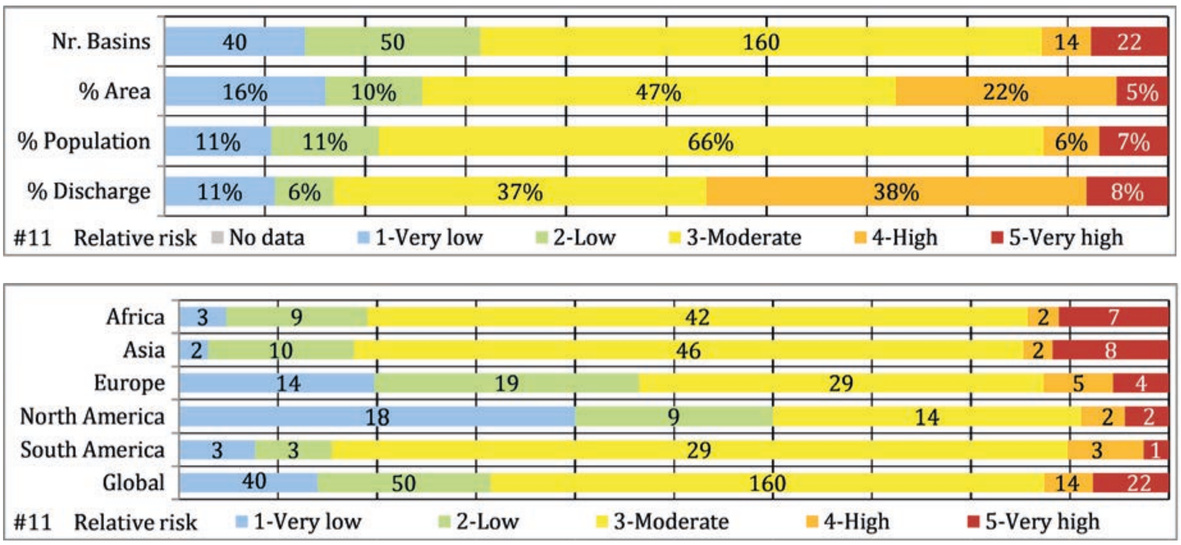


Figure 3.59. Hydropolitical Tension Relative Risk Categories by: number of basins, global TB basin % for area, population and discharge (top); and number of basins by region, 'no data' basins excluded (bottom).



Transboundary institutional capacity embodied by treaties and RBOs could also be improved in the Amazon basin, which is experiencing important water development. Water infrastructure projects also seem to be under development in Central America with little transboundary institutional capacity in place.

The regions that, according to the available data, appear to be less exposed to the risk of hydropolitical tensions are Northern America and Europe, with the exception of the southern part of the Balkans, where a number of water infrastructure projects are planned or ongoing without adequate institutional arrangements.

It is important to stress that this indicator considers the institutional capacity that is shaped by the international treaties and RBO agreements. The presence of formal arrangements is no guarantee that they are effectively enforced or even enforced at all. Thus it is highly possible that a BCU or a river basin has all the formal mechanisms in place but is still not able to deal with conflict stemming from the development of water infrastructure. In such cases this assessment shows that policy-makers will have to re-focus their efforts more toward improving the design or the actual implementation of existing provisions rather than creating new ones. Another alternative is that they will have to find the source of the hydropolitical tension in factors that are not directly related to water but have an impact on relationships between countries.

Limitations and potential for future development

The indicator is based on the identification of key institutional components that are directly related to the management of water variability in transboundary basins. The elements were selected on the basis of the existing literature and also on the availability of data to map them at a global scale (see De Stefano *et al*. 2012 and Petersen-Perlman 2014 for a detailed justification of the selection). As with any global indicator, however, they represent a simplification of the large number of factors that could have an impact on institutional vulnerability. Moreover, the indicator considers only the existence of specific institutional components and not their level of implementation or performance in practice. As is common with the majority of global water governance assessments, evaluation of the level or quality of implementation is a huge methodological challenge that has not yet been satisfactorily solved. However, one proxy measure for the performance of governance systems is the Corruption Perception Index, and further information is provided in Annex XI-3.

In future it would be extremely useful to undertake a comprehensive survey among water managers in transboundary basins to collect their perceptions of the success and effectiveness of transboundary cooperation in water management and the value of the institutional framework. Even if imperfect and with a certain degree of subjectivity, such an assessment could help provide a general idea of how much the presence of formal provisions reflects good practices in the management of a given transboundary basin.

Dam and diversion project data is based on publicly-available information, which means that there could be other projects that were not found during the data search. Furthermore, the status of these projects is changing rapidly – some may have been cancelled or completed. It is therefore desirable to set up and maintain a public dataset where international and national donors could include information about existing or planned projects.

These limitations in terms of scale and data availability affect all the basins/BCUs in a similar way; the level of confidence in the validity of the indicators and sub-indicators is therefore homogeneous across all the basins and BCUs.

3.5.3 Exacerbating Factors to Hydropolitical Tension – Projected Scenario

Rationale

Analysis of the history of conflict and cooperation over water in transboundary basins suggests that some political, socioeconomic and physical circumstances may act as exacerbating factors and increase the risk of hydropolitical tensions due to basin development in the absence of institutional capacity (Wolf *et al*. 2003). The calculation of the projected indicator combines the baseline results with a set of exacerbating factors related to water availability, presence of international and domestic conflict and economic development in the transboundary basins. This projected indicator is designed to be broadly comparable with the other projected indicators for the 2030 time period (i.e., within the next 15 years or so). However, as a measure of governance it does not attempt to consider political changes that far in the future, but rather considers the exacerbating factors that are currently known, which may have an impact in the next 10-15 years. For this reason, no attempt can be made to project this indicator to 2050.

Computation

Computation of this indicator was undertaken at a BCU level and the results aggregated to obtain basin values. Six factors were considered to express circumstances that could exacerbate transboundary hydropolitical tension stemming from basin development in the absence of adequate institutional capacity:

a) high or increased climate-driven water variability;
b) recent negative trends in water reserves;
c) intra-state armed conflicts;
d) interstate armed conflicts;
e) recent history of unfriendly relationships over water;
f) low gross national income per capita.

The factor of Climate-driven Water Variability (factor ‘a’) was calculated from the Coefficient of Variation (CV) of annual runoff for 1971-2000 (baseline) and climate change projections for 2021-2050 (representing 2030) (Schewe *et al*. 2014). Following Vörösmarty *et al*. (2005), the absolute values for coefficient of variation for each period were grouped into three levels: ‘low’ ($CV < 0.25$) ‘medium’ ($0.25 \leq CV \leq 0.75$) and ‘high’ ($CV > 0.75$) variability. If CV is at the high level (3) in both periods or if the CV is higher for the projected period than it is for 1970-2000, the final water variability hazard score is 1. Otherwise, the score is 0 (Table 3.18, column ‘a’).

Current and recent armed conflict can be an exacerbating factor to hydropolitical tension.

Recent trends in water resource reserves (factor 'b') were calculated using data from the GRACE satellites, which provide an eleven-year record of monthly terrestrial water storage anomalies (TWSA), changes in the vertical sum of water stored as snow, surface, soil and groundwater. Measurements of TWSA were obtained from the GRACE RL-05 (Landerer and Swenson 2012; Swenson and Wahr 2006) data set from NASA's Tellus website (http://grace.jpl.nasa.gov). Using 127 months of GRACE data from January 2003 to July 2013 the Sen's-slope (Sen 1968) was calculated at 1º resolution for the entire Earth. A Sen's-slope reflects the median slope of the overall data series and is not over-influenced by outlying data points. The Sen's-slope values are grouped into two classes: stable and positive (-0.1 to 0.39, -0.1 excluded), and negative (-0.1 to -0.94). The threshold for the hazard score is -0.1 (Table 3.18, column 'b').

The presence of intra-state tensions (factor 'c') was identified using data from the Minorities at Risk project (MAR 2009). This factor was included because there is evidence that the internationalization of basins, which occurs when the configuration of countries in a given region changes due to internal tensions (e.g. former Soviet Union; former Yugoslavia), makes conflicts among riparians more likely (Wolf *et al*. 2003); Thus, the presence of armed conflicts involving minorities within a given country helps to identify areas that could in the near future see the disappearance of some countries and the creation of new ones. All countries with a conflict severity value of 3 or more in the MAR database (*FACTSEV1* variable) were marked as having an intrastate conflict score of 1. All BCUs within a country were given the same intrastate conflict value (Table 3.18, column 'c').

For interstate conflicts (factor 'd'), within the UCDP/PRIO Armed Conflict Dataset (v.4-2013, 1946 – 2012), incidents were selected that occurred from 2000 to 2013 and where both sides of the conflict included a government, either in a primary or secondary (supporting) role (Themnér and Wallensteen 2012; Gleditsch *et al*. 2002) (Table 3.18, column 'd').

Data from the TFDD Water Events Database were used (Oregon State University, no date) for characterization of recent history of conflict and cooperation over water, measured using the Basin At Risk (BAR) scale, where negative values indicate events of dispute and positive ones cooperative interactions (factor 'e'). The average value was calculated for all events occurring in a BCU between 2000 and 2008 (De Stefano *et al.* 2010). Negative averages were given a hazard value of 1 (Table 3.18, column 'e').

The economic development of riparian countries (factor 'f') was calculated using the average of the most recent five years (2008-2012) of Gross National Income (GNI) per capita, Atlas method (current US$) (WB no date). Countries with GNI per capita below the $1 035 poverty threshold (WB 2013) were given a 1 for the GNI Hazard Score (Table 3.18, column 'f').

Table 3.18. Hazard score categorizations for each of the exacerbating factors for hydropolitical tension

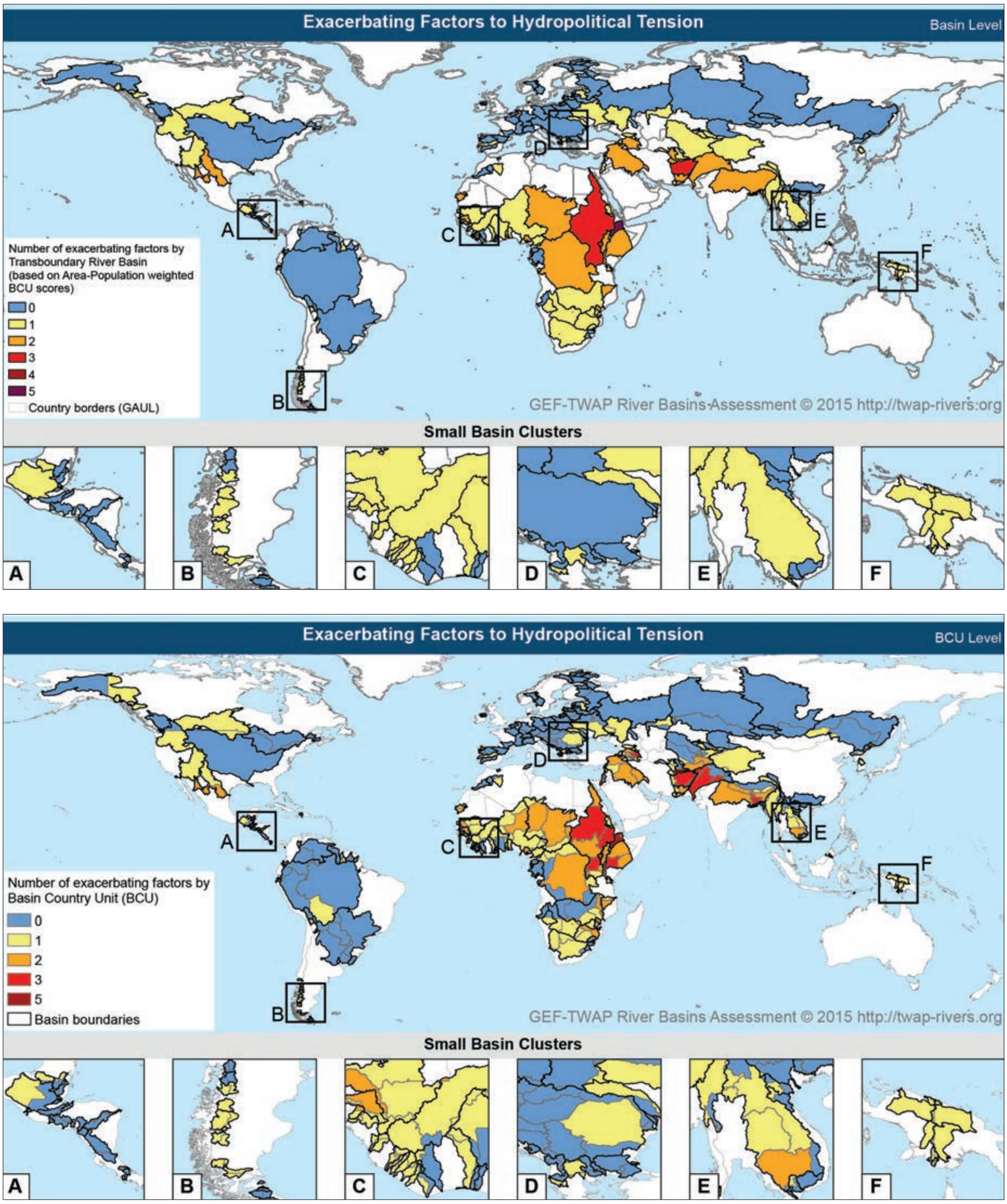
Exacerbating factor →	a	b	c	d	e	f
	Water variability	**Water variability**	**Intrastate conflict**	**Interstate conflict**	**Cooperation / conflict events**	**Development status**
Hazard Score ↓	Projected Coefficient of Variation (CV)	Sen's Slope (2003 – 2013)	Conflict severity value (2009)	Armed Conflict (2000 – 2013)	BAR scale Average (2000 – 2008)	GNI per capita, (2008 – 2012 Avg, current US$)
0	CV: No change (Med or Low) OR decrease	Stable or Positive (>-0.1 to 0.39)	< 3	No occurrence	≥ 0	≥ $1 035
1	CV: High present and future OR increase	Negative (≤-0.1 to -0.94)	≥ 3	Occurrence	< 0	< $1 035
Source	Schewe *et al.* 2014	GRACE satellite	Minorities at Risk database	UCDP/PRIO database	TFDD	World Bank

The resulting six scores were added together to obtain the overall number of exacerbating factors by BCU. The BCU counts were also aggregated by basin using the same procedure as for the baseline indicator.

Results

Out of a possible six exacerbating factors to hydropolitical tension, about 90 BCUs present two, 20 present three, and 1 presents five. Basins and BCUs in Africa, the Middle East, and central and south Asia have the greatest number of exacerbating factors.

Figure 3.60. Exacerbating Factors to Hydropolitical Tension by Basin (top) and BCU (bottom). Basins and BCUs with a high number of exacerbating factors and high hydropolitical tension may be more exposed to risks of conflicts. Exacerbating factors include decreasing water availability and increasing variability, intrastate and interstate conflict, recent history of conflicts over water, and development status. Basin level estimates are based on area-population weighted scores of the respective BCUs



Intrastate conflict, for example causing people to seek refuge in camps like these, is one potential exacerbating factor to hydropolitical tension.

Interpretation of results

In several basins in Central and Eastern Africa, the Middle East, and Central, South and South-East Asia there is a combination of several factors that might exacerbate hydropolitical tensions. In Central and Eastern Africa these are mainly related to low GNI per capita, the presence of armed conflicts, both within and between countries, and high water variability. In the Middle East, exacerbating factors are linked mainly to a history of 'unfriendly' relationships (in general and over water), high water variability and negative trends in water reserves. In Central Asia a combination of low GNI per capita, armed conflicts and variability in water availability could make it more difficult for countries to manage potential tensions associated with new water infrastructure.

Limitations and potential for future development

As with any global indicator, the factors considered to potentially exacerbate the risk of transboundary tensions represent a simplification of the large number of factors that could have an impact on international relationships over water. For example, issues such as water-quality degradation or inter-sectoral conflict between water uses (e.g. hydropower generation vs agriculture) are important factors that contribute to strained transboundary relationships and are outside the scope of this indicator. Moreover, the indicator is based on the assumption that institutional capacity in future will be as it is at present, since there is no way of foreseeing how it will evolve. However, the negotiation and signature of new treaties is often a process that can take several years so it can be assumed that the institutional context will not change drastically over the next 15 years.

The use of global indicators requires global datasets which have a coarser resolution than datasets based on case studies. Results will therefore also have coarser resolution, which may provide global trends but overlook local differences.

For two of the exacerbating factors (risk of internationalization of basins expressed by the presence of minorities involved in armed conflicts, and conflict/cooperation over water) there could be conflict or cooperation that occurred after the last update of the datasets used in the analysis.

Some of the basins/BCUs have a lower level of confidence due to: i) modelling limitations in the calculation of past and projected climate-driven water variability (baseline and projected Coefficient of Variation of annual runoff), since the size of the BCU was too small compared to the resolution of the models used; or ii) lack of data or non-recent data about GNI per capita for some countries. These basins and BCUs are marked as having lower level of confidence in the results sheets downloadable from the TWAP RB data portal.

3.5.4 Enabling Environment

Key findings

1. **One fifth of river basins have low levels of development of enabling environment:** While development of the 'enabling environment' for sustainable water resource management is advancing in its implementation in the majority of basins, around 20% of transboundary basins remain in low stages of implementation and development of crucial policies, plans and instruments for improved management of resources at the country level.
2. **Support for these basins needs to be prioritised:** Continuous support for these basins (and corresponding countries) should be maintained to ensure operationalization of integrated approaches to water resource management and elimination of barriers to implementation of policies and plans. Particular attention should be given to basins where low levels of development of enabling environment coincide with high relative risk across other thematic assessment areas.

Rationale

The two previous governance indicators focus on governance at the transboundary scale. It is, however, also important to look at governance at the national scale for countries within each transboundary basin, given that approaches to resource governance in individual countries have direct implications on a basin level.

This indicator considers the *level of development and implementation of the 'enabling environment'* for water resource management in each riparian country. Enabling environment in this context refers to the national- (or subnational/basin)-level policies, plans, legal and institutional frameworks and management instruments required for effective water resource management, development and use. A well-designed and implemented enabling environment ensures that the framework is in place to facilitate involvement of stakeholders (at all levels – community, national, private sector) in water management, and considers the needs of the different users, including the environment. A lack of appropriate enabling environment, on the other hand, can hamper effective engagement, representation and operation of stakeholders, and thus the functioning of relevant institutions and sustainable management of the resources overall.

This indicator allows identification of basins and BCUs which may be struggling with the implementation of integrated approaches to water resource management at the national level, and may therefore have less capacity to implement the changes required to address transboundary challenges.

Computation

The data used to calculate this indicator are based mainly on a survey undertaken for the 2012 UN Water Status Report on the Application of Integrated Approaches to Water Resources Management (UNEP 2012). The findings of this are based on a global country survey assessing the progress and outcomes of the application of integrated approaches to water resource management.

The full UN-Water (2012) assessment was based on two surveys: a questionnaire-based survey (Level 1) among all UN countries, and an interview-based survey (Level 2) in 30 representative countries[16]. The Level 1 survey collected responses from 133 countries using a comprehensive questionnaire covering aspects of enabling environment relevant to Integrated Water Resources Management (IWRM). The full (multiple choice) questionnaire consisted of more than 100 questions covering all aspects of IWRM implementation, whereby country officials (e.g. ministry representatives) provided a self-assessment of concerns regarding uses of water resources and threats posed by extreme events, the enabling environment, aspects of management and development, and the outcomes of actions taken.

The calculation of the Enabling Environment Indicator (#12) is based on the scoring applied in the original questionnaires (1=not relevant; 2=under development; 3=developed but implementation not yet started; 4=implementation started; 5=implementation advanced; and 6=fully implemented).

For the purposes of the TWAP RB assessment, the 133 country responses from 2012 were supplemented by an additional 15 country questionnaire responses filled by in-country experts, most of which were obtained via the Global Water Partnership (GWP) network.

The country (BCU) scores were aggregated to basin scores using population and area-based weighting of the individual BCU scores. Basins with BCU responses covering more than 80% of the basin (based on area or population) were considered to have sufficient data to generate a representative basin score and corresponding relative risk categories, resulting in indicator score coverage for 230 transboundary river basins.

The Enabling Environment Indicator builds on the following nine question groups which were selected from the original survey, and are thought to most adequately represent relevant aspects of implementation of the enabling environment (numbers in brackets refer to question grouping numbers in the original questionnaire)[17]:

1. Policy, Strategic Planning and Legal Framework

1. **Water resources policy, laws, and plans** (1.1.1): includes state of implementation of policies, laws and IWRM plans at national and sub-national levels.

2. Governance and Institutional Frameworks

2. **Institutional frameworks** (2.1.1): mechanisms (institutions) for management of freshwater resources, including decentralised structures.
3. **Stakeholder participation** (2.1.2): level of access to information and involvement of stakeholders in national- and basin-level planning and management, including civil society, NGOs, the private sector; and gender mainstreaming.
4. **Capacity building** (2.1.3): assessment of capacity needs and programmes to increase capacity at various levels.

16 The purpose of this Level 2 survey was to provide a more detailed in-depth understanding of country situations, by selecting 30 representative countries (i.e. ground-truthing of the Level 1 national official responses). The Regional Water Partnerships of the GWP facilitated the Level 2 survey.

17 Each question group had several sub-questions.

3. Management Instruments

5. **Water resource assessment and development** (3.1.1): basin studies for long term sustainable development of water resources; periodic assessments of water resources; and programmes to evaluate water-related or water-dependent ecosystem services.
6. **Water resource management programmes** (3.1.2): for efficient allocation of water resources among competing users, including the environment; demand management and re-use; to address climate-related natural disasters and climate-change adaptation; and to reverse environmental degradation.
7. **Monitoring and information management** (3.1.3): for different aspects of water quantity and quality; ecosystems; for water use; and forecasting systems.
8. **Knowledge sharing** (3.1.4): programmes for information exchange on good practices within and between countries.
9. **Financing of water resource management** (3.1.5): cost-recovery measures (e.g. progressive tariff structures for all water uses; subsidies for improving water efficiency; charges (e.g. pollution charges).

This indicator is intentionally based on the above broad range of governance issues to give an overall picture of the level of implementation of the 'enabling environment' in each riparian country and subsequently the basin.

Each sub-question received a score based on the 1-6 scale of the original survey responses described above. The sub-question scores were averaged for each question group (equal weights for each sub-question) and the nine question group scores were averaged (equal weights for each question grouping), to give an overall Enabling Environment score for each BCU.

BCUs were then 'weighted' based on the average relative portion of population and area in that BCU compared to the whole basin (establishing the relative 'relevance' of the BCU score for the basin). The weighted BCU scores were added to give a basin score.

Risk categories were assigned based on the thresholds as per Table 3.19.

Table 3.19. Enabling Environment Indicator relative risk category thresholds and interpretation

Relative risk category	Range (basin or BCU scores)	Interpretation of categories (status of enabling environment)
1 - Very Low	5.01 – 6	Highly advanced implementation
2 - Low	4.01 – 5	Advanced implementation
3 - Moderate	3.01 – 4	Some implementation
4 - High	2.71 – 3	Developed but low levels of implementation
5 - Very high	<= 2.7	Under development

Results

A total of 230 basins and 674 BCUs were assigned a relative risk category. An overview of the corresponding levels of development of enabling environment can be seen in Figure 3.61 and Figure 3.62 show the geographic spread of results.

The majority of 'very high relative risk' basins were found in Africa, particularly basins in west-central Africa (Congo/Zaire, Ogooué, Sanaga, as well as a number of smaller basins), with the second largest concentration (by number of basins) in Central America (with a number of smaller basins such as Lempa and Paz). Some 'very high' risk basins are also found in Central and South-east Asia (Ca/Song-Koi, Saigon) and Europe (Vardar, Lake Prespa).

Figure 3.61. Enabling Environment: Relative Risk by Basin (top) and BCU (bottom). Based on country- rather than basin-level governance capacity. Basins and BCUs in relative risk categories 4 and 5 may still be developing, or have not yet started, implementing policies, creating institutions and developing management instruments for effective water resources management. The more pronounced within-basin differences at the BCU level give insight into how national capacity may affect basin-level management.

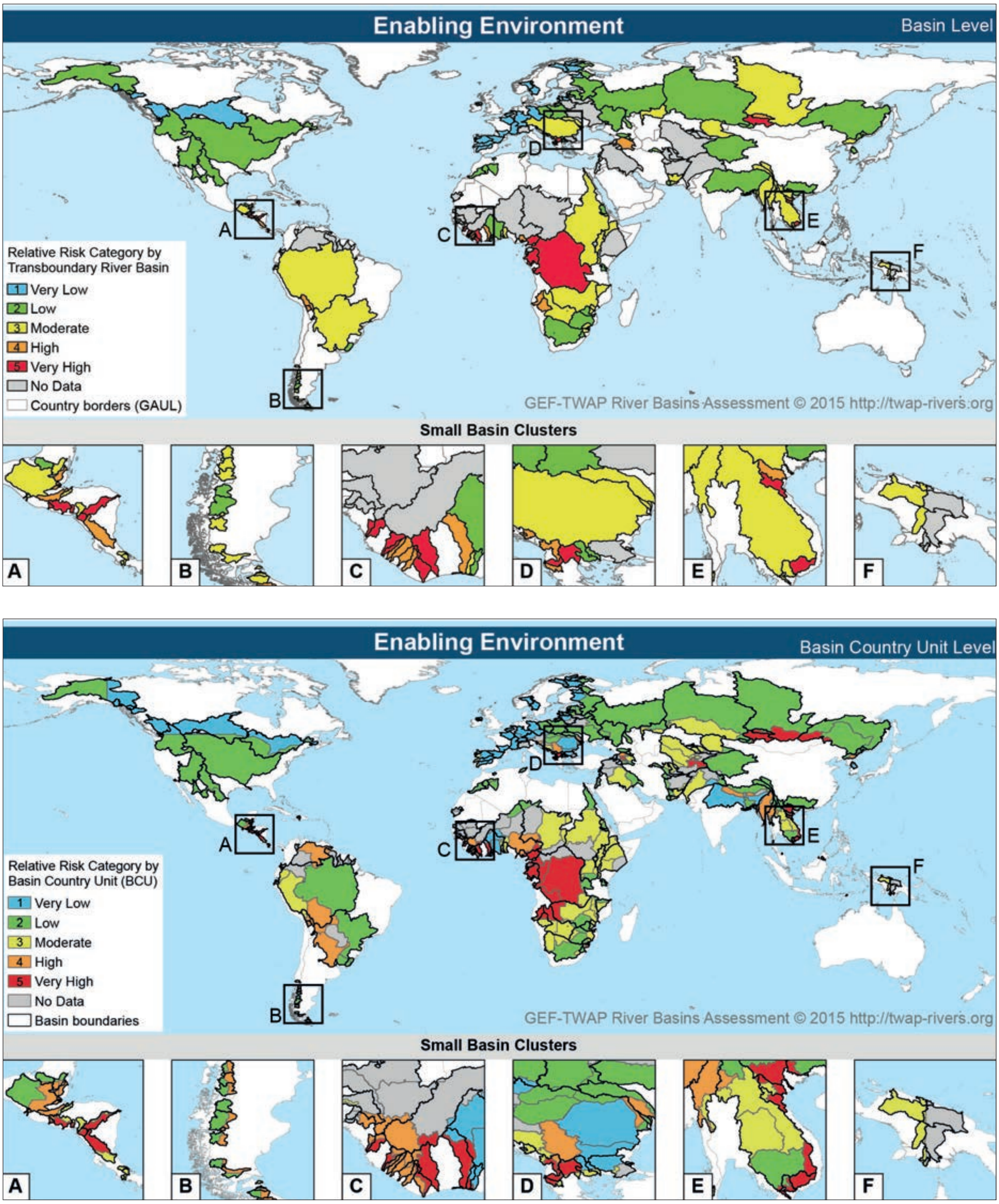
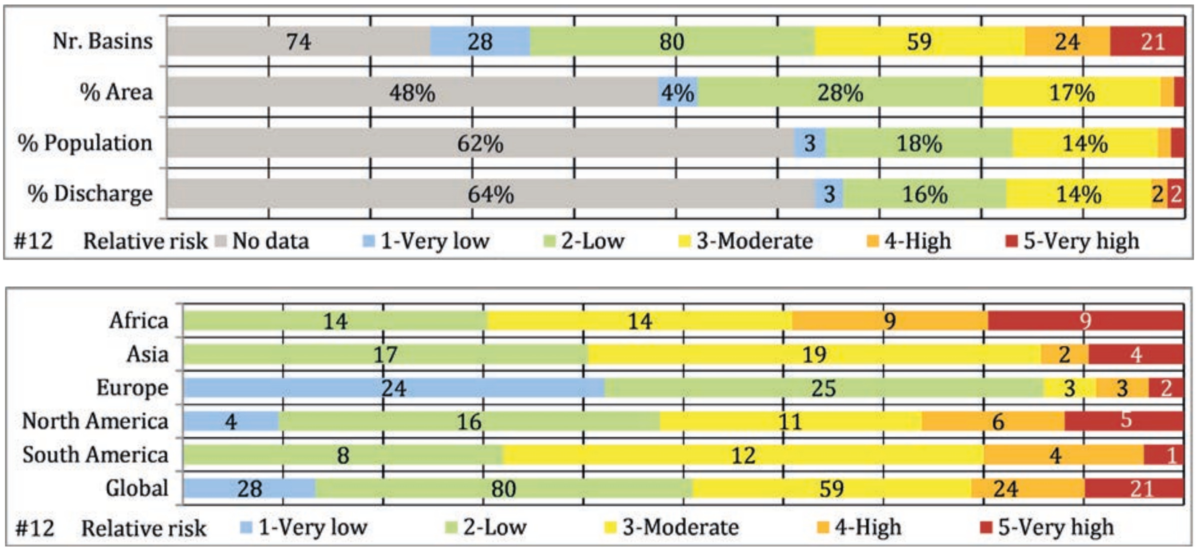


Figure 3.62. Enabling Environment Relative Risk Categories by: number of basins, global TB basin % for area, population and discharge (top); and number of basins by region, 'no data' basins excluded (bottom).



Similar trends in distribution can be seen among basins with 'high' relative risk scores (relative risk category 4). Most of these are in Africa and in Central and South America, with a few in Europe and Asia. The largest basins belonging to the 'high' relative risk include Kura-Araks in the South Caucasus and Cross River in West Africa.

Most basins globally appear to be in the intermediate phases of implementation of enabling environment for water resources (relative risk categories 2 and 3). These include some of the world's most populous basins, in particular the Ganges-Brahmaputra-Meghna, Nile, La Plata, Danube and Mississippi. The distribution is balanced overall across regions.

Nearly all the lowest relative risk basins (category 1), with advanced implementation of enabling environment, are in Europe, with 4 in North America.

Interpretation of results

The relative risk categorization approach for this indicator is based mainly on the underlying meaning of the original survey scores (see Computation section above).

Relative risk categories 4 and 5 represent basins and BCUs where the majority of the aspects of the enabling environment for IWRM are still under development, and levels of implementation are low. The lack of implementation may indicate a need for additional efforts to address barriers that prevent further implementation. Relative risk category 3 represents enabling environments, where the overall policies and plans have been developed, and some implementation has begun. The relative risk categories 1 and 2 represent basins and BCUs with advanced state of development of enabling environment, with implementation advanced or fully completed. These basins are generally considered to be better placed to tackle pressures on populations and ecosystems, because of the presence of appropriate policies, plans and regulations.

The results point to a generally lower relative risk amongst basins including high Human Development Index (HDI) countries, pointing to the need for more targeted support to countries with a low HDI, where the general national capacity may be lacking, also affecting the possibilities for creating basin-level frameworks and management instruments.

Perhaps more revealing than the basin averages are the differences between the BCU scores within basins. A map of relative risk categories by BCU is shown in Figure 3.61. High discrepancies in status of development of enabling environment may have consequences for basin-level management. For example, the Congo/Zaire includes countries with individual BCU relative risk categories ranging from 2 to 5. In the Danube, the range covers the full spectrum: 1 to 5. Similar internal discrepancies can be seen in other basins, e.g. Ganges and Mekong. Viewed in the context of basin-wide water quality/quality and ecosystem indicators, these differences may provide the basis for an interesting analysis of the importance of basin-level governance and management to enable better management of risks to people and ecosystems.

Limitations and potential for future development

The indicator is based on about 60 sub-questions from the original survey questionnaire. This breadth of questions is seen as a strength, making it a more robust assessment (compared, for example, to merely looking at the existence of policies, laws and plans). However, averaging 60 sub-questions makes it difficult to know which 'aspects' of the enabling environment are more or less developed in each country (or which are more relevant than others), and therefore which may require further development. This information is available, should a more detailed analysis be required.

For the purposes of the TWAP RB assessment, the nine sub-question groups from the survey are averaged and weighted equally to create a single BCU score, as all aspects are deemed equally relevant to achieving full implementation of the 'enabling environment'. Any potential weighting of the question groups would depend on the priorities of the country. A rough sensitivity analysis was undertaken to understand the variability in scores between the nine metrics for each basin. A significant number of basins displayed scores in three different categories when considering the nine sub-question groups individually. This would indicate that weighting the metrics in different ways could have an impact on the overall category for that BCU and therefore on basin-level scores. Investigating the implications of this may be considered as part of future development of the assessment.

While the gender is considered in one of the original survey questions, the significance of gender in capacity development and the enabling environment has not been considered in this analysis. The importance of considering gender in transboundary water management has been highlighted by Earle and Bazilli (2013), yet there are very few examples of strategies to mainstream gender in water resources development at the transboundary scale, such as in the Lower Mekong Basin (MRC 2013). This is an area that may be explored further in future assessments, not just for this indicator, but also more broadly.

Although the questionnaire answers were provided by government representatives and regional experts, the data contains a certain level of 'subjectivity', as it is part of a qualitative assessment, where the possibility of bias in the answers cannot be ruled out. However, this element of subjectivity was partially addressed through more detailed 'ground-truthing' of the results through broad-based stakeholder interviews in 30 countries (more on this in UNEP 2012).

3.5.5 Governance Thematic Group Summary

The key findings for the thematic group are given in the introduction to section 3.5. The three indicators assessed in this group are:

1. Legal Framework;
2. Hydropolitical Tension;
3. Enabling Environment.

Overall, the three indicators are designed to be complementary by looking at transboundary water governance from different perspectives. Consequently, the indicator results show quite different spatial patterns. In order to present an overall picture of governance, we have produced a governance index based on the maximum relative risk category of the three indicators. The rationale for this is that the governance capacity of the basin may be compromised by high risk in any one of the three indicators. The combined 'governance index' map highlights the hotspots of this thematic group (Figure 3.63). While this is a simplified way of viewing the three governance indicators together, and should not be seen as a definitive representation of the governance situation in any single basin, it does provide a quick global overview of geographic spread and potential basins that would benefit from further governance analysis. Figure 3.63 Governance 'Index', based on the maximum relative risk category of the Legal Framework, Hydropolitical Tension and Enabling Environment Indicators. This simplified way of viewing the three governance indicators gives a quick global overview of the basins that may benefit from further governance analysis.

Figure 3.63. is presented for illustration purposes, and it must be remembered that indicators in this thematic group look at governance issues from different perspectives. Thus it is no surprise that overall their values have a relatively low statistical correlation (section 4.1). Nevertheless it is interesting to observe their pair-wise correlations, considering BCU results (Figure 3.64 to Figure 3.66). A BCU analysis has been chosen here as it sheds more light on the within-basin differences, and recognizes that transboundary governance capacity is often dependent on national governance capacity.

Figure 3.63. Governance 'Index', based on the maximum relative risk category of the Legal Framework, Hydropolitical Tension and Enabling Environment Indicators. This simplified way of reviewing the three governance indicators gives a quick global overview of the basins that may benefit from further governance analysis.

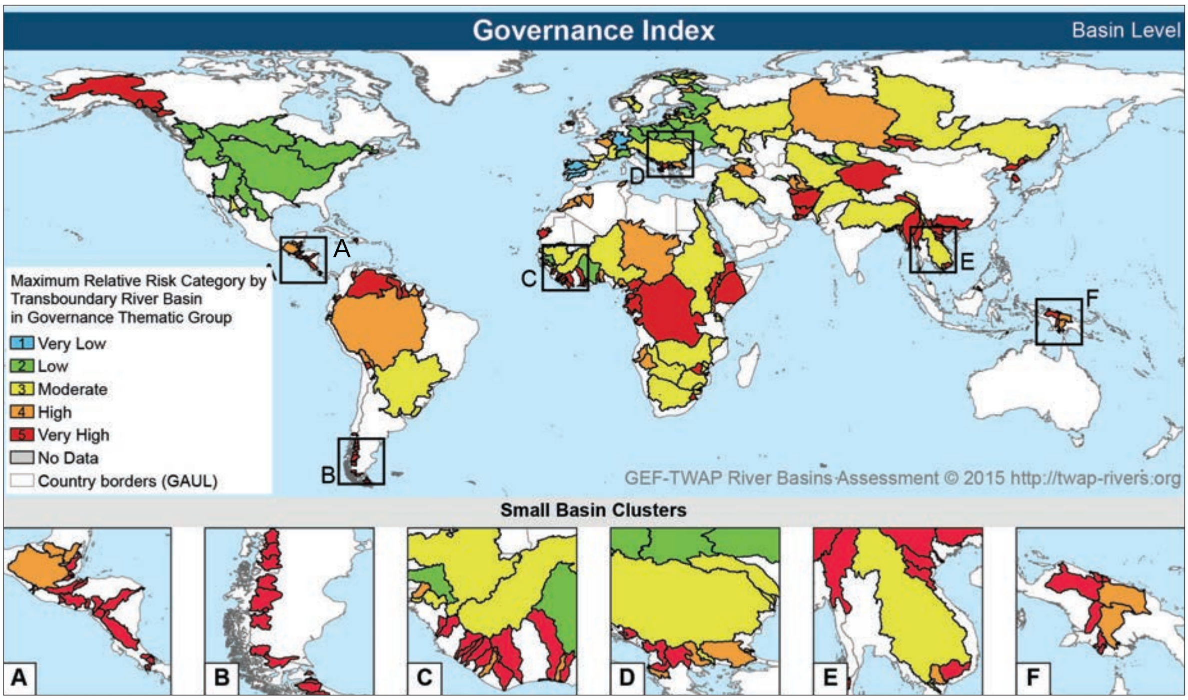
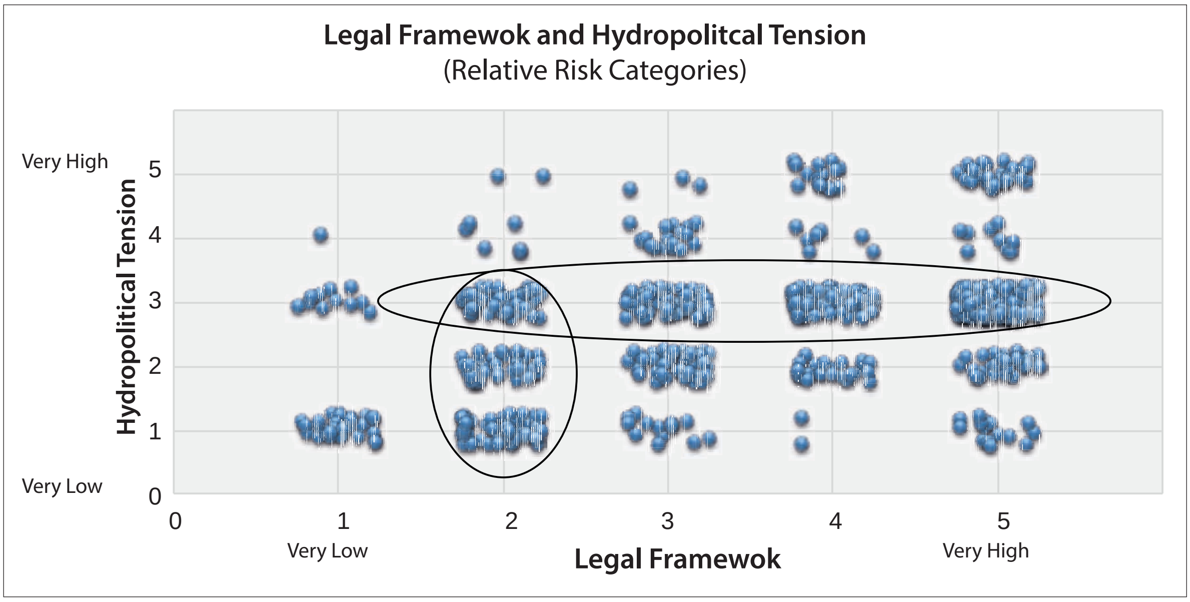


Figure 3.64. Legal Framework and Hydropolitical Tension – Pair-wise Results Correlations. There is a group of basins in the vertical ellipse that have institutional instruments to mitigate potential tensions from new infrastructure and which have treaties that reflect modern principles of international water law. There is a group of basins in the horizontal ellipse that may have mechanisms to deal with hydropolitical tension even if the treaties do not explicitly cover many of the principles of international water law.



When considering BCU values for Legal Framework (#10) and Hydropolitical Tension (#11) indicators, it can be seen that the majority of the BCUs are located in two clusters: one with low (relative) risk associated with the Legal Framework and very low to moderate risk associated with Hydropolitical Tension (vertical ellipse in figure below), and another including BCUs with few or no key principles of international law in their transboundary agreements and intermediate risk of hydropolitical tensions (horizontal ellipse in figure below)[18]. The first cluster suggests that many of the BCUs that have institutional instruments to mitigate potential tensions from new infrastructure have treaties that reflect modern principles of international water law. This trend is reasonable and expected as the design of both indicators, even if looking at different dimensions of international cooperation, assess the presence of comprehensive treaties. The second cluster, in contrast, suggests that, when focussing only on the construction of new infrastructure as a cause of tension among riparians, BCUs can have specific formal mechanisms to deal with that tension even if their treaties do not explicitly cover some of the principles of international law. It should be noted that the presence of a BCU in that cluster can also be due to the fact that currently in the BCU there is no planned infrastructure that could directly or indirectly affect transboundary relationships in the basin (but there is low capacity to deal with it if it occurs in the future).

One important consideration is the role of the private sector in transboundary water resources development and governance, particularly in the construction of large water infrastructure, as considered by the Hydropolitical Tension Indicator. Public-Private Partnerships are often a crucial factor in dam building. While the private sector was not included in this assessment, is should be considered in future assessments of transboundary governance.

The Legal Framework (#10) and Enabling Environment (#12) indicators have most of the BCUs concentrated in relative risk categories 5 and 2, respectively (Figure 3.65). BCUs with high risk (5) in indicator #10 are distributed along the values 2-5 of indicator #12, suggesting that the adoption of principles of international water law in transboundary treaties and the application of Integrated Water Resources Management (IWRM) principles in domestic water management are poorly correlated. This is interesting because both processes derive from the same international reform movement

18 To improve the visualization of the results, scores in the scatter plots have been randomly jittered around their original value.

Figure 3.65. Legal Framework and Enabling Environment – Pair-wise Results Correlations. The enabling environment at the country level is often more advanced than the legal framework at the basin level, even though both processes had the same origins in the 1990s. This shows the challenges of transboundary river basin management.

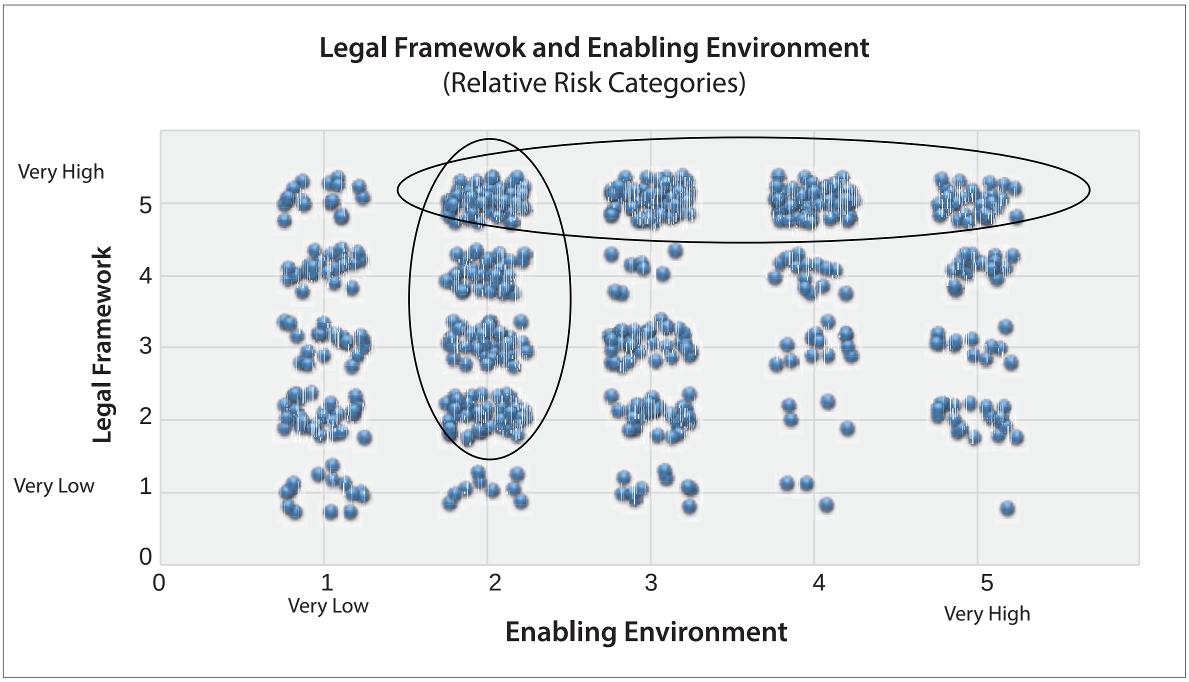
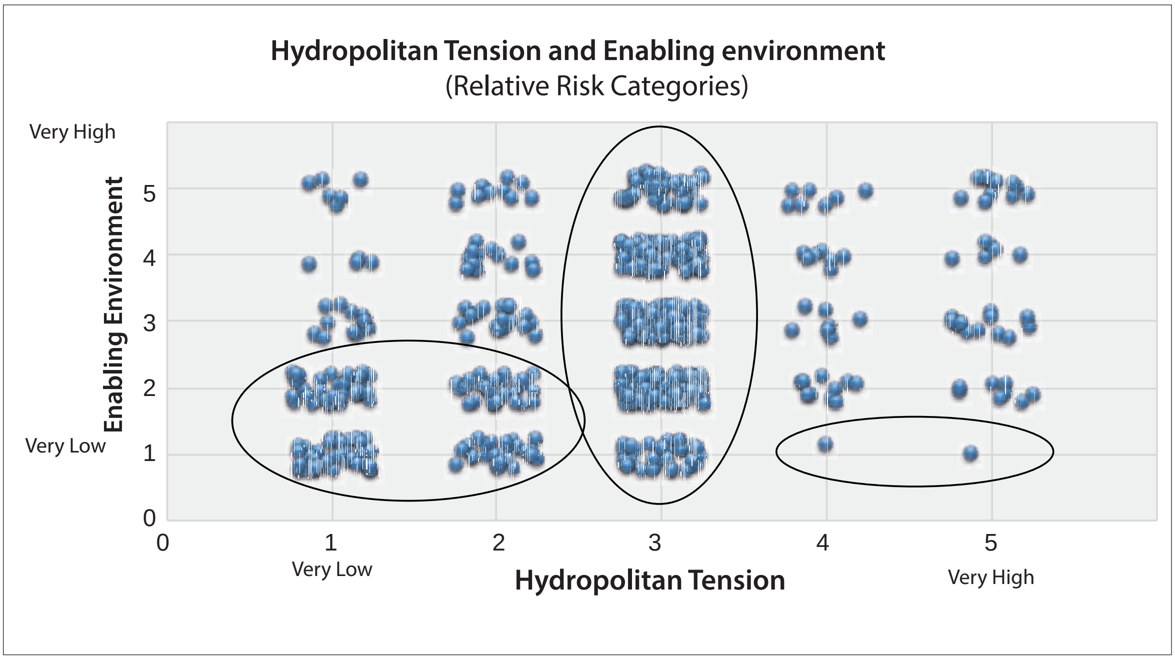


Figure 3.66. Hydropolitical Tension and Enabling Environment – Pair-wise Results Correlations. The development of transboundary institutional capacity and the application of integrated approaches to domestic water management appear to still be in progress in most of the BCUs.



originating in the 1990s and defining 'internationally acknowledged' principles that have crystallized in the IWRM paradigm and in the development of international conventions for the protection of transboundary watercourses. Thus, trends in the data for these two indicators seem to confirm that domestic institutional structures have been faster in adapting to these principles (dominance of '2' values) while transboundary governance principles have a stronger inertia (dominance of '5' values), possibly associated with the higher transaction costs of the renegotiation of a transboundary treaty relative to those of domestic water reform.

Figure 3.66 shows that most of the intermediate (relative risk category 3) values of hydropolitical tension are distributed in the intermediate categories (categories 2-4) of enabling environment, suggesting that the development of transboundary institutional capacity and the application of integrated approaches to domestic water management are still in progress in most of the BCUs. Moreover, there is a good correspondence between BCUs having low risk from lack of domestic enabling environment and low risk from transboundary tensions, while it is uncommon to have high risk of hydropolitical tension in BCUs with low risk associated with the domestic enabling environment.

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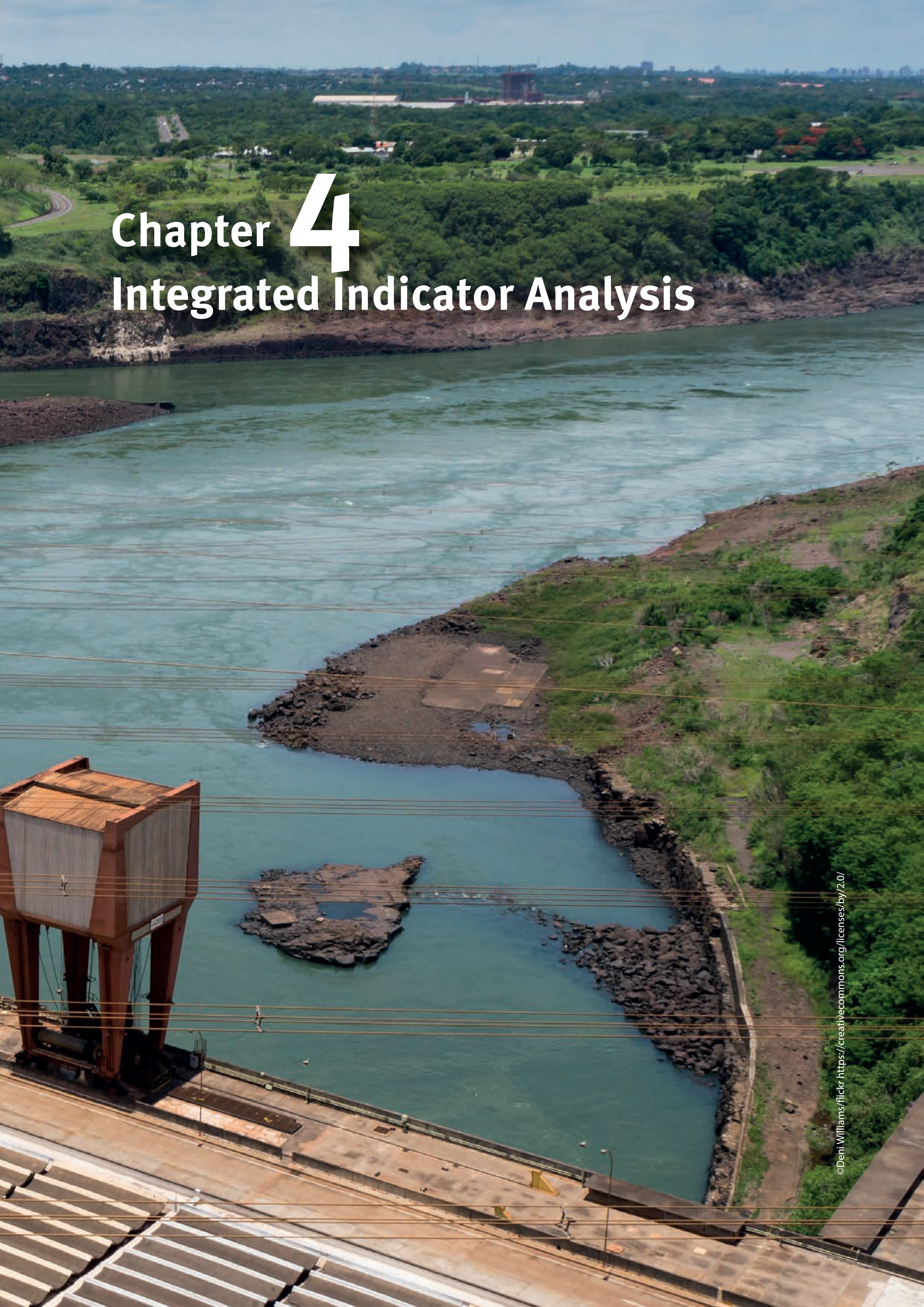
Chapter 4
Integrated Indicator Analysis



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Integrated Indicator Analysis

The previous chapter explored the results of the individual indicator assessments, covering a total of 15 indicators and their respective sub-indicators within 5 thematic groups. While the individual indicator assessment results are important for identifying basins at risk for the selected range of issues, it is also important to view the TWAP River Basins (RB) assessment in its entirety, acknowledging the fact that on the ground, the indicators represent interlinked issues. Thus the results should be seen in the context of all indicators and any on-ground action needs to be rooted in integrated river basin management with a focus on transboundary issues.

The aim of this integrated analysis is to explore the relationships between the indicators and river basins included in the TWAP RB component. In addition to summarizing the patterns among the indicators, a goal is to identify groups of basins with similar risk profiles.

There is no single optimal solution for analysing the full suite of indicators in an integrated fashion. Indeed, the design of the indicator-based analysis for an individual basin, or a group of basins, is likely to vary, depending on the interests of the user. The integrated indicator analysis of this report is therefore guided by a number of questions that may help the user to understand the results from different perspectives.

Defining a single composite score that integrates the data from a large number of indicators is often conceptually appealing; however, it can mask some of the nuances that exist in datasets such as those assembled in this analysis. Furthermore, weighting of indicators is likely to be highly dependent on the priorities of the users. For this reason, users are able to create their own indices from any combination of indicators, assigning their own weights for each indicator, using the TWAP RB data portal (twap-rivers.org/indicators).

A statistical analysis may not have the conceptual appeal of a single integrated score, but it can help elucidate interesting patterns in the dataset and provide a more rounded analysis of the basins and the indicators themselves. The types of statistical analysis and combinations of indicators presented in this chapter represent only one set of possible analyses. The options for statistical analysis and combining indicators are almost infinite, and users may download results via the data portal to undertake their own analyses.

The questions that we aim to answer in this integrated analysis include:

1. How are the individual indicators related? (section 4.1).
2. Can we classify basins with similar 'risk' profiles? (section 4.2).
3. What can we infer about the transboundary nature of the identified risks, including BCU-to-BCU and upstream-downstream relations? (section 4.3).
4. What can we say about how risks are likely to change in the future? (section 4.4).
5. Can we identify any success stories, and if so, are there any typical characteristics of such basins? (section 4.5).

To help answer these questions, a number of different analytical methods are used to provide a holistic overview of the results. These mainly include a correlation analysis, principal component analysis (PCA) and cluster analysis (see technical Annex VII for methodology and the full results of the statistical analysis). Only the 156 basins with a full set of results for each indicator were included in this analysis. These basins cover about 80% of the total area and population of all 286 transboundary river basins.

4.1 How are the indicators related?

The individual indicators of the TWAP RB assessment highlight a number of issues relevant for transboundary river basins, including water stress, pollution, ecosystem health, governance, and socioeconomics. In reality, these are rarely stand-alone problems and often represent consequences of a wider range of issues within a basin. This section therefore looks at how the individual indicators (and the issues they represent) are related statistically.

The first step was to quantify the linear correlations between all pairs of indicators and sub-indicators in the RB assessment. The next was to undertake a Principal Component Analysis (PCA), which is a multivariate technique used to reduce a large number of variables (indicators) to a more manageable set of 'principal components' which explain the dominant gradients of variation among the indicators (explained in more detail below).

For the correlation analysis, we used Pearson's correlation coefficient, denoted by r, which has a scale of -1 to 1. Two indicators with a correlation coefficient of -1 are perfectly negatively correlated with each other (meaning a high value in one indicator is always associated with a low value in the other), a coefficient of 1 indicates perfect positive correlation and a coefficient of 0 indicates the two indicators are completely uncorrelated.

Includes the correlation matrix for all indicators, and for ease of interpretation only pairs of indicators with statistically significant correlations are shown. Tests of statistical significance in the correlation analyses assess the likelihood of obtaining the observed the data, if there were no relationship between each pair of variables. This is a function of the strength of the relationship and the number of observations (basins) in the analysis. Here, we report the correlations where this likelihood is less than 5% and 10% (commonly referred to as α=0.05 and 0.1), with the latter shown in italics. Indicators with correlations above 0.5 are also shown in bold.

The clearest patterns that emerge from the correlation matrix appear between the wastewater pollution, governance and societal wellbeing indicators, and between the water stress-related indicators. There is a high positive correlation between the Wastewater Pollution (#5) and Enabling Environment (#12) indicators, but also a reasonably strong correlation with the other governance indicators and the socioeconomics indicators. This suggests that basins in regions that lack strong governance are associated with potential risks from wastewater pollution. These are generally low-income countries. In addition, high risk of wastewater pollution is associated with low risks to ecosystems from dams and threats to fish. This suggests that regions able to control risks from wastewater pollution may also have more developed water infrastructure in general, including dams which increase risks to ecosystems. Among the indicators that are related to water availability, there is a strong positive correlation between Environmental Water Stress (#1), Agricultural Water Stress (#3) and Exposure to Drought (#15b), which is a measure of inter-annual variability of flows.[19] This would imply that significant variations from natural flow regimes (#1) in a basin may often be related to irrigation requirements (#3) and that dams have been constructed to deal with high inter-annual variability of flows.

Interestingly, all of the governance indicators are negatively correlated with risks of ecosystem impacts from dams and threats to fish, albeit weakly in some cases, suggesting that basins with high dam density (typically developed over several decades) also generally have governance in place to address transboundary consequences. This may not be the case for more recently constructed dams or those that are under construction or planned. Equally, there are negative correlations between these two ecosystem indicators and the societal wellbeing indicators. These patterns suggest that high risks to ecosystems are generally associated with high levels of societal wellbeing. This would imply that basins which have been developed to support high levels of societal wellbeing may have done so at the expense of the environment.

19 Note that these three indicators were developed using similar parameters and using the WaterGAP model data. This may partly explain the strength of the correlation.

Table 4.1. Correlation Matrix for all indicators and some sub-indicators. Only those relationships that were statistically significant at the 0.05 and 0.1 level are shown.

Indicators	1	2a	2b	3	4	5	6	7	8	9	10	11	12	13	14abcd	14e	15a	15b
Water Quantity																		
1. Environmental water stress																		
2a. Human water stress A																		
2b. Human water stress B	0.35																	
3. Agricultural water stress	**0.71**		0.31															
Water Quality																		
4. Nutrient pollution	0.21			0.23														
5. Wastewater pollution		0.17			-0.12													
Ecosystems																		
6. Wetland disconnectivity						0.22												
7. Ecosystem impacts from dams	0.34			0.23	*0.13*	-0.41	-0.18											
8. Threat to fish		0.18		0.14	0.37	-0.26		0.24										
9. Extinction risk	0.12			0.11				0.16	0.24									
Governance																		
10. Legal framework	-0.18	-0.13		-0.11		0.28	*0.12*	-0.44	-0.27	-0.21								
11. Hydropolitical tension		0.20				0.44		-0.16		0.22	0.47							
12. Enabling environment	-0.11	0.14			-0.14	**0.81**	0.21	-0.39	-0.18		0.32	0.43						
Socioeconomics																		
13. Economic dependence on water resources	0.13	0.12		0.11				0.39	0.24	0.29	-0.30							
14abcd. Societal wellbeing		0.13				**0.63**	0.21	-0.29	-0.19	*-0.12*	0.19	0.25	**0.58**					
14e. Income inequality						0.24			-0.22				0.20	-0.12	0.13			
15a. Exposure to flood						0.16	0.15		0.27			0.13		0.12				
15b. Exposure to drought	**0.61**		0.28	0.43				0.18	-0.13		-0.18			0.12	0.21	0.13		

Only pairs of indicators with statistically significant correlations are shown. Correlations with an absolute value > 0.5 are shown in bold.

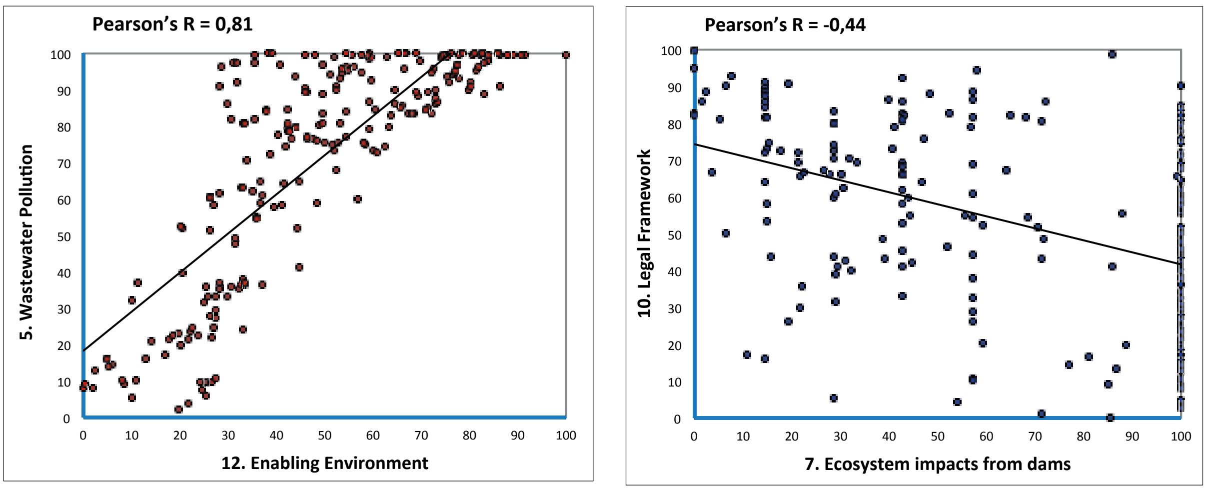
Figure 4.1 shows two visual representations of indicator correlations. Figure 4.1 a represents highly positively correlated indicators – Wastewater Pollution (#5) and Enabling Environment (#12). Positive correlation here implies that where there is high risk related to lack of enabling environment, the risk from untreated wastewater is also likely to be high. Figure 4.1 b shows moderately negatively correlated indicators – Legal Framework (#10) and Ecosystem Impacts from Dams (#7). Negative correlation here implies that in basins where there is higher risk from ecosystem impacts from dams, the risk related to weak legal frameworks is lower. This may imply a stronger incentive for strong legal frameworks in basins where there are high risks associated with dam operation, although correlation analysis alone does not assess the causality of data. There are many other factors that may affect the correlation (for example, basins that are of high economic significance may be more likely to recognize the need for appropriate legal frameworks).

Another way of looking at the relationships between the indicators is by using multivariate techniques like Principal Component Analysis (PCA) (Annex VII). The use of PCA can help understand the correlations between a large number of indicators by reducing the dimensionality of the data to a smaller set of components that summarize the correlation structure between the variables. For example, if we plot three indicators simultaneously in a three-dimensional cube, PCA identifies the axes (principal components) that account for the largest amount of variation in the data that are also uncorrelated from each other. Thus, the first principal component (PC) describes the strongest 'correlation' and is conceptually like a line of best fit that accounts for the greatest variance in the multidimensional data. The second PC explains the next largest amount of variation, while also being uncorrelated to PC1. There are as many PCs as variables (or indicators) in the analysis with each PC accounting for successively smaller amounts of variation in the data. Since each successive PC explains less of the total variation in the data, much of the meaningful variation in the data cloud can be captured by the first few PCs.

Because the PCs are uncorrelated, the scores for each basin associated with each PC encapsulate a unique aspect of the socio-ecological system (and relative risk factors) represented by the original set of indicators. Here we select six PCs which explain almost 70% of the variations in the dataset.

In addition to scores for each basin, the PCA captures factor loadings for each PC, which can be interpreted as the correlation coefficient between the indicator/sub-indicator and the overall PC, with higher absolute values implying

Figure 4.1. Examples of a) Highly positive correlation b) Moderately negative correlation.



a larger contribution to the overall PC. The factor loadings for the first six PCs are shown in Table 4.2. Indicators for which factor loadings are >0.3 (positive correlation) or < -0.3 (negative correlation) are coloured brown and blue, respectively.

Table 4.2. Factor Loadings by Principal Component (interpreted as the relative correlation between the indicator and the Principal Component)

Indicators	PC1	PC2	PC3	PC4	PC5	PC6
Water Quantity						
1. Environmental water stress	-0.193	0.465	-0.056	0.066	-0.028	0.126
2a. Human water stress A	-0.056	0.137	0.275	-0.292	0.271	0.195
2b. Human water stress B	-0.125	0.371	0.043	0.316	-0.091	-0.109
3. Agricultural water stress	-0.18	0.472	0.031	0.267	-0.137	0.026
Water Quality						
4. Nutrient pollution	-0.221	-0.161	0.347	0.119	0.283	0.232
5. Wastewater pollution	0.42	0.223	0.125	-0.056	-0.026	-0.01
Ecosystems						
6. Wetland disconnectivity	0.09	0.085	0.254	-0.043	0.403	-0.443
7. Ecosystem impacts from dams	-0.349	0.082	0.125	-0.198	0.259	0.149
8. Threat to fish	-0.212	-0.056	0.37	0.094	-0.143	-0.295
9. Extinction risk	-0.057	0.03	0.259	-0.285	-0.684	-0.047
Governance						
10. Legal framework	0.320	-0.027	0.138	0.412	0.057	0.242
11. Hydropolitical tension	0.268	0.076	0.331	0.145	-0.153	0.364
12. Enabling environment	0.407	0.143	0.101	-0.12	-0.042	-0.027
Socioeconomics						
13. Economic dependence on water resources	-0.1	0.06	0.352	-0.441	-0.078	0.159
14abcd. Societal wellbeing	0.372	0.155	0.058	-0.186	0.198	0.049
14e. Income inequality	0.118	0.179	-0.229	-0.309	0.003	-0.355
15a. Exposure to floods	0.024	0.026	0.399	0.226	0.049	-0.47
15b. Exposure to droughts	-0.07	0.474	-0.145	-0.099	0.157	0.072

The maps in Figure 4.2 to Figure 4.4 are a spatial representation of the scores of each basin on the first three principal components. Basins with highly positive values (shown in brown-red colours on the maps) represent higher scores for each component, which indicates higher risk for the factors coloured brown in Table 4.2. Basins with highly negative values (shown in green-blue on the maps) represent lower scores for each component, which indicates higher risk for the factors coloured blue in Table 4.2. Comparing the maps with the loadings in Table 4.2 indicates the spatial distribution of key risk factors.

The first Principal Component (PC) can be interpreted as an axis that discriminates between basins based on governance (#10-12), Societal Wellbeing (#14), Wastewater Pollution (#5) and Ecosystem Impacts from Dams (#7) (see factor loadings for PC 1 in Table 4.2). These are very probably related to levels of economic development, although economic development per se is not an indicator in this analysis, but rather can be estimated from the above-mentioned indicators. The component has positive loadings for Wastewater Pollution (#5), Enabling Environment (#12) (and to a lesser degree Legal Framework (#10)), and Societal Wellbeing (#14), and negative loadings for the

Ecosystem Impacts from Dams (#7). This is consistent with the strongest correlations seen in. Basins that have high positive values for this PC tend to have higher risks associated with wastewater pollution, inadequate governance and low levels of societal wellbeing. Notable examples include several basins in Central and West Africa and, to some extent, the Amazon and some Central American basins. At the other end of the component, basins that have high negative values for this PC tend to have lower risks of Wastewater Pollution (#5), governance (#10-12) and socio-economics (#13-15), but higher risks of Ecosystem Impacts from Dams (#7) (see the negative factor loading for PC 1 for this ecosystem indicator in Table 4.2). Notable examples at this end include several basins in Europe and North America.

The second principal component can be interpreted as an axis of variation which is defined by Environmental, Human and Agricultural Water Stress (#1-3), and Exposure to Drought (#15b) (see factor loadings for PC 2 in Table 4.2). Again, this is consistent with the second-strongest group of correlations in the correlation matrix. Basins with high positive scores for this PC tend to be those in drier regions with highly variable flows and high water stress, including basins in the US-Mexico border regions and parts of Africa and central Asia. Basins with high negative scores for this PC tend to be those in wetter regions with more predictable flows and include basins in far north America and Europe.

Principal Component 3 can be interpreted as an axis of broad risk across each of the thematic groups. Indicators with high positive factor loadings come from each thematic group and include Nutrient Pollution (#4), Threat to Fish (#8), Hydropolitical Tension (#11), Economic Dependence on Water (#13), Exposure to Floods (#15a) and Human Water Stress (#2) (Table 4.2). Basins with high scores for this PC include basins with large deltas and associated low-lying coastal wetlands, such as the Danube, Nile, Ganges and Mekong Rivers, with the last two also having high economic dependence on water resources coupled with hydropolitical tensions. Most of the at-risk basins for this PC are those where economic dependence on water is high yet basin development may still be ongoing, leading to greater pressures and impacts from upstream users, which may be leading to the increased risk of hydropolitical tension.

Figure 4.2. Principal Component 1: High Risk of Wastewater Pollution and Poor Enabling Environment.

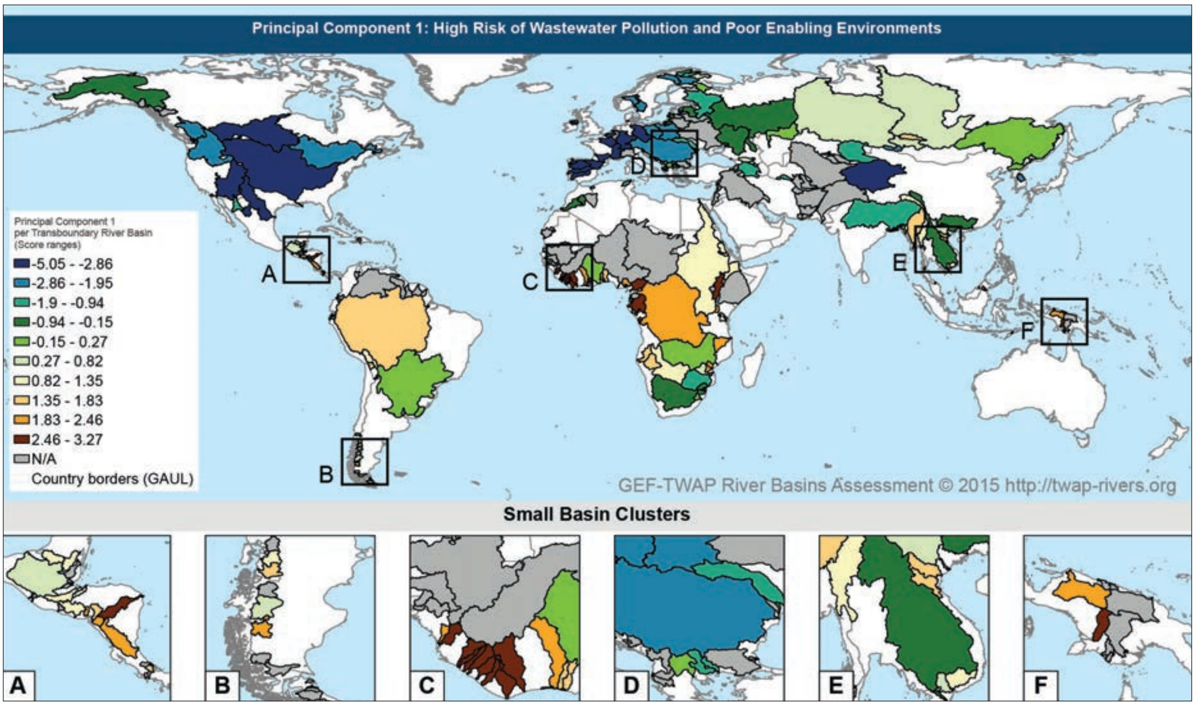


Figure 4.3. Principal Component 2: High Risk for Agriculture Water Stress, Exposure to Drought, Environmental Water Stress and Human Water Stress.

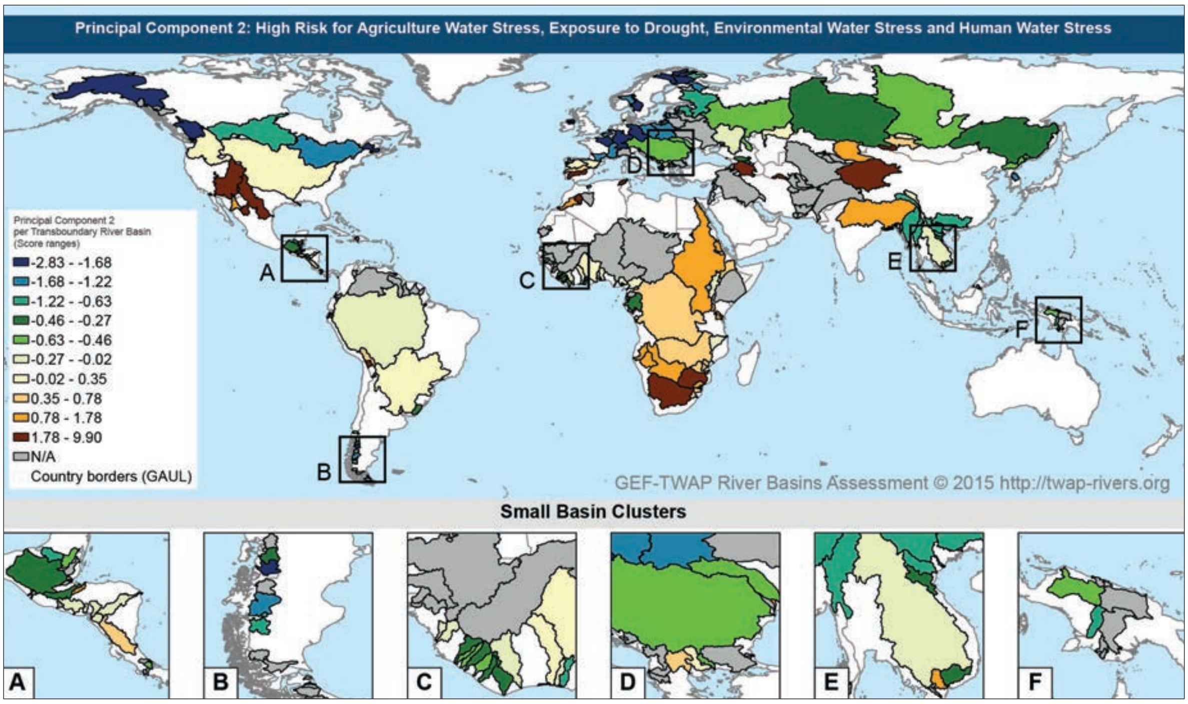
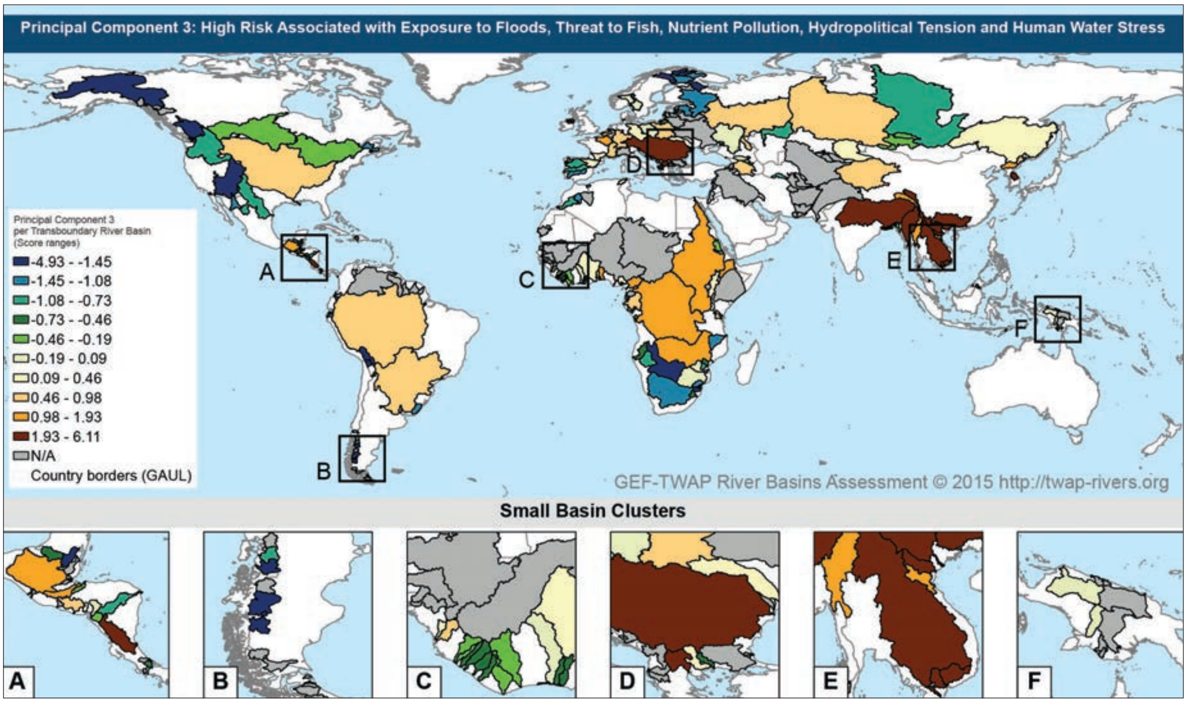


Figure 4.4. Principal Component 3: High Risk Associated with Exposure to Floods, Threat to Fish, Nutrient Pollution, Hydropolitical Tension and Human Water Stress.



The relationships described by PCs 4-6 are not as strong as the first three PCs since they explain a relatively small amount of variation in the data. More caution should therefore be used in the interpretation of these PCs. The maps and possible interpretations of PCs 4-6 can be found in Annex VII.

In summary, the results of the correlation analysis and the PCA identified broad patterns of risk that cut across geography, economic development and hydrology. The two complementary analyses integrate information from all of the indicators to provide a concise summary of the dominant gradients of transboundary risk. This helps to identify broad similarities of risk that exist between rivers in different parts of the globe, due to common causes. For example, the second principal component identifies some common characteristics of basins in North America, Southern Africa and Central Asia. An important point is that many basins in Africa show high positive scores on the first three principal components which suggests that there are few indicators for which these basins are considered low risk.

Despite the value of these results, there are several limitations to be considered when interpreting them. The first is the assumption of linearity in all of the results. The correlation analysis assesses linear relationships between two variables only. The implication of this is that two indicators which are strongly related in a non-linear manner (e.g. exponential or a power relationship), will have a low correlation coefficient despite possibly being very closely related. The same assumption applies in PCA, where the gradients defined by the principal components are linear. In addition to this, these methods require a complete dataset, which means that any basins with missing values, for even a single indicator, must be excluded from the analysis.

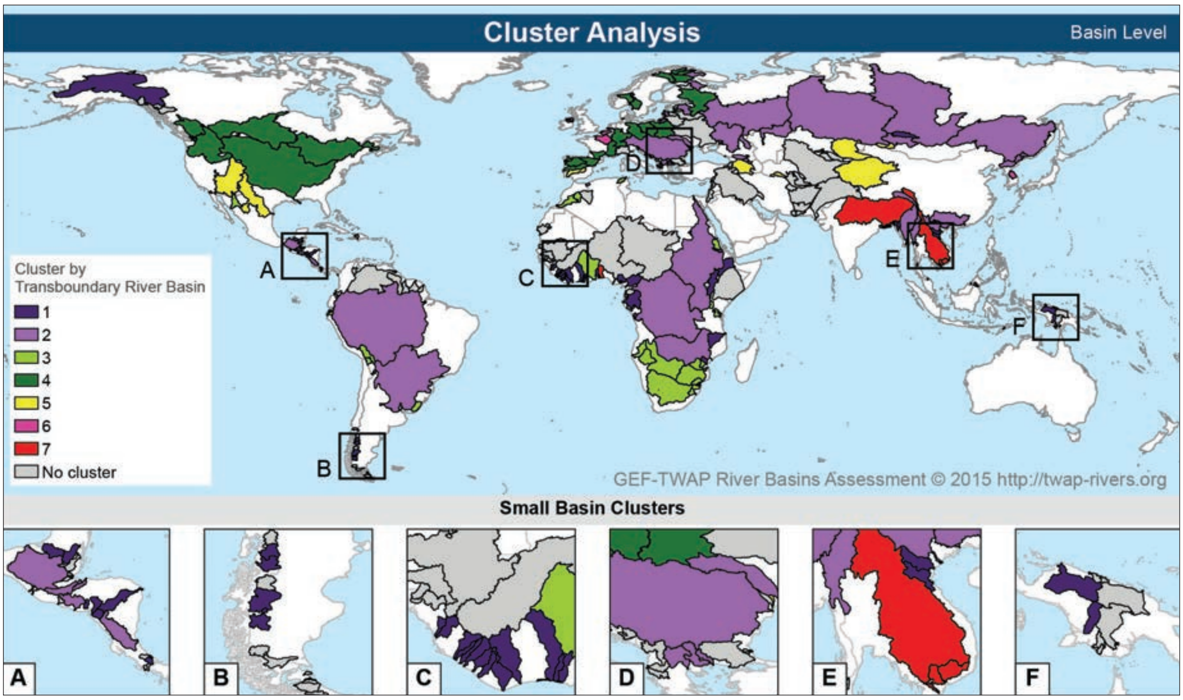
4.2 Can we classify basins with similar risk profiles?

Key findings

1. **Cluster group 1: Undeveloped basins with low pressures on water resources:** 45 basins (with a population of about 89 million) that have generally low risk across most indicators. These tend to be either small basins in various parts of Africa, presumably with little water resource development so far, or isolated basins in temperate and polar regions, presumably with low pressures on their water resources. This group represents basins that are largely undeveloped and may offer opportunities for sustainable development.
2. **Cluster group 2: Inadequate governance, high ecosystem risk despite low development of water resources:** 39 basins (869 million people) appear to have inadequate governance which manifests in high risks to ecosystems, despite relatively low levels of development of water resources. These basins present a challenge for sustainable development and the management of risk, particularly given the moderate to high levels of exposure to droughts and floods, respectively. Assessing governance needs in these basins would appear to be a priority.
3. **Cluster group 3: Poor governance, high risk, high water use:** 25 basins (84 million) have generally poor governance and generally high risks across the socioeconomics indicators, appear to be using relatively large portions of their available water resources, and have high economic dependence on them. Transboundary inter-sectoral allocation mechanisms may be useful management tools for these basins.
4. **Cluster group 4: High human wellbeing, good governance, high risk to ecosystems and human water stress:** 25 basins (282 million) tend to have high levels of societal wellbeing, and good governance, but also high risk to ecosystems and of human water stress and moderate risk of environmental water stress. Low risks of agricultural water stress but high risks of ecosystem impacts from dams implies that storage capacity has been developed to mitigate agricultural water stress, but at the expense of the environment.

This assessment covers 286 transboundary river basins. Each is unique, faces its own set of challenges, and requires tailor-made responses to these challenges. Nonetheless, understanding common traits among basins may facilitate inter-basin learning and the development of broad management approaches. One method for grouping basins is

Figure 4.5. Seven groups of basins with similar risk profiles, using K-means Cluster Analysis. Common risk profiles can facilitate inter-basin learning and shared approaches to management.



through a statistical cluster analysis. Techniques of cluster analysis are designed to identify separate groups that show high levels of within-group similarity and low levels of between-group similarity across the full suite of variables (indicators) in the analysis. Here, we employ K-means clustering[20] to identify seven groups, each comprising basins with similar risk profiles (see Figure 4.5 and Table 4.3 below).

The results of the cluster analysis provide an opportunity to define broad risk profiles based on the typical values of each indicator in each group. This can be used to identify basins at high or low risk for different groups of indicators or indeed, most indicators (Table 4.3 below). The range of values for the indicators within each cluster group shows that not all basins in each group are identical, but rather are broadly similar.

For a full list of the basins in each cluster group, see the footnote under Table 4.3. The matrix below only ranks the medians of each cluster group. For a full distribution of the indicators within each cluster group, which will facilitate a more complete interpretation of the analysis, see the box-plots in Annex VII.

20 An iterative algorithm which evaluates each basin's membership to the cluster at each iteration, by calculating the sum of square errors between clusters (see Annex VII).

Table 4.3 Matrix of Median Scores for Each Cluster Group for Each Indicator

Thematic groups	K-means cluster groups[21]						
Indicators	**1 (n=45)**	**2 (n=39)**	**3 (n=25)**	**4 (n=25)**	**5 (n=9)**	**6 (n=6)**	**7 (n=7)**
Water quantity							
1. Environmental Water Stress	Green	Amber	Red	Amber	Red	Green	Amber
2a. Human Water Stress (supply)	Amber	Amber	Green	Red	Amber	Red	Green
2b. Human Water Stress (use)	Green	Green	Amber	Amber	Red	Amber	Red
3. Agricultural Water Stress	Green	Amber	Red	Green	Red	Amber	Amber
Water quality							
4. Nutrient Pollution	Green	Amber	Amber	Amber	Green	Red	Red
5. Wastewater Pollution	Red	Red	Amber	Green	Amber	Green	Amber
Ecosystems							
6. Wetland Disconnectivity	Green	Amber	Amber	Amber	Green	Red	Red
7. Ecosystem Impacts from Dams	Green	Green	Amber	Red	Amber	Red	Amber
8. Threat to Fish	Green	Amber	Green	Red	Amber	Red	Amber
9. Extinction Risk	Green	Red	Green	Red	Amber	Amber	Amber
Governance							
10. Legal Framework	Red	Amber	Amber	Green	Green	Red	Amber
11. Hydropolitical Tension	Amber	Red	Amber	Green	Green	Red	Amber
12. Enabling Environment	Red	Amber	Red	Green	Amber	Green	Amber
Socioeconomics							
13. Economic Dependence on Water Resources	Green	Green	Amber	Amber	Amber	Red	Red
14a-d. Societal Wellbeing	Red	Amber	Red	Green	Amber	Green	Amber
14e. Income Inequality	Amber	Amber	Red	Red	Amber	Green	Green
15a. Exposure to flood	Green	Red	Green	Amber	Amber	Amber	Red
15b. Exposure to drought	Green	Amber	Red	Amber	Red	Amber	Green

Cluster groups were ranked according to their median for each indicator with the lowest two groups coloured green, the middle three groups amber and the highest two groups red. 'n' is the number of basins in each cluster group (see footnote below for list of basins). Green = low relative risk, amber = moderate, and red = high.

The 45 basins in the first cluster group (with a population of about 89 million people) tend to show lower risk across most indicators including water quantity (#1-3), ecosystems (#6-9), and socio-economics (#13-15) (Table 4.3). Curiously, these basins tend to show relatively poor governance (#10-12). There appear to be two broad types of basins here. The first is small basins in various parts of Africa, presumably with little water resource development so far, and the second is isolated basins in temperate and polar regions, presumably with low pressures on water resources. This cluster group seems to represent basins that are largely undeveloped and therefore offer an opportunity for sustainable development which may be possible with improvements to governance regimes.

21 **Basins by cluster group. 1:** Akpa, Awash, Baker, Bia, Ca/Song-Koi, Candelaria, Cavally, Cestos, Changuinola, Chilkat, Chiloango, Choluteca, Coco/Segovia, Cross, Digul, Gash, Goascoran, Great Scarcies, Hondo, Kaladan, Karnaphuli, Komoe, Lake Turkana, Lake Ubsa-Nur, Little Scarcies, Loffa, Ma, Mana-Morro, Moa, Mono, Negro, Ogooue, Pascua, Palena, Pungwe, Ruvuma, Sanaga, Sassandra, St. John (Africa), St. Paul, Sembakung, Tami, Tano, Yelcho, Yukon. **2:** Amazon, Amur, Bei Jiang/Hsi, Chamelecon, Congo/Zaire, Danube, Dniester, Don, Grijalva, Har Us Nur, Irrawaddy, Jenisej/Yenisey, La Plata, Lava/Pregel, Lempa, Mius, Motaqua, Narva, Nestos, Nile, Ob, Olanga, Oral/Ural, Red/Song Hong, Salween, Samur, San Juan, Terek, Struma, Sujfun, Sulak, Tuloma, Tumen, Valdivia, Vardar, Venta, Volga, Yalu, Zambezi. **3:** Baraka, Buzi, Cancoso/Lauca, Chira, Cuvelai/Etosha, Daoura, Dra, Incomati, Kunene, Lagoon Mirim, Lake Natron, Lake Titicaca-Poopo System, Limpopo, Maputo, Medjerda, Okavango, Orange, Pangani, Sabi, Thukela, Tumbes, Umbeluzi, Volta, Yaqui, Zarumilla. **4:** Columbia, Douro/Duero, Ebro, Elbe, Fraser, Garonne, Glama, Kemi, Klaralven, Mino, Mississippi, Nelson-Saskatchewan, Oder/Odra, Pasvik, Rhine, Rhone, Skagit, St. Croix, St. John (North America), St. Lawrence, Tagus/Tejo, Tana, Torne/Tornealven, Vistula/Wista, Vuoksa. § 5: Atrak, Colorado, Guadiana, Ili/Kunes He, Kura-Araks, Pu Lun T'o, Rio Grande (North America), Sarata, Tarim. **6:** Bann, Erne, Foyle, Han, Schelde, Seine. **7:** Fenney, Ganges-Brahmaputra-Meghna, Mekong, Muhuri (aka Little Feni), Oueme, Saigon, Song Vam Co Dong.

The 39 basins in the second cluster group (869 million people) are broadly spread across Central Africa and South America and the steppe regions of central Asia (Figure 4.5). They tend to have inadequate governance (#10-12) that manifests in high risks to ecosystems (#6-9) (particularly Extinction Risk (#9)) despite having relative low risk of Ecosystem Impacts from Dams (#7). The low risk of Ecosystem Impacts from Dams (#7) and Economic Dependence on Water Resources (#13) indicates comparatively little water resource development. With comparatively high risk levels for many indicators, and comparatively little water resource development, these basins present a challenge for sustainable development and the management of risk, particularly given the moderate to high levels of Exposure to Droughts (#15b) and Floods (#15a), respectively. Assessing governance needs in these basins would appear to be a priority.

The third cluster group comprises 25 basins (84 million people) with generally high governance risk (#10-12) (particularly Enabling Environment (#12) at the country level) and associated high risks across most socioeconomic indicators (#13-15), except Exposure to Floods (#15a). They tend to have high risks of Environmental (#1) and Agricultural (#3) Water Stress, and a high Withdrawal to Availability Ratio (#2b), despite having relatively high Water Availability per Capita (#2a). There appear to be two groups of basins within this cluster group: those that are arid but have relatively low population densities, and those that have more water resources but high population densities. In other words they appear to be utilising relatively high portions of the available water. This is supported by the moderate risk to Economic Dependence on Water Resources (#13). They are found mainly in southern Africa, as well as being scattered around parts of the rest of Africa and South America.

The 25 basins in the fourth cluster group (282 million people) tend to have high levels of Societal Wellbeing (#14), and good governance (#10-12), but with high risk to ecosystems (#6-9) and of Human Water Stress (#2) and moderate risk of Environmental Water Stress (#1). Low risks of Agricultural Water Stress (#3) but high risks of Ecosystem Impacts from Dams (#7) would tend to imply either that agriculture is relatively less important in these basins, or that sufficient storage capacity has been developed to mitigate agricultural water stress. The basins are found mainly in regions with relatively high socio-economic development in Europe and those shared between Canada and the USA.

Cluster groups 5 – 7 have relatively few basins (9, 6 and 7 respectively), so characteristics are more likely to be driven by the circumstances in a few of the basins rather than broad similarities. Nevertheless, possible interpretations follow.

The fifth cluster group (9 basins) comprises basins in drier regions of the world including the Middle East, the US-Mexico border region and Central Asia. These tend to be highly water-stressed, with high levels of Exposure to Drought (#15b), and moderate levels of Economic Dependence on Water Resources (#13), Societal Wellbeing (#14) and governance capacity at the country level (Enabling Environment Indicator (#12)). Yet they appear to have relatively strong transboundary Legal Frameworks (#10) and low risk of Hydropolitical Tension (#11), suggesting that they have governance frameworks in place to mitigate water stress.

The sixth cluster group contains five European basins, and a single basin on the Korean peninsula. The basins tend to have low Water Availability per Capita (#2a), and high risks of Nutrient Pollution (#4), to ecosystems (#6-9), and Economic Dependence on Water Resources (#3). The relatively poor transboundary governance in this group (#10 and 11) is more likely to be due to the perceived lack of need for specific transboundary arrangements, particularly as the group is dominated by relatively small basins shared between Northern Ireland and Ireland (3), and France and Belgium (2) where other management arrangements may be preferred. This is in contrast to the Han on the Korean peninsula, where the lack of transboundary governance is more likely to be due to the political situation between the two countries.

Finally, the seventh cluster group comprises basins in the tropical/monsoonal band of the world where the highest climatic risk is that of flood (#15a). This group is dominated by basins shared between Bangladesh and India (3) and Vietnam and Cambodia (3), with a single basin in west Africa (the Ouémé). These basins, including the Mekong and the Ganges, are characterized by high risks associated with Economic Dependence on Water (#13), Withdrawal to

Availability Ratio (#2b), Nutrient Pollution (#4) and Wetland Disconnectivity (#6). This group represents an opportunity for transboundary management since many of the high risks can be mitigated with appropriate infrastructure and policy measures (governance capacity appears to be moderate). Encouragingly, per capita water availability (#2a) is currently a low risk.

The list of basins within each cluster group is given in the footnote under Table 4.3 and further information in Annex VII.

In summary, the cluster analysis provides some indication of the groups of basins with similar risk profiles. While the relationships between the basins in the groups warrants further investigation, the analysis provides a useful start to understanding some of the main characteristics of risk for different basins around the world, and to facilitating the development of management strategies appropriate to the characteristics of the basins.

Although Principal Component Analysis (PCA) and cluster analysis use different methods to analyse the data, there are some similarities between PC groups and cluster groups. For example, there appear to be strong overlaps between the basins with the highest positive scores for PC1 and cluster group 1. This is discussed to a certain extent in Annex VII, but further analysis on this topic could give more insight into the nuances of the relationships between the basins in the PC groups and the cluster groups.

4.3 What can the assessment results say about the transboundary nature of risks?

Use of BCUs allows some insights into the complexities of the intra-basin environmental challenges, and the related implications for basin governance and management. The following hypotheses are tested in this section:

	Hypothesis	Approach for testing
1	Transboundary basins with greater differences between the BCUs are harder to manage and therefore the need for integrated basin governance is increased.	Investigate the level of 'disparity' between the BCUs in each basin using the differences in indicator results.
2	The more 'complex' the transboundary basin, the harder it is to manage, and therefore overall risk levels are likely to be higher.	In addition to identifying the number of BCUs per basin, investigate the 'hydrological complexity' of the basin by considering how BCUs can be classified as any combination of 'headwater', 'middle', 'contiguous' and/or 'outlet'.
3	Downstream BCUs are likely to have greater relative risk than upstream BCUs.	Investigate the risk profiles of BCUs that can be clearly classified as (i) primary headwaters and (ii) primary outlets, both as averages of all relevant BCUs, and compare the difference between each furthest downstream BCU and its furthest upstream partner.

1. Investigating the level of 'disparity' within a basin.

The hypothesis is that basins with greater differences between the BCUs are harder to manage at the basin level and therefore may have higher overall risk. Differences between BCUs can be measured in a number of ways. These include differences between all indicator results or selected indicators, and considering other parameters such as the general level of development. However, disparity between BCUs does not necessarily have negative implications. For example, it is probably preferable for basins to have large differences in pollution or societal wellbeing between the BCUs rather than high pollution or low societal wellbeing across the whole basin. It is therefore not appropriate to calculate an overall basin disparity index using all indicators. Instead, certain indicators should be selected where greater differences may indeed lead to higher levels of overall risk. Two are selected here:

- Economic Dependence on Water Resources (#13): high disparity here may mean that different levels of 'importance' are placed on the water resources in each BCU, and therefore that the basin's legal framework is weaker and there may be higher overall levels of risk.

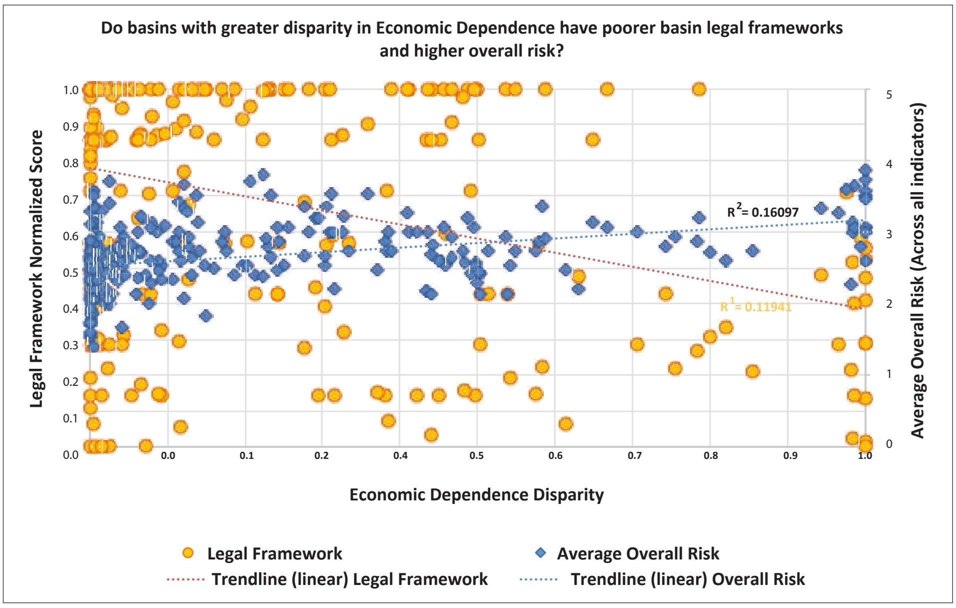
- Societal wellbeing (#14): high disparity here may mean that country capacities to deal with basin issues vary significantly, that country priorities may differ, and working towards unified goals may be more challenging. Insofar as societal wellbeing is correlated with higher GDP, it may also mean that there are significant power disparities between the riparian countries.

Disparity is assessed by calculating the difference between the maximum and minimum BCU scores for a given indicator in each basin.

The relationships between Economic Dependence on Water Resources disparity (#13 on x-axis), basin Legal Framework (#10 on primary y-axis (left)), and overall average risk (#1-15 on secondary y-axis (right)) are shown in Figure 4.6.

Figure 4.6 shows that there is no statistically significant relationship between Economic Dependence (#13) disparity and Legal Framework (#10) risk category, which would appear to disprove the first hypothesis above. If there is any relationship at all, it is a very weak negative one, which is broadly consistent with the moderately negative correlation between Economic Dependence risk and Legal Framework risk (Table 4.1). This would imply that basins with high economic dependence on water resources are more likely to have a stronger legal framework (e.g. the Danube in Europe). However, there are also cases where Economic Dependence is high and Legal Framework is weak (e.g. the Awash in Africa). From the figure above a very weak positive correlation can be seen between economic dependence disparity and overall risk, which would appear to support the hypothesis, but again the relationship is inconclusive. The relationship is likely to be dependent on a number of other factors which cannot be assessed here.

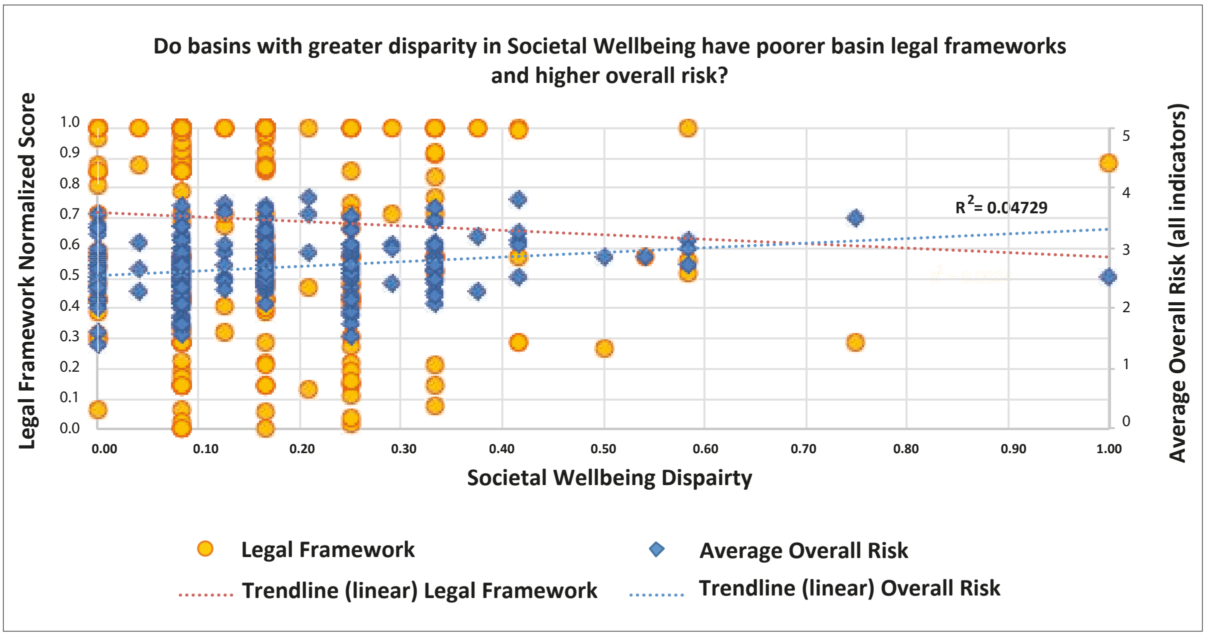
Figure 4.6. Do varying levels of Economic Dependence between BCUs in a basin have an impact on the basin Legal Framework and overall levels of risk? Results imply that basins with high Economic Dependence disparity tend to have weaker Legal Frameworks, but the relationship is very weak, and the results are inconclusive.



The relationships between Societal Wellbeing (#14 on x-axis) disparity, basin Legal Framework (#10 on primary y-axis (left)), and overall average risk (#1-15 on secondary y-axis (right)) are shown in Figure 4.7.

As with Economic Dependence disparity, patterns here are similar in direction but all very weak, so conclusions cannot be drawn with confidence.

Figure 4.7. Do varying levels of Societal Wellbeing between BCUs in a basin have an impact on the basin Legal Framework and overall levels of risk? Results imply that basins with high Societal Wellbeing disparity tend to have weaker Legal Frameworks, but the relationship is very weak, and the results are inconclusive.



An alternative disparity index could consider the relative 'significance' of the BCUs in a basin. This would allow the high/low scores of BCUs that have very little significance for the basin or the respective basin country to be 'muted' (e.g. if a BCU only represents 1 % of basin, but causes high disparity for overall basin due to its high risk score). This alternative approach was trialled by excluding all BCUs with relative BCU weights of less than 10% (based on combination of basin population and area), *unless* their relative BCU weights for the country was more than 20%, based on the same parameters. The latter condition was applied since BCUs (particularly for the larger basins) may have little significance at the basin level, but still be an important resource for the country. By applying these conditions, the overall basin disparity was reduced slightly for the majority of basins, although without any significant changes in the overall distribution (with the exception of a few outliers).

For any application of 'significance' criteria of BCUs, the specific criteria for BCU exclusion or weighting will depend on the purpose of the analysis. The scope of this assessment is global and comprehensive, therefore all BCUs have been included in the basin disparity assessment.

In summary, it seems the hypothesis is not supported by the analysis. It may be that within-basin disparity is also a driver of increased cooperation and improved environmental management. Understanding this would require further analysis.

2. Investigating the level of 'complexity' within a basin.

In addition to looking at the disparity of BCU indicator results within basins, the 'complexity' of the basins was assessed. Again, there are a number of different ways to define basin complexity, including: the number of BCUs; river length and change in altitude (giving an indication of the range of ecosystems and their services); and the 'hydrological position' of the BCUs. Here, the diversity of hydrological positions in the basin is chosen as this is expected to have an influence on the management of the basin.

Data on the hydrological position of BCUs were drawn from a Riparian Position (RIPP) dataset (OSU, 2014)[22] which codes BCUs on the basis of their riparian position within a river basin. For example, the code shows whether the river basin's primary headwaters or primary outlet is located within the BCU, as well as whether part of the country's border is defined by the basin's river. Other characteristics that are coded in the database include whether the country (BCU) is primarily a 'middle' riparian, with waters flowing into it from an upstream country and out of it into a downstream country; whether the country contains a small portion of the headwater streams in a basin; and whether multiple countries share an outlet. Some BCUs may exhibit a number of the characteristics described above, and it is the combination of these that define the 'complexity' of the basin[23]. An overview of the properties from the RIPP dataset is given below:

Code	Definition
H Primary Headwaters	1. The country contains a majority of the headwater streams in the basin 2. No H on the rare occasions where the headwaters are equally divided
X Secondary Headwaters	1. The country contains a small portion of the headwater streams in the basin 2. It may or may not be the only role played by the country in the basin 3. Two countries share a headwater
M Primary Middle	1. The country has water flowing into it from another country 2. The country has water flowing out of it into another country 3. It most clearly defines the country's status in the basin.
Z Secondary Middle	1. The country has water flowing into it from another country 2. The country has water flowing out of it into another country 3. There are other features that play a more dominant role in defining the county's status in the basin 4. In contiguous situations, the part of the border that is considered contiguous cannot play a role in determination of secondary middle (i.e. if the river serpentines across the border, for example: Ivory Coast / Liberia/Cavally or Al Nahr Al Kabir – Lebanon and Syria) 5. Where C then no Z.
C Contiguous	1. Part of the country's border is defined by the basin's river
O Primary Outlet	1. The country contains the basin's outlet to the sea/ocean 2. The country contains the majority of the internal drainage
Y Secondary Outlet	1. Two or more countries share an outlet 2. If Y then no O
I Internal Drainage	1. There is no apparent basin outlet 2. The outlet region may involve several countries
Q Does not apply	

The complexity of each basin was calculated by assigning a value of 1 to each of the BCU properties (i.e. letters, with exception of Q), then summing the respective BCU properties for BCU complexity, and the sum of BCU complexity for basin complexity.

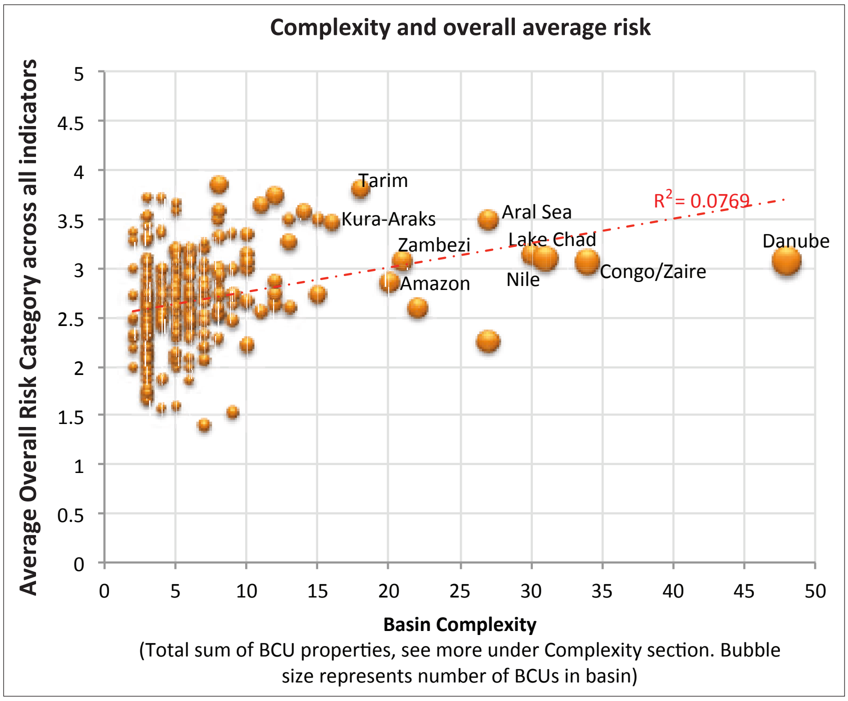
Figure 4.8 compares the basin complexity with overall average risk.

Figure 4.8 shows that there is a very weak correlation between basin complexity and average risk. Thus the hypothesis is not strongly supported by the data. However, further investigation is warranted for basins that appear to have high complexity and high average risk, since such basins may face challenges which need to be addressed in a complex context. Examples include Tarim, Aral Sea and Kura-Araks. One could also argue for attention to moderate risk basins

22 Note that the RIPP database contains information on only 727 BCUs since it has not been updated to include the additional BCUs identified during this assessment.

23 The RIPP dataset does not include length of river as one of the variables. In terms of complexity, longer rivers are likely to have higher altitude drops and go through a more diverse range of ecosystems, so they usually have greater diversity and species richness, and also often provide a greater range of ecosystem services. This analysis focuses particularly on the BCU properties within the basin, but for a more in-depth complexity analysis, river length needs to be considered.

Figure 4.8. Basin Complexity and Overall Basin Risk. There is weak evidence that basins with complex hydrological arrangements have generally higher risk.



with complex environments, since these basins mark the transition from low to high risk (or in the case of successful management, high to low). These include the Zambezi, Lake Chad and Congo basins.

3 Investigating the relationships between BCU hydrological position (upstream or downstream) and overall relative risk.

The relationships among upstream and downstream BCUs within basins are arguably one of the most important features of in-basin dynamics, whereby the risks can be spread across country borders and spill over to other BCUs. Attempts were made to model placement of upstream-downstream BCUs (and 'upstream-downstream' indicator), by exploring the possibility of building 'discharge budgets' (entering, locally generated, and leaving) for the BCUs, using higher-resolution river networks derived from HydroSheds that could more closely match the TWAP basin and BCU boundaries). Regrettably the quality of data was not satisfactory to establish these relationships with confidence[24], and the TFDD RIPP dataset was therefore used.

The simplest way to investigate upstream-downstream relations was by comparing BCUs classified as Primary Headwaters (H) with BCUs classified as Primary Outlet (O) in the same basin, as per the RIPP dataset.

Assessing the 56 basins for which there were clear Primary Headwater BCUs and Primary Outlet BCUs, and for which there were indicator results, gave the following relationships.

Figure 4.9 shows that the average risk for Outlet BCUs is marginally higher than their respective Headwater BCUs in the same basin, and that this pattern is stronger for the more 'complex' basins. And although the differences in

24 The identified issues (partly relating to the mismatch of boundaries of the two datasets) is something that could be addressed in future assessments, given sufficient time and resources, and would make a significant contribution to global data on transboundary basins and their upstream-downstream dynamics.

average risk are relatively small, Figure 4.10 shows that almost twice as many Outlet BCUs have higher risk than their respective Headwater BCUs, compared to the opposite. So the hypothesis appears to be supported by the number of BCUs, although the differences are not large. The visualisation of results is likely to be affected by the choice of 'average risk' as this would diminish the potential spread of results.

Figure 4.9. Overall Basin Risk: Outlet and Headwater BCUs. Average risk at the outlet is marginally higher than at the headwater in the majority of basins.

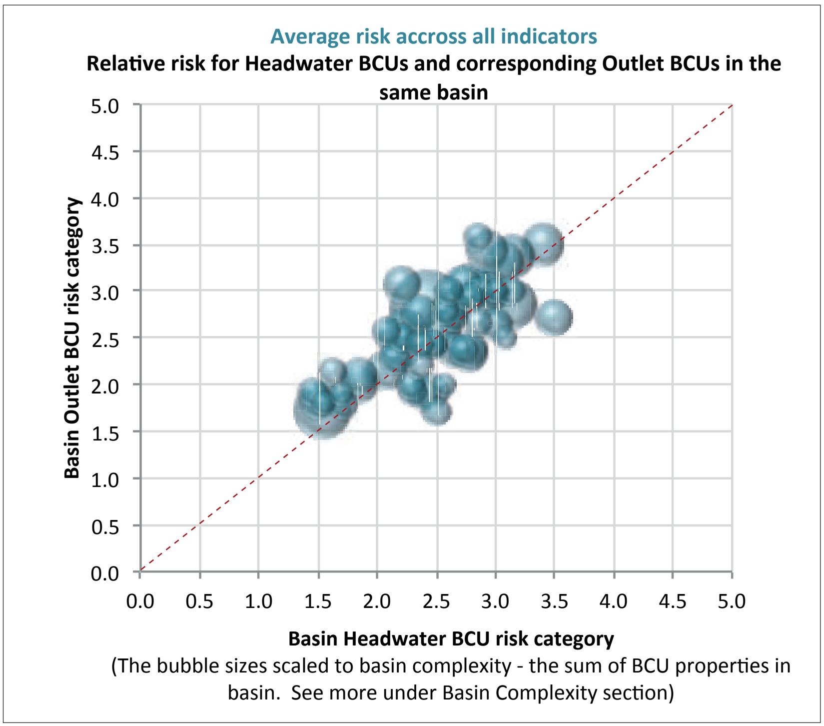
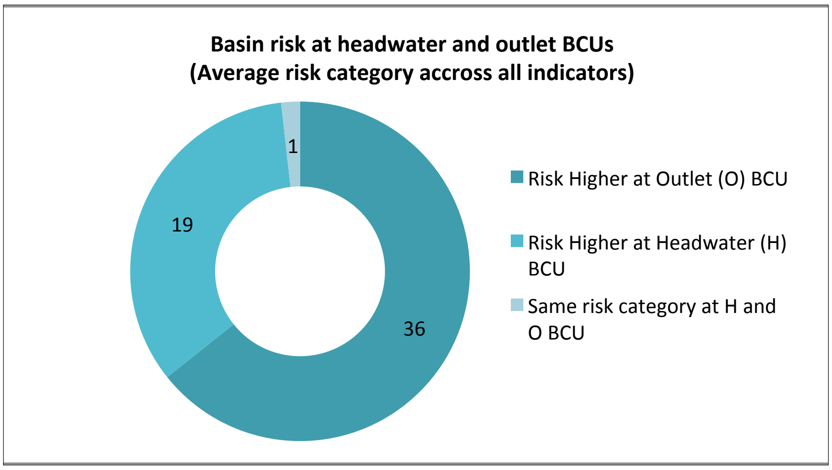


Figure 4.10. Overall Basin Risk: Comparison Between Outlet and Headwater BCUs. While differences are small, almost twice as many outlet BCUs have higher average risk than their respective headwater BCUs, compared to the opposite.



Similar patterns are found when analysing the average risk for pairs of Headwater and Outlet BCUs for each of the thematic groups of indicators (see Annex VII), although within thematic groups the representative share of basins where BCU risk for outlet and headwaters is the same, is significantly higher (often a nearly equal representation of all three groups).

4.4 How will risks change in the future?

Key findings:

Four hotspots were identified. Environmental and Human (E&H) Water Stress is expected to increase in all four:

1. **Orange and Limpopo basins, Southern Africa:** increased Environment and Human (E&H) water stress due mainly to increasing water withdrawals, and nutrient pollution due mainly to increased human sewage. Countries affected: Botswana, Lesotho, Mozambique, Namibia, South Africa, Zimbabwe.
2. **Selected Central Asia basins:** range of factors differing between basins, including increased E&H water stress due to combination of projected increases and decreases in water availability, increasing water withdrawal and population density; increased nutrient pollution and hydropolitical tensions. Basins: Tarim, Indus, Aral Sea, Helmand, Murgab, Hari, Talas, Shu and Ili. Countries affected: Afghanistan, China, India, Iran, Kazakhstan, Kyrgyzstan, Nepal, Pakistan, Tajikistan, Turkmenistan, Uzbekistan.
3. **Ganges-Brahmaputra-Meghna basin:** increased E&H water stress due mainly to increased (>50%) water demand driven by population growth. Nutrient pollution remains high with agriculture sources (fertilizer and animal manure) being major contributors and sewage becoming increasingly important, and there is increased risk of hydropolitical tension associated with new water infrastructure. Countries affected: Bangladesh, Bhutan, China, India, Myanmar, Nepal.
4. **Selected Middle East basins:** continued high to very high risk of E&H water stress due to decrease in renewable freshwater resources and higher water demand from increased population and irrigation. Nutrient pollution increases or remains in the highest risk category; increased risk of hydropolitical tension due to political context. Basins: Orontes, Jordan River, Euphrates and Tigris. Countries affected: Egypt, Iraq, Iran, Israel, Jordan, Lebanon, Palestine, Saudi Arabia, Syria, Turkey.

Background

In recent decades, water demand has been increasing and continues to increase globally, as the world population grows and nations become wealthier and consume more. As water demands get closer and closer to the renewable freshwater resource availability, each drop of freshwater becomes increasingly valuable and water must be managed more efficiently and intensively. Decreasing water quantity is not the only thing that poses a risk to human health and the environment; the degradation of water quality is also important. For example, nutrient pollution from agricultural activities, sewage, and atmospheric nitrogen deposition is an increasing problem. Planning for future development and investments requires that we prepare water projections for the future. However, estimates are complicated because the future of the world's waters will be influenced by a combination of important environmental, social, economic and political factors such as global climate change, population growth, land-use change, globalization and economic development, technological innovations, political stability and international cooperation.

In order to address the question 'How will risks change in the future?' in terms of water quantity, water quality, and governance it is important to analyse the impacts of future changes affected by key direct (e.g. climate, loadings) and indirect (e.g. population, economic development) drivers and factors expressing hydropolitical tension (e.g. negative trends in water reserves, armed conflict). Understanding pressures on surface freshwater resources and the related complex interactions between different drivers helps to identify major sources of risk and explore opportunities for measures and actions to improve the situation.

Climate change is projected to exacerbate regional and global water scarcity considerably. Nevertheless, several studies show that, for example, water stress or water scarcity will result mainly from future population and economic

development (Hanasaki *et al*. 2013; Parish *et al*. 2012; Alcamo *et al*. 2007; Vörösmarty *et al*. 2000). In a recent study based on the same key drivers that have been applied here, Schewe *et al*. (2014) showed that, up to a global warming of 2°C above current temperatures, each additional degree of warming will expose about an additional 7% of the global population to a severe decrease in water resources. In addition, climate change will increase the number of people living under absolute water scarcity (<500m³ per capita and year) by another 40%. At the same time, Schewe *et al*. (2014) identified large uncertainties associated with estimates of future changes, with both Global Climate Models (GCMs) and Global Hydrological Models (GHMs) contributing to the spread. Water availability will also increase in some regions. Changes in climate and key socio-economic drivers are very likely to influence future nutrient pollution loads and in-stream concentrations, affecting environmental and human health. River nutrient loading is expected to increase in many regions and hence the risk of coastal eutrophication and associated effects (Seitzinger *et al*. 2010; Alcamo *et al*. 2005). While climate change may not have large impacts on future total nitrogen loadings, it may have impacts on in-stream concentrations due to reduced river discharge (Reder *et al*. 2013).

To estimate future risks of transboundary river basins resulting from impacts of direct and indirect drivers, i.e. climate change and socio-economic developments, projections were generated to cover the 2030s and 2050s. In this context, we concentrated on a 'business-as-usual' socio-economic scenario (SSP2, see Section 4.2.2) and assumed a continued high GHG emission pathway (RCP8.5) for assessing future conditions of five indicators:

- Change in population density;
- Environmental stress induced by flow alteration;
- Human water stress;
- Nutrient pollution;
- Exacerbating factors to hydropolitical tensions.

The projected hydropolitical tensions indicator considers a set of six 'exacerbating factors' related to water availability, presence of international and domestic conflict and economic development that could increase the risk of hydropolitical tensions in each basin.

Additional information on changes in runoff (i.e., renewable internal freshwater resources on river basin and BCU scales) and total water withdrawals for the 2050s is shown in Figure 4.11 and Figure 4.12. The change in runoff for the 2050s has been calculated as the long-term mean of multi-model ensemble projections (from two Global Hydrological Models and four Global Climate Models) covering 2041 to 2070.

Figure 4.11. Relative Change in Ensemble Mean Annual Runoff (2050s) Compared to Baseline Conditions at River Basin (left) and BCU (right) scales. The full range of differences can be seen from minus 50% (e.g. Mediterranean region) to plus 50% (e.g. Sahel region).

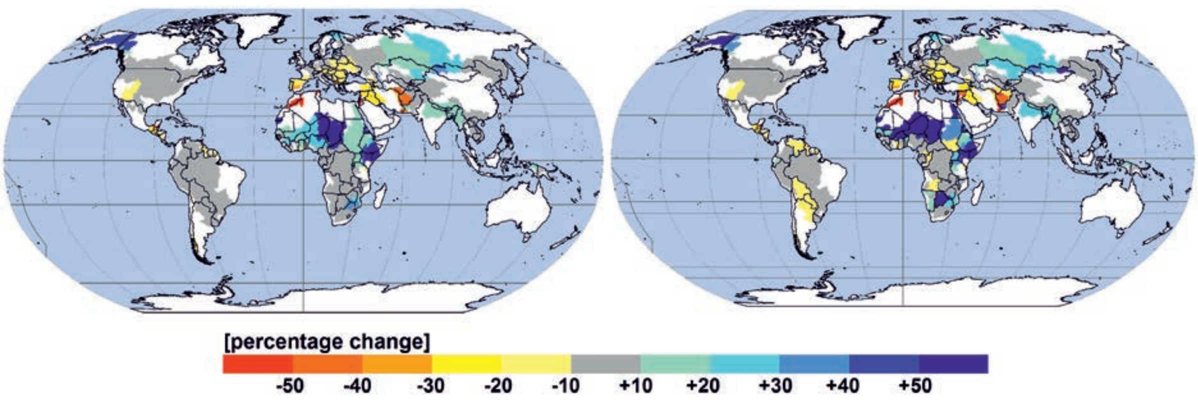
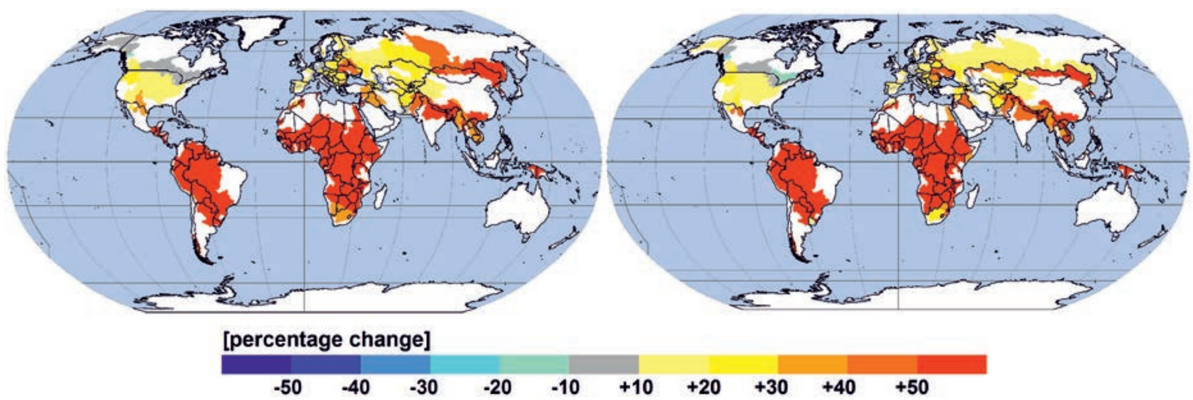


Figure 4.12. Relative Change in Total Water Withdrawals (2050s) Compared to the Base Year 2010 at River Basin (left) and BCU (right) Scales. Water withdrawals are projected to increase dramatically (e.g. >50%) in many basins of the world.



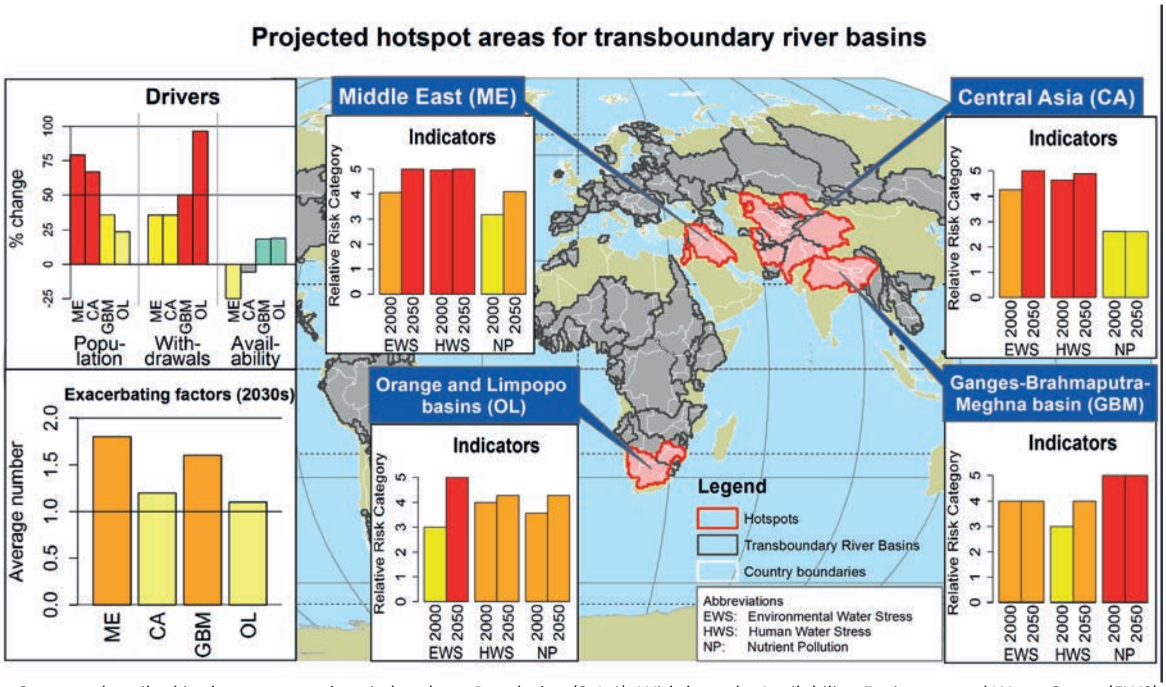
Sources: Model results are from WaterGAP. For irrigation, the long-term mean of ensemble climate projections was used (Annex X).

Results

On the basis of simulated projections for the five indicators (Sections 3.1.4, 3.2.2, 3.2.4, 3.3.1, 3.5.3) we identified four hotspot regions that are particularly exposed to socio-economic developments and climate change. These hotspots are characterized by worsening conditions as indicated by an increase in relative risk categories of the indicators listed above.

Figure 4-13 highlights the hotspot regions identified as being at risk in the 2030s and 2050s, showing the changes in indicator categories and percentage changes in key drivers. Changes between current and future conditions are derived from a weighted average of the basin values in each hotspot, calculated as the difference between the baseline and 2050.

Figure 4.13. Four projected hotspot regions: Middle East, Central Asia, Orange and Limpopo Basins and Ganges-Brahmaputra-Meghna Basin. Average relative risk categories are shown for Environmental and Human Water Stress and Nutrient Pollution, for 2000 and 2050 for each hotspot. The average percentage change of three drivers (population, total withdrawals and water availability) are shown. The average number of Exacerbating Factors to Hydropolitical Tension is also shown.



Sources: described in the report sections in brackets: Population (3.1.4), Withdrawals, Availability, Environmental Water Stress (EWS) (3.2.2), Human Water Stress (HWS) (3.2.4), Nutrient Pollution (NP) (3.3.1), Exacerbating Factors (3.5.3). Colours for the indicators correspond to risk category colours used throughout this report (section 2.4). Colours for the drivers are taken from Figure 4.12.

First, the transboundary river basins of the Middle East (Orontes, Jordan River, Euphrates and Tigris), are projected to see an increase in environmental and human water stress, which are already high or very high (Figure 4.13). Renewable freshwater resources are scarce and projected to decrease further, by about 25%. Demand for water will increase (by 36%) due to a considerable growth in population by almost 80% and water needs for irrigation. In this region, nutrient pollution increases on average from relative risk category 3 to 4, putting additional pressure on scarce water resources. The risk of hydropolitical tension is also expected to increase (category 4, see section 3.5.3) mainly because of increased water variability and negative trends in water reserves ('exacerbating factors').

Second, river basins in Central Asia (e.g. Tarim, Indus, Aral Sea, Helmand, Murgab, Hari, Talas, Shu and Ili) are at risk related to changes in environmental and human water stress. In this region, water availability will decline on average by 6% because of climate change but the direction of change differs between the basins. While the Helmand, Hari, and Murgab river basins are expected to face reductions in water availability of more than 40%, an increase of more than 20% is likely in the Shu and Ili basins. The climate signal is not as strong for the Indus, Tarim, Aral Sea, and Talas river basins, resulting in a small decrease in freshwater resources (<10%). However, population growth (almost 70%) and increasing prosperity will increase human activities and put additional pressures on freshwater resources due to increasing water withdrawals of more than 35% (Figure 4.13). In this region, increasing water withdrawal is the crucial factor causing the increase in water stress in all the transboundary basins named here. With regard to changes in population density, the risk categories in this region range from 1 to 5. The Helmand, Hari, and Murgab river basins are in the very high risk category. Further, increasing nutrient pollution could be a problem in some of the transboundary basins, leading to deterioration in human and environmental health. River basins in this region could be at higher risk of hydropolitical tension because of socio-political, economic and environmental factors that could exacerbate transboundary tensions over new or planned water infrastructure (indicated by average number of exacerbating factors >1).

Third, the Ganges-Brahmaputra-Meghna basin is also likely to remain in the high-risk category related to environmental water stress and may even experience an increase in human water stress, although water availability is expected to increase in the whole basin by about 20% in the 2050s (Figure 4.13). In particular, population growth and development is projected to lead to a substantial rise in water demand (~50%) which will counteract this effect. The change in population density is also projected to lead to a change in relative risk category (from category 1 into 2, see section 3.1.4), because total population is expected to increase by around 35%. Nutrient pollution remains in the highest risk category in this transboundary basin, posing an additional threat to freshwater resources, with agricultural sources (fertilizer and animal manure) being major contributors, but with sewage becoming increasingly important (especially for phosphorous) (Seitzinger *et al*. 2014). Hydropolitical tension associated with new water infrastructure developments is projected to increase (category 4, i.e., high risk) due to the potential exacerbating effect of increased water variability, decreased water reserves and low socioeconomic levels (exacerbating factors in Figure 4.13) in the basin.

Fourth, in the Orange and Limpopo river basins in southern Africa, environmental and human water stress in particular are expected to increase in the medium and long term, mainly because of increasing water withdrawals of more than 90% which cannot be compensated by increased water availability of about 20% (Figure 4.13). Population is projected to grow on average by around 25%, although these two river basins remain in risk category 1 in terms of population density (section 3.1.4). Nutrient pollution is also likely to increase the deterioration of water quality not only in the upstream but also in the downstream area of the basins, mainly because of increased nutrient loading from human sewage (extracted from Seitzinger *et al*. 2010). The risk of hydropolitical tensions associated with the construction of new water infrastructure in the absence of adequate transboundary agreements is likely to be similar to the current level (moderate relative risk category 3, see section 3.5.3).

In addition to these hotspots, there are regions where climate-change projections agree in pointing toward decreasing water availability. This is the case in the Mediterranean region, where the projected impact of climate change, and, to a lesser extent, the impact of socioeconomic development on water resources, will need to be addressed also at the transboundary level. For example, river basins of the Iberian Peninsula (Guadiana, Tagus, Douro and Ebro) are projected to face an increase in environmental and human water stress, driven by increasing water demand (between 10% and 20%, especially irrigation water requirements). These relative changes in water demand are

superimposed on projected substantial reductions of water availability of up to 40% and continuing levels of high nutrient pollution, which will probably exacerbate water scarcity in this region. However, the governance situation is relatively favourable to transboundary cooperation ('very low' relative risk category for all three baseline governance indicators, and exacerbating factors), and these basins are expected to be well positioned to adapt to the increasing stresses.

At the BCU level, a worsening of the situation is projected for the 2030s and 2050s in some countries. Human water stress in the entire Nile river basin, for example, is expected to fall into the low risk category, while at the BCU level Egypt and Sudan still face a very high risk of human water stress. Although the model approach is limited to the internal renewable freshwater resources of a given country (neglecting river discharge from upstream countries), it demonstrates the severe situation of upstream-downstream dependencies. The impact of changes in climate and water demand will require changes in water management in the upstream countries, causing additional pressure on downstream users. Downstream Egypt and Sudan rely on water from the upstream regions of the basin, mainly from Ethiopia and Uganda, to prevent the risk of future human water stress. The bio-physical indicators show that, as well as a worsening of the situation in the downstream countries, the risk of potential hydropolitical tensions is expected to increase, particularly in the upstream countries like Ethiopia.

Future changes in potential risks from the perspective of riparian countries (BCU level) is clearly illustrated on the basis of the selected indicators for the Nile. There are several other transboundary river basins where the riparian countries have to deal with projected transboundary waters issues arising from impacts of a combination of important environmental, social, economic and political factors, such as global climate change, population growth, development, technological innovations, political stability and international cooperation. The changes related to water withdrawals dominate the projections of water stress, as do the loadings in terms of water quality. Improvements in water-use efficiency and demand measures as well as the level of wastewater treatment and reduction of agricultural fertilizer inputs (from fertilizer and livestock) will therefore be important to address these increased risks. In this context, special attention should be paid to transboundary water management in order to balance the conflicting interests between upstream and downstream riparian countries.

4.5 Can we identify success stories?

This section aims to identify basins that represent relative 'success stories', i.e. basins that appear to cope well with certain pressures, and perform better than other basins of similar size, population density and water resource availability. Identifying basins where challenges have been dealt with successfully can provide important lessons for minimizing the risks to people and ecosystems.

Identifying success stories is not straightforward, given the baseline nature of the assessment and therefore the challenges involved in identifying cause-effect relationships, but there are a number of ways of interrogating the data that can highlight patterns that may warrant further investigation as part of additional studies, including:

1. **Considering low overall risk across most indicators:** the expectation here is that most of these basins are in sparsely-populated areas with low 'pressures' on natural resources. However, some basins may stand out, for example those with high population density and low water availability per capita but still relatively low overall risk.
2. **Considering the average relative risk from the socio-economic indicators (#13-15):** one might expect that basins with high socio-economic risks also have high relative risks across the other indicators, but again there may be some that seem to be 'coping' better.
3. **Considering basins which seem to balance human and environmental needs.**

To test the above hypotheses, the overall indicator results table has been ordered on the basis of different parameters relevant to the hypotheses; the extracts are shown below.

Table 4.4. Overview of Basins with Lowest Overall Average Risk

Geography	BASIN	Basin size (sq km)	Pop density (p/km2)	Water avail. (m3/person/yr)	1.Env W Stress	2.Human W	3.Agr W Stress	4.Nutr Pollut	5.Wastew Pollut	6.Wetl Disconn	7.Dams	8.Fish	9.Extinct Risk	10.Legal Fram	11.Hydropolit	12.Enabl Env	13.Econ Dep	14.Well-being	15. Expos FD	Av Risk Cat
EUR	Torne/Tornealven	40,834	1	136,324																1.40
EUR	Pasvik	17,961	1	231,623																1.53
N-AM	Stikine	50,877	0	17,374,293																1.57
EUR	Tana	16,872	0	316,874																1.60
N-AM	Fraser	231,593	5	59,914																1.67
EUR	Naatamo	719	2	102,648																1.67
N-AM	Alsek	28,220	0	32,575,755																1.71
EUR	Olanga	41,766	1	187,707																1.73
N-AM	Chilkat	3,967	0	3,687,927																1.73
N-AM	Yukon	838,169	0	368,795																1.73
N-AM	Firth	6,075	0	274,800																1.75
N-AM	Whiting	2,474	0	8,807,486																1.79
N-AM	Taku	17,496	0	17,692,034																1.86
N-AM	St. John (North America	55,056	7	93,721																1.87
EUR	Kemi	53,911	2	102,788																1.87
EUR	Jacobs	944	2	195,071																1.92
EUR	Tuloma	27,005	5	45,473																1.93
EUR	Fane	341	64																	2.00
EUR	Lima	2,469	49																	2.00
EUR	Narva	56,519	16	15,336																2.00
EUR	Oulu	25,972	7	39,148																2.00
N-AM	St. Croix	3,942	5	142,127																2.00
S-AM	Pascua	14,107	0	1,424,049																2.00
EUR	Lava/Pregel	14,466	74	2,475																2.07
EUR	Mino	16,679	45	13,907																2.07
EUR	Venta	11,901	30	9,253																2.07
N-AM	Hondo	12,699	13	33,279																2.07
N-AM	Skagit	8,207	10	137,405																2.07
EUR	Bidasoa	720	77	15,021																2.07
S-AM	Jurado	918	5	571,989																2.08
EUR	Lough Melvin	290	19																	2.09
EUR	Castletown	265	120																	2.11
EUR	Klaralven	50,092	18	18,550																2.13
EUR	Glama	41,375	16	19,182																2.13
EUR	Vuoksa	287,094	11	24,120																2.13
S-AM	Palena	13,230	1	2,172,037																2.13
S-AM	Baker	26,886	0	763,803																2.13
AFR	Corubal	24,300	27	27,058																2.14
EUR	Gauja	9,207	21	12,329																2.14
S-AM	Aysen	12,550	4	298,219																2.14
EUR	Flurry	201	82																	2.18
N-AM	St. Lawrence	1,057,304	43	8,465																2.20
EUR	Roia	675	38																	2.20
EUR	Erne	4,438	29	23,030																2.20
AFR	Ruvuma	155,039	17	30,934																2.20

1. The lowest overall risk, based on average relative risk category across all indicators.

A simple analysis of the average basin risk category across all indicators produces results with few surprises – most basins scoring low to very low relative risk on average are small basins with low population density and low human water stress. Table 4.4 gives an overview of the lowest-stress[25] basins across all indicators.

25 Water availability per person of more than 1 300 m3/person/yr represents low to very low human stress, as per sub-indicator 2a.

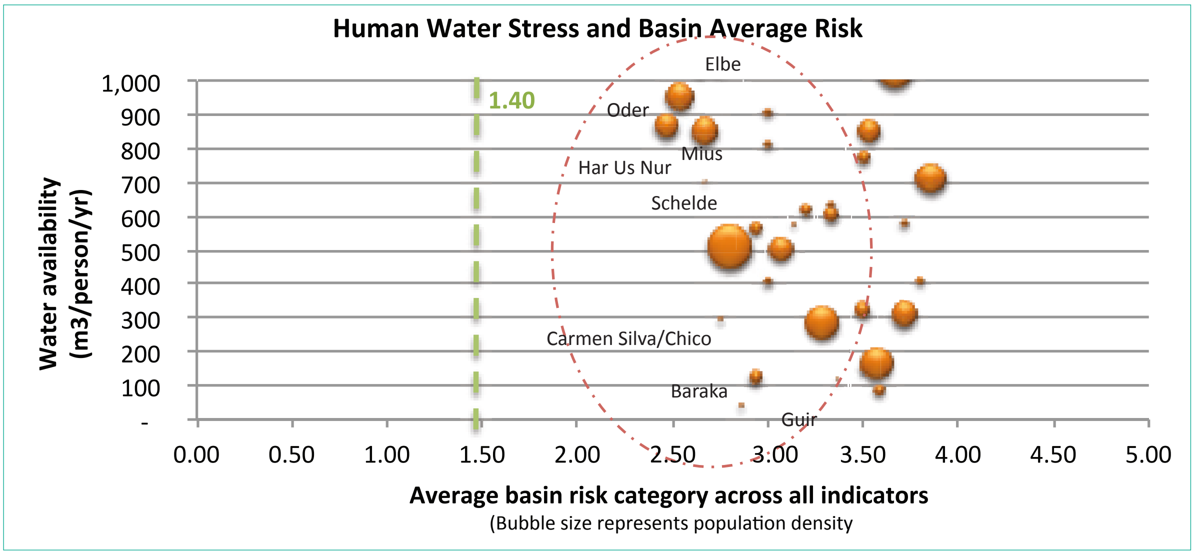
Table 4.4 shows that the average risk category itself says little about the 'success' of different water management practices, since most of the low-risk basins appear to be small basins with low human pressures (as shown by the population density and the mainly low risk categories for the Economic Dependence on Water Resources Indicator (#13)). Basins in remote locations and low population densities can be expected to have low risks across most categories, since there are few human pressures on water resources. Interestingly, many of the same 'low' average risk basins score high to very high risk for the Legal Framework Indicator (#10), which may also indirectly point to the relatively low economic and political 'significance' of these basins, hence the lack of signed international treaties. However, this may also be because a number of these basins are mostly within one country, so the relevance of a transboundary legal framework is significantly reduced.

A more interesting analysis from the 'success' point of view is to look at basins that have low water availability per capita (high Human Water Stress (#2)), yet score at lower average risk than other basins experiencing similar degrees of water quantity constraints. This may indicate some success in balancing the overall basin risk while coping with relatively scarce water resources.

Figure 4.14 looks at basins in risk categories 4 and 5 only (i.e. only the highest risk basins) for the sub-indicator 2a (Human Water Stress: Water Availability per Capita), representing water availability of 1 000 m^3/person/year or less, in comparison with overall basin risk across all indicators.

The encircled basins in Figure 4.14 could be considered relative success stories, compared with other basins that have similar low to very low water availability per capita. Despite having the highest risk categories (4 and 5) for human water stress, these basins have low to moderate overall risk (the green line indicates the lowest basin average across all indicators (1.40 from the full list of basins). This is arguably the challenge for most basins with limited water availability: how to manage the high human pressures in a way that does not compromise the integrity of ecosystems and the basin in general. Further case study analysis of the marked basins in Figure 4.14 may be interesting to see if there are any lessons to be learned.

Figure 4.14. Basins with High Human Water Stress vs Basin Average Risk.



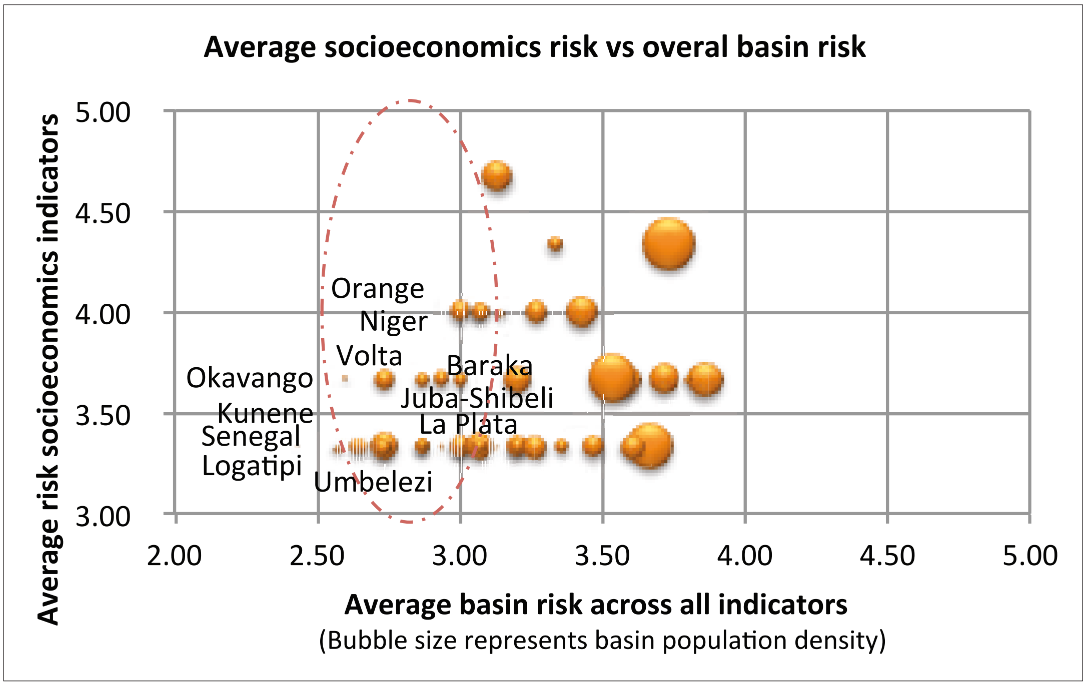
2. Average socioeconomic risk.

The hypothesis here is that basins with high risk for socioeconomic indicators (#13-15) would also have a high overall risk for all indicators, due to the pressures (essentially drivers of ecosystem degradation) stemming from the high socioeconomic risk. Analysis shows that the basins at highest (average) socioeconomic indicator risk are mainly large basins, though not all with equally high population density. This is as expected, since the larger, populous basins are usually central to economic activity, thus are also more economically dependent and potentially more vulnerable to the effects of floods and droughts.

Figure 4.15 maps all basins at the high end of average socioeconomic risk (only basins above average socioeconomic risk of 3.33 are shown), against the average basin risk across all indicators. While none of the basins score exceptionally low on overall basin risk, a number score between 2.5 and 3, i.e. low to moderate overall risk. This can be seen as a sort of 'success', particularly in basins with high population pressures. In general one cannot expect highly populated basins to be able to manage water resources to a level of risk in line with more sparsely populated ones with far fewer pressures. Maintaining low to average basin risk, despite high to very socioeconomic pressures, can therefore be said to be a success. These basins are marked in Figure 4.15.

Many of these basins are large and of high economic (and political) importance. Population density appears to be a factor of success, with population densities increasing as the average basin risk increases (see bubble sizes in Figure 4.15). In addition, about one-third of the basins mapped (i.e. high socioeconomic risk basins) have very low to low average Governance risk (average of governance indicators). For example, Orange and Volta have average governance indicator risk of only 2, which is low. Okavango, Volga and Umbeluzi have a slightly higher, but still comparatively low governance risk of 2.33.

Figure 4.15. High Socioeconomic Risk Basins vs Overall Basin Risk.



The success stories vary from basin from basin. For example, some basins do relatively well on ecosystem and governance indicators, despite a high socioeconomic risk. However, there are also basins that score very low risk for governance indicators, while having high socioeconomic and ecosystem risks (e.g. Danube and Jordan). The details of the cause-effect relationships therefore cannot be established with certainty without qualitative investigation in specific basins (e.g. were the governance mechanisms established as a response to these high risks, or are governance mechanisms present, but not effective?).

3. Balancing human and environmental needs.

Densely-populated basins with low water availability per capita for which the assessment indicates relatively low ecosystem risks can also be seen as a group of success stories. These basins appear to successfully balance human and environmental water needs despite limited water availability and what appears to be a high population and human activity pressures.

Figure 4.16 maps all *moderate to very high human water stress basins* (i.e. all basins where water availability is less than 1 300 m^3/person/year), the corresponding population densities, and the average ecosystem indicator risks.

The encircled basins are all considered to be at high to very high risk of human water stress (like all the basins in the figure), yet maintain somewhat lower overall risk to ecosystems – very low to moderate risk on average. Bubble size signifies population density, and many, though not all, basins have low population densities which may account for the greater success in managing human pressures. Even for basins with relatively low densities, not all are small in absolute population terms. For example, the Limpopo basin is home to 15 million people, the Orange to more than 13 million, the Helmand to more than 12 million.

Figure 4.16. High Human Water Stress Basins and Average Ecosystem Indicator Risk. Bubble size signifies population density.

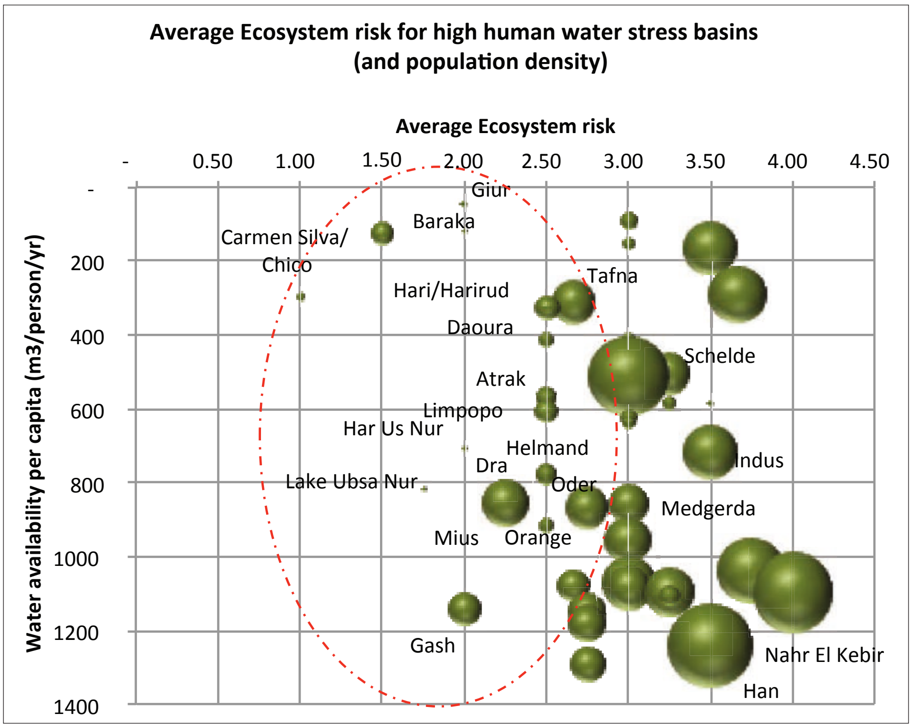


Figure 4.16 shows a general trend of average risk to ecosystems increasing with increasing population density (as opposed to total population). The same trend can be seen in Figure 4.15 for average socioeconomic risk. While not surprising in general terms, this does make the few success stories of particular interest, and particular attention should be given to those with higher population densities, with further investigation of how the densely-populated, water-scarce basins manage to maintain relatively low risk to ecosystems despite limited water resources. In this context, basins of immediate interest are the Mius, Tafna, Gash and Oder, also the Schelde.

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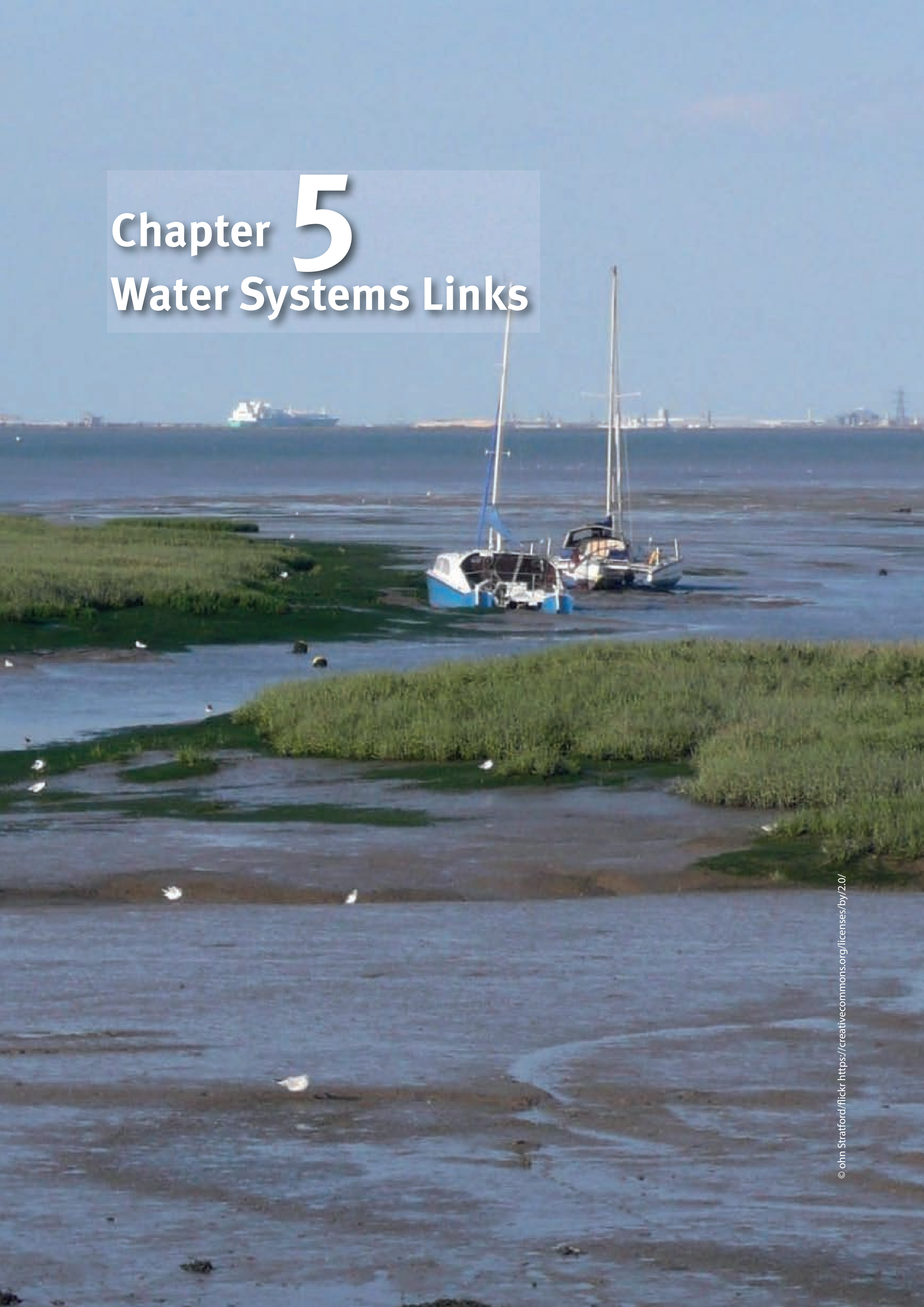
Chapter 5
Water Systems Links



Chapter 5.1 Lake Influence

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Chapter 5.2 Delta Vulnerability

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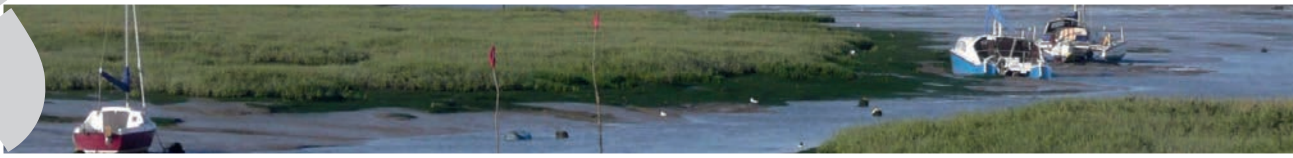
Water Systems Links



This section presents the results of indicators relating to the interactions between transboundary river basins and other water systems. While river basins interact with all other water systems assessed under TWAP (Aquifers, LMEs, Open Ocean and Lakes), either directly or indirectly, special attention under TWAP RB was given to lakes (via the Lake Influence Indicator) and Deltas (via the Delta Vulnerability indicators).

Lakes are important in providing buffering and storage capacity within transboundary river basins, thus directly influencing water quantity and quality within a given basin. The Lake Influence Indicator aims to highlight these important interactions and interdependencies, focusing on lake buffering and storage capacity within TWAP river basins.

Many river basins assessed under TWAP include deltas, occurring where a river flows into a lake or the sea. The physical geography of deltas often differs markedly from that in the neighbouring parts of the basin, in terms of relief, subsurface characteristics and hydrology. At the same time, many deltas are centres of large populations, agricultural production and economic activity, while maintaining direct connections to the health of the respective river basins. Deltas are therefore given special attention in the TWAP RB, and four Delta Vulnerability indicators were included for a selected number of deltas.

The results of Lakes and Deltas indicators are presented below. Additional water system links are explored in the TWAP Cross-cutting Perspectives Report (www.geftwap.org).

5.1 Lake Influence

Key findings

1. **Low storage capacity can make basins more vulnerable to a changing climate:** Basins which suffer from water stress, droughts or floods may be even more vulnerable if they also have low lake storage capacity to act as a buffer (e.g., north-west Africa, parts of basins in southern Africa, and the Indian sub-continent). Water demand management in these areas is key.
2. **The proportion of reservoirs to lakes can guide responses:** Considering the proportion of reservoirs to natural lakes (i.e. the degree of controllable storage) provides further information for the design of response options to challenges such as water scarcity or exposure to floods. Response options are likely to be different in basins with high proportions of controllable storage compared to basins with high proportions of natural lakes.

Rationale

The main aim of the Lake Influence Indicator is to provide information about the buffering and storage capacity of lakes within transboundary river basins. In contrast to the flowing waters of rivers, lakes store water and release it slowly or, if managed, when required. Managed or unmanaged levels of lake storage therefore provide flood protection and alleviate water shortages for residential, commercial, industrial and agricultural uses downstream. Lakes also influence water quality, including the dynamics of nutrients and pollutants in the water column. For example, because of their large volumes and long water-residence times, the natural buffering capacity of lakes can neutralize or otherwise remove pollutants entering them. At a certain point, however, the buffering capacity of a lake can be exhausted or overwhelmed, and the lake then becomes a source of pollution for downstream rivers until the pollutants contained in it are flushed out or otherwise neutralized.

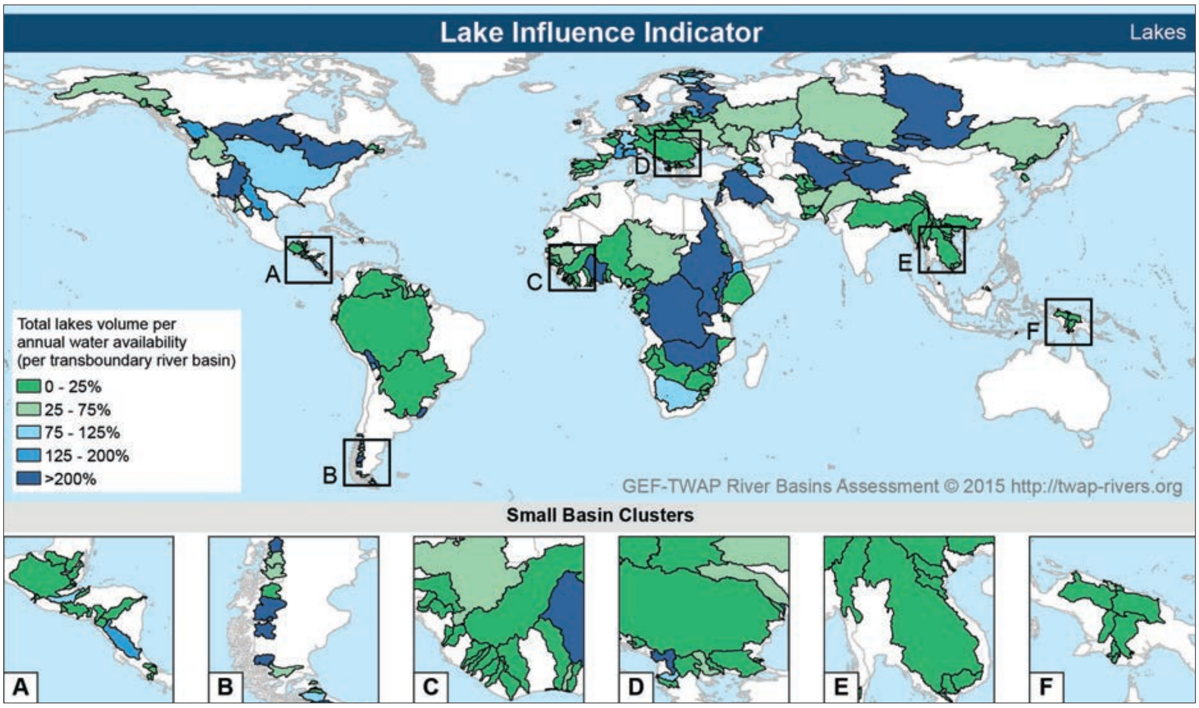
Computation

In order to determine the influence of lakes in each river basin, the storage capacity of all lakes within the basin was determined and divided by the annual surface water availability in the basin. All lakes of the Global Lakes and Wetland Database Level 1 (GLWD1, Lehner and Döll 2004) were considered. Calculation of the Lake Influence Indicator requires information on the storage capacity of lakes, which was collected from various data sources (Global Lake Database, Global Lake and River Ice Phenology Database, World Lake Database, Lake Model FLake, and single papers/studies). If data for lake volume were not available, it was calculated from lake area and mean depth. When no information on lake volume or depth was available, lake volume was estimated using methods described by Ryanzhin (2005). Mean annual water availability (taking into account human impacts) for 1971-2000 was simulated by the Global Hydrology Model WaterGAP2.2 (Müller Schmied *et al*. 2014).

Results

The lake influence in each transboundary river basin is shown in Figure 5.1 for 1971-2000. A low buffering capacity of lakes in relation to annual river discharge (i.e. <25%) is found in most river basins in South America, Eastern Europe, Spain, the Middle East and South-East Asia, and some geographically-dispersed basins in Africa. A relatively high buffering capacity (i.e. >75% of annual flow) occurs in most basins in North America, Africa in the Nile basin and basins near and south of the Equator, Northern and central Europe (e.g. Scandinavia, Eastern France, Western Germany, Switzerland and Northern Italy), and some basins in central Asia (e.g. Jenisej, Har Us Bur, Tarim, Ili, Euphrat-Tigris and Oral).

Figure 5.1. Lake Influence Indicator per Transboundary River Basin for 1971-2000, represented by the Ratio of Total Lake Volume to Mean Annual Water Availability. A relatively high buffering capacity occurs in most basins in North America, Africa in the Nile basin and basins near and south of the Equator, Northern and central Europe, and some basins in central Asia.



Interpretation of results

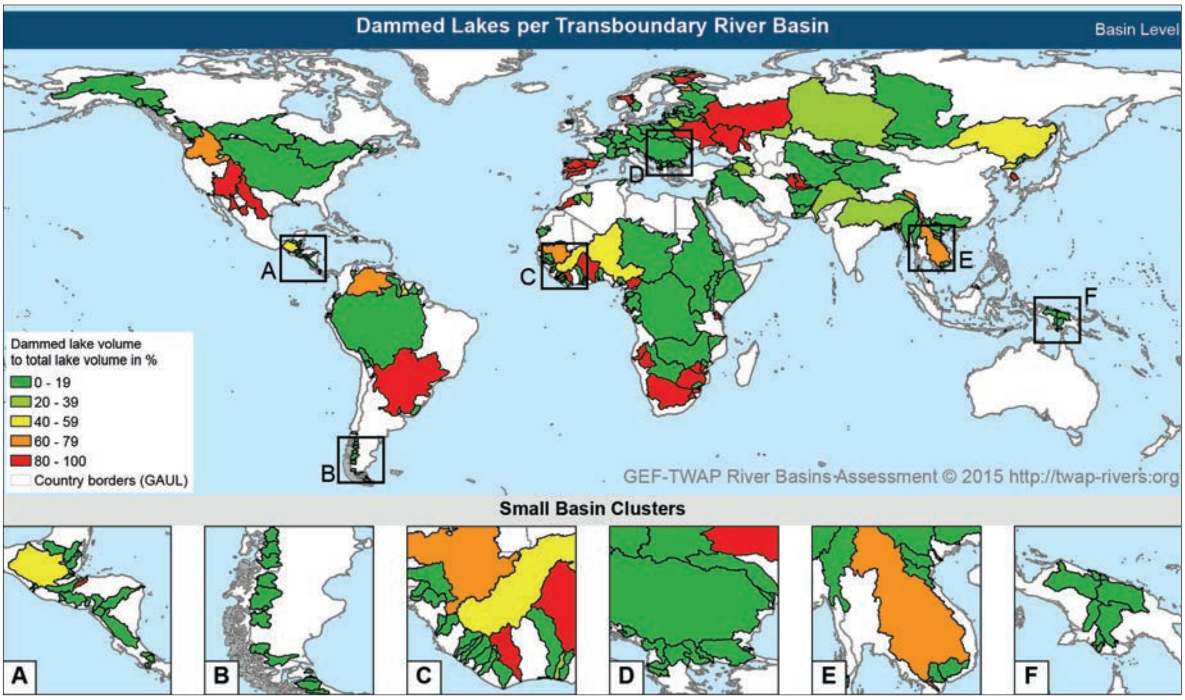
The indicator describes the relative influence of lakes in each transboundary river basin measured by the storage capacity of all lakes in the basin in relation to the mean annual river discharge. In contrast to the other indicators in TWAP, the Lake Influence Indicator does not present results in terms of risk as there is no boundary condition or limit for defining an acceptable or unacceptable storage volume. Instead, the aim of this indicator is to provide additional information which indicates how a basin as a whole may react to certain threats, and how it relates to lake or river conditions (e.g. with regard to water quantity or quality). In principle, the higher the value of this indicator, the higher the buffering capacity of the lakes within the river basin.

In relation to water stress, lakes provide temporary water storage and hence a source of freshwater. The buffering effect of lakes also means that seasonal differences in flow are less pronounced since water is released slowly. River basins with a relatively small lake capacity may therefore be more vulnerable to water stress, especially in regions of high seasonal or inter-annual variability. In the TWAP RB, water stress is addressed by the Human Water Stress (#2) and Agricultural Water Stress (#3) indicators. River basins that are prone to water stress and have a relatively low lake buffering capacity can be found particularly in the Middle East (e.g. the Indus, Helmand, Hari and Murgab river basins), in South-west (i.e. Iberian river basins) and in South-east Europe (e.g. the Danube) and in North-west Africa at the edge of the Sahara desert (e.g. the Guir, Dra and Atui river basins). In contrast, water-stressed basins in South-west U.S.A (e.g. the Colorado and Rio Grande), Central Asia (e.g. the Tarim, Ili, and Aral Sea) and the Middle East (Tigris-Euphrates) have a high buffering capacity through lakes. The same applies to the Nile basin, but large geographical disparities in the large basin need to be considered. Most of the lakes in the Nile basin are in the upper part of the basin (i.e. in Uganda, Tanzania and Ethiopia), where most of the water is generated. In the lower part of the basin (i.e. Egypt and Sudan) most of the water is withdrawn due to high irrigation demand and a high population density. Here, at least the Nasser Lake provides large water storage which acts as a buffer for water stress.

With regard to water quality, the buffering capacity of lakes can reduce water pollution of rivers downstream, e.g. by decomposing nutrients, neutralizing acids, and removing pollutants. This is because of the large water volumes and long water residence times in lakes. A large lake storage capacity within a river basin also results in lower concentrations of pollutants during dry seasons, because of the lower inter-annual variability with elevated low flows. Contamination by nutrients (particularly forms of nitrogen and phosphorous) increases the risk of eutrophication in rivers which can pose a threat to environmental and human health (e.g. algal blooms, decreases in dissolved oxygen, increases in toxins). The Nutrient Pollution Indicator (#4) (section 3.3.1) considers agricultural (e.g. fertilizer, manure, and livestock) and urban sources (e.g. sewage water), and thus diffuse and point sources. The Nutrient Pollution indicator shows that a large number of river basins in Europe have a high risk (i.e. risk category 4 or 5) of nutrient pollution. Among these basins, the lake buffering capacity is low (i.e. <25% of annual water availability) in Spain and France (e.g. in the Seine, Garonne, Ebro, and Duero basins) and in Eastern Europe (e.g. Elbe, Oder, Vistula, Neman, Danube and Maritsa basins). Other basins with a high risk of nutrient pollution together with a low lake influence are in Asia in the Ganges-Brahmaputra-Meghna, Bei Jiang, and Han basins, and in Africa in the Limpopo and Thukela basins. In North America, the Mississippi basin has a medium-high risk (i.e. risk category 4) of nutrient contamination. However, here almost 100% of the annual flow can be stored in lakes, where nutrients can be decomposed because of the long water-residence times.

While lakes act as a buffer and can reduce water quantity and quality threats, lakes and rivers interact with each other because of their hydrological connectivity. Problems of water scarcity with reduced river flows can reduce lake and wetland levels, thereby reducing aquatic habitats and harming freshwater ecosystems. The most notorious example is the demise of the Aral Sea by water diversion for irrigation, which is described in the literature as the biggest ecological catastrophe of human making. Problems of poor water quality in rivers can exhaust the buffering capacity of lakes, so that lakes themselves can become a source of pollution for rivers downstream for decades. Upstream rivers with high nutrient loadings can threaten the ecological integrity of lakes, leading to many of the eutrophication effects noted above for rivers. The water quality and quantity of lakes therefore need to be taken into account when interpreting the results of the Lake Influence Indicator.

Figure 5.2. Percentage of lake storage from dammed lakes to total lake storage within each transboundary river basin. Man-made lakes dominate in western U.S.A. and northern Mexico, the La Plata basin in South America, Spain and Portugal, Belarus, Ukraine and western Russia, southern and parts of western Africa.



For the purpose of this indicator, no distinction is made between natural and man-made lakes (reservoirs) since both provide buffering capacity. Dams can be managed in an optimal way, so that most water is stored in the reservoir in times of water scarcity and most storage capacity is reserved for flood control at times of higher flood risk. A large proportion of controllable water storage in a basin therefore offers opportunities for water management such as water supply for different water-use sectors during dry seasons, flood protection, electricity production, and navigation. So for basins with a high proportion of controllable storage, which also have high relative risk for Human Water Stress (#2), Agricultural Water Stress (#3), Exposure to Floods and Droughts (#15), further investigation may be needed into the potential for improvements in reservoir operation with the aim of reducing these other risks. Reservoir operations may already be optimized in some cases, but in others there may be scope for improvement through modelling and forecasting.

However, the benefits gained by damming of rivers have often come at great cost to river ecosystem integrity and services. (i) Dam operations alter river flow regimes and thereby compromise ecological functions and habitats, and affect the dynamics of deltas, estuaries, floodplains and riparian wetlands (Poff and Zimmermann 2010; Lloyd *et al*. 2004). (ii) Dam walls disrupt longitudinal connectivity and thereby hinder migration and distribution of many organisms, as well as transport of sediment, nutrients and organic material (Pringle 2001). (iii) Dam releases often come from the lower layer of the lake and differ markedly from reservoir inflows with regard to water quality (e.g. lower temperature and reduced dissolved oxygen) (Petts 1984), and (iv) reservoirs contribute to greenhouse gas emissions, particularly in hot climates (St. Louis *et al*. 2000). Figure 5.2 shows transboundary river basins where the lake buffering capacity is achieved mainly by man-made rather than natural lakes, providing both opportunities and ecological risk resulting from controllable storage.

These basins are in Western U.S.A. and Northern Mexico (i.e. Colorado, Rio Grande, Yakui River basins), South America (i.e. only the La Plata basin), Spain and Portugal (i.e. Duero, Tejo, Guadiana and Ebro basins), Belarus, Ukraine and Western Russia (i.e. Dnieper, Don and Volga basins), Western Africa (i.e. Sassandra, Volta, Sanaga and Nyanga basins), and Southern Africa (i.e. Orange, Limpopo, Sabi, Buzi, Etosha and Kunene basins). The ecological consequences of damming rivers are further discussed in the section on Ecosystem Impacts from Dams (#7) and Environmental Water Stress (#1). For example, hotspots of river fragmentation, flow disruption and dam density found by Indicator #7 (in North America, parts of Europe, South Africa and the Middle East) coincide quite well with the ratio of dammed lakes presented in Figure 5.2. However, in the Middle East and Eastern U.S.A., the ecological impacts are masked by the dammed lake ratio due to large existing natural lake storage in the basins (e.g. Lake Van and Dead Sea in the Middle East, and the Great Lakes in U.S.A. and Canada). Lake Van and the Dead Sea are characterized by a high salinity, making them mostly unusable for water-supply purposes.

Limitations and potential for future development

In contrast to the other indicators in TWAP, the Lake Influence Indicator does not present results in terms of risk as there is no boundary condition or limit for defining an acceptable or unacceptable storage volume. Instead, this indicator can provide additional information by combining results with risk-based indicators from both the River Basin and the Lake Basin assessment. Future analysis may consider the links between river basins and lake basins more explicitly, including comparing risks in both.

An extensive literature research was conducted for this indicator to collect lake storage capacity data from various sources. However, for about 40% of the lakes, the lake storage capacity needed to be estimated using methods described by Ryanzhin (2005). These methods depend on relationships between surface area and lake volume and entail a higher degree of uncertainty.

All lakes from the GLWD1 dataset were taken into account. This dataset contains larger lakes with a surface area ≥ 50km^2. In the future, also the GLWD-2 dataset, which comprises permanent open water bodies with a surface area ≥ 1 km^2, could be considered for this indicator. However, data on lake volume might be scarce for smaller lakes.

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5.2 Delta Vulnerability

Key Findings

1. **The vulnerability of deltas differs across the world:** The results show a geographical spread of vulnerability depending on the indicator. The Ganges-Brahmaputra-Meghna delta appears to be the most vulnerable, followed by the Niger and Volta deltas. The Amazon, Orinoco and Yukon deltas appear to have low to moderate vulnerability.
2. **Deltas in Asia are most at risk:** In general the deltas in Asia seem to have the most serious challenges in terms of human vulnerability caused by a combination of relative sea level rise and population pressures (and sometimes poor delta governance).

Rationale

The delta is a major component of many river basins. Because of their location and geomorphological characteristics, many deltas have relatively high population densities, large agricultural outputs, considerable economic and ecosystem productivity and often still contain areas of international ecological importance. Their functioning is highly dependent on the characteristics and activities in the (transboundary) river basin. Of particular importance are river flows with accompanying sediment and nutrient fluxes. The transboundary influence on deltas is a major contributing factor to their sustainability, which is further determined by 'local' characteristics, such as population pressures and sea level rise.

Delta vulnerability is a function of physical (fluvial) pressures, (local) state conditions and response capacities (governance).

Selection of Deltas

All TWAP river basins were screened for significant deltas. A worldwide dataset of 84 important deltas was created using following criteria:

- area of upstream river basin;
- delta area;
- delta population;
- ecological or agricultural importance;
- data availability.

The dataset was created by combining the World Delta Database with the overviews of Syvitsky *et al*. (2009), Ericson *et al*. (2006) and Bucx *et al*. (2010).

A subset of 40 deltas that are part of a transboundary river basin was identified and further subdivided into six classes:

*****	basin area >100 000 km^2 *and* delta area >1 000 km^2 *and* delta population >1 000 000 *and* large data availability;
****	basin area >100 000 km^2 *and* delta area >1 000 km^2 *and* delta population >1 000 000;
***	basin area >100 000 km^2 *and* delta area >1 000 km^2;
**	basin area <100 000 km^2 *or* delta area <1 000 km^2;
*	basin area <100,000 km^2 *and* delta area <1 000 km^2;
0	basin area >100 000 km^2, *but no other data*.

The 26 deltas rated *** and higher were selected for the assessment.

Delta vulnerability Indicators

Delta vulnerability is based on four indicators:

1. Relative sea level rise (RSLR);
2. Wetland ecological threat;
3. Population pressure;
4. Delta governance.

At the start of the project it was decided that only a limited set of indicators would be used for the delta assessment, which best reflect vulnerability to the most important drivers of change and pressures. The RSLR includes sea level rise resulting from climate change, subsidence (natural and anthropogenic) and delta aggradation. The wetland ecosystems in deltas are particularly under pressure from urbanization, agricultural and aquaculture expansion, and industrialization. The wetland indicator is based on the ecological value and the documented threats to the wetlands. In addition to the generally high population pressure, rapid urbanization is occurring in many of the deltas. However, population density can also differ significantly between deltas. With deltas generally being under high pressure, good governance is of extreme importance for sustainable management and development. Three principles are used for the governance indicator: adaptivity, participation and fragmentation. These are assessed at four different levels of institutionalization. Compared to the five thematic groups of the river basin assessment, the RSLR corresponds best with Water Quantity, the Wetland Ecological Threat Indicator to Ecosystems, the Population Pressure Indicator to Socio-economics and the Delta Governance Indicator to Governance.

In the course of the project it was decided that an overall Vulnerability Index as an average of the scores of the four indicators was not appropriate since most of the extremes would be levelled out to a general average value between 2 (relative low risk) and 3 (relative moderate risk). Moreover combining the indicators would involve weighting, which might be done differently by different stakeholders, depending on their point of view. The final results are therefore presented for each of the individual Delta Vulnerability indicators separately.

The assessment methodology and results for the four Delta indicators are described in the following sub-sections.

5.2.1 Relative Sea Level Rise (RSLR)

Key Findings

1. **Sea level rise threatens deltas in Asia, Africa and America:** Most of the deltas at very high risk are in Asia (Ganges, Indus, Irrawaddy and Mekong). A considerable number of deltas in Africa and America are also at (very high) risk, especially the Niger and Rio Grande. Europe has the fewest transboundary deltas, with only the Rhone at very high risk. Higher risk of relative sea level rise means increased flood risk which may result in loss of life and (severe) loss of economic and ecological assets.
2. **Population increase is a major factor in the risk of sea level rise:** One of the important factors for the RSLR is increasing population in delta (mega) cities, especially in Asia. This often results in less delta aggradation and increased human-induced (accelerated) land subsidence caused by severe ground water extraction in order to meet high(er) water demand.

Rationale

Many deltas are threatened by relative sea level rise (RSLR) resulting in increased flood risk (both coastal and freshwater), which can result in loss of life and severe impacts on human development and ecosystems. RSLR is determined by the balance between: (1) delta aggradation, (2) land subsidence and (3) sea-level rise.

(1) Delta aggradation is caused by fluvial sediment supply, but may be strongly influenced by human flood protection infrastructure inhibiting the distribution of sediments over the delta surface.

(2) Land subsidence results from various processes, some of which are natural (e.g., tectonic and isostatic movement, sediment compaction), while others are highly human-influenced, as a result of drainage activities or subsurface mining.

(3) Sea-level rise is a world-wide process, but nevertheless spatially variable because of varying gravimetric effects.

The RSLR indicator is based on the total sinking rate of the delta surface in mm/year (caused by the three components mentioned above) relative to the local mean sea level.

Computation

For the TWAP assessment, aggradation, subsidence and sea level rise are assessed for each delta from published data (Syvitski *et al*. 2009 and Ericson *et al*. 2006). On the basis of the available quantitative data, each delta is assigned to one of five relative sea level rise (RSLR) categories, largely following Ericson (2006), with category 1 representing no RSLR (<= 0 mm/yr) and category 5 representing high RSLR (>5 mm/yr).

Results

Of the transboundary deltas assessed, the most at very high risk are in Asia (Ganges, Indus, Irrawaddy and Mekong). Many deltas are also at (very high) risk in Africa and America, especially the Niger and Rio Grande. Europe has the fewest transboundary deltas, with only the Rhone at very high risk.

Figure 5.3. Relative Sea Level Rise Indicator (deltas). Includes reduction in sediment supply, land subsidence and sea level rise. Deltas in the higher risk categories have increased flood risk.

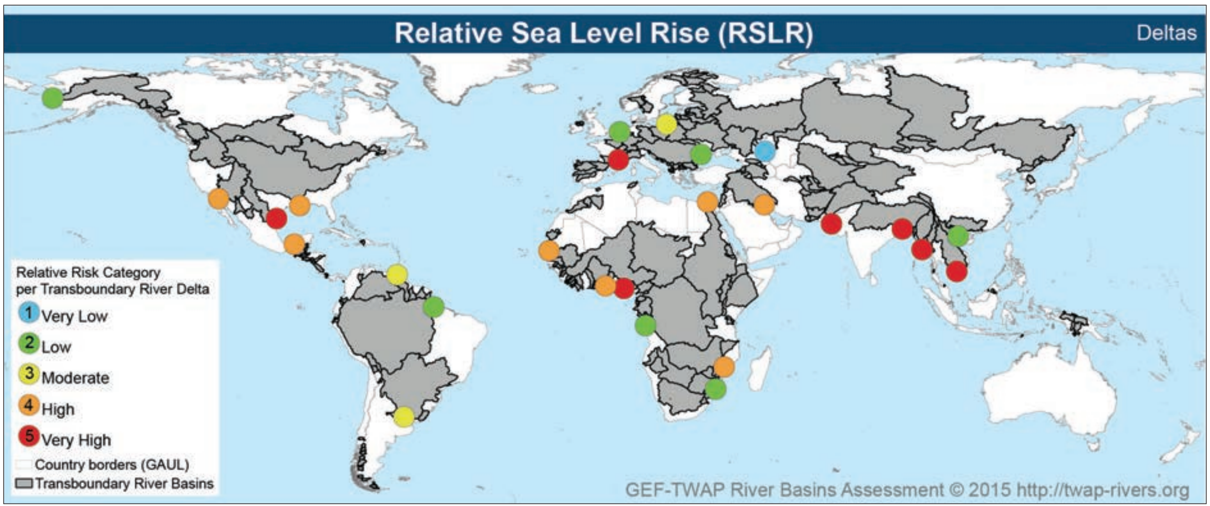


Table 5.1. Relative risk categories for Relative Sea Level Rise (RSLR) (deltas)

	Deltas	Relative risk category	RSLR (mm/ year)	Source
Americas	Amazon	2	0 - 1.5	Ericson
	Colorado	4	2- 5	Syvitski
	Grijalva	4	3 - 5	Ericson
	Mississippi	4	2 - 5	Syvitski
	Orinoco	3	0.8 - 3	Syvitski
	Parana (La Plata)	3	2 - 3	Syvitski
	Rio Grande	5	5 - 7	Ericson
	Yukon	2	0 - 1.5	Ericson
Europe	Danube	2	1.2	Syvitski
	Rhine-Meuse	2	0 - 1.5	Ericson
	Rhone	5	2 - 6	Syvitski
	Volga	1	0	Li *et al.*
	Wisla	3	1.8	Syvitski
Asia	Ganges-Brahm'a-Meghna	5	8 - 18	Syvitski
	Hong (Red)	2	0 - 1.5	Ericson
	Indus	5	> 11	Syvitski
	Irrawaddy	5	3.4 - 6	Syvitski
	Mekong	5	6	Syvitski
	Shatt-al-Arab	4	4 - 5	Syvitski
Africa	Congo	2	?	Syvitski
	Limpopo	2	0.3	Syvitski
	Niger	5	7 - 32	Syvitski
	Nile	4	4.8	Syvitski
	Senegal	4	3 - 5	Ericson
	Volta	4	3 - 5	Ericson
	Zambezi	4	5	IPCC

RSLR (mm/ year)	Relative Risk Category
<=0	1 Very low
>0 - 1.5	2 Low
1.5 - 3	3 Moderate
3 - 5	4 High
> 5	5 Very high

Higher risk of RSLR means increased flood risk, which may result in loss of life and economic and ecological assets. This involves, among others, coastal erosion, loss of (wet)lands and other natural resources, damage to (critical) infrastructure, buildings and industrial areas. The higher the risk category the more severe the impacts of actual flooding. However several kinds of adaptive measures can be implemented to reduce the risks (green/soft measures, civil engineering/hard measures and institutional/organizational measures).

One of the important factors for the RSLR is increasing population in delta (mega)cities, especially in Asia. This often results in less delta aggradation and increased human-induced (accelerated) land subsidence caused by severe groundwater extraction to meet high(er) water demand.

Results for this indicator can be compared with the river basins Water Quantity thematic group (section 3.2) to gain an understanding of the relative threat levels for deltas and their respective river basins.

Limitations and potential for future development

In the RSLR assessment, it was not possible to separately quantify the various components of aggradation, land subsidence and regional sea level rise.

Intra-delta spatial variability, which in many cases is high, is not taken into account; ranges provided are based on measurements at either different times or different areas of a delta (Syvitski 2009). Estimation of accelerated subsidence is problematic due to spatial and temporal variations depending on the location and intensity of the human activities causing the subsidence (Ericson 2006).

In the absence of reliable data, a factor of three times the natural subsidence rate is applied to define the upper limit of the potential accelerated subsidence based on the assumption that accelerated subsidence is a direct result of the magnitude of anthropogenic influence on delta sediment (Ericson 2006).

More research and data are needed for better estimation of the risk of RSLR and related impacts especially regarding land use, land subsidence and sediment supply.

5.2.2 Wetland Ecological Threat

Key Findings

1. **Valuable deltas are at risk:** The most valuable deltas (in terms of wetland area and ecological value) are the Danube and Volga deltas which still have large wetlands with high ecological value, but, as shown by the documented threats, they are also the deltas with wetland ecosystems that are most at risk.
2. **American deltas are at lower risk:** The deltas in the Americas seem to be less at risk than those in other continents. This is probably due to relative low human pressures and good governance.

Rationale

Wetlands are the most typical ecosystems in deltas. Information on wetlands in deltas provides an indication of their biodiversity value and level of natural state. In principle all types of wetlands can be found in deltas, including typical coastal wetlands such as mangrove, estuary and lagoon as well as freshwater wetlands (bogs, fens, lakes, marshes).

Computation

The determination of the Wetlands Ecological Threat Indicator is based on three main factors:

1. **The share of wetland ecosystems within the delta**, based on data from the Global Lakes and Wetlands Database (GLWD- 3) (Lehner and Döll 2004).

2. **The ecological value** determined by the presence of:
   a) Biodiversity Hotspot(s): regions of global conservation importance defined by the presence of high levels of threat (at least 70% habitat loss) in areas with high levels of species endemism (at least 1 500 endemic plant species) (Myers *et al*. 2000);
   b) Key Biodiversity Area(s) (KBA): sites identified as a conservation priority for a variety of species (birds, mammals, plants, etc.) (Langhammer *et al*. 2007);
   c) Ramsar site(s): areas that come under the Convention on Wetlands (Ramsar Convention), an intergovernmental treaty to maintain the ecological character of Wetlands of International Importance;
   d) Global 200: ecoregions with conservation priority, identified by WWF (Olson and Dinerstein 1998)[26];
   e) World Network of Biosphere Reserve(s): protected areas assigned under the Man and the Biosphere Programme (MAB-Reserve), UNESCO;
   f) Formally protected areas: covers a number of protection categories; the formal protection most relevant for biodiversity is IUCN category 1-2.

3. **The environmental threat:**
   a) Threats mentioned in descriptions of the biodiversity hotspots;
   b) Threats mentioned in the Global 200 regions;
   c) For those not covered, site descriptions from Ramsar or similar deltas were used.

The criteria are further explained in the Metadata sheet in Annex IX-6. Not all are formally recognized statuses for deltas.

'Share of wetlands' uses a score 1-5 on the basis of the share of wetlands compared to the total delta area (in %). The GLWD-3 contains 12 wetland classes, which are all given equal weight in the calculation of the fraction of the

26 The **Global 200** is the list of ecoregions identified by WWF, the global conservation organization, as priorities for conservation. According to WWF, an ecoregion is defined as a "relatively large unit of land or water containing a characteristic set of natural communities that share a large majority of their species, dynamics, and environmental conditions (Olson & Dinerstein 1998, 2002).

deltas classified as wetlands. In a few cases a correction was made for the share of wetlands, where it is known from the statistical data that they include mostly farming areas (e.g. rice paddies or other farming areas, as in the Hong, Mekong, Senegal and Volta deltas).

'Ecological value' combines the six criteria mentioned above. All were simply scored with 1 (or 0.5 if the criterion applies only for a small part of the area) and added together to determine the score for the ecological value.

'Environmental threat' is based on an inventory of the threats per delta ecosystem. Some 27 threats are cross-tabulated. The information is based on the descriptions available for the Biodiversity Hotspots and Global 200 areas (see above and meta data sheet). In the few cases where no information is available for an area, information is used for adjoining rivers with additional information from the formal Ramsar site description sheets. The number of threats are scaled using a 1 - 5 point scale.

Next, the '**Calculated average wetland ecological Value (CV)'** is determined as the average of the scores of the share of wetlands and the ecological value. This results in a value ranging from 0.75 – 4.50.

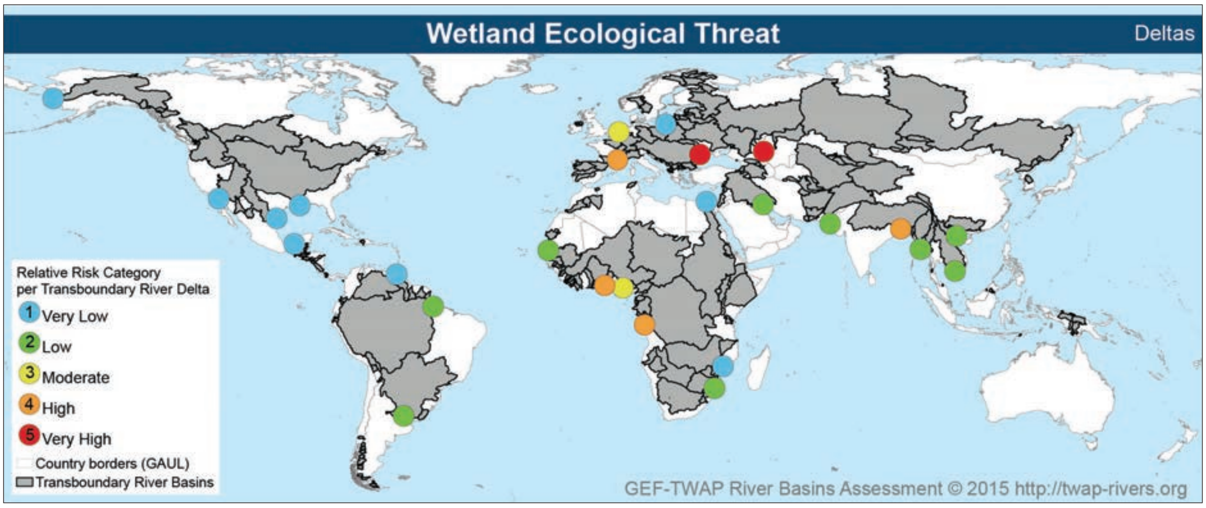
Then, the '**Wetland Ecological Threat Indicator'** is calculated by multiplying the CV by the number of threats, resulting in values ranging from 2 – 17.5. Finally, this value is re-scaled to a scale 1-5, to make it comparable with the results from the other assessments of the other indicators.

Details of the various inventories and steps are given in Annex IX-6. The main results are presented below.

Results

The ecological value of deltas is defined by the presence of wetlands, as well as the classification of (parts of) the delta as important areas for biodiversity. The most valuable are the Danube and Volga deltas which are still large wetlands, but, in combination with the documented threats, they are also the deltas with wetland ecosystems that are most at risk. Deltas with a high relative risk score are the Rhone, the Ganges-Brahmaputra-Meghna, the Congo and the Volta.

Figure 5.4. Wetland Ecological Threat Indicator (deltas). Based on the proportion of wetlands in the delta, the 'ecological value' and the threats to the wetlands. The Danube and the Volga are at highest risk.



The Deltas in the Americas seem to be less at risk than those in other continents, which is often related to the human pressures exerted, but in some cases governance may affect this result since formal conservation or acknowledgement of value may be in place.

Table 5.2. Relative risk categories for Wetland Ecological Threat Indicator for the selected deltas

Deltas	Relative Risk Category	Share wetland eco-systems (S)	Ecological value (V)	CV Calculated wetland ecological Value CV =(S+V)/2	Environ-mental threats (scaled) (T)	Wetland Ecological threat (CV*T)
America						
Amazon	2	4	0.5	2.25	3	6.75
Colorado	1	1	4	2.5	1	2.5
Grijalva	1	1	2	1.5	2	3
Mississippi	1	4	0	2	1	2
Orinoco	1	1	1.5	1.25	3	3.75
Parana (La Plata)	2	3	1.5	2.25	2	4.5
Rio Grande (R. Bravo)	1	1	1.5	1.25	2	2.5
Yukon	1	5	2	3.5	1	3.5
Europe						
Danube	5	5	4	4.5	3	13.5
Rhine-Meuse	3	3	2.5	2.75	3	8.25
Rhone	4	5	3	4	3	12
Volga	5	5	4	4.5	3	13.5
Wisla	1	1	1	1	3	3
Asia						
Ganges-Brahm'a-Meghna	4	4	4.5	4.25	3	12.75
Hong (Red River)	2	1.5*	3.5	2.5	2	5
Indus	2	3	3	2.5	2	5
Irrawaddy	2	3	2	2.5	2	5
Mekong	2	2.5*	2.5	2.5	2	5
Shatt-al-Arab	2	2	2	2	2	4
Africa						
Congo	4	2	2	2	5	10
Limpopo	2	4	1	2.5	2	5
Niger	3	3	2	2.5	3	7.5
Nile	1	1	0.5	0.75	5	3.75
Senegal	2	2.5*	1.5	2	2	4
Volta	4	2.5*	2	2.25	5	11.5
Zambezi	1	1	2.5	1.75	2	3.5

** corrected for large agricultural areas*

Wetland Ecological Threat Indicator. (CV*T)	Relative Risk Category
1 - 4	1 - Very low
4 - 7	2 - Low
7 - 10	3 - Moderate
10 -13	4 - High
>13	5 - Very high

Results for this indicator can be compared with the river basins Wetland Disconnectivity Indicator (section 3.4.1) to gain an understanding of the relative threat to wetlands in the delta and the respective river basin.

Limitations and potential for future development

The indicator developed here is currently the best available, given the available data. There are however several shortcomings. The problem for some ecological indicators, for example the presence of a Ramsar site or protected status, is the fact that the assignment of a site on the official list is a function of political will rather than ecological criteria alone. We have therefore combined different ecological indicators, which are also partly based on objective scientific criteria such as species biodiversity or ecosystem value. Aberrations are therefore levelled out.

The data are better in the more developed countries, which may provide a slight bias, e.g. in Europe.

The wetland percentage of deltas as derived from the GLWD is an important indicator of the ecological value, but in some locations (such as the Mekong, Hong, Senegal and Volta deltas), the delta is almost fully classified as wetlands according to the global lake and wetland database, while it is generally known that large parts of these deltas are used for agriculture. This is probably because a large part of the agricultural land is still under natural annual flooding. Some correction of the wetland share and the combination of this indicator with the ecological indicator leads to a balanced result.

The ecological value is only a proxy for the real value, since there is no adequate database available.

The environmental threats are based on descriptions of deltas, rivers, and regions which differ in scale, author, and ecosystem. The purpose of the descriptions differ, as do the year of description. The number of threats are therefore not based on a balanced review of all deltas, rather it is an inventory of threats mentioned on different websites, and partly based on the country reports (e.g. on the Ramsar site sheets).This makes the source data rather diverse, and as a consequence the threats are difficult to compare for each delta. A more extensive review of all threats would be required for each delta to ensure that the descriptions are more homogeneous and comparable.

5.2.3 Population Pressure

Key Findings

1. **Of the assessed deltas, those in the 'very high' relative risk category for population density are in Asia (Ganges and Hong) and Africa (Nile).**
2. **The deltas usually have much higher population densities than the river basins, which can increase pressures on upstream areas. If socio-economic indicators for the respective river basin reveal high risk and the population pressure in the delta is also high, the situation may be more acute.**

Rationale

High population pressures pose challenging demands on delta resources, such as freshwater, fertile soils, space and ecosystem regulation functions. This can also impact upstream river basin resources and their management.

Population pressure is a relative measure on a scale of 1 to 5, based on the average number of people per square km.

Computation

CIESIN (Center for International Earth Science Information Network) holds global data sets on population (http://sedac.ciesin.columbia.edu/data/collection/gpw-v3).

The Gridded Population of the World (GPWv3) shows the distribution of human population across the globe. This is a gridded, or raster, data product that renders global population data at the scale and extent required to demonstrate the spatial relationship of human populations and the environment across the globe. The data contains a projection of the number of people living in each 2.5 arcseconds gridcell for 2010, based on census data of 2000.

These data are combined with the defined extent of the deltas to calculate an average population density per delta. First, the population in all 2.5 arcsecond cells that have their centroids within the polygons of the deltas are summed. Then an average population density is calculated using the area of the delta.

Results

Of the assessed deltas of transboundary basins, the most at risk, caused by a very high population density, are in Asia (Ganges and Hong) and Africa (Nile). A few deltas in Asia, Africa and Europe are at high risk (Mekong and Irrawaddy in Asia, Niger in Africa and the Rhine-Meuse and Wisla in Europe). The deltas in South America have a very low population density and are therefore considered not at risk.

The results of this indicator can be aligned with results of the socioeconomic indicators for the respective river basin. For example, if vulnerability in the river basin is high, and population pressure in the delta is high, the situation may be more acute.

Figure 5.5. Population Density Indicator (deltas). Deltas in the 'very high' relative risk category are in the Ganges and Hong deltas (Asia) and the Nile delta (Africa).

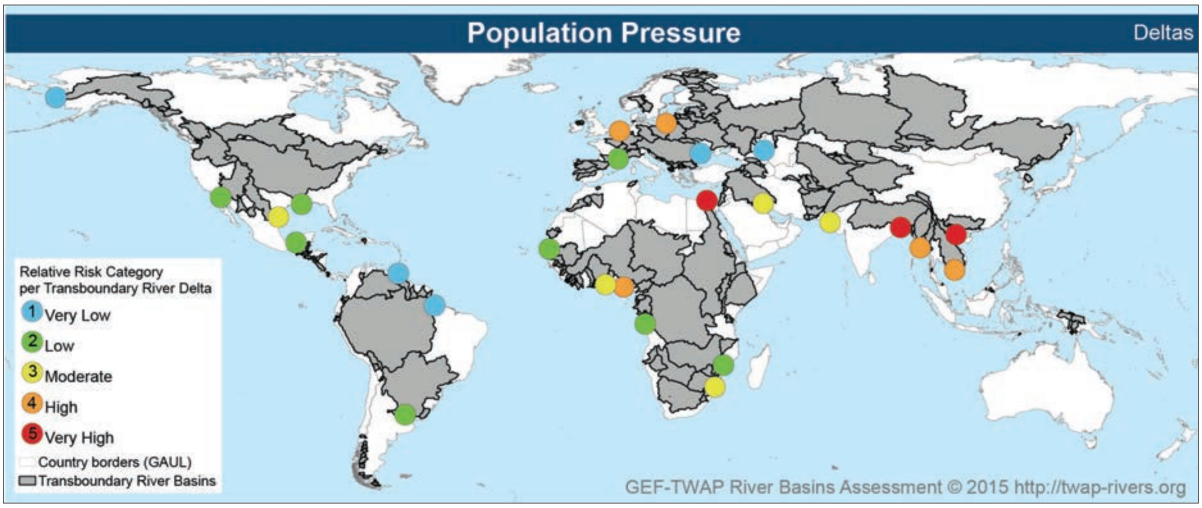


Table 5.3. Relative risk categories for the Population Density Indicator for the selected deltas

	Deltas	Relative risk category	Population Density
Americas	Amazon	1	7.2
	Colorado	2	46.1
	Grijalva	2	45.1
	Mississippi	2	62.2
	Orinoco	1	6.3
	Parana (La Plata)	2	41.7
	Rio Grande	3	141.0
	Yukon	1	0.10
Europe	Danube	1	21.7
	Rhine-Meuse	4	768.8
	Rhone	2	64.1
	Volga	1	22.4
	Wisla	4	269.2
Asia	Ganges-Brahm'a-Meghna	5	1 332.3
	Hong (Red)	5	1 491.9
	Indus	3	141.5
	Irrawaddy	4	310.4
	Mekong	4	598.5
	Shatt-al-Arab	3	179.2
Africa	Congo	2	29.2
	Limpopo	3	245.1
	Niger	4	293.2
	Nile	5	1 854.1
	Senegal	2	54.7
	Volta	3	168.4
	Zambezi	2	30.6

Population Density (persons/km²)	Relative Risk Category
0 – 25	1 - Very low
25 – 100	2 - Low
100 – 250	3 - Moderate
250 – 1 000	4 - High
> 1 000	5 - Very high

Limitations and potential for future development

The population pressure indicator quantifies the average population density in the delta. There is however no information on heterogeneity within the delta. There would be a difference if people are living together in some very densely populated cities, or are more or less spread over the total area. More detailed assessments with delineation of the urban areas are needed.

Similarly, the elevations where people live are not taken into account. Improvement of the quality of the assessment would require the use of digital elevation maps.

Vulnerability also depends, to a large extent, on the quality of housing, which very much depends on the income of the populations, which is not taken into account in this indicator. The assessments could be improved by making use of socio-economic data or surveys.

5.2.4 Delta Governance

Key Findings

1. **Delta governance risks are high in Africa and some northern deltas (Colorado and Danube):** The indicator shows that some of the least at-risk deltas are in Europe and North America. However, it also shows that some of the highest at-risk deltas are also in these continents (Colorado Delta and Danube Delta) because of the transboundary aspect. The African continent shows a moderate to very high risk for Delta Governance, thereby showing that this continent is at-risk from inadequate governance.

Rationale

Governance describes the structures and processes for collective decision-making involving governmental and non-governmental actors (Neye and Donahue 2000). Delta governance focuses on these aspects within a delta. The rationale behind this indicator is that deltas have multi-level, multi-stakeholder, multi-scale dimensions that require a specific approach for governance. As there is relatively little specific information on delta governance, the indicator assesses governance at the country level to approximate governance of the delta. Three key governance principles are used: adaptivity, participation and polycentric governance[27]. Adaptivity is a measure of the capacity of society and institutions to adapt to economic and political change. Participation focuses on transparency, accountability and participation (TAP) and can be used to analyse institutional performance as well as how stakeholders behave and relate to each other. Finally polycentric governance emphasizes the presence of several independent centres of authority in a governance domain. This creates opportunities for further development of environmental policies through policy innovation, consensus building and negotiations. It is also said to perform well regarding complex issues such as climate change adaptation.

Different levels of institutionalization are used for the calculation of the Delta Governance Indicator. A typology of levels of institutionalization is helpful when conducting comprehensive institutional analysis. The typology used is based on the work by Williamson (1998), and Koppenjan, and Groenewegen (2005). The four levels are: (1) the meta level, i.e. norms, values, codes, orientation, culture, and informal institutions, (2) the macro level, i.e. formal rules, laws, regulations, constitutions and the process arrangements that constitute them, (3) the meso level, i.e. covenants, contracts, agreements, plans and the processes that constitute them and (4) the micro level, i.e. actors and interactions, aimed at creating or influencing services, provisions, planning, and outcomes.

Computation

The assessment is done to determine how the different countries score on the three key principles of delta governance on the different levels of institutionalization. This is done on the basis of various indicators from two sources:

- Actionable Governance Indicators (AGI Data Portal) [https://www.agidata.org/site/SourceProfile.aspx?id=21];
- Hofstede Centre, [http://geert-hofstede.com/].

The Delta Governance Indicator identifies the level of existence of the three key aspects of delta governance on a scale from 1 (practically no adaptivity, participation and hardly any polycentric governance) to 4 (a high score on adaptivity, participation and highly developed polycentric governance) based on 43 sub-indicators across the four institutional levels. In some cases there may be two sub-indicators per institutional level, and in which case the scores are averaged. Ultimately this means that there is one score for each institutional level of the indicator. For each of the three key aspects, the results for each institutional level are averaged. These three scores are then averaged to give an overall average for each Delta Country Unit (DCU). The results for each DCU are averaged on the basis of the

27 In the annex and during the development of the methodology, the concept of fragmentation (Isailovic *et al*. 2013; Zelli 2011) was used. However as this concept has ambiguous connotations, it was changed to the term polycentric governance (Pahl-Wostl and Knieper 2014) as this concept explains a comparable dimension of governance, but is less ambiguous.

relative area and population in each DCU compared with the entire delta, to provide the final delta governance score. More details on the computation are given in Annex IX-6.

Results

The Delta Governance Indicator shows that, on the basis of the levels of adaptivity, (institutional) polycentric governance and participation in the specific countries, there is a certain level of (institutional) delta governance capacity available. The indicator shows that some of the least at-risk deltas are, as expected, in Europe and North America. However it also shows that some of the highest at-risk deltas are also in these continents (Colorado and Danube Delta), mainly because of the transboundary aspect.

Although the dataset used is not specifically aimed at the management of natural resources and the environment, it does provide insight into the capacity of the countries to manage both the environmental and natural resources of the delta. This is because the institutional capacity of a country has a cross-sectoral impact, which also includes natural resources and the environment. The results provide an indication of the likelihood of transboundary cooperation and the state of delta governance.

Figure 5.6. Governance Indicator (deltas). Governance risks, based on adaptivity, participation and polycentric governance, are high in Africa and some northern deltas (Colorado and Danube).

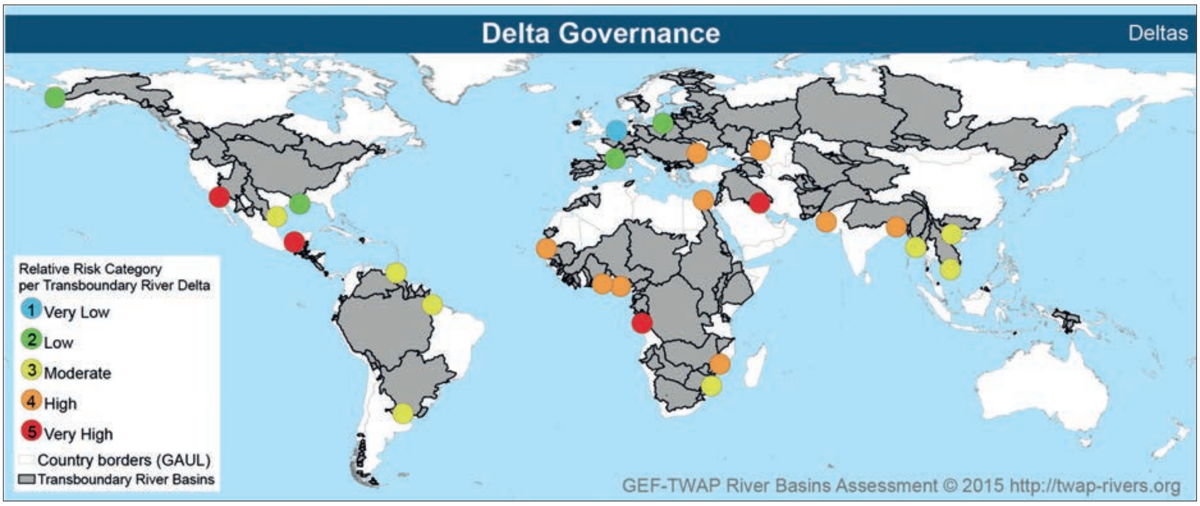


Table 5.4. Relative risk categories for the Governance Indicator for the selected deltas

	Deltas	Relative Risk Category	Governance score
Americas	Amazon	3	6.7
	Colorado	5	4.98
	Grijalva	5	4.98
	Mississippi	2	7.96
	Orinoco	3	6.90
	Parana (La Plata)	3	6.16
	Rio Grande	3	6.65
	Yukon	2	7.96
Europe	Danube	4	5.37
	Rhine-Meuse	1	8.37
	Rhone	2	7.24
	Volga	4	5.57
	Wisla	2	7.11
Asia	Ganges-Brahm'a-Meghna	4	5.53
	Hong (Red)	3	6.21
	Indus	4	5.25
	Irrawaddy	3[1]	…
	Mekong	3	6.13
	Shatt-al-Arab	5	4.90
Africa	Congo	5	4.85
	Limpopo	3	6.09
	Niger	4	5.31
	Nile	4	5.19
	Senegal	4	5.75
	Volta	4	5.72
	Zambezi	3	6.09

Governance score	Relative Risk Category
> 8	1 Very low
7 – 8	2 Low
6 – 7	3 Moderate
5 – 6	4 High
< 5	5 Very high

[1]This value is estimated since no governance data was available for the Irrawaddy delta

Limitations and potential for future development

The general limitations of governance-oriented indicators are that they are often based on survey or interview data which is often described by critics as 'subjective' and they therefore argue that the perception-based data on which these indicators are based reflect vague and generic perceptions rather than specific objective realities. Furthermore, as described above, the indicators used to construct the Delta Governance Indicator are not specifically aimed at natural resource management or the environment.

Additional assessment regarding delta governance could be done by means of (desk) research, questionnaires, interviews and (data) analyses.

5.2.5 Summary of Delta Vulnerability Results

The overall vulnerability of the individual deltas is shown in Table 5.5. The colours and numbers represent the relative risk categories.

Table 5.5. Overview of the relative risk categories for the four indicators (deltas)

	Deltas	Indicators			
		Relative Sea Level Rise	Wetland Ecological Threat	Population Pressure	Delta Governance
Americas	Amazon	2	2	1	3
	Colorado	4	1	2	5
	Grijalva	4	1	2	5
	Mississippi	4	1	2	2
	Orinoco	3	2	1	3
	Parana (La Plata)	3	2	2	3
	Rio Grande	5	1	3	3
	Yukon	2	2	1	2
Europe	Danube	2	5	1	4
	Rhine-Meuse	2	3	4	1
	Rhone	5	4	2	2
	Volga	1	5	1	4
	Wisla	3	1	4	2
Asia	Ganges-Brahmaputra-Meghna	5	2	5	4
	Hong (Red)	2	1	5	3
	Indus	5	2	3	4
	Irrawaddy	5	2	4	3
	Mekong	5	2	4	3
	Shatt-al-Arab	4	2	3	5
Africa	Congo	2	4	2	5
	Limpopo	2	2	3	3
	Niger	5	3	4	4
	Nile	4	2	5	4
	Senegal	4	2	2	4
	Volta	4	4	3	4
	Zambezi	4	2	2	3

The assessment shows a broad geographical spread of results for each of the indicators. Many deltas score relatively high on some indicators and relatively low on others. It also makes clear that many deltas are quite vulnerable and some are highly vulnerable. The Ganges-Brahmaputra-Meghna delta appears to be the most vulnerable with two relative risk scores of ‘very high’ and one score of ‘high’. The Niger and the Volta deltas follow with scores in the ‘very high’ and ‘high’ categories for three of the four indicators.

In general the deltas in Asia seem to be faced with the most serious challenges in terms of human vulnerability caused by a combination of a high score for relative sea-level rise combined with a high population pressure (and sometimes poor delta governance).

Of the 26 deltas assessed, 15 have at least two scores in the 'very high' and 'high' categories for two of the indicators. The Amazon, Orinoco and Yukon deltas appear to have relative low vulnerability.

The Relative Sea Level Rise Indicator has the highest number of 'very high' relative risk scores, followed by the Delta Governance Indicator. The Wetland Ecological Threat Indicator has the highest number of 'very low' and 'low' scores. However, this might also be a result of the methodology applied for this indicator.

Knowledge exchange between deltas (including lessons learned) and additional research are needed to address the knowledge gaps regarding the vulnerability of deltas and support the development and implementation of adaptive measures.

More in-depth information about the four indicators and incorporation of additional vulnerability indicators would give greater insight into the problems of deltas and the priorities for action to reduce their vulnerability.

More research is also needed to link the results of the delta assessment to the results of the river basin assessments in order to better understand the interaction between interventions upstream in the basin on the functioning of delta systems and vice versa.

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Chapter 6
Conclusions

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Conclusions

6.1 What can the results tell us?

This is the first truly global and comprehensive assessment of the world's 286 transboundary river basins. It covers a range of topics (natural and social sciences) and scales (from large to very small basins and Basin Country Units to grid cells).

It is primarily a baseline study of current conditions, with the aim of comparing all transboundary basins within the same framework and using the same underlying data, thus adding credibility to the results. The findings are consistent with other global assessments (such as the Human Development Index, Joint Monitoring Programme on Water and Sanitation, WWF Living Planet Report, and IPCC reports), which often have a more specific focus and are usually presented at national rather than basin and BCU scales. This assessment provides opportunities for analysis at a number of scales and perspectives. For individual indicators and combinations of indicators (multiple stressors) it provides: 1) a global perspective of the magnitude of the risks; 2) a framework for comparative analysis of risks among basins; and 3) identification of the basins most and least at risk. Overall, this provides a context for response options at global/regional levels but also at the basin and country levels, and facilitates inter-basin learning opportunities. It also can be used in combination with detailed studies on individual basins.

Significant efforts have been made to reduce the large number of data points (results from 286 basins and 796 BCUs) into five relative risk categories. These are provided to improve communication of the results, and assist decision makers in identifying priority areas and issues for intervention, recognizing that minor differences in indicator scores are not likely to be particularly meaningful in this global-level assessment.

The state of water resources in any location depends on a complex array of natural circumstances, pressures, and management responses. This assessment has attempted to cover a broad spectrum of these factors, with each indicator representing an important aspect in its own right. The results identify basins and regions where there are high and low risks of water stress, pollution, and threats to ecosystems and impacts on them. It also assesses governance capacity at the national and transboundary level to deal with threats, and the likely level of vulnerability of societies trying to cope with these risks, including changes to the hydrological regime. The key findings for each of the five thematic groups of indicators are presented below (taken from the thematic group introductory sections in chapter 3).

Key findings for each thematic group

Socioeconomics

1. **Climate-related risk is linked to economic dependence and low wellbeing:** Basins with high economic dependence, low levels of societal wellbeing and high exposure to floods and droughts have the highest climate-related risks. These basins are found mostly in Africa and south and southeast Asia. They include, at the highest levels of vulnerability, the Limpopo, the Ganges and the Mekong.
2. **Wellbeing and governance capacity to address disasters are linked:** In basins where societal wellbeing is low, governance capacity to address vulnerability to floods and droughts is also likely to be low. Women, children and people with disabilities are groups particularly vulnerable to floods and droughts. Attention might be warranted to assess governance needs and increase capacity in these countries and basins.

3. **Larger basins have larger economic dependence:** Larger basins tend to have higher levels of economic dependence on basin water resources, due mainly to the fact that larger basins are likely to include greater portions of the populations and areas of the countries. The 14 basins with the highest levels of economic dependence collectively comprise a population that is almost 50% of all transboundary basins (almost 1.4 billion people). These larger basins may be harder to manage from a transboundary point of view because of the number of countries and diversity of priorities. Management becomes even more critical to safeguard socioeconomic wellbeing in these countries.

Governance

1. **More effort is needed on transboundary agreements:** The adoption of international principles associated with the shift of water paradigms toward more sustainable development has been faster in domestic water governance arrangements than in international treaties. Focus is needed on renegotiating and implementing transboundary agreements to incorporate more integrated approaches into basin-level management.
2. **Construction of water infrastructure needs a cooperative context:** The construction of new water infrastructure is in progress or planned in many transboundary basins, including in areas where international water cooperation instruments are still absent or limited in scope. In such areas, a formal institutional framework for transboundary dialogue could help to assuage potential disputes stemming from unilateral basin development.
3. **Capacity building is required within countries to meet transboundary objectives:** There have been advances in the development of transboundary institutional capacity to deal with transboundary tensions and the application of integrated approaches to national water management, but capacity building is still work-in-progress in most countries.

Ecosystems

1. **Local-level, tailored solutions are needed to address species extinction risks:** Analysis at the BCU level gives a more detailed picture of extinction risks than analysis at the basin level, reflecting higher levels of endemic species or threats in some areas of a river basin such as the upper reaches or in large lake systems. This suggests that responses, too, should be at a more detailed level than basin-wide to address extinction risks. There is therefore an urgent need to continue to identify hotspots from transboundary impacts through basin-specific assessments (including, for example, GEF Transboundary Diagnostic Analyses (TDAs)). Conservation strategies should be focussed on ecological importance, not necessarily on scale.
2. **Decisions about dam sites and dam design are key to minimising negative ecosystem impacts:** Dam density is often a key driver of impacts on ecosystems, with impacts on flow and fragmentation of river systems. Recognizing the benefits of dams to human development, ongoing commitments are needed to improve guidelines for siting new dams, designing dams for multiple purposes and optimising the operation of dams to maximise human benefits and minimise negative ecosystem impacts. This is particularly important in a transboundary context, where dams are typically located in upstream countries.

Water quantity

1. **Action to address agricultural water stress must not increase environmental water stress:** Hotspots of environmental water stress are highly correlated with those of agricultural water stress. Addressing agricultural water stress (for example through increasing large-scale water storage) should be done with careful consideration of environmental water requirements.
2. **Human water stress needs to be addressed to mitigate projected environmental and agricultural stress:** Actions to counter human water stress should be expedited in river basins that are already prone to water stress to mitigate the increasing stress projected for most of these regions.

Water quality

1. **Water quality risks are high in many transboundary river basins:** Water quality is severely affected in more than 80% of the basins, either by nutrient over-enrichment (typically in developed regions e.g. North America and Europe) or by pathogens (generally in developing regions, e.g. South America, Africa, and in northern Asian basins with Russia), or in both (e.g. emerging economies in southern and eastern Asia).
2. **Water quality risks are projected to increase:** The projected scenario for nutrient pollution suggests that the relative risk will increase in around 30% of basins between 2000 and 2030, with the risk in two basins increasing by three categories. Between 2030 and 2050 nutrient pollution risk is projected to increase further in 21 basins, while in six basins the risk decreases by one category[28]. The effects of nutrient pollution are also likely to exacerbate risks across other indicators and water systems (e.g. ecosystem health, coastal areas and aquifers).
3. **Mitigation measures are needed in all river basins to reduce risks:** In basins with a risk of nutrient and wastewater pollution, improvements to wastewater treatment may help to reduce both risks. Improved nutrient management in agriculture (e.g. crop and livestock) will likely be needed to reduce current risks of nutrient pollution in many basins. Even in basins with relatively low risk, both strategies are likely to become more important as the global population continues to rise, which is likely to increase risks of nutrient and wastewater pollution unless adequate mitigation measures are in place.

Key findings for lakes and deltas

While river basins interact with all other water systems assessed under TWAP (Aquifers, LMEs, Open Ocean and Lakes), either directly or indirectly, special attention under TWAP RB was given to Lakes (via the Lake Influence Indicator) and Deltas (via the Delta Vulnerability indicators).

Lake influence on river basins

1. **Low storage capacity can make basins more vulnerable to a changing climate:** Basins which suffer from water stress, droughts or floods may be even more vulnerable if they also have low lake storage capacity to act as a buffer (e.g., north-west Africa, parts of basins in southern Africa, and the Indian sub-continent). Water demand management in these areas is key.
2. **The proportion of reservoirs to lakes can guide responses:** Considering the proportion of reservoirs to natural lakes (i.e. the degree of controllable storage) provides further information for the design of response options to challenges such as water scarcity or exposure to floods. Response options are likely to be different in basins with high proportions of controllable storage compared to basins with high proportions of natural lakes.

Delta vulnerability

1. **The vulnerability of deltas differs across the world:** The results show a geographical spread of vulnerability depending on the indicator. The Ganges-Brahmaputra-Meghna delta appears to be the most vulnerable, followed by the Niger and Volta deltas. The Amazon, Orinoco and Yukon deltas appear to have low to moderate vulnerability.
2. **Deltas in Asia are most at risk:** In general the deltas in Asia seem to have the most serious challenges in terms of human vulnerability caused by a combination of relative sea level rise and population pressures (and sometimes poor delta governance).

28 High confidence results only

Special attention should also be paid to the impact of upstream interventions on the most vulnerable deltas (e.g. reduction of sediment load by the construction of dams, changed hydrodynamics of rivers, pollution, and increased risk of salinity intrusion).

Integrated analysis of all indicators across thematic groups

While the baseline nature of this assessment has not made it possible to fully investigate causal chain effects, consideration of the full range of indicators is vital for the design of appropriate policy response options. Taken together, the results reveal complex links, which can be interpreted in a number of different ways (Chapter 4).

Although creating an overall risk index from all the indicators may be conceptually appealing, it would tend to mask levels of threat important for individual basins. Furthermore, the creation of such an index would be highly dependent on stakeholder priorities. Given that the intention of this assessment is to be relevant to a broad range of users at different scales, custom indices can be created from any combination of indicators in the data portal with user-defined weighting (http://twap-rivers.org/).

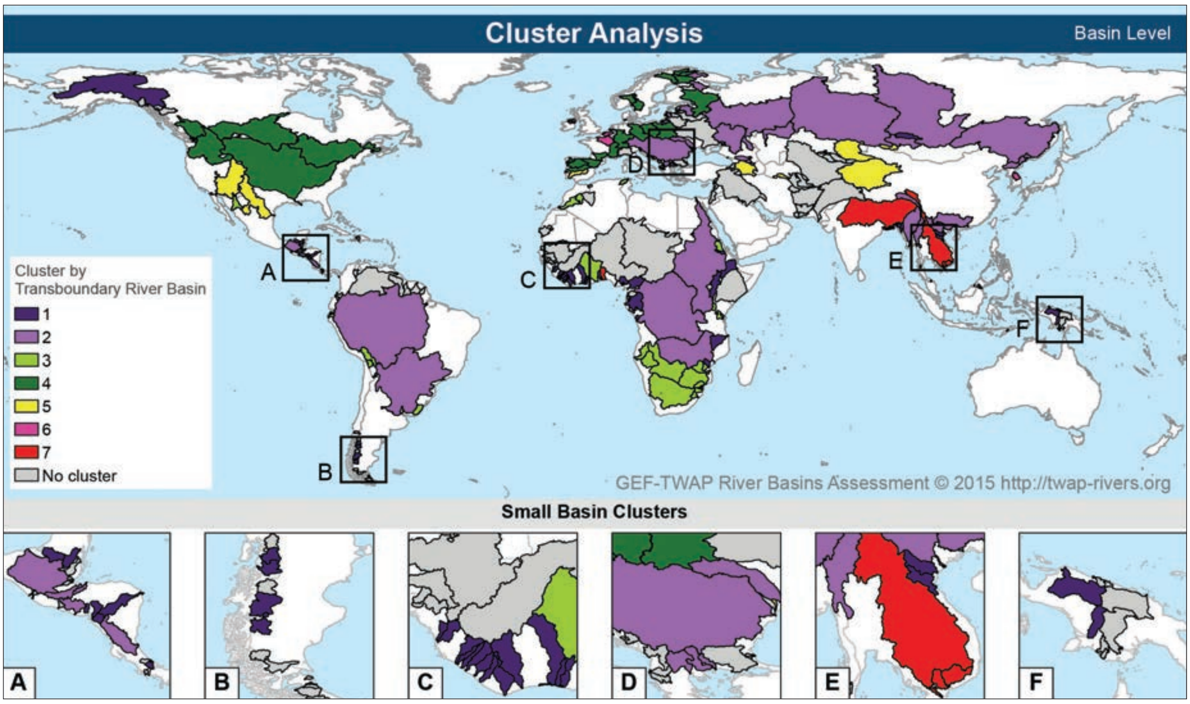
An integrated analysis of the indicators has been undertaken using a number of different techniques to examine the data from various perspectives, in an attempt to answer the questions below (Chapter 4).

Can we classify basins with similar risk profiles?

While each basin is unique, understanding similarities can facilitate inter-basin learning and the further development of broad management strategies which may be applicable to basins with certain types of risk profile. A cluster analysis was undertaken to identify such basin groups (Figure 6.1):

- **Cluster group 1: Undeveloped basins with low pressures on water resources:** 45 basins (with a population of roughly 89 million) that have generally low risk across most indicators. These tend to be either small basins in various parts of Africa, presumably with little water resource development so far, or isolated basins in temperate and polar regions, presumably with low pressures on their water resources. This group of basins represents those that are largely undeveloped and may therefore offer opportunities for sustainable development.
- **Cluster group 2: Inadequate governance, high ecosystem risk despite low development of water resources:** 39 basins (869 million people) appear to have inadequate governance which manifests in high risks to ecosystems, despite relatively low levels of development of water resources. These basins present a challenge for sustainable development and the management of risk, particularly given the moderate to high levels of exposure to droughts and floods respectively. Assessing governance needs in these basins should be a priority.
- **Cluster group 3: Poor governance, high risk, high water use:** 25 basins (84 million people) have generally poor governance and generally high risks across the socioeconomic indicators; they appear to be utilizing relatively high portions of their available water resources and have high economic dependence on water resources. Transboundary inter-sectoral allocation mechanisms may be useful management tools in these basins.
- **Cluster group 4: High human wellbeing, good governance, high risk to ecosystems and of human water stress:** 25 basins (282 million people) tend to have high levels of societal wellbeing, and good governance, but also high risk to ecosystems and of human water stress and moderate risk of environmental water stress. Low risks of agricultural water stress but high risks of ecosystem impacts from dams implies that storage capacity has been developed to mitigate agricultural water stress, but at the expense of the environment.

Figure 6.1. Seven groups of basins with similar risk profiles. Common risk profiles can facilitate inter-basin learning and shared approaches to management.



How are the individual indicators related?

Determining correlations between indicators across thematic groups can help to identify the strength of the statistical relationships between the links in the conceptual model that underpins this work. The results indicate how the human dimension of transboundary rivers, gauged by socioeconomic and governance indicators, is related to the physical dimension represented by water quality and quantity and ecosystem impacts. For example:

- Wastewater pollution, societal wellbeing and enabling environment (governance at the country level) are strongly related, suggesting that addressing wastewater pollution should occur in parallel with improvements in societal wellbeing and national governance;
- Environmental, human and agricultural water stress, and exposure to drought, which are usually worse in basins with high inter-annual variability of water flows, have high correlation levels. This confirms that in the past dams have been built to address water flow variability to meet high human and agricultural demands, with negative impacts on environmental water flows.

There is a negative correlation (although weak) between governance and societal wellbeing indicators, and between ecosystem impacts from dams and threats to fish. This would imply that basins which have been developed to support high levels of societal wellbeing may have done so at the expense of the environment.

What can the assessment results tell us about the transboundary nature of risk?

The relationships between upstream and downstream areas within each basin are arguably one of the most important features of in-basin dynamics. Upstream actions can affect downstream BCUs. For this reason, it is key to observe how risks from the source of a river relate to risks further downstream and at the mouth of the river.

- The average risk for all indicators for BCUs located at the mouth of a transboundary basin is marginally higher than their respective BCUs at the source. Almost twice as many BCUs at the river mouth have higher risk than their respective BCUs at the source, although the differences are generally not large.

- The disparity of level of risk among countries can act as a catalyst or as an obstacle for transboundary cooperation and have different effects on the overall status of the basin. However, there is no clear correlation between the level of general risk disparity and the overall level of risk in basins. Understanding and developing national and transboundary governance capacity is critical to address the transboundary nature of risk. Building national governance capacity often creates a strong basis for transboundary cooperation capacity, while a lack of national capacity can paralyze further transboundary governance.

What can we say about how risks are likely to change in the future?

Simulated projections for the 2030s and 2050s were generated on the basis of a 'business-as-usual' socio-economic scenario and an assumed continued high greenhouse gas (GHG) emissions pathway. The following indicators were considered: environmental stress induced by flow alteration, human water stress, nutrient pollution, hydropolitical tensions, and population density.

Four hotspots were identified; environmental and human (E&H) water stress is projected to increase in all four:

- **Orange and Limpopo basins, Southern Africa:** increased Environment and Human (E&H) water stress due mainly to increasing water withdrawals, and nutrient pollution due mainly to increased human sewage. Countries affected: Botswana, Lesotho, Mozambique, Namibia, South Africa, Zimbabwe.
- **Selected Central Asia basins:** range of factors differing between basins, including increased E&H water stress due to a combination of projected increases and decreases in water availability, increasing water withdrawal and population density; increased nutrient pollution and hydropolitical tensions. Basins: Tarim, Indus, Aral Sea, Helmand, Murgab, Hari, Talas, Shu and Ili. Countries affected: Afghanistan, China, India, Iran, Kazakhstan, Kyrgyzstan, Nepal, Pakistan, Tajikistan, Turkmenistan, Uzbekistan.
- **Ganges-Brahmaputra-Meghna basin:** increased E&H water stress due mainly to increased (>50%) water demand driven by population growth. Nutrient pollution remains high with agricultural sources (fertilizer and animal manure) being major contributors and sewage becoming increasingly important, and there is increased risk of hydropolitical tension associated with new water infrastructure. Countries affected: Bangladesh, Bhutan, China, India, Myanmar, Nepal.
- **Selected Middle East basins:** continued high to very high risk of E&H water stress due to decrease in renewable freshwater resources and higher water demand from increased population and irrigation. Nutrient pollution increases or remains in the highest risk category; increased risk of hydropolitical tension due to the political context. Basins: Orontes, Jordan River, Euphrates and Tigris. Countries affected: Egypt, Iraq, Iran, Israel, Jordan, Lebanon, Palestine, Saudi Arabia, Syria, Turkey.

In addition, many individual basins are at increasing risk, from a transboundary perspective, to changes in upstream-downstream pressures (e.g. the Nile).

Can we identify any success stories?

Part of the aim of this assessment has been to facilitate inter-basin learning. An attempt was therefore made to identify basins that may have relatively low risks or may be actively addressing pressures. This proved challenging due to the baseline nature of the assessment which made the analysis of causal relationships difficult. Repeat assessments with updated indicators and methodologies are needed to reveal clearer patterns over time.

6.2 What are the policy and management response options?

A number of issues related to the physical and socioeconomic environments of transboundary basins have been examined in this assessment. Some of these may be very closely linked to the natural levels of water availability and levels of population density and historic actions, which may be difficult to address through policy measures. For example, the analysis includes sub-indicator 2a Human Water Stress - water availability per capita, and indicator 7 Ecosystem Impacts from Dams, which accounts for dams constructed over the last 100 years or so. However, all the indicators provide information which can be incorporated into policy development and management planning. For example, understanding the relative level of ecosystem impacts from dams may provide impetus to further develop policies to protect the remaining ecosystems in the basin (e.g. through protected areas), or to improve dam operation to ensure environmental flow allocations.

The use of water resources will inevitably involve trade-offs, especially in basins where water is scarce. This has been demonstrated in this assessment through the high positive correlation between environmental, agricultural and human water stress and exposure to drought. The inter-dependency between indicators is a reflection of the principles of Integrated Water Resources Management (IWRM), which stress the need for coordination between sectors, and have an important role to play in transboundary river basin management (GWP and INO 2009). How best to manage trade-offs will depend on the situation in the specific basin, but to achieve sustainability this has to be done in a way that safeguards the future capacity of the ecosystems to continue functioning. With awareness of the factors that predict trade-offs (private interest, provisioning versus other ecosystem services, local stakeholders) the chances of creating win-win situations increase (Howe *et al*. 2014).

The current governance situation at transboundary and national levels underpins basin and country capacity to respond to risks. Using the three governance indicators as a guide can help to identify basins and countries where more detailed assessments of governance/capacity needs are warranted, particularly where other risks are high. Assessment of capacity needs could for example be implemented through GEF Transboundary Diagnostic Analysis (TDA) and Strategic Action Plans (SAP) which could enhance the connectivity and relevance of such assessments to wider economic and infrastructure planning and decision-making processes.

The basins in cluster groups 2 (*inadequate governance, high ecosystem risk despite low development of water resources*), 3 (*poor governance, high risk, high water use)* and 7 (*economic dependence, pollution, wetland loss but with water availability*) (Figure 6.1 and section 4.2) may require the most urgent attention, although closer examination of the individual indicators would be required to identify specific basins and BCUs.

In addition to governance considerations, classes of response options to address the risks identified in this assessment, and to achieve human and natural system water security, include (but are not limited to):

a) **Infrastructure:** either constructed or natural, for addressing risks associated with water scarcity (water quantity thematic group), water pollution (water quality thematic group), societal wellbeing (water supply and sanitation), and exposure to floods and droughts. Many win-win options are available through environmental protection for direct human gain (e.g. 'green infrastructure' for improvements to water quality, and flood and drought).

b) **Improved technical and institutional capacity:** (particularly related to the enabling environment and other governance indicators) for addressing a wide range of risks through increasing levels of knowledge to better guide policy development, planning and management. This global assessment provides pointers to where more detailed studies may be warranted.

c) **Economic incentives / investments:** cost-recovery measures (e.g. progressive tariff structures for all water uses); subsidies for improving water efficiency and charges (e.g. pollution charges).

d) **Environmental protection / rehabilitation:** basins in cluster group 2 may be particularly relevant here, with generally high species extinction risk, moderate risks across all thematic groups, and high hydropolitical tension, suggesting imminent construction of water infrastructure with a lack of adequate governance. Cluster group 4 also has high risks in the Ecosystems thematic group, but generally good governance, implying that these risks may already be being addressed.

Focus should not only be given to high risk basins; attention should also be given to low and moderate risk basins (e.g. cluster group 1) where sustainable development and management may ensure that they remain at relatively low risk.

The implementation of any of the above classes of policy responses is dependent on governance and economic capacity. Thus, basins with weaker capacity may have a much larger set of issues to address in parallel with more specific responses such as infrastructure development for improvements to societal wellbeing.

The cluster groups identified in this assessment show that some basins face similar challenges. Appropriate partnerships should therefore be developed, working together on similar issues for joint outcomes. These are likely to include greater private-sector engagement, and ultimately investment for delivering joint objectives with government and international organizations and donors such as the GEF.

6.3 Need for transboundary cooperation

In a warming world with more variable rainfall and increasing socioeconomic drivers, upstream countries may intensify their use of water, while downstream countries will probably be increasingly dependent on their upstream neighbours for water resources. Without adequate benefit-sharing agreements and cooperative approaches to integrated water resource management, economically-dependent downstream countries may be negatively impacted (UN-Water 2008).

This assessment shows that in the current situation, almost twice the number of outlet countries (downstream) have higher risks than the respective headwater countries (upstream) (section 4.3). It will be in the self-interest of downstream countries, particularly relatively affluent ones, to support improved land management, water-saving technologies, infrastructure, and technical capacity in upstream neighbours.

In this assessment, the transboundary nature of basins has been addressed mainly through the use of basin-country-units (BCUs). Using BCUs helps to show how each country contributes to the overall picture of risk in a given basin, and that the problems and solutions in transboundary basins are often directly linked to individual countries. Thus, this BCU approach contributes to identifying which countries may need to be proactive or may need more assistance to solve problems that have transboundary implications.

Vulnerability is the part of risk that can be managed and reduced through a variety of policy actions. Drivers such as population and economic growth are external to the water resource system, but there are policy and technical mechanisms to reduce the pressures they exert on water. River basins facing high risk therefore can and should work intensively on initiatives that act on the ‘controllable’ part of risks e.g. reducing or assuaging pollution. In this context, transboundary cooperation, particularly in the form of treaties, should not been considered to be a ‘panacea’ to all problems that affect international rivers, since not all forms of cooperation necessarily lead to better outcomes on the ground. Nevertheless, there is little doubt that unilateral policy actions often do not achieve their intended goals and may produce undesirable impacts that can create tensions between countries.

One example of this is water pollution control, which is unlikely to be effective if not designed and discussed across borders. Similarly, actions conceived to benefit the economy of one country (e.g. through the development of hydropower potential) could be profoundly detrimental in other parts of the basin. The associated potential international tensions could be mitigated through transboundary agreements where part of the benefits can be shared among the countries.

Results show a slight correlation between high economic dependence on water, relatively high water stress and a strong legal framework (e.g. the Orange in southern Africa and Jordan in the Middle East), possibly indicating a higher incentive for the countries in such basins to define the legal rights and obligations between States. However, even with the best intentions, it may become increasingly challenging to develop policies, laws and management arrangements for transboundary benefit during times of prolonged water scarcity or when there are tensions between national priorities and transboundary considerations. This is illustrated by the complicated transboundary cooperation surrounding dam building in upland areas such as the upper reaches of the Mekong, the Blue Nile, and the Indus rivers. UNECE has developed policy guidelines for identifying, assessing and communicating the benefits of transboundary cooperation.

6.4 Looking to future transboundary river basin assessments

There are several initiatives worldwide that could benefit from the complex methods and indicators that have been developed over the course of the TWAP River Basins component. Other mechanisms adopting the TWAP methodology, in part or in full, could also assist in realizing the potential value of the TWAP results by keeping the datasets alive and contributing to periodic assessments.

For example, there is considerable opportunity to make use of TWAP methods and indicators to support the two global international watercourses conventions (UNECE and UN) considering the current lack of monitoring mechanisms that make indicator-based comparisons between basins over time possible.

The timing of the TWAP assessment coincides with the entry into force of the UN International Watercourses (WC) Convention (17 August 2014), providing a solid baseline for this Convention. The setting in place of a mechanism to track implementation of this Convention, and the possible nature of any resulting assessments, might however be dependent on a decision being taken by the Parties to the Convention.

Regional assessments carried out so far under the UNECE Water Convention have been limited geographically to pan-Europe. The scope of UNECE's next assessment of transboundary waters — expected to be carried out from 2019 to 2021 — is open and expected to be influenced by the Convention's global launch. UNECE has developed policy guidelines for identifying, assessing and communicating the benefits of transboundary cooperation, which were published in 2015.[29]

The TWAP assessment can also support monitoring of the proposed Sustainable Development Goals (SDGs). All targets under the proposed water goal (and some under other goals) are relevant to transboundary basins. The indicators and results of this report can support a number of these targets, including those related to water quantity, water quality, sustainable use of water resources, and protection of ecosystems. The assessment framework and indicators themselves could be modified to facilitate monitoring of the SDGs. Target 6.5 explicitly mentions transboundary cooperation: "by 2030 implement integrated water resources management at all levels, including through transboundary cooperation as appropriate". All three governance indicators will be able to support this target, particularly the legal framework and enabling environment indicators.

It must be noted that, in relation to the SDGs and other global assessments, the TWAP methodology is not confined to transboundary basins. The majority of datasets are global, gridded data that can be aggregated to the desirable unit (e.g. region, country, and local area).

The assessment framework and indicators developed in this assessment may also be useful as a platform for river-basin organisations seeking to establish monitoring and evaluation systems. This basin-level information could feed back into future global analyses. It can also be used to develop the GEF Transboundary Diagnostic Analyses (TDAs) into a more science-driven, robust and comparable process.

29 http://www.unece.org/env/water/publication/ece_mp.wat_47.html

Other organizations that could benefit from the *TWAP River Basins Report* methodology and results as a complement to qualitative country/basin reports including Regional Economic Commissions, transboundary institutions and bi/tri lateral commissions, intergovernmental organizations and roundtables, development agencies, investment framework agencies, the International Network of Basin Organizations (INBO) and regional basin umbrella organisations, the World Water Assessment Programme (WWAP), Global Water Partnership (GWP), Delta Alliance and other regional institutions with a mandate for monitoring and assessment of transboundary waters. Ways in which the results and conclusions from this and future assessments can benefit such institutions include: priority setting, work programming and investment targeting, informing negotiations and collaborative economic and environmental ventures.

Importantly, the TWAP has fostered a willing partnership of institutions with the capacity to work with other interested parties to either reproduce the assessment in full or to adapt and improve aspects of the assessment to be fit for a number of purposes at many different levels. The future potential for the TWAP River Basins assessment is described in more detail in the *TWAP RB Sustaining Mechanisms* document (see http://twap-rivers.org/).

Throughout the *TWAP River Basins Report*, particularly in the indicator descriptions in Chapter 3 and the integrated analysis in Chapter 4, authors have made suggestions for potential future improvements to the methodology. The more broadly applicable suggestions include:

- A deeper understanding of drivers and impacts, in order to identify cause-effect relationships. This will probably require more in-depth analysis of (selected) basins.
- More analysis into within-basin relationships to gain better understanding of the transboundary aspects of risk. In some cases this may require more detailed datasets (some of which are currently being developed).

- Investigation of the interactions between and implications behind the water-food-energy nexus in basins, including identification of important trade-offs and opportunities presented by integrated water resource management at the transboundary level.
- A closer look at the performance and implementation of governance arrangements at national and transboundary levels and understanding of outcomes at both levels. This may include consideration of private and private-public actors, possibly illustrated by case studies.
- More 'ground-truthing' to compare the global assessment results with realities in the basins. This may involve more detailed studies of smaller, representative sub-sets of basins, and increased engagement with stakeholders in these basins.
- Further consideration (particularly for the integrated assessment) of which basins may be more relevant to consider as transboundary basins, and which may be considered as predominantly 'national'.
- Consideration of the significance of gender and gender disaggregated information in global transboundary assessments.
- Separate analyses of larger and smaller basins, which may lead to different patterns of risk being identified, and consequently improve information for developing policy and management responses.

6.5 Decision-making in the context of uncertainty

Throughout the report, the authors have sought to identify needs for further research and methods to complement those applied to this study of transboundary river basins. However, gaps in data should not be an excuse for inaction. The world has entered a phase of risk management, where risks from environmental degradation, water scarcity, and climate change are increasingly real. Here, the precautionary principal must be invoked. Failure to manage transboundary water resources may result in significant human suffering and economic losses.

Mabey *et al*. (2011) call for an increased resilience of international resource-management frameworks, concluding that "*The time to strengthen regimes is now, when the impacts of climate change are still at relatively low levels. This is also the time to actively identify gaps and critical areas where management and or governance regimes are absent, and intensify multilateral and bilateral engagements to address these gaps*." Basins with insufficient governance regimes will need to be strengthened, and basins in which there are already tensions between upstream and downstream countries will require special attention from the international community, including the GEF.

References

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Table of Transboundary River Basins and Countries

The table below lists the 286 transboundary river basins of the world, with the member countries and territories. Regional maps are provided in Annex II and a table of basins by continent, with basin codes, is provided in Annex III-1. Further information, including basin and BCU size, can be downloaded from the TWAP RB data portal (http://twap-rivers.org/).

	Basin name	Countries/territories sharing basin		Basin name	Countries/territories sharing basin
1	Akpa	Cameroon,Nigeria	144	Lough Melvin	UK of GB and Northern Ireland,Ireland
2	Alsek	Canada,United States of America	145	Ma	Lao People's Democratic Republic,Viet Nam
3	Amacuro	Guyana,Venezuela	146	Mana-Morro	Guinea,Liberia,Sierra Leone
4	Amazon	Bolivia,Brazil,Colombia,Ecuador,French Guiana,Guyana,Peru,Suriname,Venezuela	147	Maputo	Mozambique,Swaziland,South Africa
5	Amur	China,Mongolia,Dem People's Rep of Korea,Russian Federation	148	Maritsa	Bulgaria,Greece,Turkey
6	An Nahr Al Kabir	Lebanon,Syrian Arab Republic	149	Maro	Indonesia,Papua New Guinea
7	Aral Sea	Afghanistan,China,Jammu and Kashmir,Kazakhstan,Kyrgyzstan,Pakistan,Tajikistan,Turkmenistan,Uzbekistan	150	Maroni	Brazil,French Guiana,Suriname
8	Artibonite	Dominican Republic,Haiti	151	Massacre	Dominican Republic,Haiti
9	Asi/Orontes	Lebanon,Syrian Arab Republic,Turkey	152	Mataje	Colombia,Ecuador
10	Astara Chay	Azerbaijan,Iran (Islamic Republic of)	153	Mbe	Gabon,Equatorial Guinea
11	Atrak	Iran (Islamic Republic of),Turkmenistan	154	Medjerda	Algeria,Tunisia
12	Atui	Western Sahara,Mauritania	155	Mekong	China,Cambodia,Lao People's Democratic Republic,Myanmar, Thailand,Viet Nam
13	Aviles	Argentina,Chile	156	Mino	Spain,Portugal
14	Awash	Djibouti,Eritrea,Ethiopia,Somalia	157	Mira	Colombia,Ecuador
15	Aysen	Argentina,Chile	158	Mississippi	Canada,United States of America
16	BahuKalat/ Rudkhanehye	Iran (Islamic Republic of),Pakistan	159	Mius	Russian Federation,Ukraine
17	Baker	Argentina,Chile	160	Moa	Guinea,Liberia,Sierra Leone
18	Bangau	Brunei Darussalam,Malaysia	161	Moho	Belize,Guatemala
19	Bann	UK of GB and Northern Ireland, Ireland	162	Mono	Benin,Togo
20	Baraka	Eritrea,Sudan	163	Motaqua	Guatemala,Honduras
21	Barima	Guyana,Venezuela	164	Muhuri (aka Little Feni)	Bangladesh,India
22	Barta	Lithuania,Latvia	165	Murgab	Afghanistan,Turkmenistan
23	Bei Jiang/Hsi	China,Viet Nam	166	Nahr El Kebir	Syrian Arab Republic,Turkey
24	Beilun	China,Viet Nam	167	Narva	Belarus,Estonia,Latvia,Russian Federation
25	Belize	Belize,Guatemala	168	Negro	Honduras,Nicaragua
26	Benito/Ntem	Cameroon,Gabon,Equatorial Guinea	169	Nelson-Saskatchewan	Canada,United States of America
27	Bia	Côte d'Ivoire,Ghana	170	Neman	Belarus,Lithuania,Latvia,Poland, Russian Federation
28	Bidasoa	Spain,France	171	Neretva	Bosnia and Herzegovina,Croatia
29	Buzi	Mozambique,Zimbabwe	172	Nestos	Bulgaria,Greece
30	Ca/Song-Koi	Lao People's Democratic Republic,Viet Nam	173	Niger	Benin,Burkina Faso,Côte d'Ivoire, Cameroon,Algeria,Guinea,Mali, Mauritania,Niger,Nigeria,Sierra Leone, Chad

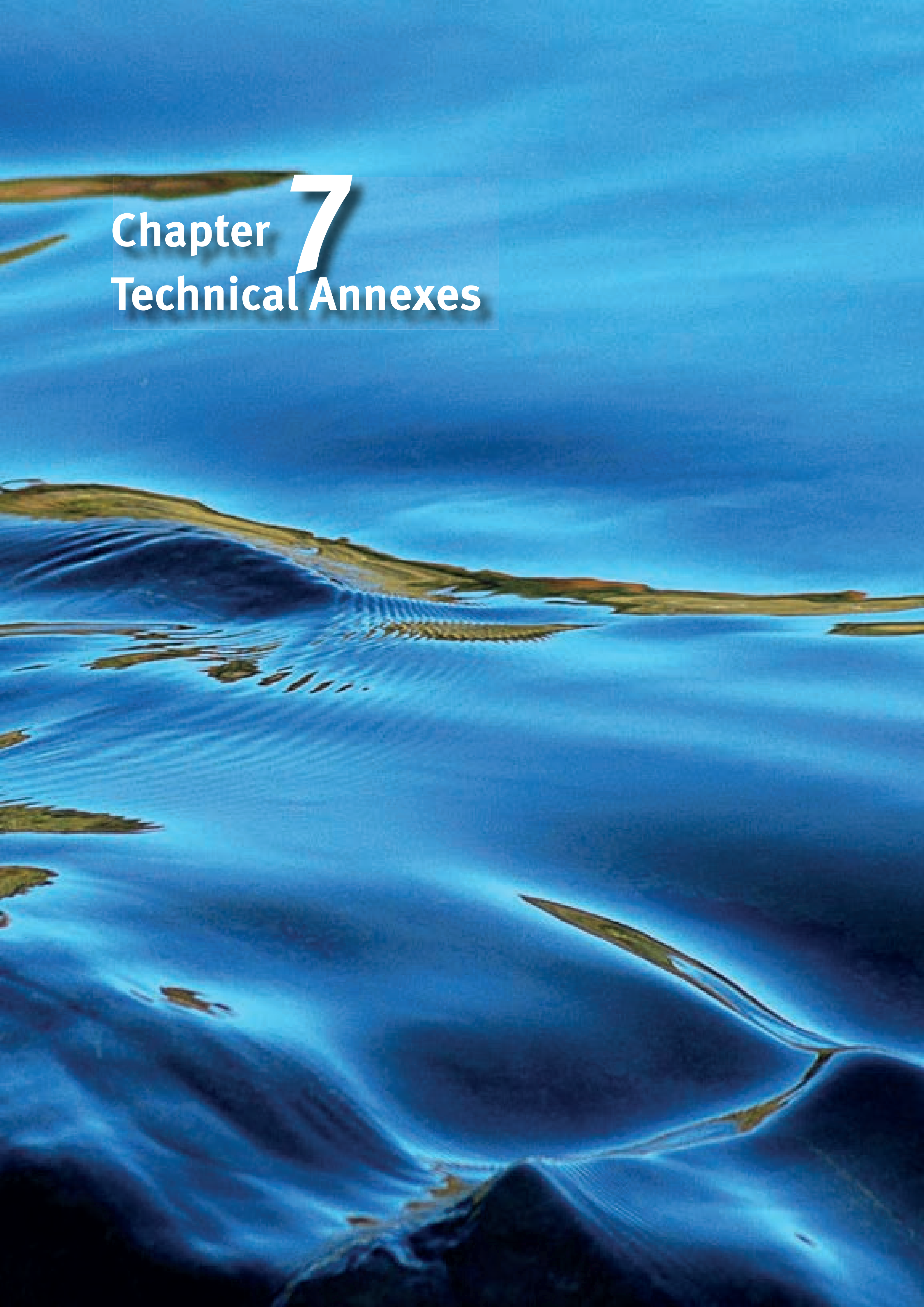
	Basin name	Countries/territories sharing basin		Basin name	Countries/territories sharing basin
31	Cancoso/Lauca	Bolivia,Chile	174	Nile	Burundi,Central African Republic,Egypt, Hala'ib triangle,Eritrea,Ethiopia,K enya, Rwanda,Sudan,Abyei,South Sudan, United Republic of Tanzania, Uganda,Dem. Republic of the Congo
32	Candelaria	Guatemala,Mexico	175	Nyanga	Congo,Gabon
33	Carmen Silva/ Chico	Argentina,Chile	176	Naatamo	Finland,Norway
34	Castletown	UK of GB and Northern Ireland, Ireland	177	Ob	China,Kazakhstan,Mongolia,Russian Federation
35	Catatumbo	Colombia,Venezuela	178	Oder/Odra	Czech Republic,Germany,Poland, Slovakia
36	Cavally	Côte d'Ivoire,Guinea,Liberia	179	Ogooue	Cameroon,Congo,Gabon,Equatorial Guinea
37	Cestos	Côte d'Ivoire,Guinea,Liberia	180	Oiapoque/ Oyupock	Brazil,French Guiana
38	Chamelecon	Guatemala,Honduras	181	Okavango	Angola,Botswana,Namibia,Zimbabwe
39	Changuinola	Costa Rica,Panama	182	Olanga	Finland,Russian Federation
40	Chilkat	Canada,United States of America	183	Oral/Ural	Kazakhstan,Russian Federation
41	Chiloango	Angola,Congo,Dem. Republic of the Congo	184	Orange	Botswana,Lesotho,Namibia,South Africa
42	Chira	Ecuador,Peru	185	Orinoco	Brazil,Colombia,Guyana,Venezuela
43	Chiriqui	Costa Rica,Panama	186	Oued Bon Naima	Algeria,Morocco
44	Choluteca	Honduras,Nicaragua	187	Oueme	Benin,Nigeria,Togo
45	Chuy	Brazil,Uruguay	188	Oulu	Finland,Russian Federation
46	Coatan Achute	Guatemala,Mexico	189	Pakchan	Myanmar,Thailand
47	Coco/Segovia	Honduras,Nicaragua	190	Palena	Argentina,Chile
48	Colorado	Mexico,United States of America	191	Pandaruan	Brunei Darussalam,Malaysia
49	Columbia	Canada,United States of America	192	Pangani	Kenya,United Republic of Tanzania
50	Comau	Argentina,Chile	193	Parnu	Estonia,Latvia
51	Congo/Zaire	Angola,Burundi,Central African Republic, Cameroon,Congo,Ga bon,Malawi,Rwanda,Sudan,So uth Sudan,United Republic of Tanzania,Uganda,Dem. Republic of the Congo,Zambia	194	Pascua	Argentina,Chile
52	Conventillos	Costa Rica,Nicaragua	195	Pasvik	Finland,Norway,Russian Federation
53	Corantijn/ Courantyne	Brazil,Guyana,Suriname	196	Patia	Colombia,Ecuador
54	Corredores/ Colorado	Costa Rica,Panama	197	Paz	Guatemala,El Salvador
55	Corubal	Guinea,Guinea-Bissau	198	Pedernales	Dominican Republic,Haiti
56	Coruh	Georgia,Turkey	199	Po	Switzerland,France,Italy
57	Cross	Cameroon,Nigeria	200	Prohladnaja	Poland,Russian Federation
58	Cullen	Argentina,Chile	201	Psou	Georgia,Russian Federation
59	Cuvelai/Etosha	Angola,Namibia	202	Pu Lun T'o	China,Mongolia
60	Danube	Albania,Austria,Bulgaria,Bosnia and Herzegovina,Switzerland,Czech Republic, Germany,Croatia,Hu ngary,Italy,Moldova, Republic of,The former Yugoslav Republic of Macedonia,Montenegro,Poland, Roma nia,Serbia,Slovakia,Slovenia,Ukraine	203	Puelo	Argentina,Chile
61	Daoura	Algeria,Morocco	204	Pungwe	Mozambique,Zimbabwe

	Basin name	Countries/territories sharing basin		Basin name	Countries/territories sharing basin
62	Dasht	Iran (Islamic Republic of),Pakistan	205	Red/Song Hong	China,Lao People's Democratic Republic, Viet Nam
63	Daugava	Belarus,Estonia,Lithuania,Latvia,Russi an Federation	206	Rezvaya	Bulgaria,Turkey
64	Digul	Indonesia,Papua New Guinea	207	Rhine	Austria,Belgium,Switzerland,Germany, France,Italy,Liechtenstein,Luxembourg ,Netherlands
65	Dnieper	Belarus,Russian Federation,Ukraine	208	Rhone	Switzerland,France,Italy
66	Dniester	Moldova, Republic of,Poland,Ukraine	209	Rio Grande (N. America)	Mexico,United States of America
67	Don	Russian Federation,Ukraine	210	Rio Grande (S. America)	Argentina,Chile
68	Douro/Duero	Spain,Portugal	211	Roia	France,Italy
69	Dra	Algeria,Morocco	212	Ruvuma	Mozambique,Malawi,United Republic of Tanzania
70	Dragonja	Croatia,Slovenia	213	Sabi	Mozambique,Zimbabwe
71	Drin	Albania,The former Yugoslav Republic of Macedonia,Montenegro,Serbia	214	Saigon	Cambodia,Viet Nam
72	Ebro	Andorra,Spain,France,Austria,Czech Republic, Germany,Poland	215	Salaca	Estonia,Latvia
73	El Naranjo	Costa Rica,Nicaragua	216	Salween	China,Myanmar,Thailand
74	Elancik	Russian Federation,Ukraine	217	Samur	Azerbaijan,Russian Federation
75	Elbe	Austria,Czech Republic,Germany,Poland	218	San Juan	Costa Rica,Nicaragua
76	Erne	UK of GB and Northern Ireland,Ireland	219	San Martin	Argentina,Chile
77	Essequibo	Brazil,Guyana,Venezuela	220	Sanaga	Central African Republic,Cameroon, Nigeria
78	Fane	UK of GB and Northern Ireland, Ireland	221	Sarata	Moldova, Republic of,Ukraine
79	Fenney	Bangladesh,India	222	Sarstun	Belize,Guatemala
80	Firth	Canada,United States of America	223	Sassandra	Côte d'Ivoire,Guinea
81	Flurry	UK of GB and Northern Ireland, Ireland	224	Schelde	Belgium,France,Netherlands
82	Fly	Indonesia,Papua New Guinea	225	Sebuku	Indonesia,Malaysia
83	Foyle	UK of GB and Northern Ireland, Ireland	226	Seine	Belgium,France
84	Fraser	Canada,United States of America	227	Sembakung	Indonesia,Malaysia
85	Gallegos/Chico	Argentina,Chile	228	Senegal	Guinea,Mali,Mauritania,Senegal
86	Gambia	Guinea,Gambia,Senegal	229	Seno Union/ Serrano	Argentina,Chile
87	Ganges-Brahmaputra -Meghna	Bangladesh,Bhutan,China,Arunachal Pradesh,India,Myanmar,Nepal	230	Sepik	Indonesia,Papua New Guinea
88	Garonne	Andorra,Spain,France	231	Shu/Chu	Kazakhstan,Kyrgyzstan
89	Gash	Eritrea,Ethiopia,Sudan	232	Sixaola	Costa Rica,Panama
90	Gauja	Estonia,Latvia	233	Skagit	Canada,United States of America
91	Geba	Guinea,Guinea-Bissau,Senegal	234	Song Vam Co Dong	Cambodia,Viet Nam
92	Glama	Norway,Sweden	235	St. Croix	Canada,United States of America
93	Goascoran	Honduras,El Salvador	236	St. John (Africa)	Côte d'Ivoire,Guinea,Liberia
94	Golok	Malaysia,Thailand	237	St. John (North America)	Canada,United States of America
95	Great Scarcies	Guinea,Sierra Leone	238	St. Lawrence	Canada,United States of America
96	Grijalva	Belize,Guatemala,Mexico	239	St. Paul	Guinea,Liberia
97	Guadiana	Spain,Portugal	240	Stikine	Canada,United States of America

	Basin name	Countries/territories sharing basin		Basin name	Countries/territories sharing basin
98	Guir	Algeria,Morocco	241	Struma	Bulgaria,Greece,The former Yugoslav Republic of Macedonia,Serbia
99	Hamun-i-Mashkel/ Rakshan	Afghanistan,Iran (Islamic Republic of), Pakistan	242	Suchiate	Guatemala,Mexico
100	Han	Republic of Korea,Dem People's Rep of Korea	243	Sujfun	China, Russian Federation
101	Har Us Nur	China,Mongolia,Russian Federation	244	Sulak	Azerbaijan,Georgia,Russian Federation
102	Hari/Harirud	Afghanistan,Iran (Islamic Republic of), Turkmenistan	245	Tafna	Algeria,Morocco
103	Helmand	Afghanistan,Iran (Islamic Rep of),Pakistan	246	Tagus/Tejo	Spain,Portugal
104	Hondo	Belize,Guatemala,Mexico	247	Taku	Canada,United States of America
105	Ili/Kunes He	China,Kazakhstan,Kyrgyzstan	248	Talas	Kazakhstan,Kyrgyzstan,Uzbekistan
106	Incomati	Mozambique,Swaziland,South Africa	249	Tami	Indonesia,Papua New Guinea
107	Indus	Afghanistan,China,Aksai Chin,Jammu and Kashmir,India,Nepal,Pakistan	250	Tana	Finland,Norway
108	Irrawaddy	China,Arunachal Pradesh,India,Myanmar	251	Tano	Côte d'Ivoire,Ghana
109	Isonzo	Italy,Slovenia	252	Tarim	Afghanistan,China,Aksai Chin,Jammu and Kashmir,Kazakhstan,Kyrgyzstan, Tajikistan
110	Jacobs	Norway,Russian Federation	253	Temash	Belize,Guatemala
111	Jayapura	Indonesia,Papua New Guinea	254	Terek	Georgia,Russian Federation
112	Jenisej/Yenisey	Mongolia,Russian Federation	255	Thukela	Lesotho,South Africa
113	Jordan	Egypt,Israel,Jordan,Lebanon,West Bank, Syrian Arab Republic	256	Tigris-Euphrates/ Shatt al Arab	Iran (Islamic Rep. of), Iraq,Jordan, Saudi Arabia,Syrian Arab Rep., Turkey
114	Juba-Shibeli	Ethiopia,Kenya,Somalia	257	Tijuana	Mexico,United States of America
115	Jurado	Colombia,Panama	258	Tjeroaka-Wanggoe	Indonesia,Papua New Guinea
116	Kaladan	Bangladesh,India,Myanmar	259	Torne/ Tornealven	Finland,Norway,Sweden
117	Karnaphuli	Bangladesh,India,Myanmar	260	Tuloma	Finland,Russian Federation
118	Kemi	Finland,Norway,Russian Federation	261	Tumbes	Ecuador,Peru
119	Klaralven	Norway,Sweden	262	Tumen	China,Dem People's Rep of Korea,Russian Federation
120	Kogilnik	Moldova, Republic of,Ukraine	263	Umba	Kenya,United Republic of Tanzania
121	Komoe	Burkina Faso,Côte d'Ivoire,Ghana,Mali	264	Umbeluzi	Mozambique,Swaziland,South Africa
122	Kowl E Namaksar	Afghanistan,Iran (Islamic Republic of)	265	Utamboni	Gabon,Equatorial Guinea
123	Krka	Bosnia and Herzegovina,Croatia	266	Valdivia	Argentina,Chile
124	Kunene	Angola,Namibia	267	Vanimo-Green	Indonesia,Papua New Guinea
125	Kura-Araks	Armenia,Azerbaijan,Georgia,Iran (Islamic Republic of),Russian Federation,Turkey	268	Vardar	Bulgaria,Greece,The former Yugoslav Republic of Macedonia,Serbia
126	La Plata	Argentina,Bolivia,Brazil,Paraguay,Ur uguay	269	Velaka	Bulgaria,Turkey
127	Lagoon Mirim	Brazil,Uruguay	270	Venta	Lithuania,Latvia
128	Lake Chad	Central African Republic,Cameroon, Algeria, Libya,Niger,Nigeria,Sudan,Chad	271	Vijose	Albania,Greece
129	Lake Fagnano	Argentina,Chile	272	Vistula/Wista	Belarus,Czech Republic,Poland, Slovakia,Ukraine

	Basin name	Countries/territories sharing basin		Basin name	Countries/territories sharing basin
130	Lake Natron	Kenya,United Republic of Tanzania, Albania,Greece,The former Yugoslav Republic of Macedonia	273	Volga	Kazakhstan,Russian Federation
131	Lake Prespa	Albania,Greece,The former Yugoslav Republic of Macedonia	274	Volta	Benin,Burkina Faso,Côte d'Ivoire, Ghana,Mali,Togo
132	Lake Titicaca-Poopo System	Bolivia,Chile,Peru	275	Vuoksa	Belarus,Finland,Russian Federation
133	Lake Turkana	Ethiopia,Kenya,Ilemi triangle,South Sudan, Uganda	276	Wadi Al Izziyah	Israel,Lebanon
134	Lake Ubsa-Nur	Mongolia,Russian Federation	277	Whiting	Canada,United States of America
135	Lava/Pregel	Lithuania,Poland,Russian Federation	278	Wiedau	Germany,Denmark
136	Lempa	Guatemala,Honduras,El Salvador	279	Yalu	China,Dem People's Rep of Korea
137	Lielupe	Lithuania,Latvia	280	Yaqui	Mexico,United States of America
138	Lima	Spain,Portugal	281	Yelcho	Argentina,Chile
139	Limpopo	Botswana,Mozambique,South Africa, Zimbabwe	282	Yser	Belgium,France
140	Little Scarcies	Guinea,Sierra Leone	283	Yukon	Canada,United States of America
141	Loes	Indonesia,Timor-Leste	284	Zambezi	Angola,Botswana,Mozambique,Malaw i,Namibia,United Republic of Tanzania, Dem. Republic of the Congo,Zambia, Zimbabwe
142	Loffa	Guinea,Liberia	285	Zapaleri	Argentina,Bolivia,Chile
143	Lotagipi Swamp	Ethiopia,Kenya,Ilemi triangle,South Sudan,Uganda	286	Zarumilla	Ecuador,Peru

Chapter 7
Technical Annexes



Contents

Annex I – TWAP River Basins Working Group Members

The institutional partners are listed in alphabetical order. Individuals listed have been involved in the assessment in some way. For a list of acknowledgements see the beginning of the main report.

TWAP River Basins Partnership

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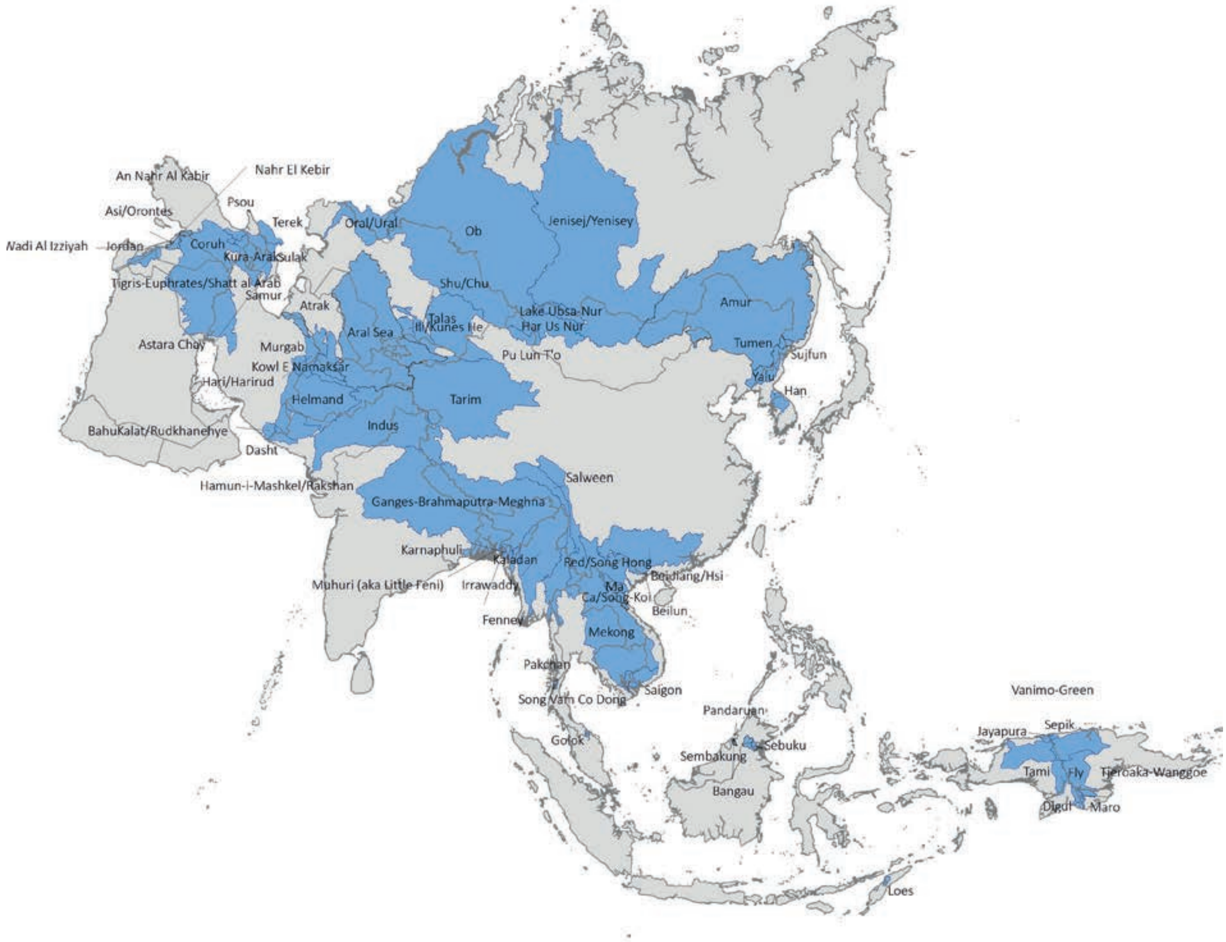
** Working group members working with TWAP RB partners on the delivery of the specific indicator results, but affiliated with an independent institution outside of the TWAP RB consortium.*

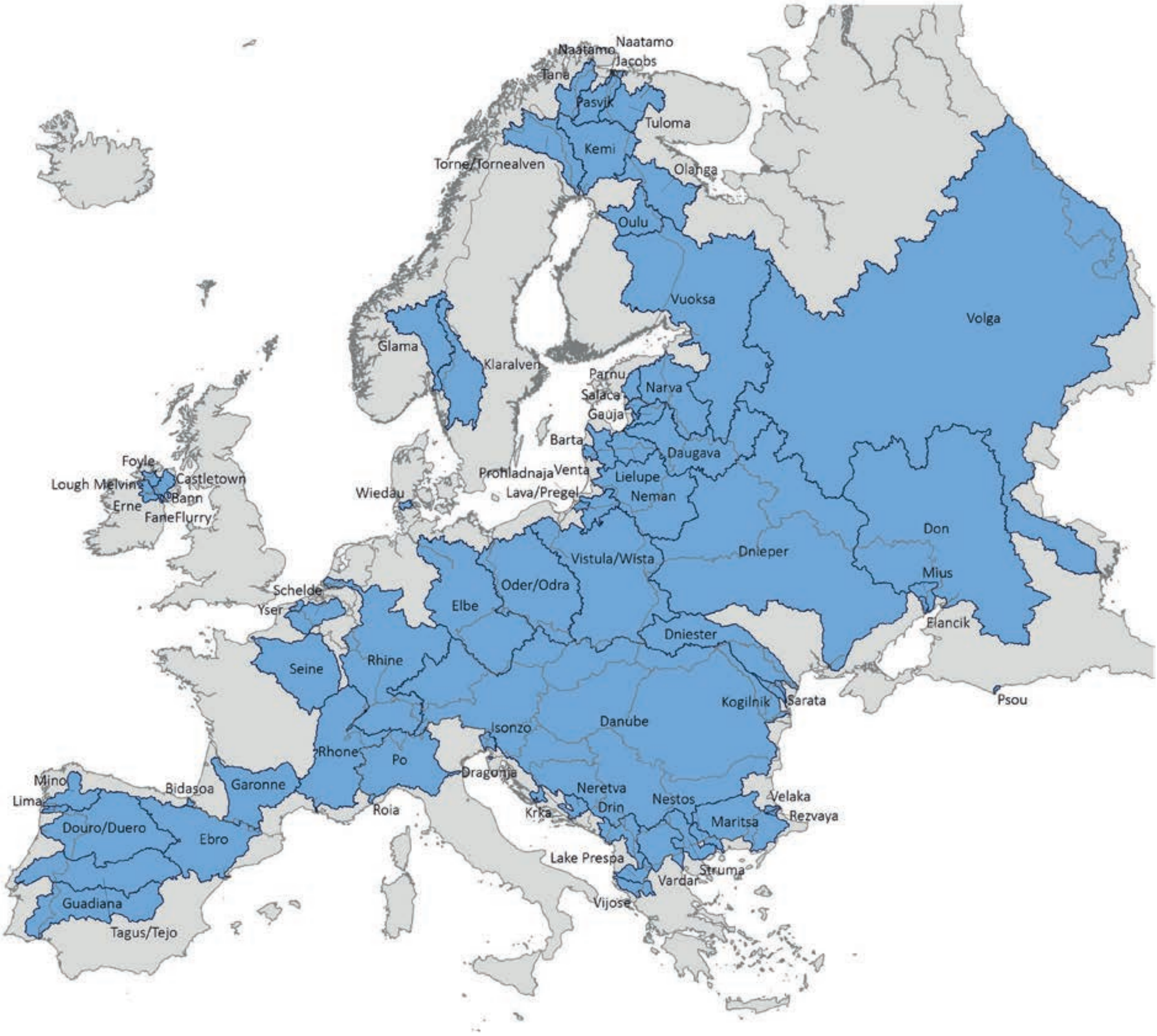
Annex II – Transboundary River Basin Maps by Continent

Transboundary River Basins of AFRICA.

Transboundary River Basins of ASIA.



Transboundary River Basins of EUROPE.



Transboundary River Basins of NORTH AMERICA.

Transboundary River Basins of SOUTH AMERICA.

Annex III – Transboundary River Basin Tables

Annex III-1: Overview Table by Continent

Africa		Asia		Europe	
River Basin	BCODE	River Basin	BCODE	River Basin	BCODE
Akpa	AKPA	Amur	AMUR	Bann	BANN
Atui	ATUI	An Nahr Al Kabir	ANAK	Bidasoa	BDSO
Awash	AWSH	Aral Sea	ARAL	Barta	BRTA
Benito/Ntem	BENT	Asi/Orontes	ASIX	Castletown	CSTL
Bia	BIAX	Astara Chay	ATCY	Danube	DANU
Baraka	BRKA	Atrak	ATRK	Dnieper	DNPR
Buzi	BUZI	Beilun	BLUN	Dniester	DNSR
Chiloango	CLNG	Bangau	BNGU	Don	DONX
Congo/Zaire	CNGO	Ca/Song-Koi	CAXX	Dragonja	DRAG
Corubal	CRBL	Coruh	CRUH	Drin	DRIN
Cross	CROS	Digul	DIGL	Daugava	DUGV
Cestos	CSTO	Dasht	DSHT	Douro/Duero	DURO
Cavally	CVLY	Fly	FLYX	Ebro	EBRO
Daoura	DAUR	Fenney	FNNY	Elbe	ELBE
Dra	DRAX	Ganges-Brahmaputra-Meghna	GANG	Elancik	ELNK
Cuvelai/Etosha	ETOS	Golok	GLOK	Erne	ERNE
Gambia	GAMB	Han	HANX	Fane	FANE
Gash	GASH	Hari/Harirud	HARI	Flurry	FLRY
Geba	GEBA	Hamun-i-Mashkel/Rakshan	HIMR	Foyle	FOYL
Great Scarcies	GSCR	Helmand	HLMD	Glama	GLAM
Guir	GUIR	Har Us Nur	HRUN	Garonne	GRON
Incomati	ICMT	Bei Jiang/Hsi	HSIX	Guadiana	GUDN
Juba-Shibeli	JUBA	Ili/Kunes He	ILIX	Gauja	GUJA
Komoe	KMOE	Indus	INDU	Isonzo	ISNZ
Kunene	KUNE	Irrawaddy	IRWD	Jacobs	JCBS
Lotagipi Swamp	LGPS	Jayapura	JAPR	Kemi	KEMI
Lake Chad	LKCH	Jordan	JORD	Kogilnik	KGNK
Lake Natron	LKNT	Kaladan	KALD	Krka	KRKA
Lake Turkana	LKTK	Karnaphuli	KNFL	Klaralven	KRLV
Limpopo	LMPO	Kowl E Namaksar	KOWL	Lava/Pregel	LAVA
Loffa	LOFF	Kura-Araks	KURA	Lima	LIMA
Little Scarcies	LSCR	Lake Ubsa-Nur	LKUN	Lake Prespa	LKPP
Mana-Morro	MANA	Loes	LOES	Lielupe	LLUP
Mbe	MBEX	Maro	MARO	Lough Melvin	LMEL
Medjerda	MDJD	Ma	MAXX	Mino	MINO

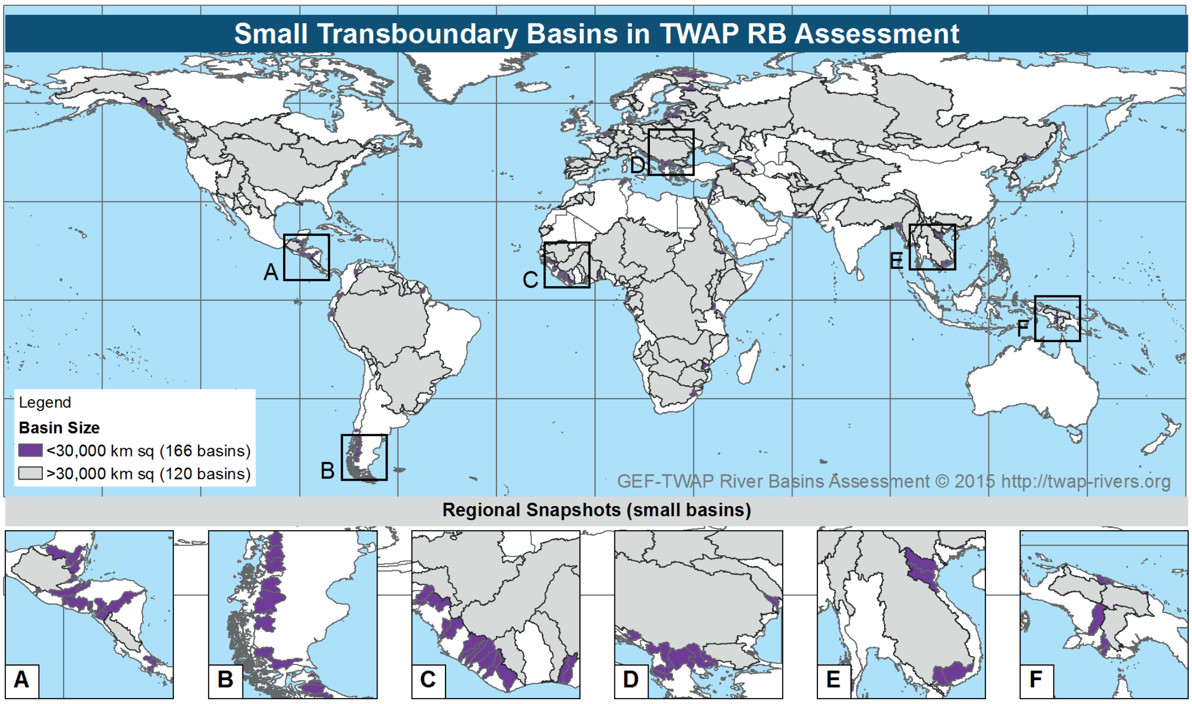
Africa		Asia		Europe	
Moa	MOAX	Mekong	MEKO	Mius	MIUS
Mono	MONO	Muhuri (aka Little Feni)	MHRI	Maritsa	MRSA
Maputo	MPUT	Murgab	MRGB	Neman	NMAN
Niger	NGER	Nahr El Kebir	NHRK	Neretva	NRTV
Nile	NILE	Ob	OBXX	Narva	NRVA
Nyanga	NYGA	Oral/Ural	ORAL	Nestos	NSTO
Oued Bon Naima	ODBN	Pakchan	PKCN	Naatamo	NAAT
Ogooue	OGOO	Pandaruan	PNDR	Oder/Odra	ODER
Okavango	OKVG	Psou	PSOU	Olanga	OLNG
Orange	ORAN	Pu Lun T'o	PULT	Oulu	OULU
Oueme	OUEM	BahuKalat/Rudkhanehye	RDKH	Po	POXX
Pangani	PANG	Red/Song Hong	REDX	Prohladnaja	PRLN
Pungwe	PUNG	Saigon	SAIG	Parnu	PRNU
Ruvuma	RVMA	Salween	SALW	Pasvik	PSVK
Sabi	SABI	Samur	SAMR	Rezvaya	REZV
Sanaga	SANA	Sebuku	SBKU	Rhine	RHIN
Sassandra	SASS	Sepik	SEPK	Rhone	RHON
Senegal	SENG	Shu/Chu	SHUR	Roia	ROIA
St. John (Africa)	SJAF	Sembakung	SMBK	Salaca	SALC
St. Paul	SPAU	Sujfun	SUJF	Seine	SEIN
Tafna	TAFN	Sulak	SULK	Schelde	SHLD
Tano	TANO	Song Vam Co Dong	SVCD	Sarata	SRTA
Thukela	THUK	Talas	TALA	Struma	STUM
Umbeluzi	UBLZ	Tami	TAMI	Tagus/Tejo	TAGU
Umba	UMBA	Terek	TERK	Tana	TANA
Utamboni	UTBN	Tigris-Euphrates/Shatt al Arab	TIGR	Torne/Tornealven	TORN
Volta	VOLT	Tjeroaka-Wanggoe	TJWA	Tuloma	TULM
Zambezi	ZAMB	Tarim	TRIM	Venta	VENT
Total:	**63**	Tumen	TUMN	Vijose	VJSE
		Vanimo-Green	VAGR	Velaka	VLKA
		Wadi Al Izziyah	WADI	Volga	VOLG
		Yalu	YALU	Vardar	VRDR
		Jenisej/Yenisey	YNSY	Vistula/Wista	VSTL
		Total:	**68**	Vuoksa	VUKS
				Wiedau	WIED
				Yser	YSER
				Total:	**71**

North America		South America	
River Basin	**BCODE**	**River Basin**	**BCODE**
Alsek	ALSK	Amacuro	AMCR
Artibonite	ATBN	Amazon	AMZN
Belize	BLZE	Aviles	AVLS
Candelaria	CDLR	Aysen	AYSN
Changuinola	CGNL	Baker	BAKR
Chamelecon	CHAM	Barima	BRMA
Choluteca	CHLT	Carmen Silva/Chico	CHIC
Chiriqui	CHRQ	Chira	CHIR
Colorado	CLDO	Chuy	CHUY
Chilkat	CLKT	Cancoso/Lauca	CNCS
Columbia	CLMB	Comau	COMA
Coco/Segovia	COCO	Corantijn/Courantyne	CRTY
Conventillos	CONV	Catatumbo	CTTB
Corredores/Colorado	CORR	Cullen	CULL
Coatan Achute	CTAT	El Naranjo	ELNA
Fraser	FRSR	Essequibo	ESQB
Firth	FRTH	Gallegos/Chico	GALG
Grijalva	GJLV	Jurado	JURD
Goascoran	GOSR	Lake Fagnano	LKFN
Hondo	HOND	Lake Titicaca-Poopo System	LKTC
Lempa	LMPA	Lagoon Mirim	LMRM
Massacre	MASS	La Plata	LPTA
Mississippi	MISS	Mira	MIRA
Moho	MOHO	Maroni	MRNI
Motaqua	MOTQ	Mataje	MTJE
Negro	NEGR	Orinoco	ORIN
Nelson-Saskatchewan	NELS	Oiapoque/Oyupock	OYPK
Paz	PAZX	Palena	PLNA
Pedernales	PDNL	Pascua	PSCU
Rio Grande	RGNA	Patia	PTIA
St. Croix	SCRO	Puelo	PUEL
Sixaola	SIOL	Rio Grande (South America)	RGSA
St. John	SJNA	Seno Union/Serrano	SENO
San Juan	SJUA	San Martin	SMAR
Skagit	SKAG	Tumbes	TUMB
St. Lawrence	SLAW	Valdivia	VDVA
Sarstun	SRTU	Yelcho	YELC
Stikine	STKN	Zapaleri	ZAPL
Suchiate	SUCT	Zarumilla	ZARM
Taku	TAKU	**Total:**	**39**
Temash	TEMA		
Tijuana	TIJU		
Whiting	WHIT		
Yaqui	YAQU		
Yukon	YUKN		
Total:	**45**		

Annex III-2: Small to very small transboundary basins

TWAP RB Assessment covers a total of 286 transboundary river basins. The size of the basins ranges from just a few km² to several million km² for large basins such as Amazon and Congo. For most model-based indicators (e.g. Environmental Water Stress Indicator, calculated using WaterGAP model), verified conclusions can only be drawn for transboundary basins larger than 25 000 – 30 000 km², broadly equivalent to 10 grid cells at the equator, depending on the grid. There are 166 basins smaller than 30 000 km² in this assessment. Thus, results for these basins are calculated, but it is acknowledged that these may have a lower level of confidence, due to modelling limitations. Full account of the small basins is given in the table below.

Map of Small Transboundary Basins in TWAP RB Assessment.



Basin	No. BCUs	Area (km²)	Population	Basin	No. BCUs	Area (km²)	Population	Basin	No. BCUs	Area (km²)	Population	Basin	No. BCUs	Area (km²)	Population
Conventillos	2	7	182	Zarumilla	2	1 628	198 291	Neretva	2	6 808	633 216	Mino	2	16 679	749 858
El Naranjo	2	24	569	Prohladnaja	2	1 791	66 898	Vijose	2	6 816	248 310	Tano	2	16 773	1 750 016
Bangau	2	130	1 495	Carmen Silva/ Chico	2	2 065	8 573	Parnu	2	6 923	114 468	Sujfun	2	16 820	501 469
Dragonja	2	154	12 665	Sarstun	2	2 165	77 911	Mius	2	7 088	1 189 275	Struma	4	16 825	945 538
Wadi Al Izziyah	2	162	48 855	Paz	2	2 177	621 752	Mbe	2	7 123	24 251	Tana	2	16 872	7 054
Flurry	2	201	16 608	Golok	2	2 320	489 877	Tafna	2	7 264	995 141	Drin	4	17 286	1 766 320
Castletown	2	265	31 747	Akpa	2	2 434	132 325	Utamboni	2	7 400	67 062	Taku	2	17 496	795
Lough Melvin	2	290	5 487	Lima	2	2 469	121 602	Lake Prespa	3	7 526	600 756	Lielupe	2	17 667	653 410
Aviles	2	296	1 729	Whiting	2	2 474	520	Mana-Morro	3	7 634	179 952	Chira	2	17 684	697 123
Pedernales	2	320	22 958	Krka	2	2 488	59 485	Great Scarcies	2	7 832	515 933	Pasvik	3	17 961	12 893
Fane	2	341	21 912	Zapaleri	3	2 507	808	Choluteca	2	8 049	1 627 485	Lempa	3	18 216	4 609 138
San Martin	2	360	704	Loes	2	2 567	186 375	Tjeroaka-Wanggoe	2	8 049	60 982	Little Scarcies	2	18 552	926 142
Oued Bon Naima	2	369	52 447	Vanimo-Green	2	2 670	16 208	Skagit	2	8 207	78 441	Schelde	3	19 069	9 158 158
Astara Chay	2	402	71 368	Barta	2	2 725	82 710	Belize	2	8 493	109 916	Moa	3	19 560	1 757 912
Psou	2	423	24 577	Goascoran	2	2 746	247 324	Rio Grande (South America)	2	8 632	26 755	St Paul	2	20 317	1 026 515
Temash	2	472	3 261	Sixaola	2	2 857	48 109	Seno Union/ Serrano	2	8 648	7 141	BahuKalat/ Rudkhanehye	2	20 633	234 086
Roia	2	675	25 866	Foyle	2	2 923	173 399	Artibonite	2	8 860	1 455 738	Kaladan	3	21 391	628 332
Coatan Achute	2	679	126 533	Fenney	2	3 028	1 778 226	Puelo	2	9 163	100 922	Coruh	2	22 039	788 676
Naatamo	2	719	1 206	Sebuku	2	3 070	15 505	Gauja	2	9 207	196 490	Patia	2	22 303	1 657 517
Bidasoa	2	720	55 354	Changuinola	2	3 216	68 125	Valdivia	2	10 239	188 351	Medjerda	2	23 175	2 554 202
Chuy	2	722	15 571	Pakchan	2	3 226	134 566	Sembakung	2	10 253	52 056	Gash	3	23 656	1 906 237
Rezvaya	2	771	30 582	Maro	2	3 319	6 672	Loffa	2	10 446	223 464	Asi/Orontes	3	23 830	4 418 230
Massacre	2	777	151 871	Isonzo	2	3 357	300 495	Mira	2	10 467	625 224	Mono	2	23 988	2 159 469
Beilun	2	840	116 863	Lake Fagnano	2	3 557	18 362	Gallegos/ Chico	2	10 753	29 294	Corubal	2	24 300	661 849
Comau	2	910	2 364	Salaca	2	3 585	48 397	Bia	2	11 328	1 198 604	Coco/ Segovia	2	24 509	895 266
Cullen	2	917	1 514	Amacuro	2	3 719	1 138	Yelcho	2	11 409	34 389	Vardar	4	24 558	2 125 676
Jurado	2	918	4 570	Muhuri (aka Little Feni)	2	3 787	3 312 578	Venta	2	11 901	352 694	Nyanga	2	24 963	100 329
Barima	2	923	110	St. Croix	2	3 942	17 804	Geba	3	12 327	497 858	Digul	2	25 484	65 143
Jacobs	2	944	1 972	Chilkat	2	3 967	1 204	Aysen	2	12 550	55 908	Oulu	2	25 972	172 018
Mataje	2	991	42 739	Kogilnik	2	3 972	178 942	Hondo	3	12 699	162 784	Oiapoque/ Oyupock	2	25 994	10 904
An Nahr Al Kabir	2	1 032	204 269	Tijuana	2	4 430	1 067 632	Cestos	3	12 723	711 346	Baker	2	26 886	11 612
Velaka	2	1 075	20 475	Chamelecon	2	4 432	1 381 999	Chiloango	3	12 996	1 169 060	Tuloma	2	27 005	123 556

Basin	No. BCUs	Area (km²)	Population	Basin	No. BCUs	Area (km²)	Population	Basin	No. BCUs	Area (km²)	Population	Basin	No. BCUs	Area (km²)	Population
Corredores/ Colorado	2	1 139	47 994	Erne	2	4 438	126 898	Palena	2	13 230	12 945	Ca/Song-Koi	2	27 246	2 740 642
Moho	2	1 189	16 646	Jayapura	2	5 253	328 736	Karnaphuli	3	13 923	6 233 894	Lake Natron	2	27 280	719 709
Pandaruan	2	1 202	13 864	Tumbes	2	5 371	184 356	Pascua	2	14 107	2 105	Catatumbo	2	27 435	1 808 743
Sarata	2	1 237	56 194	Umbeluzi	3	5 492	635 500	Sulak	3	14 108	425 005	Alsek	2	28 220	803
Wiedau	2	1 352	77 402	Bann	2	5 746	546 281	Lava/Pregel	3	14 466	1 068 308	Buzi	2	28 490	1 318 346
Elancik	2	1 380	45 263	Nestos	2	5 888	179 201	Candelaria	2	14 609	168 179	Thukela	2	29 149	1 975 380
Chiriqui	2	1 403	90 273	Firth	2	6 075	24	Song Vam Co Dong	2	15 526	5 171 971	Cavally	3	29 495	1 524 512
Suchiate	2	1 409	340 484	Negro	2	6 159	474 077	St. John (Africa)	3	16 157	761 691	Ma	2	29 512	2 984 577
Yser	2	1 560	293 784	Umba	2	6 674	499 314	Motaqua	2	16 271	3 846 114	Saigon	2	29 643	10 911 289
Nahr El Kebir	2	1 598	772 647	Samur	2	6 787	209 885								

TOTAL	166 basins
	1 551 937 sq km
	115 203981 people

Annex IV – Basin and BCU Creation Documentation

Transboundary Waters Assessment Programme (TWAP)

Basin and BCU Creation Documentation

October 2014 Prepared by Jim Eynard, Oregon State University.

This document describes the identification and creation of transboundary basin and basin-country units (BCUs), which is an update of previous basin and BCU layers within the Transboundary Freshwater Dispute Database (TFDD).

This update of these BCUs was done mainly by three people from October 2013 to August 2014:
David Allen (David.ALLEN@iucn.org), IUCN

Doug Wood (wooddo@geo.oregonstate.edu douglastwood@yahoo.com), Oregon State University
Jim Eynard (eynardj@geo.oregonstate.edu jimeynard@gmail.com), Oregon State University

Development of the Basin Shapefile

Basins were initially identified by David Allen using HydroBASINS data. HydroBASINS is a global river and lake catchment layer derived from HydroSHEDS and the global lakes and wetlands database (GLWD) (Lehner 2013). A 'MOST-DOWN' coding within the Level08 HydroBASINS was made to color-code large-scale drainages and make them visually obvious. Connected sub-basins with the same outflow were then selected (manually for small basins; automatically by 'MOST-DOWN' coding for larger basins) and given appropriate TFDD attribute codes. This initial output is a shapefile called "HydroBasins_from_David_Allen_20130830".

Development of the Country Shapefile

The country shapefile is derived from the Global Administrative Unit Layers (GAUL) (FAO 2014) polygon shapefile that is developed, managed, and distributed by the Food and Agricultural Organization (FAO) of the United Nations. The "GAUL_countries_20131201" shapefile was created by dissolving the original FAO GAUL shapefile based on the "adm0_name" attribute, so that the original shapefile of 27 761 records became a shapefile with a total of 276 multi-part features (i.e. one record in the database for each country or administrative unit in the world). The previous version of the TFDD had 242 distinct administrative features – this represents of an increase of 34 administrative features. Many of these new polygons represent disputed territories throughout the world, while a few others are actually "new" countries (e.g. South Sudan).

Identification of Transboundary Basins

To identify which basins were transboundary, Doug Wood used the HydroBASINS output, the previous TFDD basin shapefiles, and the GAUL country shapefile. The identification of transboundary river basins is a sub-selection of "HydroBasins_from_David_Allen_20130830" with modifications made where there were large discrepancies from the previous version. Other levels beyond level 8 of the HydroBASINS data were used as needed after manual inspection of the basin area. The result is the basin shapefile called "RiverBasins_ver_1_20140215". This shapefile includes all of the transboundary basins from previous versions of TFDD as well as an additional 10 basins that were not included in previous versions of the TFDD, for a new total of 286 transboundary basins.

Identification of Basin-Country Units

To obtain basin-country units (BCUs), the transboundary basin shapefile was intersected with the country shapefile. The output of the intersection of "RiverBasins_ver_1_20140215" and "GAUL_countries_20131201" shapefiles produced the "CountryBasinUnits_EqualArea_DTW_20140503" shapefile. Apart from the modifications described below, this is the culmination of efforts to update OSU's TFDD using the improved spatial precision and accuracy of the HydroBASINS and the most current administrative boundary data made available by the United Nations.

Additional Modifications to BCUs

Note that all previous filenames mentioned in this report do not have the modifications described below.

Removal of the Caspian Sea – The country shapefile was further updated to remove the Caspian Sea from the GAUL country polygons. The GAUL shapefile typically includes seas as separate from countries, but there is some ambiguity regarding the Caspian on whether it is a lake or sea, which is likely why the GAUL shapefile includes the area of the Caspian as part of the 5 countries that border the "sea". Due to inaccurate country area calculations for those 5 countries, the decision was made to erase the Caspian Sea from the GAUL shapefile. This reduced the area of the 5 countries bordering this sea to more accurately reflect the country area given in UN FAO statistics. Ultimately, this had no effect on the final BCUs as the Caspian is not considered a basin in the TFDD. The Caspian Sea polygon, which was used to erase, was obtained from Natural Earth Data (Physical Vectors – Lakes + Reservoirs, Version 3.0.0).

Adding the Great Lakes – The area of the Great Lakes was added to the GAUL shapefile to be included as part of the St. Lawrence Basin. This is the opposite problem to the Caspian Sea issue. Where the GUAL shapefile included the area of the Caspian as part of the surrounding countries, it did not include the Great Lakes, treating them as an ocean. However, the TFDD does consider the Great Lakes as part of the St. Lawrence basin and their area needs to be accounted for by the bordering countries (USA and Canada). This division of the Great Lakes was obtained from the country dataset from Natural Earth Data (1:10m Cultural Vectors - Admin 0 – Countries, Version 3.1.0). This area was then added to the BCUs of the St. Lawrence basin.

Clip Basins to GAUL – The basins shapefile was clipped to the "GAUL_countries_20131201" shapefile to eliminate discrepancies between the two shapefiles along the coastline. The basin shapefile, which was derived from the HydroBASINS shapefile, had a different, and seemingly lower resolution than the BCU shapefile, which was derived by the intersection of basins and the GAUL shapefile. The discrepancy caused the sum of BCU areas not to exactly equal the area of its respective basin. Clipping the basin shapefile to the GAUL shapefile fixed this issue. However, due to the different resolutions of HydroBASINS and GAUL, there is still some fragmentation on the coastline that should be addressed in the future. In some areas, islands of a BCU seem to be separated from their main BCU polygon (e.g. see the coastal border of KGNK_UKR and SRTA_UKR).

Area Calculations

To calculate the area of all polygons, the shapefiles were projected into World Cylindrical Equal Area projection. Using ArcGIS 10.2, the Calculate Geometry tool was used to determine the area in square kilometers.

Summary

The final BCU shapefile made from the methods described in this report, including the modifications and area calculations, is called "BCU_Master_20140813". The basin shapefile can be derived from the BCU shapefile by dissolving by 'BCODE' in ArcGIS.

Future work and potential additional modifications to these BCUs will include: 1. the identification of slivers which may cause BCUs to lose their transboundary status, 2. adjustments to the areas of the delta of certain rivers to more accurately reflect the river basin area, 3. a look at the fragmentation issue due to the differing resolutions of GAUL and HydroBASINS, and 4. the use of new basin datasets to identify additional transboundary basins.

References

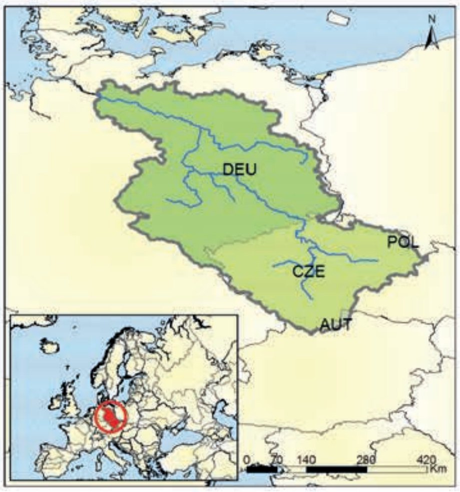
FAO (2014). Food and Agriculture Organization of the United Nations. FAO GEONETWORK. Global Administrative Unit Layers (GAUL) (GeoLayer). (Version: GAUL_countries_20131201).

Lehner, B., Grill G. (2013): Global river hydrography and network routing: baseline data and new approaches to study the world's large river systems. Hydrological Processes, 27(15): 2171–2186. Data is available at www.hydrosheds.org.

www.naturalearthdata.com

Annex V – River Basin Factsheet Sample

Elbe Basin



Geography

Total drainage area (km^2)	138,891
No. of countries in basin	4
Countries in basin	Austria (AUT), Czech Republic (CZE), Germany (DEU), Poland (POL)
Population in basin (people)	21,860,257
Country at mouth	Germany
Average rainfall (mm/year)	718

Governance

No. of treaties and agreements[1]	8
No. of RBOs and Commissions[2]	2

Geographical Overlap with Other Transboundary Systems
(No. of overlapping water systems)

Groundwater	
Lakes	1
Large Marine Ecosystems	0

A BCU (Basin Country Unit) is defined as the portion of a country within a particular river basin.
All BCUs have a BCU code which includes a Basin Code of four letters and a Country Code of three letters: XXXX-XXX

Water Resources

BCU	Annual Discharge (km^3/year)	Annual Runoff (km^3/year)	Av. Groundwater Recharge (km^3/year)	Av. Groundwater Discharge (km^3/year)	Lake and Reservoir Surface Area (km^2)	Lake and Reservoir Volume (km^3)
ELBE_AUT						
ELBE_CZE	9.56	191.71				
ELBE_DEU	19.05	216.87			110.40	0.39
ELBE_POL						
Total in Basin	28.96	208.51			110.40	0.39

Water Withdrawals

[1] For details on Treaties and Agreements please see http://www.transboundarywaters.orst.edu/
[2] For details on River Basin Organisations (RBOs) and Commissions please visit http://www.transboundarywaters.orst.edu/

River Basins TWAP TRANSBOUNDARY WATERS ASSESSMENT PROGRAMME

BCU	Total (km³/year)	Irrigation (km³/year)	Livestock (km³/year)	Electricity (km³/year)	Manufacture (km³/year)	Domestic (km³/year)	Per capita (m³/year)	Total withdrawal as a % of Total Actual Renewable Water Resources (%)
ELBE_AUT								
ELBE_CZE	1,417.71	60.86	29.20	373.17	460	494.38	238.75	
ELBE_DEU	6,044.50	551.76	93.13	2,996.62	1,333	1,069.77	381.26	
ELBE_POL								
Total in Basin	7,462.21	612.62	122.32	3,369.78	1,793.33	1,564.15	341.36	25.77

Socioeconomic Geography

BCU	Area ('000 km²)	BCU area in basin (%)	Population ('000 people)	Population density (people/km²)	Annual pop. growth (%)	Rural population ratio (% pop. rural)	Urban population ratio (% pop. urban)	Large Cities (>500,000)	GDP per capita (USD)	No. of dams	Dam Density (No./000.000 km²)
ELBE_AUT	1	0.01	47	50.89	0.39	0.00	100.00	0	49,053.82	0	0.00
ELBE_CZE	50	0.36	5,938	119.06	0.53	0.00	100.00	2	18,861.43	21	421.07
ELBE_DEU	88	0.63	15,854	180.47	-0.06	0.00	100.00	14	45,084.87	21	239.05
ELBE_POL	0	0.00	21	86.98	0.06			0	13,431.95	0	0.00
Total in Basin	139	1.00	21,860	157.39	0.21	0.00	99.91	16	37,940.27	42	302.40

TWAP RB Assessment Results: BCU and Basin Relative Risk Category per Indicator[3]

Thematic group	Water Quantity			Water Quality			Ecosystems			Governance			Socioeconomics		
BCU	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
ELBE_AUT					2	3			2	4	3		1	1	1
ELBE_CZE	1	2	2		2	1	5	4	2	2	1	1	4	1	3
ELBE_DEU	2	4	2		1	1	5	3	2	2	1	1	3	1	3
ELBE_POL					2				2	2	1	2	1	1	1
River Basin	2	4	2	5	1	1	5	4	2	2	1	1	4	1	3

Indicators

1 - Environmental water stress 2 – Human water stress 3 – Agricultural water stress 4 – Nutrient pollution 5 – Wastewater pollution 6 – Wetland disconnectivity 7 – Ecosystem impacts from dams 8 – Threat to fish 9 – Extinction risk 10 – Legal framework 11 – Hydropolitical tension 12 – Enabling environment 13 – Economic dependence on water resources 14 – Societal well-being 15 – Exposure to floods and droughts

TWAP RB Assessment Results: BCU and Basin Relative Risk Category per Projected Indicator

3 Lined (or dotted) cells indicate a lower degree of confidence in results due to global modelling limitations and other gap-filling methods.

Projected Indicator	1.Environmental water stress		2.Human water stress		4.Nutrient pollution		16.Change in population density		11.Hydropolitical tension
Basin BCU	P-2030	P-2050	P-2030	P-2050	P-2030	P-2050	P-2030	P-2050	Projected
ELBE_AUT									3
ELBE_CZE	2	2	2	2			1	1	1
ELBE_DEU	2	2	4	4			1	1	1
ELBE_POL									1
River Basin	2	2	4	4	5	5	1	1	1

TWAP RB Assessment results: Water System Linkages

Thematic group	Lake Influence Indicator	Delta Vulnerability Index			
Basin/Delta	17	18	19	20	21
River Basin	1				

Indicators

17 – Lake influence indicator **18** – Relative sea level rise (RSLR) **19** – Wetland ecological threat **20** – Population pressure **21** – Delta governance

Disclaimer

The results and information of factsheet is produced and maintained by the River Basins Component of the GEF Transboundary Water Assessment Programme (GEF TWAP).

GEF TWAP is the first global-scale assessment of all transboundary water systems. The TWAP consists of five independent indicator-based water system assessments and the linkages between them, including their socioeconomic and governance-related features. The United Nations Environment Programme (UNEP) is the implementing agency of TWAP. Project Coordination Unit (PCU) in Nairobi, Kenya coordinates the work of UNESCO-IHP, ILEC, UNEP-DHI and the IOC of UNESCO on Transboundary Aquifers, Lake Basins, River Basins, Large Marine Ecosystems and Open Ocean respectively. Each executing partner engages a broad network of data and information rich partners with responsibilities either of a thematic or geographic nature. More on TWAP full size project at http://www.geftwap.org .

The TWAP River Basins component (TWAP RB) carried out a global comparison of 286 transboundary river basins, in order to enable the prioritisation of funds for basins at risk from a variety of issues, covering water quantity, water quality, ecosystems, governance and socio-economics. It also considered risks to deltas from threats of a transboundary nature, and considered the relative influence of lakes on these river basins. TWAP RB is an indicator–based assessment, allowing for an analysis of basins, based on risks to both societies and ecosystems. It also includes provisional outlook projections to 2030 and 2050 for a limited number of indicators.
Values given in the present fact-sheet represent an approximate guide only and should not replace recent local assessments.

For more information on data sources, indicator calculation methodologies, limitations and more consult indicator metadata sheets available on TWAP RB Data portal on http://twap-rivers.org .

Annex VI – Sample Basin Results Summary Table

An excerpt from the basin results summary table. All summary tables (Basin, BCU, Water System Links, and Projected Indicators) available for download from twap-rivers.org

RIVER BASIN	RIVER BASIN CODE	Area [000' km2	Population (000	Runoff [km3]	1. Environmental Water Stress	2. Human Water Stress	3. Agricultural Water Stress	4. Nutrient Pollution	5. Wastewater Pollution	6. Wetland Disconnectivity	7. Ecosystem Impacts from Dams	8. Threat to Fish	9. Extinction Risk
Indus	INDU	855	189912	206	0,70	1,00	0,43	0,75	0,87	0,51	0,76	0,67	0,27
Tarim	TRIM	1097	10322	12	1,00	1,00	1,00	0,25	0,81	0,17	0,66	0,79	0,28
Ganges-Brahmaputra-Meghn	GANG	1654	704221	860	0,52	0,50	0,08	1,00	0,92	0,72	0,79	0,64	0,30
Kowl E Namaksar	KOWL	42	470	45	1,00	1,00	0,62	0,25	0,98	1,00	0,42	0,23	0,24
Tafna	TAFN	7	995	42	0,94	1,00	0,53	1,00	0,62	0,37	0,50		0,27
Song Vam Co Dong	SVCD	16	5172	565	0,07	1,00	0,19	0,75	1,00	0,82	0,59	0,97	0,18
Tigris-Euphrates/Shatt al Arab	TIGR	869	65437	170	0,62	1,00	0,29	0,50	0,71	0,35	0,86	0,66	0,30
Vardar	VRDR	24	2126	303	0,27	0,75	0,14	0,75	0,91	0,05	0,86	0,45	0,15
Dasht	DSHT	31	629	62	1,00	1,00	0,20	0,25	0,96				0,22
Medjerda	MDJD	23	2554	106	0,83	0,75	0,20	0,75	0,70	0,32	0,90	0,29	0,21
Saigon	SAIG	30	10911	1158	0,02	0,25	0,02	0,75	1,00	0,37	0,68	0,83	0,17
Helmand	HLMD	403	12042	79	1,00	1,00	0,39	0,50	0,99	0,36	0,46	0,43	0,19
Hari/Harirud	HARI	119	5668	74	1,00	1,00	0,80	0,50	0,97	0,34	0,55	0,42	0,17
Aral Sea	ARAL	1218	50052	103	0,53	0,75	0,35	0,25	0,98	0,46	0,61	0,41	0,21
Hamun-i-Mashkel/Rakshan	HIMR	116	1073	53	0,76	1,00	0,08	0,25	0,97				0,23
Jordan	JORD	46	9584	117	1,00	1,00	0,19	1,00	0,37	0,33	0,82	0,63	0,22
Kura-Araks	KURA	191	14462	133	0,69	1,00	0,34	0,50	0,86	0,18	0,83	0,36	0,21
Artibonite	ATBN	9	1456	307	0,04	0,25	0,04	0,75	0,99	0,77	0,33		0,24
Muhuri (aka Little Feni)	MHRI	4	3313	1320	0,26	0,50	0,09	1,00	0,98	0,60	0,72	0,48	0,11
Murgab	MRGB	94	1844	93	0,88	1,00	0,25	0,25	0,95	0,03	0,54	0,20	0,31
Drin	DRIN	18	1766	869	0,08	0,00	0,01	0,75	0,93		0,82	0,84	0,99
Shu/Chu	SHUR	76	2077	62	0,44	1,00	0,27	0,25	0,91	0,47	0,67	0,48	0,22
Limpopo	LMPO	407	15159	47	0,47	0,75	0,08	1,00	0,76	0,32	0,88	0,39	0,09
Bei Jiang/Hsi	HSIX	402	77098	726	0,03	0,50	0,02	1,00	0,82	0,25	0,80	0,67	0,39
BahuKalat/Rudkhanehye	RDKH	21	234	79	0,74	1,00	0,11	0,25	0,97				0,21
Massacre	MASS	0	152	30	0,13		0,81	0,75	0,99				0,21
El Naranjo	ELNA	0	1	-1					0,92				
Tijuana	TIJU	4	1068	92	0,99	1,00	0,11	1,00	0,58		0,64	0,80	0,10
Mekong	MEKO	773	58743	647	0,04	0,25	0,01	0,50	0,91	0,43	0,60	0,92	0,44
San Juan	SJUA	41	3443	1213	0,00	0,00	0,00	0,50	0,94	0,94	0,59	0,32	0,27
Lake Prespa	LKPP	7	601	599	0,20	0,25	0,06	0,75	0,96		0,71	0,58	0,39
Irrawaddy	IRWD	375	28583	1470	0,00	0,00	0,00	0,50	0,98	0,58	0,55	0,47	0,21

Annex VII – Statistical Analysis of Indicator Results

TWAP River Basins Component - Statistical Analysis
CIESIN - Columbia University
Australian Rivers Institute

1. Introduction and General Methodology

Summarizing and integrating the information from multiple indicators can be a difficult task with many potential pitfalls along the way. Defining a single composite score that integrates the data from a large number of indicators is often conceptually appealing; however, it can mask some of the nuances that exist in datasets such as that assembled for the TWAP River Basins analysis. A statistical analysis may not have the conceptual appeal of a single integrative score, however, it can help elucidate interesting patterns that exist in the dataset and provide a more statistical summary of the basins and the indicators themselves. The purpose of this annex is to report the results of such an analysis.

The goals of this integrated analysis are to explore the relationships between the indicators and river basins included in the TWAP River Basins component. In addition to summarizing the patterns between the indicators, a goal is to identify groups of basins with similar risk profiles.

To quantify the relationships between the indicators as fully as possible, we used the continuous indicator data rather than the risk categories presented in the main body of the TWAP report. Additionally, we used a mix of sub-indicators and indicators to explore the relationships between all available variables in the raw dataset. This provided additional information about each basin which would be lost if uncorrelated sub-indicators such as two human water stress indicators were combined as their average. Based on an assessment of the correlation structure of the data, we used indicators except in a few cases as follows: we separated the two human water stress sub-indicators, grouped the first four of the societal wellbeing sub-indicators as “societal wellbeing” and the last one as “income inequality”, and separated sub-indicators for exposure to floods and droughts.

The approach to analysis involved a bivariate and multivariate analysis. Bivariate analyses involve the analysis and comparison of two variables to quantify the nature of the relationship between them. In contrast, multivariate analysis considers more than two variables at a time and is commonly used to decompose complex multi-variable datasets into the dominant underlying gradients of variation between the variables or to identify distinct groups of objects, in this case river basins.

The first stage of the analysis was to generate a complete correlation matrix to compare the correlation between all pairs of indicators and sub-indicators in this analysis (Section 2). We used Pearson’s correlation coefficient, denoted by *r*, which has a scale of -1 to 1. Two variables with a correlation coefficient of -1 are perfectly negatively correlated with each other, a coefficient of 1 indicates complete positive correlation and a coefficient of 0 indicates the two variables are completely uncorrelated.

Subsequent to the correlation analysis we undertook a Principal Components Analysis (PCA), which is a multivariate technique used to explore the relationships between the variables further, and examine the basins in terms of the dominant gradients of variation within the data. Finally, we used cluster analysis to group the basins into categories based on their similarity across all indicators.

We start with an assessment of the correlation matrix (Section 2), turn to the results of the principal components analysis (PCA) (Section 3), and conclude with a section presenting results of a cluster analysis (Section 4). Note that the correlation analysis and PCA were performed on normalized scores, where the original values were converted to a score ranging from 0-100, where 0 refers to lowest risk and 100 refers to highest risk. While retaining the underlying data distribution, this avoids the issue of interpretation of signs, since high is always considered "bad", whereas in the raw data high values were often "good" (e.g., high values for enabling environment on the raw scale were considered good).

All analyses were performed using the R statistical software and contributed packages such as plyr (for joining and aggregating datasets), Hmisc (for correlation analysis), stats (for PCA), and the R script for k-means cluster analysis created by Matthew Peeples.

2. Correlation analysis

Table 1 includes the correlation matrix for the themes, and only indicators with significant correlations above the 0.10 level (in *italics*) and 0.05 levels are shown. Bold type face refers to indicators with higher correlations (Pearson's r > 0.5). Indicators with high correlations show similar spatial patterns across the world and do not necessarily provide additional, unique information about the basins. This also identifies the manner in which basins may be statistically associated.

The clearest pattern that emerges from the correlation matrix surrounds some of the pollution indicators and those associated with governance and between water stress-related indicators. There is a high positive correlation between wastewater pollution and the enabling environment, which suggests that basins in regions that lack strong governance are associated with high pollution levels. These are generally countries with poor societal wellbeing, as confirmed by high correlation between indicator wastewater pollution and societal wellbeing. Among the indicators that are related to water endowments, there is a high positive correlation between environmental water stress, agricultural water stress, and exposure to drought.

Table 1. Correlation matrix

Indicators	1	2a	2b	3	4	5	6	7	8	9	10	11	12	13	14abcd	14e	15a	15b
1. Environmental water stress																		
2a. Human water stress A																		
2b. Human water stress B	0.35																	
3. Agricultural water stress	**0.71**		0.31															
4. Nutrient pollution	0.21			0.23														
5. Wastewater pollution		0.17			-0.12													
6. Wetland disconnectivity						0.22												
7. Ecosystem impacts from dams	0.34			0.23	*0.13*	-0.41	-0.18											
8. Threat to fish		0.18		0.14	0.37	-0.26		0.24										
9. Extinction risk	0.12			0.11				0.16	0.24									
10. Legal framework	-0.18	-0.13		-0.11		0.28	*0.12*	-0.44	-0.27	-0.21								
11. Hydropolitical tension		0.20				0.44		-0.16		0.22	0.47							
12. Enabling environment	-0.11	0.14			-0.14	**0.81**	0.21	-0.39	-0.18		0.32	0.43						
13. Economic dependence on water resources	0.13	0.12		0.11				0.39	0.24	0.29	-0.30							
14abcd. Societal wellbeing		0.13				**0.63**	0.21	-0.29	-0.19	*-0.12*	0.19	0.25	**0.58**					
14e. Income inequality						0.24			-0.22				0.20	-0.12	0.13			
15a. Exposure to flood						0.16	0.15		0.27			0.13		0.12				
15b. Exposure to drought	0.61		0.28	0.43				0.18	-0.13		-0.18			0.12	0.21	0.13		

3. Principal Component Analysis

A. Introduction

We use principal component analysis (PCA) to reduce the number of indicators to a set of latent components to account for the variance of the original data. The approach uses Eigen analysis to summarize the statistical properties of the indicators simultaneously by identifying a set of *n* uncorrelated principal components (PCs), (where *n* = the number of indicators). The PCs are linear combinations of the indicators that are conceptually similar to a line of best fit through the data cloud. The first PC explains the largest amount of variation in the n-dimensional data cloud, and the second PC explains the next largest amount of variation, subject to the constraint that it is orthogonal (or uncorrelated) to the first PC. Because the PCs are uncorrelated, the scores associated with each PC encapsulate a unique aspect of the socio-ecological system (and relative risk factors) represented by the original set of indicators.
The number of PCs defined in the analysis equals the number of indicators, however, since each successive PC explains less of the total variation in the data, much of the meaningful variation in the data cloud can be captured by the first few PCs. A common method to determine how many components to retain and interpret is the Keiser criterion, which suggests keeping all components with an eigenvalue higher than 1.

Prior to running a PCA, the data were standardized as z-scores by subtracting the mean and dividing by the standard deviation, so that all the variables are presented on the same scale with the standard deviation of each variable equal to 1. Hence, a z-score of 0 would represent the mean across all basins, a z-score of 2 represents a value two standard deviations above the mean, and a z-score of -2 represents two standard deviations below the mean. Each PC, then, can be interpreted as a z-score, though the directionality (whether positive z-scores represent high or low risk) needs to be tested against the underlying data.

One advantage of the PCA, as applied here, is that it can help illuminate the statistical relationships between the indicators in a spatial context. Each PC captures spatial correlation between the indicators, and different PCs reflect uncorrelated patterns. A PC can be interpreted conceptually as a reflection of the indicators with the highest loadings (equivalent to correlation coefficients). This approach allows the developer to identify where different aspects of risk are most intensely present. Additionally, each basin has a score for each PC which shows how they are related along the main axes of variation in the data. These scores can be displayed graphically to illustrate how the basins are related along these major gradients.

Because PCA requires a complete set of data for each basin across all 18 indicators, some smaller basins with incomplete indicator coverage were omitted from this analysis. As such, a total of 156 out of 286 transboundary basins were retained.

B. Results

Only the first six principal components had Eigen values greater than one, suggesting their retention for interpretation (Table 2). The first component accounted for more than a fifth of the variance in the underlying indicators (~22.15%) and the retained components together explain more than 69% of the variance in the overall data set.

Table 2. Principal Component Analysis – variance explained

	PC1	PC2	PC3	PC4	PC5	PC6
Variance (eigenvalues)	3.98	2.71	2.12	1.42	1.17	1.07
Percentage of Variance explained	22.15	15.07	11.79	7.87	6.50	5.97
Cumulative Percentage	22.15	37.23	49.02	56.89	63.38	**69.35**

The factor loadings for each principal component (PC) are found in Table 3. Factor loadings can be interpreted as the correlation coefficient between the indicator/sub-indicator and the overall PC, with higher loadings implying a larger contribution to the overall PC. Indicators for which factor loadings are >0.3 or < -0.3 are colored in blue and red, respectively.

Each component captures uncorrelated dimensions of risk. The maps in Figures 1a-e are a spatial representation of the first six principal components. In the maps, the unit of measurement is deciles, and highly positive (brown color) represents high risk. The maps, together with an analysis of the factor loadings, can assist with the interpretation of results.

C. Interpreting the principal components

The first PC can be interpreted as an axis that discriminates between basins based on levels of economic development. The component has positive loadings for wastewater pollution, enabling environment (and to a lesser degree legal framework), and social wellbeing, and negative loadings for the ecosystem impact of dams. Basins in developed regions will typically have low risk for the first set of indicators, and high risk for dam impacts following investments in water resource infrastructure to mitigate pollution and guarantee water supply, while countries in developing regions typically show an inverse pattern. For example, Africa as a whole has a lot fewer dams per kilometer of river than Europe, and also tends to score poorly on wastewater, enabling environment, and societal wellbeing.

The second PC loads highest on environmental and agricultural water stress, human water stress, and exposure to droughts. This PC discriminates between drier basins with high variability in river flows and high water stress (e.g., the Colorado Basin in the USA), and those basins that are relatively water-abundant (e.g., a number of basins in Europe). PC3 has highly positive loadings for nutrient pollution, exposure to floods, economic dependence, hydropolitical tension and threat to fish. One possible interpretation of this PC, which would require more testing, is that this PC discriminates between highly and lightly populated basins. PC4 has high positive loadings on legal framework, high negative loadings on economic dependency on water resources, human water stress and moderately negative loadings on social wellbeing (inequality as reflected in the Gini coefficient). This PC has basins with good legal frameworks (low risk) and higher economic dependency on water in the basin (high risk) and relatively high water stress and income inequality. PC5 appears to be related to ecosystems. Extinction risk has a negative loading on this component and wetland disconnectivity has a high positive loading. Potential reasons for this would need to be investigated at the indicator level. Finally, PC6 has high negative loadings on exposure to floods, wetland loss and income inequality, and positive loading on hydropolitical tension.

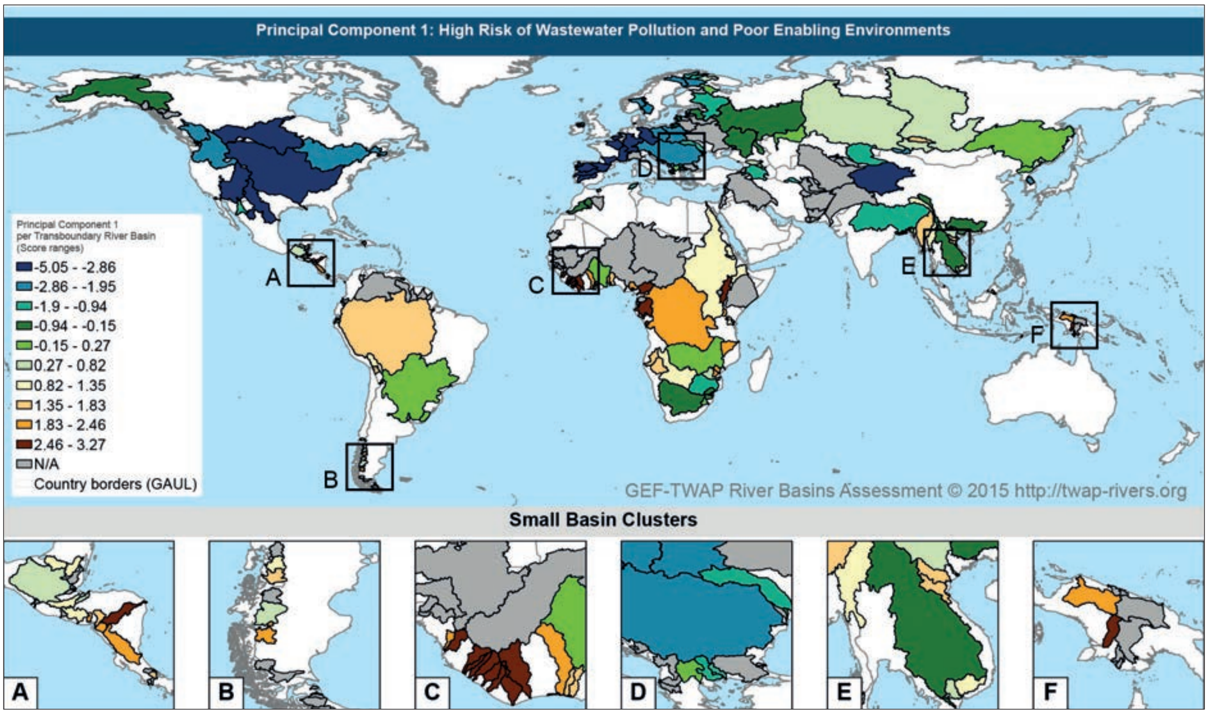
Table 3. Factor loadings by principal component

Indicators	PC1	PC2	PC3	PC4	PC5	PC6
Water Quantity						
1. Environmental water stress	-0.193	0.465	-0.056	0.066	-0.028	0.126
2a. Human water stress A	-0.056	0.137	0.275	-0.292	0.271	0.195
2b. Human water stress B	-0.125	0.371	0.043	0.316	-0.091	-0.109
3. Agricultural water stress	-0.18	0.472	0.031	0.267	-0.137	0.026
Water Quality						
4. Nutrient pollution	-0.221	-0.161	0.347	0.119	0.283	0.232
5. Wastewater pollution	0.42	0.223	0.125	-0.056	-0.026	-0.01
Ecosystems						
6. Wetland disconectivity	0.09	0.085	0.254	-0.043	0.403	-0.443
7. Ecosystem impacts from dams	-0.349	0.082	0.125	-0.198	0.259	0.149
8. Threat to fish	-0.212	-0.056	0.37	0.094	-0.143	-0.295
9. Extinction risk	-0.057	0.03	0.259	-0.285	-0.684	-0.047
Governance						
10. Legal framework	0.320	-0.027	0.138	0.412	0.057	0.242
11. Hydropolitical tension	0.268	0.076	0.331	0.145	-0.153	0.364
12. Enabling environment	0.407	0.143	0.101	-0.12	-0.042	-0.027
Socioeconomics						
13. Economic dependence on water	-0.1	0.06	0.352	-0.441	-0.078	0.159
14abcd. Societal wellbeing	0.372	0.155	0.058	-0.186	0.198	0.049
14e. Income inequality	0.118	0.179	-0.229	-0.309	0.003	-0.355
15a. Exposure to flood	0.024	0.026	0.399	0.226	0.049	-0.47
15b. Exposure to drought	-0.07	0.474	-0.145	-0.099	0.157	0.072

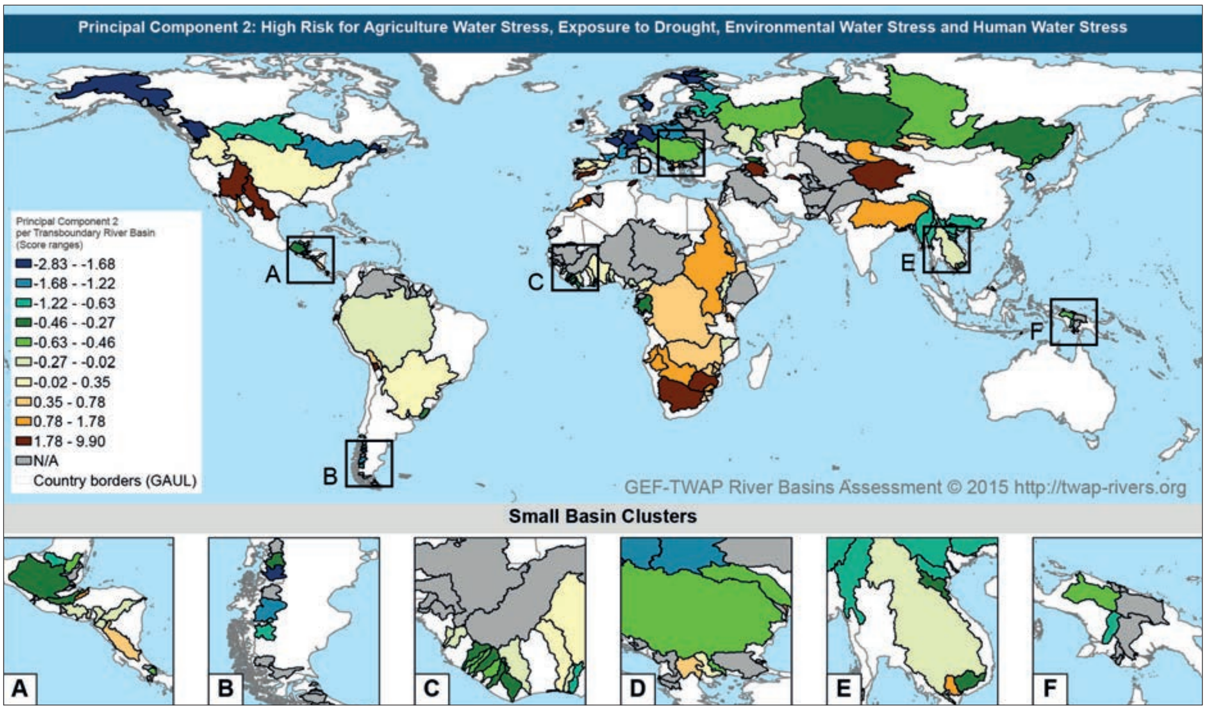
Maps of each PC are included in Figure 1. A high positive score (orange to red colors) indicates a basin with higher risk for indicators that, according to Table 3, have a high positive loading on the component and a lower risk for those indicators that have a high negative loading on the component. In contrast, a high negative score (green to blue colors) indicates a basin with higher risk for indicators that have a high negative loading on the component and a lower risk for indicators that have a high positive loading on the component.

Figure 1. Maps of Principal Components with basins coloured according to their score along each principal component.

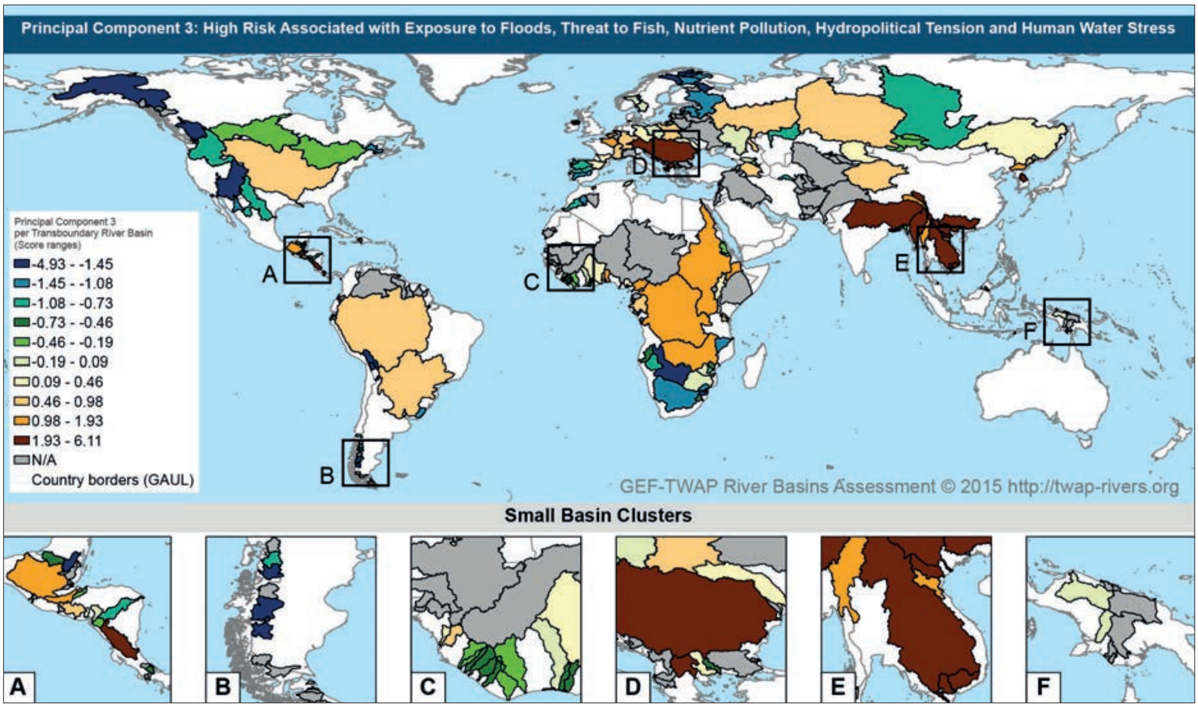
a) PC1: High risk of wastewater pollution and poor enabling environment



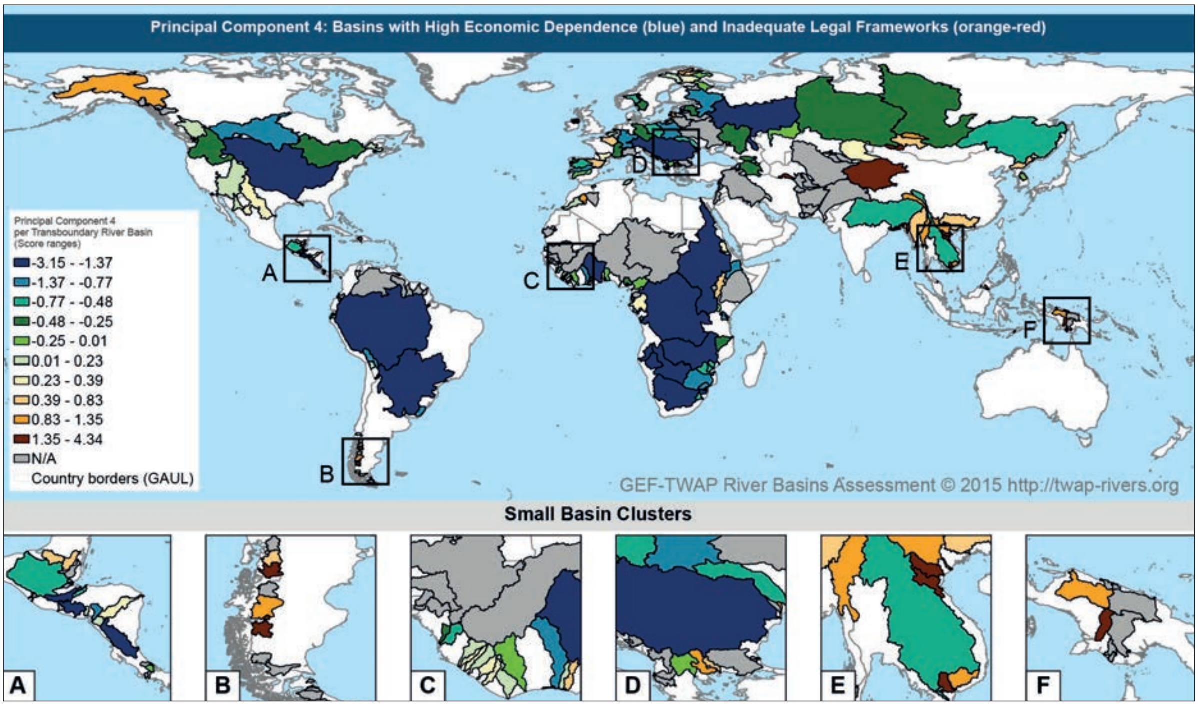
b) PC2: High risk for agriculture water stress , exposure to drought, environmental water stress and human water stress



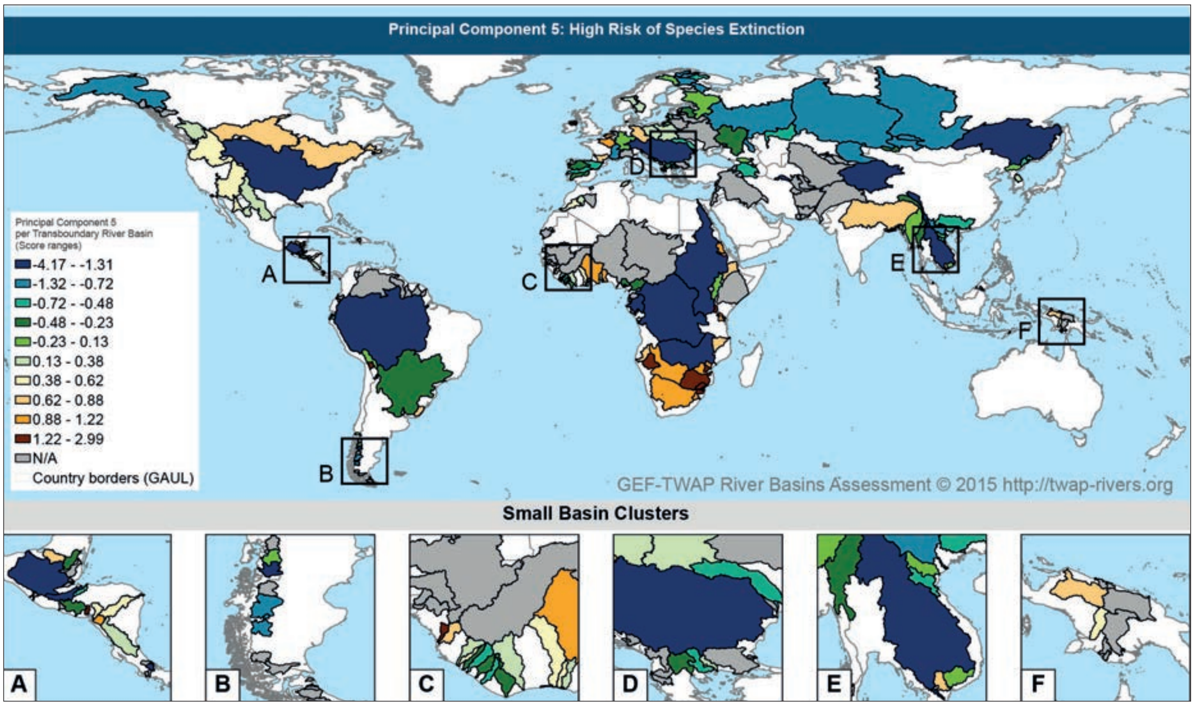
c) PC3: High risk associated with exposure to floods, threat to fish, nutrient pollution, hydropolitical tension and human water stress



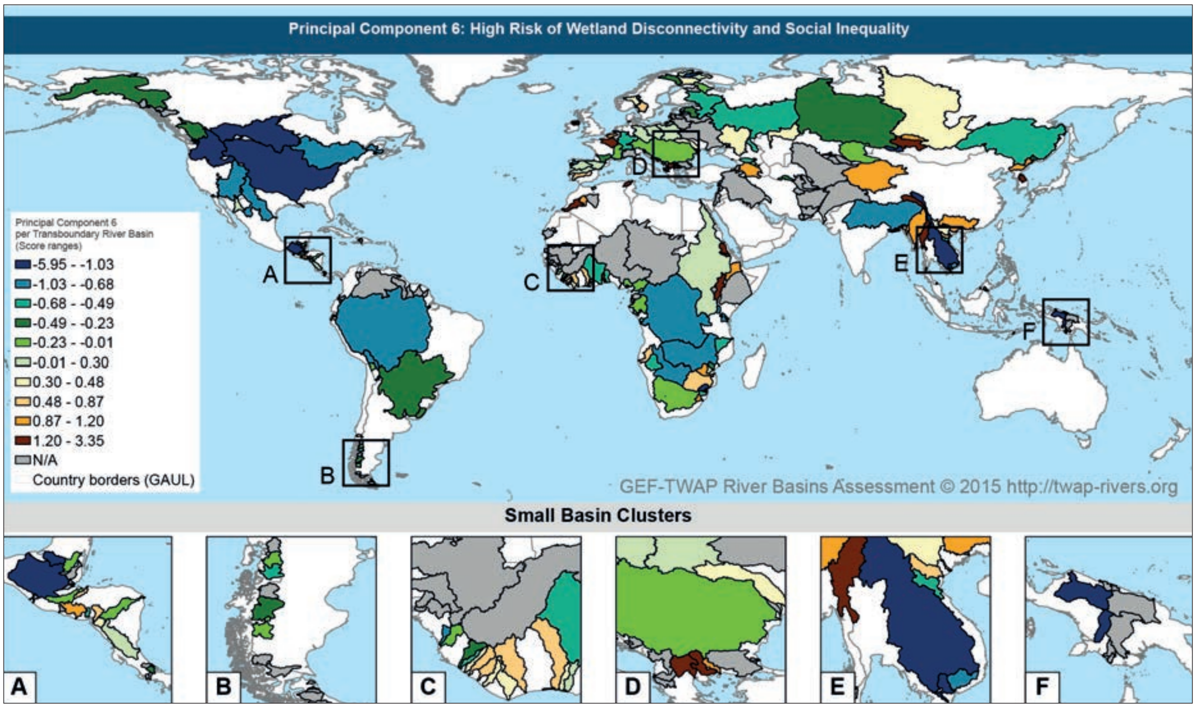
d) PC4: Basins with high economic dependence (blue) and inadequate legal frameworks (orange-red) stress



e) PC5: High risk of species extinction



f) PC6: High risk of wetland disconnectivity and social inequality



4. Cluster Analysis

The purpose of cluster analysis is to find group of similar basins based on the full suite of indicators used in this analysis. Cluster analysis is the natural complement to principal components analysis as it uses Euclidian distance to define the clusters in such a way that variability of basins within the clusters is reduced and the variability between the clusters is maximized.

Analysis of the data via calculation of the sum of square errors between clusters (using the actual and 1 000 random generated data) suggested that nine cluster groups was the most optimal solution. This K-Means cluster algorithm is an iterative process (we set the number of iterations to 1 000), which means that each basin's membership to the cluster is re-evaluated at each iteration, according to the center of the clusters calculated at each iteration.

A map representing the spatial distribution of clusters is found in Figure 8, while the table including the basin names and cluster location are included in Appendix A. We also calculated average indicator z-scores for each cluster (Table 6), positive values representing high risk, and negative values representing low risk.

The results of the cluster analysis provide an opportunity to define broad risk profiles based on the typical values of each indicator in each group. This can be used to identify which basins tend to be of high or low risk across different groups of indicators or indeed, most indicators (Figure 5). The range of values for the indicators within each cluster group shows that not all basins in each group are identical, but rather are broadly similar.

Basins in cluster groups 1, 2 and 3 tend to show moderate and low water stress for humans, the environment and agriculture, moderately high wastewater pollution but differentiate along governance and societal wellbeing indicators, group 1 being at highest risk in these areas compared with the other two groups.

Basins in groups 4 and 6 have low risk for wastewater pollution, and also have comparable scores for human water stress, ecosystem impact from dams and threat to fish (moderate high), yet they differ in terms of nutrient pollution, as group 6 is at highest risk among all cluster groups. Countries included in group 4 also fair better for governance indicators (legal framework, hydropolitical tension and enabling environment), having the lowest risk among all the clusters.

Basins in groups 5 are water scarce and those in group 7 are prone to floods. Although the basins in this group have moderate scores for all other indicators, basins in group 5 score slightly better for governance and societal-well-being indicators, while basins in group 7 do better in terms of inequality, the ecosystem impact from dams and threat to fish.

The relationships evident in Figure 5 are also visible when examining the biplot of the PCA, which shows the basins and indicators arrayed on the first two PCs, identified by cluster group (Figure 6).

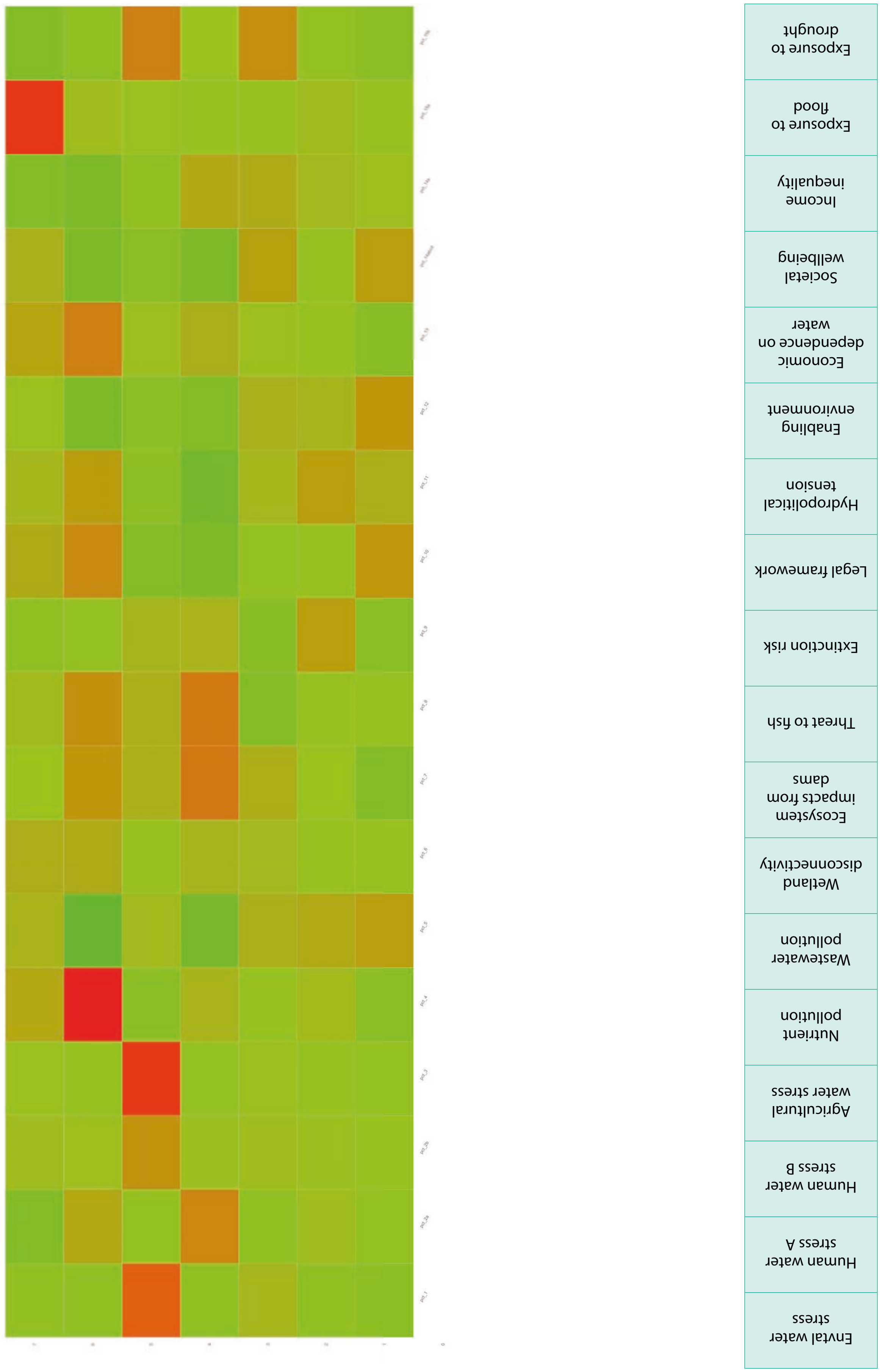


Figure 5. Heat map of median scores for each cluster group for each indicator (low risk is displayed in green, high risk in red)

Figure 6. Biplot showing the first two axes of the principal components analysis with basins identified by K-means cluster group
Note: This plot is for the K-means

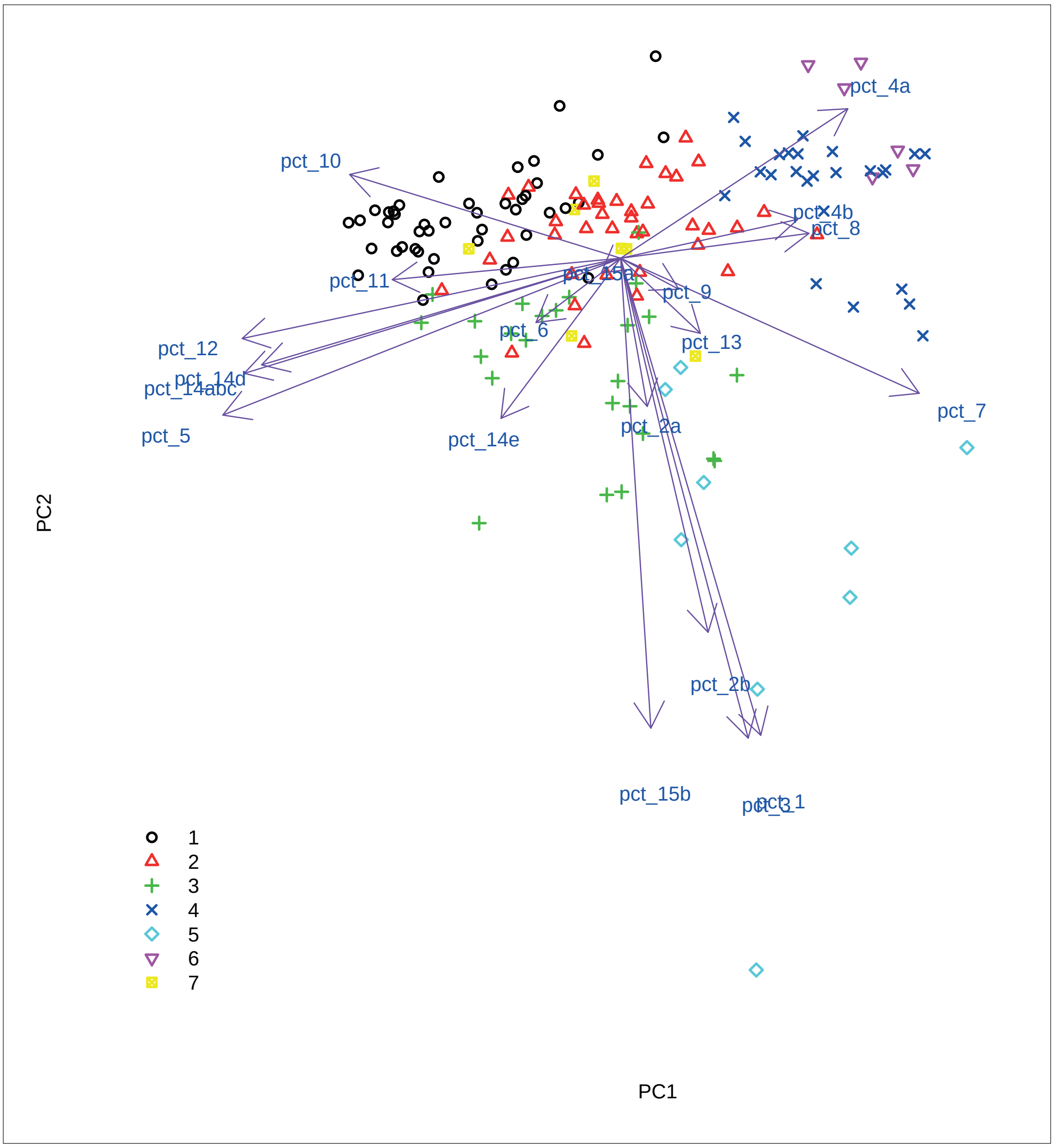
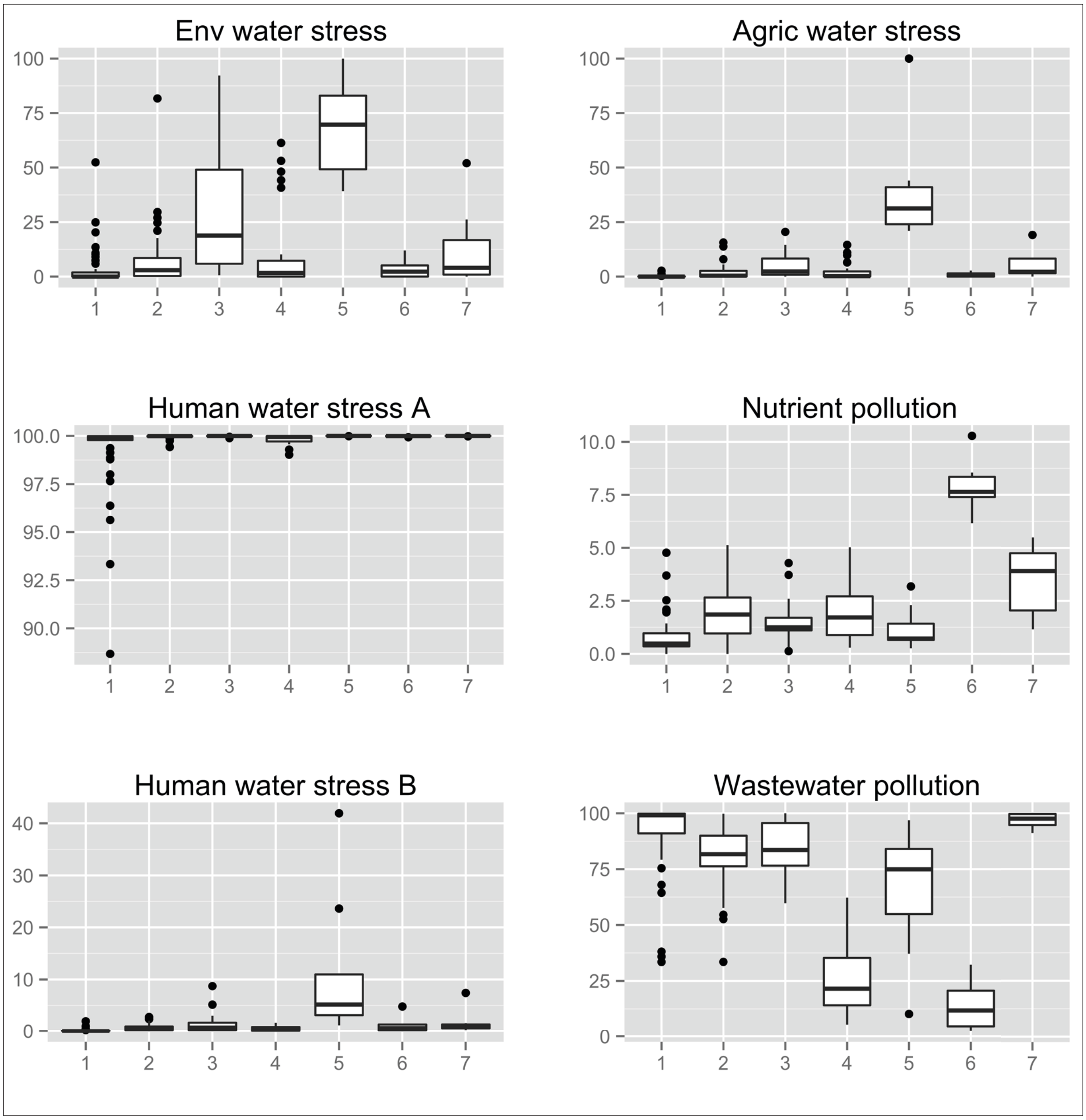
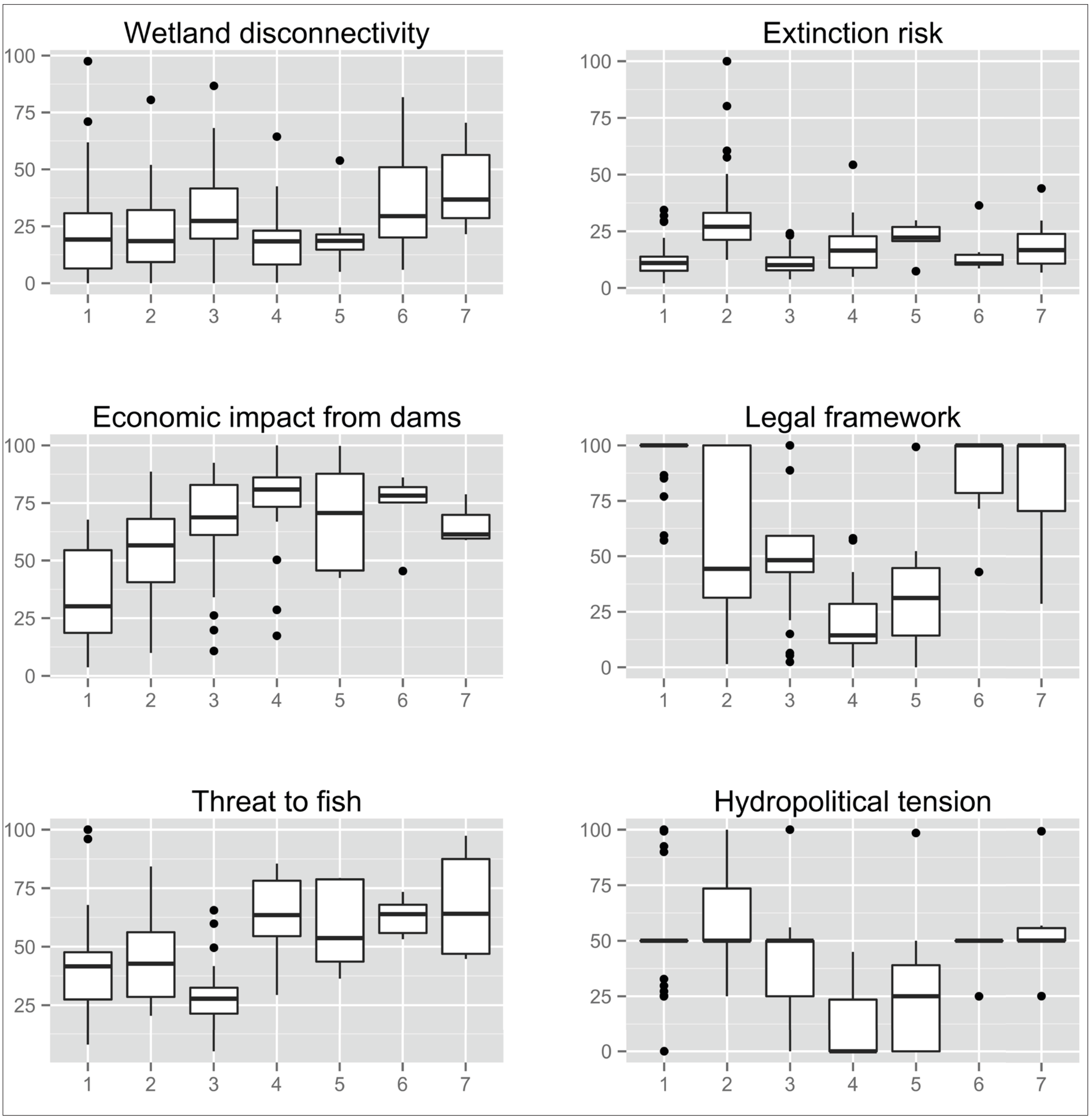


Figure 7. Boxplots showing the distribution of values for each cluster group




Wetland disconnectivity
Extinction risk
Economic impact from dams
Legal framework
Threat to fish
Hydropolitical tension
0
25
50
75
100
1
2
3
4
5
6
7

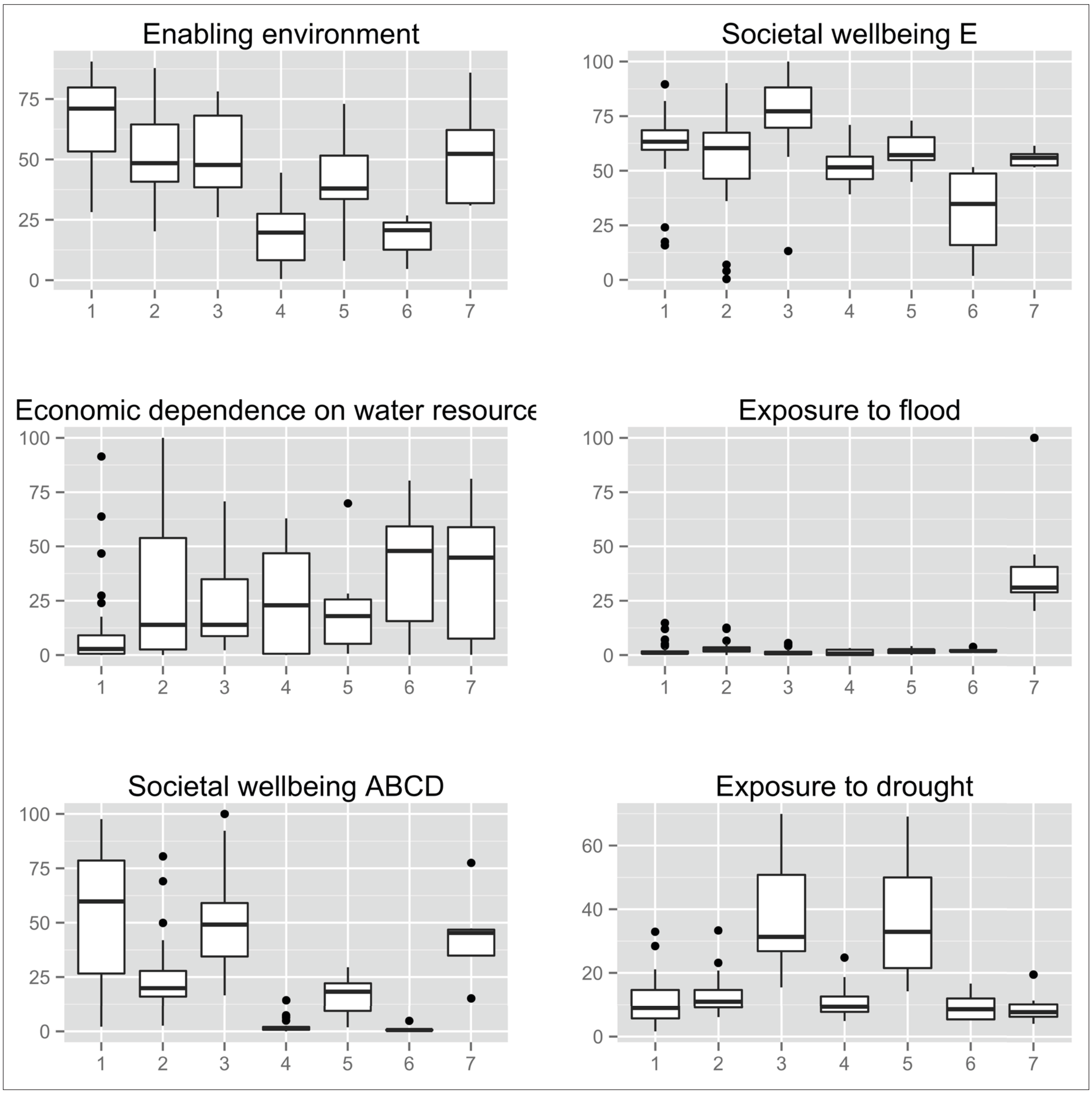

Enabling environment
Societal wellbeing E
Economic dependence on water resource
Exposure to flood
Societal wellbeing ABCD
Exposure to drought

Figure 8. Map of the Cluster analysis showing the locations of the basins within each cluster group.

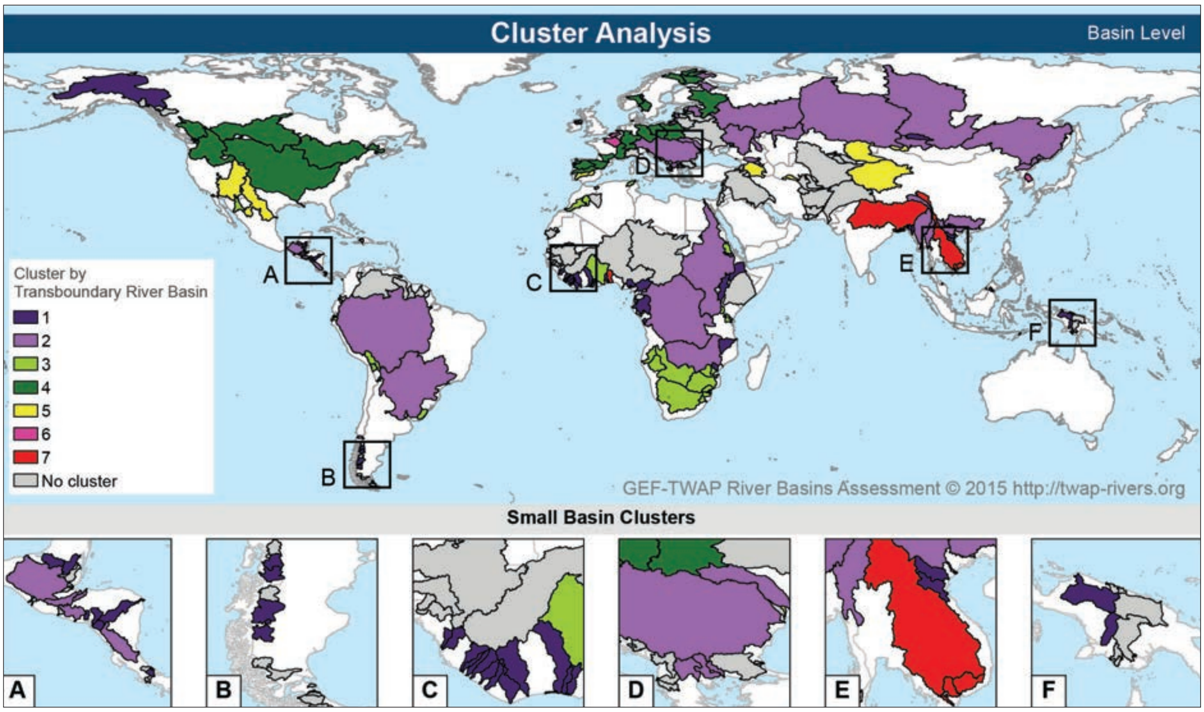


Table 6. Mean indicator z-score by cluster

Indicators	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6	Cluster 7
Water Quantity							
1. Environmental water stress	-0.46	-0.25	0.51	0.03	2.33	-0.44	-0.16
2a. Human water stress A	-0.3	-0.1	-0.5	1.54	-0.48	0.44	-0.97
2b. Human water stress B	-0.29	-0.15	0.02	-0.13	2.32	0.08	0.04
3. Agricultural water stress	-0.43	-0.22	0.08	-0.12	3.36	-0.34	0.06
Water Quality							
4. Nutrient pollution	-0.55	0.01	-0.28	0.44	-0.37	3.52	0.42
5. Wastewater pollution	0.64	0.37	0.25	-1.42	-0.4	-2.1	0.31
Ecosystems							
6. Wetland loss	-0.13	-0.17	0.21	0.03	-0.28	0.95	0.49
7. Ecosystem impacts from dams	-0.85	-0.16	0.08	1.49	0.18	0.81	-0.21
8. Threat to fish	-0.41	-0.2	-0.86	1.54	0.24	0.97	0.2
9. Extinction risk	-0.53	0.89	-0.66	0.35	0.02	-0.18	-0.29
Governance							
10. Legal framework	0.92	-0.16	-0.43	-0.93	-0.91	1.04	0.11
11. Hydropolitical tension	0.28	0.65	-0.2	-1.22	-0.72	0.51	0.11
12. Enabling environment	0.77	0.18	0.03	-1.08	-0.5	-1.38	-0.36
Socioeconomics							
13. Economic dependence on water resources	-0.51	0.16	-0.02	0.41	-0.14	0.98	0.32
14abcd. Societal wellbeing	0.75	-0.29	0.62	-1.06	-0.66	-1.15	0.21
14e. Income inequality	-0.02	-0.19	0.42	0.59	-0.36	-1.31	-0.85
15a. Exposure to flood	-0.19	-0.07	-0.28	-0.25	-0.23	-0.12	3.87
15b. Exposure to drought	-0.49	-0.32	1.4	-0.16	1.37	-0.52	-0.8

References:

Peeples, Matthew A. (2011) R Script for K-Means Cluster Analysis. [online]. Available: http://www.mattpeeples.net/kmeans.htmll

Appendix A. K-Means Cluster Grouping

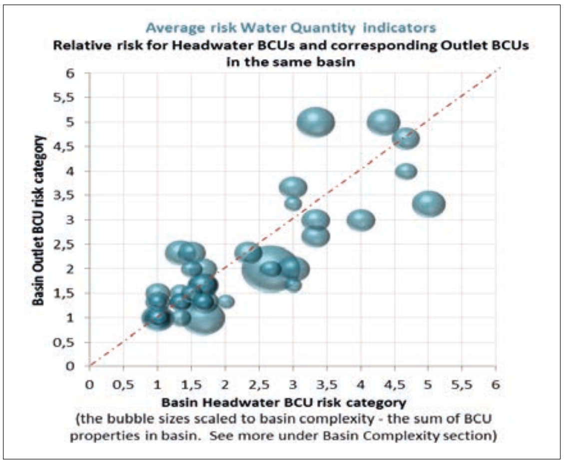
Basin name	Cluster number
Akpa	1
Awash	1
Baker	1
Bia	1
Ca/Song-Koi	1
Candelaria	1
Cavally	1
Cestos	1
Changuinola	1
Chilkat	1
Chiloango	1
Choluteca	1
Coco/Segovia	1
Cross	1
Digul	1
Gash	1
Goascoran	1
Great Scarcies	1
Hondo	1
Kaladan	1
Karnaphuli	1
Komoe	1
Lake Turkana	1
Lake Ubsa-Nur	1
Little Scarcies	1
Loffa	1
Ma	1
Mana-Morro	1
Moa	1
Mono	1
Negro	1
Ogooue	1
Pascua	1
Palena	1
Pungwe	1
Ruvuma	1
Sanaga	1
Sassandra	1
St. John (Africa)	1
St. Paul	1
Sembakung	1

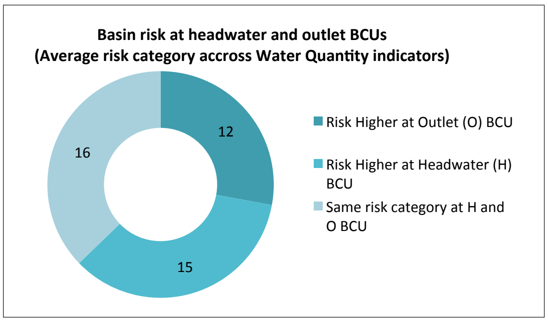
Basin name	Cluster number
Tami	1
Tano	1
Yelcho	1
Yukon	1
Amazon	2
Amur	2
Bei Jiang/Hsi	2
Chamelecon	2
Congo/Zaire	2
Danube	2
Dniester	2
Don	2
Grijalva	2
Har Us Nur	2
Irrawaddy	2
Jenisej/Yenisey	2
La Plata	2
Lava/Pregel	2
Lempa	2
Mius	2
Motaqua	2
Narva	2
Nestos	2
Nile	2
Ob	2
Olanga	2
Oral/Ural	2
Red/Song Hong	2
Salween	2
Samur	2
San Juan	2
Terek	2
Struma	2
Sujfun	2
Sulak	2
Tuloma	2
Tumen	2
Valdivia	2
Vardar	2
Venta	2
Volga	2

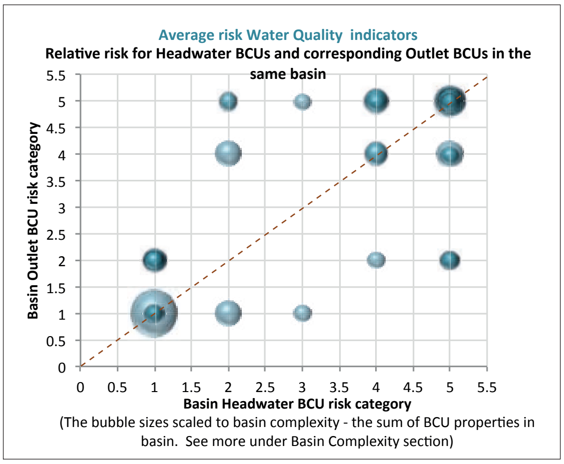
Basin name	Cluster number
Yalu	2
Zambezi	2
Baraka	3
Buzi	3
Cancoso/Lauca	3
Chira	3
Cuvelai/Etosha	3
Daoura	3
Dra	3
Incomati	3
Kunene	3
Lagoon Mirim	3
Lake Natron	3
Lake Titicaca-Poopo System	3
Limpopo	3
Maputo	3
Medjerda	3
Okavango	3
Orange	3
Pangani	3
Sabi	3
Thukela	3
Tumbes	3
Umbeluzi	3
Volta	3
Yaqui	3
Zarumilla	3
Columbia	4
Douro/Duero	4
Ebro	4
Elbe	4
Fraser	4
Garonne	4
Glama	4
Kemi	4
Klaralven	4
Mino	4
Mississippi	4
Nelson-Saskatchewan	4
Oder/Odra	4
Pasvik	4
Rhine	4
Rhone	4

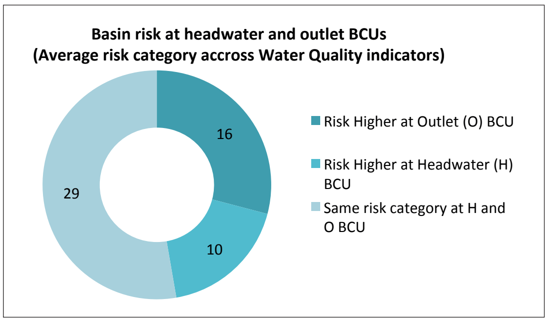
Basin name	Cluster number
Skagit	4
St. Croix	4
St. John (North America)	4
St. Lawrence	4
Tagus/Tejo	4
Tana	4
Torne/Tornealven	4
Vistula/Wista	4
Vuoksa	4
Atrak	5
Colorado	5
Guadiana	5
Ili/Kunes He	5
Kura-Araks	5
Pu Lun T'o	5
Rio Grande (North America)	5
Sarata	5
Tarim	5
Erne	6
Foyle	6
Han	6
Bann	6
Schelde	6
Seine	6
Fenney	7
Ganges-Brahmaputra-Meghna	7
Mekong	7
Muhuri (aka Little Feni)	7
Oueme	7
Saigon	7
Song Vam Co Dong	7

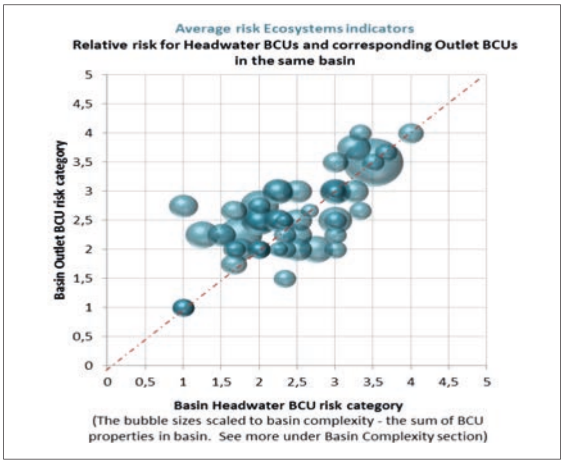
5. Upstream Downstream Correlation Analysis by Indicator Thematic Groups

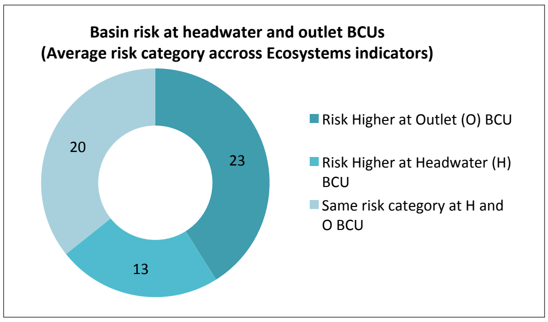




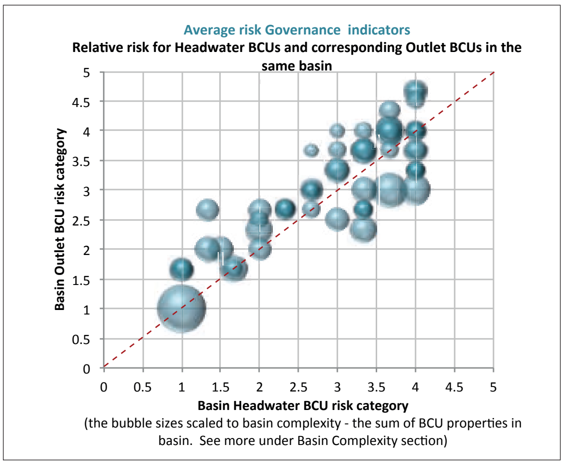


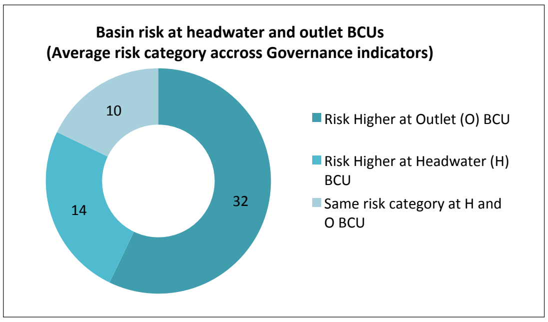


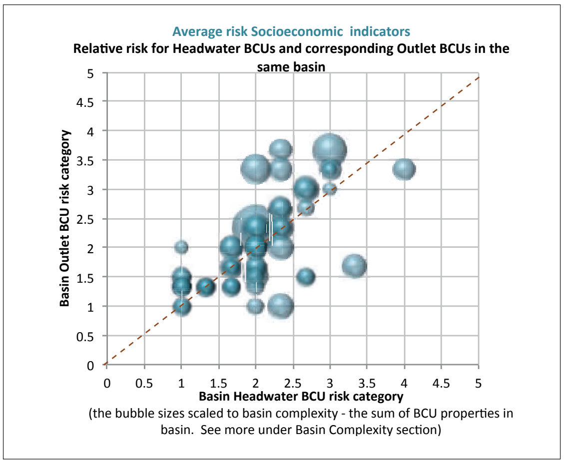


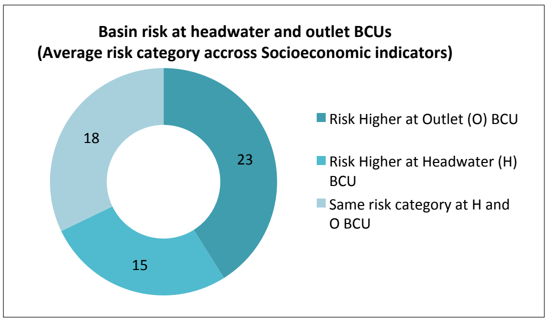


5. Upstream Downstream Correlation Analysis by Indicator Thematic Groups









Annex VIII – Indicator Metadata Sheet Template

Indicator No. and Name

Title:	***Either indicator title, sub-indicator title or other dataset title***
Indicator Number:	***if applicable (e.g. 1-15, followed by a letter for sub-indicators)***
Thematic Group:	***e.g. Water quantity, Ecosystems, Socioeconomics***
Rationale:	Brief description of the indicator in the context of: • why the issue is important globally; • what are some of the impacts of the issue (these two may overlap); • what the results of the indicator show; and how they can be interpreted.
Links :	Gives a brief overview of how the indicator is important to the four other IW systems, if relevant. The abbreviations are: GW – Groundwater; Lakes (no abbreviation); LMEs – Large Marine Ecosystems; OO – Open Ocean. Copy-paste from indicator sheets and update where necessary.
Description:	Description of the indicator itself – underlying indicators, how they are combined, etc.
Metrics:	This field provides following information: • Name of metric, few words on rationale (incl. national or grid based) • Year of baseline data • Data source/provider for each metric (full references, incl. year of publication)
Computation:	Step by step description of how the indicator was calculated, using the above metrics. Includes the weighting of each metric if applicable, and how national-level data is aggregated to the basin/BCU level. In general, grid-based data is computed to provide an average basin score and BCU score for each indicator.
Units:	Final units of the indicator.
Risk categorization	Describes how and why the indicator scores are assigned to 1 of 5 risk categories. Should include table with proportion and number of basins and BCUs in each risk category.
Limitations:	• Including issues which may not be covered by the indicator, as well as any cautionary notes in interpreting the results. • They may also be seen as 'challenges' which still need to be addressed.
Spatial Extent:	
Spatial Resolution:	
Year of Publication:	Year results are published or released.
Time Period:	Time period represented by the indicator.
Additional Notes:	
Date:	Date of upload or completion of version of dataset.
Format:	e.g. Microsoft Excel
File Name:	Of results data
Contact person:	Person responsible for compiling the indicator (not for underlying datasets which may be held by other institutions)
Contact details:	

Annex IX – Indicator Metadata Sheets and Supplementary Material

Annex IX-1: Water Quantity

Environmental Stress induced by Flow Regime Alterations

Title:	***Environmental Water Stress: Environmental Stress Induced by Flow Regime Alterations***
Indicator Number:	***1***
Thematic Group:	***Water Quantity***
Rationale:	Over the past few decades the value of the environment has become better understood (MA, 2005). In some parts of the world environmental systems are being restored, but mainly, environmental systems are coming under increasing threat from both demand for water from other sectors (water quantity) and available water being polluted (water quality). The TWAP RB Environmental Water Stress indicator focuses on the water quantity aspect and considers hydrological alterations from monthly dynamics of the natural flow regime due to anthropogenic water uses and dam operations. The natural flow regime is assumed to provide the optimum conditions for the river ecosystem. In direct response to the natural flow regime and over evolutionary time spans, native biota has developed different morphological, physiological and behavioural traits. Provided habitats are exploited, all ecological niches are occupied and the natural range of flows can be tolerated by the endemic biota. Consequently, in basins/ BCUs with dam management and/ or high amounts of water abstractions, the natural flow regime may be altered beyond some admissible threshold. This is likely to increase the risk of ecosystem degradation and favour invasive species at the expense of adapted endemic species. Finally, this indicator can be compared to the human and agricultural water stress indicators to see which issue is likely to be of greatest importance to the basin in terms of water quantity.
Links :	GW: Some ecosystems are dependent on healthy GW supplies, linked to recharge from rivers. Lakes: Lakes and river ecosystems are strongly interrelated, and environmental water stress in rivers is also likely to have an impact on lakes. LMEs: Quantity of water output to LMEs, particularly affecting estuarine areas where freshwater/ saltwater interactions are important.
Description:	This indicator addresses environmental stress induced by flow regime alterations due to anthropogenic impacts such as dam operation and water use. Therefore, modified flow regimes are compared to the natural flow by means of 24 different sub-indicators which address monthly flow magnitudes (12 sub-indicators for Jan to Dec) as well as inter-annual flow variability (12 sub-indicators for Jan to Dec) of the monthly flow magnitudes. The underlying assumption of this approach is that the greater the deviations of the flow regime from natural flow conditions, the more severe are the negative impacts on the river ecosystem.

Metrics:	• Natural river discharge per grid cell for the time period 1971-2000 computed by CESR at 30 min. grid using the Global Hydrology sub-model WaterGAP2.2 (Müller Schmied et al. 2014). The meteorological data from WATCH (Weedon et al., 2011) are used to drive the model.
	• Modified river discharge per grid cell for the time period 1971-2000 considering human impacts such as dam management (Hanasaki et al. 2006) and water use. Water use is calculated by the Global Water Use sub-models of WaterGAP2.2 (made up of:
	  ◦ Domestic demand: based on relationship between water use intensity and income using 'sigmoid curves' (Flörke et al. 2013).
	  ◦ Thermal electricity production demand (Flörke et al. 2013).
	  ◦ Manufacturing industry demand (Flörke et al. 2013),
	  ◦ Agricultural demand: based on irrigation and livestock demand (Alcamo et al. 2003, aus der Beek et al. 2010, Döll and Siebert 2002). Considers area equipped for irrigation (GMIAv5, Siebert et al. 2013).
	• A differentiation of water withdrawn from surface and groundwater is made (Döll et al. 2012).

Title:	***Environmental Water Stress: Environmental Stress Induced by Flow Regime Alterations***
Computation:	Calculation of indicator: 1. Simulation of natural river discharge for each grid cell (i.e., river discharge in the absence of human impacts) 2. Simulation of modified river discharge for each grid cell (i.e., river discharge influenced by dam management and water use of different water use sectors) 3. Calculation of the mean monthly magnitudes derived from the median of the monthly flow data of each year (12 sub-indicators) 4. Calculation of the inter-annual variability of the monthly flow data derived from the inter-quartile range (IQR) (12 sub-indicators) 5. Computation of the percentage alteration for each of the 24 sub-indicator and each grid cell 6. Applying a scoring system to determine the degree of flow regime alteration in each grid cell 7. Calculation of an average value for each BCU/ basin Simulation of underlying data (1, 2): In order to simulate monthly river discharge for the baseline period 1971-2000 (climate normal period), the global water model WaterGAP2.2 (Müller Schmied et al. 2014) was applied, while the WATCH Forcing Data (WFD, Weedon et al. 2011) were used as meteorological input. All calculations were performed on the WaterGAP2.2 grid cell raster of 30 arc minute (longitude and latitude). In order to take into account water consumption of the domestic and industry sectors (Flörke et al. 2013) as well as of irrigation and livestock, the global water use sub-models of WaterGAP2.2 were applied (Flörke et al. 2013, aus der Beek et al. 2010, Döll and Siebert 2002, Alcamo et al. 2003). To represent the changes in hydrologic dynamics due to reservoir management, the reservoir operation algorithm of Hanasaki et al. (2006) is applied in WaterGAP2.2 with minor modifications described by Döll et al. (2009). Based on information of the GRanD database (Lehner et al. 2011) and, in the case of Europe, additionally the EEA Eldred2, European Lakes, Dams and Reservoirs Database (Croutez, 2008), 1 748 reservoirs (658 irrigation, 1 090 non-irrigation) have been implemented in WaterGAP2.2. The criterion of implementation was a minimum reservoir storage volume of 0.1 km^3. The hydrological model of WaterGAP2.2 is calibrated and validated against measured river discharge and its reservoir algorithm against observed reservoir outflow (Döll et al. 2009, Müller Schmied et al. 2014). In addition, the water use sub-models were calibrated for the year 2005 and tested against historical trends (Flörke et al. 2013, aus der Beek et al. 2010). For the year 2005, simulated global water withdrawals of 3 878 km^3 are in good agreement with the latest value of 3 752 km^3 for the year 2006 provided by the FAO (2012). In order to allow for a spatially explicit analysis, country-wide values of domestic and manufacturing water use were allocated to the model's grid cells using demographic and socio-economic data (Flörke et al. 2013), while cooling water requirements were calculated location-specific, i.e. already assigned to a grid cell. Water requirements for irrigated crops are computed on a 0.5° grid. Calculation of mean magnitudes and inter-annual variability (3, 4): The selected 24 sub-indicators address the monthly flow magnitudes (Jan to Dec) and variability (Jan to Dec) and are derived from monthly flow data per year of record and per grid cell. In order to gain a single value per sub-indicator across the entire period, the magnitude is described by the median (i.e., 50th percentile) and the inter-annual variability by the inter-quartile range (IQR; i.e., difference between 75th and 25th percentiles) (Richter et al. 1997). Computation of the percentage alteration (5): After computing the sub-indicators for the natural flow regime and the modified flow regime, the percentage differences were determined for each sub-indicator in each grid cell. Applying a scoring system (6): The underlying assumption of this approach is that the greater the deviation of the flow regime from natural flow conditions (and the more sub-indicators are substantially modified), the more severe is the impact on the maintenance and health of a river ecosystem. Consequently, five different threshold levels were considered for this approach: ±20%, ±40%, ±60%, ±80% and ±100%. In case of one of these thresholds was exceeded by one of the 24 sub-indicators, a score of one (>±20%), two (>±40%), three (>±60%), four (>±80%), or five (>±100%) was added to the exceedance score. Hence, the exceedance score can range from 0 (=no substantial change to the natural flow regime) to 72 (=severe flow regime modification). Determination of average BCU/ basin values (7): As results of the TWAP project are presented per BCU and transboundary river basin, the threshold exceedance score of all grid cells belonging to a BCU/transboundary river basin were summed and divided by the total number of grid cells assigned to that BCU/ transboundary river basin. The indicator has been calculated for all TWAP basins which could be assigned on the WaterGAP2.2 grid cell raster. However, here it is necessary to note that verified conclusions can only be drawn for transboundary basins > 25 000 km^2, broadly equivalent to 10 grid cells at the equator. Hence, results for smaller basins are provided but might contain a higher level of uncertainty.
Units:	A threshold exceedance score (see Computation)

Title:	***Environmental Water Stress: Environmental Stress Induced by Flow Regime Alterations***
Scoring system:	Basins/ BCUs with a higher calculated score have a higher environmental water stress. The original scores for the basins/ BCUs were normalized to a range from 0 to 1 and the relative risk categories were assigned in the following way:

Relative risk category	Range (normalized score)	No. of Basins	Proportion of Basins	No. of BCUs	Proportion of BCUs
1 - Very low	0.00	115 (69*)	49%	313 (241*)	49%
2 - Low	0.001–0.24	103 (25*)	38%	209 (65*)	33%
3 - Moderate	0.25–0.49	20 (6*)	7%	38 (6*)	6%
4 - High	0.50–0.74	15 (3*)	6%	38 (6*)	6%
5 - Very high	0.75–1.0	17 (4*)	6%	38 (17*)	6%

* Number of basins/BCUs for which results have been calculated, but bear a lower level of confidence due to modelling limitations

Increasing deviations from natural flow patterns lead to increasing ecological consequences. Consequently, the higher the relative risk category, the more likely it is that the natural flow regime is altered due to water abstractions and dam management beyond some admissible threshold. This is likely to increase the risk of ecosystem degradation and to favour invasive species at the expense of adapted endemic species (flora and fauna).

Limitations:	• Does not consider water quality (i.e. the indicator focuses on environmental water stress due to flow regime alterations. Further environmental stress can be caused by water quality issues. • Uncertainty of thresholds (i.e. no generalizable ecological-flow relationships are available for large-scale assessments. The applied thresholds are based on the 20 per cent rule likely indicating moderate to major changes in ecosystem structure and functions (Richter et al. 2012). Further, the same threshold was applied for all months.) • Verified conclusions can only be drawn for basins > 25 000 km^2. Results for basins smaller than this are calculated but are subject to much lower levels of con*fidence in results due to modelling limitations.*
Spatial Extent:	Global (transboundary river basins)
Spatial Resolution:	Basin country unit (BCU) + river basin scale
Year of Publication:	-
Time Period:	1971-2000
Additional Notes:	
Date:	22.01.2015
Format:	Microsoft Excel Worksheet
File Name:	TWAP_RB_indicator_01_results.xlsx
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Projected Environmental Stress for the 2030s induced by Flow Regime Alterations

Title:	***Environmental Water Stress: Environmental stress induced by Flow Regime Alterations (projected for 2030s and 2050s)***
Indicator Number:	***1 – projected 2030 and 1 – projected 2050***
Thematic Group:	***Water Quantity***
Rationale:	Over the past few decades the value of the environment has become better understood (MA, 2005). In some parts of the world environmental systems are being restored, but mainly, environmental systems are coming under increasing threat from both demand for water from other sectors (water quantity) and available water being polluted (water quality). The TWAP RB Environmental Water Stress indicator focuses on the water quantity aspect and considers hydrological alterations from monthly dynamics of the natural flow regime due to anthropogenic water uses, dam operations and climate change. The natural flow regime is assumed to provide the optimum conditions for the river ecosystem. In direct response to the natural flow regime and over evolutionary time spans, native biota has developed different morphological, physiological and behavioural traits. Provided habitats are exploited, all ecological niches are occupied and the natural range of flows can be tolerated by the endemic biota. Consequently, in basins/ BCUs with dam management and/ or high amounts of water abstractions, the natural flow regime can be altered beyond some admissible threshold. In the coming decades climate change will further modify river flow regimes by changes in precipitation patterns and amounts, as well as temperature (affecting evapotranspiration and snowmelt). These alterations are likely to increase the risk of ecosystem degradation and favour invasive species at the expense of adapted endemic species.
Links :	GW: Some ecosystems are dependent on healthy GW supplies, linked to recharge from rivers. Lakes: Lakes and river ecosystems are strongly interrelated, and environmental water stress in rivers is also likely to have an impact on lakes. LMEs: Quantity of water output to LMEs, particularly affecting estuarine areas where freshwater/ saltwater interactions are important.
Description:	This indicator addresses environmental stress in the 2030s and 2050s induced by flow regime alterations due to anthropogenic impacts such as dam operation, water use and climate change. The modified flow regimes are compared to the natural flow by means of 24 different sub-indicators which address monthly flow magnitudes (12 sub-indicators for Jan to Dec) as well as inter-annual flow variability (12 sub-indicators for Jan to Dec) of the monthly flow magnitudes. The underlying assumption of this approach is that the greater the deviations of the flow regime from natural flow conditions, the more severe are the negative impacts on the river ecosystem.
Metrics:	• Natural river discharge per grid cell computed for the time period 1971-2000 by CESR at 30 min. grid using the Global Hydrology sub-model WaterGAP2.2 (Müller Schmied et al. 2014). The meteorological data from WATCH (Weedon et al., 2011) are used to drive the model. • Modified river discharge per grid cell computed for the time period 2021-2050 considering human impacts such as dam management (Hanasaki et al. 2006), future water use and climate change. Climate change is taken into account by considering projections of climate variables from 4 different GCMs (HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, and NorESM1-M) combined with an RCP8.5 emission-scenario. Future water use of the 2030s and 2050s is calculated by the Global Water Use sub-models of WaterGAP2.2 (made up of: • *D*omestic demand: based on relationship between water use intensity and income using 'sigmoid curves' (Flörke et al. 2013). • Thermal electricity production demand (Flörke et al. 2013). • Manufacturing industry demand (Flörke et al. 2013), • Agricultural demand: based on irrigation and livestock demand (Alcamo et al. 2003, aus der Beek et al. 2010, Döll and Siebert 2002). Considers area equipped for irrigation (GMIAv5, Siebert et al. 2013). • A differentiation between water withdrawn from surface and groundwater is made • (Döll et al. 2012).

<table>
<tr><td>Title:</td><td>Environmental Water Stress: Environmental stress induced by Flow Regime Alterations (projected for 2030s and 2050s)</td></tr>
<tr><td>Computation:</td><td>
Calculation of indicator was done in following steps:
1. Simulation of natural river discharge for each grid cell (i.e., river discharge in the absence of human impacts)
2. Simulation of modified river discharge for each grid cell and for each climate projection (i.e., river discharge influenced by dam management, water use of different water use sectors, and climate change)
3. Calculation of the mean monthly magnitudes derived from the median of the monthly flow data of each year (12 sub-indicators)
4. Calculation of the inter-annual variability of the monthly flow data derived from the inter-quartile range (IQR) (12 sub-indicators)
5. Computation of the percentage alteration for each of the 24 sub-indicator and each grid cell
6. Applying a scoring system to determine the degree of flow regime alteration in each grid cell
7. Calculation of an average value for each BCU/ basin for each climate projection
8. Calculation of ensemble medians for the 2030s and 2050s.

Simulation of underlying data (1, 2):
In order to simulate monthly river discharge for the natural flow regime (1971-2000; climate normal period) and the future modified flow regime (2030s and 2050s), the global water model WaterGAP2.2 (Müller Schmied et al. 2014) was applied. While the WATCH Forcing Data (WFD, Weedon et al. 2011) were used as meteorological input for the baseline, climate projections from 4 different GCMs (HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, and NorESM1-M) combined with an RCP 8.5 emission scenario were used for the 2030s and 2050s. All calculations were performed on the WaterGAP2.2 grid cell raster of 30 arc minute (longitude and latitude).

In order to take into account future water consumption of the domestic and industry sectors (Flörke et al. 2013) as well as of irrigation and livestock, the global water use sub-models of WaterGAP2.2 were applied (Flörke et al. 2013, aus der Beek et al. 2010, Döll and Siebert 2002, Alcamo et al. 2003). To represent the changes in hydrologic dynamics due to reservoir management, the reservoir operation algorithm of Hanasaki et al. (2006) is applied in WaterGAP2.2 with minor modifications described by Döll et al. (2009). Based on information of the GRanD database (Lehner et al. 2011) and, in the case of Europe, additionally the EEA Eldred2, European Lakes, Dams and Reservoirs Database (Croutez, 2008), 1 748 reservoirs (658 irrigation, 1 090 non-irrigation) have been implemented in WaterGAP2.2. The criterion of implementation was a minimum reservoir storage volume of 0.1 km^3. The hydrological model of WaterGAP2.2 is calibrated and validated against measured river discharge and its reservoir algorithm against observed reservoir outflow (Döll et al. 2009, Müller Schmied et al. 2014). In addition, the water use sub-models were calibrated for the year 2005 and tested against historic trends (Flörke et al. 2013, aus der Beek et al. 2010). For the year 2005, simulated global water withdrawals of 3 878 km^3 are in good agreement with the latest value of 3 752 km^3 for the year 2006 provided by the FAO (2012). In order to allow for a spatially explicit analysis, country-wide values of domestic and manufacturing water use were allocated to the model's grid cells using demographic and socio-economic data (Flörke et al. 2013), while cooling water requirements were calculated location-specific, i.e. already assigned to a grid cell. Water requirements for irrigated crops are computed on a 0.5° grid.

Calculation of mean magnitudes and inter-annual variability (3, 4):
The selected 24 sub-indicators address the monthly flow magnitudes (Jan to Dec) and variability (Jan to Dec) and are derived from monthly flow data per year of record and per grid cell. In order to gain a single value per sub-indicator across the entire period, the magnitude was described by the median (i.e., 50th percentile) and the inter-annual variability by the inter-quartile range (IQR; i.e., difference between 75th and 25th percentiles) (Richter et al. 1997).

Computation of the percentage alteration (5):
After computing the sub-indictors for the natural flow regime and the modified flow regime, the percentage differences were determined for each sub-indicator in each grid cell.

Applying a scoring system (6):
The underlying assumption of this approach is that the greater the deviation of the flow regime from natural flow conditions (and the more sub-indicators are substantially modified), the more severe is the impact on the maintenance and health of a river ecosystem. Consequently, five different threshold levels were considered for this approach: ±20%, ±40%, ±60%, ±80% and ±100%. In case of one of these thresholds was exceeded by one of the 24 sub-indicators, a score of one (>±20%), two (>±40%), three (>±60%), four (>±80%) or five (>±100%) was added to the exceedance score. Hence, the exceedance score can range from 0 (=no substantial change to the natural flow regime) to 72 (=severe flow regime modification).

Determination of average BCU/ basin values (7):
Since results of the TWAP project are presented per BCU and transboundary river basin, the threshold exceedance score of all grid cells belonging to a BCU/transboundary river basin were summed and divided by the total number of grid cells assigned to that BCU/ transboundary river basin.

Calculation of ensemble means for the 2030s and 2050s (8):
For the final map, ensemble medians were calculated from the 4 different model runs for the 2030s and 2050s.

The indicator has been calculated for all TWAP RB basins which could be assigned on the WaterGAP2.2 grid cell raster. However, here it is necessary to note that verified conclusions can only be drawn for transboundary basins > 25 000 km^2, broadly equivalent to 10 grid cells at the equator. Hence, results for smaller basins are provided but might contain a lower level of confidence.
</td></tr>
<tr><td>Units:</td><td>A threshold exceedance score (see Computation)</td></tr>
</table>

Title: ***Environmental Water Stress: Environmental stress induced by Flow Regime Alterations (projected for 2030s and 2050s)***

Scoring system:

Basins/ BCUs with a higher calculated score have a higher environmental water stress. For the baseline assessment, original scores were normalized to a range from 0 to 1. In order to be able to compare scenario with baseline results (i.e. to have the same relative risk category boundaries), the original scores for the basins/ BCUs were normalized here by the maximum values of the baseline, so that values above 1 are possible. The relative risk categories were assigned in the following way (2030s):

Relative risk category	Range (normalized score)	No. of Basins	Proportion of Basins	No. of BCUs	Proportion of BCUs
1 - Very low	0.00	1 (1*)	0%	2 (2*)	0.3%
2 - Low	0.001–0.24	110 (55*)	41%	256 (166*)	40.3%
3 - Moderate	0.25–0.49	68 (30*)	25%	155 (87*)	24.4%
4 - High	0.50–0.74	35 (11*)	13%	69 (31*)	10.9%
5 - Very high	0.75–1.63	56 (9*)	21%	153 (57*)	24.1%

And for the 2050s:

Relative risk category	Range (normalized score)	No. of Basins	Proportion of Basins	No. of BCUs	Proportion of BCUs
1 - Very low	0.00	0 (0*)	0%	0 (0*)	0%
2 - Low	0.001–0.24	67 (38*)	25%	176 (113*)	28%
3 - Moderate	0.25–0.49	84 (30*)	31%	198 (116*)	31%
4 - High	0.50–0.74	33 (20*)	12%	70 (73*)	11%
5 - Very high	0.75–1.65	86 (19*)	32%	191 (73*)	30%

* Number of basins/BCUs for which results have been calculated, but bear a lower level of confidence due to modelling limitations.

Increasing deviations from natural flow patterns lead to increasing ecological consequences. Consequently, for basins in the higher relative risk categories, it is very likely that the natural flow regime is altered beyond some admissible threshold. This is likely to increase the risk of ecosystem degradation and to favour invasive species at the expense of adapted endemic species (flora and fauna).

Limitations:

- Does not consider water quality (i.e. the indicator focuses on environmental water stress due to flow regime alterations. Further environmental stress can be caused by water quality issues.)
- Uncertainty of thresholds (i.e. no generalizable ecological-flow relationships are available for large-scale assessments. The applied thresholds are based on the 20 per cent rule probably indicating moderate to major changes in ecosystem structure and functions (Richter et al. 2012). Further, the same threshold was applied for all months)
- Verified conclusions can only be drawn for basins > 25 000 km^2. Results for basins smaller than this will still be produced, but with much higher levels of uncertainty.

Spatial Extent: Global (transboundary river basins)

Spatial Resolution: Basin country unit (BCU) + river basin scale

Year of Publication: 2015

Time Period: 2030s (2021-2050) and 2050s (2041-2070)

Additional Notes:

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Human Water Stress

Title:	***Human Water Stress***
Indicator Number:	***2***
Thematic Group:	***Water Quantity***
Rationale:	Water scarcity is a, if not the, key limiting factor to development in many transboundary basins. Water stress can be caused by a combination of increasing demands from different sectors and decreasing supply due to climate change-related variability. Human water stress has been defined in a number of different ways since Falkenmark (1989, Rijsbeman 2005).
Links:	GW (some of the renewable water supply is available from aquifers) (and many non-renewable sources), Lakes (this is also a reflection of the pressure on lake water), LMEs (indication of the quantity of water likely to reach the coast).
Description:	This indicator deals with the quantity of water available per person per year relative to the internal and upstream area water supplies, on the premise that the less water available per person, the greater the impact on human development and well-being, and the less water there is available for other sectors. Water benefits must be defined not only by the locally generated runoff but also by remote runoff transported horizontally through river corridors as discharge often across international borders. Along the way the supply can be withdrawn, depleted, redirected, and/or polluted, thus setting up constraints on the accessible water resource system or potential for human water stress. Two (sub)indicators of human water stress were constructed to address the different facets of water supply and water use/withdrawals: **a) Renewable Water Supply (Sub-indicator 2a)** **b) Relative Water Use (Sub-indicator 2b)** All data were computed in 30' latitude-longitude (i.e., 0.5° degree) gridded format in the Geographic projection over the TFDD basin-country-unit (BCU) and transboundary basin regions.
Metrics:	Center for International Earth Science Information Network (CIESIN)/Columbia University, International Food Policy Research Institute (IFPRI), The World Bank, and Centro Internacional de Agricultura Tropical (CIAT), 2011. Global Rural-Urban Mapping Project, Version 1 (GRUMPv1): Population Count Grid. NASA Socioeconomic Data and Applications Center (SEDAC), Pallisades, NY. Charles J. Vörösmarty, Pamela Green, Joseph Salisbury, and Richard B. Lammers Global water resources: Vulnerability from climate change and population growth. Science 289: 284-288 (in Reports). Charles J. Vörösmarty, C. Leveque, C. Revenga (Convening Lead Authors) Coordinating Lead Authors: Chris Caudill, John Chilton, Ellen M. Douglas, Michel Meybeck, Daniel Prager, 2005. Chapter 7: Fresh Water. In: Millennium Ecosystem Assessment, Volume 1: Conditions and Trends Working Group Report. Island Press. Charles J. Vörösmarty, Ellen M. Douglas, Pamela A. Green, and Carmen Revenga. Geospatial Indicators of Emerging Water Stress: An Application to Africa, Ambio, 34 (3): 230-236, 2005b. Malin Falkenmark. "The massive water scarcity threatening Africa-why isn't it being addressed." Ambio 18, no. 2 (1989): 112-118. Malin Falkenmark. "Rapid Population Growth and Water Scarcity: The Predicament of Tomorrow's Africa." Population and Development Review (Population Council) 16 (1990): 81-94. Malin Falkenmark and C Widstrand. Population and Water Resources: A Delicate Balance. Population Bulletin, Population Reference Bureau, 1992. Lila Warszawski, Katja Frieler, Veronika Huber, Franziska Piontek, Olivia Serdeczny, and Jacob Schewe, The Inter-Sectoral Impact Model Intercomparison Project (ISI–MIP): Project framework, PNAS 2014 111 (9) 3228-3232; published ahead of print December 16, 2013, doi:10.1073/pnas.1312330110. Wisser D, Fekete BM, Vörösmarty CJ, Schumann AH (2010) Reconstructing 20th century global hydrography: a contribution to the Global Terrestrial Network- Hydrology (GTN-H). Hydrol Earth Sys Sci 14:1-24.

Title:	***Human Water Stress***

Computation:

Renewable Water supply: Computed as the internal water supplies available to the basin/BCU divided by the total population in the transboundary basin/BCU.
Water Supply / Number of people

Where Water Supply = sum of volume of discharge generated locally in the TFDD BCU/basin regions (long-term annual average discharge over years 1971-2000 from ISI-MIP Project Warszawski et al 2013; Wisser et al 2010); Number of people in region = sum of local gridded population (GPW3, CIESIN 2011) for year 2010 in TFDD BCU/basin regions.

The sub-indicator was ranked according to five relative risk categories from very low to very high risk based on scientifically agreed thresholds for human water stress (Falkenmark 1989, 1990; Falkenmark and Widstrand 1992; Vorosmarty et al 2000, 2005) as noted below:

	Relative risk categories	m^3/person/year
1	Very low	>1 700
2	Low	1 300–1 700
3	Moderate	1 000–1 300
4	High	500–1 000
5	Very high	<500

2. Relative water Use: Computed as the mean annual withdrawals (by sectoral and total water use) divided by internal and upstream water supplies available to the BCU/transboundary basin:
Total Water Withdrawals / Water Supply

Where Total Water Withdrawals = sum of volume of water withdrawals (km^3/yr) from the domestic, electricity production, manufacturing and agricultural sectors for year 2010 (from ISI-MIP Project, Warszawski et al 2013) in the TFDD basin-country-unit /basin regions; Water Supply = sum of volume of discharge generated locally in the TFDD basin-country-unit/basin regions (long-term annual average discharge over years 1971-2000 from ISI-MIP Project Warszawski et al 2013; Wisser et al 2010).

Sub-indicator was ranked according to five relative risk categories from very low to very high risk based on scientifically agreed thresholds (Falkenmark 1989, 1990; Falkenmark and Widstrand 1992; Vorosmarty et al 2000, 2005) as noted below:

	Relative risk categories	Ratio water demand/supply
1	Very low	>0.1
2	Low	0.1–0.2
3	Moderate	0.2–0.4
4	High	0.4–0.8
5	Very high	>0.8

Units:	See description

Scoring system:

The Human Water Stress (Main) indicator is defined as the greater ranking relative risk category of the two sub-indicators above. Results of the **Human Water Stress** indicator are summarized below:

Relative risk category	Range	No. of Basins	Proportion of Basins	No. of BCUs	Proportion of BCUs
1 - Very low	-	153 (84*)	62%	350 (227*)	61%
2 - Low	-	24 (9*)	10%	55 (24*)	10%
3 - Moderate	-	23 (6*)	9%	41 (15*)	7%
4 - High	-	19 (5*)	8%	49 (22*)	8%
5 - Very high	-	28 (8*)	11%	83 (38*)	14%

* Number of basins/BCUs for which results have been calculated, but bear a lower level of confidence due to modelling limitations

Title:	***Human Water Stress***
Limitations:	Does not consider water quality explicitly, although it can be compared to the aggregate inland water threat mapping, as well as the water quality subcomponents thereof (Vörösmarty et al. 2010). The level of water stress may also be impacted by the water quality, as the available water needs to be of a certain standard fit for the required use. This indicator can therefore be viewed in the context of the two TWAP RB water quality indicators. To maintain the integrity of the approach, only results for basins greater than 25 000 – 30 000 km^2 can be provided with a scientifically credible level of certainty and thus used in the ranking system. Results for basins smaller than 25 000 – 30 000 km^2 have been provided with the tabular information for reference only and were not used in the calculation of rankings. Risk calculation for basins less than 30 000 km^2 may be calculated using a higher resolution data. The higher resolution approach could involve the construction of basin-specific high resolution stream networks (based on Hydrosheds of the order of km in length scale) or the simulation of composite hydrologic behaviors integrating the behavior of the full basin or major tributaries. In either case, there would be mismatches with several of the underlying data sets for which the remainder of the TWAP analysis is configured (i.e., 30' L/L). Alternative resampling or downscaling would need to be explored. Reconciling these inconsistencies, in order to establish the level of trust in the outputs will require additional analysis.
Spatial Extent:	Global
Spatial Resolution:	30- X 30-min Lat X Lon
Year of Publication:	2010
Time Period:	2000
Additional Notes:	
Date:	16.02.2015.
Format:	Excel Spreadsheet
File Name:	TWAP_RB_indicator_02_results.xlsx
Contact person:	Charles J. Vörösmarty, Pamela Green
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Agricultural Water Stress

Title:	***Agricultural water stress***
Indicator Number:	***3***
Thematic Group:	***Water Quantity***
Rationale:	Throughout history, agriculture has been an important user of water resources. Today, agriculture accounts for approximately 70% of all water abstraction worldwide (FAO statistics 2012), of which most of the water is withdrawn for irrigation purposes. In the year 2000, more than 30% of the global crop production was generated on irrigated areas, which account for almost 24% of the total global cropland (Portmann et al. 2011). Consequently, the impact of agriculture on global water resources is large and often the main originator for the appearance of water stress. Higher levels of irrigation will generally indicate higher levels of water withdrawal, less available water for other sectors, and potential vulnerability to decreases in rainfall as a result of climate change. On the other hand, agriculture is important for food security and livelihoods in many countries, and can be a key source of export income. Indeed, agriculture is the most important economic sector in many developing countries. The Agricultural Water Stress indicator identifies agricultural water stress of agricultural land under irrigation. Here, the irrigation consumption-to-availability(c.t.a.) ratio is applied for estimating agricultural water stress. In a further step, the share of groundwater being used for irrigation purposes can be estimated (Siebert et al. 2010).The results of this indicator can be compared to the human and environmental water stress indicators to see which issue is likely to be of greatest importance to the basin in terms of water quantity.
Links :	GW: potential abstraction & recharge Lakes: potential abstraction & inflow LMEs: quantity of water output to LMEs
Description:	Mean annual irrigation water consumption divided by the sum of mean annual runoff (MMR).
Metrics:	• Mean Annual Runoff (MAR) – 1971-2000 data computed by CESR based on WATCH meteorological input (Weedon et al., 2011) at 30 min. grid using the Global Hydrology sub-model of the WaterGAP 2.2 model (Müller Schmied et al 2014). • Irrigation water consumption per gird cell for the climate normal period 1971-2000 (Alcamo et al. 2003, aus der Beek et al. 2010, Döll and Siebert 2002) considering latest available data on area equipped for irrigation. • Area equipped for irrigation around the year 2005 (GMIAv5, Siebert et al. 2013)
Computation:	Calculation of indicator was done in following steps: 1. Mean annual irrigation water consumption per grid cell summed per basin/BCU; 2. MAR computed per grid cell and summed per basin/ BCU; 3. Irrigation water consumption divided by MAR and calculated for each basin/ BCU. Simulation of underlying results: The amount of water required by irrigated crops depends on many factors. For this indicator, the global water model WaterGAP2.2 has been used to simulate net and gross irrigation water requirements for the climate normal period 1971-2000 based on climate, local topography, crop type, area equipped for irrigation, and the irrigation project efficiency (aus der Beek et al. 2010, Döll and Siebert 2002). In order to simulate mean monthly runoff (MMR) for the climate normal period, the hydrological component of WaterGAP2.2 (Müller Schmied et al 2014) was applied. For both runoff and irrigation water use, the WATCH Forcing Data (WFD, Weedon et al. 2011) were used as input to drive WaterGAP2.2. All calculations were performed on a 30 arc minute grid cell raster and summed to the BCUs. By using this indicator, it is assumed that a drainage basin suffers from severe water stress if c.t.a. > 0.3 or, in other words, if irrigation consumption exceeds 30% of the reliable annual (or seasonal) water availability. A c.t.a. below 0.3 indicates low to moderate water stress. The thresholds are chosen arbitrarily, but have been derived from EEA (2003) which shows a figure for the water consumption index ranging from (almost) zero to 30% in Europe. The agricultural water stress indicator has been calculated for all TWAP basins and BCUs which could be assigned on the WaterGAP2.2 grid cell raster (corresponding to a spatial extent of more than 2 000 km^2). However, it is necessary to note that verified conclusions can only be drawn for transboundary basins > 25 000 km^2, broadly equivalent to 10 grid cells at the equator. Hence, results for smaller basins are provided but might contain a lower level of confidence.
Units:	[million m^3 water consumed per million m^3 water available]

Title:	***Agricultural water stress***

Scoring system:

Basins/ BCUs with the highest scores have the highest agricultural water stress. In relation to the c.t.a. ratio the following (relative) risk categorization was applied:

Relative risk category	Range (normalized score)	No. of Basins	Proportion of Basins	No. of BCUs	Proportion of BCUs
1 - Very low	0.00	59 (28*)	22%	166 (124*)	26%
2 - Low	0.01–0.05	156 (9*)	58%	344 (24*)	54%
3 - Moderate	0.06–0.20	30 (12*)	11%	66 (26*)	11%
4 - High	0.21–0.3	10 (2*)	3%	15 (5*)	2%
5 - Very high	>0.30-	15 (2*)	6%	45 (12*)	7%

* Number of basins/BCUs for which results have been calculated, but bear a lower level of confidence due to modelling limitations

Category 5 indicates basins/ BCUs with very high levels of irrigation water consumption which leads to less available water for other sectors, and potential vulnerability to decreases in rainfall as a result of climate change. In addition, food security, export income and livelihoods might be threatened in basins/ BCUs of Category 5.

Limitations:	Considers areas equipped for irrigation rather than real irrigated areas
Spatial Extent:	Global (transboundary river basins)
Spatial Resolution:	Basin country unit (BCU) + river basin scale
Year of Publication:	-
Time Period:	1971-2000
Additional Notes:	-
Date:	27.01.2015
Format:	Microsoft Excel Worksheet
File Name:	TWAP_RB_indicator_03_results.xlsx
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Annex IX-2: Water Quality

Nutrient Pollution (Baseline 2000; and Projections 2030 and 2050)

Title:	*Nutrient Pollution*
Indicator Number:	*4*
Thematic Group:	*Water Quality*
Rationale:	River nutrient pollution is caused mainly by agricultural activities (fertiliser use and wastes from livestock), urban wastewater, and atmospheric deposition of nitrogen. Contamination by nutrients (particularly forms of nitrogen and phosphorous) increases the risk of eutrophication in rivers, which can pose a threat to environmental and human health (e.g. algal blooms, decreases in dissolved oxygen, increase in toxins making water unsafe for humans and wildlife). This indicator considers river pollution from nitrogen and phosphorus. The indicator is based on 2 sub-indicators: a) Dissolved inorganic nitrogen (DIN) (sub-indicator 4a) b) Dissolved inorganic phosphorous (DIP) (sub-indicator 4b) These represent the nutrient forms that contribute rapidly to eutrophication and have strong anthropogenic sources. Five risk categories for each sub-indicator were developed based on published national river water quality criteria, with a risk factor of 5 being the highest risk for eutrophication and 1 the lowest. The combined Nutrient Pollution indicator score for each basin was then calculated as the higher of the 2 sub-indicator risk factors.
Links :	The river nutrient pollution indicator has links with the TWAP LME component. The same river watershed model (NEWS) was used for calculating N and P for both the River Basin and LME components of TWAP. Both of these components used amounts as well as nutrient ratios in the development of sub-indicators and a combined indicator, although the approaches differed due to differences in freshwater and marine ecosystem responses to nutrients. Furthermore, the base year conditions and the scenario for future projections (2030 and 2050) were the same for both components.
Description:	The river Nutrient Pollution indicator is divided into two sub-indicators corresponding to nitrogen (N) and phosphorus (P) nutrient forms representative of water quality impairment: dissolved inorganic N and P (DIN, DIP). Each sub-indicator represents annual-scale mean river nutrient concentration for the entire basin. This assessment is originally derived for Global NEWS 2 basins (Mayorga et al, 2010; Seitzinger et al, 2010) by assuming that the mean annual concentration at the basin mouth (where the mainstream river drains to the coast or to endorheic terminal points) is representative of river channel concentrations across the basin. Concentration values for TFDD river basins are calculated based on spatial intersection with Global NEWS 2 basins, as described under "Computation". The Global NEWS 2 model run used here is referred to as the Realistic Hydrology Model Run for reference year 2000 (RH2000), and corresponds to near-contemporary conditions using the year 2000 as a reference for all basin model inputs and forcings (Mayorga et al, 2010). RH2000 is based on observed climate forcings and river discharge corrections from river gauge observations, and was developed to represent contemporary conditions more realistically than the year 2000 reference model run used in the Millennium Ecosystem Scenarios (MEA) assessment presented in Seitzinger et al. (2010) and related publications. **For future projections (2030 and 2050)**, model inputs and forcings were based on the Global Orchestration (GO) scenario of the MEA (Seitzinger et al. 2010). The GO scenario is an internally consistent, plausible global future and focuses on implications for ecosystem services. The forcing data include not only climate change, hydrology, water use, population, and GDP, but also nutrient management options for agriculture (crop and livestock) and sewage treatment. GO describes a globalized world with a focus on economic development with rapid economic and urbanization growth, and a reactive environmental management.

Title:	***Nutrient Pollution***
Metrics:	Average annual river yields of DIN and DIP were calculated using the Global Nutrient Export from WaterSheds 2 (NEWS 2) model. Output is in kg N or P per year normalized by basin area. Results output is average for the basin, but most input data sets (for sources of pollutants) are calculated at 0.5 degree grids. River concentrations were then calculated as yield divided by water runoff. Basin area – part of NEWS inputs based on STN30 watershed delineations, presented in km^2. The Computation section below describes processing steps and data sources in more detail. Sub-indicators are based on global river nutrient export modelling results from the Global NEWS group, published in 2010 as Global NEWS 2. More information can be found in the two publications listed below and on the Global NEWS web site: http://www.marine.rutgers.edu/globalnews/ - Mayorga, E., S.P. Seitzinger, J.A. Harrison, E. Dumont, A.H.W. Beusen, A.F. Bouwman, B.M. Fekete, C. Kroeze and G. Van Drecht. 2010. Global Nutrient Export from WaterSheds 2 (NEWS 2): Model development and implementation. Environmental Modelling & Software 25: 837-853, doi:10.1016/j.envsoft.2010.01.007 - Seitzinger, S.P., E. Mayorga, A.F. Bouwman, C. Kroeze, A.H.W. Beusen, G. Billen, G. Van Drecht, E. Dumont, B.M. Fekete, J. Garnier and J.A. Harrison. 2010. Global river nutrient export: A scenario analysis of past and future trends. Global Biogeochemical Cycles 24: GB0A08, doi:10.1029/2009GB003587
Computation:	The sub-indicator annual-scale nutrient concentrations for TFDD basins were calculated by transferring nutrient model output created for Global NEWS 2 using a slightly modified version of the STN-30p version 6.01 30-minute (0.5 degree) global river system and basins dataset (Mayorga et al, 2010). The computational procedures used are as follows: 1. The final TFDD basin-scale dataset (updated and distributed for the TWAP project in February 2014, as the shape file "RiverBasins_ver_1_20140215.shp") was re-projected to a "geographic" projection (EPSG:4326) as preparation for GIS overlay with NEWS 2 STN-30p basins. In addition, small inconsistencies in geometric type representations (single polygon vs. multi-polygon features, and presence of "geometry collection" types) were corrected during this pre-processing. The TFDD dataset contains 286 transboundary river basins. 2. To enable the transfer of attributes and data from NEWS 2 basins to TFDD basins, the NEWS 2 STN-30p basins polygon dataset was spatially intersected with the final TFDD basins polygon dataset. The result was 1 881 individual component polygons, each polygon having core basin attributes from the two original GIS datasets. Three very small TFDD basins (CONV/Conventillos, 7km^2; ELNA/El Naranjo, 24km^2; PDNL/Pedernales, 320km^2) had no intersecting NEWS 2 STN-30p basin, and therefore could not be assigned nutrient results. A brief quality assessment of the dataset spatial overlay is presented under Additional Notes. 3. NEWS 2 basin-scale data was transferred to TFDD basins as area-weighted means of the component NEWS 2-derived basin polygons for each TFDD basin (from step #2, above). These annual-scale NEWS 2 attributes are: actual runoff (river discharge at the mouth normalized by NEWS 2 basin area), and nutrient yields (river nutrient form loads at the mouth normalized by NEWS 2 basin area) for the each of the 2 nutrient forms (dissolved inorganic N (DIN) and dissolved inorganic P (DIP)). 4. Once NEWS 2 attributes were transferred to TFDD basins, sub-indicator (DIN, DIP) nutrient concentrations (mg N/L or mg P/L) were calculated by dividing the corresponding nutrient yield by runoff. If the TFDD-basin-scale runoff was zero, a nutrient concentration was not calculated and was left as a Null value. For the 6 small TFDD basins that had no intersecting NEWS 2 basins, a nutrient concentration could not be calculated directly and was left as a Null value. 5. Out of the 286 transboundary basins, 153 were classified as "uncertain" (Fig. 3), and thus while included in the maps, are not included in the discussion of results. The "lower confidence" flagging is the result of four different tests: if any of below conditions are true, the 'lower confidence in results' flag is set: 1) TFDD basin area < 20 000 km^2; 2) TFDD basin has a corresponding dominant NEWS basin (largest contributing area percentage) made up of < 10 0.5-degree grid cells; 3) the intersection of the TFDD basin with the NEWS/STN30 basin with the largest geographical overlap/overlay with that basin amounts to < 50% of the area of this TFDD basin (an assessment of the geographical coincidence between TFDD and NEWS/STN30 basins); and 4) <60% of the TFDD basin is covered (overlapped) by NEWS/STN30 basins. In NEWS 2 (following an analysis done by the original STN-30p dataset developers), watersheds made up of < 10 0.5° x 0. 5° grid cells (approximately 25 000 km^2 at the equator, and smaller at higher latitudes) are deemed to have lower confidence in results due to scale limitations. It should be noted that TFDD basins are mainly relatively small, with a median basin area of 22,185 km^2. Additional uncertainty in the transferring of results from NEWS 2 to TFDD basins involves the robustness or quality of spatial overlays between TFDD and NEWS basins.
Units:	mg N/L or mg P/L

Title:	*Nutrient Pollution*

Scoring system:

DIN and DIP concentrations were used to establish 5 relative risk categories for the DIN and for the DIP sub-indicators. Published national water quality criteria were used as guidelines for establishing the concentration ranges in each category as indicated below (Table 1).

After ranking DIN and DIP for each river basin from 1-5, the higher of the 2 sub-indicator risk categories for a basin was used as the combined nutrient (NP) indicator risk category.

For DIN:

Conc. Range mg N/L	Relative risk category	Description
≤0.15	1	Very low
≤0.15 and ≤0.50	2	Low
≤0.50 and ≤1.00	3	Moderate
≤1.00 and ≤2.00	4	High
≤2.00	5	High high

For DIP:

Conc. Range mg N/L	Relative risk category	Description
≤0.01	1	Very low
≤0.01 and ≤0.03	2	Low
≤0.03 and ≤0.10	3	Moderate
≤0.10 and ≤0.50	4	High
≤0.50	5	High high

Summary of Nutrient Pollution indicator results can be seen in the table below:

Relative risk category	Range (normalized score)	No. of Basins	Proportion of Basins	No. of BCUs	Proportion of BCUs
1 - Very low	-	7 (1*)	2%	-	-
2 - Low	-	107 (65*)	38%	-	-
3 - Moderate	-	77 (25*)	28%	-	-
4 - High	-	59 (34*)	21%	-	-
5 - Very high	-	30 (22*)	11%	-	-

* Number of basins/BCUs for which results have been calculated, but bear a lower level of confidence due to modelling limitations. See more in section 'Computation'

No BCU level results are provided for this indicator. See more information under section 'Additional notes'.

Limitations:

1. Indicator only provides basin averages, so does not identify hotspots within basins. If additional funding becomes available, some sub-basin information on indicators and sources could be provided.

2. As noted above, out of the 286 transboundary basins, 147 were classified as having results with "low confidence" due primarily to their small size, while there were no results for 6 of the basins.

3. Indicator only considers N and P concentrations, and doesn't consider factors such as hydrology that can affect ecosystem response to nutrients.

Spatial Extent:	Global
Spatial Resolution:	Calculations are based on the polygon representation of basins draining to the coast or to endorheic terminal points. The spatial resolution is therefore highly variable. The raster resolution of the basins dataset used and of the majority of original model drivers is 0.5 degrees.
Year of Publication:	2010 (publication of original, source Global NEWS 2 results that supported the TWAP analyses)
Time Period:	2000 (2030 and 2050 for projections)

Title:	***Nutrient Pollution***
Additional Notes:	1. Only TFDD basin-scale results are provided; as the scale of the STN-30p basin definitions is coarser than that of TFDD basins, operating only with TFDD basin units (and not basin country units). 2. Most GIS operations were carried out using PostGIS, the spatial extension of the open-source PostgreSQL Relational Database Management System. 3. It is possible that NEWS 2 STN-30p basins could intersect only a small fraction of a TFDD basin, resulting in poorly supported mean nutrient concentration sub-indicators. This possibility was examined. Excluding the 3 very small TFDD basins (CONV/Conventillos, 7km2; ELNA/El Naranjo, 24km2; PDNL/Pedernales, 320km2) with no intersecting NEWS 2 STN-30p basin, all but 1 TFDD basins have > 50% of their area covered by NEWS 2 basins, and all but 10 TFDD basins have > 80% of their area covered by NEWS 2 basins. Other assessments of reliability of basin-intersection and attribute transfer were generated.
Date:	16.02.2015.
Format:	Excel (results template provided on Data Portal)
File Name:	TWAP_RB_indicator_4_results.xlsx (Combined single indicator), TWAP_RB_indicator_4a_results.xlsx (DIN sub-indicator), and TWAP_RB_indicator_4b_results.xlsx (DIP sub-indicator)
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Supplementary Material – Nutrient Pollution Indicators

Published river water quality criteria for:

a) Nitrogen from various sources:

mg N/l		Reference	Comment
NO_3	2.9	(Canadian Council of Ministers of the Environment, 2003)	Canadian WQ guidelines
NO_3	2	(Camargo, Alonso, & Salamanca, 2005)	Literature review
DIN	2.6	(Laane, Brockmann, van Liere, & Bovelander, 2005)	WQ objective for European rivers (no range given)
TN	0.8 – 5.0	(Laane, Brockmann, van Liere, & Bovelander, 2005)	Range in the minimum and max of quality objective in European river presented by 10 EU countries
TN	0.625-1.25 high 1.25-5.0 very high	(Swedish Environmental Protection Agency, 2000)	Typical of Swedish eutrophic lakes
TN	0.12-2.18 (0.67 aver.)	(US Environmental Protection Agency, 2001)	Recommended EPA criteria – range across 14 aggregate ecosystems for rivers and streams in USA; conc. To protect against eutrophication
TN	0.75-1.5 moderately eutrophic 1.5-2.5 strongly eutrophic	(UN/ECE, 1992)	ECE standards surface water quality

b) Phosphorus from various sources:

µg P/l		Reference	Comment
TP	10 - 76	(US Environmental Protection Agency, 2001)	Recommended EPA criteria – range across 14 aggregate ecosystems for rivers and streams in USA; conc. To protect against eutrophication
DIP	10 - 1938	(Laane, Brockmann, van Liere, & Bovelander, 2005)	Range in the minimum and max of quality objective in European river presented by 10 EU countries (e.g., Netherlands 10 summer "very bad" – France 1938 "strong pollution"
TP	50-970	(Laane, Brockmann, van Liere, & Bovelander, 2005)	Range in the minimum and max of quality objective in European river presented by 10 EU countries
TP	75 – 100	Guidance for Implementing Wisconin's Phosphorus water quality standards for point source discharges (2012)	To protect the fish and aquatic life uses established in s. NR 102.04 (3) on rivers and streams that generally exhibit unidirectional flow, total phosphorus criteria
DIP	Hi 20-50 Good 40-120 Moderate 150-250 Poor 500 1000	UK Technical Advisory Group on the WFD (UK Environmental Standards and conditions – Phase 1) 2008	Standards associated with diatom communities in rivers at High and Good Status
DIP	Hi 19.24 Good 28-69 Moderate 87-173 Poor 752-1003	Environment Agency UK , UK Technical Advisory Group. 2013. Phosphorus Standards for Rivers, Updated recommendations.	Ranges include low to high alkalinity, and lowland to upland rivers

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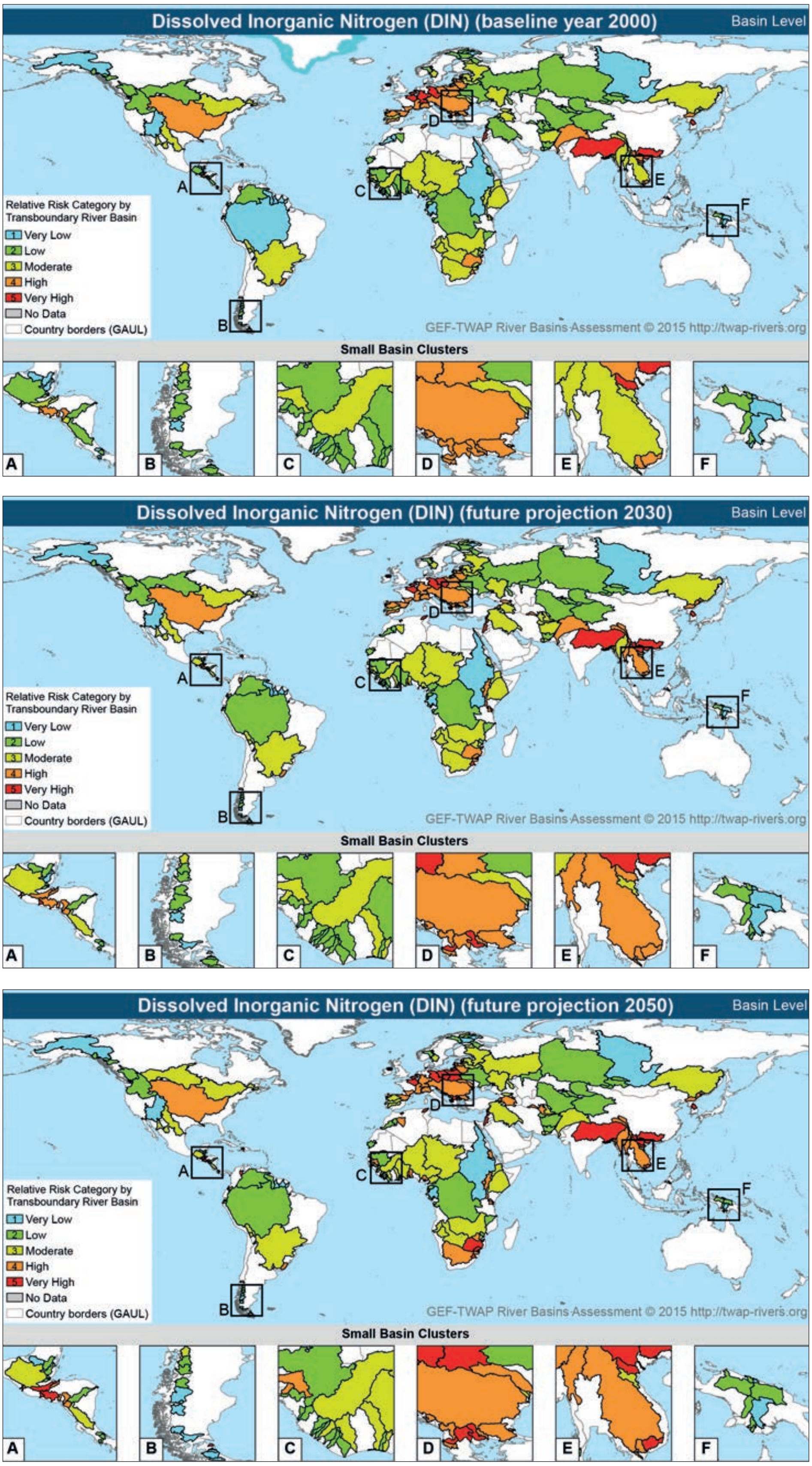
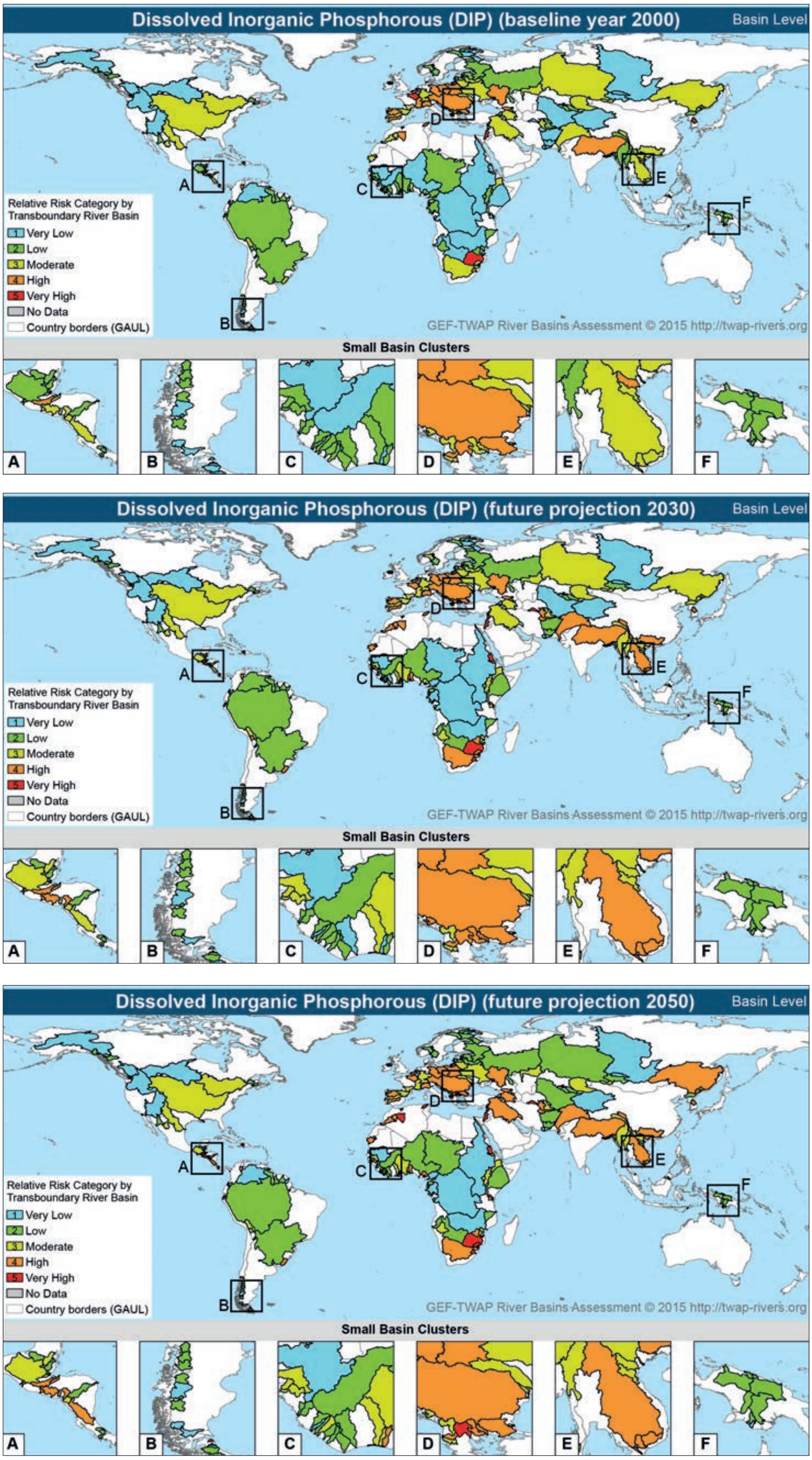
US Environmental Protection Agency. (2001). Ambient water quality criteria recommendations: Rivers and streams. from http://water.epa.gov/scitech/swguidance/standards/upload/2007_09_27_criteria_nutrient_ecoregions_rivers_rivers_1.pdf

Wisconsin-Guidance for Implementing Wisconin's Phosphorus water quality standards for point source discharges. (2012). Guidance Number:3800-2011-02

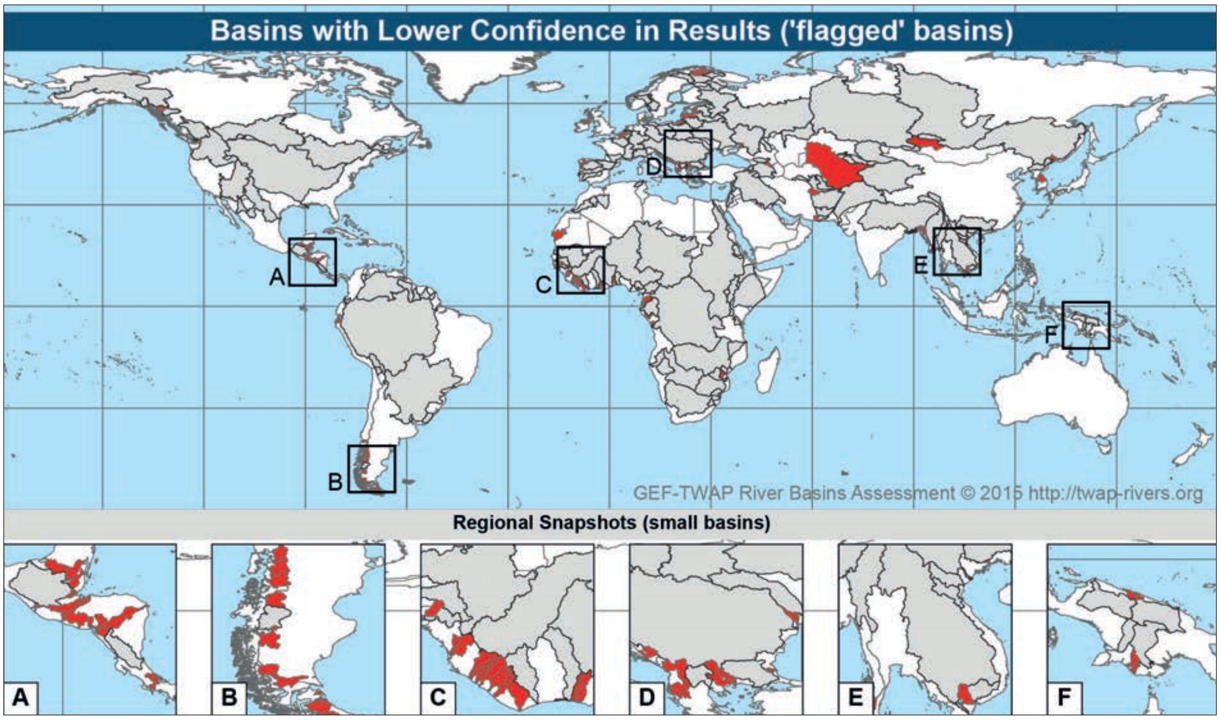
DIN nutrient sub-indicator risk categories for TFDD basins for 2000, 2030 and 2050.



DIP nutrient sub-indicator risk categories for TFDD basins for 2000, 2030 and 2050.



Nutrient Pollution "Flagged basins"



Input data sets used in the Global NEWS model for DIN, DON, DIP, DOP, PN and PP

(Table adapted from Mayorga et al. (2010))

Dataset	Resolution	Time-varying	DIN	DON	DIP	DOP	PN, PP	Sources
Hydrography, areas and regions								
Basins and river networks	0.5°		X	X	X	X	X	1
Cell and land area	0.5°		X	X	X	X	X	1, 2, 3
Continents, oceans[a]	basin		X	X	X	X	X	1, 4
Latitude bands[a]	basin		X	X	X	X	X	5
Geophysical								
Lithology	1°						X	6, 7
Topography	0.5°						X	6, 8
Climate and Hydrology								
Precipitation	0.5°	X					X	2, 9, 10
Runoff & Discharge	0.5°	X	X	X	X	X	X	9
Consumptive water use	0.5° & basin	X	X	X	X	X		9, 11
Reservoirs	0.5° & dams	X	X		X		X	9, 12
Land Use and Ecosystems								
Agriculture & sub-classes	0.5°	X	X	X	X	X		2
Wetland rice & marginal grassland	0.5°	X					X	2
Wetlands	0.5 minute							13
Humid tropical forests (Koppen Climate Zones)	0.5°		X					14
Point Sources (socioeconomic and sanitation drivers)								
Gross Domestic Product	nation	X	X	X	X	X		15
Total and urban population density	0.5°	X	X	X	X	X		
Sanitation statistics	nation/region	X	X	X	X	X		
Detergent emissions	nation/region	X			X	X		
Diffuse Sources								
Fertilizers, manure, crop harvest & animal grazing N fixation, atmospheric N deposition 0.5°	0.5°	X	X	X	X	X		2
	X	X						2

[a]Used for analysis of results.

Data sources: [1](Vörösmarty et al., 2000) [2](Bouwman et al., 2009); [3](Processed as described in Global NEWS model description (Mayorga et al., 2010); [4](Bouwman et al., 2009); [5](Bouwman et al., 2009); [6](Beusen et al., 2009); [7](Bouwman et al., 2009); [8](Bouwman et al., 2009); [9](Fekete et al., 2010); [10](New et al., 1999); [11](Meybeck and Ragu, 1996); [12](Vörösmarty et al., 2003); [13](Lehner and Döll, 2004); [14](Kottek et al., 2006); [15](Van Drecht et al., 2009)

Wastewater Pollution

Title:	***Wastewater Pollution***
Indicator Number:	***5***
Thematic Group:	***Water Quality***
Rationale:	Untreated wastewater from human activities is one of the major threats to water quality and human health today. After use for domestic and commercial purposes, and industrial activities, water often contains remains of the respective activity – e.g. nutrients, chemical residues and other pollutants. Untreated wastewater can threaten human health, lead to algal blooms and eutrophication (which can lead to fish die-off due to lack of oxygen). With rapidly expanding cities, often without adequate sanitation services and regulatory frameworks to control this pollution, wastewater is a significant problem in many parts of the world.
Links :	GW (contaminated recharge), Lakes (contamination, eutrophication), LMEs (quality of water), OO (persistent pollutants)
Description:	The Wastewater Pollution indicator measures the estimated levels of wastewater treatment in Basin Country Units (BCUs) (based on national data), rather than absolute volumes of wastewater polluting waterways. This gives an indication of the risks from pathogens which may be highly relevant to vulnerable populations at local scales, and the aggregated scores give an indication of threats stemming from poor wastewater treatment performance on a basin level. This indicator is largely based on data and methodology from the Wastewater Treatment Performance indicator developed by the EPI (Environmental Performance Index) team at The Yale Center for Environmental Law & Policy (Malik et al. 2015). This indicator compiles wastewater treatment statistics for 183 countries and was deemed to be the most comprehensive, up-to-date data source available.
Metrics:	EPI Wastewater Treatment Performance Indicator (national level data) Based on two metrics: wastewater treatment and connection rate (Malik et al. A global indicator of wastewater treatment to inform the Sustainable Development Goals (SDGs), Environmental Science & Policy, Volume 48, April 2015, Pages 172–185). Wastewater is defined as "water that has been used by households, industries, and commercial establishments that, unless treated, no longer serves a useful purpose and may contain contaminants" The EPI Wastewater Treatment Performance indicator is based on two variables: a) wastewater treatment - the amount of wastewater that is treated within a country relative to the amount of wastewater that is collected, generated, or produced; b) connection rate – the population connected to municipal sewerage systems relative to the population living in the country. The indicator assesses national wastewater treatment performance, normalizing treatment scores by the population connected to municipal sewerage systems, using following calculation: wastewater treatment level x connection rate Underlying data sources: • Pinsent Masons Water Yearbook (2013) • United Nations Statistics Division (2011) • OECD (2013) • FAO (2013) • National-level data gap-filled from reports and *on national statistics websites* Weighted BCU scores based on population and area Population data from GPW v.3 2010 future estimates, from CIESIN; area data from TWAP River Basins and BCUs shapefile.
Computation:	The scores for the TWAP RB Wastewater Pollution indicator were calculated following these steps: The national EPI wastewater treatment performance scores were assigned to the corresponding BCUs of the transboundary basins (for the purposes of the Wastewater Treatment indicator, these scores were inverted, i.e. Wastewater pollution = (1 – wastewater treatment score)). These BCU scores were multiplied by the BCU weights to give weighted BCU scores, where the BCU weights were calculated based on the population in the BCU relative to the basin, given that population (as opposed to area), is the most significant driver in this dataset. Weighted BCU scores were then added to provide basin scores Risk categories were assigned
Units:	Unit-less

Title:	***Wastewater Pollution***
Scoring system:	Basin and BCU results were categorized using equal quintiles with highest raw scores representing 'high' risk, and vice versa – basins and BCUs with low scores representing low risk to ecosystems and human health (thus high wastewater treatment performance). Results summary: (see table below) * Number of basins/BCUs for which results have been calculated, but bear a lower level of scientific confidence All basins with least 80% of the basin population represented by the BCUs with results were included in the assessment. This threshold was considered reasonable by the authors, after evaluating the data. Results for the 4 basins with between 80 and 99% of the population coverage were thus included but deemed to have a lower degree of confidence in results. The number of these basins across risk categories is indicated by * in the table above.

Relative risk category	Range (normalized score)	No. of Basins	Proportion of Basins	No. of BCUs	Proportion of BCUs
1 - Very low	0–0.2	25 (0*)	9%	98 (0*)	12%
2 - Low	0.2–0.4	37 (1*)	13%	75 (0*)	10%
3 - Moderate	0.4–0.6	19 (0*)	7%	37 (0*)	5%
4 - High	0.6–08	43 (0*)	15%	94 (0*)	12%
5 - Very high	0.8–1.0	160 (3*)	56%	472 (0*)	61%

Limitations:	• Data are based on national-level data, where available, thus regional in-country differences in wastewater treatment and collection might exist that have not been accounted for (e.g. larger cities vs smaller cities, better off vs poorer regions of the same country) • Underlying EPI Wastewater Indicator data have been supported by gap-filling and some assumptions (see more in Malik et al, 2015). Specific limitations relating to the EPI Wastewater Indicator include: *a)* reporting definitions are inconsistent across countries; b) wastewater performance trends vary regionally, and by income; c) for countries where national-level data not available, data have been gap-filled based on subnational statistical reports for major cities (i.e. rural wastewater treatment not taken into consideration, where not available), or utility-reported data; d) in some instances data gap-filled based on peer-reviewed academic literature for relevant wastewater treatment statistics or experts and government officials; e) National-level data based on the most recent year available. For data with no record of year reported, the year was estimated based on the given data source; f) for some countries values *are estimated based on available nominal descriptions*
Spatial Extent:	Global
Spatial Resolution:	BCU and Basin level
Year of Publication:	2014
Time Period:	1990-2013 (national data based on the most recent year for which data is available)
Additional Notes:	Calculated based on data from EPI Wastewater indicator national scores: Omar A. Malik, Angel Hsu, Laura A. Johnson and Alex de Sherbinin, A global indicator of wastewater treatment to inform the Sustainable Development Goals (SDGs), in review
Date:	01.04.2015
Format:	Microsoft Excel Worksheet
File Name:	TWAP_RB_indicator_05_results.xlsx
Contact person:	Maija Bertule
Contact details:	UNEP-DHI, mabe@dhigroup.com

Annex IX-3: Ecosystems

Wetland Disconnectivity

Title:	***Wetland Disconnectivity***
Indicator Number:	***6***
Thematic Group:	***Ecosystems***
Rationale:	Wetland disconnectivity is defined as the proportion of wetlands occupied by dense cropland or urban areas, assuming that human occupancy results in severing the natural physical and biological connections between river channels and their floodplains. Many cases of disconnectivity feature destruction and overt draining of wetlands to make them suitable for human use. Vast floodplain areas have been made dysfunctional by levee construction and river channelization to protect urban areas. Wetland disconnectivity can lead to distortion of flow patterns and the loss of local flood protection, water storage, habitat, nutrient processing and natural water purification.
Links :	Wetlands are an essential part of catchment hydrology. The definition of wetlands includes rivers, lakes and near-shore marine areas, and boundaries cannot be clear-cut. Hence the obvious links with the other water systems. Depending on the gradient of the groundwater table and topography of the land surface, wetlands also perform the important function of aquifer recharge or discharge.
Description:	Wetland disconnectivity is defined as the proportion of wetlands occupied by dense cropland or urban areas, assuming that human occupancy results in severing the natural physical and biological connections between river channels and their floodplains.
Metrics:	Charles J. Vörösmarty, Ellen M. Douglas, Pamela A. Green, and Carmen Revenga. Geospatial Indicators of Emerging Water Stress: An Application to Africa, Ambio, 34 (3): 230-236, 2005b. Lehner, B. & Döll, P. Development and validation of a global database of lakes, reservoirs and wetlands. J. Hydrol. 296, 1–22 (2004). Data set information available at http://www.worldwildlife. org/science/ data/GLWD _Data_Documentation.pdf; data available at: http://www. worldwildlife. org/science/data/ item1877.html Eldridge, C. D. et al. Global distribution and density of constructed impervious surfaces. Sensors 7, 1962–1979 (2007). Available at http://www.ngdc.noaa.gov/dmsp/download_global_isa.html Ramankutty, N., Evan, A. T., Monfreda, C. & Foley, J. A. Farming the planet: geographic distribution of global agricultural lands in the year 2000. Global Biogeochemical Cycles 22, GB1003 (2008). Data available at: http://www.geog.mcgill.ca/~nramankutty/Datasets/ Datasets.html
Computation:	The indicator was computed as the Wetland Disconnectivity threat driver from Vörösmarty et al. 2010 over the TFDD basin-country-unit (BCU) and transboundary basin regions. Wetland areas were defined as Classes 3-10 of the Global Lakes and Wetlands Database (Lehner & Doll 2004); lakes and reservoirs (Classes 1 and 2) were excluded. The wetland area occupied by cropland was based on a global data set on agricultural lands (i.e., croplands and pasture) in use around the year 2000 (Ramankutty et al 2008); data on wetlands occupied by urban use was based on a global inventory of the distribution and density of constructed Impervious Surface Area (Eldridge et al 2007). Average Wetland Disconnectivity threat over the TFDD BCU and basin regions was calculated as the area-weighted average of the grid cells within each TFDD BCU and basin. Winsorization (replacing extreme data values with less extreme values) was applied to limit the weighting influence of a handful of small basins/BCUs comprised mainly of grid cells with high wetland disconnectivity. Given that the data were previously normalized on a 0-1 scale, the winsorization was applied to the count of basins falling in equally spaced bins with the top 2.5% by count assigned as the range max value. For basin averages, the top 2.5% was applied at values of 0.725 and greater. For BCUs the top 2.5% was applied at values of 0.825 and greater. To maintain the integrity of the approach, only results for basins greater than 25 000 – 30 000 km^2 can be provided with a scientifically credible level of certainty and thus used in the ranking system. Results for basins smaller than 25 000 – 30 000 km^2 have been provided with the tabular information for reference only and were not used in the calculation of rankings. All data were computed in 30' latitude-longitude (i.e., 0.5° degree) gridded format in the Geographic projection over the TFDD BCU/transboundary basin regions.
Units:	See description

<table>
<tr><th>Title:</th><th>Wetland Disconnectivity</th></tr>
<tr><td>Scoring system:</td><td>
Due to the standardized nature of the original Vörösmarty et al. 2010 datasets, risk categories were defined as 20% equal-interval classes with the lowest corresponding to very low relative risk and the highest corresponding to very high relative risk

The results for the Wetland Disconnectivity indicator are summarized below:
<table>
<tr><th>Relative risk category</th><th>Range (normalized score)</th><th>No. of Basins</th><th>Proportion of Basins</th><th>No. of BCUs</th><th>Proportion of BCUs</th></tr>
<tr><td>1 - Very low</td><td>0.0–0.19</td><td>69 (29*)</td><td>34%</td><td>196 (91*)</td><td>36%</td></tr>
<tr><td>2 - Low</td><td>0.2–0.39</td><td>78 (25*)</td><td>38%</td><td>141 (45*)</td><td>26%</td></tr>
<tr><td>3 - Moderate</td><td>0.4–0.59</td><td>28 (8*)</td><td>14%</td><td>101 (36*)</td><td>19%</td></tr>
<tr><td>4 - High</td><td>0.6–79</td><td>17 (7*)</td><td>8%</td><td>56 (20*)</td><td>10%</td></tr>
<tr><td>5 - Very high</td><td>0.8–1.00</td><td>13 (10*)</td><td>6%</td><td>48 (23*)</td><td>9%</td></tr>
</table>
* Number of basins/BCUs for which results have been calculated, but bear a lower level of confidence due to modelling limitations. See more in section 'Computation'
</td></tr>
<tr><td>Limitations:</td><td>The lack of detailed descriptive attributes in Class 3-10 items of the GLWD, such as names or volumes, may hamper analysis at level-2 scale; however GIS information could be derived from data sources other than remote sensing, including Ramsar site data in Ramsar Information Sheets (RIS) format.</td></tr>
<tr><td>Spatial Extent:</td><td>Global</td></tr>
<tr><td>Spatial Resolution:</td><td>30- X 30-min Lat X Lon</td></tr>
<tr><td>Year of Publication:</td><td>2010</td></tr>
<tr><td>Time Period:</td><td>2000</td></tr>
<tr><td>Additional Notes:</td><td></td></tr>
<tr><td>Date:</td><td>16.02.2015.</td></tr>
<tr><td>Format:</td><td>Excel spreadsheet</td></tr>
<tr><td>File Name:</td><td>TWAP_RB_indicator_06_results.xlsx</td></tr>
<tr><td>Contact person:</td><td>Charles J. Vörösmarty, Pamela Green</td></tr>
<tr><td>Contact details:</td><td>cvorosmarty@ccny.cuny.edu, pgreen.ccny@gmail.com</td></tr>
</table>

Ecosystem Impacts from Dams

Title:	*Ecosystem Impacts from Dams*
Indicator Number:	*7*
Thematic Group:	*Ecosystems*
Rationale:	In addition to core geophysical and chemical indicators of water quantity and quality in international river basins, assessment of ecosystem state is also needed to fully evaluate basin condition. Drinking water quality, sustainable fisheries, and other basin services depend on the collective role of a diverse flora and fauna to maintain ecosystem function. While the aggregate impact of many stressors defines the state of modern river basins, one factor in particular was highlighted in recent work (Vörösmarty et al. 2010) as having a pre-eminent negative impact on aquatic biota: human management of water systems. And, among these management systems, impoundment and reservoir operation was emblematic of stresses on aquatic ecosystems and resident biodiversity. The negative impacts on ecosystems of altering waterways through river fragmentation and flow disruption by dams, water transfers and canals must be considered for managing water resources in a sustainable way. It is no longer acceptable to draw water from nature for use in agriculture, industry, and everyday life without taking into account the role that ecosystems play in sustaining a wide array of goods and services, including water supply. Very large dams account for 85 per cent of registered water storage worldwide. In order to compensate for considering only the impacts of very large dams on river fragmentation and flow disruption, dam density has also been factored in this indicator.
Links :	GW (reduction in mean annual discharge due to impoundments may affect the amount of groundwater recharge), Lakes (reduction in the rate of sedimentation in lakes and reservoirs), LMEs (reduction in the amount of nutrients that reaches marine ecosystems).
Description:	Three sub- indicators were developed for this indicator to address the various impacts dams can have on ecosystem: **a) River Fragmentation (sub-indicator 7a)** **b) Flow Disruption (sub-indicator 7b)** **c) Dam Density (sub-indicator 7c)** All data are computed in 30' latitude-longitude (i.e., 0.5° degree) gridded format in the geographic projection over the TFDD basin-country-unit (BCU) and transboundary basin regions.
Metrics:	C.J. Vorosmarty, P.B. McIntyre, M.O. Gessner, D. Dudgeon, A. Prusevich, P. Green, S. Glidden, S.E. Bunn, C.A. Sullivan, C. Reidy Liermann, and P.M. Davies Nature 467, 555-561 (30 September 2010) doi:10.1038/nature09440 Lehner, B., C. Reidy Liermann, C. Revenga, C. Vörösmart, B. Fekete, P. Crouzet, P. Döll, M. Endejan, K. Frenken, J. Magome, C. Nilsson, J.C. Robertson, R. Rodel, N. Sindorf, and D. Wisser. 2011. High-Resolution Mapping of the World's Reservoirs and Dams for Sustainable River-Flow Management. Frontiers in Ecology and the Environment 9:494-502. DOI: 10.1890/100125. ICOLD (International Commission on Large Dams). World Register of Dams. Paris, France (1998).
Computation:	**1. River Fragmentation (sub-indicator 7a):** Computed as the River Fragmentation threat driver from Vörösmarty et al. 2010 at 30-minute grid cell resolution. Described as the 'swimmable area' between barriers that remains accessible to aquatic species, river fragmentation is a measure of the swimmable distance in any direction from a grid cell to the nearest barrier. The GWSP-GRAND data set of geo-referenced large dams was used to define swimmable barriers. **2. Flow Disruption (sub-indicator 7b):** Computed as the Flow Disruption threat driver from Vörösmarty et al. 2010 at 30-minute grid cell resolution. Flow disruption was calculated as the magnitude of flow distortion as the residence time of water in large reservoirs. **3. Dam Density (sub-indicator 7c):** Computed as the Dam Density threat driver from Vörösmarty et al. 2010 at 30-minute grid cell resolution. Dam density represents the density and distribution of very large and medium to large dams mapped at the global scale. **Ecosystem Impacts from Dams (Main indicator):** Numerical average of the three sub-indicators was calculated at the 30-minute grid cell level then rescaled to fit a 0-1 scale. Average Ecosystem Impacts from Dams over the TFDD BCU and basin regions was calculated as the area-weighted average of the grid cell values within each TFDD BCU and basin. To maintain the integrity of the approach, only results for basins greater than 25 000 – 30 000 km^2 can be provided with a scientifically credible level of certainty and thus used in the ranking system. Results for basins smaller than 25 000 – 30 000 km^2 have been provided with the tabular information for reference only and were not used in the calculation of rankings.
Units:	See description

<table>
<tr><th>Title:</th><th>Ecosystem Impacts from Dams</th></tr>
<tr><td>Scoring system:</td><td>
Due to the standardized nature of the original Vörösmarty et al. 2010 datasets, risk categories were defined as 20% equal-interval classes with the lowest corresponding to very low risk and the highest corresponding to very high risk.
Table below summarizes results of the combined indicator:
<table>
<tr><th>Relative risk category</th><th>Range (normalized score)</th><th>No. of Basins</th><th>Proportion of Basins</th><th>No. of BCUs</th><th>Proportion of BCUs</th></tr>
<tr><td>1 - Very low</td><td>0.00–0.19</td><td>35 (22*)</td><td>15%</td><td>63 (44*)</td><td>11.4%</td></tr>
<tr><td>2 - Low</td><td>0.20–0.39</td><td>40 (25*)</td><td>17%</td><td>95 (65*)</td><td>17.2%</td></tr>
<tr><td>3 - Moderate</td><td>0.40–0.59</td><td>63 (26*)</td><td>26%</td><td>140 (71*)</td><td>25.5%</td></tr>
<tr><td>4 - High</td><td>0.60–079</td><td>57 (26*)</td><td>24%</td><td>152 (83*)</td><td>27.6%</td></tr>
<tr><td>5 - Very high</td><td>0.80–1.00</td><td>43 (7*)</td><td>18%</td><td>101 (45*)</td><td>18.3%</td></tr>
</table>
* Number of basins/BCUs for which results have been calculated, but bear a lower level of confidence due to modelling limitations. See more under 'Computation' section.
</td></tr>
<tr><td>Limitations:</td><td>

The dam density map used should not be construed as the spatial distribution of dams, because it reflects a probabilistic estimation of spatial patterns within each country, and excludes a very large number of small dams and other structural barriers for which global data are unavailable.
The rate of dam construction in some regions is so high that the indicator may change faster than the ability to update the reference base.
The inclusion of additional dams for which no data are available may alter the impact classification for a given river basin. Therefore, the indicator represents the minimum level of impact.
Dam and reservoir operation is more-or-less unknown over the domains analysed

</td></tr>
<tr><td>Spatial Extent:</td><td>Global</td></tr>
<tr><td>Spatial Resolution:</td><td>30- X 30-min Lat X Lon</td></tr>
<tr><td>Year of Publication:</td><td>2010</td></tr>
<tr><td>Time Period:</td><td>2000</td></tr>
<tr><td>Additional Notes:</td><td>For detailed information on the threat drivers see http://www.nature.com/nature/journal/v467/n7315/extref/nature09440-s1.pdf</td></tr>
<tr><td>Date:</td><td>16.02.2015.</td></tr>
<tr><td>Format:</td><td>Excel Spreadsheets</td></tr>
<tr><td>File Name:</td><td>TWAP_RB_indicator_07_results.xlsx
TWAP_RB_indicator_07a_results.xlsx
TWAP_RB_indicator_07b_results.xlsx
TWAP_RB_indicator_07c_results.xlsx</td></tr>
<tr><td>Contact person:</td><td>Charles J. Vörösmarty, Pamela Green</td></tr>
<tr><td>Contact details:</td><td>cvorosmarty@ccny.cuny.edu, pgreen.ccny@gmail.com</td></tr>
</table>

Threat to Fish

Title:	***Threat to Fish***
Indicator Number:	***8***
Thematic Group:	***Ecosystems***
Rationale:	*I*n addition to loss of fish habitat and environmental degradation, the main factors threatening inland fisheries are fishing pressure and non-native species. Overfishing is a pervasive stress in rivers worldwide due to intensive, size-selective harvesting for commerce, subsistence, and recreation (Vörösmarty, et al., 2010). More commonly, non-native species introductions may result from species being released for hunting or biological control as well as to form part of fish catches. Invasive alien species threaten native species as direct predators or competitors, as vectors of disease, by modifying the habitat, or by altering native species dynamics.
Links :	Lakes (as fish are free to move along rivers, fishing or introductions in one river basin area can have consequences for species diversity and composition of lakes in other basin areas). LMEs owing to anadromous fish migration.
Description:	The Threat to Fish indicator is composed of two sub-indicators: **a) Fishing Pressure (sub-indicator 8a)** **b) % Non-native Fish (sub-indicator 8b)** All data were computed in 30' latitude-longitude (i.e., 0.5° degree) gridded format in the geographic projection over the TFDD basin-country-unit (BCU) and transboundary basin regions.
Metrics:	C.J. Vorosmarty, P.B. McIntyre, M.O. Gessner, D. Dudgeon, A. Prusevich, P. Green, S. Glidden, S.E. Bunn, C.A. Sullivan, C. Reidy Liermann, and P.M. Davies Nature 467, 555-561 (30 September 2010) doi:10.1038/nature09440 UN Food and Agriculture Organisation's (FAO) FishStat Plus database (http://www.fao.org/fishery/statistics/software/fishstat/en) LePrieur, F., Beauchard, O., Blanchet, S., Oberdorff, T. & Brosse, S. Fish invasions in the world's river systems: when natural processes are blurred by human activities. PLoS Biol. 6, e28 (2008).
Computation:	**1. Fishing Pressure (Sub-indicator 8a):** Computed as the Fishing Pressure threat driver from Vörösmarty et al. 2010 at 30-minute grid cell resolution. Fishing pressure distribution was calculated based on a scaling relationship between country-level fish catches, net primary productivity and discharge. **2. Number of Non-native Fish (Sub-indicator 8b):** Computed as the % Non-native Fish threat driver from Vörösmarty et al. 2010 at 30-minute grid cell resolution. The number of non-native fish species in each river basin was taken from LePrieur et al. **Threat to Fish (Main indicator):** For the final indicator score, the numerical average of the two sub-indicators was calculated at the 30-minute grid cell level then rescaled to fit a 0-1 scale. Average Threat to Fish over the BCU and basin regions was calculated as the area-weighted average of the grid cell values within each TFDD BCU and basin. To maintain the integrity of the approach, only results for basins greater than 25 000 – 30 000 km^2 can be provided with a scientifically credible level of certainty and thus used in the ranking system. Results for basins smaller than 25 000 – 30 000 km^2 have been provided with the tabular information for reference only and were not used in the calculation of rankings.
Units:	See description

Scoring system:	Due to the standardized nature of the original Vörösmarty et al. 2010 datasets, risk categories were defined as 20% equal-interval classes with the lowest corresponding to very low risk and the highest corresponding to very high risk. Table below summarizes results of the combined indicator: (see table below) * Number of basins/BCUs for which results have been calculated, but bear a lower level of confidence due to modelling limitations. See more in section 'Computation'
Limitations:	• The indicator assumes that terrestrial primary productivity either directly supports fish production or serves as an adequate proxy for the aquatic primary production that supports fish. A proxy is necessary owing to the lack of sufficient observational data. • Annual catch for each grid cell has been based on estimated fish catches from rivers. However, historic trends in fisheries statistics are normally available only for a few well-studied rivers, and, because of the multispecies composition of the catch in most inland water bodies, particularly in developing countries, assessments of the condition of the resources are hard to carry out. • The negative impacts of non-native species on aquatic ecosystems are a function of both the absolute number of non-native species and the proportion of fauna represented by non-native species. Here, only proportion is considered. Moreover, these data cover 1 055 basins which amount to 80% of global land area.
Spatial Extent:	Global
Spatial Resolution:	
Year of Publication:	2010
Time Period:	2000
Additional Notes:	For detailed information on the threat drivers see http://www.nature.com/nature/journal/v467/n7315/extref/nature09440-s1.pdf.
Date:	16.02.2015.
Format:	Excel Spreadsheets
File Name:	TWAP_RB_indicator_08_results.xlsx TWAP_RB_indicator_08a_results.xlsx TWAP_RB_indicator_08b_results.xlsx
Contact person:	Charles J. Vörösmarty, Pamela Green
Contact details:	cvorosmarty@ccny.cuny.edu, pgreen.ccny@gmail.com

Relative risk category	Range (normalized score)	No. of Basins	Proportion of Basins	No. of BCUs	Proportion of BCUs
1 - Very low	0.00–0.19	22 (13*)	10%	69 (50*)	13%
2 - Low	0.20–0.39	73 (29*)	32%	185 (95*)	36%
3 - Moderate	0.40–0.59	82 (36*)	37%	170 (90*)	33%
4 - High	0.60–079	32 (10*)	14%	74 (31*)	14%
5 - Very high	0.80–1.00	15 (4*)	7%	22 (14*)	4%

Extinction risk

Title:	*Extinction risk*
Indicator Number:	*9*
Thematic Group:	*Ecosystems*
Rationale:	A threatened species is one that is listed under the IUCN Red List Categories as Vulnerable, Endangered or Critically Endangered (i.e. species that are facing a high, very high or extremely high risk of extinction in the wild). Species are included in these categories according to a range of data regarding their abundance, populations, ecology, and the threats they face. Increasing numbers of species assessed as threatened or extinct represent actual or potential declines in the status of biodiversity. Decreasing numbers of species assessed as threatened, over a suitable time period following management interventions, is strongly indicative of successful conservation measures. The Convention on Biological Diversity (CBD) recognises that biodiversity has its own intrinsic value and that biodiversity maintenance is essential for human life and sustainable development through the provisioning of ecosystem goods and services. Although this metric captures trends in one particular aspect of biodiversity (i.e. the rate species are moving towards extinction or becoming extinct) and does not encompass the wider spectrum of biodiversity (e.g. genes and ecosystems), losing species through extinction, or a reduction in the viability of remaining populations, is a particularly tangible and readily understandable component of biodiversity loss and has clear relevance to ecosystem function. The IUCN Red List of Threatened Species™ is widely recognized as the most authoritative and objective system for classifying species by their risk of extinction. The 2013 (version 2) Red List contained assessments for 71 576 species for which spatial data exist for just over 45 000 species, including all known species of amphibians, mammals, freshwater decapods, and birds, and for *all know species of many other taxa, such as freshwater fish, in many regions of the world.*
Links :	GW: Many species of freshwater molluscs and fish are found in groundwater hydrological systems; significant numbers of these species are assessed as threatened on the IUCN Red List, frequently as a result of water abstraction, pollution, and the loss or degradation of habitat. Many of these species have highly restricted ranges therefore increasing their vulnerability to extinction. Lakes: Freshwater lakes are key resident and migratory habitats for many freshwater species such as fish, and bivalve molluscs that depend on migratory fish for reproduction. Lakes, especially those with significant seasonal variations in area, are often significant for migratory and resident birds and support important fisheries. LMEs: Coastal and brackish ecosystems are vital to many migratory animals e.g., birds and diadromous fish.
Description:	The Extinction Risk indicator allows for the identification of transboundary basins with the highest risk of species extinction. It is based on the IUCN Red List Categories and Criteria (IUCN, 2012) for selected freshwater biodiversity taxa.
Metrics:	The IUCN Red List of Threatened SpeciesTM is a database that provides a measure of the extinction risk and distribution ranges for individual species. Source: IUCN 2013. IUCN Red List of Threatened Species. Version 2013.2. <www.iucnredlist.org>. HydroBASINS is a global river and lake catchment layer derived from HydroSHEDS and the global lakes and wetlands database (GLWD) and is the spatial layer to which all freshwater species are mapped in this analysis. Source: Lehner, B. 2012. HydroBASINS Version 1.b. Global watershed boundaries and sub-basin delineation derived from HydroSHEDS data at 15 second resolution. The two main aspects reported when assessing the status of freshwater biodiversity are vulnerability (i.e. threats to biodiversity leading to its loss) and irreplaceability (i.e. the uniqueness or endemism of the biodiversity within a basin) (Margules and Pressey 2000, Brooks et al. 2006). The Extinction Risk indicator uses IUCN Red List data (threat status and distribution maps) only for freshwater species from taxonomic groups for which all described species have had their extinction risk assessed in a basin to avoid any bias in the results. Some taxonomic groups (mammals, birds, amphibians, crabs, crayfish and shrimps) have been globally assessed and are therefore included in development of the indicator for all TWAP RB basins. Other groups (fish, molluscs, dragonflies and damselflies, and selected aquatic plant families) have, however, so far only been comprehensively assessed for Africa, Europe, several Biodiversity Hotspots (Indo-Burma, Western Ghats, Mediterranean Basin and the Eastern Himalaya), the Arabian Peninsula and New Zealand, and are therefore only included in the indicator development for the TWAP RB basins in these regions. Addition of these taxonomic groups increases the taxonomic breath of coverage and so provides a greater degree of confidence in the results for these regions. These additional taxonomic groups are highly speciose, represent a range of trophic levels and play important roles in supporting ecosystem functioning (and services) of freshwater systems. Assessments are also underway for the Tropical Andes Hotspot and Canada such that the resulting data sets might also be incorporated to further improve the confidence of the indicators developed for these regions. All freshwater fish of the United States have been assessed. The IUCN Global Species Programme's Freshwater Biodiversity Unit (www.iucn.org/species/freshwater) is currently soliciting for funds to complete the assessments of these additional groups across all remaining regions.

Title:	***Extinction risk***
Computation:	Indicator results computation was undertaken in following steps: **Step 1.** Extinction Risk calculations. The extinction risk for each species on the IUCN Red List has been assessed according to the IUCN Red List Categories and Criteria (IUCN 2012). Information collated on each species includes taxonomy, distribution, abundance, population trends, threats, habitat preferences, basic ecology, and current and recommended conservation actions. The IUCN Red List Categories are: Extinct (EX), Extinct in the Wild (EW), Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concern (LC) and Data Deficient (DD). All species tagged as 'freshwater' in the 'System' field on the IUCN Red List are included in the analysis. **Step 2.** Collation of species distribution data. IUCN Red List species distribution maps (based on species presence within individual HydroBASINS) were collated for the above-mentioned taxonomic groups. Species distribution catchment records coded as 'Presence' 1 (Extant), 2 (Probably Extant), 4 (Possibly Extinct), and 5 (Extinct) were included in the analyses. Map records coded as 'Possibly Present' and 'Presence Uncertain' were excluded from the analysis. Species catchment records marked as 'Origin' 1 (Native) and 2 (Reintroduced) were included. Records marked as 3 (Introduced), 4 (Vagrant) or 5 (Origin Uncertain) were also excluded. Datasets compiled prior to September 2012 employed different geo-spatial frameworks including: Hydro1k, HydroSHEDS, and non-catchment-based polygons. Maps based on these earlier spatial frameworks were subsequently migrated to a standard spatial layer for the TWAP indicator analysis called HydroBASINS at Level 8. Species distributions were migrated using a combination of R scripts (R Development Core team 2010), ArcGIS 10.1 and Geospatial Modelling Environment v 0.7.2.1 (Beyer 2009-2012). Following migration of maps to HydroBASINS, they were checked against original maps for range boundary and attribute consistency, resolution of partial duplicate conflicts (i.e. conflicting attribute values assigned to the same catchment), removal of duplicate records and species names spelling consistency. Where a given species appeared in multiple regional datasets the distribution was combined into a single global distribution and the most recent data were used for any overlapping segments. Species mapped after September 2012 have been mapped directly to the HydroBASINS layer, at either Level 8 or Level 10. **Step 3.** Identification of species presence in TWAP basins and BCUs. A spatial layer with matching extent to the BCU layer was produced for both HydroBASIN Level 8 and Level 10 sub-catchments. The HydroBASIN layers were then intersected with the BCU layer to obtain HYBAS_ID, BCCODE pairs to indicate which HYBAS_ID overlapped with each BCCODE. All species mapped to a HYBAS_ID could then be mapped to the corresponding BCCODE (and subsequently aggregated to the corresponding BCODE). Any intersections with areas smaller than the smallest level 10 HydroBASIN were omitted as a rule as in reality they tended to be shared borders rather than area overlap. **Step 4.** Calculation of % threatened species per basin and BCU. The percentage of threatened species (CR, EN and VU Categories) for each basin and BCU was calculated as a mid-point (MID) estimate, i.e. we assumed the DD species (those species for which insufficient information was available to assess a level of extinction risk) are threatened in the same proportion as the species for which there are sufficient data, as follows: % threat = (CR + EN + VU) / (total assessed - EX - EW - DD). The taxonomic groups included in the calculation of % threatened species for the basins and BCUs in Africa, Europe and south Asia (Eastern Himalaya and Indo-Burma) were freshwater mammals, amphibians, birds, crabs, crayfish, shrimps, fish, molluscs, dragonflies and damselflies, and aquatic plants. For the other regions of the world with less complete Red List assessments the indicator calculations was based on freshwater mammals, amphibians, birds, crabs, crayfish, and shrimps only. A Kendal Correlation test was undertaken to see if there were any significant similarities between the % threat per basin between taxon groups. We found that there was no significant positive correlation at the basin level for the level of threat between any of the taxon groups (see table 1). However, two groups showed relatively high levels of (negative) correlation, birds-crayfish and crayfish-shrimps. This finding confirms the importance on broadening the taxonomic scope of the indicator through inclusion of the 'additional' groups (fish, molluscs, dragonflies and damselflies, aquatic plants) as no one group will accurately reflect (i.e. be a surrogate for) the status of another. Broadening the taxonomic breadth of the indicator through incorporation of the additional groups increases confidence in the result.

Title:	*Extinction risk*

Computation

Table 1. Kendal Correlations for % threat per basin between taxon groups.

	Amph	Birds	Crabs	Crayf	Mamm	Shrimps	Fish	Moll	Odon	Plants
Amphibians	1.000									
Birds	-0.016	1.000								
Crabs	0.336	-0.065	1.000							
crayfish	0.271	-0.586	NA	1.000						
Mammals	0.226	0.040	0.312	-0.178	1.000					
Shrimps	0.169	0.355	0.069	-0.771	-0.025	1.000				
Fish	0.156	0.167	0.136	-0.132	-0.040	0.219	1.000			
Molluscs	0.013	0.242	0.055	0.166	-0.175	0.272	0.322	1.000		
Odonata	0.374	0.086	0.387	-0.037	0.219	0.034	0.167	0.124	1.000	
Plants	0.190	0.096	-0.004	0.002	0.059	0.102	0.133	0.117	0.136	1.000

Step 5. Calculate proportion of species endemism per basin and BCU.
All species occurring outside the extent of the BCU were excluded as none could be considered endemic to any single BCCODE or BCODE. The number of BCCODEs occupied by each of the remaining species was calculated and those restricted to single BCCODEs were marked as endemic. The results were then aggregated to test for cumulative levels of endemism at the BCCODE level.

The proportion of endemic species in each basin and BCU was then calculated. The taxonomic groups included in calculation of the endemism scores for the basins and BCUs in Africa, Europe and south Asia (Eastern Himalaya and Indo-Burma) were the mammals, amphibians, birds, crabs, crayfish, shrimps, fish, molluscs, dragonflies and damselflies, and aquatic plants. The groups included for the rest of the world were mammals, amphibians, birds, crabs, crayfish, and shrimps. The percent of the species that are endemic to each basin and CBU, was then normalized to a 0-1 scale (using the '(value - min)/(max-min)' formula).

Step 6 Calculation of river length per basin and BCU.
An intersect of rivers (U.S. Geological Survey, Digital Charts of the World) with the BCU layer was undertaken to create a river layer for just the TWAP basins. This river layer was then projected to the World Equidistant Cylindrical projection so that each river segment length could be measured (in km) using the ESRI GIS calculate geometry function. A spatial join was then used to join the BCU polygons to the rivers lines layer using JOIN_ONE_TO_ONE, and the river length field was summed for each BCU polygon using the Merge Rule > SUM. The river length was then scaled up for the basin level. The river length (in km) for each basin and CBU was normalized to a 0-1 scale (using the '(value - min)/(max-min)' formula).

Step 7 Application of weighting to the % threatened species score.
Weighting of the percent threatened species score was undertaken by first multiplying the river length normalized score by 0.5, so greater importance was given to endemism as it represents one of the two principles of conservation planning (irreplaceability). Then an average of the two normalized scores (river length and endemism) was taken and multiplied against the threatened species score (using the '(% threatened species score) x (1 + average weighting score)' formula).

Step 8 Assignment of final Risk Categories.
Scores were placed into risk categories from 1 - 5, where 1 represents very low 'risk' and 5 very high 'risk' (see below).

Units:

Proportion of threatened species relative to non-threatened species weighted by percentage endemic species and river length in km.

Scoring system:

To present the results, the scores were placed into categories (based on the normalized scores) from 1 - 5, where 1 represents very low extinction risk and 5 very high extinction risk. The thresholds were based on a compromise between the 'natural breaks' in the results from the river basins and results from the BCU's (using Jenks approach). Standardizing the thresholds between basin and BCU results allows for easier comparison between the two scales.

Overview of results can be seen below:

Relative risk category	Range (normalized score)	No. of Basins	Proportion of Basins	No. of BCUs	Proportion of BCUs
1 - Very low	0–0.09	73 (42*)	26%	140 (30*)	18%
2 - Low	0.1–0.19	106 (34*)	38%	278 (26*)	35%
3 - Moderate	0.2–0.39	88 (51*)	31%	290 (133*)	37%
4 - High	0.4–0.69	12 (7*)	4%	70 (42*)	9%
5 - Very high	0.7–1.00	3 (1*)	1%	7 (4*)	1%

* Number of basins/BCUs for which results have been calculated, but bear a lower level of confidence due to computation limitations. See more in section 'Limitations'

Title:	***Extinction risk***
Limitations:	The major limitation to this indicator is reduced confidence in the results for the 47% of basins where only the globally-assessed groups are used. The only way to improve this is to undertake IUCN Red List assessments for the fish, molluscs, dragonflies and damselflies and aquatic plants globally so that these highly speciose groups that are important for ecosystem functioning and services can be used to inform conservation and development planning. The IUCN Global Species Programme is currently trying to fund projects to fill these taxonomic data gaps. The river length weighting score incorporates a bias towards the temperate regions, as two basins with equal river length one temperate and one tropical would have the same weighting, but in reality the tropical basin would contain more species. This bias could be reduced in the future by incorporating a latitudinal weighting to the river length score, or river discharge/ or water volume data could be used as a surrogate for species richness. Ideally if all the taxonomic groups were assessed globally (see above point) then no surrogate for species richness would be needed. Some of the very smallest basins (4) and BCUs (11) have no data for the Extinction Risk indicator as the IUCN Red List species data is mapped to a larger resolution of basin than the basin/BCU so that species data were not associated with these basins/BCUs during the automated overlap analysis in GIS.
Spatial Extent:	Global
Spatial Resolution:	All analyses were based on species distributions held in level 08 HydroBASINS, and resolution is defined by the size of the individual level 08 HydroBASINS that comprise individual species distributions. Level 08 HydroBASINS range in area from 0.001 km^2 to 374 357 km^2, with a mean area of 571 km^2. Original species distributions where produced in a variety of formats. (i) Molluscs, fish, odonata, shrimps, crabs and Aquatic Plants were mapped to level 08 HydroBASINS. (ii) Other species groups (Birds, Mammals, Crayfish, and Reptiles) were originally mapped as irregular polygons and subsequently migrated to the relevant overlapping level 08 HydroBASINS.
Year of Publication:	Global Red List data are available on the IUCN Red List website (www.iucnredlist.org) and this database is updated annually. The Red List data and maps used in this analysis were as downloaded from the IUCN Red List Version 2.
Time Period:	2003 (est.) - 2013
Additional Notes:	The Red List Index or RLI (Butchart et al. 2004; 2007) was originally proposed as the metric for biodiversity loss in the Methodology for the Assessment of Transboundary River Basins (UNEP-DHI, 2011). The RLI is based on the number of species moving between Red List Categories in repeated assessments over time where the change in Category is considered a result of a genuine improvement/ deterioration in status (i.e. Category changes owing to revised taxonomy or improved knowledge are excluded). An RLI value of 1.0 equates to all species being categorised as Least Concern, and hence that none are expected to go extinct in the near future. An RLI value of zero indicates that all species have gone extinct. The index shows how the value of the RLI changes over time as species are re-assessed. Additional information on application of the RLI can be found here. Such a metric as the RLI has further potential to illustrate the effectiveness of national, regional and global measures designed to conserve biological diversity and ensure that its use is sustainable, including the measures implemented in fulfilment of obligations accepted under the CBD and under the Millennium Development Goals (UNDESA 2007). In addition, the IUCN's Red List Index is being considered for adoption as biodiversity indicator under the proposed Sustainable Development Goal 9, targets a and b. Given the relatively low temporal resolution of the RLI, with updates every 4-5 years as possible, it is not able to detect rapid changes in biodiversity status and is also relatively insensitive to the slow deterioration of common species as a result of general environmental degradation. The RLI is nevertheless the most widely-accepted indicator for temporal change in the global status of biodiversity. **References:** Margules, C.R. and Pressey, R.L. 2000. Systematic conservation planning. Nature 405:243-253 Brooks, T. M., Mittermeier, R. A., da Fonseca, G. A. B., et al. 2006. Global biodiversity conservation priorities. Science, 313, 58–61
Date:	31.03.2015.
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Annex IX-4: Governance

Legal Framework

Title:	***Legal Framework***
Indicator Number:	***10***
Thematic Group:	***Governance***
Rationale:	This indicator is based on the assumption that the governance of a transboundary basin is guided by (among other things) the legal agreements in place and that they provide a framework for the allocation of resources for different uses between States. Principles of international water law have been defined to guide dialogue between riparians for creating effective transboundary water resource management. This assessment maps the presence of widely recognized key international legal principles in transboundary treaties of which countries (i.e. the respective Basin Country Units) are part, to determine the extent to which the legal framework of the basin is guided by these principles. By focusing on the transboundary legal framework, this indicator complements the Enabling environment (11) indicator (which considers the development of the 'enabling environment' for water resource management in each riparian country, based on a broad spectrum of issues including the policy, planning and legal frameworks, governance and institutional frameworks, and management instruments) and the Hydropolitical Tension indicator (12) (which focuses on governance at the transboundary scale, mapping the existence of resolution mechanisms in transboundary treaties and mapping it against the hydrological variability of the basin).
Links :	GW (indication of the likelihood of sustainable abstraction levels from aquifers), Lakes (results likely to be similar for lakes overlapping with transboundary river basins), LMEs (may be overlap of jurisdictions between river basins and LMEs)
Description:	The overall aim of this indicator is to assess the degree of correspondence/alignment of existing international freshwater treaties (in each basin) with key legal principles of international water law. *i.e. principle of equitable and reasonable utilization, principle of not causing significant harm, principle of environmental protection, principle of cooperation and information exchange, principle of notification, consultation or negotiation, principle of consultation and peaceful settlement of disputes* (ILC, 1996; ILC, 2004; McCaffrey, 2003)[29]. These principles represent important customary and general principles of international law applicable to transboundary water resource management that are accepted globally and incorporated in modern international conventions, agreements and treaties, including the Convention on the Protection and Use of Transboundary Watercourses and International Lakes (hereinafter referred to as the UNECE Water Convention) and the United Nations Convention on the Law of Non-Navigational Uses of International Watercourses (hereinafter referred to as the UN WC Convention)[30 31]. Since the UNECE Water Convention and the UN WC Convention incorporate all the above-mentioned principles and are both global in scope[32], the countries' ratification of these two Global Water Conventions have also been taken into consideration as part of this assessment.

29 ILC. 1996. The Helsinki Rules on the Uses of the Waters of International Rivers. Report of the Committee on the Uses of the Waters of International Rivers. 52nd Committee of the International Law Association.;
ILC, 2004. The Berlin Rules on Water Resources. Berlin Conference – International Water Law.;
McCaffrey, 2003. The Law of International Watercourses. Oxford University Press (April 10, 2003).
Consideration of environmental protection is not always listed as a key principle of international water law, but is included in both the Helsinki Rules on the Uses of the Waters of International Rivers (ILA, 1996) and the Berlin Rules on Water Resources (ILA, 2004) and has since become part of customary international water law. After consultations held at the UNECE 2nd Workshop "River basin commissions and other joint bodies for transboundary water cooperation: technical aspects" (May 2014) it was determined that environmental protection represents an important stand-alone principle and that it should be considered in this assessment.

30. Convention on the Protection and Use of Transboundary Watercourses and International Lakes, 17 Mar. 1992 (in force 6 Oct. 1996), reprinted in 31 I.L.M. 1312 (1992) ("ECE Convention").
31. United Nations Convention on the Law of Non-Navigational Uses of International Watercourses, UN Doc. A/51/869, 21 May 1997, reprinted in 36 Int'l Legal Mat'ls 700.
32. The amendment to the UNECE Water Convention allowing membership from non-UNECE member states has entered into force.

Title:	***Legal Framework***
Metrics:	Data on the existence of key legal principles were drawn from the International Freshwater Treaties Database which is part of the Transboundary Freshwater Dispute Database (TFDD) at Oregon State University (hereinafter referred to as the "TFDD treaty database"). The TFDD treaty database includes information on a total of 686 international freshwater treaties and represents the most comprehensive and updated data source of transboundary freshwater treaties worldwide. The agreements in the data base relate to international freshwater resources, where the concern is water as a scarce or consumable resource, a quantity to be managed, or an ecosystem to be improved or maintained. Documents concerning navigation rights and tariffs, division of fishing rights, and delineation of rivers as borders or other territorial concerns are not included, unless freshwater as a resource is also mentioned in the document, or physical changes are being made that may impact the hydrology of the river system (e.g., dredging of river beds to improve navigation, straightening of a river's course). In large part, the documents in the database concern: water rights, water allocation, water pollution, principles for equitably addressing water needs, hydropower/reservoir/flood control development, and environmental issues and the rights of riverine ecological systems. Out of the 686 listed international freshwater treaties, 481 were assessed. The remaining treaties were considered and deemed not relevant for this assessment (more detailed information on this can be found under "interpretation of the information in the TFDD treaty database" below). Information on the presence of all identified key principles was readily available in the TFDD treaty database with the exception of the "no harm principle". This principle was therefore defined (for more information, see "defining the no harm principle" below) and all relevant treaties in the database (where the treaty text could be accessed) were assessed to determine its presence. Following resources have been used to define and select the key legal principles of international water law listed above: Rieu-Clarke 2004. A Fresh Approach to International Law in the Field of Sustainable Development –What Lessons from the Law of International Watercourses[33]. Convention on the Law of the Non-navigational Uses of International Watercourses[34]. Berlin Rules: International Law Association Berlin Conference (2004) Water Resources Law[35] 1966 International Law Association Helsinki Rule on the Uses of the Waters of International Rivers[36] 1992 Convention on the protection and use of transboundary watercourses and international lakes[37] Expert advice, from Dr. Alistair Rieu Clark, Reader in International Law at the UNESCO Center for Water Law and Policy[38]

33. Rieu-Clarke A. 2004 A Fresh Approach to International Law in the Field of Sustainable Development –What Lessons from the Law of International Watercourses. Available at http://discovery.dundee.ac.uk/portal/en/theses/a-fresh-approach-to-international-law-in-the-field-of-sustainable-development(9d84d8f5-7439-4ed9-9b18-f86bc9f3e95c).html, last accessed 20140613
34. Supra note 2
35. International Law Association Berlin Conference (2004) Water Resources Law, available at http://internationalwaterlaw.org/documents/intldocs/ILA_Berlin_Rules-2004.pdf, last accessed 20140613
36. Helsinki Rules on the Uses of the Waters of International Rivers, adopted by the ILA at the 52nd Conference, Helsinki, Finland, Aug. 1966, available at: http://www.internationalwaterlaw.org/documents/intldocs/helsinki_rules.html, last accessed 20140613
37. Supra note 2
38. http://www.dundee.ac.uk/water/staff/staff/alistairrieu-clarke/

Title:	*Legal Framework*
Computation:	The calculation of the basin scores were undertaken in two steps, after which results were categorized. Step 1: A BCU receives a score of one for each of the key principles of international water law that are present in any of the transboundary freshwater treaties it has signed. The maximum score per BCU per principle is one, even if several treaties contain the principle in question. A value of 0 indicates that the presence of the principle in question in any treaty signed by the BCU could not be verified through the data available for this assessment. Each BCU that has signed either of the key global water conventions (UN WC Convention or the UNECE Water Convention) receives a score of one Overview: Calculation of the BCU treaty score (for each BCU)

BCU (basin country unit) assessment criteria	Possible value
At least one treaty covering principle of equitable and reasonable utilization	0/1
At least one treaty covering obligation not to cause significant harm	0/1
At least one treaty covering the principle on environmental protection	0/1
At least one treaty covering the principle on cooperation and information exchange	0/1
At least one treaty covering the principle on notification, consultation or negotiation	0/1
At least one treaty covering consultation and peaceful settlement of disputes	0/1
BCU has ratified UN WC Convention and/or UNECE Water Convention	0/1
BCU treaty score	0 to 7

STEP 2:
To calculate a basin legal framework score the follow steps has been taken:
The above BCU score is weighted based on an average of the relative area and population in the BCU compared to the basin.
Each weighted BCU score is summed to a basin treaty score between 1-7. The basin treaty scores have been calculated according to the table below.

Calculation of the basin treaty score (for each basin)

BCUs in Basin	BCU treaty score (from above)	BCU weight	Weighted BCU score
BCU1	0 to 7	up to 1	BCU treaty score * BCU relative importance = weighted BCU score
BCU2	0 to 7	up to 1	
BCU3	0 to 7	up to 1	
BCU4	0 to 7	up to 1	
		Sum of all BCU weights in Basin = 1	**Basin treaty score** = Sum of all weighted BCU scores (0 to 7)

Title: ***Legal Framework***

Computation:

Interpretation of the information in the "TFDD treaty database":

This assessment relies on the availability of information on treaties in the TFDD treaty database[39], including its indication on the presence of five out of six key principles indicated above.

Treaties falling under types 4, 5, 6, 7, 8, 10 and 11 in column G (Type) of the TFDD treaty database have been included in this assessment, while treaties following under categories 1, 2, 3 and 9 (for description of types, see footnote[40]) have been excluded as they were not deemed relevant in relation to the legal framework of basins.

For the five principles where the TFDD treaty database provides a value, the resulting score of this assessment was determined as follows:

	Equitable and reasonable utilization		Environmental protection		Principle of cooperation and information exchange		Principle of notification, consultation or negotiation, consultation		Peaceful settlement of disputes	
TFDD column	AP (equity or sustainability)		V (environment)		BY (information exchange)		W (prior notifica-tion)		Z (conflict resolution)	
Score[13]	TFDD Y N,N.A	Result 1 0	TFDD 1 -1	Result 1 0	TFDD Y N,N.A	Result 1 0	TFDD 2,3,4 0, 1	Result 1 0	TFDD 1,2,3,4,5 0,-1	Result 1 0

Defining the "no harm principle"
Information on the presence of the "obligation not to cause significant harm" was not available in the TFDD treaty database and had to be assessed separately. The principle was defined to facilitate consistent assessment over its presence or non-presence in transboundary freshwater treaties. The definition used was:

"The obligation not to cause significant harm also forms part of the theory of limited territorial sovereignty and with this principle no state in an international drainage basin is allowed to use the watercourses in their territory in a way that would cause significant harm to other basin states or their environment. Some treaties link the no significant harm rule to equitable and reasonable utilization in the sense that some significant harm may be permitted if it is deemed equitable and reasonable. In this assessment the this would include:

- *When a treaty specifically refers to no transboundary harm, i.e. a parties responsibility not to cause harm/damage/cause negative effects on the other parties.*
- *No harm could both refer to impacts of activities in a broader sense or to impacts of specific activities (as in the context of issue-specific treaties/agreements)*
- *Any reference to no (zero) harm as well as no significant harm"*

All treaties of types 4, 5, 6, 7, 8, 10 and 11 listed in the TFDD treaty database (where the treaty text could be accessed[41]) were assessed to determine its presence. Interpreting International water law can however be difficult and for this exercise, with the number of treaties, it was not possible to do a full legal analysis of cases where it was uncertain if a treaty really included the "obligation not to cause significant harm" even using the above-mentioned definition. International lawyers were consulted for guidance in such cases. If a treaty's consideration to the "obligation not to cause significant harm" still remained uncertain after this process, a decision was taken to consider the principle as included in that treaty rather than not included.

Units: Unit-less

39. File used: Treaty_Database_Final_07-23-09_for SIWI.xls and Treaty Database Design (with Descriptions)_:for SIWI.doc
40. 1 – Not a treaty: The document is not a treaty signed by the respective parties
2 - Semi-international treaty: The treaty has not been concluded between sovereign states, for example an agreement between one state and an international organization or an agreement between a provincial government and a state.
3 – Does not fit TFDD inclusion criteria: the treaty does not deal with water as a consumable resource
4 - Primary Agreement: The first water treaty signed between the parties about a particular issue area.
5 - Replacement of a Primary Agreement: Replaces a previously signed water agreement on the same issue area.
6 - Amendment to a Primary Agreement: Amends parts of a previously signed water agreement on the same issue area
7 - Protocol to a primary agreement: A treaty adding further aspects to an already signed water treaty and potentially modifying parts of the original treaty
8 - Financial agreement related to international waters: A treaty dealing exclusively with the financing of particular aspects related to water management, not with water itself (and thus not part of core TFDD collection)
9 – Missing
10 – Available but not translated to English
11 – Available but not coded
41. 85 out of 481 treaties could not be found, hence generating some uncertainty for the lower categories (4 & 5), see "Limitations".

Title:	*Legal Framework*
Risk categorization	A relative risk category score was developed with scores between 1 and 5, where 1 indicates a high presence of key principles of international water law in the legal framework of the basin (very low relative risk) and 5 a low presence of key principles (very high relative risk). The legal framework would include the existing basin treaties and the basin countries' ratification or signing of the global water conventions (UN WC and/or UNECE Water Convention).The interpretation of the relative risk categories for this indicator is the following: **Relative Risk Category 1**: Practically all assessed international principles are present in the existing basin treaties and the majority of basin countries have ratified or signed the UNWC Convention and/or the UNECE Water Convention. The basin legal framework is guided by key principles of international water law to a very strong degree. **Relative Risk Category 2**: The majority of the assessed international principles are present in the legal framework of the basin. The basin legal framework is guided by key principles of international water law to a strong degree. **Relative Risk Category 3:** Some of the assessed international principles are present in the legal framework of the basin. The basin legal framework is guided by key principles of international water law to a medium degree. **Relative Risk Category 4**: A limited number of the assessed international principles are present in the legal framework of the basin. The basin legal framework is guided by key principles of international water law to a limited degree. **Relative Risk Category 5:** Practically none of the principles are present in the legal framework of the basin. The basin legal framework in the basin is not guided by key principles of international water law. Given that this is the first time such an assessment has been undertaken at the global level, the category ranges are determined to suit the particular needs of this assessment. They are defined in such a way as to highlight those basins where practically all or practically none of the principles are present in the legal framework (through defining very narrow ranges for the categories 1 and 5) and with a fairly even distribution between the low, moderate and high ranges. Table below summaries the results of the Legal framework indicator assessment:

Relative risk category	Range (original score)	No. of Basins	Proportion of Basins	No. of BCUs	Proportion of BCUs
1 - Very low	6.8 - 7	8 (0*)	3%	42 (0*)	5%
2 - Low	4.5 – 6.79	51 (3*)	18%	160 (0*)	20%
3 - Moderate	2.5 – 4.49	56 (3*)	20%	144 (7*)	18%
4 - High	0.2 – 2.49	63 (1*)	22%	125 (4*)	16%
5 - Very high	0 – 0.19	108 (2*)	37%	321 (1*)	41%

* Number of basins/BCUs for which results have been calculated, but have a lower level of confidence due to data limitations (See more in Limitations section).

Title:	***Legal Framework***
Limitations	• The assessment does not measure performance of the cooperation in a certain basin, the implementation of the treaties or the application of the principles in question, it only provides an assessment of the legal governance framework in place. • The method is designed mainly to compare the legal framework in place at the basin level, while still recognizing the value of any ratification of the two global water conventions by riparian states. As a result, "basin treaties" are of higher relative importance to the final BCU or basin score (generating a score between 0-6 depending on how many key principles are included in such treaties) than the countries' ratification of the two global conventions (generating a maximum score of 1). This needs to be considered when interpreting the results. • The assessment relies to a large extent on the information in the TFDD treaty database. The TFDD treaty database is considered the most comprehensive existing global data source for transboundary freshwater agreements. However, it has been outside the scope of this assessment to verify the extent of comprehensiveness or correctness of the TFDD treaty database. It is acknowledged that relevant treaties, or principles within treaties, may exist that have been overlooked by this assessment. As an example, the TFDD treaty database was last updated in 2009 so the assessment does not take into consideration treaties that may have been signed in recent years. • A score 0 in the methodology indicates that the principle could not be verified, in some cases because of lack of information. Thus the degree of confidence for the "lower" ratings (relative risk categories 4-5) can be seen as slightly lower than that of the "higher" ratings (relative risk categories 1-3) • The method does not take into account the jurisdiction and scope of the agreement. The method does however weigh the relative importance of a treaty based on each of the signatories' significance to the basin. Some treaties incorporating key principles may concern only a limited technical scope, such as the construction of a dam or similar, and not the entirety of cooperation in that basin. The method does not factor in such limited "technical scope" – such treaties are dealt with in the same way as more "overarching" treaties. Treaties of limited technical scope are however often only signed by a few countries and not by all countries in a basin. • The method does not take into consideration whether the principles above have been covered by the BCUs' ratification of the same or of several different treaties (same score for one or several treaties). An assessment focusing primarily on the "main basin treaties" and excluding treaties of limited "technical scope" may paint a slightly different picture. • Taking the above limitations into consideration, this assessment provides a good overview and possible comparison on a broader scale between regions and basins with regard to the legal framework in place. However, the information generated should not be interpreted in "absolute terms" with regard to specific BCUs or basins. ***Potential for future development*** • A repeated assessment should cover agreements signed after 2007. • The results from this indicator should be read together with the results from the two other indicators on enabling environment and hydropolitical tension in order to provide a more comprehensive picture of the risks associated with governance in basins. • This indicator has considered all relevant treaties, also those of limited technical scope. Even though this could be seen as providing a more comprehensive view of the legal frameworks in place, an assessment focusing primarily on the "main basin treaties" may paint a slightly different picture. • A repeated assessment could be combined with a thorough and extended analysis of the legal framework in place for selected basins in the different categories. Such an in-depth analysis should also include consideration of implementation/compliance and effectiveness of the legal framework.
Spatial Extent:	Global
Spatial Resolution:	BCUs and basins
Year of Publication:	2015
Time Period:	-
Additional Notes:	
Date:	16.02.2015
Format:	Excel sheet
File Name:	TWAP_RB_indicator_10_results.xlsx
Contact persons:	Anna Forslund, Birgitta Liss Lymer
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Hydropolitical Tension

Title:	Hydropolitical Tension: Risk of Potential Hydropolitical Tensions due to Basin Development in the Absence of Adequate Institutional Capacity
Indicator Number:	***11***
Thematic Group:	***Governance***
Rationale:	Formal management institutions governing transboundary river basins, in the form of international water treaties (including specific provisions such as water allocation, conflict resolution, and variability management) and river basin organizations, can be particularly instrumental in managing disputes between fellow riparians arising from the development of new water infrastructure. This Indicator maps risk of potential hydropolitical tension that exists when basins may be ill-equipped to deal with transboundary disputes associated with the development of new water infrastructure. The results of this indicator are based on the estimation of institutional vulnerability (expressed by the absence of relevant treaty provisions and river basin organizations), which is juxtaposed with the respective basin's ongoing and planned development of water infrastructure.
Links :	GW (indication of the level of formal transboundary cooperation in aquifers overlapping within transboundary basins), Lakes (results likely to be similar for lakes overlapping with transboundary river basins)
Description:	Combination of institutional vulnerability level, based on formal institutional capacity, and hazard level, calculated based on the development of on-going and planned water infrastructure.
Metrics:	• Categorization of international water treaties – 2010 data calculated by Oregon State University (De Stefano, *et al.,* 2012; Giordano et al., 2013). Based on 796 basin-country units from 286 transboundary river basins. • Data on existence of river basin organization (RBO) in basins – data hosted by Oregon State University (Schmeier, no date). • Data on new water infrastructure in basins, whose construction is ongoing or planned. Data source: Petersen-Perlman (2014), based on the United Nations Framework Convention on Climate Change's Clean Development Mechanism projects (http://cdm.unfccc.int), International Rivers Network, and other organizations' websites known to fund or catalogue dam and water diversion construction (e.g., World Bank) • Weighting of Basin-Country Unit (BCU) values based on share of BCU population in basin. Population values are taken from GPW v.3, 2010 projection http://sedac.ciesin.columbia.edu/data/set/gpw-v3-population-density-future-estimates (CIESIN, 2005). • Weighting of BCU scores based on area – the share of BCU area in relation to basin area.

Title:	**Hydropolitical Tension: Risk of Potential Hydropolitical Tensions due to Basin Development in the Absence of Adequate Institutional Capacity**

Computation:

The computation of Hydropolitical Tension indicator scores required following steps of computation at a BCU level:

1. Calculation of the institutional resilience score, which expresses the capacity of each BCU to deal with tensions associated with new dam and water diversion development, by recording five components of formal transboundary cooperation (Table 1). These components are then combined to create the treaty-RBO score. One point is given to a BCU for each treaty and RBO component present in that BCU, resulting in a treaty-RBO resilience score ranging from zero to five. The definitions and data for this step of the computation were obtained from De Stefano et al. (2012) and complemented by data on the existence of additional conflict resolution mechanisms embedded in international RBOs using data from OSU (Schmeier, no date).

Treaty-RBO component	Possible value
At least one water treaty. *A treaty is meant as a formal agreement between sovereign nation-states substantively referring to water as a scarce or consumable resource, a quantity to be managed, or an ecosystem to be improved or maintained (Hamner & Wolf, 1998). Geographic scope must be specific enough to identify that, at minimum, the treaty applies to all waters shared between signatories*	0/1
At least one treaty with an allocation mechanism, *for allocating water for water quantity and/or hydropower uses*	0/1
At least one treaty with a flow variability management mechanism, *for facing flood and/or drought events or other specific variation in flow*	0/1
At least one treaty with a conflict resolution mechanism, *i.e. mechanisms specified to address disagreements between the signatories, including arbitration, diplomatic channels, a commission, third-party involvement, and/or a permanent judicial organ*	0/1
At least one river basin organization, *meant as a bilateral or multilateral body of officials representing participating governments in dialogue about coordinated management of international water bodies.*	0/1
Total possible value for a basin-country unit	**0 to 5**

Table 1

2. The BCU score obtained in step 1 was then grouped into three institutional vulnerability levels for each BCU, with 'low' representing a treaty-RBO score of four or five, 'medium' representing a score of two or three, and 'high' representing a score of zero or one (Table 2).

Treaty-RBO value	Vulnerability score
4, 5	1 – LOW V
2, 3	2 – MED V
0, 1	3 – HIGH V

Table 2

3. The estimate of potential tension due to new water infrastructure development was calculated by gathering information regarding dams (exceeding 10 MW in capacity) and diversion projects diverting quantities greater than 100 000 m^3 that are planned, proposed, or under construction. A number of sources were used to build the dataset: the United Nations Framework Convention on Climate Change's Clean Development Mechanism (http://cdm.unfccc.int), International Rivers Network, the International Commission on Large Dams (ICOLD), and other organizations' websites known to fund infrastructure construction (e.g., World Bank). The analysis also considered that new dams or diversions may bring impacts to BCUs located downstream of that infrastructure. For dams constructed on a river segment that serves as the border between riparian countries, both BCUs received a score indicating the presence of a dam. Ultimately, the BCUs were labeled high hazard if there is a presence or they are downstream of a presence of a water infrastructure development project, and low hazard if there is no presence of such developments (Table 3).

Title:	Hydropolitical Tension: Risk of Potential Hydropolitical Tensions due to Basin Development in the Absence of Adequate Institutional Capacity

Computation:

Water Developments (Large Dam and Water Diversion Projects)	Score ("hazard")
No presence (in the BCU or upstream of it)	1 - LOW
Presence (in the BCU or upstream of it)	3 - HIGH

Table 3

4. The vulnerability values obtained in step 2 were multiplied by the hazard values calculated in step 3 as shown in Table 4.

Vuln↓/ Haz→	1 - LOW	3 - HIGH
1 (low V)	1	3
2 (med V)	2	6
3 (high V)	3	9

Table 4

5. The values obtained in step 4 were grouped into 5 categories (Table 5). The resulting values represent the **risk of potential hydropolitical tensions due to basin development in absence of institutional capacity at a BCU level**.

Risk scores from Table 4	Risk categories
1	1 –Very low risk
2	2
3	3
6	4
9	5 – Very high risk

Table 5

6. To obtain aggregated values by basin, a weighted BCU score was calculated for each BCU by calculating the average of the BCU area and population weighting in basin. The resulting BCU weight is then multiplied by the baseline indicator value (step 5) for each BCU.

7. To obtain a basin indictor score, the values of the respective BCUs were summed.

8. The resulting basin scores were grouped into 5 relative risk categories (Table 6). The resulting basin indicator scores represent the **risk of potential hydropolitical tensions due to basin development in the absence of institutional capacity at a basin level**.

Risk score	Relative risk category
1.00-1.50	1 – Very low risk
1.51-2.50	2
2.51-3.50	3
3.51-4.50	4
4.51-5.00	5 – Very high risk

Table 6

Units:	*Unit-less, relative risk categories*

Title: **Hydropolitical Tension: Risk of Potential Hydropolitical Tensions due to Basin Development in the Absence of Adequate Institutional Capacity**

Risk categorization

Basins with lower scores have lower levels of potential hydropolitical tension due to basin development in the absence of institutional capacity.

Table below presents and overview of the indicator results.

Relative risk category	Basin Risk Score	No. of Basins	Proportion of Basins	No. of BCUs	Proportion of BCUs
1 - Very low	1.00-1.50	40 (0*)	14%	116 (0*)	15%
2 - Low	1.51-2.50	50 (0*)	17%	138 (0*)	17%
3 - Moderate	2.51-3.50	160 (0*)	56%	452 (0*)	57%
4 - High	3.51-4.50	14 (0*)	5%	40 (0*)	5%
5 - Very high	4.51-5.00	22 (0*)	8%	50 (0*)	6%

* Number of basins/BCUs for which results have been calculated, but have a lower level of confidence due to modelling /methodological limitations

Limitations:

The Hydropolitical Tension indicator is based on the identification of key institutional components that are directly related to the management of water variability in transboundary basins. These elements were selected based on the extant literature and also on the availability of data to map them at a global scale (see De Stefano et al., 2012 and Petersen-Perlman (2014) for a detailed justification of the selection). As with any global indicator, however, they represent a simplification of the large number of factors that could have an impact on hydropolitical tensions.

Moreover, this indicator considers only the *existence* of specific institutional components and does not assess the level of implementation or performance of these components in practice.

Dam and diversion project data are based on publicly-available information only. This means that there could be additional water infrastructure projects that were not found during the data search, for which information is not up to date or not publicly available. Also the status of these projects is changing rapidly – some of these projects may have been canceled or completed since the last updates of the respective databases.

Spatial Extent:	Global
Spatial Resolution:	BCU, basin
Year of Publication:	NA
Time Period:	NA

Additional Notes:

Cited references

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Giordano, M.; Drieschova, A.; Duncan, J.A.; Sayama, Y.; De Stefano, L. & A. T. Wolf (2013) A review of the evolution and state of transboundary freshwater treaties

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Schmeier, Susanne (no date): International RBO Database, Transboundary Freshwater Dispute Database (TFDD), Corvallis, OR: Oregon State University

http://www.transboundarywaters.orst.edu/research/RBO/RBO_Database.html, accessed 27 Jul 2014

Date:	01-02-2015
Format:	Excel file
File Name:	TWAP_RB_metadata_Ind_11_HydropolTens.xlsx
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Hydropolitical Tension – Projected

Title:	***Risk of Potential Hydropolitical Tensions due to Basin Development in Absence of Adequate Institutional Capacity – projected scenario***
Indicator Number:	***11 Projected***
Cluster:	***Governance***
Rationale:	The analysis of the history of past conflict and cooperation over water in transboundary basins suggests that some political, socioeconomic and physical circumstances might act as exacerbating factors and increase the risk of hydropolitical tensions due to basin development in the absence of institutional capacity (Wolf et al., 2003). The calculation of the projected scenario for the Hydropolitical Tension Indicator combines the results from the baseline indicator (11) with a set of exacerbating factors.
Links :	GW (results likely to be similar for lakes overlapping with transboundary river basins), Lakes (results likely to be similar for lakes overlapping with transboundary river basins)
Description:	Hazards scores are calculated based on a combination of 6 exacerbating factors (high or increased climate-driven water variability, recent trends in water reserves, risk of internationalization of basins due to presence of intrastate armed conflicts, presence of active international armed conflicts, recent history of non-cooperation over water and level of per capita income). Hazard scores from the exacerbating factors are added to the baseline indicator results to produce a projected indicator value at the BCU level.
Metrics:	• Climate-Driven Water Variability – Coefficient of Variation • Sen's Slope – GRACE satellite. Monthly terrestrial water storage anomalies measurements obtained from the GRACE RL-05 (Swenson and Wahr, 2006; Landerer and Swenson, 2012)which are independent of the actual GRACE data, are used to extrapolate the GRACE TWS estimates from their effective spatial resolution (length scales of a few hundred kilometers dataset from NASA's Tellus website (http://grace.jpl.nasa.gov). • Risk of Internationalization – Minorities at Risk (MAR) Dataset, developed by the Center for International Development and Conflict Management (CIDCM). http://www.cidcm.umd.edu/mar/data.asp • Armed Conflicts – UCDP/PRIO Dataset, developed by the Uppsala Conflict Data Program/International Peace Research Institute. http://www.pcr.uu.se/research/ucdp/datasets/ucdp_prio_armed_conflict_dataset/ • Basins at Risk (BAR) Scale – Recent history of water events. Developed by Oregon State University http://www.transboundarywaters.orst.edu/database/interwatereventdata.html • Gross National Income, GNI per capita, Atlas method (current US$), http://data.worldbank.org/indicator/NY.GNP.PCAP.CD and http://data.un.org/Default.aspx • Weighting of Basin-Country Unit (BCU) values by population. Population values are taken from GPW v.3, 2010 projection. http://sedac.ciesin.columbia.edu/data/set/gpw-v3-population-density-future-estimates (CIESIN, 2005). • Weighting of BCU values by area – GAUL shapefile using World Cylindrical Equal Area projection. http://www.fao.org/geonetwork/srv/en/metadata.show?id=12691

<table>
<tr><th>Title:</th><th>Risk of Potential Hydropolitical Tensions due to Basin Development in Absence of Adequate Institutional Capacity – projected scenario</th></tr>
<tr><td>Computation:</td><td>
The computation of the projected indicator required the following steps to calculate BCU-level scores:
9. Calculation of Climate-driven Water Variability Hazard Score (Change in Coefficient of Variation) – following Vörösmarty et al. (2005), the absolute values for coefficient of variation were grouped into three levels: 'low' (CV < 0.25) 'medium' (0.25 ≤ CV ≤ 0.75) and 'high' (CV > 0.75) variability. The change in the CV from 2000 to 2030 was then calculated. For BCUs where the CV was at the high level (3) in both years, the final water variability hazard score assigned was 1. Where CV was higher in 2030 than in 2000, the final water variability hazard score assigned was also 1. Otherwise, the final water variability hazard score assigned was 0 (Table 1).
<table>
<tr><th>Water variability</th><th>Water Variability Hazard Score</th></tr>
<tr><td>CV: No change (Med or Low) OR decrease</td><td>0</td></tr>
<tr><td>CV: High present & future OR increase</td><td>1</td></tr>
</table>
Table 1
10. Calculation of Sen's Slope Hazard Score[42] (Recent Trends in Water Resource Reserves). The Sen's Slope values range from -0.94 to 0.39. The values were grouped into two classes: stable and positive (>-0.1 to 0.39) and negative (≤-0.1 to -0.94). The threshold for the hazard score is -0.1 as shown in the Table 2.
<table>
<tr><th>Sen's Slope</th><th>Sens Slope Hazard Score</th></tr>
<tr><td>Stable or Positive (>-0.1 to 0.39)</td><td>0</td></tr>
<tr><td>Negative (≤-0.1 to -0.94)</td><td>1</td></tr>
</table>
Table 2
11. Calculation of Minorities at Risk (Risk of Internationalization) – In the CIDCM database, conflicts during the time period of 2004-2006 are recorded and coded by level of severity. All countries with a conflict severity values (FACTSEV1) equal to or greater than 3 were marked as having a MAR score of 1. All BCUs within a country were assigned the same MAR value. All countries with no data were assigned a score of 0 as the MAR value (no conflict) (Table 3).
<table>
<tr><th>FACTSEV1 value</th><th>MAR Hazard Score</th></tr>
<tr><td>< 3</td><td>0</td></tr>
<tr><td>≥ 3</td><td>1</td></tr>
</table>
Table 3
12. Calculation of Armed Conflict / War Hazard Score – Within the UCDP/PRIO Armed Conflict Dataset, incidents were selected that occurred between years 2000 and 2013, and where both sides of the conflict included a government, either in a primary or secondary (supporting) role (SideA or SideA2nd and SideB or SideB2nd). All intensity levels (Int) were included. The War Hazard scores were assigned as per Table 4.
<table>
<tr><th>Armed Conflict 2000 to 2013 (UCDP/PRIO Dataset)</th><th>War Hazard Score</th></tr>
<tr><td>No occurrence</td><td>0</td></tr>
<tr><td>Occurrence</td><td>1</td></tr>
</table>
Table 4
13. Calculation of Basins at Risk (BAR) Hazard Score – The BAR average value was calculated for all events occurring between 2000 and 2008 in each BCU. Negative average values were given a BAR Hazard score of 1. Averages of 0 or greater were given a score of 0 (Table 5).
<table>
<tr><th>BAR scale Average (2000-2008 period)</th><th>BAR Hazard Score</th></tr>
<tr><td>≥ 0</td><td>0</td></tr>
<tr><td>< 0</td><td>1</td></tr>
</table>
Table 5
</td></tr>
</table>

42. Sens Slope values are calculated from GRACE satellite data, which provide an eleven-year record of monthly terrestrial water storage anomalies, changes in the vertical sum of water stored as snow, surface, soil and groundwater.

Title:	***Risk of Potential Hydropolitical Tensions due to Basin Development in Absence of Adequate Institutional Capacity – projected scenario***

Computation:

14. Calculation of Gross National Income Hazard Score – GNI for each country was calculated as an average of the five most recent years in the dataset: 2008-2012. The variable used was GNI per capita, Atlas method (current US$). Countries with GNI per capita greater than $1 035 were given a GNI Hazard score of 0. Countries below the threshold were given a score of 1 (Table 6).

GNI per capita, Atlas method (2008-2012 Average, current US$)	GNI Hazard Score
≥ 1 035 $	0
< 1 035 $	1

Table 6

15. The resulting six exacerbating factor hazard scores were added together. The sum was then used to convert the baseline indicator values (Hydropolitical Tension Indicator no. 11) to projected risk values based on Table 7. The final values range from 1 to 5, and Projected Risk Values higher than 5 are considered equal to 5.

Sum of Exacerbating Factors by BCU	Effect on BASELINE RISK INDICATOR score of a BCU		Projected Risk Value
0	Baseline Risk doesn't change		1 Low Risk
1			2 - Low Risk
2	+1 to Baseline Risk	=	3 - Moderate Risk
3			4 - High Risk
4	+2 to Baseline Risk		5 - High Risk
5			* Final Risk Values > 5 are considered equal to 5
6			

Table 7

16. To obtain basin scores, a weighted score was calculated for each BCU of the basin by taking an average of the area ratio and the population ratio (BCU area/population weight within basin). This BCU weight (in basin) was then multiplied by the projected indicator value for each BCU.

17. The basin score was calculated as the sum of the resulting BCU values for the respective basin.

18. The resulting basin scores were regrouped into 5 relative risk categories (Table 8). The resulting values represent the risk of potential hydropolitical tensions due to basin development in the absence of institutional capacity at a basin level.

Weighted Basin Risk Score	Relative Risk category
1.00-1.50	1 – Very Low Risk
1.51-2.50	2 - Low Risk
2.51-3.50	3 - Moderate Risk
3.51-4.50	4 - High Risk
4.51-5.00	5 – Very High Risk

Table 8

Units: Unit-less, risk categories

Title:	***Risk of Potential Hydropolitical Tensions due to Basin Development in Absence of Adequate Institutional Capacity – projected scenario***
Risk categorization	Basins with lower scores have lower levels of risk of potential hydropolitical tension due to basin development in the absence of institutional capacity (see table below) * Number of basins/BCUs for which results have been calculated, but bear a lower level of confidence due to modelling /methodological limitations in climate change projections for future water variability.
Limitations:	As with any global indicator, the factors considered to potentially exacerbate risk of transboundary tensions certainly represent a simplification of the large number of factors that could have an impact on international relationships over water. For example, issues such water quality degradation or inter-sectorial conflict between water uses (e.g. hydropower generation vs agriculture) are other important factors that contribute to strain transboundary relationships and that are outside the scope of this indicator. The indicator is based on the assumption that institutional capacity in the future will be as it is at present, as there is no way of foreseeing how it will evolve. However, the negotiation and signature of new treaties is often a process that can take several years, so it can be assumed that the institutional context will not change drastically within the next 15 years. For two of the exacerbating factors (risk of internationalization of basins expressed by the presence of minorities involved in armed conflicts and conflict/cooperation over water) there could be situations of conflict or cooperation that occurred after the last update of the datasets used in the analysis.
Spatial Extent:	Global
Spatial Resolution:	BCU, basin
Year of Publication:	NA
Time Period:	NA
Additional Notes:	For data sources see 'Metrics' Cited Literature: Landerer, F. W., and S. C. Swenson (2012), Accuracy of scaled GRACE terrestrial water storage estimates, Water Resour. Res., 48(4), W04531, doi:10.1029/2011wr011453. Swenson, S., and J. Wahr (2006), Post-processing removal of correlated errors in GRACE data, Geophys. Res. Lett., 33(8), L08402, doi:10.1029/2005gl025285. Vörösmarty, Charles J; Ellen M Douglas, Pamela A Green & Carmen Revenga (2005) Geospatial indicators of emerging water stress: An application to Africa. Ambio 34(3):230(3):4 Wolf, A. T., Yoffe, S. B., and Giordano, M. 2003. International waters: identifying basins at risk. Water Policy. 5 (1): 29-60.
Date:	01.02.2015.
Format:	Excel file
File Name:	TWAP_RB_metadata_Ind_11_HydropolTens_Projected .xlsx
Contact person:	Lucia De Stefano and James Eynard, Oregon State University
Contact details:	luciads@geo.ucm.es; jimeynard@gmail.com

Relative risk category	Weighted Basin Risk Score	No. of Basins	Proportion of Basins	No. of BCUs	Proportion of BCUs
1 - Very low	1.00-1.50	37 (0*)	13%	107 (29*)	13.4%
2 - Low	1.51-2.50	44 (0*)	15%	129 (53*)	16.2%
3 - Moderate	2.51-3.50	153 (0*)	54%	400 (243*)	50.3%
4 - High	3.51-4.50	28 (0*)	10%	104 (36*)	13.1%
5 - Very high	4.51-5.00	24 (0*)	8%	56 (29*)	7.0%

Enabling Environment

Title:	*Enabling Environment*
Indicator Number:	***12***
Thematic Group:	***Governance***
Rationale:	Legal Framework (Indicator number 10) and Hydropolitical Tension (Indicator number 11) indicators focus on governance at the transboundary scale, but it is also important to look at governance at the national scale for countries within each transboundary basin. This indicator considers the development of an 'Enabling Environment' for water resources management in each riparian country. This is based on a broad spectrum of issues including the policy, planning and legal framework, governance and institutional frameworks, and management instruments. The final results of the indicator show the status of development of an enabling environment in BCUs and Basins, aggregated based on national-level information received from countries.
Links :	GW (indication of the likelihood of sustainable abstraction levels from aquifers), Lakes (results likely to be similar for lakes overlapping with transboundary river basins), LMEs (may be overlap of jurisdictions between river basins and LMEs)
Description:	This indicator considers the level of development and implementation of an 'enabling environment' for water resource management in each riparian country. Enabling environment in this context refers to the national (or subnational/basin) level policies, plans, legal and institutional frameworks and management instruments required for effective water resource management, development and use. A well-designed and implemented enabling environment ensures that the framework is in place to facilitate involvement of stakeholders (at all levels - community, national, private sector) in water management, and considers the needs of the different users, including the environment. This indicator builds on monitoring work to measure progress on "the application of integrated approaches to the development, management and use of water resources" as called for in Agenda 21 of the 1992 'Earth Summit' (UNCED 1992). The underlying data for this indicator builds on the survey undertaken for the 2012 UN Water Status Report on the Application of Integrated Approaches to Water Resources Management (UNEP 2012). Results show the development of the enabling environment for each basin country unit (BCU). A weighted 'importance' of each BCU to the basin based on the share of population and area is used to produce weighted BCU scores. The sum of the weighted BCU scores is used to aggregate basin score.
Metrics:	The majority of the data for this indicator come from a survey undertaken during 2011 involving all 192 UN member states at that time. 133 country responses were received to the survey. For the purposes of TWAP RB, additional responses were collected from 15 countries in 2013, using in-country experts (with assistance from GWP and OSU) to fill identical survey questionnaires. Status of development of the 'enabling environment' was assessed based on the following factors (numbers in brackets refer to question numbers in the original questionnaire): 1. Water resources policy, laws, and plans (1.1.1) 2. Institutional frameworks (2.1.1) 3. Stakeholder participation (2.1.2) 4. Capacity building (2.1.3) 5. Water resource assessment and development guidelines (3.1.1) 6. Water resource management programmes (3.1.2) 7. Monitoring and information management (3.1.3) 8. Knowledge sharing (3.1.4) 9. Financing of water resource management (3.1.5) The status of enabling environment in the country questionnaires take 2011 as the reference year.

Title:	***Enabling Environment***

Computation:

Computation of indicator scores was done in following steps:

1. Assigning scores to each BCU based on the average scores of the national response for each of the 9 metrics (calculated from a number of sub-questions under each question from the country surveys).

Status	Score
Not relevant	1
Under development	2
Developed, but implementation not yet started,	3
Implementation started	4
Implementation advanced	5
Fully implemented	6

2. Calculating the average score considering all 9 metrics for each BCU, but removing any responses given as 'not relevant' (response of 1), to give a single value for each BCU. All 9 metrics were weighted equally.

3. Calculating the 'importance' of each BCU within basin based on the proportion of population and area that the respective BCU represents compared to the basin. The sum of the BCU relative importance values within basin is 1.

4. Multiplying average score ('2') by relative importance ('3') to get a weighted score for each BCU.
5. Add these scores to obtain a total score for the basin*.

* Basins with responses for more than 80% coverage of the basin (based on area or population represented by the BCU responses), were considered to have sufficient information to generate basin scores and results categories, resulting in indicator score coverage for 230 basins.

Units: Unit-less

Scoring system:

Table below shows distribution of basins and BCUs across risk categories.

For the 230 transboundary basins (and corresponding BCUs) assessed, the risk categories were assigned as above resulting in the following number of basins/BCUs in each category:

Relative risk category	Range (normalized scrore)	No. of Basins	Proportion of Basins	No. of BCUs	Proportion of BCUs
1 - Very low	5.01–6	29 (1*)	13%	110 (29*)	16%
2 - Low	4.01–5	84 (4*)	36%	212 (53*)	32%
3 - Moderate	3.01–4	66 (7*)	29%	162 (243*)	24%
4 - High	2.71–3	25 (1*)	11%	106 (36*)	16%
5 - Very high	<=2.7	26 (5*)	11%	84 (29*)	12%

* Number of basins in brackets, indicates number of basins that did not have 100% of area and population coverage based on BCU data, but for which scores were generated based on 80% - 99% coverage (deemed sufficient for purposes of this assessment).

The relative risk categories are mainly based on the original survey (see original scoring table under 'Computation' section).

Basins and BCUs in the relative risk categories 4 and 5 represent enabling environments for IWRM that are generally still under development, but implementation has not yet started.

Category 3 represents enabling environments that have been developed, and some implementation has begun.

The lowest relative risk categories 1 and 2 represent more advanced enabling environments, where implementation is advanced or fully completed.

Title:	*Enabling Environment*
Limitations:	- The indicator is based on approximately 60 sub-questions from the original survey questionnaire. This breadth of questions is seen as a strength, making it a more robust assessment (compared, for example, to merely looking at the existence of policies, laws and plans). Averaging of 60 sub-questions does however make it difficult to know which 'aspects' of the enabling environment are more or less developed in each country (or which are more relevant than others), and therefore which may require further development. - For the purposes of TWAP RB assessment, the nine sub-question groups from the survey are averaged and weighted equally to create a single BCU score, since all aspects are deemed equally relevant to achieving full implementation of the 'enabling environment'. Any potential weighting of the question groups would depend on the priorities of the country. - The data is based on subjective views in response to a questionnaire.
Spatial Extent:	Global
Spatial Resolution:	BCUs and Basins
Year of Publication:	2012
Time Period:	2011
Additional Notes:	
Date:	01.04.2015
Format:	Microsoft Excel Worksheet
File Name:	TWAP_RB_indicator_11_results.xlsx
Contact person:	Maija Bertule
Contact details:	UNEP-DHI, mabe@dhigroup.com

Annex IX-5: Socioeconomics

Economic Dependence on Water Resources

Title:	***Economic Dependence on Water Resources***
Indicator Number:	***13***
Thematic Group:	***Socioeconomics***
Rationale:	Withdrawal from water systems is often related to human activities aimed at supporting /enabling production activities to sustain economic growth (Grey 2006), for example freshwater is often abstracted to provide for irrigated agriculture as well as domestic and industrial needs. Understanding the degree to which economic activity is concentrated in given basins, and therefore the level of dependence on freshwater resources within basins, will help to illuminate the risk to economies within a basin should water supplies be substantially altered. This same metric can also help to assess the level of human pressure on water resources.
Links :	Water consumption associated with economic activities that underpin growth and contribute to GDP may be associated with impacts on water resources and an upstream- downstream complex of problems. Outtakes from a river system in terms of quantity will impact linked water systems as a result of less water flowing into connected systems. Water consumption for production activities could also give rise to other negative impacts (Barua 2009) associated with consequences of production such as harmful discharges and altered sedimentation levels.
Description:	The economic dependence indicator measures the degree to which economies are dependent on the water resources of transboundary basins. This is assessed through a weighted average of the economic activity of each BCU compared to the rest of the respective country. A complete valuation of ecosystem services represented by the water resources in all basins included in this assessment is not possible, but this indicator is a useful proxy. This indicator is composed of the following sub-indicators: • Urban activity fraction: a measure of urban economic activity, including domestic, commercial and industrial; • Agricultural activity fraction: a measure of irrigation activity.
Metrics:	**For the urban activity fraction** sub-indicator, we used night-time lights (NTL) data from the Defence Meteorological Satellite Program-Optical Line Scanner (DMSP-OLS). These data are commonly used for identifying human settlements and economic activity (at least urban and industrial activity). Night-time lights radiance data were summed by BCU and by country, and the BCU total was divided by the country total to get an urban activity fraction per BCU. The BCU results were then aggregated to the basin level by taking the weighted average of the BCUs, with weights based on an average of the proportional share of population and land area in each BCU, compared to the basin total. This is a measure of the urban economic dependence of the countries that share a basin on the water resources within that basin. **For the agricultural activity fraction sub-indicator**, we used water withdrawal data for irrigation from the WaterGAP 2.2 model (Müller Schmied et al. 2014). We applied an identical process to the urban activity fraction, calculating the fraction of irrigation water withdrawal for each BCU compared to the respective country totals, and then calculating the weighted average of BCU scores to develop a basin score. Because of WaterGAP grid cell resolution, 158 BCUs out of 796 did not have the agricultural activity fraction sub-indicator.
Computation:	The urban and agricultural activity fractions were somewhat correlated (Pearson's $r = 0.36$, $p<001$), so we averaged the two together to create an overall economic dependency measure. BCUs without the agricultural activity fraction are based entirely on the urban activity fraction. Fractions were then converted to the five risk categories based on expert opinion as shown in the Table below
Units:	(1) Digital numbers and (2) m^3/year

Title:	*Economic Dependence on Water Resources*

Scoring system:

The table below shows distribution of basins and BCUs across risk categories.

All data were heavily left-skewed, with long tails to the right.

The indicators were log-transformed, the tails were trimmed at 2.5% and 97.5% of the distribution, and the indicators were transformed to z-scores and added together without weights. The z-score was then transformed to a percentile. The top 10% countries with the highest dependency (fractions of economic activity and withdrawals) were considered to be the highest risk category 5 (28 basins), followed by the next 10% in category 4 (28 basins), 30% in category 3 (83 basins), 40% in category 2 (110 basins), and 10% in category 1 (28 basins).

Relative risk category	Weighted Basin Risk Score	No. of Basins	Proportion of Basins	No. of BCUs	Proportion of BCUs
1 - Very low	0–0.1	170	59%	569	71%
2 - Low	0.1–0.2	35	12%	51	6%
3 - Moderate	0.2–0.4	39	14%	61	8%
4 - High	0.4–0.6	28	10%	53	7%
5 - Very high	0.6–1.0	24	5%	62	8%

* Number of basins/BCUs with lower degree of scientific confidence. See more under Limitations section.

Limitations:

This indicator would benefit from looking at the patterns of dependence between the riparian countries within the individual BCUs. Currently, large countries with a very small proportion the basin land area, population, and river flow bias the results, Because the vast majority of their economic activity is outside the basin, it tends to bring the fractions of overall economic activity within the basin down significantly. The best way to address this is to calculate the fraction of economic activity occurring within each BCU, and then to aggregate the BCU fractions as a weighted average based on an average of the proportion of the basin land area, population, and river flow.

A total of 158 BCUs (out of 796) did not have the agricultural activity fraction sub-indicator. In these cases the BCU score was entirely based on the urban activity fraction sub-indicator. This is owing to the grid cell resolution of the WaterGAP 2.2 data (0.5°), which prevented reporting of results for the smallest BCUs (i.e. those which could not have a 0.5° grid cell assigned to them in the hydrological model). A further 343 BCUs are assigned between 1 and 9 grid cells, and hence are considered to have a lower degree of scientific confidence than those with 10 or more. However, these 501 BCUs account for approximately 1% of total BCU area, thus the overall interpretation of results at the global level is valid.

For the economic activity fraction sub-indicator, the analysis is limited mainly by the assumptions regarding the relationship between night-time lights, economic activity, and water withdrawals. It is assumed that this indicator most closely tracks with domestic and industrial withdrawals. Statistical analyses showed that this indicator was highly correlated with results processed in an analogous manner for energy withdrawals and industrial withdrawals based on the WaterGAP 2.2 model. Thus there would appear to be moderate levels of confidence in these results.

Spatial Extent:	Global
Spatial Resolution:	(1) 30 arc seconds, (2, 3, 4) 0.5 decimal degrees
Year of Publication:	2013
Time Period:	(1) 2010, (2, 3, 4) average annual for 1970-2000
Additional Notes:	
Date:	01.04.2015
Format:	Microsoft Excel Worksheet
File Name:	TWAP_RB_indicator_13_results.xlsx
Contact person:	(1) Chris Elvidge, (2) Christof Schneider
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Societal Wellbeing

Title:	***Societal Wellbeing***
Indicator Number	***14***
Cluster:	***Socioeconomic***
Rationale:	Low levels of socioeconomic development and human wellbeing put populations at higher risk from low and high flow extremes, and from water pollution. This indicator is composed of five sub-indicators, so the rationale for each is described in turn. (1) Access to improved drinking-water supply will indicate the efficiency of the basin's water governance structure. It will also be an indication of the population health since a lack of improved drinking-water often lead to an increase in water-related diseases such as cholera and diarrhoea. Access to improved drinking water can also provide economic benefits if less time is spent on securing household water supply. Access to improved water supply is of high global importance, as manifested by the global community in the Millennium Development Goal 7. (2) Access to improved sanitation will be an indication of population health since a lack of improved sanitation often leads to an increase in water-related diseases such as cholera and diarrhoea. There are also economic aspects to consider since the diseases related to poor sanitation prevent people from working. Access to improved sanitation is of high global importance, as manifested by the global community in the Millennium Development Goal 7. (3) Adult literacy will indicate the level of education in the basin and provide an indication of the knowledge capacity to deal with issues in the basin. An educated population can more easily take on the development challenges it faces, such as ensuring environmental sustainability, increasing productivity and empowering women and creating gender equality. (4) Infant mortality rates (IMRs) serve as a useful proxy for overall poverty levels because they are highly correlated with many poverty-related metrics such as income, education levels and health status (de Sherbinin 2008). Low IMRs are an indication of a society where the population has access to nutritious food and healthcare, whereas high IMRs are a sign of low levels of economic development. Where IMRs are highest one would expect that fluctuations in water levels or growing water stress will have a detrimental impact on human wellbeing. Infant mortality is one of many parameters related to environmental health concerns and the health care service available to the population and this follows administrative borders. The indicator can therefore be relevant for other water systems within the same administrative borders. (5) Gini coefficients represent the level of inequality in a basin. Societal inequality is an important dimension of welfare, and indicates likely levels of participation in governance, representation in public authorities, and capacity for sound environmental management, where conflicts may occur between welfare needs and environmental concerns. Gross inequality may lead to social or political unrest, which puts at risk efforts to create healthy, educated societies resilient to pressures on their water resources. The potential impacts related to economic inequalities within political units affect water systems with little differentiation with regard to type of water system. Thus the problems related to poor wealth distribution will potentially add to existing problems within basins and existing links between water systems.
Links :	(1, 2) The governance systems for improved drinking-water supply are not limited to river basins, but follow administrative borders. The indicator can therefore be relevant for other water systems within the same administrative borders. (3) Adult literacy is dependent on the level of education available and this follows administrative borders. The indicator can therefore be relevant for other water systems within the same administrative borders. (4) Life expectancy is one of many parameters related to the health care service available to the population and this follows administrative borders. The indicator can therefore be relevant for other water systems within the same administrative borders. (5) The potential impacts related to economic inequalities within political units affect water systems with little differentiation with regard to type of water system. Thus the problems related to poor wealth distribution will potentially add to existing problems within basins and existing links between water systems.

Title:	***Societal Wellbeing***
Description:	(1) Percentage of population using an improved drinking-water source. Improved drinking-water sources include; piped water into dwellings, piped water to yards/plots, public taps or standpipes, tubewells or boreholes, protected dug wells, protected springs, rainwater. (Definition for improved drinking water is taken from the JMP, and further information can be found at http://www.wssinfo.org/ definitions /infrastructure.html). (2) The definition of this indicator is the proportion of the population with improved sanitation. According to the Joint Monitoring Programme of the WHO and UNICEF, improved drinking-water sources include: flush toilets, piped sewer systems, septic tanks, flush/pour flush to pit latrines, ventilated improved pit latrines, pit latrines with slab, and composting toilets. The data sets used for this indicator include the percentage of a country's rural and urban populations with access to improved drinking water (updated 2010). (3) The definition of the indicator is the proportion of the population aged 15 or above that can both read and write a short simple statement on their everyday life. The definition is taken from the UNDP Human Development Report (HDR) indicator on adult literacy. (4) Infant mortality rates at a subnational level were compiled from a number of sources, including country vital statistics, Demographic and Health Surveys, and Multiple Indicator Cluster Surveys. The subnational rates were adjusted to correspond to 2008 national-level IMRs published by UNICEF. The data were gridded at 5 arc-minute resolution. (5) The Gini index is an estimate of inequality. It measures the extent to which the distribution of income (or, in some cases, consumption expenditure) between individuals or households within an economy deviates from a perfectly equal distribution. A Gini index score of zero implies perfect equality while a score of 100 implies perfect inequality (World Development Indicators Online. World Bank, 2009).
Metrics:	(1, 2) These sub-indicators were calculated using data from the WHO / UNICEF Joint Monitoring Programme (JMP) for Water Supply and Sanitation (WSSinfo.org) (downloaded June 2013). (3) The data were obtained from the UNESCO Institute for Statistics (2012) and represent 2010 for almost all countries. (4) For this indicator we used CIESIN's gridded IMR data (CIESIN 2005) but updated for 2008, which is a compilation of subnational data. (5) Gini coefficients were obtained for each country from the World Bank World Development Indicators. Because Gini coefficients are not calculated for all countries in all years, we used data ranging from 2000 to 2010. All data is collected at national level, and data are not typically reported by urban/rural breakdown.
Computation:	(1, 2) The computation steps were as follows: 1. Utilize CIESIN's Global Rural-Urban Mapping Project (GRUMP) urban/rural population grid to identify the proportion of the population that is urban and rural in each BCU. 2. Multiply '1' by the urban/rural percentage improved drinking-water supply coverage to obtain an average percentage of population with improved drinking-water supply per BCU. 3. Aggregate to basin level with weighting based on size of population in each BCU. The result is a measure of the average percentage of the population with access to improved drinking water supply in each basin. (3) All data is collected at national level, and data are not typically reported by urban/rural breakdown. To calculate this indicator, we used population count data from the GRUMP data set, and calculated the proportion of the basin population in each BCU. We used the proportion of the population in the basin to create a basIn-level weighted average of the national-level literacy rates for each riparian country. (4) IMRs are measured as the number of deaths per 1 000 live births among 0-1 year olds. We used the gridded IMR data set and simply averaged the IMR for each basin using zonal statistics in ArcGIS 10.1. (5) To calculate this indicator, we used population count data from the GRUMP data set, and calculated the proportion of the basin population in each BCU. We used the proportion of the population in the basin to create a basin-level weighted average of the national-level Gini coefficients for each riparian country.
Data Source/provider:	(1, 2) WHO / UNICEF Joint Monitoring Programme (JMP) for Water Supply and Sanitation, (3) UNESCO, (4) DHS, MICS, and country vital statistics, (5) World Bank World Development Indicators

Title:	***Societal Wellbeing***
Spatial Extent:	Global
Spatial Resolution:	Country level
Year of Publication:	2013
Time Period:	2010-11 for most countries
Unit:	(1, 2, 3) Percentage, (4) deaths per 1,000 live births, (5) Gini coefficient ranging from 0 (low inequality) to 100 (high inequality)
Risk categorization	Risk categories were defined by the following distribution: Risk categories 1, 2 and 5 include 10% of all basins (28 basins in each category), whereas risk category 3 includes 30% of all basins (83 basins), and risk category 4 includes 40% of all basins (110 basins). Raw values for the untransformed data varied across the different indicators. As an example, the highest risk category (category 5) had 9-65% coverage for access to improved water sources, and Infant Mortality rates of between 20 and 133 deaths per 1 000 live births.
Additional Notes:	
Date:	24 Aug. 2013
Format:	Excel
File Name:	multiple
Contact person:	Alex de Sherbinin
Contact details:	CIESIN, Columbia University, PO Box 1000, Palisades NY 10964, Tel. +1-845-365-8936, adesherbinin@ciesin.columbia.edu

Exposure to Floods and Droughts

Title:	***Exposure to floods and droughts (Vulnerability to Climate-related Natural Disasters)***
Indicator Number:	***15***
Cluster:	***Socioeconomics***
Rationale:	Floods and droughts cause the greatest loss of life and economic losses of all natural disasters each year, and the likelihood and severity of floods and droughts is likely to increase with climate change. Impacts of floods and droughts are felt by humans and ecosystems, and include impacts on food security, damage to infrastructure, and displacement of people. Global analyses have been undertaken by CIESIN in 2005 (Dilley, et al., 2005) and the UNEP Global Assessment Report in 2009 and 2013. Hydrological variability induced by climate change will affect flow patterns in river systems. The risk of droughts and floods will increase, affecting both quantity and quality of water being transported through water systems. Potential human efforts to mitigate climate change effects by constructions on river systems will probably further impact downstream areas. This indicator is composed of two sub-indicators: (1) Coefficient of variation of monthly river discharge. The rationale for this indicator is that high variability in discharge signifies greater exposure to climate extremes, and particularly drought. (2) Aggregated economic exposure (in US dollars) to flood hazards divided by basin area. The rationale for this indicator is that flood hazards take a significant economic toll on economies, sometimes setting back development progress by a decade or more (Solomon et al. 2013).
Links :	Hydrological variability induced by climate change will affect flow patterns in river systems. The risk of droughts and floods will increase, affecting both quantity and quality of water being transported through water systems. Potential human efforts to mitigate climate change effects by constructions on river systems will probably further impact downstream areas.
Description:	(1) For each grid cell in the WaterGap 2.2. model, the mean, maximum and minimum, standard deviation, variance, and coefficient of variation (CV) of runoff was calculated. The statistical parameters were calculated from monthly discharge data for the climate normal period 1971-2000. The coefficient of variation (CV) is defined as the ratio of the standard deviation to the mean. Higher CVs imply greater variation in flows. (2) Data on Economic Exposure to Floods from the UNEP Global Assessment Report for 2013 provide the economic exposure in US Dollars for major rivers in each basin.
Metrics:	(1) See above. (2) Data on economical exposition to flood were obtained from UNEP PREVIEW (http://preview.grid.unep.ch/).
Computation:	(1) This indicator was calculated using data processed by Christof Schneider of the University of Kassel using the WaterGap 2.2 model. Using the CV of flow as calculated by Christof, CIESIN averaged the CV over each basin. The result is a measure of the flow variability, and therefore the dependability of flow for human activities. A total of 276 basins are included in this analysis. (2) The gridded data representing economic exposure were summed by basin and divided by river basin area to come up with a measure of total economic exposure per basin area.
Data Source/provider:	(1) Center for Environmental Systems Research (CESR), computations for basin averages by CIESIN, and UNEP PREVIEW (http://preview.grid.unep.ch/).
Spatial Extent:	Global
Spatial Resolution:	(1) 0.5° by 0.5° grid cell raster, (2) ??
Year of Publication:	(1) 2013, (2) 2011
Time Period:	(1) 1971-2000, (2) 2011
Unit:	(1) Coefficient of variation, (2) US Dollars per sq. km.
Additional Notes:	
Date:	24 Aug. 13
Format:	
File Name:	

Title:	***Exposure to floods and droughts (Vulnerability to Climate-related Natural Disasters)***
Contact person:	(1) Christof Schneider, (2) Pascal Peduzzi
Contact details:	(1) Center for Environmental Systems Research, Kurt-Wolters-Str.3, 34109 Kassel schneider@usf.uni-kassel.de, Phone: +49.561.804.6128, (2) UNEP/DEWA/GRID-Europe, 11, ch. des Anémones, Châtelaine, Genève, CH-1219, Switzerland, Phone: (+41 22) 917 82 37 & Fax: +41 22 917 8029

Annex IX-6: Water Systems Links

Lake Influence Indicator

Title:	*Lake Influence Indicator*
Indicator Number:	*17*
Thematic Group:	*Water System Links*
Rationale:	The Lake Influence Indicator is a link between the River Basins component and the Lake Basins component of the TWAP project. The main objective of the indicator is to provide information about the buffering and storage capacity of lakes within transboundary river basins. In contrast to the flowing waters of rivers, lakes store water and release it slowly or when required. Hence, managed or unmanaged levels of lake storage provide flood protection and alleviate water shortages for residential, commercial, industrial and agricultural uses downstream. Furthermore, lakes influence water quality, including the dynamics of pollutants and nutrients in the water column. For example, because of their large water volumes and long water-residence times, the natural buffering capacity of lakes can neutralize or otherwise remove pollutants entering them. At a certain point, however, the buffering capacity of a lake can be exhausted or overwhelmed, with the lake subsequently becoming a source of pollution for downstream rivers until the pollutants contained in it are flushed out or otherwise neutralized.
Links :	*Lakes: Lakes and rivers are strongly interrelated. The buffering capacity of lakes affects water quantity and quality issues within a river basin.*
Description:	Storage capacity of all lakes in a river basin divided by annual water availability in the river basin.

Metrics:	• Data on lake storage capacity has been collected from different available data sources (Global Lake Database, Global Lake and River Ice Phenology Database, World Lake Database, Lake Model FLake, Wikipedia and single papers/ studies). Where data for lake volume were not available, the estimated volume was computed by means of lake area and mean depth (Lake volume V = Lake Area A * Lake mean depth d). Where no information on lake volume and/or depth was available, lake volume was estimated according to Ryanzhin (2005). All lakes of the Global Lakes and Wetland Database Level 1 (GLWD1) are considered in the calculation of this indicator. Thereby, for the purpose of this indicator, no distinction was made between natural and dammed lakes.
	
	• Mean annual renewable water availability (taking into account human impacts such as water use and dam management) for the time period 1971-2000 computed by CESR at 30 min. grid using the Global Hydrology model WaterGAP2.2 (Müller Schmied et al. 2014). The meteorological data from WATCH (WFD, Weedon et al. 2011) were used to drive the model. Water consumption, which is subtracted from the natural water availability, was calculated by the Global Water Use sub-models of WaterGAP2.2, made up of:
	  • Domestic demand (Flörke et al. 2013);
	  • Thermal electricity production (Flörke et al. 2013);
	  • Manufacturing industry demand (Flörke et al. 2013);
	  • Agricultural demand (Alcamo et al. 2003, aus der Beek et al. 2010, Döll and Siebert 2002); and
	  • Area equipped for irrigation (GMIAv5, Siebert et al. 2013).

Computation:	Steps for calculation of the indicator: 1. Storage capacity of all lakes determined 2. Storage capacity of all lakes within the same river basin summed 3. Mean annual renewable water availability (including human impacts such as water consumption and dam management) calculated per river basin 4. Storage capacity of all lakes within the basin (2.) divided by mean annual water availability in the basin (3.)
Units:	[%], i.e. the percentage of annual river discharge that can be stored in the available lakes within a river basin
Scoring system:	No risk categorization is applied for this indicator as the indicator provides additional information to the selected indicators in TWAP RB. It shows the buffering capacity of lakes within each transboundary river basin – information which needs to be related to the water quantity and quality conditions in the river basin for further interpretation.

Title:	***Lake Influence Indicator***
Limitations:	Values for storage capacity (or mean depth) are not available in the literature/ datasets for all lakes, so that storage capacity needed to be estimated for some of the lakes according to Ryanzhin (2005). There is no boundary condition for defining an acceptable vs. unacceptable storage volume since it relates to either lake or river condition (e.g. water quality parameters or water scarcity).
Spatial Extent:	Global (for all transboundary river basins)
Spatial Resolution:	Lakes and Wetlands Database Level 1 (GLWD1) Hydrology and water use at 0.5° grid cells
Year of Publication:	GLWD (Lehner & Döll, 2004) WaterGAP2.2 (Müller Schmied et al. 2014)
Time Period:	1971-2000
Additional Notes:	
Date:	27.01.2015
Format:	Microsoft Excel Worksheet
File Name:	TWAP_RB_indicator_17_results.xlsx
Contact person:	Christof Schneider
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Delta Vulnerability: Relative sea level rise

Title:	***Relative sea level rise indicator***
Indicator Number:	***18***
Cluster:	***Deltas***
Rationale:	Many deltas are threatened by relative sea level rise (RSLR), which is basically determined by the balance between: (1) delta aggradation, (2) land subsidence and (3) sea-level rise.
Links :	Relevant to TWAP lakes (delta aggradation being affected by reservoirs), groundwater (land subsidence can be caused by over-abstraction from coastal aquifers), and LMEs and open ocean (sea-level rise).
Description:	The RSLR indicator is based on the total sinking rate of the delta surface relative to the local mean sea level in mm/year. This involves (1) delta aggradation, (2) land subsidence and (3) sea-level rise. Delta aggradation is caused by fluvial sediment supply, but may be strongly influenced by human flood protection infrastructure inhibiting the distribution of sediments over the delta surface. Land subsidence results from various processes, some of which are natural (e.g., tectonic and isostatic movements, sediment compaction), whereas others are highly human-influenced, being a result of drainage activities or subsurface mining. Sea-level rise is a world-wide process, but nevertheless spatially variable because of varying gravimetric effects. The RSLR indicator is based on the total sinking rate of the delta surface (caused by the three components mentioned above) relative to the local mean sea level in mm/year.
Metrics:	
Computation:	For the TWAP assessment, aggradation, subsidence and sea level rise is assessed for each delta from published data (Syvitski et al 2009 and Ericson et al 2006). Based on the available quantitative data, each delta is assigned to one of five relative sea level rise (RSLR) categories, largely following Ericson (2006), with category 1 representing no RSLR (<= 0 mm/yr) and category 5 representing high RSLR (>5 mm/yr).
Units:	Dimensionless scale
Scoring system:	Point scale: 1 - 5
Limitations:	In the RSLR assessment, it is not possible to separately quantify the various components of aggradation, land subsidence and regional sea level rise. Intra-delta spatial variability, which in many cases is high, is not taken into account; the ranges provided cover either different times or different areas of a delta (Syvitski, 2009). Ericson states that the estimation of accelerated subsidence is problematic due to spatial and temporal variations based on the location and intensity of the human activities causing the acceleration (Ericson, 2006). Ericson notes that, in the absence of reliable data, a factor of three times the natural subsidence rate is applied to define the upper limit of the potential accelerated subsidence based on the assumption that accelerated subsidence is a direct result of the magnitude of anthropogenic influence on delta sediment (Ericson, 2006). Coastal erosion is not taken into account although it may be related to land subsidence.
Spatial Extent:	Delta (average value over total delta area); for 26 deltas
Spatial Resolution:	Depending on data source (i.e. SRTM and MODIS imagery, areal photographs, digitized historical maps, PSMSL data (global databank for long-term sea level change information)
Year of Publication:	2006 or 2009 References Syvitsky, J.P.M., A.J. Kettner, I. Overeem, E.W.H. Hutton, M.T. Hannon, G.R. Brakenridge, J. Day, C. Vörösmarty, Y. Saito, L. Giosan & R.J. Nicholls, 2009, Sinking deltas due to human activities. Nature Geoscience 2, pp. 681-686. Ericson, J.P., Vörösmarty, C.J., Dingman, S.L., Ward, L.G. & M. Meybeck, 2006, Effective sea-level rise and deltas: causes of change and human dimension implications. Global and Planetary Change 50, pp. 63-82.
Time Period:	Depending on data source; up to 2003 (?) for Ericson, up to 2007 for Syvitski

Title:	***Relative sea level rise indicator***
Additional Notes:	
Date:	April 2014
Format:	
File Name:	
Contact person:	Delta-Alliance: Tom Bucx / Cees van de Guchte
Contact details:	tom.bucx@deltares.nl / cees.vandeguchte@deltares.nl

Delta Vulnerability: Wetland ecological threat

Title:	***Wetland ecological threat indicator***
Indicator Number:	***19***
Cluster:	***Deltas***
Rationale:	Wetlands are the most typical (characteristic / natural) ecosystems in deltas. Information on wetlands in deltas provides an indication of their biodiversity value and level of natural state. In principle all types of wetlands can be found in deltas, including typical coastal wetlands such as mangrove, estuary and lagoon as well as freshwater wetlands (bogs, fens, lakes, marshes).
Links :	The indicator may be important for LMEs – Large Marine Ecosystems;

Description:	The determination of the wetlands ecosystems indicator is based on three main factors:
	• the **share of wetland ecosystems** within the delta;
	• the **ecological value** determined by the presence of/in:
	    • Biodiversity Hotspot(s)
	    • Key Biodiversity Area(s) (KBA)
	    • Ramsar site(s)
	    • Global 200 region
	    • Man and Biosphere Reserve (MAB-Resreve)
	    • Formally protected area (IUCN Category 1 or 2);
	• the **environmental threat** estimated based on the threats mentioned in the descriptions for:
	    • Biodiversity Hotspot(s)
	    • Global 200 region.
	
	Occasionally, additional information can be gained from the site-descriptions (sheets) for similar Global 200 regions or site description form(s) for Ramsar site(s).
	
	The indicators are further explained below. Note that not all are formally recognised statuses for deltas.
	
	Description of the criteria
	The '**Share of wetland percentage of delta area'** is based on the Global Wetlands Data Base. This dataset shows the global distribution of wetlands. It was produced at UNEP-WCMC from various sources alongside the publication 'Wetlands in Danger", Dugan, P ed. (1993). http://www.unep-wcmc.org/global-wetlands-1993_719.html . This database has been updated by Lehner and Döll into the Global Lakes and Wetlands Database (GLWD- 3). It can be found at: http://www.wwfus.org/science/data.cfm (Center for Environmental Systems Research, University of Kassel, Germany *AND* World Wildlife Fund US, Washington, DC USA).
	
	Biodiversity Hotspots (Myers et al., 2000) are regions of global conservation importance defined by the presence of high levels of threat (at least 70% habitat loss) in areas with high levels of species endemism (at least 1 500 endemic plant species). These hotspots represent the broad-scale priority regions identified by Conservation International. The hotspots are currently terrestrially focused, but the process of identifying marine hotspots is under way. The hotspots are described at http://www.conservation.org/where/priority_areas/hotspots/Pages/hotspots_main.aspx and a map is found at: http://en.wikipedia.org/wiki/File:Biodiversity_Hotspots.svg.
	
	The Global 200 are ecoregions with conservation priority, identified by WWF (Olson and Dinerstein, 1998). The list includes all types of habitats, not necessarily marine areas or deltas. A list of the ecoregions is found at: http://wwf.panda.org/about_our_earth/ecoregions/ecoregion_list/ and a map can be found at: http://assets.panda.org/img/original/ecoregions_map.jpg
	
	In some cases, use is made from descriptions of KBAs, IBAs or Ramsar Sites.
	
	Key Biodiversity Areas KBAs are sites identified as a conservation priority for a variety of species (not only birds but also mammals, plants, etc.) (Penny F. Langhammer et al., 2007). The selection is based on quantitative criteria used for BirdLife's Important Bird Areas (IBAs, see: http://www.birdlife.org/datazone/sitefactsheet.php?id=8060) or Important Plant Areas (IPAs). Sites are selected using standardized, globally applicable, threshold-based criteria, driven by the distribution and population of species that require site-level conservation. The criteria address two key issues for site conservation: vulnerability and irreplaceability. In some cases an indication is given of potential threats, mainly related to land use.
	
	Ramsar sites resort under the Convention on Wetlands (Ramsar Convention), an intergovernmental treaty that embodies the commitments of its member countries to maintain the ecological character of their Wetlands of International Importance. The principle of "wise use", or sustainable use applies. Ramsar is not affiliated with the United Nations system of Multilateral Environmental Agreements.
	A map with Ramsar sites is found at: https://www.ibatforbusiness.org/map and also at: http://ramsar.wetlands.org/Database/SearchforRamsarsites/tabid/765/Default.aspx

Description:	**MAB- Reserves** are assigned to existing protected areas by UNESCO. These reserves are not covered by any one international convention and instead form part of the UNESCO Man and the Biosphere (MAB) Programme. The protected areas do not necessarily protect unique or important areas, and may exhibit a variety of objectives including research, monitoring, training and demonstration, as well as conservation. A characteristic is the sustainable use of the protected area, in which human presence and use of resources is promoted. A map and list of the MAB-sites is found at: http://www.unesco.org/mabdb/bios1-2.htm. In some cases areas are named as 'biosphere reserve', but not included in the UNESCO list, in those cases the list is misleading. **Protected area** encompasses a number of protection categories, however, the most formal protection relevant for biodiversity is IUCN category 1-2. Category 1 is based on its importance for Science, in particular for areas of land and sea possessing outstanding or representative ecosystems, geological or physiological features and/or species, available primarily for scientific research and/or environmental monitoring, also wilderness protection for large, unmodified or slightly modified areas, with the aim of preserving their natural condition. Category 2 includes ecosystem protection and recreation, to protect the ecological integrity of the ecosystems and to exclude it from exploitation. A map of protected areas is at: https://www.ibatforbusiness.org/map . A further description of the conservation categories is found at: http://www.iucn.org/about/work/programmes/gpap_home/gpap_quality/gpap_pacategories/
Metrics:	See above
Computation:	For the '**Share of Wetlands'**, the score 1-5 on the basis of the share of wetlands compared to the total delta area (in %) is given below the table of results. The GLWD- 3 distinguished 12 'wetland classes', which are all given equal weight in the calculation of the fraction of the delta classified as wetlands. In a few cases a correction was done for the share of wetlands, where it is known from the statistical data that they include mostly farming areas (e.g. rice paddies or other farming areas, as is the case for the Hong, Mekong, Senegal and Volta deltas). For the '**Ecological value**' we combined the six criteria mentioned above. All these six criteria were simply scored with 1 (or 0.5 in the case that only for a small part of the area the criterion applied) and added together to determine the score for the ecological value. The **'Environmental threat'** is based on an inventory of the threats per delta ecosystem. Some 27 threats are cross-tabulated; the information is based on the descriptions as available for the Biodiversity Hotspots and Global 200 areas (see above and meta data sheet). In few cases where no information is available for an area, information is used for adjoining rivers with additional information from the formal Ramsar site description sheets. The number of threats are scaled in a 1 - 5 points scale. Next, the **Calculated average wetland ecological Value (CV)** is determined as the average of the scores of the share of wetlands and the ecological value. This results in a value ranging from 0.75 – 4.50. Subsequently, the **Wetland ecological threat indicator** is calculated by multiplying the CV by the number of threats, which resulted in values ranging from 2 – 17.5. Finally, this value is re-scaled to a scale 1-5, to make it comparable with the results from the other assessments of the other indicators.
Units:	Point scale 1 to 5
Scoring system:	See above.
Limitations:	The problem for some ecological indicators, like the presence of a Ramsar site or the protection status, is the fact that the assignment of a site on the official list is a function of political will rather than of ecological criteria alone. Therefore we combine different ecological indicators, which are partly also based on objective scientific criteria such as species biodiversity or ecosystem value. Aberrations will therefore be levelled out. Depending on two databases is rather limited, and may result in biased results, particularly since the mentioned threats may not be exhaustive. Only six deltas are located in a hotspot, some 10 in the Global 200 sites, and 10 contain (one or more) Ramsar sites. For a larger number of deltas there is no information on threats. The available data is better in the more developed countries, which may provide a slight bias e.g. in Europe. The wetland percentage of deltas is an important indicator for the ecological value, but it is based on statistics and in some locations (such as the Mekong, Hong, Senegal and Volta Deltas), the delta is almost fully classified as wetlands according to the global lake and wetland database, while it is known that large proportions of these deltas are used as agricultural area. Some correction of the wetland share and the combination of this indicator with the ecological indicator leads to a balanced result. The environmental threats are based on descriptions of deltas, rivers, and regions which differ in scale, author, and ecosystem. The purpose of the descriptions differed as well as the year of description. This makes the source data rather diverse, and therefore the threats are difficult to compare for each delta. A more extensive review of all threats would be required for each delta to ensure that the descriptions are more homogeneous and comparable.

Spatial Extent:	26 deltas
Spatial Resolution:	Not applicable
Year of Publication:	**References** Myers, N., Mittermeier, R.A., Mittermeier, C.G., da Fonseca, G.A.B., Kent, J., 2000. Biodiversity hotspots for conservation priorities. 403, 853-858. Olson, D.M., Dinerstein, E., 1998. The Global 200: a representation approach to conserving the Earth's most biologically valuable ecoregions. Conservation Biology 12, 502-515. Penny F. Langhammer, Mohamed I. Bakarr, Leon A. Bennun, Thomas M. Brooks, Rob P. Clay, Will Darwall, Naamal De Silva, Graham J. Edgar, Güven Eken, Lincoln D.C. Fishpool, Gustavo A.B. da Fonseca, Matthew N. Foster, David H. Knox, Paul Matiku, Elizabeth A. Radford, Ana S.L. Rodrigues, Paul Salaman, Sechrest, W., Tordoff, A.W., 2007. Identification and gap analysis of key biodiversity areas: targets for comprehensive protected area systems. IUCN, Gland, Switzerland. See also references to internet sites 'Description'
Time Period:	
Additional Notes:	
Date:	20 June 2014
Format:	
File Name:	Metadata sheet Wetland ecosystem indicator
Contact person:	Wim van Driel
Contact details:	Wim.vandriel@wur.nl

Delta Vulnerability: Population pressure

Title:	***Population pressure Indicator***
Indicator Number:	***20***
Cluster:	***Deltas***
Rationale:	High population pressure poses challenging demands on delta resources, such as demands for freshwater, fertile soils, space and ecosystem regulation functions.
Links :	The indicator can be important for Groundwater
Description:	Population pressure index is a relative measure on a scale of 1 to 5 based on the average number of people per square km.
Metrics:	See below
Computation:	CIESIN (Center for International Earth Science Information Network) holds global data sets on population (http://sedac.ciesin.columbia.edu/data/collection/gpw-v3) The Gridded Population of the World (GPWv3) depicts the distribution of human population across the globe. This is a gridded, or raster, data product that renders global population data at the scale and extent required to demonstrate the spatial relationship of human populations and the environment across the globe. The data contains a projection of the amount of people living in each 2.5 arcseconds gridcell in the year 2010, based on census data of the year 2000 with an extrapolation. These data are combined with the defined extent of the deltas to calculate the average population density per delta. First, the population in all 2.5 arcsecond cells that have their centroids within the polygons of the deltas are summed. Subsequently an average population density is calculated using the area of the delta.
Units:	The average number of people per square km is translated into a 5 point scale from very low to very high.
Scoring system:	See above
Limitations:	• The population pressure index quantifies the average population density in the delta. There is however no information on heterogeneity within the delta. It could however make a difference whether people are living together in some very dense cities, or are more or less spread over the total area. • Similarly, the elevations where people live are not taken into account • The vulnerability is to a large extent also dependent on the quality of housing, which is very much dependent on the income of the populations, which is not taken into account in this indicator
Spatial Extent:	26 deltas
Spatial Resolution:	
Year of Publication:	
Time Period:	2010
Additional Notes:	
Date:	24 June 2014
Format:	
File Name:	Metadata sheet Population Pressure Indicator
Contact person:	Wim van Driel
Contact details:	Wim.vandriel@wur.nl

Delta Vulnerability: Delta governance indicator

Title:	*Delta Governance Indicator*
Indicator Number:	***21***
Cluster:	***Deltas / Delta Vulnerability Index***
Rationale:	In addition to governance issues in river basins, the Delta Governance Indicator signifies how the different countries score on governance of the delta. Therefore three key principles will be used: adaptivity, participation and fragmentation. The reason for those key principles lies with the definition of Governance. Adaptivity is how a contemporary state adapts to its economic and political environment with respect to how it operates. Participation focuses on transparency, accountability and participation (TAP) and can be used to analyse institutional performance as well as how stakeholders behave and relate to each other. Finally fragmentation is also said to be a necessary and to some extent unavoidable structural characteristic and quality of global governance[43] architectures in and beyond the environmental domain. It creates opportunities for further development of environmental policies through policy innovation, consensus building and negotiations.
Links :	*Governance of the delta may be relevant to LMEs and coastal aquifers.*
Description:	The Delta Governance Indicator measures how the different countries score on governance of the Delta
Metrics:	The Institutional Profiles Database (IPD) provides an original measure of the institutional characteristics of countries through composite indicators from perception data. The database was designed in order to facilitate and stimulate research on the relationship between institutions, long-term economic growth and development. • The 2012 edition of the database follows on from the 2001, 2006 and 2009 editions. • It covers 143 countries and contains 130 indicators. • The edition of the IPD is a result of a collaboration between the French Development Agency (AFD) and the Directorate General of the Treasury (DG Tresor). The perception data needed to build the indicators were gathered through a survey completed by country/regional Economic Services of the Ministry for Economy and Finance and the country AFD offices. The Centre for Prospective Studies and International Informative (CEPII) and the University of Maastricht are partners in this project.
Computation:	Each indicator is based on different sub-indicators. Each sub-indicator has the same factor, which means that all the sub-indicators combined and divided by the total sub-indicators. All the countries that lie in the same delta are also combined and divided by two. It is important to stress here that the DCU factor is used for combining the countries.
Units:	*Score 1-5 Very weak – Very strong*
Risk categorization	*Should describe how and why the indicator scores are assigned to 1 of 5 risk categories. Should include table with proportion and number of basins and BCUs in each risk category.*
Limitations:	Including issues which may not be covered by the indicator, as well as any cautionary notes in interpreting the results. They may also be seen as 'challenges' which still need to be addressed.
Year of Publication:	2013.
Time Period:	*The 2012 edition of the database follows on from the 2001, 2006 and 2009 editions.*
Date:	*31/07/2015*
Format:	*Microsoft Excel*
File Name:	
Contact person:	*Gerald Jan Ellen / Cees van de Guchte (Deltares)*
Contact details:	geraldjan.ellen@deltares.nl

43 Isailovic, M., O. Widerberg,. P. Pattberg. (2013). Fragmentation of Global Environmental Governance Architectures. IVM Institute for Environmental Studies. Amsterdam

Annex X – Projections: methodology summary & supplementary results

Annex X-1: Projections methodology summary

This annex summarizes the rationale and underlying scenarios and datasets (forcings) used in the five TWAP RB projected indicators for time periods representing 2030 and 2050:

1. Environmental stress induced by flow alteration;
2. Human water stress;
3. Nutrient pollution;
4. Exacerbating factors to hydropolitical tension;
5. Change in population density.

These indicators are described individually in Chapter 3 of the main TWAP RB report and in more detail in the metadata sheets in Annex IX.

The aim of the projections assessment was to undertake projections for a selection of indicators which broadly reflected the five thematic groups of the baseline assessment, for the 2030s and 2050s, approximating a 'business-as-usual' scenario.

Given the challenges of 'projecting' governance capacity into the future, the projected governance indicator assesses six current 'exacerbating' factors which are likely to have in impact in the near future (i.e. 10-15 years, which makes it comparable to the 2030s time period of the other projected indicators).

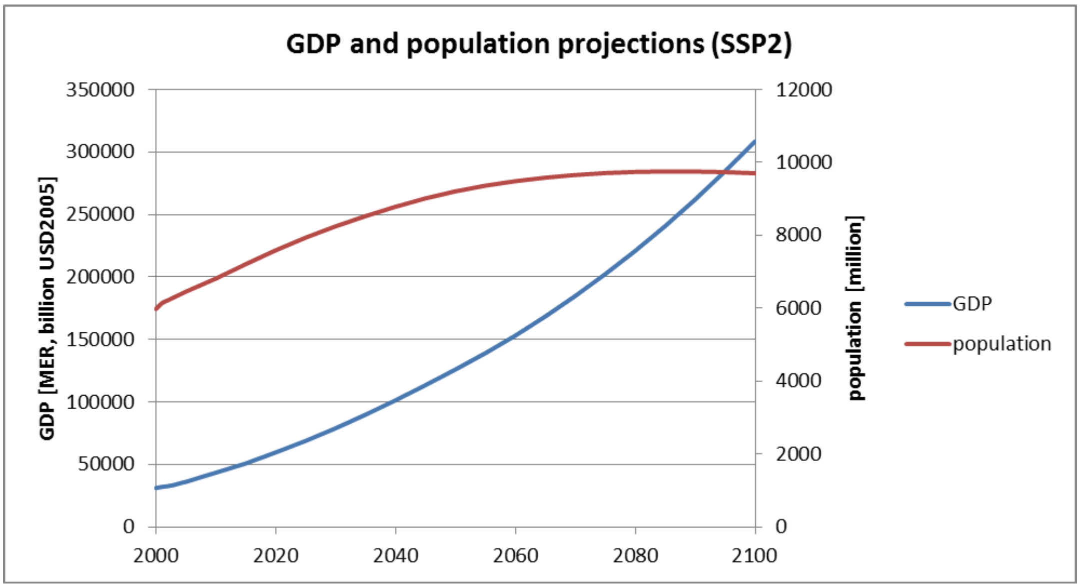
Three of the projected indicators ('Population density', 'Environmental stress induced by flow alteration', and 'Human water stress') are based on drivers and assumptions generated within ISI-MIP (Warszawski et al. 2014) and used in the IPCC Fifth Assessment Report (AR5, 2014). The 'Nutrient pollution' indicator is mainly forced by drivers developed on the basis of the Millennium Ecosystem Assessment storylines (MA, Alcamo et al. 2005) which were downscaled to countries or national sub-regions and further disaggregated into a 0.5 x 0.5 degree grid. Although the absolute numbers differ between the scenarios selected, the overall trends between the scenarios (e.g. SSP2 and Global Orchestration) are comparable.

Table 1 Main drivers of projections

Indicator	Climate change	Socio-economic development	Governance
Change in population density (2030, 2050)		Projection follows the Shared Socioeconomic Pathway, SSP2 (O'Neill et al. 2014, Kriegler et al. 2010). Figure 1	
Environmental stress induced by flow alteration (2030s, 2050s)	Projected monthly river discharge as calculated by WaterGAP2.2 (Müller Schmied et al. 2014) and WBM_{plus} (Wisser et al. 2010) models within the ISI-MIP project (Schewe et al 2014). Indicators are developed as long-term averages based on the ensemble mean of four different projections. These projections are characterized by different climatology. Climate variables (e.g. precipitation, temperature, solar radiation) used from four Global Climate Models (GCMs) of the CMIP5 archive (Taylor et al. 2012) for the 2030s (2021-2050) and 2050s (2041-2070). HadGEM2-ES (Met Office, UK) IPSL-CM5A-LR (Institut Pierre-Simon Laplace, France) MIROC-ESM-CHEM (Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute) NorESM1-M (Norwegian Climate Centre) The selected projections follow a Radiative Forcing Pathway leading to 8.5 W/m^2 (i.e., RCP8.5, Figure 3) at the end of the century. Compared to the SRES emission scenarios, the RCP8.5 average global temperature increase would be in line with the SRES A1FI but slightly above the SRES A2 at the end of the 21st century (cf. Rogelj et al. 2012).	Water use projections and population development follow the Shared Socioeconomic Pathway, SSP2, (O'Neill et al. 2014, Kriegler et al. 2010, van Vuuren et al. 2011)	
Human water stress (2030s, 2050s)			
Exacerbating factors to hydropolitical tension (2030s)		Level of economic development calculated as average of the most recent five years (2008-2012) of Gross National Income (GNI) per capita (World Bank 2013)	Intrastate tensions based on the Minorities at Risk project (MAR 2009), interstate conflicts from UCDP/PRIO Armed Conflict Dataset (2012), recent history of conflict and cooperation over water based on the OSU TFDD Water Events Database (2010).
Nutrient pollution (2030s, 2050s)	Projections of climate (precipitation and temperature) based on HadCM2 GCM climate forcings scaled through the IMAGE model for the 'Global Orchestration' scenario as developed within the Millennium Ecosystem Assessment (MEA; Alcamo et al. 2005, Bouwman et al. 2009, Seitzinger et al. 2010); and monthly river discharge, nutrient retention in projected hydropower reservoirs, and consumptive water use from Fekete et al. (2010).	Population based on MEA regional scenarios [Alcamo et al., 2006] downscaled to countries based on country UN [2006] projections according to Van Vuuren et al. [2007], and using a scaled population density spatial distribution grid from the IMAGE model. Other model input and assumptions to calculate nutrient loads were derived from the Global Orchestration scenario as developed within the MEA (Alcamo et al. 2006) and downscaled to 0.5 by 0.5 degree resolution by IMAGE model. This included agricultural trends in production and fertilizer use efficiency, and sewage trends in access to improved sanitation, sewage connection and treatment. For a detailed description of the calculation of fertilizer and manure input see Bouwman et al. (2009), for GDP, total and urban population density; for sewage calculations see van Drecht et al. (2009). See Figure 2.	

Socio-economic drivers: For the 'Population density', 'Environmental stress induced by flow alteration', and 'Human water stress' indicators, population and GDP numbers were applied from the newly-developed Shared Socio-economic Pathways SSP2 (Figure 1). This scenario is characterized by moderate population growth, with higher growth in low-income countries, slowing population growth in middle-income countries, and limited to negative population growth in most industrialized countries. Migration between countries continues at intermediate levels owing to the restriction of labour markets. Urbanization proceeds at rates and in patterns consistent with historical experience in different world regions. Development and income growth proceeds unevenly, with only some countries making relatively good progress. Most economies are politically stable. Globally-connected markets continue to function imperfectly. The energy sector continues to rely on fossil fuels, including unconventional oil and gas resources, however, regional diversity in energy demand and intensity dominate. Technological developments proceed apace, but without major breakthroughs. Thus, only moderate transformation toward environmentally-friendly processes is achieved. (O'Neill et al. 2014)

Figure 1. GDP and population projections according to SSP2.



The 'Nutrient pollution' indicator was calculated for the Global Orchestration scenario of the MA which in general portrays a globally-connected society that focuses on global trade and economic liberalization and takes a reactive approach to ecosystem problems, but also takes strong steps to reduce poverty and inequality and invest in public goods, such as infrastructure and education (Seitzinger et al. 2010). Overall, the Global Orchestration scenario shows the highest population increases in Africa and South Asia (Figure 2). Economic growth is assumed to be above historic averages for several regions, due to a combination of trade liberalization, economic cooperation, and rapid spread of new technologies. Food production increases are greatest in South Asia, although overall efficiency of agricultural nitrogen use in this region increases only slightly relative to 2000 (Bouwman et al. 2010). Essentially all regions increase their percentage of the population connected to sewage infrastructure (Van Drecht et al. 2009). The highest rates of technological development are assumed under Global Orchestration because this scenario has several features that are favorable to technology development. It should be noted that the technology development will not necessarily be environmentally friendly.

Climate: Climate uncertainty is covered by the selection of four different GCMs. Focusing on the selected GCMs, the global mean temperature (GMT) increase over time is presented in Figure 3 for all RCPs. Overall, GMT increase for

Figure 2. Anthropogenic drivers of nutrient flows for eight world regions for 1970, 2000, and 2030 for the Global Orchestration (GO) and Adapting Mosaic (AM) scenarios (figure from Seitzinger et al. 2010 based on Alcamo et al. 2006, Bouwman et al., 2010, Van Drecht et al., 2009). AFR, Africa; SAM, South America; OCE, Oceania; SAS, South Asia; EUR, Europe; NAM, North America; AUS, Australia; NAS, North Asia.

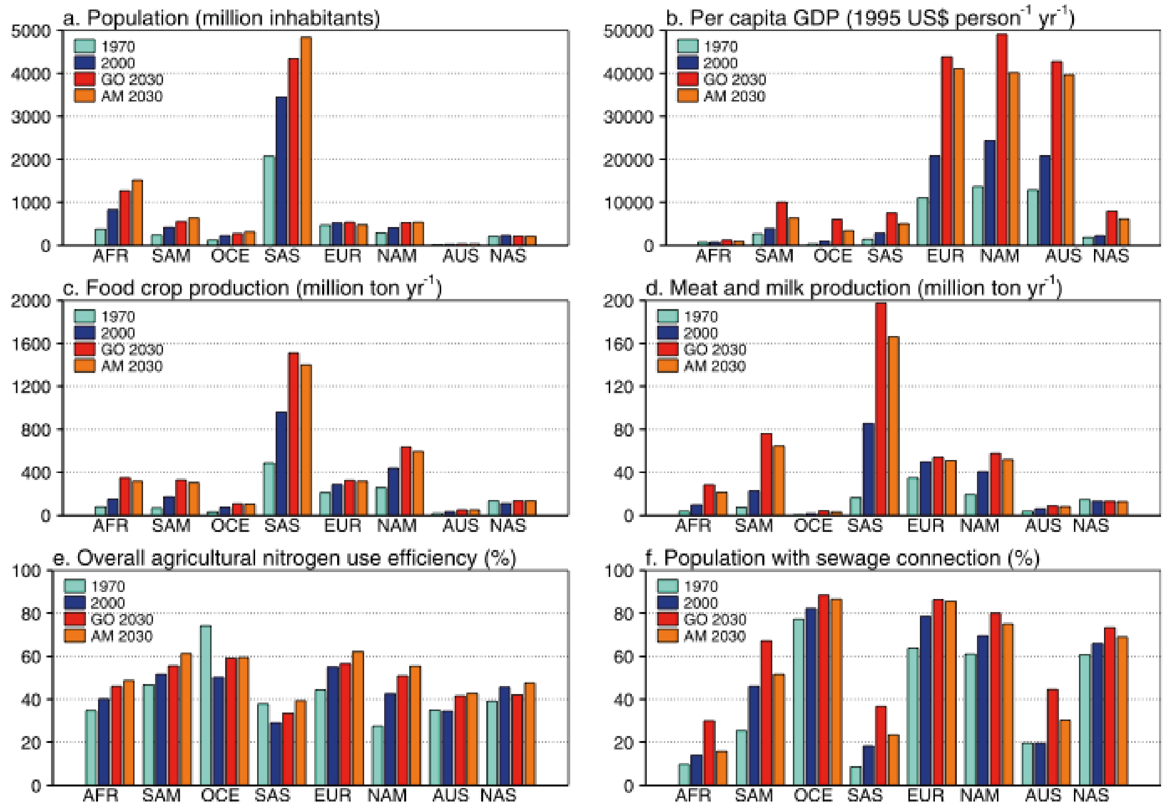
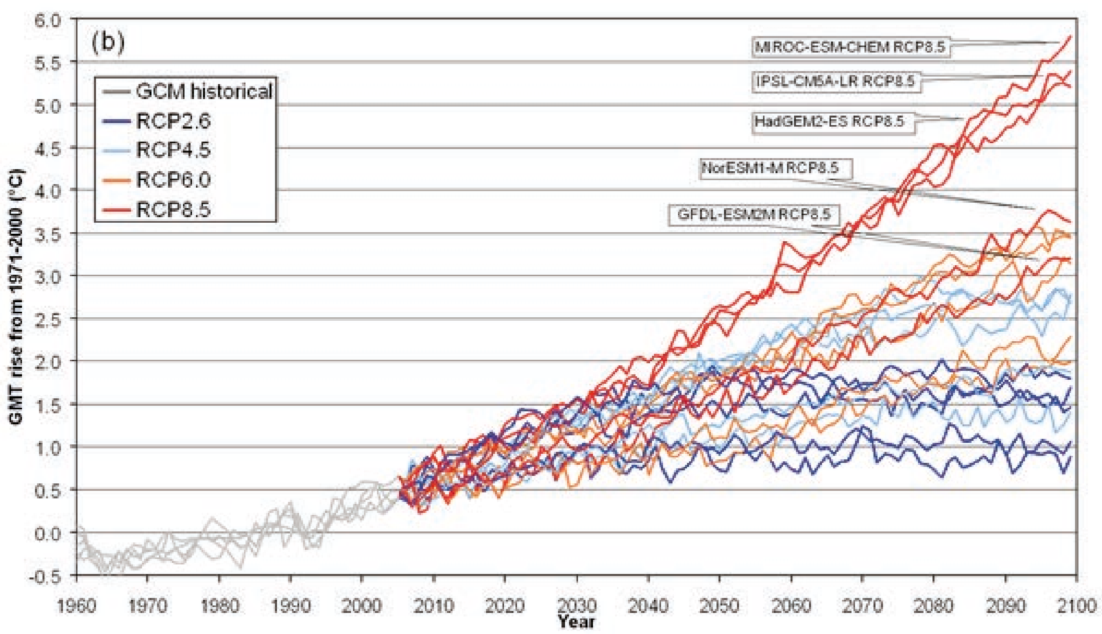


Figure 3. Global mean temperature (GMT, without bias-correction) for historical periods until 2005, and starting in 2006 for RCPs 2.6, 4.5, 6.0, and 8.5, for five different GCMs, respectively (Portmann et al. 2013).

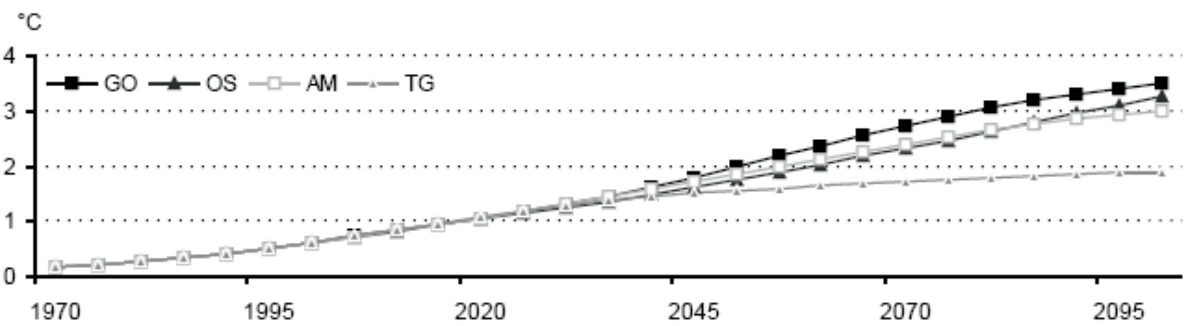


RCP8.5 is about 1°C and 1.5°C between the GCMs but the spread between the models is already significant in 2050 where the range is between 1.5°C and 2.7°C. Highest GMT values can be expected from the MIROC-ESM-CHEM, IPSL-CM5A-LR and HadGEM2-ES models while NorESM1-M and GFDL-ESM2M (not part of the TWAP ensemble) show a moderate GMT development.

The outcomes of two global hydrology models (GHMs) in terms of surface runoff and river discharge build the basis for the indicators 'environmental stress induced by flow alteration', 'human water stress' and 'hydropolitical tension'. To ensure comparability between the projected indicators and to follow the same evaluation approach as utilized for the assessment of current conditions, the ensemble mean was used for river discharge (and surface runoff). First, river discharge is calculated for each GHM forced by the climate input of the different GCMs. Second, the ensemble mean of the eight realizations (two GHMs and four GCMs) is calculated for the whole time period. Third, the long-term averages for the time slices 2030 (represented by the time period 2021-2050) and 2050 (represented by the time period 2041-2070) are determined. This methodology ensures harmonization between the models.

By 2050, the results of the Global Orchestration scenario show an increase up to 2°C (relative to pre-industrial levels) for a medium value for climate sensitivity (2.5 °C). The increase is nearly 3.5 °C under the higher emissions growth of Global Orchestration (Figure 4). Acknowledging the uncertainty in climate sensitivity in accordance with the range indicated by IPCC (1.5 to 4.5 °C), would lead to a wider range of temperature increase. The highest emissions scenarios (Global Orchestration and Order from Strength) show somewhat lower emissions than the highest of the IPCC scenarios.

Figure 4. Development in global mean temperature up to 2100 for the MA scenarios. Scenario names: GO – Global Orchestration, OS – Order from Strength, AM – Adapting Mosaic, TG – Techno Garden (adopted from Alcamo et al 2005, Figure 9.10).



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Alcamo et al. (2005). Chapter 9. Changes in Ecosystem Services and Their Drivers across the Scenarios. In: CARPENTER, S., PINGALI, P., BENNET, E. & ZUREK, M. (eds.) Millennium Ecosystem Assessment. Volume 2: Scenarios. Washington: Island Press.

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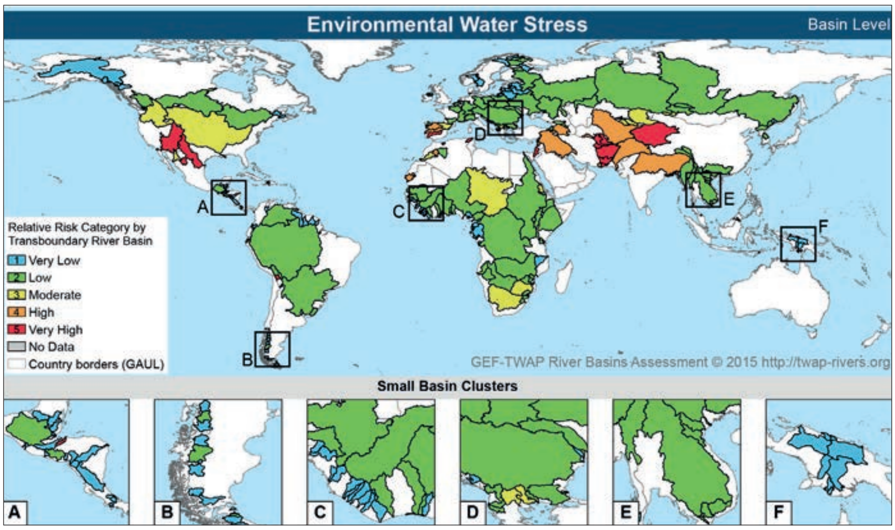
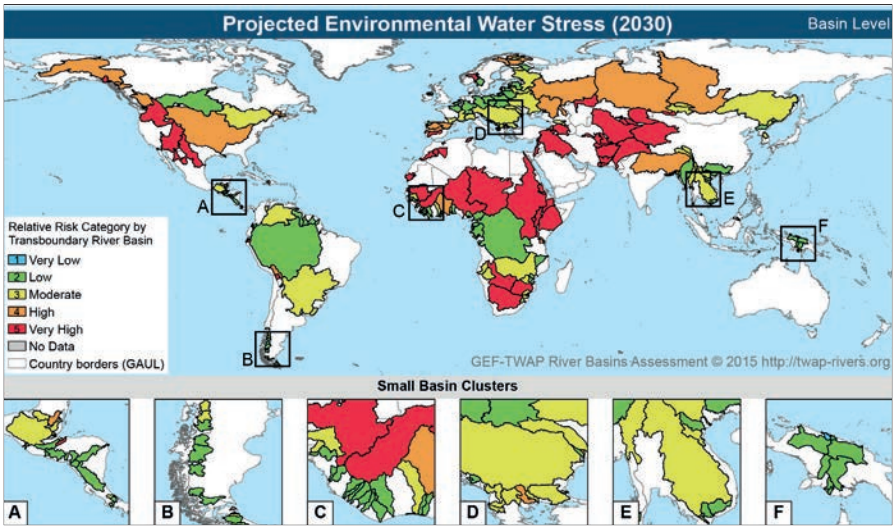
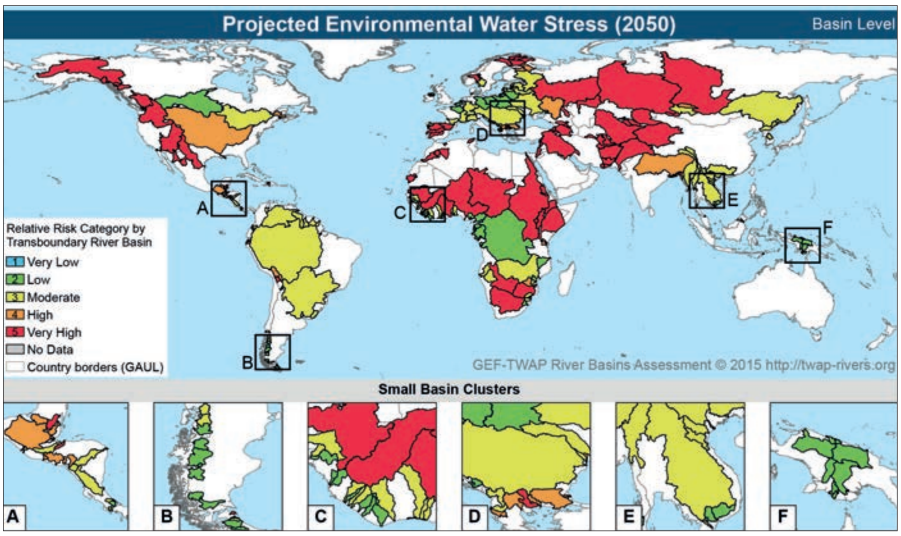
Annex X-2: Projections supplementary results

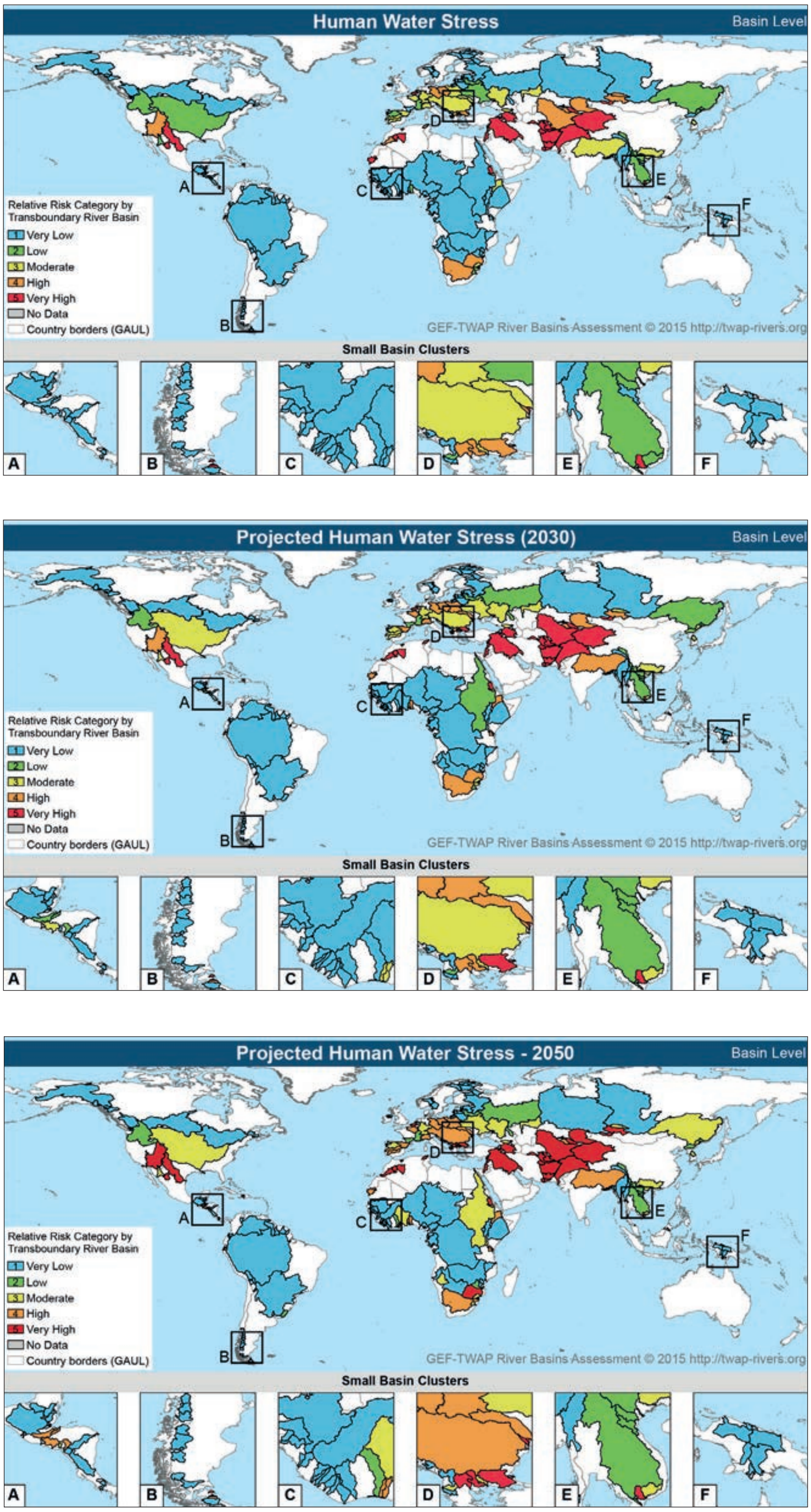
Environmental Water Stress by TB River Basin – Baseline (top) and Projected (2030 (middle) & 2050 (bottom)).



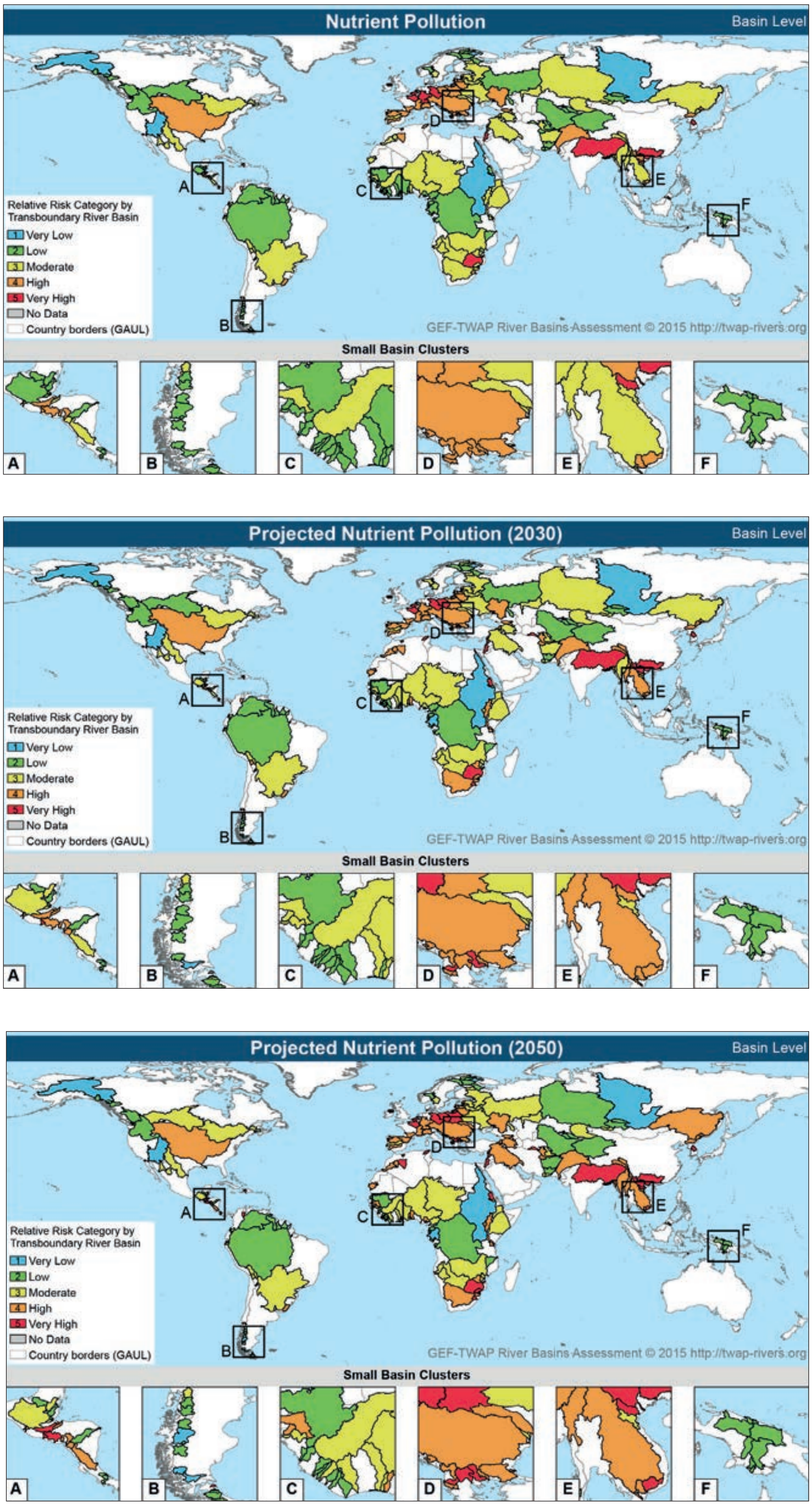




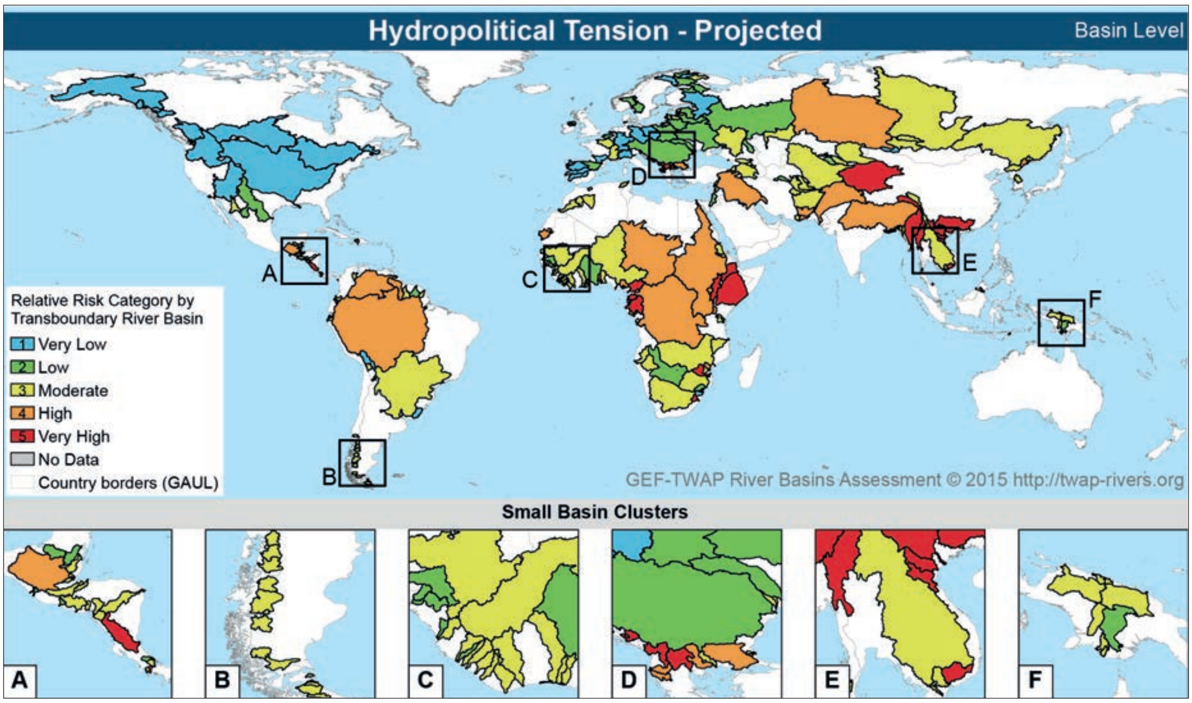
Human Water Stress by Transboundary River Basin – Baseline (top) and Projected (2030 (middle) & 2050 (bottom)).

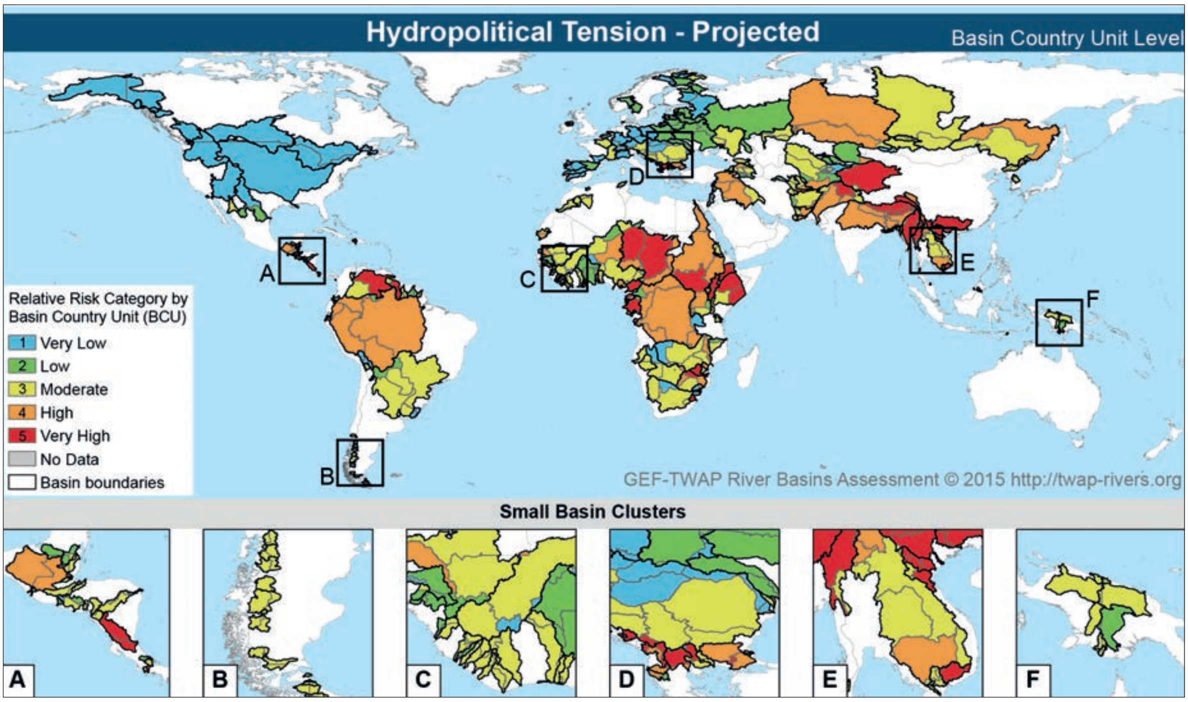


Nutrient Pollution by Transboundary Basin (combined DIN & DIP risk categories) for: a) contemporary conditions (yr. 2000 – top) and based on the MEA Global Orchestration secenario; b) 2030 (middle) and c) 2050 (bottom)).



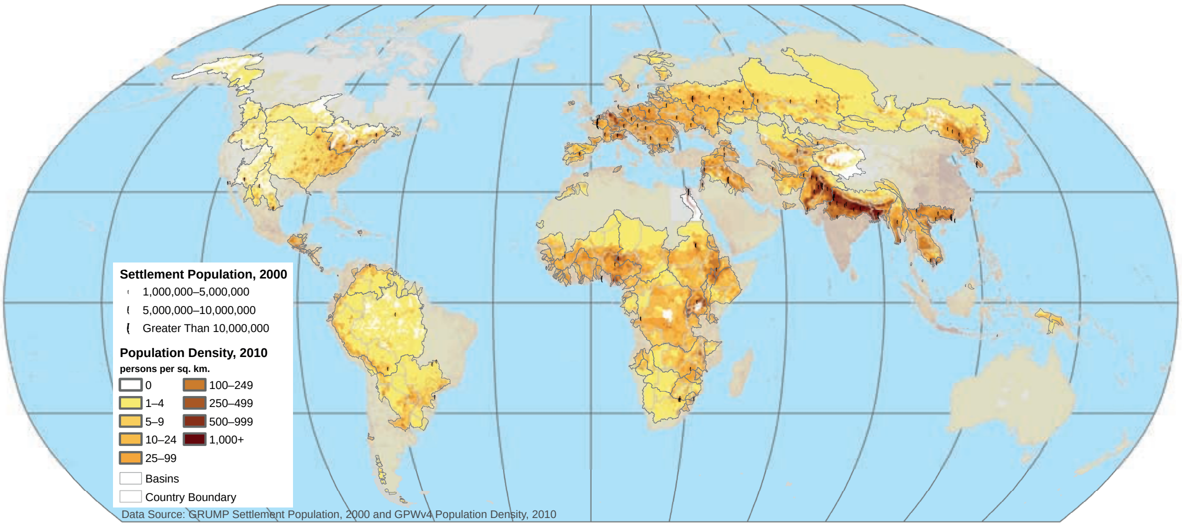
Hydropolitical tension considering potential exacerbating factors by transboundary river basin (top) and BCU (bottom). Based on 'current' exacerbating factors which may have implications in the next 10-15 years, and which is therefore broadly comparable with the 2030 time period as used for the other projected indicators.





Annex XI – Supplementary Analyses

Annex XI-1: Population Density and Settlements



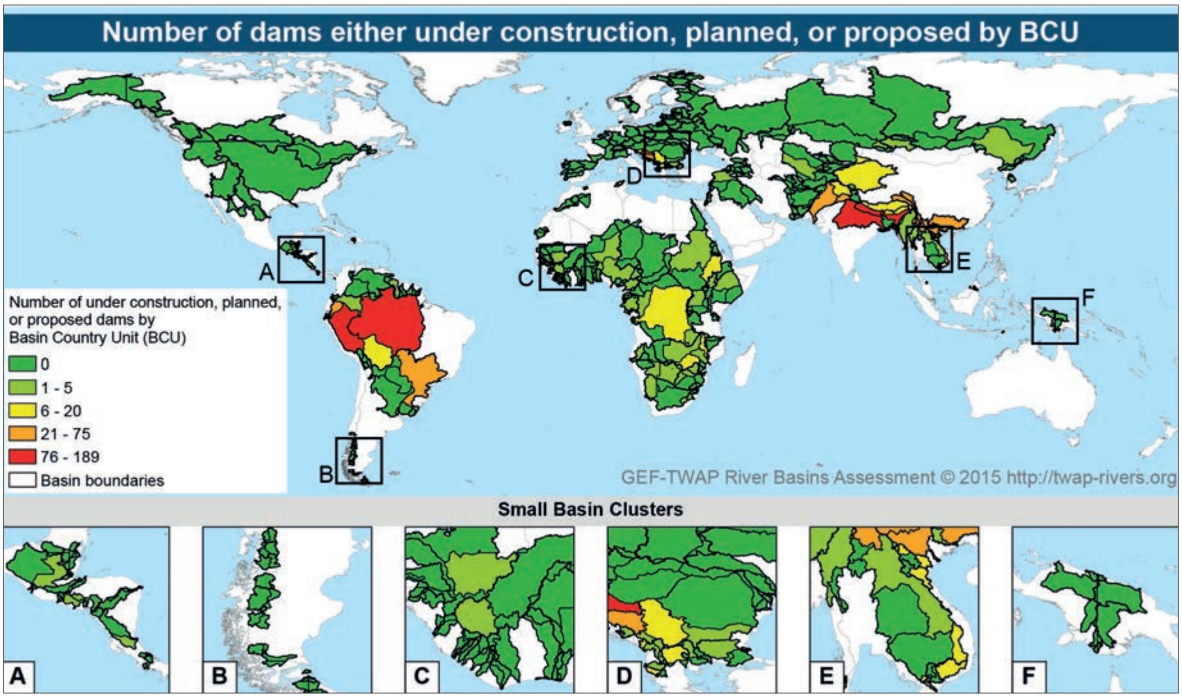
The above map shows the global distribution of settlements greater than 1 million inhabitants (year 2000), as well as the population density (year 2010), in transboundary river basins. It gives an indication of where challenges associated with urbanization are likely to be significant.

The map is intended to add another layer of information to complement the indicators used in the assessment, as many of these will be affected by urbanization, for example, #2 Human water stress; #5 Wastewater pollution; and the projected change in population density.

Annex XI-2: Planned, proposed and under-construction dams

The rate of dam construction and planning is so high that keeping up-to-date datasets is challenging. The map below shows the number of dams that are either under construction, planned, or proposed, by BCUs, to give some idea of contemporary and future locations of ecosystem risks from dams.

There is no harmonized and updated global dataset of current and planned dams. Hence we have used the most up-to-date and comprehensive dataset available (Petersen-Perlman et al, forthcoming)



Note that while the information provided was verified to the best of our ability, the nature of dam statuses changes rapidly and quickly becomes out of date.

Sources: the United Nations Framework Convention on Climate Change's Clean Development Mechanisms (http://cdm.unfccc.int), International Rivers Network, the International Commission on Large Dams (ICOLD), and from other organizations' websites known to fund dam construction (e.g., World Bank)

References:

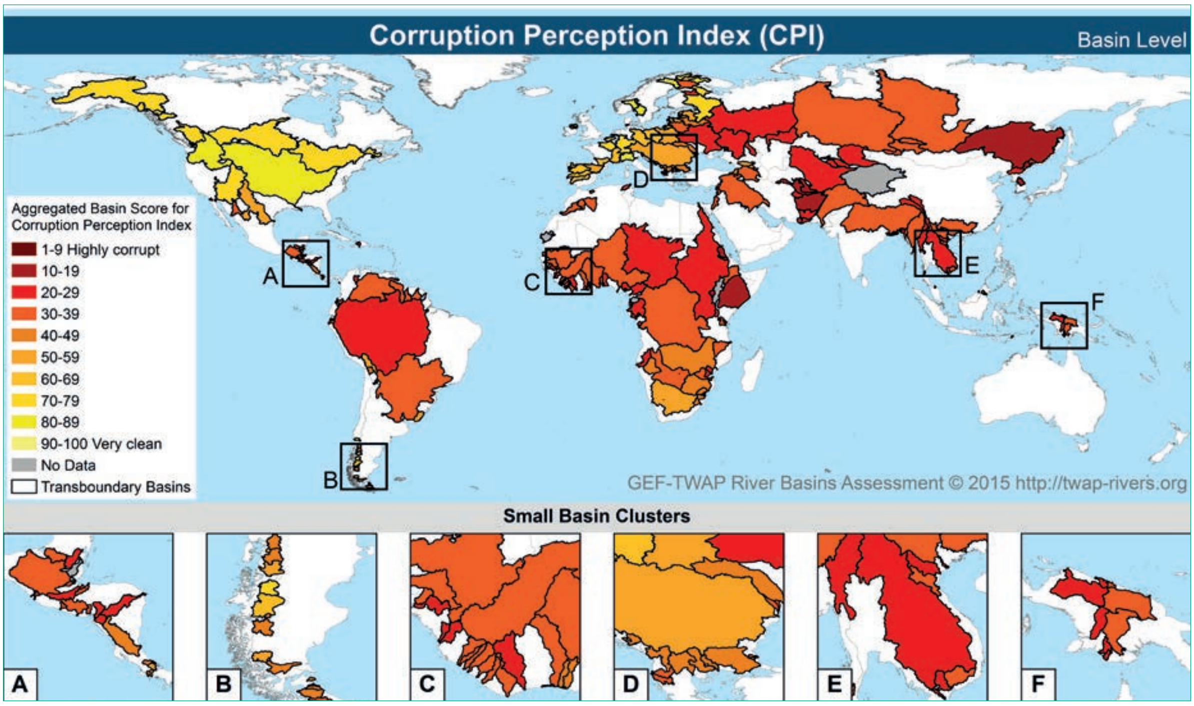
Petersen-Perlman, J., Eynard, J. et al, forthcoming. To be published from PhD dissertation "Mechanisms of cooperation for states' construction of large-scale water infrastructure projects in transboundary river basins", June 2014. Supervisor: Prof. Aaron Wolf, Oregon State University.

Annex XI-3: Corruption Perception Index

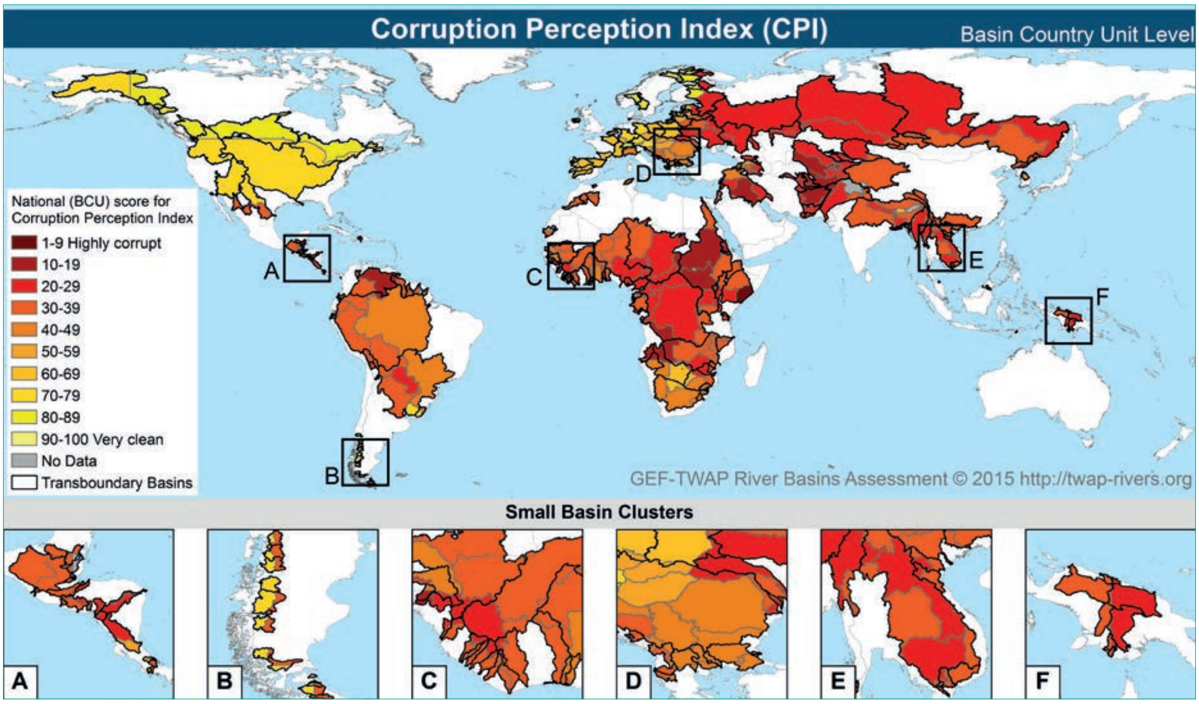
The Corruption Perception Index (CPI) is developed by Transparency International at the country level. It is a measure of the perceived levels of public sector corruption in 175 countries and territories.

Pahl-Wostl and Knieper (2014) found the CPI to be a strong explanatory variable for poor performance of governance systems. Thus, by considering 'performance', it complements the governance indicators in the TWAP RB assessment which focus mainly on the existence of governance architecture (e.g. plans, treaties, legislative frameworks and institutions). It would in particular complement #12 Enabling Environment, which is primarily a measure of governance at the national level.

2014 Corruption Perception Index by Transboundary River Basin. Basin values taken as a weighted average of BCU values based on proportion of population and area in each BCU compared to the basin total.



2014 Corruption Perception Index by Basin Country Unit (BCU). BCU values derived directly from country values.



Source: Transparency International 2014.

References:

Pahl-Wostl, C. and Knieper, C. 2014. The capacity of water governance to deal with the climate change adaptation challenge: using fuzzy set Qualitative Comparative Analysis to distinguish between polycentric, fragmented and centralized regimes. Global Environmental Change, 29: 139-154

Transparency International (2014). Corruption Perceptions Index. http://www.transparency.org/cpi2014/results (accessed 7 May 2015).

The water systems of the world – aquifers, lakes, rivers, Large Marine Ecosystems (LMEs), and the open ocean – sustain the biosphere and underpin the health and socioeconomic wellbeing of the world's population. Many of these systems are shared by two or more nations. The transboundary waters, which stretch over 71% of the planet's surface, in addition to the transboundary subsurface aquifers, and the water systems entirely within the boundaries of the individual countries, comprise humanity's water heritage.

Recognizing the value of transboundary water systems, and the reality that many of them continue to be overexploited and degraded, and managed in fragmented ways, the Global Environment Facility (GEF) initiated the Transboundary Waters Assessment Programme (TWAP) Full Size Project in 2012. The Programme aims to provide a baseline assessment to identify and evaluate changes in these water systems caused by human activities and natural processes, as well as the possible consequences of these changes for the human populations that depend on them. The institutional partnerships forged in this assessment are expected to seed future transboundary assessments.

The final results of the GEF TWAP are presented in six volumes:

Volume 1 – ***Transboundary Aquifers and Groundwater Systems of Small Island Developing States: Status and Trends***
Volume 2 – ***Transboundary Lakes and Reservoirs: Status and Trends***
Volume 3 – ***Transboundary River Basins: Status and Trends***
Volume 4 – ***Large Marine Ecosystems: Status and Trends***
Volume 5 – ***The Open Ocean: Status and Trends***
Volume 6 – ***Transboundary Water Systems: Crosscutting Status and Trends***

A ***Summary for Policy Makers*** accompanies each volume.

This document – Volume 3 – presents the first truly global baseline assessment of the world's 286 transboundary river basins, which include 151 countries and in which more than 40% of the earth's population live.

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