Chapter 3
Transboundary River Basins
Indicator Assessment
Chapter 3.1 Socioeconomics

Lead Authors
Alex de Sherbinin (Center for International Earth Science Information Network, Columbia University).

Contributing Authors


Chapter 3.2 Water Quantity

Lead Authors
Martina Flörke, Christof Schneider (Center for Environmental Systems Research, University of Kassel); Pamela Green, Charles Vörösmarty (Environmental CrossRoads Initiative, City University of New York)


Chapter 3.3 Water Quality

Lead Authors
Sybil Seitzinger (International Geosphere Biosphere Programme); Emilio Mayorga (University of Washington); Maija Bertule (UNEP-DHI).

Contributing Authors
Carolien Kroeze (Wageningen UR); Paul Glennie (UNEP-DHI).


Chapter 3.4 Ecosystems

Lead Authors
Pamela Green, Charles Vörösmarty (Environmental CrossRoads Initiative, City University of New York); Kevin Smith, Stefano Barchiesi (IUCN).

Contributing Authors
David Allen, James Dalton, William Darwall, (IUCN); Irina Dopson (City University of New York)


Chapter 3.5 Governance

Lead Authors
Lucia De Stefano (Oregon State University); Anna Forslund, Birgitta Liss Lymer (SIWI), Maija Bertule (UNEP-DHI).

Contributing Authors
Kata Molnar (SIWI); Paul Glennie, Peter Koefoed Bjørnsen (UNEP-DHI); Jim Eynard, Jacob Petersen-Perlman, Aaron Wolf (Oregon State University); Eric Sproles (Centro de Estudios Avanzados en Zonas Aridas).

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 the 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.
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.

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.
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<0.001), 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

<table>
<thead>
<tr>
<th>Relative risk categories</th>
<th>Average of Economic Activity and Agriculture Activity Fractions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - Very low</td>
<td>0.0 - 0.1</td>
</tr>
<tr>
<td>2 - Low</td>
<td>0.1 - 0.2</td>
</tr>
<tr>
<td>3 - Moderate</td>
<td>0.2 - 0.4</td>
</tr>
<tr>
<td>4 - High</td>
<td>0.4 - 0.6</td>
</tr>
<tr>
<td>5 - Very high</td>
<td>0.60 - 1.0</td>
</tr>
</tbody>
</table>

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.
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);

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**

<table>
<thead>
<tr>
<th>Relative risk categories</th>
<th>Average of sub-indicators $a$, $b$, and $c$ (%)</th>
<th>Sub-indicator $d$. IMR</th>
<th>e. Gini Coefficient</th>
<th>Average of sub-indicator $a$-$b$-$c$, $d$, and $e$ category scores</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Very low</td>
<td>$&gt;=95$</td>
<td>$&lt;=$15</td>
<td>$&lt;=$25</td>
<td>$0.0-1.5$</td>
</tr>
<tr>
<td>2 Low</td>
<td>80-95</td>
<td>15-32</td>
<td>25-30</td>
<td>1.5-2.5</td>
</tr>
<tr>
<td>3 Moderate</td>
<td>60-80</td>
<td>32-65</td>
<td>30-35</td>
<td>2.5-3.3</td>
</tr>
<tr>
<td>4 High</td>
<td>40-60</td>
<td>65-100</td>
<td>35-40</td>
<td>3.5-4.0</td>
</tr>
<tr>
<td>5 Very high</td>
<td>$&lt;40$</td>
<td>$&gt;=100$</td>
<td>$&gt;=40$</td>
<td>$&gt;4.0$</td>
</tr>
</tbody>
</table>

Metadata on each of these sub-indicators can be found in Annex IX. The first four indicators are highly correlated (Pearson’s $r$ coefficients $>0.55$, $p<0.001$). 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.
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.
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

<table>
<thead>
<tr>
<th>Relative risk categories</th>
<th>Flood Economic Exposure as % of GDP</th>
<th>CV of Inter-Annual Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Very low</td>
<td>&lt;=1</td>
<td>&lt;=0.4</td>
</tr>
<tr>
<td>2 Low</td>
<td>1-10</td>
<td>0.5-0.6</td>
</tr>
<tr>
<td>3 Moderate</td>
<td>10-30</td>
<td>0.6-0.8</td>
</tr>
<tr>
<td>4 High</td>
<td>30-80</td>
<td>0.8-1.0</td>
</tr>
<tr>
<td>5 Very high</td>
<td>&gt;=80</td>
<td>&gt;=1.0</td>
</tr>
</tbody>
</table>

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.
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 (ISIMIP) 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>
<thead>
<tr>
<th>Table 3.4. Projected Changes in Population Density relative risk categorization</th>
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</thead>
<tbody>
<tr>
<td>Relative risk categories</td>
</tr>
<tr>
<td>----------------------------</td>
</tr>
<tr>
<td>1 - Very low</td>
</tr>
<tr>
<td>2 - Low</td>
</tr>
<tr>
<td>3 - Moderate</td>
</tr>
<tr>
<td>4 - High</td>
</tr>
<tr>
<td>5 - Very high</td>
</tr>
</tbody>
</table>

**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.
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.

<table>
<thead>
<tr>
<th>Basins with very high risk of economic dependency and...</th>
<th>Basins with very high risk to societal wellbeing and...</th>
<th>Basins with very high risk of exposure to flood and drought and...</th>
</tr>
</thead>
<tbody>
<tr>
<td>High to very high risk to societal wellbeing</td>
<td>High to very high risk of economic dependency</td>
<td>High to very high risk of economic dependency</td>
</tr>
<tr>
<td>Awash</td>
<td>Zambezi</td>
<td>Ganges-Brahmaputra-Meghna</td>
</tr>
<tr>
<td>Congo/Zaire</td>
<td>Congo/Zaire</td>
<td>Oueme</td>
</tr>
<tr>
<td>Nile</td>
<td>Lake Chad</td>
<td>Limpopo</td>
</tr>
<tr>
<td>Zambezi</td>
<td>Artibonite</td>
<td>Orange</td>
</tr>
<tr>
<td>Niger</td>
<td></td>
<td>Mekong</td>
</tr>
<tr>
<td>Oueme</td>
<td></td>
<td>Baraka</td>
</tr>
<tr>
<td>Volta</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High to very high risk of exposure to flood and drought</td>
<td>High to very high risk of exposure to flood and drought</td>
<td>High to very high risk to societal wellbeing</td>
</tr>
<tr>
<td>Ganges-Brahmaputra-Meghna</td>
<td>Oueme</td>
<td>Oueme</td>
</tr>
<tr>
<td>Jordan</td>
<td>Okavango</td>
<td>Okavango</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Limpopo</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cancoso/Lauca</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lake Natron</td>
</tr>
</tbody>
</table>
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.
References


Redford, K., Levy, M., Sanderson, E. and de Sherbinin, A. (2008). What is the role for conservation organizations in poverty alleviation in the world’s wild places? Oryx 42(4), 516-528


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.
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 km²). 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.
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.](image)
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
Transboundary river basins indicate assessment

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

<table>
<thead>
<tr>
<th>Global Climate Model (GCM)</th>
<th>Institute full name</th>
</tr>
</thead>
</table>
| 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 km²), 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; Rijsberman 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
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>
<thead>
<tr>
<th>Relative risk category</th>
<th>a. Renewable water supply m³/person/yr</th>
<th>b. Relative water use ratio water withdrawals/supply</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Very low</td>
<td>&gt; 1 700</td>
<td>&lt; 0.1</td>
</tr>
<tr>
<td>2 Low</td>
<td>1 300 – 1 700</td>
<td>0.1-0.2</td>
</tr>
<tr>
<td>3 Moderate</td>
<td>1 000 – 1 300</td>
<td>0.2-0.4</td>
</tr>
<tr>
<td>4 High</td>
<td>500 – 1 000</td>
<td>0.4-0.8</td>
</tr>
<tr>
<td>5 Very high</td>
<td>&lt; 500</td>
<td>&gt; 0.8</td>
</tr>
</tbody>
</table>

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).
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 (~25 000 km² area). These results have a higher degree of scientific confidence. Results for basins smaller than 25 000 – 30 000 km² (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/m² (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.
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 (~25 000 km² area). These results have a higher degree of scientific confidence. Results for basins smaller than 25 000 – 30 000 km² (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’ \( \text{c}_{\text{iirr}, \text{t.a.}} \) 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 km²). 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.
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.
References


SSP Database (2013). Shared Socioeconomic Pathways Database, Version 0.9.3. https://secure.iiasa.ac.at/web-apps/ene/SspDb


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. 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.

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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 (R4) 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

<table>
<thead>
<tr>
<th>Relative risk category</th>
<th>Conc. range mg N/l</th>
<th>Conc. range mg P/l</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Very low</td>
<td>≤0.15</td>
<td>≤0.01</td>
</tr>
<tr>
<td>2 Low</td>
<td>&gt;0.15 and ≤0.5</td>
<td>&gt;0.01 and ≤0.03</td>
</tr>
<tr>
<td>3 Moderate</td>
<td>&gt;0.5 and ≤1.0</td>
<td>&gt;0.03 and ≤0.1</td>
</tr>
<tr>
<td>4 High</td>
<td>&gt;1.0 and ≤2.0</td>
<td>&gt;0.1 and ≤0.5</td>
</tr>
<tr>
<td>5 Very high</td>
<td>&gt;2.0</td>
<td>&gt;0.5</td>
</tr>
</tbody>
</table>

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 km² 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.
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 km², 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 at 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.
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.
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.
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.
References


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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).
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.
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.
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 km² area). These results have a higher degree of scientific confidence. Results for basins smaller than 25 000 – 30 000 km² (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
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 \((X - \text{min})/(\text{max}-\text{min})\). 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.
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 km² area). These results have a higher degree of scientific confidence. Results for basins smaller than 25 000 – 30 000 km² (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 \((X – \text{min})/(\text{max}-\text{min})\) 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.
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 km² area). These results have a higher degree of scientific confidence. Results for basins smaller than 25,000 – 30,000 km² (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.
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).
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 \(\frac{(value - min)}{(max - min)}\)).

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 \(\frac{(value - min)}{(max - min)}\)).

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, \(\frac{Endemism\ normalised \times (0.5 \times River\ Length\ normalised)}{2}\). Extinction risk is thus: \((\text{percentage threatened species score}) \times (1 + \text{average weighting score})\).

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.

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\(^{10}\) 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).

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<th>% Discharge</th>
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<td>17</td>
<td>13</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>South America</td>
<td>73</td>
<td>106</td>
<td>88</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Global</td>
<td>73</td>
<td>106</td>
<td>88</td>
<td>12</td>
<td></td>
</tr>
</tbody>
</table>

**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:
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).
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).
References


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 led 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). Since the UNECE Water Convention and the UN WC Convention incorporate all the above-mentioned principles and both are global in scope, ratification by countries of these two Global Water Conventions has also been taken into consideration as part of this assessment.

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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)**

<table>
<thead>
<tr>
<th>BCU treaty score</th>
<th>Possible value</th>
</tr>
</thead>
<tbody>
<tr>
<td>At least one treaty covering principle of equitable and reasonable utilization</td>
<td>0/1</td>
</tr>
<tr>
<td>At least one treaty covering obligation not to cause significant harm</td>
<td>0/1</td>
</tr>
<tr>
<td>At least one treaty covering the principle of environmental protection</td>
<td>0/1</td>
</tr>
<tr>
<td>At least one treaty covering the principle of cooperation and information exchange</td>
<td>0/1</td>
</tr>
<tr>
<td>At least one treaty covering the principle of notification, consultation or negotiation</td>
<td>0/1</td>
</tr>
<tr>
<td>At least one treaty covering consultation and peaceful settlement of disputes</td>
<td>0/1</td>
</tr>
<tr>
<td>BCU (country) has ratified UN WC Convention and/or UNECE Water Convention</td>
<td>0/1</td>
</tr>
<tr>
<td>BCU treaty score</td>
<td>0 to 7</td>
</tr>
</tbody>
</table>
Step 2:
Calculating a basin score required the following 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>
<thead>
<tr>
<th>BCUs in Basin</th>
<th>BCU treaty score (from step 1)</th>
<th>BCU weight</th>
<th>Weighted BCU score</th>
</tr>
</thead>
<tbody>
<tr>
<td>BCU1</td>
<td>0 to 7</td>
<td>up to 1</td>
<td>BCU treaty score x BCU weight = weighted BCU score</td>
</tr>
<tr>
<td>BCU2</td>
<td>0 to 7</td>
<td>up to 1</td>
<td></td>
</tr>
<tr>
<td>BCU3</td>
<td>0 to 7</td>
<td>up to 1</td>
<td>Sum of each BCU weight = 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Basin treaty score = Sum of all weighted BCU scores (0 to 7)</td>
</tr>
</tbody>
</table>

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>
<thead>
<tr>
<th>Relative Risk Category</th>
<th>Range (basin treaty score)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 – Very Low</td>
<td>6.8 - 7</td>
</tr>
<tr>
<td>2 - Low</td>
<td>4.5 - 6.79</td>
</tr>
<tr>
<td>3 - Moderate</td>
<td>2.5 - 4.49</td>
</tr>
<tr>
<td>4 - High</td>
<td>0.2 - 2.49</td>
</tr>
<tr>
<td>5 – Very High</td>
<td>0 - 0.19</td>
</tr>
</tbody>
</table>

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.
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>
<thead>
<tr>
<th>Geographical area (km$^2$)</th>
<th>Cat 1-2 (%)</th>
<th>Cat 3-5 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 49 999</td>
<td>11%</td>
<td>89%</td>
</tr>
<tr>
<td>50 000 – 99 999</td>
<td>33%</td>
<td>67%</td>
</tr>
<tr>
<td>100 000 – 499 999</td>
<td>30%</td>
<td>70%</td>
</tr>
<tr>
<td>500 000 – 999 999</td>
<td>62%</td>
<td>38%</td>
</tr>
<tr>
<td>larger than 1 000 000</td>
<td>53%</td>
<td>47%</td>
</tr>
</tbody>
</table>

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**

<table>
<thead>
<tr>
<th>Treaty-RBO component</th>
<th>Possible value</th>
</tr>
</thead>
<tbody>
<tr>
<td>At least one water treaty</td>
<td>0/1</td>
</tr>
<tr>
<td>At least one treaty with an allocation mechanism</td>
<td>0/1</td>
</tr>
<tr>
<td>At least one treaty with a flow variability management mechanism</td>
<td>0/1</td>
</tr>
<tr>
<td>At least one treaty with a conflict resolution mechanism</td>
<td>0/1</td>
</tr>
<tr>
<td>At least one river basin organization</td>
<td>0/1</td>
</tr>
<tr>
<td><strong>Total possible value for a basin-country unit</strong></td>
<td><strong>0 to 5</strong></td>
</tr>
</tbody>
</table>
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 m³/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

<table>
<thead>
<tr>
<th>Water Developments (presence of Large Dam and Water Diversion Projects)</th>
<th>Score (Hazard)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No presence (in the BCU or upstream of it)</td>
<td>1 - LOW</td>
</tr>
<tr>
<td>Presence (in the BCU or upstream of it)</td>
<td>3 - HIGH</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Vuln ↓ / Haz →</th>
<th>1 - LOW</th>
<th>3 - HIGH</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (low V)</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>2 (med V)</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>3 (high V)</td>
<td>3</td>
<td>9</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Risk scores from Table 3</th>
<th>Relative Risk categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 Very low</td>
</tr>
<tr>
<td>2</td>
<td>2 Low</td>
</tr>
<tr>
<td>3</td>
<td>3 Moderate</td>
</tr>
<tr>
<td>6</td>
<td>4 High</td>
</tr>
<tr>
<td>9</td>
<td>5 Very High</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Relative risk score</th>
<th>Relative risk category</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00 - 1.50</td>
<td>1 Very low</td>
</tr>
<tr>
<td>1.51 - 2.50</td>
<td>2 Low</td>
</tr>
<tr>
<td>2.51 - 3.50</td>
<td>3 Moderate</td>
</tr>
<tr>
<td>3.51 - 4.50</td>
<td>4 High</td>
</tr>
<tr>
<td>4.51 - 5.00</td>
<td>5 Very high</td>
</tr>
</tbody>
</table>

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.
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 ≤ CV ≤ 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’).
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 1° 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

<table>
<thead>
<tr>
<th>Exacerbating factor</th>
<th>a Water variability</th>
<th>b Water variability</th>
<th>c Intrastate conflict</th>
<th>d Interstate conflict</th>
<th>e Cooperation / conflict events</th>
<th>f Development status</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>CV: No change (Med or Low) OR decrease</td>
<td>Stable or Positive (&gt;0.1 to 0.39)</td>
<td>&lt; 3</td>
<td>No occurrence</td>
<td>≥ 0</td>
<td>≥ $1 035</td>
</tr>
<tr>
<td>1</td>
<td>CV: High present and future OR increase</td>
<td>Negative (≤-0.1 to -0.94)</td>
<td>≥ 3</td>
<td>Occurrence</td>
<td>&lt; 0</td>
<td>&lt; $1 035</td>
</tr>
</tbody>
</table>

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.
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. 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):

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>
<thead>
<tr>
<th>Relative risk category</th>
<th>Range (basin or BCU scores)</th>
<th>Interpretation of categories (status of enabling environment)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - Very Low</td>
<td>5.01 – 6</td>
<td>Highly advanced implementation</td>
</tr>
<tr>
<td>2 - Low</td>
<td>4.01 – 5</td>
<td>Advanced implementation</td>
</tr>
<tr>
<td>3 - Moderate</td>
<td>3.01 – 4</td>
<td>Some implementation</td>
</tr>
<tr>
<td>4 - High</td>
<td>2.71 – 3</td>
<td>Developed but low levels of implementation</td>
</tr>
<tr>
<td>5 - Very High</td>
<td>&lt;= 2.7</td>
<td>Under development</td>
</tr>
</tbody>
</table>

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.
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 Bazili (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;

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.
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)\(^\text{18}\). 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 focusing 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, it 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.
References


Petersen-Perlman, J.D. (2014). Mechanisms of cooperation for states’ construction of large-scale water infrastructure in transboundary river basins. Ph.D. Dissertation, Oregon State University, USA


