

**Metadata Sheet: Projected Environmental Water Stress for 2050s
(Indicator No. 1 – projected)**

Title:	<i>Environmental Water Stress: Environmental stress induced by Flow Regime Alterations (projected for 2050s)</i>
Indicator Number:	<i>1 – projected 2050</i>
Thematic Group:	<i>Water Quantity</i>
Rationale:	<p><i>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 both demand for water from other sectors (water quantity) and available water being polluted (water quality). The TWAP RB Environmental Water Stress indicator focuses on the water quantity aspect and considers hydrological alterations from monthly dynamics of the natural flow regime due to anthropogenic water uses, dam operations and climate change.</i></p> <p><i>The natural flow regime is assumed to provide the optimum conditions for the river ecosystem. In direct response to the natural flow regime and over evolutionary time spans, native biota has developed different morphological, physiological and behavioural traits. Provided habitats are exploited, all ecological niches are occupied and the natural range of flows can be tolerated by the endemic biota. Consequently, in basins/ BCUs with dam management and/ or high amounts of water abstractions, the natural flow regime can be altered beyond some admissible threshold. In the coming decades climate change will further modify river flow regimes by changes in precipitation patterns and amounts, as well as temperature (affecting evapotranspiration and snowmelt). These alterations are likely to increase the risk for ecosystem degradation and favour invasive species at the expense of adapted endemic species.</i></p>
Interlinkages:	<p><i>GW: Some ecosystems are dependent on healthy GW supplies, linked to recharge from rivers.</i></p> <p><i>Lakes: Lakes and river ecosystems are strongly interrelated, and environmental water stress in rivers is also likely to have an impact on lakes.</i></p> <p><i>LMEs: Quantity of water output to LMEs, particularly affecting estuarine areas where freshwater/saltwater interactions are important.</i></p>
Description:	<p>This indicator addresses environmental stress in the 2050s induced by flow regime alterations due to anthropogenic impacts such as dam operation, water use and climate change. The modified flow regimes are compared to the natural flow by means of 24 different sub-indicators which address monthly flow magnitudes (12 sub-indicators for Jan to Dec) as well as inter-annual flow variability (12 sub-indicators for Jan to Dec) of the monthly flow magnitudes. The underlying assumption of this approach is that the greater the deviations of the flow regime from natural flow conditions, the more severe are the negative impacts on the river ecosystem.</p>
Metrics:	<ul style="list-style-type: none"> ▪ Natural river discharge per grid cell computed for the time period 1971-2000 by CESR at 30 min. grid using the Global Hydrology sub-model WaterGAP2.2 (Müller Schmied et al. 2014). The meteorological data from WATCH (Weedon et al., 2011) are used to drive the model. ▪ Modified river discharge per grid cell computed for the time period 2041-2070 considering human impacts such as dam management (Hanasaki et al. 2006), future water use and climate change. Climate change is taken into account by considering projections of climate variables from 4 different GCMs (HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, and NorESM1-M) combined with an RCP8.5 emission-scenario. Future water use of the 2050s is calculated by the Global Water Use sub-

	<p>models of WaterGAP2.2 (made up of:</p> <ul style="list-style-type: none"> ○ Domestic demand: based on relationship between water use intensity and income using 'sigmoid curves' (Flörke et al. 2013). ○ Thermal electricity production demand (Flörke et al. 2013). ○ Manufacturing industry demand (Flörke et al. 2013), ○ Agricultural demand: based on irrigation and livestock demand (Alcamo et al. 2003, aus der Beek et al. 2010, Döll and Siebert 2002). Considers area equipped for irrigation (GMIv5, Siebert et al. 2013). <p>A differentiation of water withdrawn from surface and groundwater is made (Döll et al. 2012).</p>
<p>Computation:</p>	<p>Calculation of indicator was done in following steps:</p> <ol style="list-style-type: none"> 1. Simulation of natural river discharge for each grid cell (i.e., river discharge in the absence of human impacts) 2. Simulation of modified river discharge for each grid cell and for each climate projections (i.e., river discharge influenced by dam management, water use of different water use sectors, and climate change) 3. Calculation of the mean monthly magnitudes derived from the median of the monthly flow data of each year (12 sub-indicators) 4. Calculation of the inter-annual variability of the monthly flow data derived from the inter-quartile range (IQR) (12 sub-indicators) 5. Computation of the percentage alteration for each of the 24 sub-indicator and each grid cell 6. Applying a scoring system to determine the degree of flow regime alteration in each grid cell 7. Calculation of an average value for each BCU/ basin for each climate projection 8. Calculation of an ensemble median for the 2050s <p>Simulation of underlying data (1, 2):</p> <p>In order to simulate monthly river discharge for the natural flow regime (1971-2000; climate normal period) and the future modified flow regime (2050s), the global water model WaterGAP2.2 (Müller Schmied et al. 2014) was applied. While the WATCH Forcing Data (WFD, Weedon et al. 2011) were used as meteorological input for the baseline, climate projections from 4 different GCMs (HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, and NorESM1-M) combined with an RCP 8.5 emission scenario were used for the 2050s. All calculations were performed on the WaterGAP2.2 grid cell raster of 30 arc minute (longitude and latitude). In order to take into account future water consumption of the domestic and industry sectors (Flörke et al. 2013) as well as of irrigation and livestock, the global water use sub-models of WaterGAP2.2 were applied (Flörke et al. 2013, aus der Beek et al. 2010, Döll and Siebert 2002, Alcamo et al. 2003). To represent the changes in hydrologic dynamics due to reservoir management, the reservoir operation algorithm of Hanasaki et al. (2006) is applied in WaterGAP2.2 with minor modifications described by Döll et al. (2009). Based on information of the GRanD database (Lehner et al. 2011) and, in the case of Europe, additionally the EEA Eldredz, European Lakes, Dams and Reservoirs Database (Crutez, 2008), 1748 reservoirs (658 irrigation, 1090 non-irrigation) have been implemented in WaterGAP2.2. The criterion of implementation was a minimum reservoir storage volume of 0.1 km³. The hydrological modul of WaterGAP2.2 is calibrated and validated against measured river discharge and its reservoir algorithm against observed reservoir outflow (Döll et al. 2009, Müller Schmied et al. 2014). In addition, the water use sub-models were calibrated for the year 2005 and tested against historical trends (Flörke et al. 2013, aus der Beek et al. 2010). For the year 2005, simulated global water withdrawals of 3878 km³ are in good agreement with the latest value of 3752 km³ for the year 2006 provided by the FAO (2012). In order to allow for a spatially explicit analysis, country-wide values of domestic and</p>

manufacturing water use were allocated to the model's grid cells using demographic and socio-economic data (Flörke et al. 2013), while cooling water requirements were calculated location specific, i.e. already assigned to a grid cell. Water requirements for irrigated crops are computed on a 0.5° grid.

Calculation of mean magnitudes and inter-annual variability (3, 4):
 The selected 24 sub-indicators address the monthly flow magnitudes (Jan to Dec) and variability (Jan to Dec) and are derived from monthly flow data per year of record and per grid cell. In order to gain a single value per sub-indicator across the entire period, the magnitude was described by the median (i.e., 50th percentile) and the inter-annual variability by the inter-quartile range (IQR; i.e., difference between 75th and 25th percentiles) (Richter et al. 1997).

Computation of the percentage alteration (5):
 After computing the sub-indicators for the natural flow regime and the modified flow regime, the percentage differences were determined for each sub-indicator in each grid cell.

Applying a scoring system (6):
 The underlying assumption of this approach is that the greater the deviation of the flow regime from natural flow conditions (and the more sub-indicators are substantially modified), the more severe is the impact on the maintenance and health of a river ecosystem. Consequently, five different threshold levels were considered for this approach: ±20%, ±40%, ±60%, ±80% and ±100%. In case of one of these thresholds was exceeded by one of the 24 sub-indicators, a score of one (>±20%), two (>±40%), three (>±60%), four (>±80%) or five (>±100%) was added to the exceedance score. Hence, the exceedance score can range from 0 (=no substantial change to the natural flow regime) to 72 (=severe flow regime modification).

Determination of average BCU/ basin values (7):
 As results of the TWAP project are presented per BCU and transboundary river basin, the threshold exceedance score of all grid cells belonging to a BCU/transboundary river basin were summed up and divided by the total number of grid cells assigned to that BCU/transboundary river basin.

Calculation of an ensemble mean for the 2050s (8):
 For the final map, an ensemble median was calculated out of the 4 different model runs for the 2050s.

The indicator has been calculated for all TWAP RB basins which could be assigned on the WaterGAP2.2 grid cell raster. However, here it is necessary to note that verified conclusions can only be drawn for transboundary basins > 25,000 km², broadly equivalent to 10 grid cells at the equator. Hence, results for smaller basins are provided but might contain a lower level of confidence.

Units: A threshold exceedance score (see Computation)

Scoring system: Basins/ BCUs with a higher calculated score have a higher environmental water stress. For the baseline assessment, original scores were normalized to a range from 0 to 1. In order to be able to compare scenario with baseline results (i.e. to have the same relative risk category boundaries), the original scores for the basins/ BCUs were normalized here by the maximum values of the baseline, so that values above 1 are possible. The relative risk categories were assigned in the following way:

Relative risk category	Range (normalized score)	No. of Basins	Proportion of Basins	No. of BCUs	Proportion of BCUs
1 - Very low	0.00	0 (0*)	0 %	0 (0*)	0 %

	2 - Low	0.01 – 0.24	67 (38*)	25 %	176 (113*)	28 %
	3 - Moderate	0.25 – 0.49	84 (30*)	31 %	198 (116*)	31 %
	4 - High	0.50 – 0.74	33 (20*)	12 %	70 (41*)	11 %
	5 - Very high	0.75 – 1.60	86 (19*)	32 %	191 (73*)	30 %
	<p>* Number of basins/BCUs for which results have been calculated, but bear a lower level of confidence due to modeling limitations.</p> <p>Increasing deviations from natural flow patterns lead to increasing ecological consequences. Consequently, for basins in the higher relative risk categories, it is very likely that the natural flow regime is altered beyond some admissible threshold. This is likely to increase the risk for ecosystem degradation and to favour invasive species at the expense of adapted endemic species (flora and fauna).</p>					
Limitations:	<ul style="list-style-type: none"> Does not consider water quality (i.e. the indicator focuses on environmental water stress due to flow regime alterations. Further environmental stress can be caused by water quality issues.) Uncertainty of thresholds (i.e. no generalizable ecological-flow relationships are available for large-scale assessments. The applied thresholds are based on the 20 per cent rule likely indicating moderate to major changes in ecosystem structure and functions (Richter et al. 2012). Further, the same threshold was applied for all month) Verified conclusions can only be drawn for basins > 25,000 km². Results for basins smaller than this will still be produced, but with much higher levels of uncertainty. 					
Spatial Extent:	Global (transboundary river basins)					
Spatial Resolution:	Basin country unit (BCU) + river basin scale					
Year of Publication:	2015					
Time Period:	2050s (2041-2070)					
Additional Notes:						
Date:	27.01.2015					
Format:	Microsoft Excel Worksheet					
File Name:	TWAP_RB_indicator_01_2050s_results.xlsx					
Contact person:	Christof Schneider					
Contact details:	Center for Environmental Systems Research, Kurt-Wolters-Str.3, 34109 Kassel schneider@usf.uni-kassel.de, Phone: +49.561.804.6128					