12. Water stress

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12.1. Water consumption impacts on human health

12.1.1. Areas of protection and environmental mechanisms covered

The impact assessment method for assessing water consumption concerning the area of protection of human health is described based on Pfister et al. (2009) for the impact pathway (marginal CF), Pfister and Hellweg (2011) for uncertainty assessment, and Pfister and Bayer (2013) for average CFs.

Description of impact pathway

Water for food is one of the main global issues and irrigation is a limiting factor in agricultural production. Food supply is a vital human need and insufficient nutrition accounts for ~3% of overall global health impacts (WHO 2014) and further contributes to impacts form other diseases. While many factors contribute to this issue, reduced water availability caused by water consumption leads to reduced availability for food production and consequent yield losses. The impact pathway for this issue is addressing lack of water for agricultural food production and consequent effects on human health caused by water consumption as described in figure 12.1 and equation 12.1. There are two main parts: (1) a fate factor for water consumption coupled with an exposure factor of for agricultural water consumption, which is summarized as water deprivation factor on watershed level (WDF [$m^3_{deprived}/m^3_{consumed}$]) and (2) the effect factor (EF [cases· yr/$m^3_{deprived}$]), which relates malnutrition cases to a lack of water in agriculture. The fate and exposure is modeled by the water stress index (WSI), which indicates general water deprivation (affecting all users) and the share of water used in agriculture ($WU_{\%A}$) in order to account for the share that agriculture is affected by water deprivation, both ranging from zero to one.

The effect model relates lack of water in food production to malnutrition cases using statistical data analysis and minimum water requirements for personal food provision (WR_{MN}), resulting in a malnutrition potential caused by a lack of water for agriculture. The second part of the effect model accounts for the fact that reduced food production might be compensated by advanced means of technology to enhance food production (e.g. fertilization or irrigation with desalinated water) or imports from other regions. For this purpose the human development factor (HDF) ranging from zero to one, is derived based on the regression analysis of the human development index (HDI, a socio-economic development indicator) of a region and related malnutrition occurrence.

Finally, a damage factor (DF_{MN} [DALY/(yr·case)]) is applied, which relates disability-adjusted life years lost (DALY) from malnutrition to cases of undernourished person.

The counterintuitive fact that irrigated food production might lead to malnutrition due to a lack of water for other agricultural production is due to the fact that in LCA beneficial services of the system are covered in the functional unit (e.g. a kg of potato) and not discounted from the impact assessment. The overall effect of food production might therefore be beneficial for human health. However, whether the output is used for local food supply (directly avoiding the impact pathway), international food markets or biofuel production is part of the system definition and interpretation and therefore all potential impacts should be addressed by this impact pathway, even if water is consumed for crop production and not just for industrial or municipal purposes, especially when comparing two crops with different origins and life cycle water consumption.

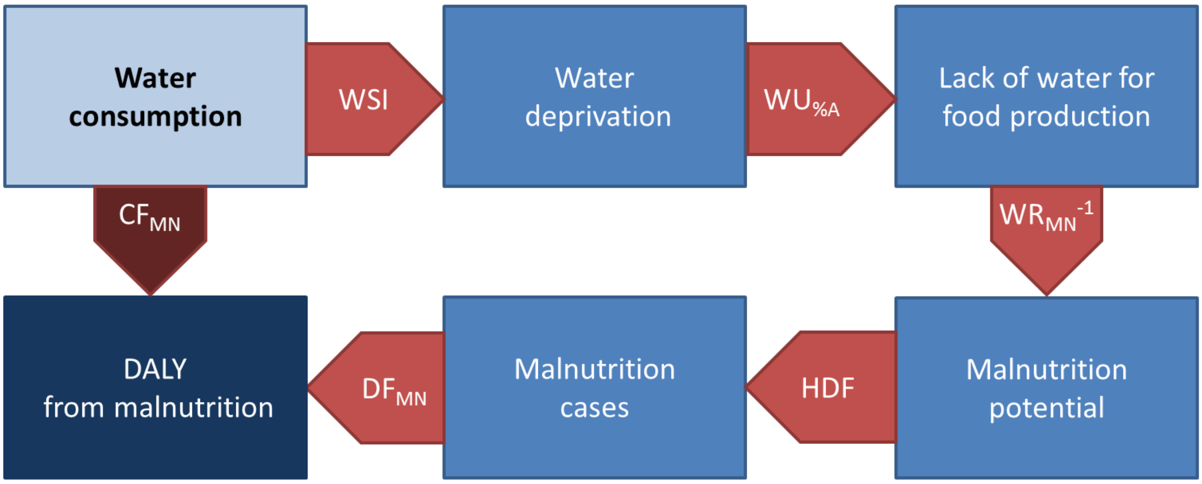

Figure 12.1: Cause-effect chain for human health impacts caused by water consumption. The interim steps of the impact pathways are depicted and the factors leading to them are described in equation 12.1.

$$CF_{end,MN,i} = \underbrace{WSI_i \cdot WU_{\%A,i}}_{WDF_i} \cdot \underbrace{HDF_i \cdot WR_{MN}^{-1}}_{EF_i} \cdot DF_{MN}$$

Equation 12.1

where $CF_{end,MN,i}$ [$DALY/m^3_{consumed}$] is the expected specific endpoint damage per unit of water consumed in watershed i (as specified in the LCI-phase) for malnutrition (MN).

Description of all related impact categories
This impact pathway only affects human health.

Methodological choice
Two different methods are available: (1) marginal CFs, which are typically used in LCA to address impacts of additional water consumption (marginal change in water consumption rate) and (2) average CFs, which are used to assess total impacts of water consumption within a region and to characterize the impact of an activity proportionally to the impact of total water consumption.

Spatial detail
The method was applied to >11'000 watersheds with varying sizes, resulting in a global coverage. Country-average CFs are available too. A global average is not considered meaningful but provided for background processes.

12.1.2. Calculation of the characterization factors at endpoint level

Marginal effect

The characterization factor is defined at the endpoint level in terms of DALY related to water consumption as described in figure 12.1 and equation 12.1. The specific factors are described below.

The water stress index (WSI) is used to indicate the ratio of water consumed that deprives other users in the same watershed of water. Water stress is commonly defined by the ratio of total annual freshwater withdrawals to hydrological availability (WTA), with moderate and severe water stress occurring above a threshold of 20% and 40%, respectively (Vorosmarty et al. 2000, Alcamo et al. 2000). However, such stress values on global level are expert judgments and thresholds for severe water stress might vary from 20% to 60% (Alcamo et al. 2000) if local conditions are accounted for. For this CF, the concept is extended to calculate a water stress index (WSI) for LCIA, ranging from zero to one. To calculate WSI, the WTA ratio of more than 10'000 individual watersheds described in WaterGAP2 global model (Alcamo et al. 2003) was used. This data is based on annual averages, but both monthly and annual variability of precipitation may lead to changed water stress during specific periods. Especially insufficient water storage capacities or evaporation of stored water may increase the stress. Such increased stress cannot be fully compensated by periods of low water stress (Alcamo et al. 2000). Therefore a variation factor (VF) is introduced to calculate a modified WTA (WTA^*, equation 12.2, figure 12.2), which differentiates watersheds with strongly regulated flows (SRF) from others, as defined by Nilsson et al. (2005). For SRF's, storage structures weaken the effect of variable precipitation significantly, but may cause increased evaporation and a reduced correction factor was applied (square-root of VF):

$$WTA^* = \begin{cases} \sqrt{VF} \times WTA & \text{for } SRF \\ VF \times WTA & \text{for } non\text{-}SRF \end{cases}$$

Equation 12.2

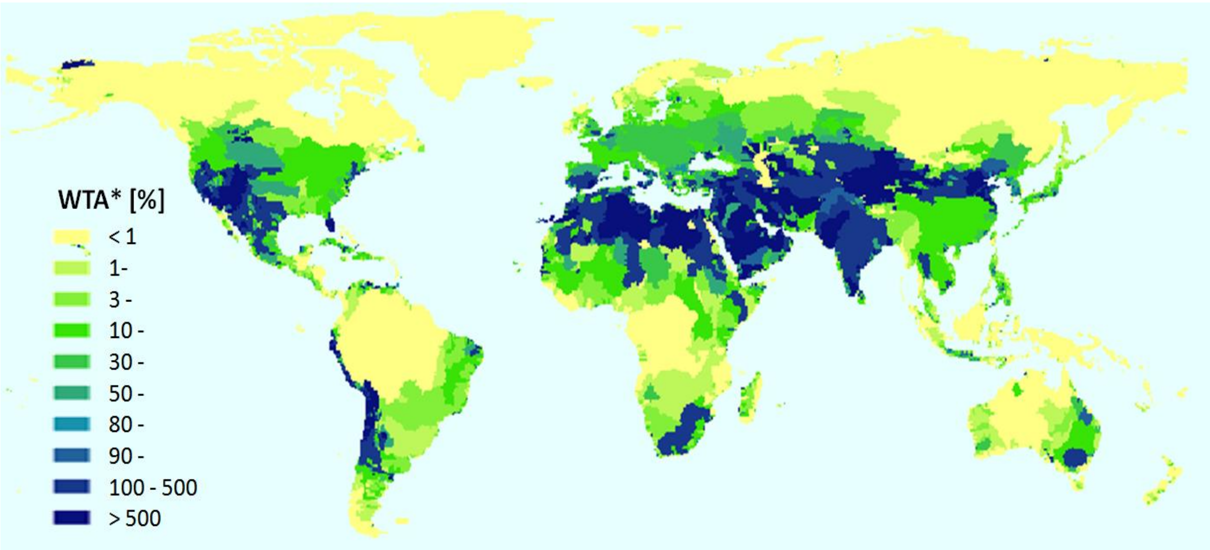

Figure 12.2: WTA^* calculated for each watershed in %. Adopted from Pfister et al. (2009).

VF was derived from the standard deviation of the monthly precipitation time series of CRU TS2.0 (Mitchell and Jones 2005). Since log-normal distribution was found to match better than normal distribution, VF was defined as the aggregated measure of dispersion of the multiplicative standard deviation of monthly (s^*_{month}) and annual precipitation (s^*_{year}), assuming a log-normal distribution and considering precipitation data from 1961-1990 (Mitchell and Jones 2005):

$$VF = e^{\sqrt{\ln(s^*_{month})^2 + \ln(s^*_{year})^2}}$$

Equation 12.3

Variation factors for each grid cell i (VF_i) are aggregated on a watershed-level (VF_{ws}, figure 12.3), weighted by the mean annual precipitation P_i [m] in grid cell i:

$$VF_{WS} = \frac{1}{\sum P_i} \sum_{i=1}^{n} VF_i \cdot P_i$$

Equation 12.4

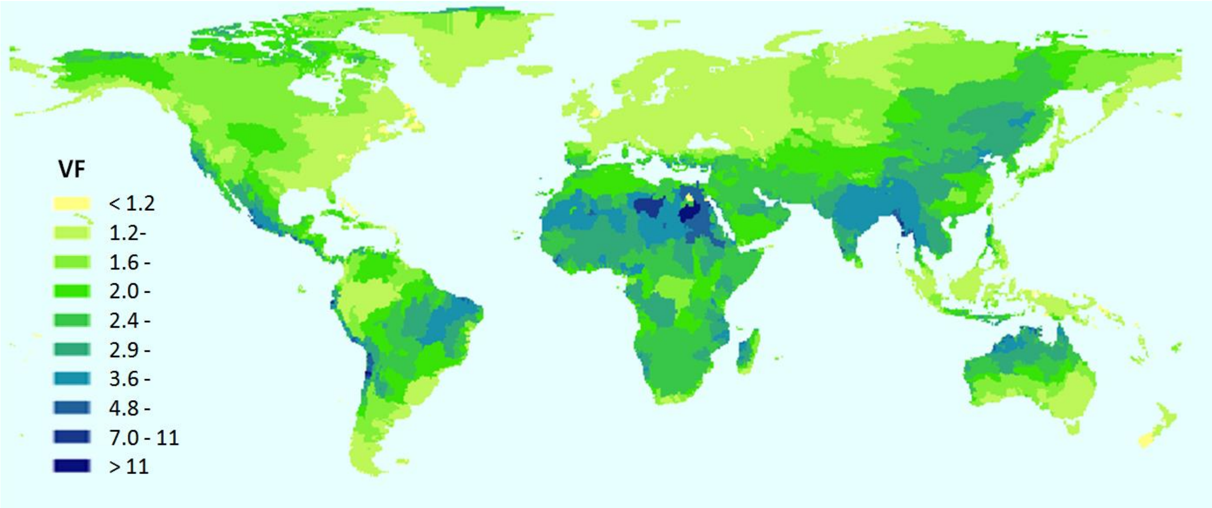

Figure 12.3: VF calculated for each watershed based on data for each 0.5° grid cell. Adopted from Pfister et al. (2009).

Water stress is an indicator for competition and therefore effects are not linear to WTA^* as also indicated by the water stress definitions. The water stress index (WSI, figure 12.4) is therefore adjusted to a logistic function to achieve continuous values between 0.01 (marginal effect in all regions) and 1:

$$WSI = \frac{1}{1 + e^{-6.4 \cdot WTA^*} \left(\frac{1}{0.01} - 1 \right)}$$

Equation 12.5

The curve is tuned to result a WSI of 0.5 for a WTA of 0.4, which is the threshold between moderate and severe water stress, when applying the median variation factor of all watersheds (VF_{median} = 1.8, WTA^* = 0.72). Accordingly, WTA of 0.2 and 0.6 result in WSI of 0.09 and 0.91, respectively (Figure 12.5a).

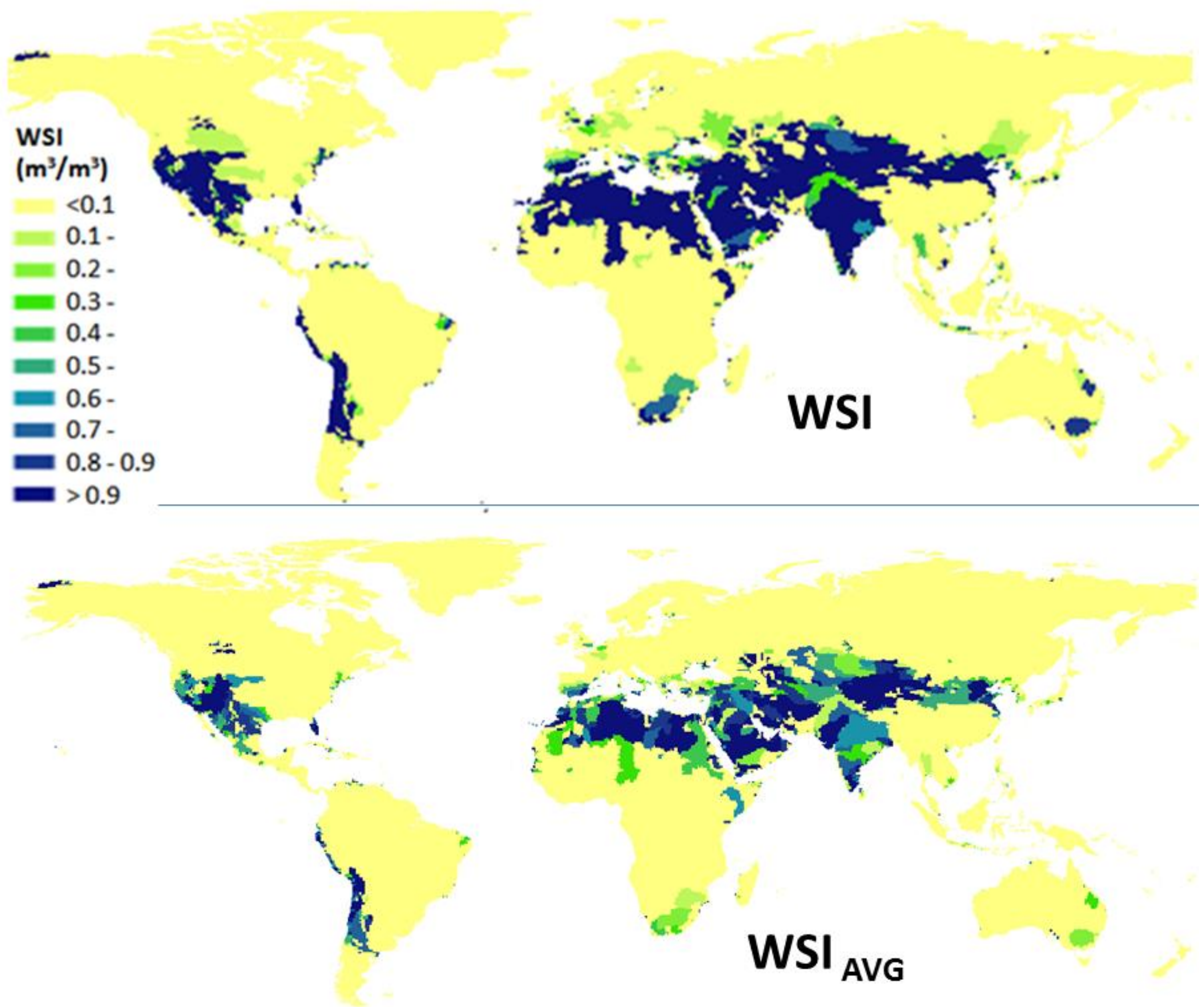

Figure 12.4: Top: Water stress index (WSI) indicating water deprivation potential (adopted from Pfister et al. 2009). Bottom: Average WSI (WSI_{AVG}, equation 12.8)

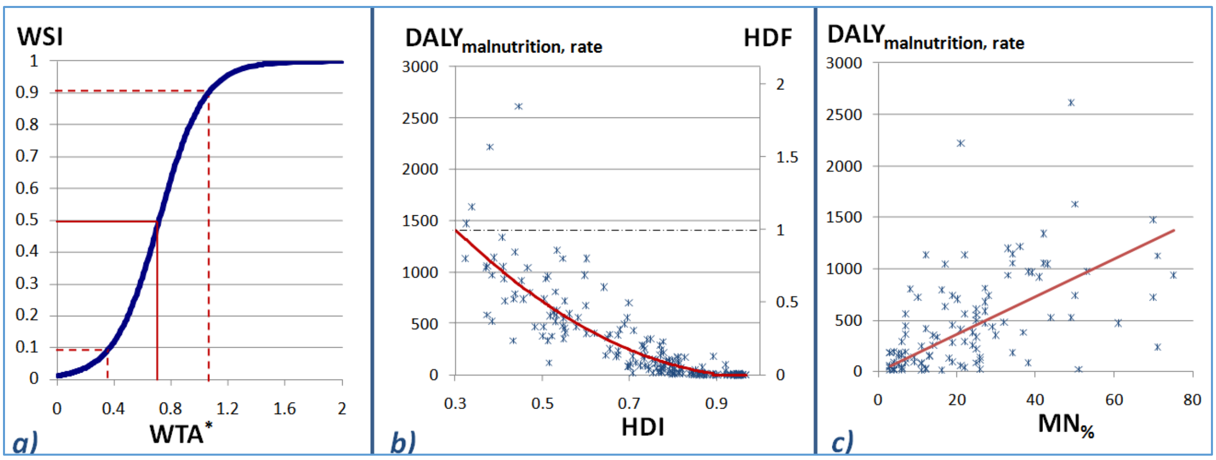

Figure 12.5: Inputs to the impact pathway: a) relation between WSI and WTA* (blue line, logistic function), b) $DALY_{malnutrition,rate}$ for each country (blue stars) and HDF modeled (red line, $R^2 = 0.71$) based on HDI, c) $DALY_{malnutrition,rate}$ for each country (blue stars) against corresponding $MN_{\%}$ and linear regression (red line, $R^2 = 0.26$). Adopted from Pfister et al. (2009).

Agricultural water use share ($WU_{\%,A,i}$) is calculated for each watershed based on 0.5° grid-data (Vorosmarty et al. 2000) and aggregated without further changes (figure 12.6). It accounts for the fact that agricultural water users might only be affected by the share of agricultural water use. In general agriculture is the most important user except in urban areas.

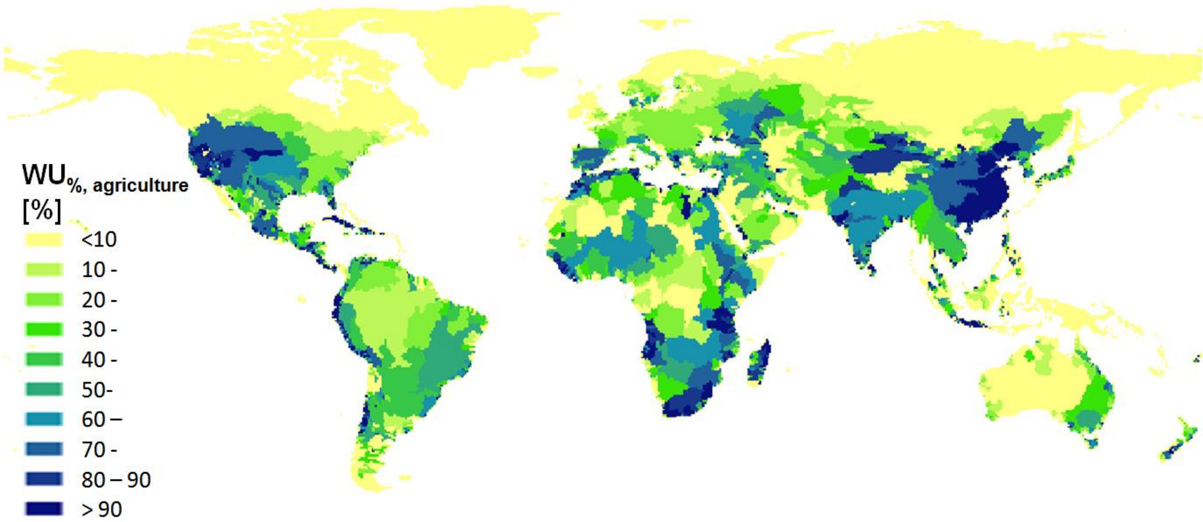

Figure 12.6: Agricultural water use ($WU_{\%,A}$) for each watershed (adopted from Pfister et al. 2009)

The human development factor ($HDF_{MN,i}$) relates the human development index (HDI) to malnutrition vulnerability. National HDIs are reported for all countries (UNDP 2008) and regional HDIs are applied for the large and spatially diverse emerging economies of India, Brazil, China, and Russia (see Pfister et al. 2009 for details). HDF_{MN} is derived from a polynomial fit of DALY values for malnutrition per 100'000 people in 2002 (WHO 2008) with corresponding HDI data (Figure 12.5b):

$$HDF_{MN} = \begin{cases} 1 & \text{for } HDI < 0.30 \\ 2.03\,HDI^2 - 4.09\,HDI + 2.04 & \text{for } 0.30 \le HDI \le 0.88 \\ 0 & \text{for } HDI > 0.88 \end{cases}$$

Equation 12.6

Regions with HDI > 0.88 are considered to have no direct local human health impacts due to adaptation capacity. The regional HDI values are attributed to watershed level based on the area intersections for cross-regional watersheds.

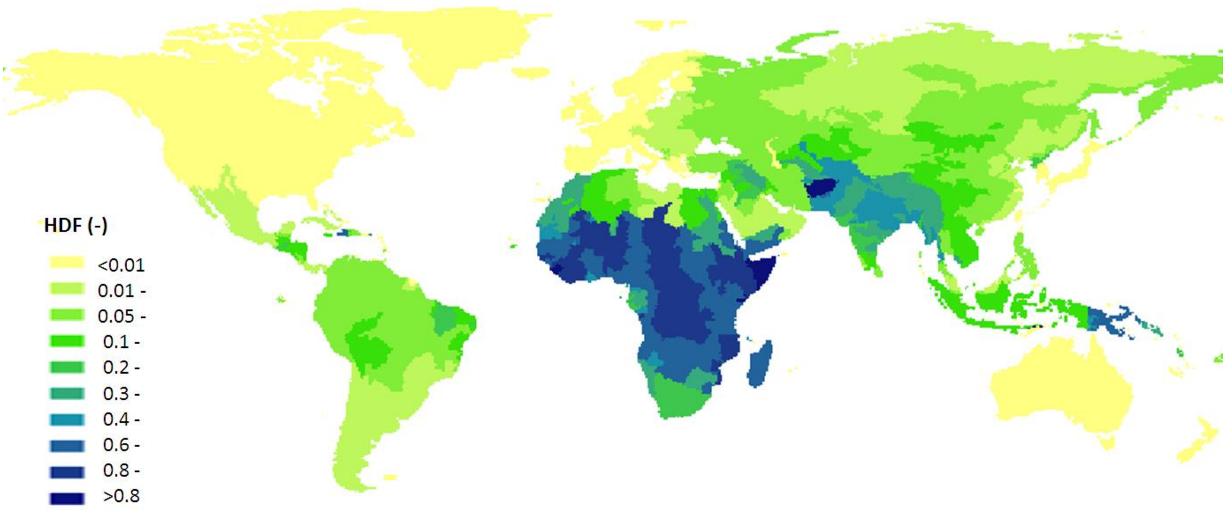

Figure 12.7: HDF_{MN} on watershed level (adopted from Pfister et al. 2009).

Water requirements (WR_{MN}) are used to relate cases of malnutrition to the lack of water for food production. WR_{MN} is set equal to 1,350 $m^3/(yr\cdot capita)$, which is the minimum direct human dietary requirement, including blue and green water (Falkenmark and Rockstrom 2004), accounting for food demand and water productivity of crops. This value matches modeled water resource thresholds for food security (Yang and Abbaspour 2003). While malnutrition already occurs before a person is completely deprived of food (e.g. at a lack of 20%), other compensation effects are assumed to happen (e.g. land use expansion, diet changes). The regression analysis of irrigation water consumption and malnutrition in water scarce developing countries on a global level by Pfister and Hellweg (2011) supported this value, resulting 0.0007 malnourished capita·yr per m^3 of water consumption, which corresponds to a WR_{MN} of ~1400 $m^3/(yr\cdot capita)$. $WR_{malnutrition}$ is a global factor and independent of location.

The damage factor (DF_{MN}) denotes the damage caused by malnutrition and is derived from linear regression of the malnutrition rate ($MN_{\%}$, Nilsson and Svedmark 2002) and $DALY_{malnutrition,rate}$ on country level (WHO 2008, Figure 12.5c) resulting in a per-capita malnutrition damage factor of $1.84\cdot10^{-2}$ DALY/(yr·capita).

DALY without age-weighting and discounting for malnutrition are 2.0 times the standard DALYs (3% discounting; age-weighting) originally used in Pfister et al. (2009), based on malnutrition DALY analysis from WHO reports (WHO 2008; WHO 2014)

Average effect

The characterization factor described above defines the marginal effect and is therefore a marginal CF. For the average CF ($CF_{end,MN, AVG}$), the average water stress index (WSI_{AVG}) is applied to quantify the average deprivation of other users. The other elements are already regional averages and do not have to be changed:

$$CF_{end,MN,AVGi} = WSI_{AVG,i} \cdot WU_{\%A,i} \cdot HDF_i \cdot WR_{MN}^{-1} \cdot DF_{MN}$$

Equation 12.7

$$WSI_{AVG} = \frac{\ln\left(e^{-6.4 \cdot WTA^*_{monthly}} + \left(\frac{1}{0.01} - 1\right)\right) - \ln\left(e^{-0} + \left(\frac{1}{0.01} - 1\right)\right)}{6.4 \bullet WTA^*}$$

Equation 12.8

12.1.3. Value choices

There are two sets of CFs available for (1) a marginal approach and (2) an average approach. However, within both sets there are no value choices.

Time horizon

The time horizon is infinite, assuming steady-state conditions. The effect of water consumption is described through competition for a renewable resource and therefore current stress levels are relevant. Monthly WSI assessment compatible to this approach have been recently published (Pfister and Bayer 2013) but the impact on human health through food production is based on annual water stress since food production is often based on different crops with different growth periods over several months and therefore a monthly assessment is difficult with currently existing data and is not considered to improve the results significantly.

Level of robustness

The model for human health impacts relies on global datasets and statistical analysis. There is no experimental data for this impact pathway and epidemiological data cannot definitely answer the cause-effect relation. Therefore the level of robustness is moderate for the whole characterization model and in comparison to other impact categories considered to have high level of robustness.
Excluded, due to a low level of robustness, is the effect of decreased food production on international markets and consequent effects in other countries through increased prices in globalized markets, as described in Motoshita et al. (2010b). They assume that if a loss in food production is not leading to local malnutrition effects it will lead to additional food import or reduced food exports and therefore affect countries with lower purchase power and lead to consequent effects on malnutrition in these countries. It might be included in future in the extended CF, once a full publication is available.
The level of robustness for impacts on human health due to a lack of water for domestic use (and consequent impacts on communicable diseases), as partially addressed by Motoshita et al. (2010a) and Boulay et al. (2011), are considered to be very low (Rijsberman 2006, Mila i Canals 2009, UNESCO 2003) and therefore this potential cause-effect chain is excluded.

12.1.4. Results

The range of CFs is from zero in economically developed regions up to ~10^{-4} DALY per m^3 of water consumed in economically less developed regions. In order to properly apply the CFs the geographic location needs to be known for attributing the proper watershed to the inventory. In cases where only national geographic information is available, country average CFs can be applied. Watershed characterization factors are aggregated to country level as withdrawal-weighted average based on the withdrawal data reported by WaterGAP2 (Alcamo et al. 2003) on watershed level. For cross-boundary watersheds, the withdrawal data has been allocated to countries according to the area share in each country. The results of the spatially explicit marginal and average CF are presented in Figure 12.8 on watershed level and. Country-aggregated CFs are provided as Excel table and in Table 12.1. The global average marginal CF 1.8 E-07 DALY /m^3 and the average CF is 1.3 E-07 DALY /m^3.

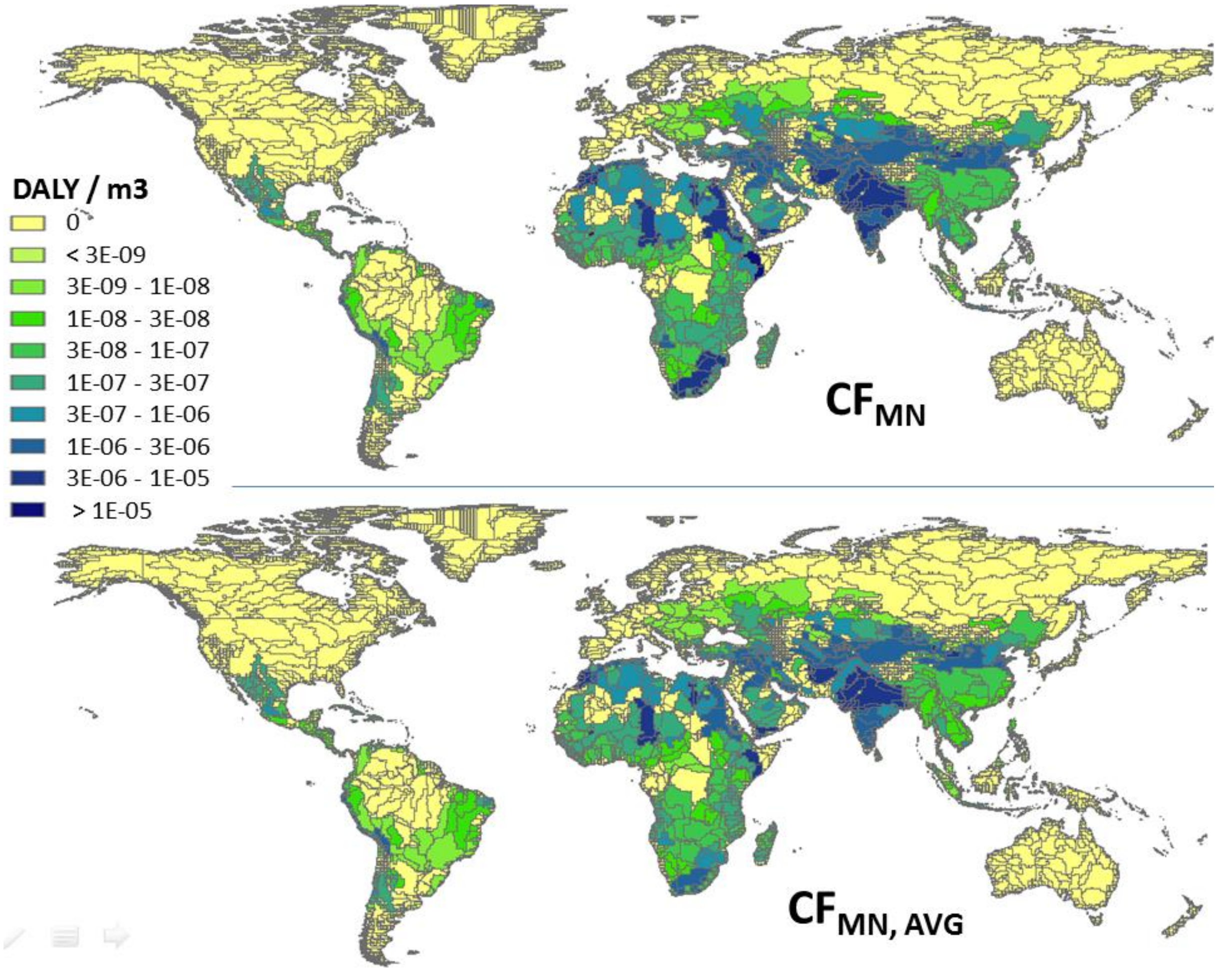

Figure 12.8: CFs for human health impacts caused by water consumption (adapted from Pfister et al. 2009). Top: Marginal CF ($CF_{MN, AVG}$); bottom: average CF ($CF_{MN, AVG}$).

Table 12.1: Overview of CFs on country basis for both marginal and average approach. All CFs are the same for all four CF versions, i.e. there is no distinction according to effects or time horizon (see also Excel file).

Country	$CF_{marginal,HH}$ [DALY/m^3]	$CF_{average,HH}$ [DALY/m^3]
Afghanistan	3.2E-06	3.2E-06
Albania	1.1E-07	5.0E-08
Algeria	1.5E-06	1.5E-06
Angola	1.7E-07	1.3E-07
Argentina	7.2E-08	3.2E-08
Armenia	1.3E-06	1.3E-06
Australia	0.0E+00	0.0E+00
Austria	8.6E-09	3.8E-09
Azerbaijan	1.2E-06	1.2E-06
Bangladesh	4.3E-06	1.9E-06
Belarus	9.8E-09	4.3E-09
Belgium	0.0E+00	0.0E+00
Belize	9.6E-09	9.4E-09
Benin	1.2E-07	1.0E-07
Bhutan	8.0E-08	6.6E-08
Bolivia	9.4E-07	4.1E-07
Bosnia and Herzegovina	6.8E-09	3.0E-09
Botswana	2.3E-06	2.3E-06
Brazil	3.9E-08	3.9E-08
Brunei	0.0E+00	0.0E+00
Bulgaria	1.6E-07	7.2E-08
Burkina Faso	8.2E-08	6.7E-08
Burundi	9.8E-08	9.0E-08

Cambodia	1.3E-07	5.9E-08
Cameroon	2.7E-08	2.6E-08
Canada	0.0E+00	0.0E+00
Central African Republic	5.0E-09	5.0E-09
Chad	1.7E-07	1.4E-07
Chile	3.1E-07	3.1E-07
China	6.3E-07	2.8E-07
Colombia	2.9E-08	2.9E-08
Congo (Democratic Republic of the)	2.6E-08	2.6E-08
Congo (Republic of the)	3.5E-08	3.5E-08
Costa Rica	1.8E-08	1.5E-08
Cote d'Ivoire	5.4E-08	5.0E-08
Croatia	8.8E-09	8.8E-09
Cuba	2.0E-07	9.0E-08
Cyprus	0.0E+00	0.0E+00
Czech Republic	2.5E-09	1.1E-09
Denmark	0.0E+00	0.0E+00
Djibouti	4.6E-07	4.6E-07
Dominican Republic	2.5E-07	1.1E-07
Ecuador	4.0E-07	1.8E-07
Egypt	3.5E-06	3.5E-06
El Salvador	4.7E-08	3.9E-08
Equatorial Guinea	5.3E-11	5.2E-11
Eritrea	1.0E-06	4.5E-07
Estonia	8.2E-10	6.7E-10
Ethiopia	1.5E-06	6.7E-07
Fiji	1.8E-08	1.8E-08
Finland	8.8E-11	3.9E-11
France	0.0E+00	0.0E+00
French Guiana	1.8E-12	1.8E-12
Gabon	1.1E-09	1.1E-09
Gambia, The	6.5E-08	5.3E-08
Georgia	9.1E-07	9.1E-07
Germany	1.0E-09	4.4E-10
Ghana	2.5E-07	2.5E-07
Greece	5.6E-08	5.6E-08
Guatemala	3.3E-08	3.0E-08
Guinea	1.5E-07	1.2E-07
Guinea-Bissau	1.4E-07	1.3E-07
Guyana	2.0E-08	1.9E-08
Haiti	3.8E-07	3.8E-07
Honduras	4.7E-08	4.5E-08
Hungary	8.8E-09	3.9E-09
Iceland	0.0E+00	0.0E+00
India	4.5E-06	4.5E-06
Indonesia	3.9E-07	1.7E-07
Iran	1.4E-06	1.4E-06
Iraq	2.1E-06	2.1E-06
Ireland	0.0E+00	0.0E+00
Israel	2.2E-07	2.2E-07
Italy	0.0E+00	0.0E+00
Jamaica	2.0E-08	1.8E-08
Japan	0.0E+00	0.0E+00
Jordan	8.8E-07	8.8E-07
Kazakhstan	4.9E-07	2.2E-07
Kenya	1.2E-07	9.8E-08
Korea, Democratic People's Republic of	1.2E-06	5.5E-07
Korea, Republic of	0.0E+00	0.0E+00
Kuwait	1.3E-08	1.3E-08
Kyrgyzstan	1.6E-06	1.6E-06
Laos	3.6E-08	2.9E-08
Latvia	9.2E-10	7.5E-10

Lebanon	1.1E-06	1.1E-06
Lesotho	3.2E-06	3.2E-06
Liberia	1.2E-07	1.2E-07
Libya	9.4E-07	9.4E-07
Lithuania	1.1E-09	1.1E-09
Luxembourg	0.0E+00	0.0E+00
Macedonia	4.4E-07	1.9E-07
Madagascar	2.2E-07	1.8E-07
Malawi	1.1E-07	1.0E-07
Malaysia	8.4E-09	8.4E-09
Mali	3.1E-06	1.4E-06
Mauritania	1.4E-07	6.2E-08
Mexico	3.4E-07	3.4E-07
Moldova	7.2E-08	3.2E-08
Mongolia	2.9E-08	2.9E-08
Morocco	3.9E-06	3.9E-06
Mozambique	9.7E-07	4.3E-07
Myanmar (Burma)	4.8E-08	3.9E-08
Namibia	5.4E-08	4.4E-08
Nepal	5.8E-06	5.8E-06
Netherlands	0.0E+00	0.0E+00
New Zealand	0.0E+00	0.0E+00
Nicaragua	7.0E-08	5.7E-08
Niger	1.2E-06	5.5E-07
Nigeria	2.4E-06	1.0E-06
Norway	0.0E+00	0.0E+00
Oman	7.7E-07	7.7E-07
Pakistan	4.4E-06	4.4E-06
Palestine Territory (West Bank)	4.2E-07	4.2E-07
Panama	1.3E-08	1.2E-08
Papua New Guinea	0.0E+00	0.0E+00
Paraguay	7.4E-09	7.1E-09
Peru	1.3E-06	1.3E-06
Philippines	3.1E-07	1.4E-07
Poland	3.9E-09	3.9E-09
Portugal	0.0E+00	0.0E+00
Puerto Rico	0.0E+00	0.0E+00
Qatar	2.4E-07	2.4E-07
Romania	1.3E-08	5.5E-09
Russia	1.1E-07	4.8E-08
Rwanda	6.8E-08	5.5E-08
Saudi Arabia	1.1E-06	1.1E-06
Senegal	1.3E-07	5.9E-08
Serbia and Montenegro	1.4E-08	6.2E-09
Sierra Leone	1.9E-07	1.9E-07
Slovakia	8.4E-09	3.7E-09
Slovenia	8.8E-09	3.9E-09
Solomon Islands	0.0E+00	0.0E+00
Somalia	1.8E-06	7.8E-07
South Africa	2.4E-06	2.4E-06
Spain	0.0E+00	0.0E+00
Sri Lanka	1.9E-06	8.3E-07
Sudan	9.8E-07	4.3E-07
Suriname	1.4E-08	1.3E-08
Swaziland	3.1E-07	2.5E-07
Sweden	0.0E+00	0.0E+00
Switzerland	1.9E-10	8.3E-11
Syria	1.9E-06	1.9E-06
Tajikistan	2.6E-06	2.6E-06
Tanzania, United Republic of	1.3E-07	1.3E-07
Thailand	3.2E-07	1.4E-07
Timor Leste	0.0E+00	0.0E+00
Togo	6.0E-08	5.1E-08

Trinidad and Tobago	2.0E-07	8.7E-08
Tunisia	1.8E-06	1.8E-06
Turkey	1.1E-06	1.1E-06
Turkmenistan	1.8E-06	1.8E-06
Uganda	6.8E-08	5.5E-08
Ukraine	2.9E-07	1.3E-07
United Arab Emirates	4.3E-07	4.3E-07
United Kingdom	0.0E+00	0.0E+00
United States	4.3E-09	1.9E-09
Uruguay	4.6E-09	4.5E-09
Uzbekistan	2.2E-06	2.2E-06
Vanuatu	0.0E+00	0.0E+00
Venezuela	2.3E-07	1.0E-07
Vietnam	7.8E-07	3.4E-07
Western Sahara	4.2E-10	1.9E-10
Yemen	5.2E-06	5.2E-06
Zambia	9.6E-08	9.4E-08
Zimbabwe	7.2E-07	3.2E-07

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12.2. Water consumption impacts on ecosystems

12.2.1. Areas of protection and environmental mechanisms covered

The description of the impact assessment approach for quantifying impacts from water consumption on biodiversity is based on Verones et al. (2017), which is a continuation from Verones et al. (2013a) and Verones et al. (2013b), as well as Chaudhary et al. (2015).

Description of impact pathway

Water is one of the most important resources for both humans and ecosystems. The human population consumes 1-2 trillion m^3 of water each year (WATCH 2011). Of all water used ~70% are used for agriculture as irrigation water, of which 71 % is withdrawn from surface water (World Water Assessment Programme 2009). It is expected that water for crop production will keep increasing in many parts of the world, because of climate change as well as a growing population with consequently larger food demands (Palmer et al. 2009). This might increase irrigation water consumption by ~60% by 2050 (Pfister et al. 2011b). The expansion of human water consumption, increases the pressure on ecosystems that are competing for the same resource (Vörösmarty et al. 2005), which is already highly problematic in many regions. Here, we cover biodiversity impacts of water consumption in wetlands as proxies for aquatic and riparian habitat, as well as impacts of water consumption on vascular plants as proxy for more terrestrial systems. According to the Ramsar Convention, wetlands are defined as "areas of marsh, fen, peatland, or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish, or salt, including areas of marine water the depth of which at low tide does not exceed six metres" (Ramsar Convention 1994). We only include freshwater systems in our wetland assessment and thus exclude marine and coastal, saltwater influenced wetlands. In these coastal systems a lack of water is often less of a problem, since missing freshwater can be replaced by saltwater. This changes the salinity of the wetlands, which is another impact pathway (Amores et al. 2013) than the one described here, which is focusing on the physical availability of water only. In order to represent biodiversity as good as possible it is advantageous to use a combination of multiple taxonomic groups (Larsen et al. 2012). Species from 5 taxonomic groups were included as proxies for biodiversity (amphibians, reptiles, birds, mammals and vascular plants).

<u>Aquatic and riparian habitats</u>

The quantification of impact consists of a fate and an effect part (Figure 12.9). The fate factor (FF) [$m^2 \cdot yr/m^3$] quantifies the potential change in wetland area[1] due to an increase of water consumption. We distinguish between changes in either groundwater table or surface water volume that both ultimately lead to change in wetland area. The effect factor (EF) [species-eq/m^2] quantifies the potential loss of species diversity on each square meter of lost wetland area. In addition to counting the number of species that is lost, we also introduce a vulnerability score for each taxon (VS) into the effect factor. VS is informing about the global vulnerability of species to extinction, by taking into account the threat levels of the IUCN Redlist and the individual geographic range area of each species (IUCN 2012). Aggregating the species-equivalents, as described in the framework chapter, results in the CFs being in PDF·yr/m^3. Both fate and effect factors are calculated for more than 20'000 wetlands globally and then assigned to watersheds based on the individual catchment of each wetland, in order to account for the spatial aspect of water consumption. Some wetlands are not included and therefore CF may underestimate the impacts in some areas.

[1] note that we use the term "wetland" for all waterbodies, according to the Ramsar convention, i.e. for lakes, rivers, swamps, etc.

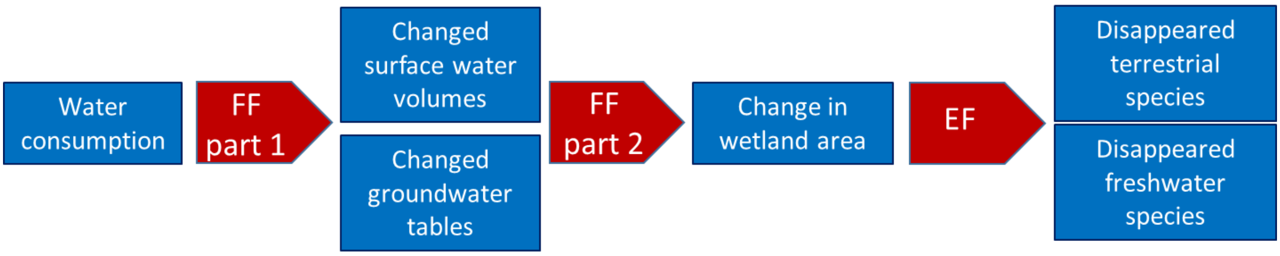


Figure 12.9: Cause-effect chain for modelling the potential loss of species due to water consumption in aquatic and riparian habitat.

The characterization factor at endpoint level ($CF_{end,\ i,t}$) for each watershed i and taxonomic group t is thus calculated according to equation 12.9. Taxonomic groups used are birds, mammals, reptiles and amphibians.

$$CF_{end,i,t} = \frac{\sum_{i,k=1}^{n} FF_{k,t} \cdot EF_{k,t}}{S_t \cdot VS_t}$$

Equation 12.9

Where $FF_{k,t}$ is the fate factor of wetland k and taxonomic group t and $EF_{k,t}$ is the effect factor of wetland k and taxonomic group t. S and VS are the species richness and vulnerability score of taxonomic group t, respectively and are used to transform the species-equivalents to PDF again. Keep in mind that these are global extinctions. These CFs have a spatial coverage indicating the "catchment" area of each wetland (i.e. the area that has an influence on the respective wetland). Note that the CF can vary within one watershed, since not all wetlands are affected by all water consumption in the watershed (i.e. they are not affected if they lie upstream of the location where water consumption happens) (see also explanation further below and figures 12.13 and 12.14).

Terrestrial habitats

The characterization factor consists of a fate and an effect part (Figure 12.10).

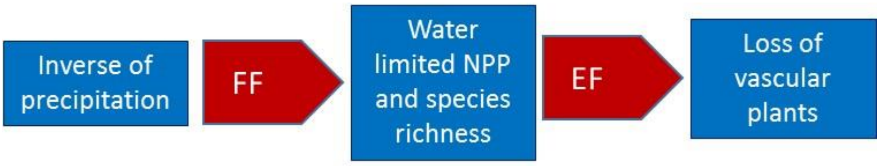


Figure 12.10: Cause-effect chain for modelling the potential loss of species due to water consumption in terrestrial habitat.

The FF [$m^2 \cdot yr/m^3$] indicates for each watershed the land occupation required to generate a volume of water consumed as the inverse of precipitation (see also Pfister et al. (2009)). The FF thereby accounts for the fact, that the water cycle includes interactions with soil and terrestrial ecosystems from a more conceptual perspective. The EF [species-eq/m^2] is quantifying vascular plant species loss per region, based on the water limited share of net primary productivity of plants, endemic species richness and the regional species accumulation factor z (Pfister et al. 2010). The CFs are calculated on a watershed basis w for the taxonomic group of vascular plants. In order to derive global PDF, we divide with the global richness of vascular plants (equation 12.10)

$$CF_{end,w} = \frac{FF_w \cdot EF_w}{S_{plants}}$$

Equation 12.10

Where FF_w is the average fate factor on a watershed basis and EF_w is the effect factor on a watershed basis for vascular plants. S is the global species number of vascular plants. Due to unavailability of data VS was assumed to be 1 for plants.

Description of all related impact categories

This impact pathway only affects ecosystem quality.

Methodological choice

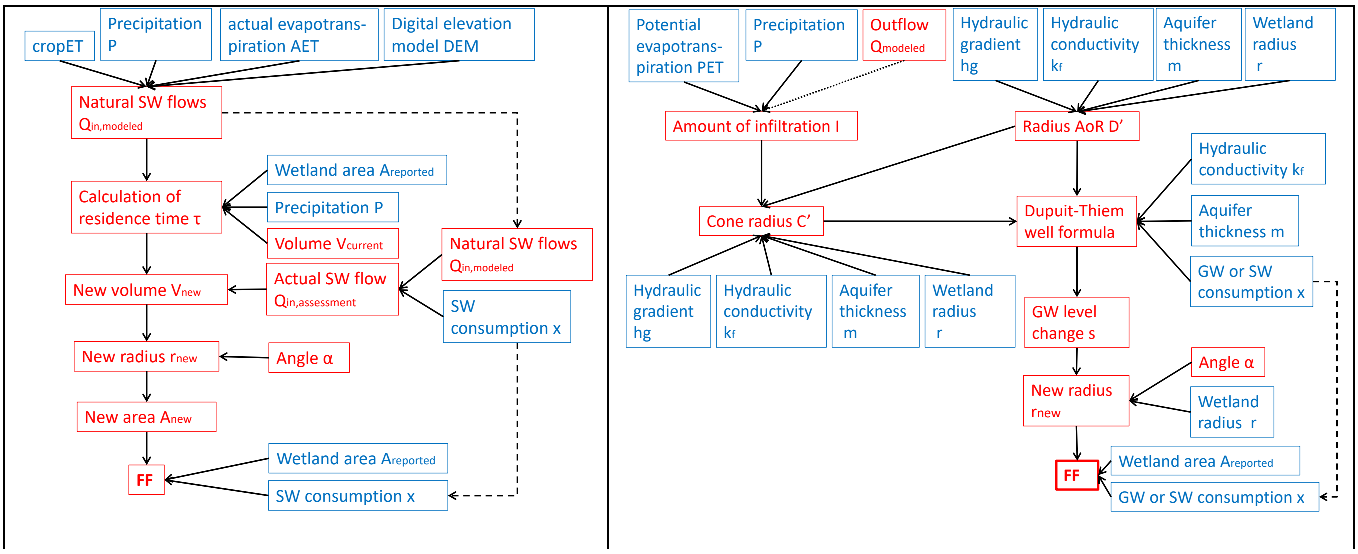
There is one method available, which assesses impacts on wetland biodiversity (animal species) from marginal changes in water consumption and one that assesses the marginal impacts on vascular plants species. We include a vulnerability score for animal species. The aggregation procedure between the taxonomic groups is described in the framework chapter. The aggregation between plants and animals is achieved by taking the average between the aggregated animal CF and the plant CF.

Spatial detail

Characterization factors (CFs) are available for the globe with a resolution of 0.05° x 0.05° (see also explanation on assigning wetland specific factors to hydrologically relevant units below). Country-averaged CFs and continental averages are available too. A global average is provided for background processes. Averaging was based on total consumption of the year 2010 (for irrigation, livestock, municipal use, electricity generation and manufacturing) based on Pfister et al. (2011a) and WATCH (2011).

12.2.2. Calculation of the characterization factors at endpoint level – animal species

The fate factor (FF) is used to indicate the change in wetland area due to water consumption. In the modelling procedure we distinguish between wetlands that are fed by surface water (e.g. by rivers and creeks, precipitation or snowmelt) and wetlands that are predominantly fed by groundwater. The former are only affected by surface water consumption, the latter only by groundwater abstraction. We assume that there is no interaction between surface and groundwater and a wetland is either purely dependent on surface water or purely dependent on groundwater, in order to account for the dominant hydrological process. All wetlands are modelled as circular cones. A graphical representation of the modelling procedure is shown in Figure 12.11.



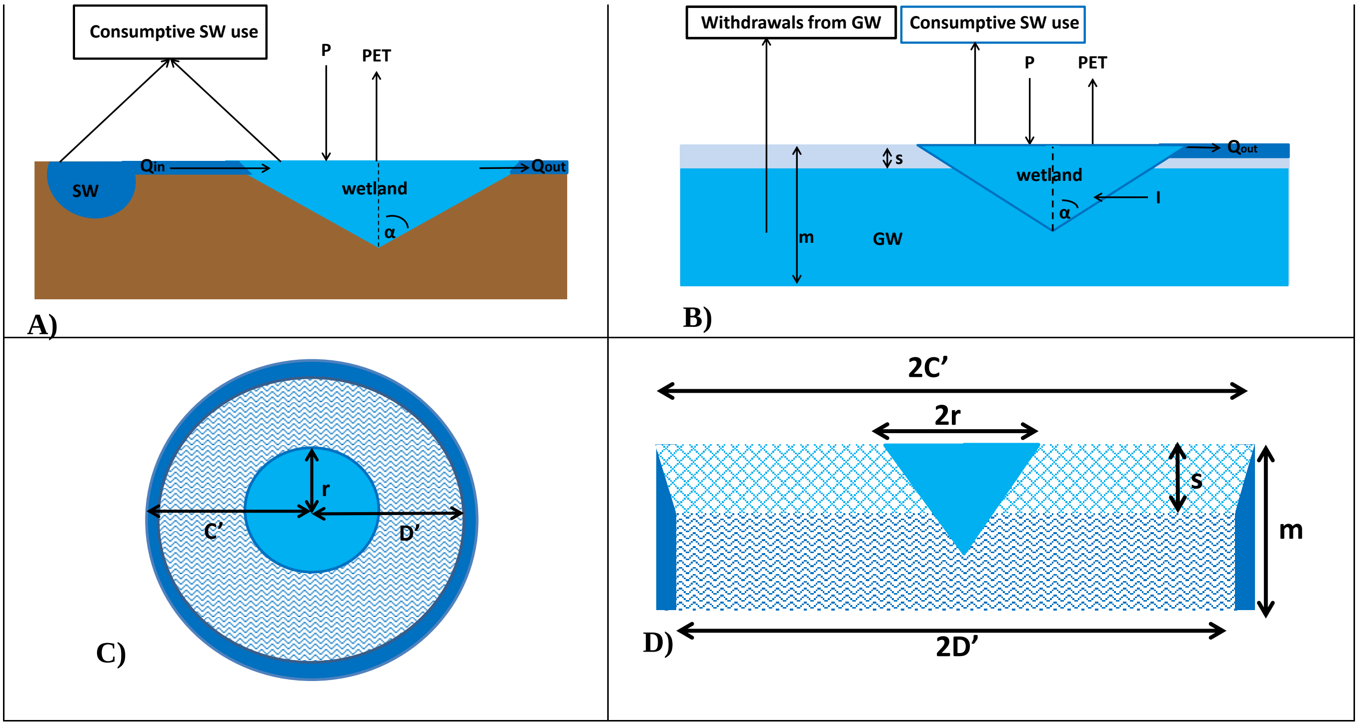


Figure 12.11: Schematic representation of the calculation procedure of the FF for A) surface water-fed (SW) wetlands and B) groundwater-fed (GW) wetlands. Red boxes show modelled parameters, blue boxes show empirical data inputs (for data sources see Verones et al. (2013a)). The dotted lines in pictures A) and B) show that this parameter is only required in some cases. The dashed lines show that parameters in those boxes are the same. Pictures C and D show schematically the way of calculating groundwater drawdowns. The radius of the wetland is r. The defined area of relevance (radius D') is assumed as the hypothetical well, leading to a depression cone with radius C'. In picture D a cross section of the situation in C is shown, with the aquifer thickness m. The wetland is shown as blue triangle. Picture adopted from Verones et al. (2013a).

The FF for both surface water (SW)-fed and groundwater (GW)-fed wetlands is calculated for each wetland k as shown in equation 12.11 where $A_{reported}$ is the reported, empirically known wetland area and A_{new} is the modelled wetland area after water consumption x. We assume x to be an increase in consumption of 1000 m^3/yr.

$$FF_k = \frac{(A_{reported,k} - A_{new,k})}{x_k}$$

Equation 12.11

For SW-fed wetlands A_{new} is calculated according to equation 12.12, based on a new wetland radius r_{new}. The new wetland volume V_{new} is estimated based on a change in residence time τ and a change in water inflow, due to water consumption x. Angle α is the angle between the embankment of the wetland and an imaginary, vertical line at the center of the wetland, estimated from actual wetland depth and size.

$$A_{new} = r_{new}^2 \cdot \pi = \left(\left(\frac{3}{\pi} \cdot V_{new} \cdot \tan(\alpha) \right)^{\frac{1}{3}} \right)^2 \cdot \pi$$

Equation 12.12

For groundwater-fed wetlands we assume that the wetland is acting like a pump (through evapotranspiration and outflow). Thereby the evapotranspiration is the driving force and causes water from a certain area around the wetland (denoted area of relevance, AoR) to flow towards the wetland.

The AoR is at least the size of the wetland itself and is calculated based on the infiltration into a wetland, hydraulic conductivity and aquifer thickness of at each wetland's site. Both hydraulic conductivity and aquifer thickness are empirical data inputs. The new wetland area A_{new} is calculated as shown in equation 12.13 where $r_{reported}$ is the radius from the reported wetland area and s is the drawdown of the water level in the wetland that is created due to water abstraction.

$$A_{new} = r_{new}^2 \cdot \pi = \left(-s \cdot tan(\alpha) + r_{reported}\right)^2 \cdot \pi$$

Equation 12.13

Assuming steady-state conditions the depth of the depression cone stems from equation 12.14, which is the well formula of Thiem-Dupuit (Stelzig 2012). We set x_{GW} to 1000 m^3/yr and used this equation to determine the drawdown s.

$$x_{GW} = k_f \cdot \pi \cdot \frac{m^2 - (m-s)^2}{ln\frac{C'}{D'}}$$

Equation 12.14

C' and D' are the radius of the depression cone and the radius of the area of relevance, respectively. The latter is calculated based on the amount of infiltration I that reaches the wetland in a given hydrogeological setting with hydraulic conductivity k_f, aquifer thickness m and a pre-defined minimal hydraulic gradient to have an influence (a gradient is needed for water to flow). The radius of the area of relevance D' is at least the same value like the wetland radius r before water consumption. D' is used to determine the area of the respective CF. The radius of the cone C' is calculated analogously, but in addition to the infiltration amount required to sustain the wetland at the area it is now, also the amount x_{GW} has to be covered and therefore the CF is non-linear and depending on the x_{GW} used. Further details and formulae can be found in Verones et al. (2013a).

The effect factor (EF) is based on the species-area relationship for estimating the potential loss in species. The number of lost species is quantified with equation 12.15 where S_{lost} is the number of lost species, A_{new} and $A_{reported}$ are the new and empirically reported wetland area and $S_{original}$ is the original species richness. The exponent z indicates the slope of the species-area relationship and differs for each taxonomic group (birds: 0.37, mammals: 0.34, amphibians: 0.2, reptiles: 0.33). We calculated these values from Drakare et al. (2006), as explained in further detail in Verones et al. (2013b).

$$S_{lost} = \left(1 - \left(\frac{A_{new}}{A_{reported}}\right)^z\right) \cdot S_{original}$$

Equation 12.15

The values for $S_{original}$ are taken from global species maps that we calculated from IUCN data on geographical ranges of individual species (IUCN 2013b). Note that these maps (see example in Figure 12.12) are based on current species richness, i.e. species that are already extinct are excluded.

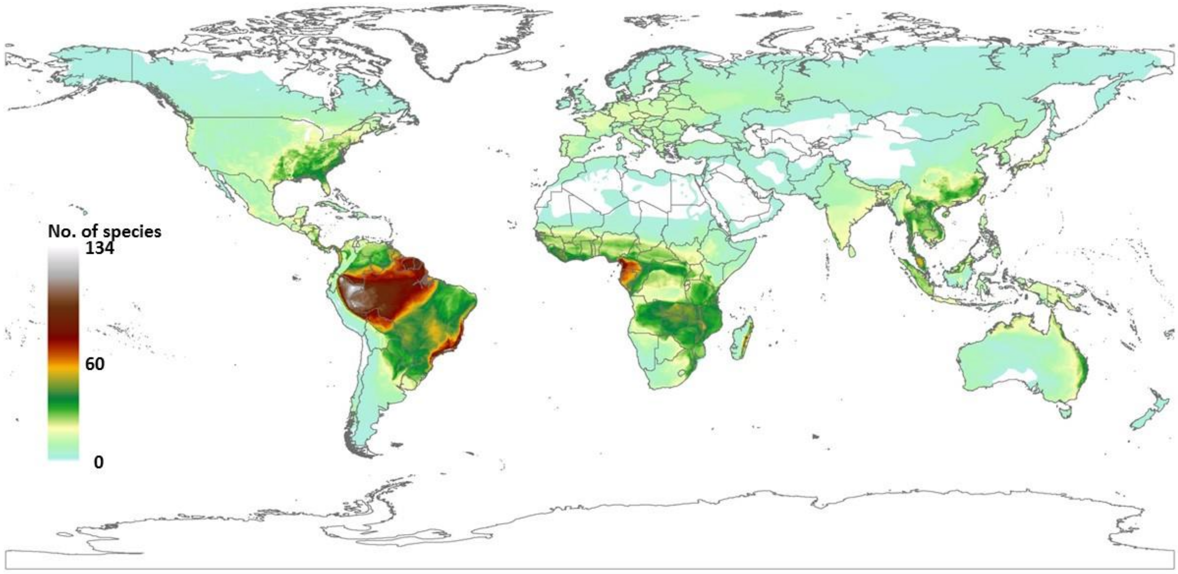


Figure 12.12: Map showing the species numbers of amphibians with a resolution of 0.05° x 0.05°. Data from IUCN (2013b). Adopted from Verones et al. (submitted).

The EF of wetland k for taxonomic group t is then calculated as shown in equation 12.16 based on the numbers of lost species S_{lost} per taxonomic group t and the loss in area that has already been calculated in the fate factor calculation. $VS_{k,t}$ is the vulnerability score of taxonomic group t in wetland k. This is important to translate local species loss into global species loss equivalents.

$$EF_{k,t} = \frac{S_{lost,k,t}}{A_{reported,k} - A_{new,k}} \cdot VS_{k,t}$$

Equation 12.16

The vulnerability score is derived from information on IUCN threat levels (IUCN 2013a) and the geographical range areas of species (IUCN 2013b) for each taxonomic group t according to equation 12.17. TL is the threat level of species i and GR is the geographical range of species i. The average VS of all species within a taxa is calculated on a pixel level (0.05° x 0,05°), denoted j. VS varies between 0 and 1. The values for the TL are chosen on a linear scale: 0.2-least concern, 0.4-near threatened, 0.6-vulnerable, 0.8-endangered, 1-critically endangered.

$$VS_{t,j} = \frac{\sum_{i=1}^{n} \frac{TL_{i,j} \cdot GR_{i,j}}{\sum_{i,j=1}^{m} GR_{i,j}}}{S_{t,j}}$$

Equation 12.17

An example of a vulnerability score map with resolution 0.05° x 0.05° is shown in Figure 12.13.

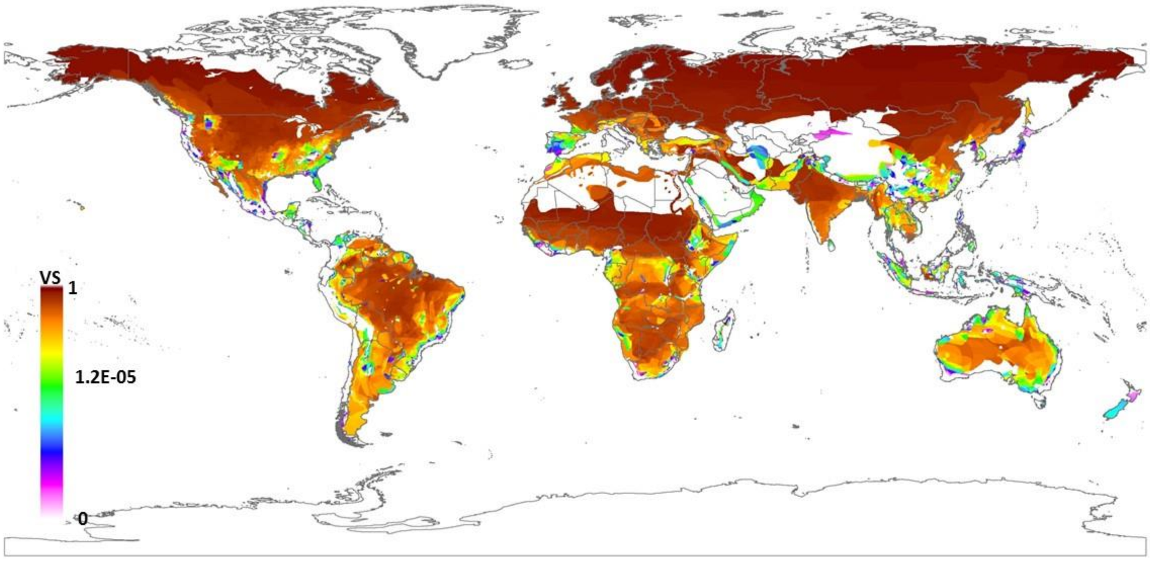


Figure 12.13: Vulnerability score for amphibians with a resolution of 0.05° x 0,05°. Data from IUCN (2013b) and (IUCN 2012). Adopted from Verones et al. (submitted).

Characterization factors (CFs) are calculated for each wetland individually (multiplication of fate and effect factor). Then, these values are assigned to the hydrologically relevant parts of major watersheds. For surface water-fed wetlands these relevant regions within a major watershed are determined from a hydrologically corrected digital elevation model. We selected all parts of a major watershed that were at the same or at higher elevation that the wetland itself, excluding parts that do not have a physical connection to the wetland in question. The CF of a wetland is applicable in that area, since any upstream water consumption deprives the wetland of water. The areas with CFs of all wetlands in a specific location are superimposed and summed. This is schematically shown in Figure 12.14.

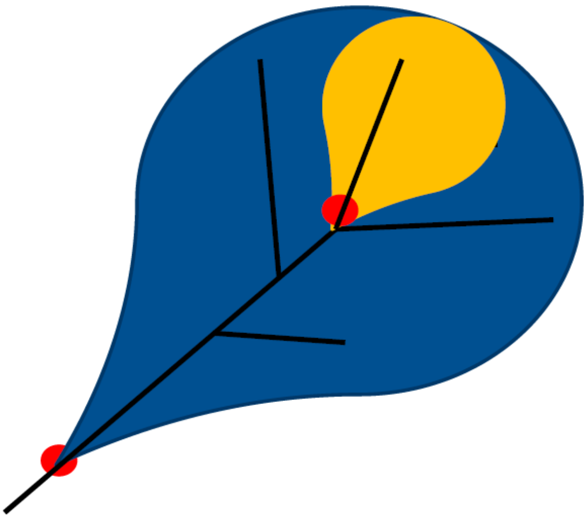


Figure 12.14: Schematic representation of the procedure for assigning values to watersheds for surface water-fed wetlands. Two wetlands are depicted with red dots; the river network is shown in black. The individual catchment of the two wetlands are shown in orange and blue. Where the orange and blue catchments overlap the CFs of both wetlands are summed. Water consumption in that area will deprive both wetlands of water and thus damages both. Water consumption in the blue area, does not affect the wetland with the orange catchment, thus in this area inly the CF of the second wetland is applicable. Adopted from Verones et al. (2013b).

For groundwater-fed wetlands a similar procedure is used. The characterization factor is assumed to be applicable in the whole area of relevance (AoR) around the wetland, i.e. within the area from which water is drawn towards the wetland. If two or more of these areas of relevance overlap, the respective

CFs are summed, since water consumption in that area would damage multiple wetlands (Figure 12.15).

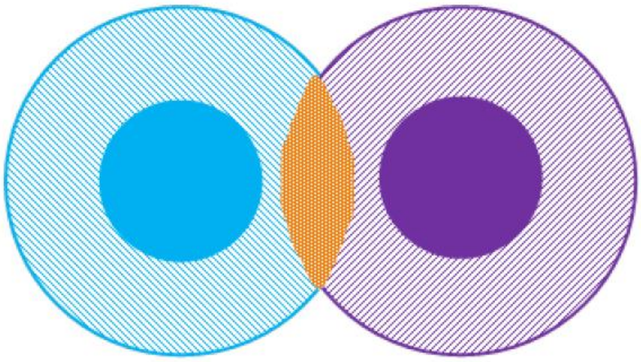


Figure 12.15: In solid blue and solid violet two groundwater-fed wetlands are shown. The hatched areas around them are the areas of relevance, in which the CF of each wetland is applicable. In the orange part the two areas of relevance overlap and the CFs of both wetlands is summed. Adopted from Verones et al. (2013b).

Note that CFs are first calculated for each taxonomic group separately in spercies-eq·yr/m^3. In order to be consistent with all impact categories, we follow the aggregation procedure described in the framework chapter, to provide final CFs in PDF·yr/m^3, aggregated over all taxonomic groups considered.

12.2.3. Calculation of the characterization factors at endpoint level – vascular plants

The fate factor is taken from Pfister et al. (2009). They assume that in water-limited environments plant growth may be obstructed by water consumption, since plants will be deprived of the water they need for growing by avoided floods or decreased groundwater levels. There is no distinction between the source of water. The fate factor is calculated as the inverse of spatially-differentiated precipitation with a minimum of 10^{-2} m/year), which is used to indicate the area-time that is affected by a certain water consumption volume for each watershed. By doing so, it is a rather conservative approach.

The effect factor for vascular plants is taking the plant species richness S,, the endemism richness factor ERF the water-limited net primary productivity $NPP_{water\text{-}limited}$ and a species accumulation factor z into account (equation 12.18). This effect factor thus gives the potential damage in endemic species-equivalents.

$$EF_i = NPP_{water-limited} \cdot z_i \cdot S_{vascular\ plant,i}$$

Equation 12.18

The $NPP_{water-limited}$ is the net primary productivity (NPP) share that is water-limited (see Pfister et al. (2009). The species accumulation factor z is used to account for regional species loss by the species-area relationship, as described in ReCiPe method (Goedkoop et al. 2009), and is depending on ecosystem conditions (Pfister et al. 2010). In order to account for the total of potentially lost species, we apply species richness S of vascular plants taken from Kreft et al.(2007).

The characterization factor is calculated by multiplying effect and fate factors on a watershed level. For this, the regional EFs and FFs are averaged on a watershed level. In order to transform the unit to PDF, we use the global species richness of vascular plants (315'903, Kier et al. (2009)).

12.2.4. Uncertainties

Sensitivity analyses were performed for water depth, the chosen wetland geometry, and the amount of water consumed (10 m^3/yr and 1'000'000 m^3/yr instead of 1000 m^3/yr). For surface water-fed wetlands the amount of water inflow was changed from the own model to WaterGap values (WATCH 2011) and for groundwater-fed wetlands we also tested the influence of the hydraulic conductivity.

The sensitivity of the groundwater-fed wetlands was much larger than for the surface water-fed wetlands. CFs can vary more than 1000% in extreme cases, depending on the parameter changed (Verones et al. 2013b). Largest influence had the amount of water consumed, because of the non-linear character of the Dupuit-Thiem well formula. Also the hydraulic conductivity leads to substantial influence on the groundwater-fed wetlands, leading to less robust values for groundwater consumption than for surface water consumption (see also the Supporting Information of Verones et al. (Verones et al. 2013b)).

Surface water-fed wetlands proved to be only slightly sensitive to changes in water depth (less than 1%, see Verones et al. (Verones et al. 2013a)). Hydrological inflow data did have implication (up to 100% difference, see Verones et al. (Verones et al. 2013a)), especially because of differences in river width and the exact geographical course of the river (based on hydrologically corrected DEMs)

Differences between an ellipsoid or a straight cone assumption for the wetland geometry proved to be marginal. An overview of all other tested parameters and their influence is shown in the appendix. It is not possible to quantitatively analyse all of the identified uncertainties. Monte Carlo simulations are for example not automatically possible for groundwater-dependent wetlands, because the CFs cannot be derived in an analytical way, but need numerical iterations. However, we attempted to highlight relevant uncertainties and, if possible assess their impact in a qualitative way.

For the effect factor uncertainties are due to the range models of the taxonomic groups. Geographical ranges overestimate the species richness present in a certain location and thus we have to assume that our values are rather high.

12.2.5. Value choices

Time horizon

There are no value choices to be made for the time horizon. It is an infinite time horizon, assuming steady-state conditions.

Level of robustness

The level of robustness varies strongly between surface water-fed wetlands, groundwater-fed wetlands and terrestrial habitats, and hence between surface water consumption and groundwater consumption. It is recommended to use aggregated characterization factors for surface water consumption and terrestrial habitats for certain values and only include groundwater-fed wetlands if the complete impact shall be assessed (all effects). We consider groundwater-fed wetlands to be of low level of robustness since they have much larger uncertainties and considerably less data available.

12.2.6. Results

The CFs range from 1.4E-18 PDF·yr/m^3 to 1.2E-11 PDF·yr/m^3 for the certain effects values and from 1.4E-18 PDF·yr/m^3 to 6.4E-11 PDF·yr/m^3 for the “all effects” CFs. Both are considering vulnerabilities of animal taxa. CF maps are shown in Figure 12.16 and 12.17. Global averages are shown in Table 12.2. In Table 12.3 and in the associated Excel files country averages for the CFs are listed. Table 12.4 shows continental averages. Spatially explicit characterization factors are available as Google Earth layers (on a country level) and as ArcGIS raster files (pixel specific).

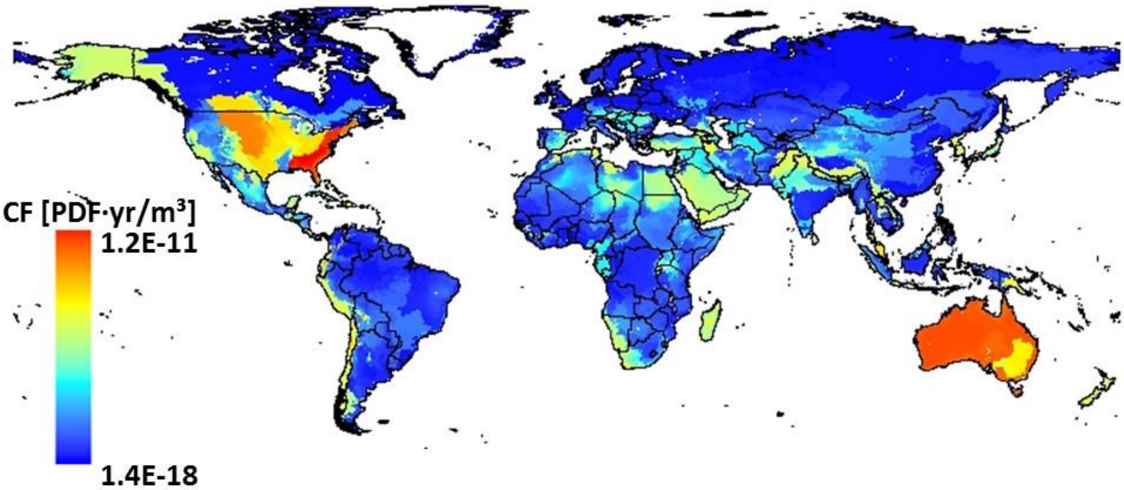


Figure 12.16Ccharacterization factors for impacts from surface water consumption on all animal taxa and impacts from water consumption on vascular plants (certain effects). Aggregated across taxa as described in the framework document.

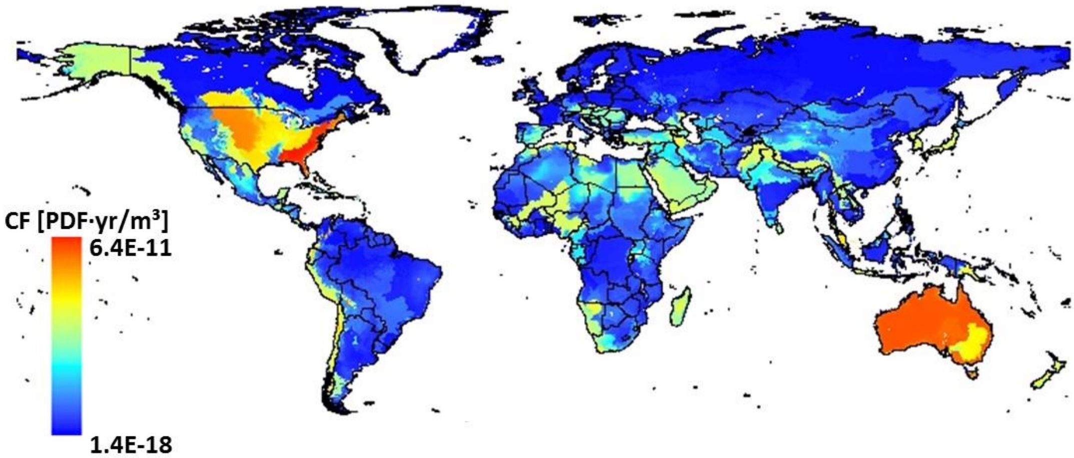


Figure 12.17: Characterization factors including all effects. In addition to the values from Figure 12.16, also impacts from groundwater consumption on animal taxa is included here.

Table 12.2: Global averages for the CFs.

	CF certain effects [PDF·yr/m³]	**CF all effects [PDF·yr/m³]**
Ecosystem quality	1.63E-13	1.65E-13

Table 12.3: CFs per country. For the certain effects, only surface water consumption (SW) is considered for anima taxa, in addition to water consumption impacts on vascular plants. Groundwater consumption (GW) is considered only in the "all effects" CF. The unit is always [PDF·yr/m³]. Values shown here include vulnerabilities of animal species.

Country	CF certain effects [PDF·yr/m³]	CF all effects [PDF·yr/m3]
Afghanistan	1.57E-14	1.57E-14
Albania	3.15E-15	3.24E-15
Algeria	4.93E-14	7.70E-14
Angola	3.00E-15	4.28E-15
Argentina	2.52E-15	2.63E-15
Armenia	1.05E-13	1.13E-13
Australia	2.25E-12	2.34E-12
Austria	1.60E-14	3.56E-13
Azerbaijan	1.39E-14	2.11E-14
Bahamas, The	8.80E-12	8.80E-12
Bangladesh	3.73E-15	4.04E-15
Belarus	3.69E-16	6.24E-16
Belgium	3.31E-16	3.31E-16
Belize	5.21E-15	7.74E-15
Benin	5.25E-16	1.26E-14
Bhutan	2.97E-14	3.06E-14
Bolivia	1.36E-13	1.36E-13
Bosnia and Herzegovina	7.99E-15	1.24E-14
Botswana	3.12E-15	3.12E-15
Brazil	2.76E-15	2.85E-15
Brunei	2.68E-15	2.68E-15
Bulgaria	9.50E-15	1.75E-14
Burkina Faso	1.57E-15	1.58E-14
Burundi	2.82E-14	2.82E-14
Cambodia	1.63E-15	1.63E-15
Cameroon	1.29E-14	2.97E-14
Canada	2.83E-13	2.85E-13
Cape Verde	0.00E+00	0.00E+00
Central African Republic	4.09E-15	4.09E-15
Chad	4.37E-15	9.44E-15
Chile	8.86E-14	8.86E-14
China	2.32E-15	2.35E-15
Colombia	6.94E-14	6.94E-14
Comoros	0.00E+00	0.00E+00
Congo	2.93E-15	2.93E-15
Congo DRC	2.16E-15	2.16E-15
Cook Islands	0.00E+00	0.00E+00
Costa Rica	2.12E-14	2.12E-14
Croatia	8.66E-15	1.34E-14
Cuba	1.07E-14	1.07E-14
Cyprus	5.51E-14	5.51E-14
Czech Republic	4.08E-15	5.39E-15
Denmark	4.91E-16	4.91E-16
Djibouti	6.42E-15	6.43E-15
Dominican Republic	1.17E-13	1.18E-13
Ecuador	1.83E-13	1.83E-13
Egypt	1.73E-14	1.74E-14
El Salvador	6.31E-15	8.92E-15
Equatorial Guinea	1.28E-14	1.28E-14
Eritrea	5.86E-15	5.86E-15
Estonia	2.82E-16	2.95E-16
Ethiopia	6.60E-15	6.63E-15
Falkland Islands (Islas Malvinas)	0.00E+00	0.00E+00
Faroe Islands	0.00E+00	0.00E+00
Fiji	4.84E-14	4.84E-14
Finland	3.68E-16	8.99E-16

France	6.19E-16	7.03E-16
French Guiana	2.39E-15	2.39E-15
French Polynesia	0.00E+00	0.00E+00
Gabon	9.24E-15	9.24E-15
Gambia, The	1.82E-15	1.82E-15
Georgia	1.25E-14	1.75E-14
Germany	4.21E-15	5.12E-15
Ghana	9.01E-16	9.01E-16
Greece	5.52E-15	5.54E-15
Greenland	7.10E-17	7.10E-17
Guadeloupe	0.00E+00	0.00E+00
Guatemala	1.52E-14	1.60E-14
Guinea	7.77E-15	2.89E-14
Guinea-Bissau	5.49E-16	5.49E-16
Guyana	1.30E-15	1.30E-15
Haiti	8.42E-14	8.43E-14
Honduras	7.88E-15	9.36E-15
Hungary	1.30E-14	2.05E-14
Iceland	4.90E-16	4.90E-16
India	1.12E-14	1.12E-14
Indonesia	2.92E-14	2.92E-14
Iran	2.31E-14	2.47E-14
Iraq	1.00E-14	1.08E-14
Ireland	7.59E-16	5.48E-15
Israel	1.77E-14	1.77E-14
Italy	3.41E-15	3.48E-15
Ivory Coast	5.06E-15	8.66E-15
Jamaica	6.40E-15	6.40E-15
Japan	1.28E-14	5.25E-14
Jordan	3.47E-13	3.48E-13
Kazakhstan	1.93E-15	1.93E-15
Kenya	5.74E-15	5.75E-15
Kiribati	0.00E+00	0.00E+00
Kuwait	2.53E-14	2.55E-14
Kyrgyzstan	7.61E-15	7.61E-15
Laos	2.42E-14	2.42E-14
Latvia	2.42E-16	4.32E-16
Lebanon	5.86E-14	5.86E-14
Lesotho	1.46E-15	1.46E-15
Liberia	3.31E-15	3.31E-15
Libya	4.26E-14	4.88E-14
Lithuania	2.74E-16	2.74E-16
Luxembourg	5.65E-15	5.65E-15
Macedonia	2.77E-15	2.79E-15
Madagascar	9.74E-14	9.75E-14
Malawi	1.99E-15	1.99E-15
Malaysia	2.40E-13	2.40E-13
Mali	1.60E-15	4.54E-14
Mauritania	1.13E-15	1.49E-15
Mauritius	0.00E+00	0.00E+00
Mexico	1.24E-14	1.25E-14
Moldova	2.22E-15	5.17E-15
Mongolia	3.72E-15	3.72E-15
Montenegro	5.77E-15	7.12E-15
Morocco	8.61E-15	1.63E-14
Mozambique	2.81E-15	2.81E-15
Myanmar (Burma)	1.63E-14	1.63E-14
Namibia	1.88E-14	6.65E-14
Nepal	1.33E-14	1.42E-14
Netherlands	5.24E-16	5.32E-16
New Caledonia	1.23E-14	1.23E-14
New Zealand	4.08E-14	4.87E-14
Nicaragua	6.54E-15	6.80E-15

Niger	2.22E-15	3.59E-14
Nigeria	3.11E-15	2.88E-14
North Korea	3.78E-14	3.79E-14
Norway	4.00E-16	4.00E-16
Oman	3.36E-14	3.39E-14
Pakistan	3.58E-14	3.59E-14
Panama	8.56E-15	8.56E-15
Papua New Guinea	4.57E-14	4.57E-14
Paraguay	3.30E-15	3.50E-15
Peru	5.76E-14	5.76E-14
Philippines	2.69E-14	2.69E-14
Poland	4.30E-16	5.64E-16
Portugal	4.23E-15	5.99E-15
Puerto Rico	2.57E-12	2.57E-12
Qatar	1.83E-14	1.85E-14
Reunion	0.00E+00	0.00E+00
Romania	4.21E-15	9.86E-15
Russia	3.74E-15	3.75E-15
Rwanda	3.07E-14	3.07E-14
Sao Tome and Principe	0.00E+00	0.00E+00
Saudi Arabia	2.89E-14	2.91E-14
Senegal	6.20E-16	6.20E-16
Serbia	1.29E-14	2.00E-14
Sierra Leone	5.26E-15	5.26E-15
Slovakia	1.07E-14	1.67E-14
Slovenia	2.67E-14	4.19E-14
Solomon Islands	2.36E-15	2.36E-15
Somalia	3.21E-15	3.21E-15
South Africa	1.76E-14	1.76E-14
South Korea	3.99E-14	4.75E-14
Spain	1.18E-14	1.45E-14
Sri Lanka	2.25E-14	2.25E-14
St. Vincent and the Grenadines	0.00E+00	0.00E+00
Sudan	5.37E-15	5.38E-15
Suriname	9.48E-16	9.48E-16
Svalbard	1.15E-16	1.15E-16
Swaziland	5.43E-15	5.43E-15
Sweden	4.63E-16	5.11E-16
Switzerland	7.66E-15	7.73E-15
Syria	4.16E-14	4.19E-14
Taiwan	2.96E-13	2.96E-13
Tajikistan	3.60E-15	3.60E-15
Tanzania, United Republic of	4.65E-15	4.66E-15
Thailand	3.41E-14	3.41E-14
Togo	3.84E-16	3.84E-16
Trinidad and Tobago	1.78E-15	1.78E-15
Tunisia	6.21E-14	1.01E-13
Turkey	1.92E-14	1.95E-14
Turkmenistan	1.22E-14	1.22E-14
Uganda	1.13E-14	1.13E-14
Ukraine	1.02E-15	1.43E-15
United Arab Emirates	3.95E-14	3.98E-14
United Kingdom	6.32E-16	2.68E-15
United States	1.15E-12	1.15E-12
Uruguay	1.77E-15	1.91E-15
Uzbekistan	4.07E-15	4.07E-15
Vanuatu	0.00E+00	0.00E+00
Venezuela	2.33E-15	2.33E-15
Vietnam	3.36E-15	3.36E-15
Virgin Islands	0.00E+00	0.00E+00
West Bank	2.20E-14	2.20E-14
Western Sahara	2.01E-15	2.60E-15
Western Samoa	0.00E+00	0.00E+00

Yemen	5.81E-14	5.87E-14
Zambia	2.94E-15	2.94E-15
Zimbabwe	2.54E-15	2.54E-15

Table 12.4: CFs per continent. For the certain effects, only surface water consumption (SW) is considered for anima taxa, in addition to water consumption impacts on vascular plants. Groundwater consumption (GW) is considered only in the "all effects" CF. The unit is always [PDF·yr/m³]. Values shown here include vulnerabilities of animal species.

Continent	CF certain effects [PDF·yr/m³]	CF all effects [PDF·yr/m3]
Africa	1.58E-14	1.96E-14
Antarctica	0.00E+00	0.00E+00
Asia	1.46E-14	1.52E-14
Australia	2.23E-12	2.32E-12
Europe	4.57E-15	9.02E-15
North America	9.83E-13	9.84E-13
Oceania	4.22E-14	5.05E-14
South America	3.19E-14	3.20E-14

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12.2.7. Appendix

Overview of assumptions and possible implications for the outcome of the FF calculation. Taken from Verones et al. (2013a)

Assumption/uncertainty	**Implications for outcome**	**Tested/described?**	**Justification**
Wetland areas as circles	area loss might be different with different form fragmentation of wetland area is not included	not tested, described in SI	Some wetlands in Germany and Florida modelled as "ideal" or "circular" cones. For GW-fed wetlands: depression cone around pumping well is also a circle, thus geomteric form used for both. Cannot be tested for GW-fed wetlands, since depression cones could not be rectangles (e.g.) Fragmentation is important for wetlands but cannot be modelled on a global scale
Cone	volume can be different and thus loss of wetland area	tested, described in SI	Difference between ellipsoid or straight cone is marginal, problems as for circle areas remain (see above)
Dupuit-Thiem well formula	strong implications, because non-linear	discussed, parameters within formula varied	We varied parameters within the formula, however, we did not test replacement of the formula itself. It is a commonly used formula for unconfined aquifers and steady-state conditions. Unless groundwater models are established for every single wetland, this is the simpification that can be used.
Steady-state assumption GW	Fate might be occurring over longer or shorter time scales and affect the effect factor	not specifically described/tested	steady-state assumptions are common in hydrology and do not need further justification. In LCA, impacts are generally aggregated over time
Delineation of AoR	influence on the Dupuit-Thiem well formula, thus influence potentially high (non-linear influence)	described	We did not test alternative approaches for the AoR delineation. Again, simple equations are almost non-existent for the complex topic of groundwater and aquifers. Unless groundwater models are established for every single wetland, simplifications are necessary.
Surface water flows	large implications, depending on the river courses, width of rivers and amounts of water	tested and described	We used our own model (whose uncertainty we did not quantify, since we do not have the uncertainty of the underlying data) and WaterGap, in order to test their influence.
Water consumption	large implications for GW-fed wetlands	tested and described	We calculated for each wetland two different FFs with different water consumption, thus testing the influence of this parameter on the FFs.
Residence time constant	Small implications	tested and described	We assumed the residence time to remain constant and tested this assumption. We only found negligible differences.
Hydraulic gradient	Potentially larger implications because it enters a non-linear equation	not tested	We chose a conservative value that is in the range of the natural hydraulic gradients

Uncertainty in underlying data	P, PET, AET, A, water source, depth kf, m could influence the FF	- A changed from Ramsar to waterbody area - global flows used from two different models - k_f varied by factor 100 - depth varied - water source not varied - m not varied Those that were changed were described and tested	We varied some of the parameters that we used, such as water depth, underlying area or also the surface water volumes used. However, we did not vary the aquifer thickness m for example. We also do not know the uncertainty if the data itself, i.e. the uncertainty of the precipitation, Ramsar areas or potential evapotranspiration and thus cannot check for further uncertainties.