GLOBAL COMMISSION on the ECONOMICS OF WATER

TECHNICAL REPORT

The Water Cycle and the Economy

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We give our deepest respects to their Elders, past and present, who have been and always will be the Traditional Custodians of Australia's waters including its aquifers, streams, and rivers. We acknowledge that Australia's Indigenous nations have long-standing cultural, social, environmental, spiritual, and economic values, rights and responsibilities with respect to their Country.

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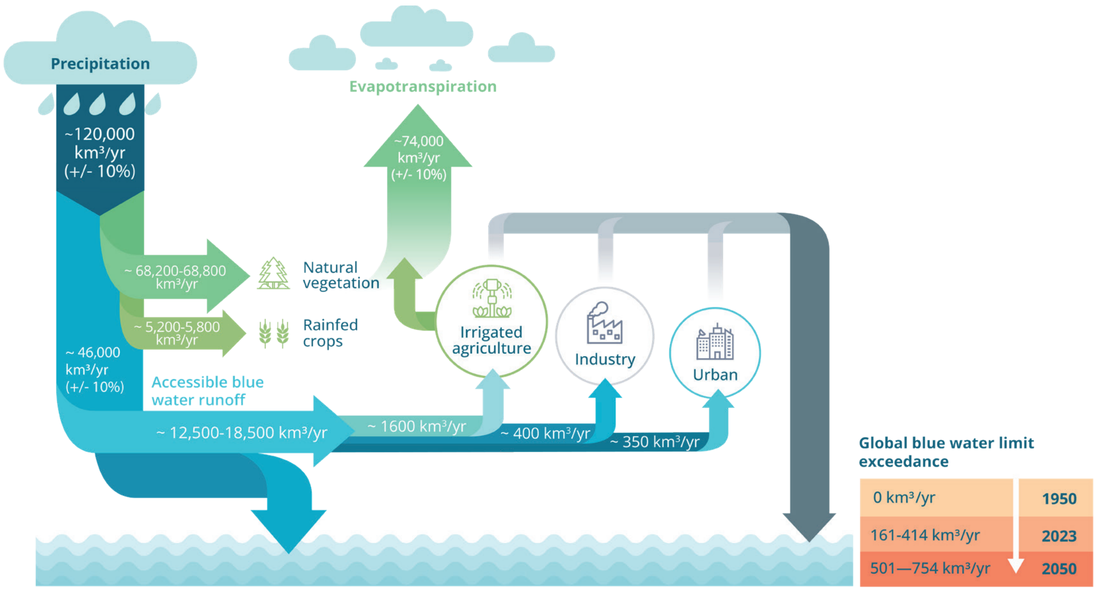
This technical note provides details of the calculations and data sources in relation to Figure 2.2, "The water cycle, global water consumption by sector and blue water consumption exceedance", within "The What, Why and How of the World Water Crisis' Review and Findings of the Global Commission on the Economics of Water" review prepared for the UN 2023 Water Conference, March 2023.



Annual precipitation on land

Precipitation: 102,000 km³/year (Scanlon et al., 2023).

Caretta et al. (2022) for the IPCC AR6 estimate precipitation on land**:** 120,000 km³/year (+/- 10%), land evaporation (ET) 74,000 km³/year (+/- 10%), and land runoff 46,000 km³/year (+/- 10%).

The 1981–2012 mean evapotranspiration (ET) across the global land surface (not including water bodies and permanent ice surfaces) is 538.1 ± 56.5 mm/year (i.e. 63.2 × 10^3 km³/year) or ~67% of mean annual P (805.6 ± 41.7 mm/year (from Zhang et al., 2016, Figure 41). This gives us a global land surface area of 117,450,288 km².

Global green water consumption (ET)

Total global green water availability is estimated as 63,200 km³/year (Zhang et al., 2016) and 70,000 m³/year (Rockström et al., 1999), which is approximately 67% of annual precipitation (94,000 km³/year).

Caretta et al.'s (2022) alternative estimate of ET is 74,000 km³/year, which is 62% of estimated precipitation of 120,000 km³/year.

Green water consumption (ET) for crops

Global estimates of annual, total crop water consumption vary between 6,800 km^3/year and 7,500 km^3/year (Postel, 1998; Rockström et al., 1999;). The Comprehensive Assessment estimate is 7,130 km^3/year. If we subtract our preferred blue water consumption estimate for irrigated agriculture of 1,600 km^3/year (see *Green and blue water consumption (ET) in irrigation* below) from the minimum and maximum estimates of total (green and blue) water consumption for crops, we obtain 5,200 km^3/year and 5,900 km^3/year.

Land runoff

Caretta et al. (2022) estimated global land runoff at 46,000 km^3/year (land runoff (P-ET) = 120,000-74,000 = 46,000 km^3/year). This is higher than Döll et al. (2009) who estimated global total land runoff (discharge into oceans) at 38,164 km^3/year; with an estimated reduction of 1,385 km^3/year due to human activity. Döll et al. 2009: 2430) note:

> "One sixth of the global land area (excluding Greenland and Antarctica) has suffered from a significant decrease of long-term average annual river discharge (of more than 10%), mainly due to water withdrawals and in particular irrigation, which accounts for more than 90% of global consumptive water use. The average decrease in these areas has been 35%."

Scanlon et al. (2023) estimated land runoff at 42,000 km^3/year.

Accessible blue water runoff is estimated at 12,500 km^3/year (Jackson et al., 2001: 8) after subtracting from an estimated 40,000 km^3/year remote or inaccessible flows of 7,800 km^3/year (Amazon, Congo, and other northern hemisphere rivers) and uncaptured floodwater of 20,400 km^3/year. If we use a higher land runoff estimate of 46,000 km^3/year we obtain a higher accessible blue water runoff of 18,500 km^3/year.

Global blue water consumption (ET)

Total human blue water consumption (all purposes) is estimated at between 3,800 km^3/year (Oki and Kanae, 2006: 1068) and 4,370 km^3/year (Jaramillo and Destouni, 2015: 1249), of which 3,563 km^3/year (~82 to 94 % of total blue water consumption) is flow regulation and irrigation (Jaramillo and Destouni, 2015: 1248).

Wada and Bierkens (2014: 14) estimated total blue water withdrawal in 2025 at 5,078 km^3/year and blue water consumption at 2,107 km^3/year.

Döll et al. estimated 3,000 km^3/year total blue water withdrawals of which 1,700 km^3/year for irrigation, 30 km^3/year for livestock, 350 km^3/year for domestic, 340 km^3/year for manufacturing and 590 km^3/year for thermal power.

Jackson et al. (2001: 8) estimated 4,430 km^3/year total blue water withdrawals, of which agriculture accounts for 2,880 km^3/year, industry 975 km^3/year, municipalities 300 km^3/year and reservoir losses of 275 km^3/year.

Blue and green water consumption (ET) in irrigation

Blue water consumption irrigation is estimated at: 1,083 km^3/year (Rosa et al., 2020: 5), 1,550 km^3/year (Molden, 2007: 6), and 1,422 km^3/year (for 2025, Wada and Bierkens, 2014, p. 14).

Green water consumption in irrigated agriculture is estimated at: 650 km^3/year (Molden, 2007: 60) with 1,550 km^3/year from blue water sources (Molden, 2007: 6). Our preferred estimate is from Molden (2007).

Siebert et al. (2010) estimate 1,277 km^3/year blue water consumed in agriculture, of which 545 km^3/year is groundwater and the remainder is attributed to water consumed from rivers/wetlands.

Groundwater depletion

The current rate of groundwater depletion is 283 km^3/year in 2000 (Wada et al., 2010), 304 km^3/year in 2010 (Wada and Bierkens, 2014: 13), 241.4 km^3/year in 2010 (Dalin et al., 2017), and 113 km^3/year (Döll et al., 2014), which represents about 17% of total groundwater abstractions. Scanlon et al. (2023) simulated cumulative groundwater storage depletion (1960 to 2010) which ranged from ~27,000 km^3 (flux approach; ignoring capture and evapotranspiration variations) to 4,200 km^3 (including capture and ET). Thus, their **minimum** estimate of groundwater depletion is 84 km^3/year over the 50-year period, and their **maximum** estimate is 540 km^3/year.

Gleeson et al. (2012) estimated a global groundwater footprint and estimated current use is twice what is sustainable if no groundwater is allocated to environmental flows and 3.5 times greater if environmental flows are included.

Estimating a current global blue water limit exceedance

Lehner et al. (2011) estimated that humans have appropriated more than half the global accessible freshwater runoff, creating a cumulative reservoir storage capacity of about 6,197 km^3, leaving only an estimated 23% of the world's large rivers (>1000 km in length) flowing uninterrupted into the ocean (Grill et al 2019).

(a) Groundwater limit
Using the median of estimates of global groundwater depletion, we estimate groundwater depletion at 241.4 km^3/year (from Dalin et al., 2017).

(b) Surface water limit
Pastor et al. (2022) estimate, based on environmental flow requirements for rivers globally, that planetary boundaries have been crossed in relation to surface waters. According to their estimates, human actions contribute between 260 and 545 km^3/year of this blue water exceedance.

We assume that 10% of the median existing estimates of *surface* blue water consumption in irrigation is unsustainable. This is estimated as follows: median estimate of blue water consumption in irrigation 1,422 km^3/year (from Wada and Bierkens, 2014), of which we estimate 71% is from surface water (using the groundwater fraction in Döll et al., 2014: 5703) and of which 10% is assumed to be unsustainable. That is, 1,422 x 0.71 x 0.1 = 101 km^3/year.

Median

The addition of median groundwater depletion and surface water depletion gives us a **median estimate of unsustainable (exceedance of the sustainable limit) global blue water consumption = 341 km^3/year**.

Minimum

If we use the lowest estimate of global groundwater depletion of 84 km^3/year (after Scanlon et al., 2023) and use the lowest estimate of blue water consumption in irrigation (after Rosa et al., 2020) of 1,083 km^3/year or 77 km^3/year, we obtain a **lower bound estimate of unsustainable (exceedance of the sustainable limit) global blue consumption of 161 km^3/year**.

Maximum

If we use the highest estimate of global groundwater depletion of 304 km^3/year (after Wada and Bierkens, 2014) and use the highest estimate of blue water consumption in irrigation of 1,550 km^3/year (after Molden, 2007: 6) we obtain an **upper bound estimate of unsustainable (exceedance of the sustainable limit) global blue consumption of 414 km^3/year**.

Rosa et al. (2020, p. 5 out of 10) estimated blue water consumption exceedance globally at **273 km^3/year.** This is calculated as estimated global blue water consumption 1,083 km^3/year for irrigation less sustainable blue water consumption of 810 km^3/year. Jaramillo and Destouni (2015: 1249–1250) indicated that unsustainable total blue water consumption could be **370 km^3/year**. Their estimate of global water exceedance is total blue water consumption estimated at 4,370 km^3/year (3,563 km^3/year for agriculture and 807 km^3/year for other water consumption) LESS the estimated blue water planetary boundary of Steffen et al. (2015) of 4,000 km^3/year.

Estimating a 2050 global blue water limit exceedance

Rockström et al. (2009) estimated that it requires 1,300 km^3/year of water, combined green and blue water, to sustain a food per capita of 3,000 Kcal per day. At a global human population of 8 billion, we obtain a minimum total water consumption (blue and green) of = 10,400 km^3/year, of which 9,000 km^3/year is assumed to be green water.

Note that Gerten et al. (2011: 886) argue that the minimum water requirement exceeds 1,300 m^3/year of water.

Hoekstra and Mekonnen (2012: 3234) estimated for 1996-2005 total (blue and green) water consumption of 9,087 km^3/year, of which 6,684 km^3/year is green water and 2,403 km^3/year is blue water (which includes 1,378 for grey water). By sector, they estimated 7,404 km^3/year for crop land, 913 km^3/year for pasture, 400 km^3/year for industry, and 324 km^3/year for domestic supply.

By 2050, assuming a human population of 9.7 billion, and with current blue-green ratios in relation to current global water consumption, we would need ~13,000 km^3/year, of which 1,750 km^3/year is blue water. This is an additional 340 km^3/year of new blue water consumption. When added to the current lower bound, median, and upper bound estimates of current global blue water exceedance, respectively, of 161 km^3/year, 341 km^3/year, and 414 km^3/year, we obtain an estimate of global blue water limit exceedance in 2050 of **501 km^3/year (lower bound)**, **681 km^3/year (median),** and **754 km^3/year (upper bound)**.

Using the median 2050 estimate means that the world must find ~681 km^3/year of green, treated black, and grey water to replace this volume of consumed blue water. This is about a 10% increase in total green water consumed for crop lands by 2050.

Given that green water and associated land will be needed for tree plantations or ecological restoration, there will be trade-offs between blue water and green water depending on tree densities and rooting depths in new tree plantations on former agriculture and pasture land (Ilstedt et al 2016; Ellison et al., 2017; Clark et al., 2021).

In terms of agriculture, the additional green water consumption requirement if blue water consumption is reduced (median estimate of 681 km^3/year) will have to come from land currently under natural or semi-natural vegetation (57,695 km^3/year), of which forests and wetlands account for about 41,400 km^3/year green water (Rockström et al., 1999).

Existing forests must be conserved if the world is to avoid unacceptably high costs from climate change and biodiversity loss, and precipitation (Smith et al. 2023). This implies, therefore, an expansion of rainfed agriculture into temperate and tropical grasslands that use about 15,100 km^3/year green water (Rockström et al., 1999) to ensure the global blue water exceedance is avoided by 2050. This expansion would result in loss of grassland biodiversity and could come into conflict with 30% target of land under conservation, as recommended by COP15 of the Convention on Biological Diversity (CBD, 2022).

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GLOBAL COMMISSION on the ECONOMICS OF WATER

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