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A Water Perspective on the Water–Energy–Food Nexus

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A Water Perspective on the Water–Energy–Food Nexus

Carole Dalin

Introduction

Water resources are essential to sustain human life, livelihoods and natural ecosystems on our planet. Water crucially links all sectors of human activity to each other and with the natural environment. Indeed, the provision of basic services, such as food, energy and sanitation, can be harmful to the environment if relying on improper water use; conversely, inadequate water-related environmental conditions (e.g. drought or flood) can hinder the provision of these basic services. In addition, agriculture, industry and cities rely on inputs and outputs from each other, and compete for increasingly pressured water resources, due to socio-economic and population growth and climate change. Water is thus a key, cross-cutting component of the water–energy–food(–climate) nexus, and an essential issue to be accounted for in promoting and implementing sustainable development measures. Approaches accounting for global linkages, notably through international trade, are needed. In particular, virtual water trade – trade of commodities requiring water for their production, or transfer of 'embedded water' – has the potential to improve global water use sustainability significantly by producing food in relatively more water-productive and water abundant areas for export to regions with low water productivity and availability. This chapter will address the role of water in sustainable development across all sectors of human activity and the environment, and explore concepts and applications of virtual water trade to reduce water stress.

Benefits of Water for Sustainable Development

Water, Energy, and Food Security

Water security is defined as 'the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water *for sustaining* livelihoods, human well-being, and socio-economic development, *for ensuring* protection against water-borne pollution and water-related disasters, and *for preserving* ecosystems in a climate of peace and political stability' (UN-Water, 2013).

Evident in this definition is the far-reaching, key role of water in supporting sustainable development. The framework set by the United Nations in 2015 consists of 17 **Sustainable Development Goals** (SDGs, Figure 60.1). Water is directly targeted by Goal 6, aimed at providing clean water and sanitation, but is also fundamental to reduce poverty (Goal 1) and hunger (Goal 2), to ensure health and well-being (Goal 3), access to energy (Goal 7), and sustainable cities (Goal 11), and to preserve land and aquatic ecosystems (Goals 14 and 15).

Figure 60.1Sustainable Development Goals set by the United Nations. (Goals 2, 6, and 7 relate directly to the water–energy–food services. Water and the wider environment are also essential for goals 14 and 15).

Source: United Nations 2015 (http://www.un.org/sustainabledevelopment/sustainable-development-goals/)

Water resources are needed to ensure water security, food security (as an essential input in agricultural production), and energy security (as a major player in hydropower and thermal power production). More generally, water resources play a unique role in maintaining and providing ecosystem services.

Ecosystem services have been classified in four types: supporting, provisioning, cultural, and regulating services (Table 60.1). Water bodies and the water cycle deliver key ecosystem services of all four types: supporting services via water cycling; provisioning of domestic and industrial water, as well as a key input for food (rainfall and irrigation) and energy (cooling and processes) provision; cultural services via its importance in environmental settings and species diversity (rivers, lakes, oceans), and regulating services via climate regulation (e.g. evaporative cooling).

The UK NEA (Mace & Bateman, 2011) emphasizes that the way people manage ecosystems (e.g. water resources) for the provision of final ecosystem services (e.g. food or drinking water) often inadvertently affects ecosystem processes, sometimes with deleterious consequences (e.g. eutrophication from nutrient leaching into rivers). We will further discuss this aspect in the section below on water-related risks for sustainable development.

Table 60.1Ecosystem services in the UK NEA classified according to both ecosystem service type (provisioning, regulating, cultural, and supporting) and whether or not they are final ecosystem services or intermediate services and/or processes. For each final ecosystem service an example of the good(s) it delivers is provided in italics.

Table 60.1 Ecosystem services in the UK NEA classified according to both ecosystem service type (provisioning, regulating, cultural, and supporting) and whether or not they are final ecosystem services or intermediate services and/or processes. For each final ecosystem service an example of the good(s) it delivers is provided in italics.

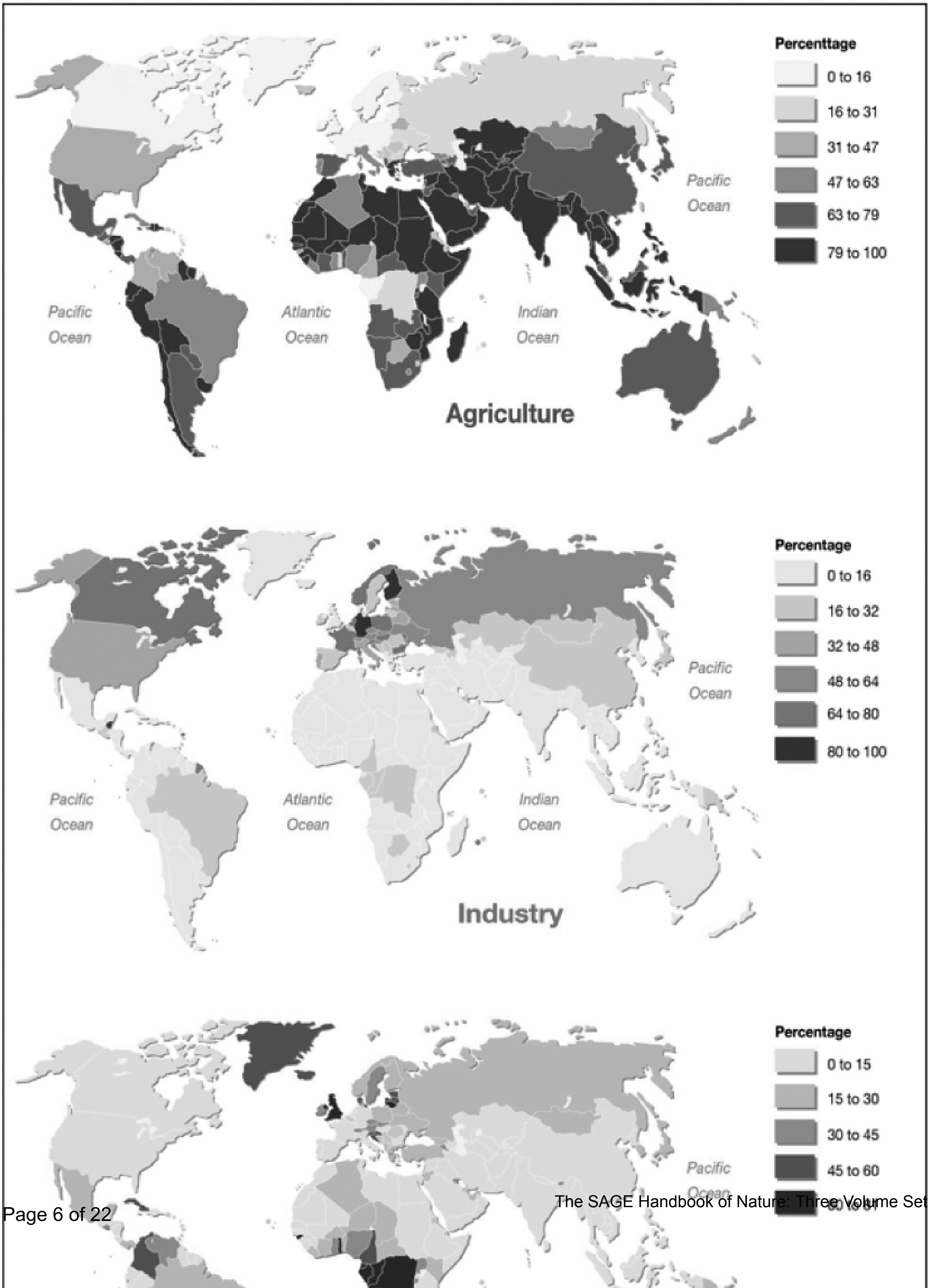
	Ecosystem processes/ intermediate services		*Final ecosystem services (example of goods)*
Supporting services	• Primary production • Soil formation • Nutrient cycling • Water cycling	**Provisioning services**	• Crops, livestock, fish *(food)* • Trees, standing vegetation, peat *(fibre, energy, carbon sequestration)* • Water supply *(domestic and industrial water)* • Wild species diversity *(bioprospecting, medicinal plants)*
	• Decomposition • Weathering • Climate regulation • Pollination • Disease and pest regulation • Ecological interactions • Evolutionary processes • Wild species diversity	**Cultural services**	• Wild species diversity (*recreation)* • Environmental settings (*recreation, tourism, spiritual/ religious)*
		Regulating services	• Climate regulation (equable climate) • Pollination • Detoxification and purification in soils, air and water (pollution control) • Hazard regulation (erosion control, flood control) • Noise regulation (noise control) • Disease and pest regulation (disease and pest control)

Source: Mace, G. and I. Bateman. Conceptual Framework and Methodology (2011) In: *The UK National Ecosystem Assessment Technical Report*. UK National Ecosystem Assessment, UNEP-WCMC, Cambridge.

Central Resource Linking Agriculture, Industry, and Residential Sectors

Water is a key input in the three main sectors of human activities: residential and municipal (domestic use, e.g. drinking water, hygiene, and sanitation), agricultural (crop and livestock production) and industrial (e.g. energy production and manufacturing) sectors.

Figure 60.2Share of agriculture, industry and domestic use in water withdrawals, by country, around year 2000.


Percenttage
0 to 16
16 to 31
31 to 47
47 to 63
63 to 79
79 to 100
Pacific Ocean
Atlantic Ocean
Indian Ocean
Pacific Ocean
Agriculture
Percentage
0 to 16
16 to 32
32 to 48
48 to 64
64 to 80
80 to 100
Pacific Ocean
Atlantic Ocean
Indian Ocean
Pacific Ocean
Industry
Percentage
0 to 15
15 to 30
30 to 45
45 to 60
Pacific

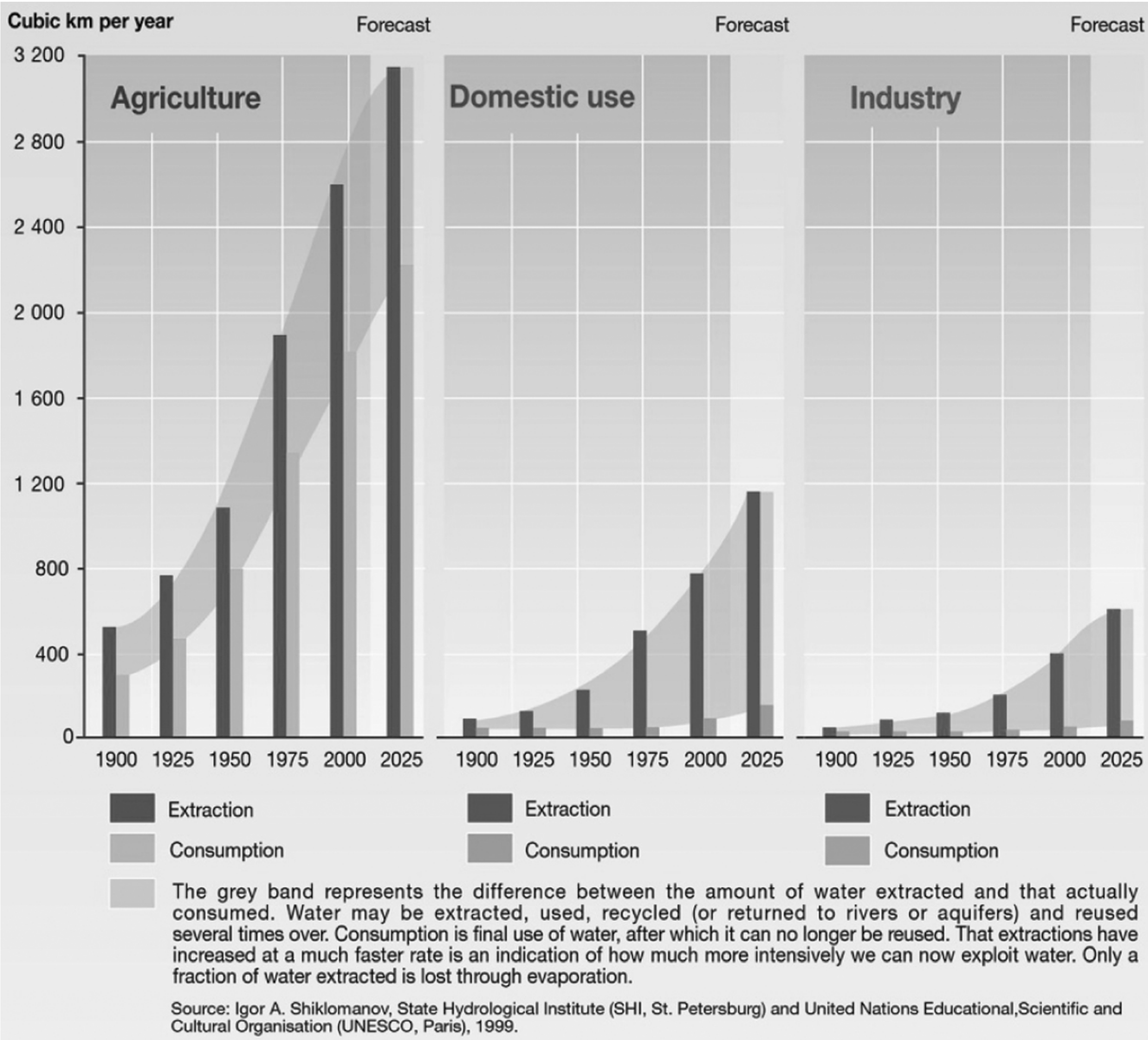
Source: World Resource Institute (http://www.wri.org/publication/world-resources-2000-2001)

The majority of water withdrawals for human activity is destined to the agricultural sector, for irrigation purposes: 70–80% on a global average. In 2000, globally, agriculture, the domestic sector, and industry accounted for 2,600 km^3, 800 km^3 and 400 km^3 of water withdrawals, respectively (Figure 60.3). However, the importance of withdrawals for irrigation across different countries varies according to the level of industrialization (driving the extent of agriculture) and the local climate (driving irrigation needs) in each country (Figure 60.2). In Central Asia, irrigation accounts for 80% to 100% of water withdrawals, and only less than 16% in Northern Europe and Canada, where the industrial or domestic sectors account for most water withdrawals.

Importantly, water withdrawals – i.e. extraction of water from a surface or underground water body for use in human activities – are distinct from water *consumption*, which is the portion of withdrawn water that is not returned to surface or groundwater in the same watershed from which it was abstracted.

The difference between water withdrawal (extraction) and water consumption is shown in Figure 60.3 for agriculture, industry, and domestic use. The agricultural sector accounts for both the largest withdrawals and the largest share of withdrawals eventually considered consumed. Indeed, most water applied as irrigation evaporates into the atmosphere and is displaced outside of its original watershed.

Figure 60.3Global extraction and consumption of water, by sector, from 1900 to 2025 (projections after 2000).



Source: Shiklomanov, 1999 http://hydrologie.org/DON/html/PART'3/HTML/Tb_18.html

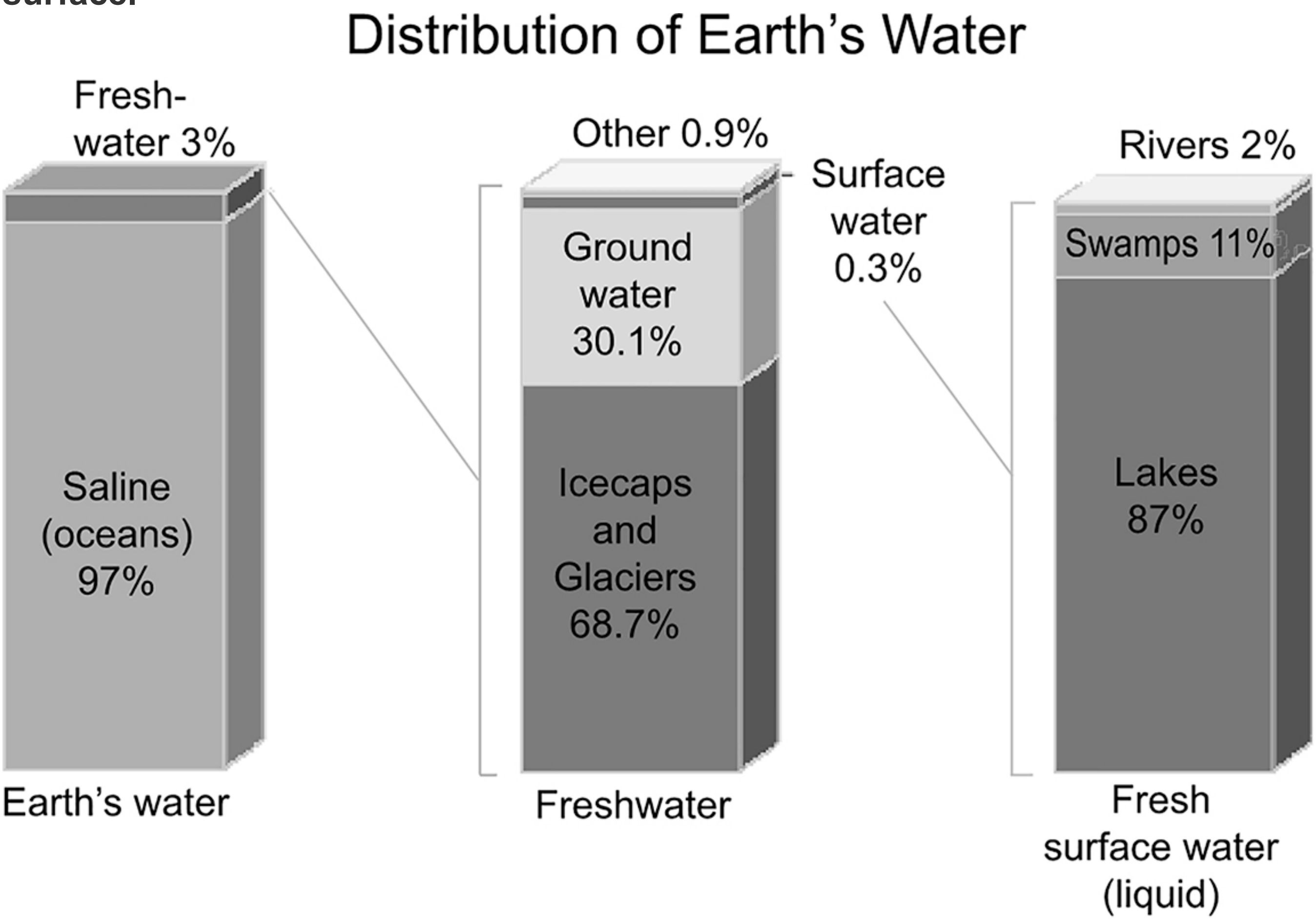
Due to socio-economic and population growth, the global demand for industrial goods, food, and domestic water provision has been increasing, and with it the global demand for water has rapidly increased over time, and is projected to continue to do so in the next decades (Figure 60.3). Because the capacity of accessible and adequate water reservoirs (i.e. liquid freshwater bodies – lakes, rivers, and some aquifers – of appropriate quality) to replenish themselves is limited or relatively slow, this increasing demand for water resources is posing threats to ecosystems as well as challenges for ensuring water, energy, and food security.

Water-Related Risks for Sustainable Development

Water Resources and Water Stress

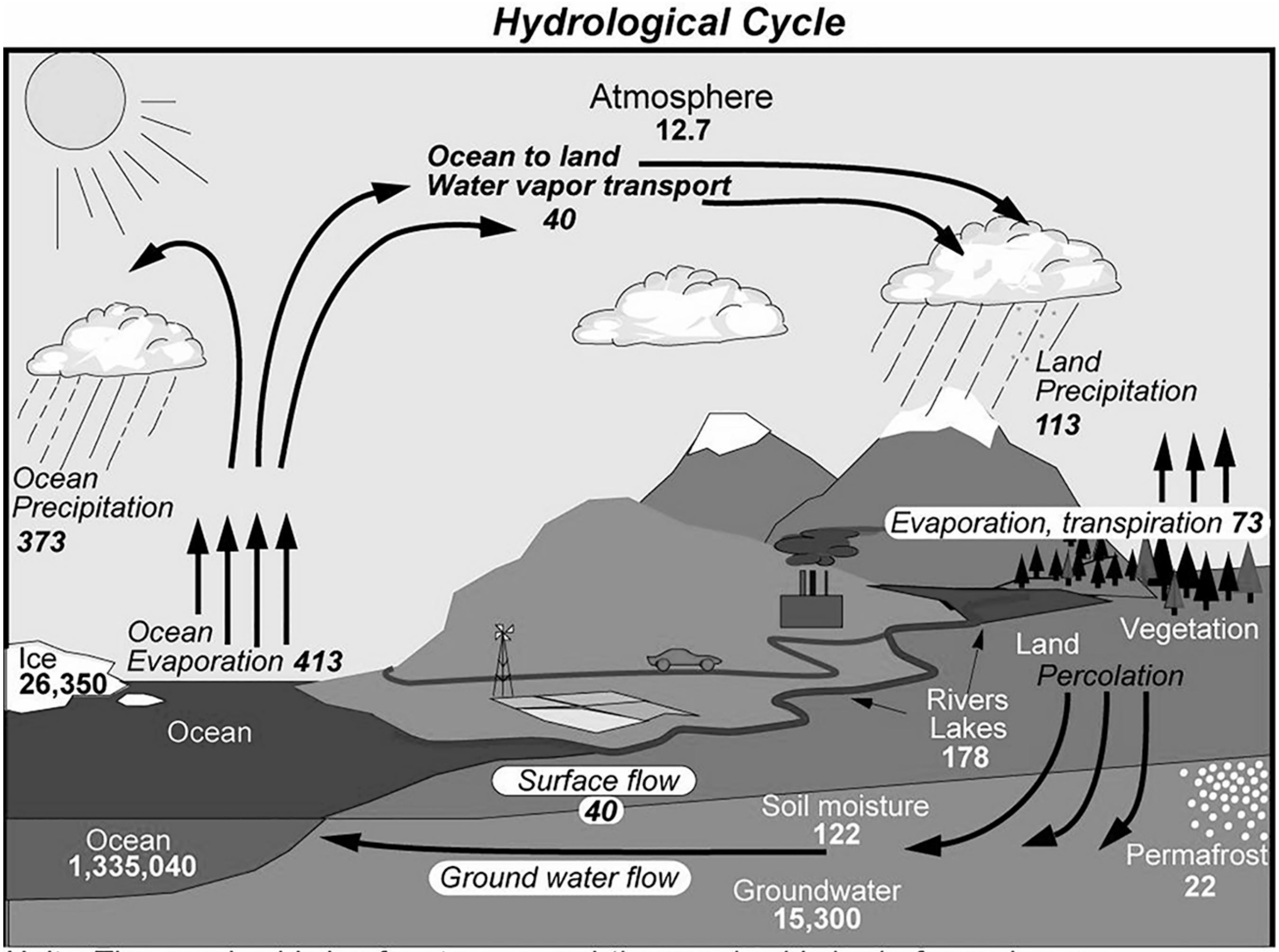
Water resources are essential for human life, livelihoods, and ecosystems. On our ‘blue’ planet, this element can seem plentiful. However, while 1.38 billion km^3 of water are present on Earth, mostly as salted water in oceans (97.5%), but also in ice caps, lakes, rivers, aquifers, and in the atmosphere, freshwater is only a small fraction (2.5% or 34.6 million km^3), and an even smaller fraction is readily available for human use, terrestrial plants and animal species in lakes and rivers: a tiny 0.0075% or 0.1 million km^3 (Figure 60.4).

Figure 60.4 Distribution of water on Earth, and shares of freshwater, liquid and surface.



Water in different states (solid, liquid, and gas) and forms (salted or fresh) is stored in seven main types of reservoirs, in order of size: the oceans (salted liquid water), ice (solid water), groundwater (liquid water), rivers and lakes (liquid freshwater), upper soil moisture (liquid freshwater), permafrost (solid freshwater),and the atmospehre (water vapor). As water constantly flows through and across these reservoirs via the ‘hydrological cycle’ (Figure 60.5), this resource is in a sense limited but renewable. Obviously, however, human use or ecosystem needs require a specific quality and location of available water, e.g. drinking liquid freshwater near cities or villages. Moreover, the rate of replenishment of a water body once a certain volume has been withdrawn is highly variable across types of reservoirs, local natural conditions, and season. This makes ensuring water security a challenge, and an increasing number of studies have found high levels of water stress or scarcity in different regions of the world (e.g. Vörösmarty et al., 2000).

Figure 60.5 Water cycle: water storages and exchanges between them.Source: Trenberth et al., 2007. ©American Meteorological Society. Used with permission.



It has been recently highlighted that four billion people, or two-thirds of the world's population, live under severe water scarcity conditions for at least one month per year (Mekonnen & Hoekstra, 2016). This can be suprising, particularly as this scarcity is not necessarily felt in many of the concerned areas, or at least not yet. Indeed, this finding is based on a definition of water scarcity that measures how much human water withdrawals exceed natural rates of replenishment, which actually measures the sustainability of current practices. This means that water resources are poorly managed, but not necessarily exhausted yet, or past a critical threshold of environmental degradation. Unfortunately, many areas are indeed beyond such threshold, and many others are heading towards it at a high speed.

Conditions of water stress can reveal the interlinkages across the energy, residential, and agricultural sectors. Indeed, these links become more evident when different sectors compete for scarce water resources. During the drought in California, restrictions on water use have been applied in the residential–municipal sector, while agriculture, utilizing the vast majority (74%, USGS, 2010[1]) of freshwater withdrawals in the state, did not see any specific immediate restriction. Interestingly, while it may seem unfair to urban dwellers that their use is controlled while the largest consuming sector suffers no immediate restriction, these people also benefit from agricultural production, via state profits from food exports and direct availability of food products to them. In arid northern China, rivers and aquifers are highly stressed: river flow is decreasing and aquifers are depleting, partially due to irrigation needed to satisfy an increasing demand for food from a growing and wealthier population. Meanwhile, demand for energy is also increasing, and coal mining, which requires large volumes of water, also occurs in northern agricultural regions, leading to a competition between the energy and food sectors. Similarly, mining activities for power production and agriculture compete for increasingly stressed water resources in South Africa.

How Can Using Water Harm the Environment?

Impacts of water use on the environment highly depend on the type of use and the local biophysical and social conditions.

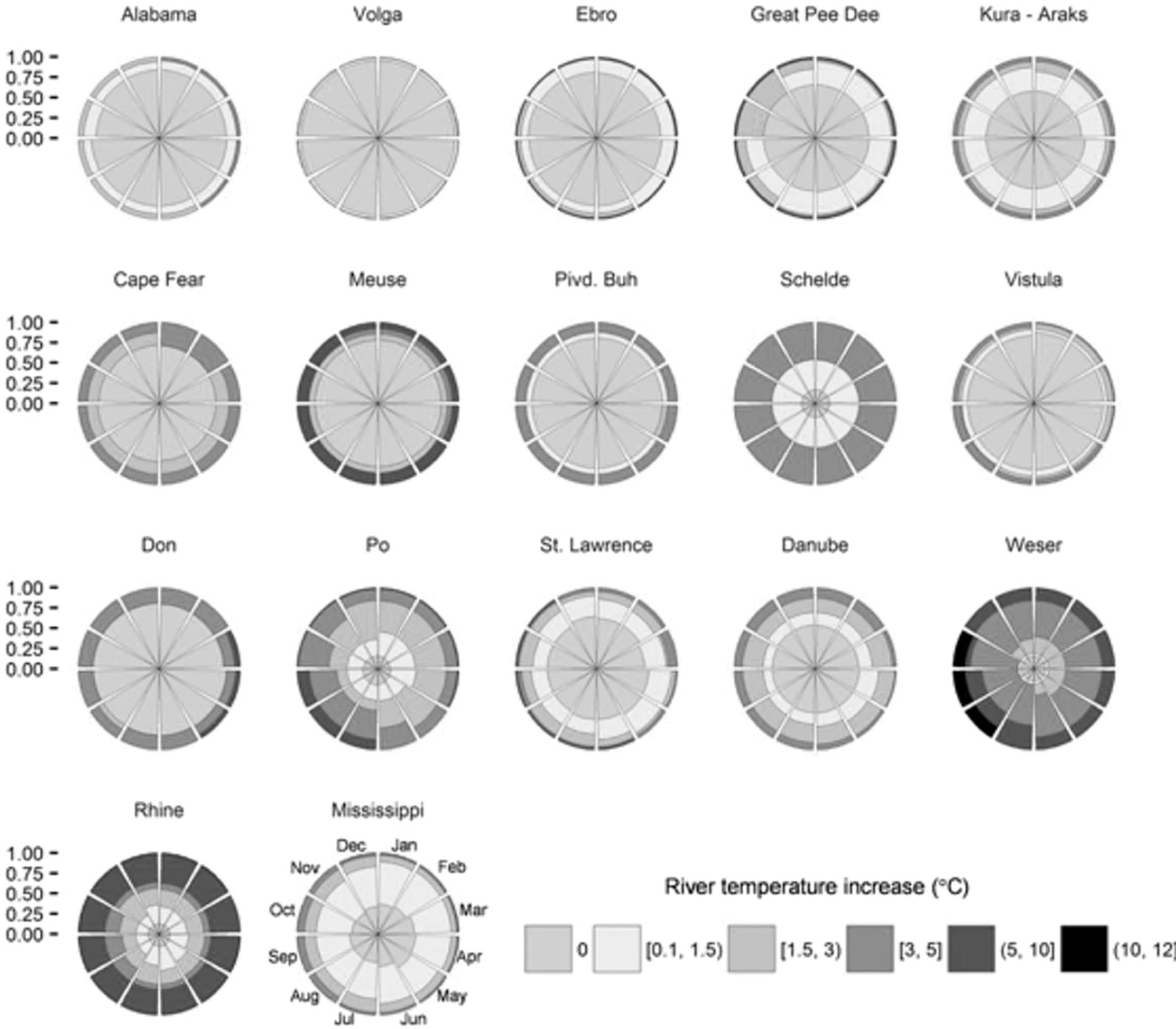
Withdrawals from natural bodies is always necessary for water use (except in the case of rainfed agriculture), and can be followed by a variety of steps, including evaporation and return to natural water bodies, with an altered temperature or chemical composition. Processes leading to the evaporation of water (e.g. crop growth) are often considered as consuming water (consumptive use), because the evaporated water cannot be reused locally. However, some of this water may fall back again as precipitation in the same or another watershed, and thus be available for other uses. A significant amount of water withdrawal is used by the energy sector for cooling in power generation processes. In this case, some water is returned to the local water cycle but at a higher than normal temperature, which can affect freshwater ecosystems. This is referred to as thermal pollution. Finally, water used for industrial processes or running off land covered with fertilizers will return to the natural water cycle with an altered chemical composition (i.e. chemical pollution).

Water withdrawals can thus lead to altered quantity or quality of available freshwater, which can in turn hinder other activities requiring water and negatively affect ecosystems and human health.

Regarding freshwater quantity, threats to humans and ecosystems have been measured with various water stress indicators. These indicators most commonly assume a threshold for the so-called ‘environmental flow requirements’ of Q90 (flow naturally exceeded 90% of the year) as an acceptable quantity for ecosystems (NGPRP, 1974), and a threshold of 20 to 40% of withdrawals relative to availability – accounting for the environmental flow requirements – indicating high to severe water stress (Vörösmarty et al., 2000). While this general definition allows the level of water stress relevant to humans and ecosystems globally to be estimated, it has been argued that it may not accurately reflect the impact of water use in all cases. Indeed, given the highly spatial and temporal variability of water use and availability, and the different characteristics of various freshwater sources (soil moisture, river flow, reservoirs, renewable and fossil aquifers, desalinated seawater, recycled water, etc.), a similar withdrawal to availability ratio in two regions or two seasons may not have the same consequences for the local population and ecosystems.

Regarding freshwater quality, both physical and chemical alterations can have an important, sometime synergetic, effect on aquatic ecosystems and can often make the resource unsuitable for human uses, such as irrigation or drinking. One of the largest sources of freshwater thermal pollution is found in the thermoelectric power sector (Hester & Doyle, 2011). A recent global study (Raptis et al., 2016) identified river basins where thermal pollution is the highest, either as the absolute volume of water affected (e.g. in the Mississippi) or as the affected volume of water relative to the watershed total flow (e.g. the Rhine and Wesser basins, Figure 60.6). A commonly set limit for an acceptable level of temperature increase is 3°C. Under projected global climate change, some regions exposed to heatwaves and droughts, with an associated increase in power demand for air cooling and refrigeration, may suffer even greater impacts in the future.

Figure 60.6 For the most affected basins (at least one instance of water temperature increase ≥3°C in any given grid cell at any given month of the year): the monthly variation of portions of the flow unaffected and affected by thermal pollution (according to the defined temperature increase grades) as a fraction of the total watershed flow (the temporal legend is provided in the plot for the Mississippi basin).Source: Raptis, 2016.



Other quality impacts include chemical pollution from industrial wastewater or from runoff of fertilized agricultural lands.

Treatment of industrial wastewater can be managed by the municipality along with standard sewage, or by specialized treatment units when pollutants require particular processes. The costs of treatment, in particular in absence of the valuation of the loss of ecosystem services associated with water pollution, are often prohibitive for industries. This explains the large portion of wastewater not treated, especially in developing countries, where 70% of industrial waste is discharged untreated into water bodies (Sato et al., 2013).

The food sector contributes to about half of the production of organic water pollutants. In particular, increased concentrations of nitrogen and phosphorus in lakes and rivers, from excess fertilizers, have led to eutrophication in numerous regions of the world (e.g. the Gulf of Mexico, from runoff of the Mississippi basin).

The United Nations Economic Commission for Europe (UNECE) and FAO report (FAO, 1996) on the impacts of fertilizer on water quality describes the following issues:

- Fertilization of surface waters (eutrophication) results in, for example, explosive growth of algae, which causes disruptive changes to the biological equilibrium (including fish kills). This is true both for inland waters (ditches, river, lakes) and coastal waters.
- Groundwater is being polluted mainly by nitrates. In most countries, groundwater is an important source of drinking water. In several areas, the groundwater is polluted to an extent that it is no longer fit to be used as drinking water according to present standards.

Besides mineral fertilizers, the extensive and intensive application of organic fertilizers (manure) can also play a significant role in water pollution in some areas (FAO, 1996).

European studies of nitrogen water pollution found that agricultural emissions of nitrogen to freshwater exceed 10 kg/ha/year across some European regions, with values exceeding 20 kg/ha/year in parts of Denmark, southern Sweden and Norway, western United Kingdom, Ireland, Belgium, Netherlands, Brittany (France), and the Po Valley (Italy) (Bouraoui et al., 2009). Reactive nitrogen – whether from animal-raising facilities, manufactured fertilizer, septic systems, or other sources – has raised nitrate concentrations in the waterways of most industrialized nations. Concentrations in rivers of the northeastern United States and much of Europe have increased 10- to 15-fold in the last 100 years (Fields, 2004).

The impact on ecosystems can also be significant in coastal zones. Where nitrate loading to bays and costal zones increases, it can provide such a steady source of nutrients that algae bloom uncontrollably, and reduce the oxygen amount when decomposing. If too much oxygen is removed, the water body develops a ‘dead zone’ – an area that can no longer support finfish, shellfish, or most other aquatic life. A well-known dead zone is found in the Gulf of Mexico, which is fed by the nitrate-rich Mississippi River and covers an area of the sea that fluctuates between 8,000 to 21,000 square kilometers. There are also oxygen-starved areas in the Baltic Sea, the Adriatic Sea, the Gulf of Thailand, the Yellow Sea, and the Chesapeake Bay (Fields, 2004).

Water-intensive activities can also affect other environmental functions, such as soil fertility. For example, intensive irrigation in dry areas can increase **soil salinity.** Salts remain in the soil and near the surface after applied irrigation water is taken up by plants or evaporated. This alters the land's arability, except for a few salt-tolerant crops, like cotton and date palm.

How Can we Sustainably Use Water Across the Water–Energy–Food Nexus?

About a third of the global population lives in areas of water stress (Hanasaki et al., 2013; Schewe et al., 2014; Vörösmarty et al., 2000), i.e. where water withdrawals exceed 40% of water availability on an annual basis. With projected population and economic growth on the one hand, and expected increase in drought frequency on the other hand, we can expect more challenges in the future. Water stress can be reduced via supply-side and demand-side approaches.

While much efforts in the past decades have been focused on the supply side – via the construction of reservoirs, canals, and pipelines – it has become apparent that, as overexploitation of water resources is spreading across many regions of the world, water stress reduction also requires demand-side measures.

Supply-side solutions to water stress include improving the efficiency of water transport and storage, for example by reducing leakage from pipes, which are often important (e.g. 50% losses in irrigation pipes in China (Deng et al., 2004)), or reducing sedimentation in reservoirs. Desalinization is another potential way of increasing freshwater availability, although it is only practical in coastal regions and is highly energy-intensive (Wada et al., 2014).

Demand-side water stress mitigation can be done by improving the water productivity of processes – for example via water recycling or crop yield increase – or by reducing demand for water-intensive goods and services, for example via diet adaptation or population growth control (Wada et al., 2014).

Each solution to water stress also has potential risks for the environment, agriculture, and energy production and interacts with economic, social, legal, and political issues.

Water resources must thus be managed in an integrated way in order to effectively reduce water stress across sectors, in an environmentally, economically, and socially sustainable manner.

For this reason, managing water quantity is not enough. Water quality, and environmental quality generally (of air, soil, oceans), biodiversity, human health and well-being, economic viability, and political stability also need to be included as important goals of water stress policies. Once interlinkages are established and quantified, which is often challenging, experts must evaluate trade-offs and/or synergies associated with each measure. Then, the relative importance of different goals can be set by decision makers, according to various interests of the relevant stakeholders. Useful tools can be employed to help support these decisions, such as multi-objective optimization, which has been applied in the context of city water supply planning (Matrosov et al., 2015) and environmental conservation (Hurford & Harou, 2014).

Negative environmental impacts of water-intensive activities discussed in the previous section can also be mitigated in different ways.

Water pollution from fertilizers can be minimized by:

1. reducing the input of fertilizer per unit output, by improving efficiency (e.g. applying fertilizer at different times to avoid large runoff) or changing crop type;
2. reducing leaching into rivers with buffer zones between field and water streams; changing management type, reducing erosion via no tillage, etc.
3. treating water resources downstream, which may be a costly option.

Similarly, chemical water pollution from industries can be reduced by adapting the processes to reduce pollutant discharge, treating wastewater before discharge, or afterwards. Because in this case the source of pollution is a very localized point-source (e.g. the wastewater pipe of a plant), it could be less costly to treat wastewater before discharge into natural water bodies. This must be supported by regulations and incentives to ‘internalize negative externalities', i.e. account for the negative consequences on ecosystems and other users.

To prevent the accumulation of salts at the land surface, excess irrigation can be applied to flush the salts away from the root zone. In this case, avoiding soil salinization to preserve the soil quality requires a greater water use. Other solutions exist without additional water requirements, such as using – when possible – water with low salinity to irrigate, and managing surface and subsurface drainage systems adequately.

The concept of integrated water resource management (IWRM) was introduced in the early 1990s, motivated by the recognition of interlinkages of sectors, users, and ecosystems via water resources. IWRM aims to develop water resources management plans that account for several key water users, in an efficient, equitable, and sustainable manner. It can be applied for example when upstream and downstream users are competing for surface water resources. However, IWRM remains centered around water use and thus focuses mainly on how different activities use water, and less on how water supply or other water-intensive sectors also need inputs from these activities (e.g. energy input is required for groundwater pumping in irrigation). Unlike IWRM, the nexus perspective encompasses all resources and bilateral connections among them, and also aims to consider cross-regional links, such as trade relationships and climate effects.

The first step in building a nexus approach towards water security is to identify all the relevant areas of interest that may be affected by changes in the area of policy intervention, and to quantify the key interlinkages between these areas and the target area. The obtained relationships between the targeted area (for example water productivity in a farm) and other relevant areas (e.g. soil fertility, riverine ecosystems, air quality, nutrition, farmer welfare, etc.) allow the effects of the policy (e.g. improving water productivity by changing crop type) on the key related issues to be quantified.

The second step, no less challenging, is to translate these changes into a measure of impact on key goals (e.g. food security, energy security, and water security). This is a difficult task because it requires a consensus on the relevant and meaningful metrics to use in order to compare the outcomes of a policy on each goal. This metric could be expressed in a variety of units, such as monetary value, or level of environmental sustainability (e.g. resource use versus natural rate of replenishment of this resource).

Third, a qualitative assessment of the policy outcome is also needed to account for socio-economic, cultural, and political forces. In recent years, water has been recognized in some contexts as a fundamental human right. However, this ‘right to water’ appears to focus on access to sufficient and safe water for drinking and sanitation purposes, whereas, in a broader definition, it could also include water needed for essential activities like food and energy production. Another key aspect in water security is equity, as discussed by many authors, including Zeitoun (2013), asking the question ‘water security for whom?'. The FAO definition emphasizes that access needs to be ensured for all people. However, the economic incentives may play against certain groups for which infrastructure investment, for example, may not be attractive. In these cases, it should be the role of states to ensure equitable access, or at least a minimum acceptable level of access to all. However, this may be challenging, especially in developing countries with less availability of state welfare. Even in developed countries, this can be a challenge, as illustrated by the recently reported water supply lead contamination in Flint, Michigan (USA).

Role of Virtual Water Trade in Water–Energy–Food Security

Water Footprint – A Common Accounting Tool Across Sectors

The water footprint approach quantifies the amount of water consumption associated with the production and provision of goods and services. It enables (i) an understanding of the importance of water required by these goods and services and (ii) links to be drawn between local water consumption and remote demand for goods and services. Much of the water footprint literature has focused on food commodities because agriculture is by far the largest water consuming sector. However, the concept has also been applied to industrial goods. The common unit can then be, for example, volume of water per unit monetary value of good. Water footprints thus reveal the water consumption associated with different products across sectors, including food commodities and supplied energy (Table 60.2).

Food Trade – Spatial Linkages of Food Systems

Increasing international trade in the past few decades has strengthened links between different regions and different steps of the food supply chain. It has been found that the number of connections in the food trade network – i.e. the number of country pairs trading food with each other – has more than doubled in the two decades from 1986 to 2007 (Dalin et al., 2012a, Figure 60.7). Moreover, the quantity of food commodities exchanged has also rapidly grown. For example, a growing portion of soybean meal fed to pigs in China originates from Brazil and Argentina, to support the rising demand for animal products in Chinese diets. This production requires significant amounts of land area and water resources, and can be a concern due to the important ecosystem services lost, for example from deforestation in the Amazon. Global food trade allows access to more products, with a wider variety, thus contributing to improve food security – for example it can help cope with drought-induced food production declines (e.g. in 1992 in southern Africa (Dalin & Conway, 2016a)). However, it can have both positive or negative environmental consequences that may go unnoticed by consumers, as they occur in a different region of the world.

Table 60.2 Virtual water content of agricultural products (in cubic meters of water per ton of product) and water footprint of electricity and heat production (in cubic meters of water per TJ), on a global average circa year 2000.

Agricultural Product[1]	**Virtual Water Content − Green (m^3/ton)**	**Virtual Water Content − Blue (m^3/ton)**
Beef	7.5	1.0
Poultry	6.0	1.5
Pork	4.8	1.2
Soy	1.7	0.8
Barley	2.0	1.0
Corn	2.2	0.8
Wheat	2.0	0.5
Rice	1.6	0.3
Energy Production by Source[2]	**Water Footprint (m^3/TJ)**	
Firewood	100000	
Hydropower	10000	
Nuclear	1000	
Oil	1000	
Coal	1000	

Geothermal	800	
Natural gas	500	
Solar	200	
Wind	2	

[1]Numbers from Konar et al. 2011

[2]Numbers from Mekonnen 2015

Virtual Water Trade Network – Link Water Resources Across Regions

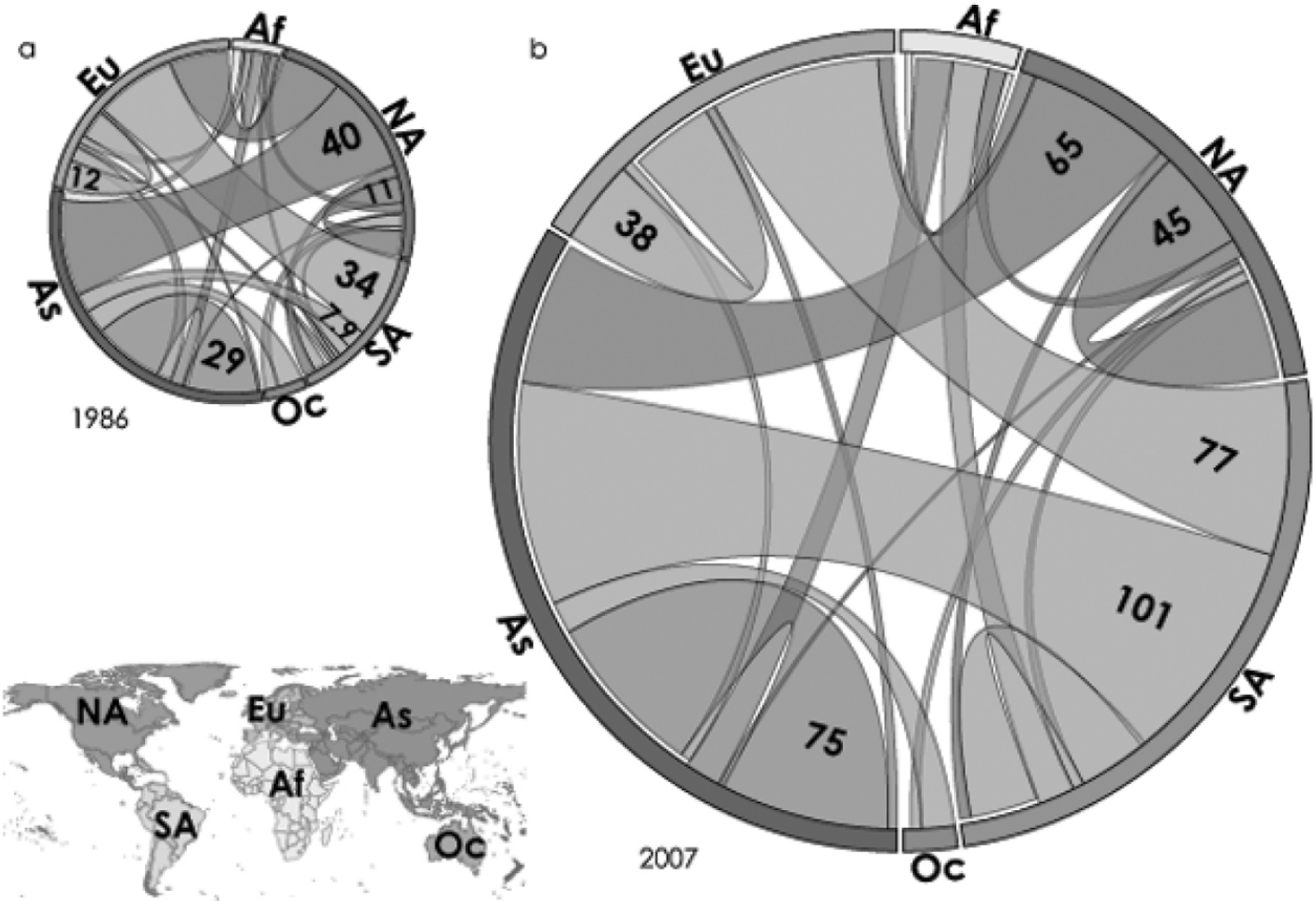
Not only food is exchanged but also water, in a virtual manner (not the physical water content but virtually embedded water, or water footprint of the traded good). Just as the carbon footprint can reveal that developed countries have outsourced the production of carbon-intensive goods, virtual water trade analysis shows that some countries import highly water-intensive commodities from other regions.

Estimates of virtual water trade enable the allocation of water uses for food production to the country where these food products are eventually consumed. It is then possible to compare the consumption-based water footprint (associated with national consumption of products made both domestically and abroad) with its production-based water footprint (associated with domestic production inside borders).

Studies of the global virtual water trade network – i.e. the system of countries linked by trade flows, weighted as the volume of virtual water involved – have found it to be highly heterogeneous, with a few countries dominating both in terms of connectivity (the number of trading partners) and weighted flow (the volume of water imported or exported). These countries include the USA, Brazil, Argentina, China, and some European countries (Dalin et al., 2012a; Hoekstra & Hung, 2002; Konar et al., 2011).

Major drivers of virtual water trade are the nation's Gross Domestic Product (for connectivity, i.e. engaging in trade), rainfall and agricultural area (for virtual water exports) and population (for virtual water imports) (Dalin et al., 2012b). Modelling and projections found that the importance of large importers is expected to further increase under future climate and socio-economic and population growth (Dalin et al., 2012b).

Figure 60.7 Embedded water volumes (in cubic km per year) in trade of major agricultural products for years 1986 (a) and 2007 (b), between world regions.



Source: Carole Dalin, Megan Konar, Naota Hanasaki, Andrea Rinaldo, and Ignacio Rodriguez-Iturbe. Evolution of the global virtual water trade network PNAS 2012 109 (16) 5989–5994; published ahead of print April 2, 2012, doi:10.1073/pnas.1203176109

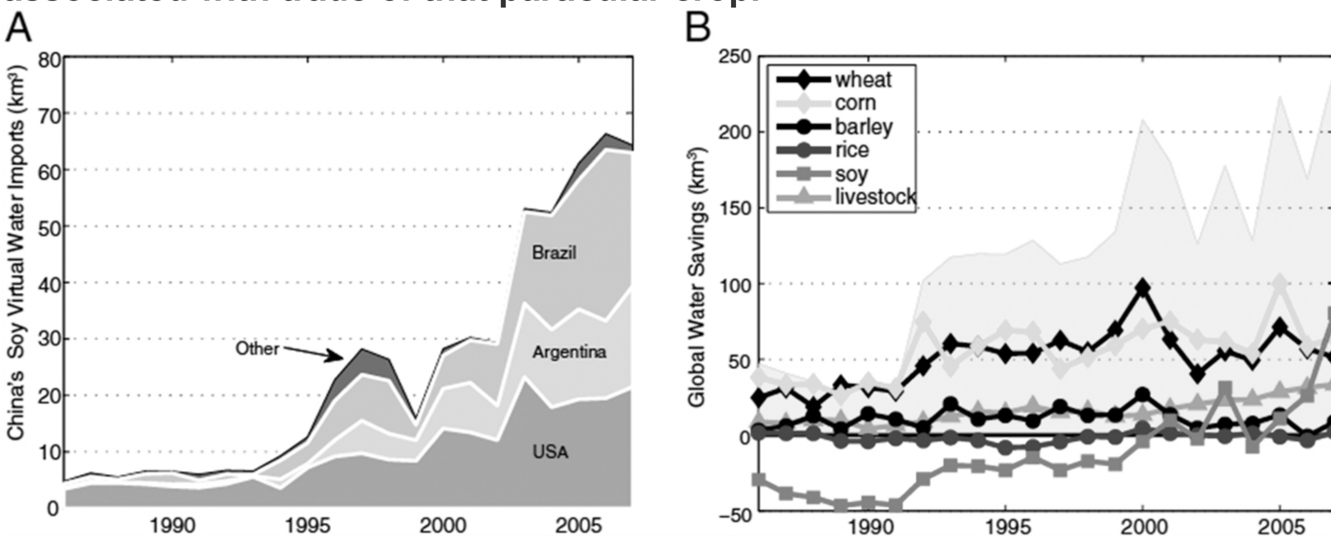
Water Savings – Potential to Improve Food and Water Security

Water savings have been defined as the difference between the volume of water that would be consumed to produce imported goods in the country of consumption and the volume of water currently consumed in its partner country to produce these goods.

In other words, positive global water savings associated with a trade relationship indicate that the goods are exchanged from the relatively more water-productive country to the less water-productive country, thus leading to a reduced global water use relative to an autarky situation (no trade).

International food trade has been found to lead to positive and increasing global water savings over time (Dalin et al., 2012a). This result indicates that, on a global average, food tends to be exported from relatively more water-productive countries to less water-productive ones; however, this does not exclude the fact that, for particular relationships or products, trade may go the other way and lead to global water losses (Dalin & Rodriguez-Iturbe, 2016b). The increase in global water savings over time may be due to (i) increasing volume of food trade on water-efficient relationships, or (ii) increasing water productivity gap between partner countries, or (iii) appearance of new water-efficient relationships. In the case of soybean imported by China, it has been found that both the gap in soybean water productivity between China and its partners (Brazil, USA, and Argentina) and the volume of soybean trade increased between 1997 and 2007 (Figure 60.8).

Figure 60.8Evolution of important features of virtual water trade. (A) China's virtual water imports associated with soy over time broken down into the corresponding exporting countries and (B) global water savings over time. The shaded area shows the total global water savings from crops and livestock (beef, poultry, and pork) trade. Individual lines show the global water savings associated with trade of that particular crop.



Source: Carole Dalin, Megan Konar, Naota Hanasaki, Andrea Rinaldo, and Ignacio Rodriguez-Iturbe Evolution of the global virtual water trade network PNAS 2012 109 (16) 5989–5994; published ahead of print April 2, 2012, doi:10.1073/pnas.1203176109

Note that the dramatic increase in global water savings from soy trade corresponds to the increase in China's imports from more efficient countries of production (the United States, Argentina, and Brazil) (Dalin et al., 2012a).

To apply such findings in, for example, trade policy decisions aimed at reducing one's food environmental footprint, two important aspects should be considered alongside the direct conclusions from water savings estimates: (i) not all water use is equal and (ii) food production has other important environmental impacts.

First, 'not all water is equal' is a simple way to point out that direct water footprint estimates, quantifying the volume of water use, even when separating sources of water such as rainfall, surface, and groundwater, does not account for differences in local water availability. To improve on this aspect, a few recent studies have introduced a factor of water scarcity in virtual water analyses (Mekonnen & Hoekstra, 2016; Ridoutt & Pfister, 2010).

Second, as previously mentioned with the example of Brazilian soybean, a product with a small footprint on local water resources can be associated with detrimental environmental impacts, e.g. deforestation, water pollution, etc. (Dalin & Rodriguez-Iturbe, 2016b). If irrigation is based on dams, or groundwater pumping, the associated materials and energy use can also significantly impact the environment.

Moreover, promoting food production in one region, and deciding to import food instead of producing it in another will have potentially important implications for the energy sector and water services. Accounting for these interactions can help avoid unintended consequences of agricultural policies.

Thus, the water–food system should not be considered in isolation and a nexus approach encompassing energy, land, and materials is better suited to support effective environmental policy making.

The water–energy–food nexus is increasingly globalized, via trade of goods and services and via global climate change. Water-intensive agricultural products are processed and consumed far from where they are grown; oil and gas are burned on the other side of the planet from where they were extracted. Besides, greenhouse gas emissions from coal power plants, livestock farms, or biomass burning affect the climate in remote locations. The nexus approach should also include these important and growing teleconnections.

Conclusions

Water resources are increasingly stressed due to rising demand for water and water-intensive goods and services, in particular food and animal products, associated with the global economic and population growth. Water is at the center of several major challenges of the 21st century, as highlighted in the Sustainable Development Goals.

Water withdrawals can lead to altered quantity or quality of available freshwater, which can in turn hinder other activities requiring water and negatively affect ecosystems and human health. Thus, water stress policies must go beyond management of water volumes and also account for environmental quality, biodiversity, human health and well-being, economic viability, and political stability. Once interlinkages are established and quantified, experts must evaluate trade-offs and synergies associated with each measure. Then, the relative importance of different goals can be set by decision makers, according to various interests of the relevant stakeholders.

IWRM can be easier to implement in practice than a ‘full’ nexus approach. Indeed, it keeps the focus on one resource: water, which is central and thus covers many key linkages. While most governments and agencies are still founded on a silo structure, water agencies are common, and these can provide a readily available framework to implement and develop IWRM. However, we have discussed the importance of bilateral linkages and the growing importance of the energy sector, with associated environmental impacts. Besides, we also highlighted increasing linkages across regions via trade, and climate change is another important factor in global interactions. The nexus can thus complement IWRM and cover other important relations.

Implementation of solutions to water stress can be much more effective if a nexus approach is taken. This will require interdisciplinary work from scientists and experts to provide the relevant supportive evidence to policy and decision makers, and those actors will need to increasingly work across thematic silos to build integrated policies towards sustainable water–energy–food security. Different tools and frameworks such as natural capital accounting, virtual water footprint and trade, and multi-objective optimization can help include interlinkages in assessment and decision making.

Note

1. http://ca.water.usgs.gov/water_use/california-water-use-resources.html

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- water
- water resources
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- water cycle

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