Part Two

CHAPTER 8

WATER RESOURCES

Rising water demand creates shortages, depletes groundwater sources, and results in high salt levels in soils. At the same time, wetlands are rapidly disappearing due to drainage, conversion, and the disruption of natural flows. These trends have serious health and environmental impacts: reducing ecosystem services and biodiversity, and resulting in high carbon emissions, soil subsidence, loss of productive land, and water insecurity. The current business model for agriculture, energy, and industry, including water pricing and trading, creates perverse incentives to waste water. Rapid unplanned urbanization and climate change make things worse.

An integrated approach to land and water resource management is essential: this entails reducing demand and increasing use efficiency, protecting and restoring wetlands and watersheds in our working landscapes, providing incentives for sustainable use, and designing more sustainable cities. We have the technical know-how to sustainably manage global water supplies, but we need coordinated action and the political will to incentivize equitable water sharing and improve management practices at progressively larger scales.

INTRODUCTION

Throughout history, the success and failure of human communities have been closely linked to the effectiveness of water management. The first great civilizations developed on the banks of major rivers – like the Nile in Egypt,[1] Tigris and Euphrates of Mesopotamia, Indus in India and Pakistan, and Hwang Ho in China – drawing on seasonal plenty to supply irrigation systems and create agricultural surpluses. Irrigation systems also helped farmers move into arid areas, or survive changing weather patterns.[2] The eventual breakdown of these civilizations was triggered in part by the failure of their water systems,[3] through mismanagement leading to problems such as desiccation, water-logging, and salinization.[4]

Today the world faces growing problems relating to land-water interactions and water security, which have reached crisis levels in many countries and regions. Key issues include over-use and waste; fluctuations in abundance, with an increasing frequency of both droughts and floods; poor water quality with impacts on environmental and human health; and the knock-on effects of land degradation. The world is becoming increasingly urban, with half of the population already living in cities and likely to increase to 66 per cent by 2050,[5] putting urban water supply and sanitation systems under even more pressure. While extreme water scarcity and floods are in many cases human-induced, the impacts of climate change add a potent new factor that aggravates an already precarious situation.

Water goods and services from wetlands contribute significantly to the global economy. A recent analysis of over 300 ecosystem service valuations estimated an average contribution of USD 25,682 per hectare, per year for inland waters and USD 4,267 per hectare, per year for lakes and rivers,[6] often regarded as "free goods" in conventional economic analysis. Inland and coastal wetlands continue to be degraded or lost at an alarming rate;[7] they are key to the global water cycle and in regulating local water availability and quality. The total value of wetland services is estimated at USD 70 billion per year for Asia.[8] While some countries recognize the nature of the risks and benefits and make strategic investments in their water management systems, others have done little in terms of addressing water stress through either policy or innovation.

Despite massive demographic and environmental changes, water problems are rooted more in management approaches, business models, outdated policies and practices rather than in physical limitations. The technical basis for sustainable water management is well understood, suggesting that solutions need to be aimed primarily at changing behavior and encouraging a multi-functional systems approach to water management.[9] Getting water management right is absolutely critical for the future well-being of people and the environment.

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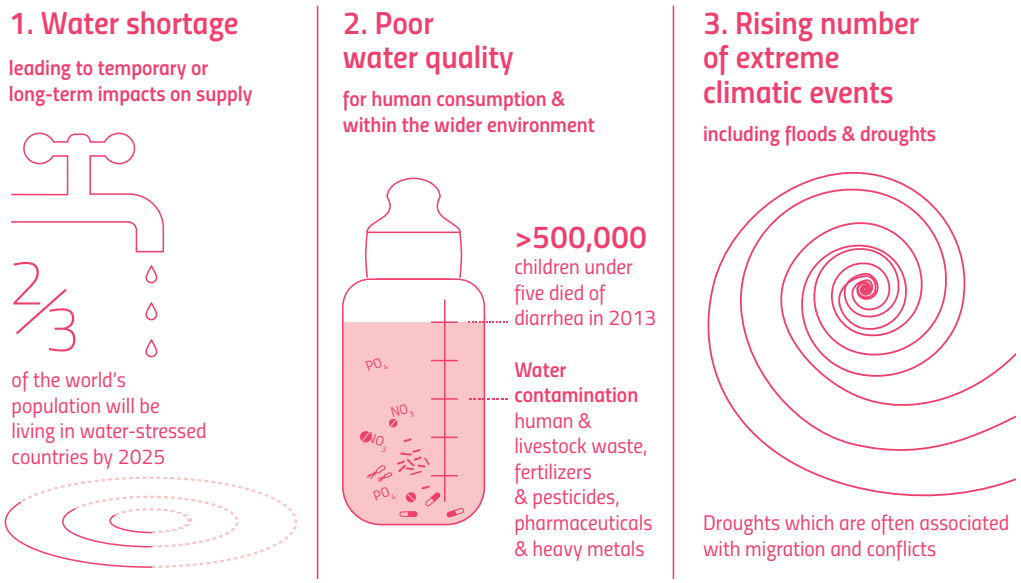


SEVEN ASPECTS OF WATER INSECURITY

Despite years of effort during the "Water for Life" UN Decade for Action (2005-2015), the World Economic Forum's *Global Risk Report 2016* identified potential water crises among the top ten risks facing the world and ranked them as the number three global risk in terms of potential impact.[10] Yet water is still often sidelined in discussions about the role of land and natural resources in economic development.

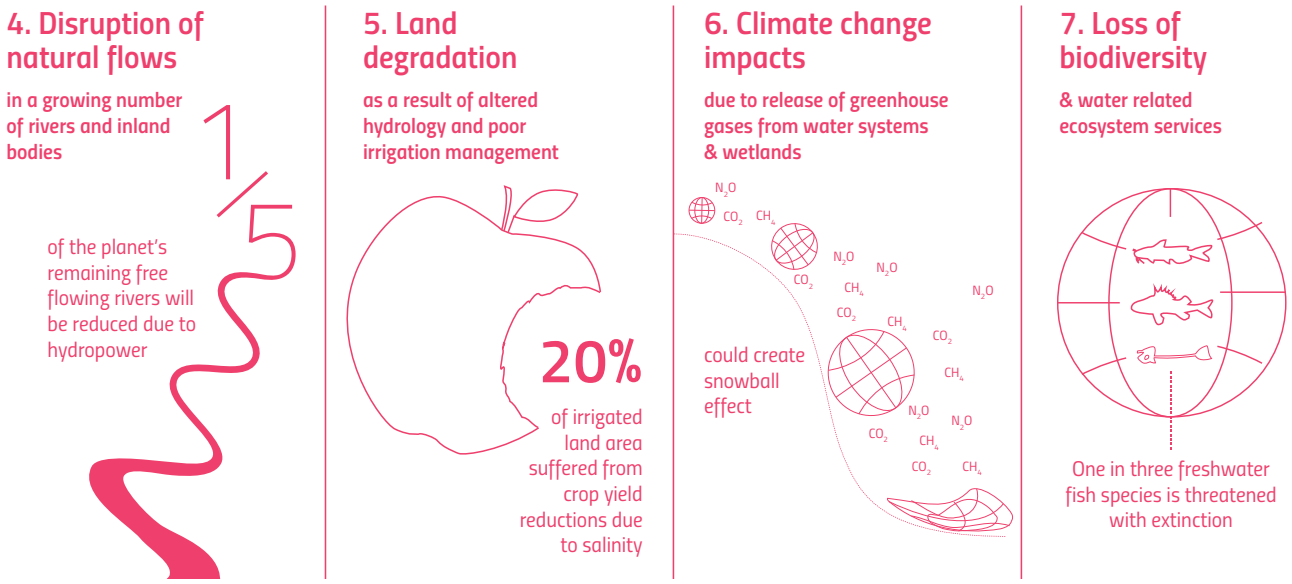
Sustainable Development Goal 6, "*Clean Water and Sanitation: ensure availability and sustainable management of water and sanitation for all,*" will hopefully bring greater attention to these issues.[13] A healthy water cycle is perhaps the most critical component of sustainable and equitable land management policies and practices.

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.[14]

The World Water Congress 2015 noted: "*In spite of its relevance in terms of security, water is often not regarded as a key determinant for development, absent from many political agendas.*"[11] The *World Water Development Report 2012* recognized that *"water-related hazards account for 90% of all natural hazards, and their frequency and intensity is generally rising."* Furthermore, the corresponding report in 2015 emphasized the links between water and poverty, environment, and governance: with poor water management impacting negatively on all three issues.[12]

Here we discuss seven distinct aspects of water insecurity:

1. **Water shortages** leading to temporary or long-term impacts on supply
2. **Poor water quality** for human consumption and within the wider environment
3. **Rising number of extreme climatic events** including floods and droughts
4. **Disruption of natural flows** in a growing number of rivers and inland water bodies
5. **Land degradation** as a result of altered hydrology and poor irrigation management
6. **Climate change impacts** due to greenhouse gas emissions from water systems and wetlands
7. **Loss of biodiversity** and water-related ecosystem services



1. Water shortages

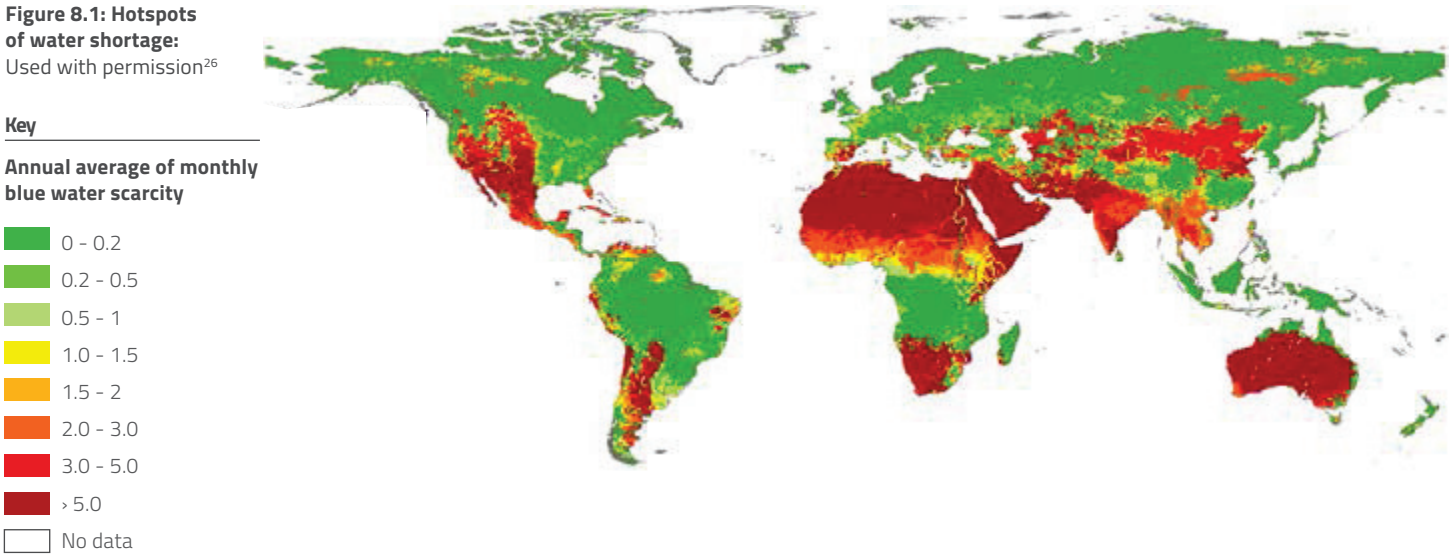
Over 1.7 billion people already live in river basins where water use is greater than the rate of natural replenishment; if this trend continues, two-thirds of the world's population will be living in water-stressed countries by 2025.[15] Other estimates are even more pessimistic with up to 4 billion people, over half the population of the planet, already facing severe water stress for at least one month of the year and half a billion suffering permanent water stress;[16] 71 per cent of the world's irrigated area and 47 per cent of major cities experience at least periodic water shortages.[17]

Shortages are driven not only by a growing population but also by the disproportionate increase in the levels of use and waste as well as the loss of the water retention and supply capacity of wetlands. As humans become more disconnected from water resources, they generally become more careless in their use. At the same time, the lack of pricing regimes in many industrial, energy, and agricultural production systems effectively treats water as a free or very cheap input, further encouraging waste. In the last century, the world population tripled while water consumption increased six-fold,[18] largely due to agricultural use.[19] Various projections indicate that water demand will soon exceed reliable water supplies at a global scale.[20,21,22] Our understanding of the severity and location of water stress is improving; increasingly sophisticated models can identify hotspots by river system and catchment as well as critical areas of shortage.[23,24,25]

Water shortages are a function of both availability and use: some very dry regions do not appear as hotspots due to low population density or efficient management practices whereas heavily populated or industrialized regions can suffer water scarcity even if they have more rainfall. Some of the world's most dramatic drying events, such as the notorious loss of the Aral Sea lying between Kazakhstan and Uzbekistan,[27] and the drying of Lake Chad between Chad, Niger, and Nigeria,[28] are almost entirely due to the diversion of upstream water flows. Current hotspots of scarcity include much of India and China, large areas of the central and western United States, southern Africa, the Mediterranean region, Central Asia and the western rim of South America. Some areas that have yet to face shortages, such as large parts of Africa, are projected to face major problems due to population growth and urbanization.[29] Hotspots of scarcity or floods can be related to the seasonal loss of water retention capacity in the catchment due to the degradation of wetlands, in particular high mountain wetlands or peatlands in southeast Asia and Russia which results in extreme water shortages in dry years and the potential for increased fire risk.[30]

Water insecurity can contribute to social instability and political insecurity, causing tensions within[31] and between countries. Several river basins are particularly at risk, including the Ganges–Brahmaputra, Han, Incomati, Kunene, Kura-Araks, Lake Chad, La Plata, Lempa, Limpopo, Mekong, Ob (Ertis), Okavango, Orange, Salween, Senegal,

Figure 8.1: Hotspots of water shortage: Used with permission[26]



Tumen, and Zambezi.[32] While some believe tensions could eventually create open conflict, so-called "water wars,"[33,34] others question the extent to which tensions could grow into conflict between states.[35] The debate continues as some point to rainfall variability as being a more important factor in promoting conflict, or even to water abundance as a cause, while others focus on the role of dams in interrupting water flows between countries. Nations are well aware of the tensions and over 680 water treaties have been signed since 1820 to explore negotiated approaches to disputes about freshwater resources, and the number of treaties is increasing.[36] Most analysts agree that the chances of tensions spilling into conflict are greater at local than at global scale,[37] in fact, the reality of localized, often violent, conflict due in part to environmental degradation is already well recognized.[38]

One outcome of water stress, in countries running short of surface water sources, is the increased use of groundwater sources. Some of these are being exploited faster than they are replenished; while this may be due partly to the reduction in recharge to the groundwater system resulting from climatic variation, the so-called "mining" of non-renewable water sources is not considered a sustainable option. While some groundwater reservoirs remain very large with reserves predicted to last many decades into the future, water security is being threatened by the rapid depletion of others,[39] particularly in drylands,[40] including the North China Plain, parts of Australia, the Northwest Sahara Aquifer System, the Guarani Aquifer in South America, the High Plains and Central Valley aquifers of the United States, and aquifers beneath north-western India and the Middle East.[41] Globally, 1.7 billion people live in areas where groundwater resources and/or groundwater-dependent ecosystems are under threat.[42] Groundwater accounts for up to a third of global water withdrawals, supplying 2 billion people and over 40 per cent of the irrigation water.[43] The countries with the largest areas using groundwater irrigation systems are India (39 million ha), China (19 million ha), and the USA (17 million ha).[44] Knowledge about the extent of reserves remains very limited in some areas,[45] and the lack of regulation has frequently led to unregulated use.

Agriculture is by far the most important driver of water shortages around the world; irrigation accounts for 70 per cent of global water withdrawals, and even more in some places facing critical water stress.[46] Most new land brought into production in the last fifty years is being irrigated,[47] and some estimates suggest that water demand in agriculture could double by 2050 due to growing demands for food.[48] Intensive or mono-cropping agriculture generally uses more water; other uses are divided between the demand from the industrial and energy sectors (20 per cent) and municipalities (10 per cent). The typical contributing factors to excessive water use in agriculture are leaky irrigation systems, wasteful field application, and the cultivation of crops with high water needs. Among the world's most water-intensive crops are cotton (7,000-29,000 liters per kg); rice (3,000-5,000 liters per kg); sugar cane (1,500-3,000 liters per kg), soya (2,000 liters per kg), and wheat (900 liters per kg).[49] Due to the sheer amount grown, rice accounts for 21 per cent of total water used by crops and wheat 12 per cent.[50]

Box 8.1: Blue, green, and grey water

The term "blue water" refers to water in rivers, lakes, and underground reservoirs commonly used for the irrigation of crops through construction of infrastructure such as dams, irrigation channels, and wells. "Green water" is the water that falls as rain, enters the soil root zone, and returns to the atmosphere as vapor from evaporation or transpiration by plants. After irrigation with blue water, the consumptive portion used by a crop returns to the atmosphere as the green water portion of the hydrological cycle. Green water is free, in that it requires no significant built infrastructure for its delivery, but will vary in availability within and between years. Blue water, by its nature, has more storage capacity and thus less short-term fluctuation, particularly in the case of lakes and groundwater, but overuse of blue water can deplete the resource in the long term. With proper treatment, "grey water" or domestic wastewater can be recycled and put to good use. These uses include water for household functions and the irrigation of both food and non-food crops, which can take advantage of the nutrients in the grey water, such as phosphorus and nitrogen.

Livestock production is even less water efficient, particularly if animals are grain-fed and raised within confined spaces. Beef production uses the most water; measurements in the United States found that beef requires 11 times the average amount of water used in other forms of livestock production.[51] A significant water footprint is also created by draining wetlands for agriculture, including the intensive use of peatlands for grazing of livestock (e.g., in the Netherlands and the Tibetan Plateau) and for palm oil and wood pulp. Besides the water loss, the drainage often results in land degradation and ultimately the loss of the peat layer (from oxidation) impacting biological productivity.[52]

Assessing the extent of water use is further complicated because water use in one country may be supporting lifestyles in another when agricultural products are exported. The *water footprint* concept identifies the real extent of water use per country in relation to the consumption of their population. The internal water footprint of a country is the volume of domestic water used, while the external water footprint is the volume of water used in other countries to produce goods and services imported and consumed by that country. The sum gives the total national water footprint. Four major factors influence the national water footprint: volume of consumption (related to the gross national income); consumption patterns (e.g., high versus low meat consumption); climate (plant growth conditions); and agricultural practices (water use efficiency).[53] Inefficiencies in agriculture are probably the most important single factor affecting water security and therefore need to be considered as a high priority for the reform of policies and practices.

2. Poor water quality

Equally challenging is the issue of water quality, both in terms of access to potable drinking water and the wider impacts of pollution on the environment. Almost 3 billion people face problems accessing safe drinking water. The UN's Millennium Development Goal to *reduce by half, by 2015, the proportion of people without sustainable access to safe drinking water*[54] was achieved by 2010, when measured by access to safe drinking water.[55] This was supported by a vigorous campaign by the UN and formation of the Global Water Operators Partnership Agreement to build regional platforms for cooperation and utility partnerships to deliver safe water to the poorest.[56] While the goal was reached overall, showing that major improvements are possible on a global scale, this was not the case in almost half the low- or middle-income countries for which data are available. Even where piped water was introduced, there is no clear data about how much is safe.[57] Lack of access to potable drinking water remains a major health hazard; in 2014, it was estimated that 1.8 billion people still used unsafe supplies, with 1.1 billion more using sources with at least moderate risk.[58,59] In Africa, over 300 million people lack access to clean drinking water,[60] including 17 per cent of city dwellers south of the Sahara.[61]

Unsafe drinking water carries a huge toll in terms of illness and death. Diarrhea is caused primarily by drinking water and infant formula contaminated with human or animal waste. This can be attributed to a number of underlying factors: shallow, contaminated wells; the illegal or ad-hoc nature of new settlements, which hampers government investment; governments overwhelmed by growing urban populations; inadequate transfer of funds from central to local governments; and limited funding due to debt.[62] Over half a million children under five died of diarrhea in 2013; a fall of over 4 per cent per year since 2000[63] but still a massive and largely preventable death toll.

Water is not only contaminated by human and livestock waste, but also and increasingly so by nitrate and phosphate fertilizers and pesticides,

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Rainfall is becoming increasingly erratic due to climate change, with the increased risks of flooding and droughts often affecting the same places at different times.

pharmaceuticals, heavy metals and other industrial pollutants. Since the 1960s, the use of synthetic nitrogen fertilizers has grown nine-fold, with further increases of 40-50 per cent expected over the next half century, while phosphate use has tripled.[64] Increasing fertilizer use, livestock production, and fossil fuel burning is leading to higher levels of reactive nitrogen in the environment, raising nitrate levels above safe thresholds for human and ecosystem health,[65] including in drinking water[66] and through the eutrophication of fresh and coastal waters.[67] Total global leaching and run-off of nitrogen is estimated at 32.6 million tons per year, the large majority from poor agricultural practices.[68] Excess phosphate exacerbates the impacts of nitrate pollution.[69] Other forms of agricultural run-off, including pesticides, herbicides, and fungicides which enter freshwater and marine ecosystems, have harmful impacts on biodiversity,[70] including sometimes at concentrations that current legislation in many countries deem safe.[71] So while there have been welcome improvements in drinking water quality in terms of gross contamination, there is still a long way to go, and conversely other aspects of quality, such as contamination with agricultural chemicals, appear to be worsening.

3. Rising number of extreme climatic events

Rainfall is becoming increasingly erratic due to climate change, with the increased risks of flooding and droughts often affecting the same places at different times.[72] There is already increased precipitation in the higher latitudes of the Northern Hemisphere, decreased rainfall in parts of China, Australia, and the Pacific Islands, and more variability in equatorial regions[73] impacting the frequency and severity of floods and droughts.[74] In 2000, 30 per cent of global urban land was situated in high risk flood areas and will likely grow to 40 per cent by 2030.[75] The intensity and frequency of extreme rainfall events are also likely to increase the magnitude and frequency of landslides.[76] Flooding, like the effects of shortages and poor water quality disproportionately impact the poorest and most vulnerable in many societies.[77]

Erratic bursts of high rainfall create increased hazards for communities living near rivers and wetlands. Since 1900, 90 per cent of disasters from natural hazards have been related to water.[78] Flooding accounted for 47 per cent of weather-related disasters from 1995-2005, with over 3,000 flood disasters affecting 2.3 billion people and killing 157,000; impacts were highest by far in Asia.[79] Water-related disasters are the most frequent

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When poorly managed, drought becomes a humanitarian catastrophe, threatening security at all levels.

of all so-called natural disasters.[80] Floods also carry high economic costs: for example, the 2006 Danube flood in Europe cost over USD 630 million in damage to infrastructure and crops.[81]

Lack of rainfall is also a serious problem. Over 50 million people around the world were affected by droughts in 2015.[82] The frequency and intensity of droughts are both likely to increase due to climate change as will their impacts as we continue to use more water. Drought can cause enormous damage to the environment, economy, and social stability. From 1950-2000, there were 296 large-scale drought events (i.e., those greater than 500,000 km^2 and longer than 3 months) reported across the world,[83] and the frequency, intensity, length, and extent of droughts are all steadily increasing,[84] particularly in the tropics and sub-tropics. For example, in Somalia droughts were the primary causes of an estimated 258,000 human deaths from 2011-2013.[85] Between 1900 and 2013, global economic losses totaling USD 135 billion were recorded from drought disasters.[86] When poorly managed, drought becomes a humanitarian catastrophe, threatening security at all levels. Droughts are often associated with migration and conflicts, particularly in areas where political tensions, weak institutions, economic problems, and group rivalries are already present.

Climate change could create an escalating effect in the future.[87] The year 2015 was the driest since record-keeping began over a century ago and one of the hottest, producing drought conditions across much of the globe with over 50 per cent of the people affected in Africa.[88] The 2015 drought was aggravated by one of the strongest ever-recorded El Nino events.[89] In Africa, the Middle East, and the Mediterranean, the severity of drought impacts are exacerbated by higher demands for water.[90] Droughts cause human hardship and ecological stress; when they occur in poorly-adapted communities and ecosystems, as recently occurred in parts of the Amazon, they can also result in major, long-term changes in the ecology.[91] Droughts related to the El Niño–Southern Oscillation (ENSO) are increasingly linked to major fires affecting millions of hectares of peatlands in southeast Asia, causing major smog events. In 2015, Indonesia incurred over USD 16 billion in economic losses[92] with over 106,000 premature deaths[93] as a result of peatland fires and smog. The occurrence of unexpectedly severe droughts in many parts of the world, such as the 2001-2009 "Millennium Drought" in southeast Australia,[94] is forcing a rethink about agricultural strategies and the viability of some long-established traditional societies. Shifting climatic norms along with more frequent and more intense climatic extremes together have major impacts on both water and food security.

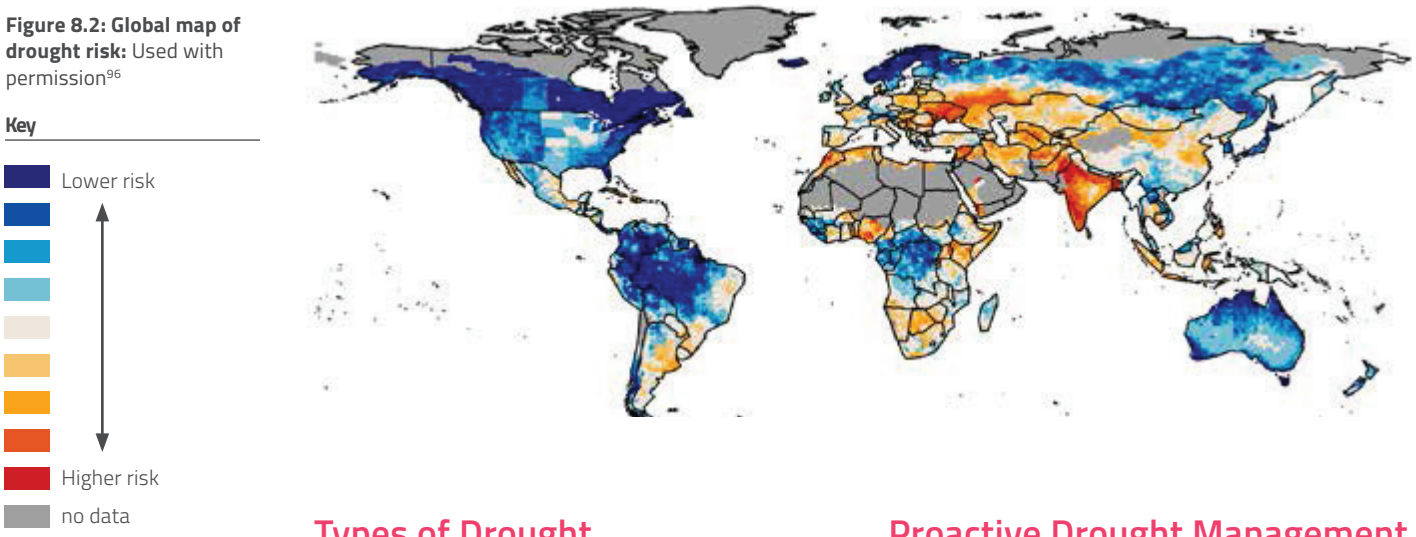

Figure 8.2: Global map of drought risk: Used with permission[96]

Types of Drought

Meteorological drought: lack of precipitation/ moisture, made worse by dry winds and high temperatures can create a water crisis if prolonged and can begin and end suddenly.

Agricultural drought: changes in atmospheric moisture to the extent that soil moisture is reduced, affecting crops and animals and evapotranspiration.

Hydrological drought: decline in quantity and quality of surface water and groundwater, due to lack of precipitation and overuse for farming and often a consequence of meteorological drought.

Socio-economic drought: supply of goods and services such as energy, food, and drinking water are reduced or threatened by changes in meteorological, hydrological, and soil conditions.[95]

Proactive Drought Management

The key pillars for enhanced drought preparedness and resilience are:

Drought Monitoring and Early Warning Systems: To assess the adequacy of meteorological weather stations, water resources, hydrological networks, and satellite information, etc.; To establish a comprehensive drought monitoring and early warning system which integrates climate, water, and soil parameters as well as socio-economic indicators at the national and sub-national levels; To produce high resolution gridded precipitation data over the country and produce a map of risk zones using drought early warning systems by computing drought standard indices.

Vulnerability Risk and Impact Assessment: To identify the processes that contribute to vulnerability and community resilience; To develop the risk profile of vulnerable communities and regions prior to the onset of droughts; To capture drought impacts after the incidence of droughts.

Drought Risk Mitigation Measures: To increase water supply through rainwater harvesting, land rehabilitation, groundwater recharge, potential new sources, etc.; To reduce demand through efficient use of water such as the review of water allocation, adopting/reviewing water tariffs, adjusting legal and institutional framework, water pricing, water treatment and use of wastewater/ recycling, etc. but in particular to increase the efficiency of agricultural water use; To increase drought resilience for livestock production through the balancing of livestock in irrigated areas, managing pasture and rangeland supportive capacity, use of indigenous feed and fodder, genotypes of mammals/low water use, etc.

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4. Disruption of natural flows

Rapid hydrological changes in many of the world's major river systems, mainly due to dam construction for hydroelectric power and surface water storage, are causing additional stresses on freshwater ecosystems and surrounding communities. Dam building provides great benefits in terms of power but has major social and environmental side-effects, which are becoming more evident over time[97] and leading to growing resistance from local communities and civil society organizations.[98] Globally, at least 3,700 major dams, each with a capacity of at least one megawatt, are either planned or under construction. These will in theory increase global hydropower by 73 per cent, to about 1,700 GW, but will reduce the planet's remaining free flowing rivers by over a fifth.[99]

The operation of dams can result in extreme drought conditions downstream. For example, in the Upper Niger Basin it is estimated that the combined impact of water diversions for planned hydropower and irrigation schemes could reduce fish catches in the delta by 31 per cent and reduce pastures by 28 per cent, with disastrous consequences for communities depending on these resources. Unless there are sufficiently large and correctly timed flood releases from dams, these measures would create conditions similar to the last major drought in 1984, when three-quarters of the delta dried out and people fled *en masse*.[100]

Blocking the free flow of rivers has a number of damaging effects, given the loss of both longitudinal and lateral connectivity of freshwater ecosystems. Dams negatively impact fish and other aquatic species, downstream sedimentation and water availability, livelihoods, and transportation. Water storage in reservoirs can also alter downstream water temperatures.[101] Dam construction itself causes direct ecosystem loss, and encourages settlement which triggers further land conversion and loss of ecosystems.[102] Deforestation, whether or not it is associated with dam construction, creates a negative feedback, increasing siltation and changing hydrology, reducing the output and lifetime of the hydroelectric power system.[103] Dams are also associated with high methane emissions, contributing significantly to climate change.[104] Reduced flooding in downstream floodplains can also reduce groundwater recharge and contribute to decreases in regional rainfall. But the attraction of such major power sources means that the wider trade-offs are often given insufficient attention.

Box 8.2: Changing hydrology in the Amazon[105]

A massive increase in dam construction for hydroelectric power is changing the flow and integrity of rivers throughout the Amazon:[106] impacting ecology, migratory catfish and river dolphins; blocking critical annual water pulses; trapping fish larvae and young;[107] disrupting river transport and food supply; and dramatically reducing downstream and coastal sedimentation.[108] There are already 154 large dams in operation, mainly in Brazil, generating 18,000 MW,[109] along with tens of thousands of small dams to collect water for cattle.[110] An estimated 277 more large dams are in the initial planning stages,[111] including in protected areas and indigenous lands,[112] with an installed capacity of around 95,000 MW.[113] If these all go ahead, there will only be three free-flowing tributaries remaining in the Amazon Basin,[114] permanently affecting ecology, economics, and climate.[115] One study concluded that due to projected forest losses, hydroelectric power generation could be reduced by up to 75 per cent of maximum output by 2050.[116] Basin scale planning and incorporating social and environmental criteria into decision making are both needed to ensure that energy production does not undermine other ecosystem services.[117]

5. Land degradation

Although water scarcity is a global problem, the conversion of natural forests and grasslands to agricultural land has increased water in soils at a local scale.

Poorly managed irrigation systems directly damage the land, reducing yields, raising water tables, and increasing salinity and alkalinity (e.g., sodic soils). Although water scarcity is a global problem, the conversion of natural forests and grasslands to agricultural land has increased water in soils at a local scale. Even when crops are not irrigated, the conversion from natural vegetation can impact water availability and quality. Over the past 300 years, rainfed cropland has increased by 460 per cent and pastureland by 560 per cent, decreasing evapotranspiration and increasing recharge (two orders of magnitude) and stream flows (one order of magnitude).[118]

At the same time, increased water quantity in agricultural systems has further degraded water quality by mobilizing salts and increasing salinization, due to shallow water tables and the leaching of fertilizer into aquifers and surface waters.[119] Irrigation with mineralized groundwater also increases soil salinity and decreases crop productivity. As early as 1993, the World Bank estimated that 20 per cent of irrigated land area suffered from crop yield reductions due to salinity,[120] and some estimate that up to half of the irrigated land is now affected by abnormal salt levels.[121] For example, salinity now affects 70-80 per cent of the Murray-Darling Basin, half the Aral Sea Basin, a third of the Nile Delta,[122] 28 per cent of the United States, and a quarter of Pakistan and Uzbekistan.[123]

The drainage of peatlands is linked to various forms of land degradation.[124] In parts of Central Asia and China it has led to the desertification of former peatland dominated landscapes, major soil erosion from overgrazing, and subsequent loss of productivity. Peatland drainage inevitably causes soil compaction and peat carbon oxidation, resulting in soil subsidence posing significant risks in lowland regions. As the base of the peat layer often lies at or below sea or river level, soil subsidence over time will result in enhanced flood risks. In many countries, this has been mitigated by the construction of dikes and pumping systems, however, given the inevitable continuation of subsidence of drained peat soils, entire landscapes may eventually lie below sea level. For example, half of the Netherlands lies below sea level as a result of centuries of peatland drainage, causing significant risks in terms of water security and salt water intrusion as well as high costs in terms of maintenance of infrastructure (projected at 25 billion Euro between 2010 and 2050 for the remaining 200,000 ha of Dutch peatlands).[125] Whereas the Netherlands has long since reached a point of no return, in southeast Asia the drainage of lowland peatlands started only in the 1970s. In the tropics, peatland drainage results in high CO_2 emissions,[126] causing subsidence of 3 to 6 cm per year.[127] However, the high levels and seasonal pattern of precipitation may exclude options for mitigation by dike and pumping systems. Continued drainage can lead to devastating consequences, including massive flooding risks and the loss of productive land.[128]

Land degradation directly impacts water security by reducing overall water quality: from high salt levels in groundwater to the increased flow of suspended solids and agrochemicals into both surface and groundwater. The loss of vegetation and subsequent soil erosion around reservoirs can lead to rapid siltation and a dramatic shortening of the lifespan of impoundments and hydroelectric power plants.[129] Erosion can lead to dramatically degraded landscapes of gullies and wind-blown sand deposits. It can also reduce agricultural productivity in more subtle ways. Bare, degraded, and eroding soil has less water retention capacity, either for storing water throughout the year or for absorbing sudden excesses and minimizing flooding after heavy rains.[130]

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6. Climate change impacts

Wetland management has a significant effect on the climate. In general, wetlands tend to be sinks for carbon and nitrogen but can be sources of other greenhouse gases such as methane;[131] the balance determines whether a wetland is a net source or sink of greenhouse gases.[132] While caution needs to be exercised in estimating the extent to which wetlands contribute to climate change mitigation through sequestration,[133] it is clear that their ability to store carbon provides a substantial global carbon store. Coastal wetlands are particularly important in taking up carbon dioxide and sequestering it in sediments, thus building large stores of carbon. Globally wetlands hold a disproportionate amount of Earth's total soil carbon, approximately 30 per cent of the total despite occupying only 5-8 per cent of its land surface.[134] Conversely, draining or burning peat increases carbon and smoke emissions,[135] as does draining or disturbing other wetland types. Wetland destruction ultimately leads to carbon release,[136] and the poor management of wetlands can also result in large carbon losses[137] although uncertainties remain about the total quantity of the overall carbon stocks contained in wetlands.[138]

While peatlands only cover about 3 per cent of the land surface, they contain the planet's largest store of carbon believed to be equivalent to that contained in all other terrestrial biomes,[139] particularly in boreal tundra. Intact peatlands contain up to 1,300 tons of carbon per ha[140] and 550 Gt of carbon are estimated to be stored in peatlands globally.[141] Peat "hotspots" include tropical forests in southeast Asia and tundra in Russia, Canada, Alaska, and Scandinavia. Drainage for plantation establishment, such as oil palm, creates a sharp rise in emissions.[142] It is estimated that 0.5-0.8 Gt of carbon per year is already being lost as a result of peatland conversion, mainly in the tropics.[143] For example, emissions from drained peat in southeast Asia equaled 355-874 Mt per year in the early years of the 20th century, with a further 1,400 Mt of emissions per year from 1997 to 2006 due to peat fires, mainly in Indonesia.[144] While carbon losses from the boreal tundra are currently much lower, they have the potential to exceed those from the tropics as warming thaws ice and dries peat. Some sites in Alaska have already switched from being sinks to sources of carbon,[145] and there are fears of a sudden pulse of carbon being released from the Arctic.[146]

Experience in Canada found that CO_2 losses from cut peat areas could be slowed through restoration and revegetation.[147] Successful peatland restoration has taken place in Ireland following past industrial cutting,[148] and similar positive results are reported from southeast Asia, Russia, Argentina, and the Himalayas.[149] Efforts to restore coastal wetlands (e.g., salt marshes, mangroves, sea grass beds) are increasing as a means to recover their natural ability to sequester carbon. Large-scale mangrove restoration is, for instance, currently underway in countries such as Kenya, Tanzania, Sri Lanka, and India.[150]

7. Loss of biodiversity and water-related ecosystem services

Wetland loss is continuing at a more rapid rate than for other ecosystems along with a disproportionate loss in ecosystem services.

Despite efforts to conserve and wisely use wetlands,[151] between 64 and 71 per cent have been lost since 1900,[152] and many others have been degraded by pollution, flow disruptions, over-harvesting, and invasive species.[153] Wetland loss is continuing at a more rapid rate than for other ecosystems along with a disproportionate loss in ecosystem services.[154] Between 1970 and 2008, the extent of natural wetlands declined globally on average by about 30 per cent.[155]

These losses have subsequent effects on freshwater biodiversity as well as the health and productivity of the surrounding lands and their communities. Open freshwater bodies occupy less than 1 per cent of the Earth's surface but contain as much as 12 per cent of all known species, including a third of all vertebrate species.[157] Freshwater biodiversity is declining[158] and one in three freshwater fish species[159] and 30 per cent of amphibians[160] are threatened with extinction. For example, catfish make up 39 per cent of known Amazon fish species, which rely on the integrity of critical spawning areas in the upper catchment,[161] but their survival is under threat from proposals to dam major rivers[162] and overexploitation.[163] Beyond species survival, fisheries are an important source of food and income, with per capita consumption of fish averaging 94 kg per year for riverside communities.[164] An analysis of 145 major watersheds found that those with the highest biological value were generally the most degraded.[165] Other freshwater groups are also threatened. Many mollusks are range-restricted and thus vulnerable; out of over 1,200 spring glass snail species (*Hydrobiidae*), 182 are listed as threatened on the IUCN Red List.[166]

Box 8.3: The Ramsar Convention

The Ramsar Convention on Wetlands, signed in Ramsar, Iran in 1971, is an international agreement aimed towards the "*conservation and wise use of wetlands and their resources.*" Parties to the Convention are obligated to designate at least one suitable wetland (typically more are listed) within their territory as a *Wetland of International Importance*. While all Ramsar sites are committed to sustainable management, some are also official protected areas while others remain open to multiple uses. The Ramsar Convention provides technical guidance on the management and evaluation of wetlands, working closely with the IUCN and with other international organizations to promote the sustainable management of global wetlands.

The Convention also promotes the wise use of wetlands as a fundamental element of its mission, and defines wise use as "the maintenance of their ecological character, achieved through the implementation of ecosystem approaches, within the context of sustainable development." Wise use is the conservation and sustainable use of wetlands and all the services they provide, for the benefit of people and nature. Practical aspects include adoption of national wetland policies; ensuring wetland inventory, monitoring, research, training, education, and public awareness; and developing integrated management plans at wetland sites.[156]

When freshwaters and their biodiversity are degraded or destroyed, their ecosystem services are also lost. These services are usually worth more to society than the productive uses that replace them[167] since the benefits are often distributed among many people, whereas the benefits of conversion and production tend to be concentrated in the hands of a few. Ecosystem services are often not really noticed until they disappear, and their restoration, if possible, is almost always expensive compared to protecting the functioning ecosystem in the first place. Table 8.1 summarizes some of the key water-related ecosystem services.

Table 8.1: Typology of ecosystem services from wetlands[168]

Services	Ecosystem service	Example
Supporting	Primary production	Photosynthesis in aquatic plants and wetland vegetation.
	Nutrient cycling	Highest total economic value of all wetland ecosystem services[169] although this value is generally not realized at present.
	Biodiversity conservation	The Amazon has around 6,000-8,000 fish species,[170] and the Mekong 850 fish species.[171]
	Nursery function	Breeding grounds for aquatic species important for both commercial and subsistence purposes.
	Soil formation	Sediments in the Mekong support over 50 per cent of Viet Nam's staple food production.[172]
	Marine productivity	Sediments carried by rivers also maintain offshore ecosystems. Every year, 500-1,000 million tons of mud from the Amazon and Orinoco Rivers[173] create huge mud banks[174] that support mangroves,[175] and maintain highly productive fisheries.[176]
	Recharging aquifers	Standing wetlands are a key resource for aquifer recharge, which is often the least cost option for stabilizing and ensuring supply.[177]
Provisioning	Capture of fish and other species	African freshwater fish catch exceeds 2.5 Mt per year;[178] the Niger Delta producing 40-80,000 t/year.[179] The Mekong yields 2 Mt per year;[180] supplying 80% of animal protein in Cambodia.[181] Yet fisheries are at risk: 4 out of 11 species caught commercially in the North American Great Lakes are now extinct.[182]
	Collection of plants	Many freshwater species are collected for food and feed.[183]
	Collection of materials	Papyrus, reeds, rushes, etc. are used for roofing, tools, fencing, etc.
	Livestock grazing	Wetlands are often very productive pastures, providing seasonal grazing for pastoralists and ranchers.
	Crop growing	Rich peat soils support productive agriculture.
	Energy source	Hydro-electric power is a critical energy source. Papyrus is compacted into fuel briquettes in Rwanda. Peat-cutting is still an important domestic fuel in parts of Ireland and Scotland.
	Raw materials	Fuelwood and building timber is collected from riparian forests.
	Medicines	Freshwater plant species are often used as medicines.
Regulating	Flooding	Wetlands absorb floodwater providing disaster risk reduction.[184]
	Storm protection	Riparian forests and seasonal wetlands slow flooding and protect downstream communities.[185]
	Carbon sequestration	Wetlands and particularly peatlands are the planet's largest carbon store,[186] containing up to 1,300 tons of carbon per ha.[187]
	Climate stabilization	Evaporation from lakes helps to reduce climatic extremes.
	Water provision	Some forests types, including montane cloud forests[188,189] and some old eucalyptus forests,[190] increase net water flow.
	Water purification	Forested watersheds and wetlands provide cleaner water, reducing the need for water treatment.[191]
Cultural	Recreational	Wetlands can be a tourist attraction: the Okavango Delta in Botswana attracts 120,000 tourists per year.[192]
	Cultural and artistic	Lakes and rivers have inspired artists, musicians, and writers.
	Spiritual	Many wetlands have local sacred values or are important pilgrimage sites, such as sacred high altitude lakes in India.[193]
	Science and education	Freshwaters provide important research and educational centers.

INDIRECT CAUSES OF WATER INSECURITY

The section above addressed some of the direct causes of water insecurity: poorly managed irrigation and livestock production, demand from industry, energy, and urban sectors, pollution, dam construction, changing climate, and population growth. Below we discuss some of the indirect causes:

1. A fragmented approach to water management
2. Policies and business models that drive water-intensive management systems
3. Trading and pricing patterns that act as perverse incentives
4. Demographic changes and rapid urbanization
5. Climate change

1. A fragmented approach to water management

Single sector water use, without an integrated water policy,[194] often leads to serious negative impacts. Spectacular examples include the Aral Sea in Central Asia, which by 2016 had shrunk to one tenth of its size in 1961; this was because most of the water from two tributary rivers was diverted for irrigation.[195] Lake Chad in Africa has decreased over 90 per cent by area in the last forty years due to drought and irrigation.[196] Conversely, the benefits of integrated or "nexus" approaches to water management have been known for a century, with a few prominent examples showing the way.[197]

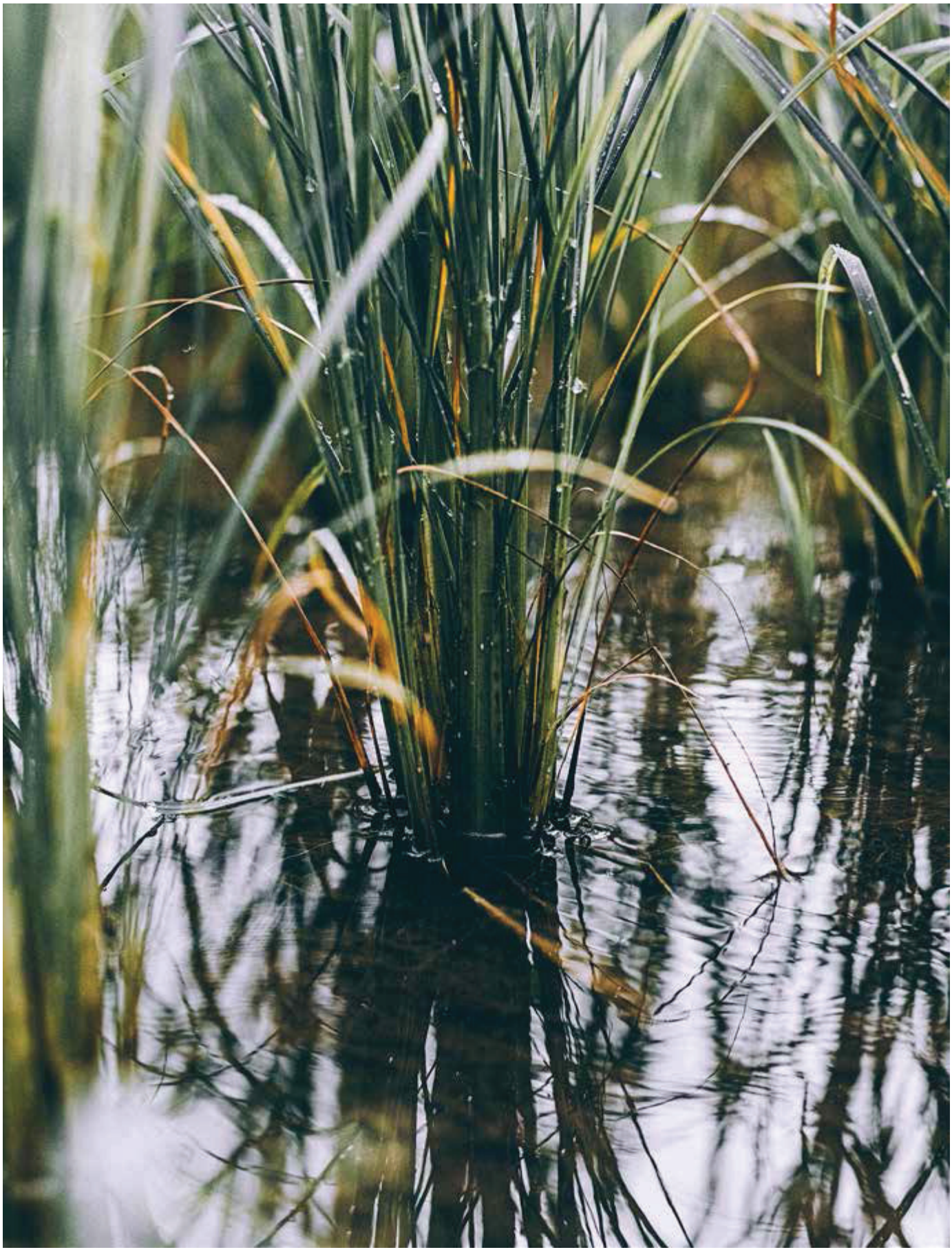
Still, cooperation at relatively large scales remains rare. Water planning (where it occurs at all) tends to follow a piecemeal or siloed approach, with different sectors (and even different individuals within a single sector) competing rather than collaborating at the expense of the common good.

2. Policies and business models that drive water intensive management systems

An emphasis on monocultures in modern agriculture tends to increase the use of and impacts on water (see Chapter 7). For example, in the last 50 years, the area devoted to soybeans has grown tenfold to over 1 million km^2: the area of France, Germany, Belgium, and the Netherlands combined.[199] Growth has been mainly in South America where production grew by 123 per cent between 1996 and 2004.[200] Projections suggest a further 140 per cent increase to 515 million tons by 2050.[201] Soybean cultivation is primarily rain-fed in South America but irrigated elsewhere.[202] Large-scale conversion to intensive soybean cultivation will likely continue to reduce water availability.[203] Water quality is also impacted by soil erosion and agrochemical residues as a result of heavy pesticide use, as documented in soybean fields in Argentina.[204] Yet soybeans are a multi-billion dollar business selling high-value products like animal feed. Alternative production systems that use water resources more efficiently cannot compete economically with soybeans, especially when water is underpriced.

Other crops also put hydrological systems under stress. Analysis in Thailand found rice (paddy) production had the highest water use; followed by maize, sugar cane, and cassava. The production of a second rice crop puts some watersheds under considerable pressure.[205] The drainage of peatlands for grazing and agricultural crops reduces their water retention capacity, leading to increased water shortages in dry periods and flood peaks in wet periods.[206]

Increasing imports of agricultural products have been advocated as one solution for water scarce countries. This strategy might provide a sustainable solution if crops are grown in water-rich countries. But if they use up scarce water supplies, disadvantage poor communities, degrade land, and increase water stress, they should be considered environmentally and socially unsustainable.



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Box 8.4: Integrated land and water resource management in the North China Plain

Intensive irrigation in northern China had dramatically reduced river flow in the Hai River Basin and seriously depleted aquifers subject to irrigation pumping. The Government of China had identified the need for urgent action aimed at the restoration of water resources and reducing over-exploitation. The International Waters Focal Area of Global Environmental Facility (GEF) supported a major restoration effort highlighting three key processes in integrated water management: (1) formation of national inter-ministry committees; (2) analysis of the status of the river or aquifer basin, different sector water uses, conflicts, and future projections; and (3) development of a strategic programme of policy, legal, and institutional reforms and investments, through multi-stakeholder, participative processes across sectors to balance competing uses, negotiate trade-offs, and form partnerships for action.[198]

The seven year Hai River Basin IWRM project pioneered water and land management reforms to improve water quality in the river and aquifers, and to reduce water use in irrigation. It introduced higher charges for irrigation water; a new water rights/allocation system under Chinese law based on estimates of evapotranspiration (ET) rather than standard withdrawal amounts; the use of satellite technology to support issuing and enforcing water allocations; and other water saving irrigation technologies with the aim of rebalancing food and water security and environmental objectives in the basin. The project included water quality improvement measures, capacity building for the basin water resources commission, and use of ATM cards for individual farmers. Pumping allocations were limited to ensure water savings: once an individual's allocation was exhausted, no more water could be pumped. Satellite data on estimated ET (at a 30 by 30 meter scale) was used with simulation models to identify reduced allocations to farmer-led water user associations that distributed the quotas to over 100,000 farmer households. Extension services also assisted by recommending practices for on-farm green water savings, best management practices (e.g., mulching, cropping patterns, drip technology), and the planting of alternative crops to increase farmer income. After seven years, per capita income increased by 193 per cent, water efficiency increased by 82 per cent, and consumptive use decreased 27 per cent. These water savings helped to stabilize aquifer draw-down and made more water available for ecosystem functioning.

The success of this project encouraged the Government of China to introduce the remote sensing/water rights/water allocation system for all new water allocations. This led to the application of the ET-based allocation system to the entire Tarim Lake basin and a subsequent GEF/World Bank/China-funded project for the entire Hai Basin system. Other project achievements included formal agreements among ministries that never worked together and a knowledge management system established for the revitalized basin commission. Finally, the setting of project targets consistent with GEF policy proved to be important measuring and evaluating progress over time.

3. Trading and pricing patterns that act as perverse incentives

Land grabbing is also water grabbing when, as is increasingly the case, large-scale land acquisitions by foreign investors come with guarantees of water.

Land grabbing or large-scale land acquisitions for agricultural exports are discussed in Chapter 5, but one important related issue is the export value of agricultural products in the form of "virtual water" (the hidden flow of water that grows food that is exported). Land grabbing is also water grabbing[207] when, as is increasingly the case, large-scale land acquisitions by foreign investors come with guarantees of water.

The virtual water trade is growing, and this particular trade balance between countries is shifting over time. China, until recently a net exporter of virtual water related to trade in non-edible animal and plant products used for manufacturing, is now the world's largest virtual water importer for these same products.[208] This can lead to the displacement of small farmers, accelerated land degradation, and the abuse of water resources, along with the creation of downstream or aquifer conflicts, particularly when weak institutions are unable or unwilling to regulate water use. The corporate control of water is an increasingly divisive and politicizing issue.[209] Pricing policies, such as those implemented to reduce food prices to consumers by major food retail companies, squeeze farmer profits and encourage unsustainable use, such as intensive irrigation.

4. Demographic change and urbanization

Growing populations are recognized as often putting water resources under stress.[210] But as important as the total numbers is the issue of demographic movements, either gradual through urbanization and economic migration, or rapid shifts in population as a result of disaster, war, or internal conflict. Urbanization is now a global phenomenon. Almost half the world's city dwellers live in relatively small settlements of less than 500,000 inhabitants while around one in eight live in the 28 mega-cities with over 10 million inhabitants. Until recently most of the world's largest cities were found in the North but today are increasingly concentrated in the South. The fastest growing urban centers are medium-sized cities and cities with less than one million inhabitants located in Asia and Africa.[211]

Africa provides a striking example of urbanization and its impact on water. In 1960, there were only 11 cities in Africa with over half a million inhabitants and just five in sub-Saharan Africa, which was overwhelmingly rural. By 2015, there were 84 such cities south of the Sahara, including megacities like Lagos with over 13 million inhabitants. By 2030 there will probably be over 140.[212] Current estimates indicate that new urban residents in Africa will increase by over 300 million in the period between 2000 and 2030: more than twice rural population growth.[213] Wetlands and watersheds provide both provisioning services (e.g., food, water, raw materials) and regulating services (e.g., flood control, climate stabilization) to urban populations. But throughout Africa, urbanization is encroaching upon both types of services, either directly through urban sprawl draining wetlands for housing or because population density increases pressure on natural resources, releases more pollutants, introduces invasive species, and requires more water for agriculture, industry, and domestic use.

Box 8.5: Water and African cities

Rapid urban and peri-urban expansion in many African cities is putting pressure on surrounding water resources, at the very time when their ecosystem services are needed more than ever. For example, rapid urban sprawl and a booming horticultural industry are threatening Lutembe Bay wetland around Kampala in Uganda. Lutembe Bay, which is a Ramsar site, is almost completely cut off from the rest of Lake Victoria by a papyrus island. Swamps filter silt, sediments, and excess nutrients from surface run-off, sewage, and industrial waste. But the wetland is rapidly being lost to agriculture and horticulture; a horticultural firm illegally infilled some in 2013.[214] Similarly, wetlands around Harare are the water source for half the population of the country, recharging the water table, filtering and purifying water (thus reducing purification costs), preventing siltation and flooding, and providing a valuable carbon sink. The wetlands are also an important bird sanctuary and again a Ramsar site. However, the hydrology is being damaged as a result of land use change, informal agriculture, fertilizer pollution, and the extensive use of commercial boreholes, which have resulted in an average fall in the water table of 15-30 meters over the past 15 years. Building capacity and generating awareness among city planners and government staff of the importance of wetlands protection is a major priority.[215]

5. Climate change

Rapid climate change is exacerbating almost all of the aspects of water insecurity outlined above. Climate change will have multiple impacts on water supply, including the melting of glaciers and ice caps, changes in snow and rainfall, increasingly fluctuating weather patterns and greater climatic extremes. Overall water scarcity is likely to increase.[216] The Intergovernmental Panel on Climate Change concluded (with robust evidence, high agreement) that climate change is likely to reduce renewable surface and groundwater resources in most dry subtropical regions. Conversely, in the higher latitudes water availability is likely to increase. The composition, structure, and function of many wetlands will also change, and many freshwater species will face increased risks of extinction.[217]

AN INTEGRATED APPROACH TO GLOBAL WATER SECURITY

New approaches to managing water resources are urgently needed.[218] Sustainable Development Goal (SDG) 6 on water and sanitation includes an emphasis on improving water quality (target 6.3) and protecting and restoring water-related ecosystems (target 6.6). Improved water management is also a critical component of SDG 2, on food security, and SDG 15 to combat desertification, and halt and reverse land degradation, and halt biodiversity loss. Such a nexus approach focuses on system efficiency, rather than on the productivity of isolated sectors, by reducing trade-offs and generating additional benefits that outweigh the transaction costs associated with stronger integration across sectors. Such gains would accelerate progress towards sustainable development and encourage governments, the private sector, and civil society to enhance water security.[219]

Maximizing water security is neither a simple technical fix nor the responsibility of a single sector.

Maximizing water security is neither a simple technical fix nor the responsibility of a single sector. It requires a range of responses relating to the provision and quality of water for human uses; the management of land resources, in particular soils; the protection and where necessary the restoration of wetlands and watersheds; and the regulation of water flows and long-term availability.[220] Key elements of an integrated approach to water management include:

- **Managing water resources through sustainable land management, especially in agriculture**
- **Protecting and restoring natural ecosystems for water-related goods and services**
- **Working towards sustainable cities**
- **Policy reform at a local, national, and international level**

Water-related ecosystems cannot be managed in isolation since water basins or watersheds connect over vast areas and the global water cycle ultimately functions as a single system. Integrated Water Resources Management (IWRM)[221] promotes the coordinated development and management of water, land, and related resources in order to maximize economic and social welfare in an equitable manner without compromising the functioning and sustainability of our working landscapes.

Managing water resources through sustainable land management

Irrigation carries high water costs, but also high rewards from crop production. In the United States, 7.5 per cent of crop and pasture land is irrigated, producing 40 per cent of agricultural value and accounting for 80-90 per cent of consumptive water use.[222] Maximizing the efficiency of irrigation technologies and their application is clearly a priority focusing on all aspects of irrigation from sourcing and distribution to field application. Even small increases in crop-water productivity in precipitation-limited areas would have important implications for both overall food productivity and water availability.[223] In addition, there are a number of proven, cost-effective land management practices that reduce waste and conserve water in agriculture while providing additional benefits to the environment and long-term productivity (see Table 8.2). The fact that these practices are not used more widely is due to factors such as a lack of capacity or investment, and subsidies, regulations, and other perverse incentives that discourage efficient use. In some countries, cultural and religious customs also play a part, for instance a reluctance to use grey water.

IWRM has been an aspiration for decades but has often failed in practice due to entrenched sectoral interests, political and governance barriers, and the failure to engender a sense of collective responsibility. Water managers traditionally have been focused on managing water in isolation, whereas good water management depends in large part on managing land sustainably.[243] The wider concept of integrated land and water resource management continues to gain currency as is reflected in a growing number of applications around the world.

One of several examples from China, the seven year Hai River Basin IWRM project pioneered water and land management reforms to improve water quality in the river and aquifers, and to reduce water use in irrigation.[245] The project demonstrates some of the essential elements of a national water conservation programme including a central organization with comprehensive water laws; regional and watershed-level land and water use planning; decision-making frameworks based on long-term water supply and demand; adequate research, demonstration, and extension services; a system of demand management; quality control of equipment; promotion of water user associations; and, where needed, land reform and agricultural credit for irrigation.

Table 8.2: Some examples of water saving approaches in agriculture

Technique	Details
Increasing water availability/efficiency	
Improved infrastructure	Poorly constructed irrigation canals and ditches leak water, causing water-logging and productivity loss. Pipes are more efficient but also more expensive.
Improved irrigation systems	Earth canal networks are the least efficient, followed by lined canals, pressure pipes, hose irrigation, sprinkler systems, microjet sprinklers, and drip irrigation: efficiencies ranging from a low of 40% to 80-90%.[224]
Conservation agriculture	Combines minimum tillage with cover crops and rotations to reduce evaporation, run-off, and erosion[225]
Organic agriculture	A production system that relies on ecological processes, biodiversity and cycles adapted to local conditions avoiding the use of synthetic fertilizers, pesticides, GMO, growth hormones and antibiotics;[226,227] some argue that this maximizes the recycling of nutrients and increases in soil organic matter, thus enhancing soil water holding capacity[228]
Eco-agriculture	Emphasizes the restoration of ecosystem services and biodiversity, increasing support for water-related ecosystem services
Agroforestry	Mixing tree and ground crops to conserve water by reducing evaporation and transpiration; in Kenya soil evaporation was reduced by an average of 35%.[229]
Participatory irrigation management	Cooperation between users can increase efficiency, in New Zealand cost savings of 65% were achieved through local control.[230]
Rainwater harvesting	Various options exist, from channels running to open pools to film-covered ridges and underground storage.[231]
Contour ploughing, bunding, and terraces	Traditionally used to reduce soil erosion and increase efficiency of water retention.[232]
Mulching	Reduces water loss and improves yields; its viability is often constrained by lack of mulching material (e.g. because of burning or grazing on stubble after harvest).[233]
Early sowing varieties and high water-use efficiency	Three factors are important: reducing losses; increasing biomass for given water; and partitioning more biomass into harvested product.[234] For example, varieties sown earlier can grow in cooler times of the year when less water evaporates.
Pumps	Can raise groundwater and maintain year-round productivity in countries with a pronounced wet and dry season. Treadle pumps are a simple, cheap system.[235]
Reducing water use	Watering can sometimes be reduced at certain periods without reducing crop yields.[236]
Weather forecast texts	Use of mobile phones to share texts on weather forecasts for planting times has improved water efficiency in countries of the Niger basin.[237]
Radio station alerts of rain or drought	In Senegal, 915 village chiefs and many radio stations have signed up for a service covering up to half the country's population.[238]
Grey water and sewage effluent use	Wastewater separated from industrial effluent can be used for irrigation; waste water from 100,000 people irrigates around 1,000 ha using efficient systems.[239]
Soil and plant moisture sensing devices. computer crop-growth simulation	Use has reduced water losses by 20% in South Africa.[240] Technology, such as precision agriculture, offers enormous opportunities for increasing efficiency but requires investment; less than 10% of US farms use these methods[241]
Reducing the need for water	
Crop choice	Avoiding crops with heavy water requirements in arid or semi-arid regions. Choosing perennial crops that hold soils and stimulate mycorrhiza systems.
Climate-smart agriculture	An amalgamation of many of the techniques and technologies mentioned above with a focus on locally appropriate climate resilient practices.
Farmer support	
Weather index insurance	Banks can provide climate-smart financial services for climate resilient agricultural value chains.[242]

Box 8.6: Rainwater harvesting in Brazil[244]

The north-east of Brazil is a semi-arid region, characterized by severe lack of water and droughts that contribute to underdevelopment of the region. The "One Million Rainwater Harvesting Programme" (P1MC) was launched by civil society groups in the region, targeting rural families without a secure drinking water source close to their home. By December 2007, 228,541 families had been mobilized; 221,514 rainwater harvesting (RWH) systems constructed and 5,848 masons trained under the programme. The objective of P1MC was to construct one million RWH systems for decentralized access to drinking water to one million families. This programme benefited women in particular as it reduced their daily work of fetching water. In 2012, Brazil experienced one of the most severe droughts ever recorded, causing major crop and cattle losses, and reducing several reservoirs to critical level. The drought caught the attention of different decision makers, experts, and international and local media, as well as the population. Brazil has since aimed to move from reactive crisis management to proactive risk-based approaches.

Protecting and restoring natural ecosystems

Protected areas of various sorts already cover around 20.7 per cent of the world's remaining lakes and wetlands.

Ensuring the future delivery of freshwater ecosystem services requires a suite of coordinated strategies, operating at the level of a watershed or catchment, integrated with the management of the surrounding terrestrial ecosystems. While investment in necessary built infrastructure is a critical component of such management,[246] "natural infrastructure"[247] or "green infrastructure"[248] will need to play an increasingly central role[249] in providing long-term water security for human societies via maintenance of natural freshwater ecosystems.[250] For example, forested watersheds and some wetlands can supply cleaner water than other ecosystems.[251] Certain forests, such as mountain cloud forests,[252] increase the net flow out of the catchment. Forests and wetlands also supply important flood control mechanisms by providing space for floods to dissipate safely and by blocking the rate of flow as well as other important ecosystem services.[253]

Recognition of these multiple roles means that natural ecosystems are less often regarded as unproductive and suitable only for human exploitation, but as essential components for maintaining the health and livelihoods of populations. This recognition is the first step in achieving long-term water security.

Protected areas therefore have a central role to play in catchment-scale sustainable management approaches,[254] although specific protection of freshwater ecosystems has often been overlooked in this respect.[255] Protected areas of various sorts already cover around 20.7 per cent of the world's remaining lakes and wetlands[256] helping to shape overall water policies and enable large-scale rehabilitation and restoration. These areas are vitally important in sustaining water services by protecting natural flow regimes, excluding non-native species, and sometimes providing whole basin conservation.[257] Integrating them more consciously and centrally into IWRM approaches is an important component still missing from many national water strategies.

Many good examples of IWRM integration already exist, which show the value of a joined up approach to conservation and sustainable development. Cities like New York[259] and Melbourne[260] have found it cost-effective to protect and restore forests as suppliers of clean water rather than to invest in new purification plants. The cloud forests and high mountain peatlands (paramos) in protected areas around Quito and Tegucigalpa provide a high

Box 8.7: Wastewater use

Judicious use of wastewater to grow crops will help solve water scarcity in the agriculture sector. At a time when we need to produce more food to feed an ever-increasing population, wastewater can be used by farmers either directly through irrigation, and indirectly by recharging aquifers. In Tunisia, wastewater is being widely used in agroforestry projects, supporting both wood production as well as efforts to combat desertification. In central Mexico, municipal wastewater has long been used to irrigate crops. In the past, ecological processes helped reduce health risks. More recently, crop restrictions (some crops can be safely grown with wastewater, while others cannot) and the installation of water treatment facilities have been added to the system. Properly managed, wastewater can be used safely to support crop production – directly through irrigation or indirectly by recharging aquifers – but doing so requires diligent management of health risks through adequate treatment or appropriate use.

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quality water supply for these two important Latin American cities.[261] An increasing number of countries rely on strategically located protected areas as part of their disaster risk reduction policies.[262] The protection and restoration of wetlands can help in reducing carbon losses and thus mitigating climate change, particularly the huge carbon stores in peatlands that are currently under threat.[263]

With political will and stakeholder participation, the establishment and management of protected areas is a relatively straightforward policy or regulatory tool to maintain natural infrastructure, and usually comes with the associated legal or customary protection to ensure a degree of permanence, along with employment, capacity, and management policies.[264] However, the responsibility for conservation within most legal frameworks is usually separate from the responsibility for other services and civil defense, meaning that the cross-linkages are often missed in practice.

Box 8.8: Protecting Natural Forests for Flood Control

Irregular rainfall patterns in Argentina cause both floods and droughts. Under all climate change scenarios, these weather extremes will continue and be more frequent. Currently, about a quarter of the country is repeatedly flooded, particularly in the north-east, which has three major rivers (Paraná, Paraguay, and Uruguay), extensive, low-lying plains, and over half the human population. A flood protection programme provided cost-effective activities for the most important economic and ecological areas and a strategy to address recurrent floods: maintenance of flood defense installations, early flood warning systems, environmental guidelines for flood-prone areas, and flood emergency plans. In addition, extensive areas of natural forest were protected as part of the flood defense system, thus providing a relatively inexpensive alternative to costly infrastructure with high biodiversity conservation benefits.[258]

Box 8.9: Water services from protected areas

Most of the world's population lives downstream of forested watersheds.[265] These offer higher quality water than watersheds under alternative land uses, which tend to have less vegetation cover (hence more soil erosion and sediment) and are likely to be more polluted (e.g., with pesticides and fertilizer or toxic waste).[266] The benefits that forests provide have been recognized for many years by companies that depend on high quality water: for example, the mineral water company Perrier-Vittel pays to restore forests in the catchment where it collects water in France.[267] One-third (33 out of 105) of the world's largest cities source a significant proportion of their drinking water directly from protected areas. At least five other cities in this group obtain water from sources that originate in distant watersheds that include protected areas; and at least eight more obtain water from forests managed in a way that gives priority to their ecological functions in providing water.[268] Many areas originally protected for scenic or wildlife values are now also considered vital for their water-related benefits. Yosemite National Park in California, USA, for example, helps supply high quality water to San Francisco; the cloud forests of La Tigra National Park in Honduras provide more than 40 per cent of the annual water supply to the capital city, Tegucigalpa and about 80 per cent of Quito's 1.5 million population receive drinking water from two protected areas.[26]

Box 8.10: Water Management in South Africa

South Africa is one of the 30 driest countries in the world. While the average water use per capita per day is 173 liters, South Africans use 62 per cent more water on average.[277] In order to match demand and supply, South Africa has made significant progress in the last decades to increase water use efficiency. Firstly, in 1994 the government published a White Paper on Water and Sanitation Policy, which led to the Water Services Act of 1997. Secondly, the National Water Act (NWA) No. 36 of 1998, promoted an integrated and decentralized water resource management approach, which emphasized the importance of economic efficiency, environmental protection, equity, and the empowerment of people.[278]

South Africa is one of the few countries in the world that enshrines the basic right to sufficient water in its Constitution, stating that "Everyone has the right to have access to (...) sufficient food and water." Building on this foundation, both Acts are complementary and provide a framework for sustainable water resource management while enabling improved and broadened service delivery. The NWA requires water managers and policymakers to have a thorough understanding of the economic values of water and its various uses as well as information systems that integrate hydrological, economic, and social dimensions of water supply and demand within the framework of an integrated water resource management (IWRM) system.[279]

Payment for Ecosystem Services (PES) schemes help to provide people living in areas that supply water services with economic incentives to maintain healthy managed or natural ecosystems. One approach is to collect user fees from people and companies benefiting from drinking water to help pay for these catchment benefits provided by protected area management, or by local communities. Such PES schemes are increasingly considered as viable economic models provided there is an identifiable source of compensation (those willing to pay a fee), low transaction costs, good information flows, and a method to transfer benefits equitably among individuals.[270]

Protection alone is no longer enough. The world has already lost so much wetland area and major efforts are needed to restore free flowing rivers, lakes and ponds, groundwater reservoirs, and functioning wetlands. Restoration is therefore another important component of managing freshwaters for their ecosystem services.[271] Restoration does not simply mean putting back areas of water or taking away redundant dams. For example, river restoration embraces "the re-establishment of natural physical processes (e.g., variation of flow and sediment movement), features (e.g., sediment sizes and river shape), and physical habitats of a river system (including submerged, bank and floodplain areas)."[272] Similar principles can be applied in the restoration of coastal areas to halt erosion, involving a "Building with Nature" approach, using permeable dams to reduce wave energy and stimulate sedimentation.[273]

A combination of planned restoration and judicious protection of watersheds can therefore together ensure greater water security for downstream users.

Working towards sustainable cities

Although cities pose particular challenges for water supply and management, they also offer a range of innovative solutions by connecting people, transferring know-how, and supporting clusters of firms doing similar things. Forward-looking local authorities can stimulate rapid improvements. Efficient urban transport systems, renewable energy, and sewage control can all reduce water consumption and waste while information campaigns, coupled with pricing policies, can make consumers more water-aware.

Sustainable cities depend on well-managed ecosystems. Degradation far away can impact city dwellers. People living in the port of Mombasa, in Kenya, rely on water from the Chyulu Hills, a hundred miles away. Despite Chyulu being a protected area, poor management capacity means illegal logging and settlement continue, threatening the security of urban water.[274] It often makes sense for municipal authorities to invest in ecosystem management, but it takes an imaginative set of civil servants to make the connection and procure the necessary funds. Pricing policies that encourage more efficient use of water are one universal way of addressing urban shortages, although the relative effectiveness of this as compared to technical measures and public awareness campaigns remains inconclusive.[275] Steps towards more sustainable urban planning are described in Chapter 11.

Policy reform

Many of the changes identified above can only be achieved if they are supported by strong policies and laws at the national level, set against a background of international agreements and a global recognition of the need to manage water more carefully to avoid crisis. Proactive approaches are required, focusing on maintenance of natural infrastructure for multiple benefits, increasing resilience of hydrological systems in the face of environmental change, and more equitable access to clean and adequate supplies of water. Changing consumer behavior is also a critical part of this process, and attempts to do this can draw on public awareness campaigns, technological changes, regulation, and pricing policies. While all may be useful in different contexts, there is still debate about their relative effectiveness.[276] Policies not only need to be set, but communicated effectively to stakeholders in government, industry, and communities so that there is a thorough understanding of the importance of and the practical means to achieve a safe and sustainable supply of water.

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CONCLUSION

Water security is being undermined, in particular by the combination of unsuitable agricultural models, rapid demographic changes, and the destabilizing effects of climate change. Poor choices from the individual to the national level exacerbate the situation. Countries and communities are suffering from both shortages and excesses. The loss of wetlands, declines in water quality, and dramatic changes to the flow regimes of major hydrological systems are leading to a collapse in freshwater biodiversity and essential ecosystem services.

Improving water security requires an integrated, cross-sectoral approach which capitalizes on the links between the land management practices and the health of hydrological systems. In sum, some of the most critical steps include: more efficient water use in agriculture, industry, energy, and households; regulation and legislation, including pricing and allocation, to encourage efficiency; and increased protection and restoration to improve overall ecosystem functioning in the watershed. The technical know-how to help solve the water crisis is largely known; the next step is to apply these lessons learned at the scale required.

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