

3. Wetland Services

Diversity and Value of Wetland Services

Wetland ecosystems provide a diversity of services vital for human well-being and poverty alleviation (C19, C20). (See Table 3.1.) It is *well established* that provisioning services from wetlands, such as food (notably fish) and fiber are essential for human well-being. Supporting and regulating services (such as nutrient cycling) are critical to sustaining vital ecosystem functions that deliver many benefits to people. The delivery of fresh water is a particularly important service both directly and indirectly. In addition, wetlands have significant aesthetic, educational, cultural, and spiritual values and provide invaluable opportunities for recreation and tourism.



The principal supply of renewable fresh water for human use comes from an array of inland wetlands, including lakes, rivers, swamps, and shallow groundwater aquifers (C7.2.1). The renewable resource base expressed as long-term mean runoff has been estimated to fall between 33,500 and 47,000 cubic kilometers per year. By one estimate, one third of global renewable water supply is accessible to humans, when taking into account both its physical proximity to population and its variation over time, such as when flood waves pass uncaptured on their way to the ocean. Inland waters and mountains provide water to two thirds of global population and drylands to one third. Inland wetlands serve 12 times as many people downstream through river corridors as they do through locally derived runoff.

Groundwater, often recharged through wetlands, plays an important role in water supply, providing drinking water to an estimated 1.5–3 billion people (C7.2.1). It also serves as the source water for 40% of industrial use and 20% of irrigation. Despite its importance, sustainable use of groundwater has often not been sufficiently supported through appropriate pricing and management action.

Another important water supply is represented by the widespread construction of artificial impoundments that stabilize river flow. Today, approximately 45,000 large dams (more than 15 meters in height or more than 5 meters high and holding 3 million cubic meters) and possibly 800,000 smaller dams have been built for municipal, industrial, hydropower, agricultural, and recreational water supply and for flood control. Recent estimates place the volume of water trapped behind (documented) dams at 6,000–7,000 cubic kilometers.

Fish and fishery products are particularly important ecosystem services derived from inland waters (C20.2.5). Inland fisheries are of special importance in developing countries as they are sometimes the primary source of animal protein for rural communities. For example, people in Cambodia obtain about 60–80% of their total animal protein from the fishery in Tonle Sap and associated floodplains; in Malawi, 70–75% of the total animal protein for both urban and rural low-income families comes from inland fisheries. A large proportion of the recorded inland fisheries catch comes from developing countries, and the actual catch is thought to be several times the official 2001 figure of 8.7 million tons, as much of the inland catch is under-reported. An estimated 2 million tons of fish and other aquatic animals are consumed annually in the lower Mekong Basin alone, with 1.5 million tons originating from natural wetlands and 240,000 tons from reservoirs; the total value of the catch is about \$1.2 billion. In Africa, fishing and harvesting of aquatic plants from the large floodplains and swamps associated with major lakes are significant sources of subsistence and income for local communities.

Coastal wetlands such as estuaries, marshes, mangroves, and coral reefs deliver many services for people (C19.3.2). They are especially important for providing food (capture fisheries in coastal waters alone account for \$34 billion in yields annually

Table 3.1. RELATIVE MAGNITUDE (PER UNIT AREA) OF ECOSYSTEM SERVICES DERIVED FROM DIFFERENT TYPES OF WETLAND ECOSYSTEMS (Derived from C19 Table 19.2, C20 Table 20.1)

Scale is low ●, medium ●, to high: ●; not known = ?; blank cells indicate that the service is not considered applicable to the wetland type. The information in the table represents expert opinion for a global average pattern for wetlands; there will be local and regional differences in relative magnitudes.

Services	Comments and Examples	Permanent and Temporary Rivers and Streams	Permanent Lakes, Reservoirs	Seasonal Lakes, Marshes, and Swamps, Including Floodplains	Forested Wetlands, Marshes, and Swamps, Including Floodplains	Alpine and Tundra Wetlands	Springs and Oases	Geothermal Wetlands	Underground Wetlands, Including Caves and Groundwater Systems
Inland Wetlands									
Provisioning									
Food	production of fish, wild game, fruits, grains, and so on	●	●	●	●	●	●		
Fresh water	storage and retention of water; provision of water for irrigation and for drinking	●	●	●	●	●	●		●
Fiber and fuel	production of timber, fuelwood, peat, fodder, aggregates	●	●	●	●	●	●	●	
Biochemical products	extraction of materials from biota	●	●	?	?	?	?	?	?
Genetic materials	medicine; genes for resistance to plant pathogens, ornamental species, and so on	●	●	?	●	?	?	?	?
Regulating									
Climate regulation	regulation of greenhouse gases, temperature, precipitation, and other climatic processes; chemical composition of the atmosphere	●	●	●	●	●	●	●	●
Hydrological regimes	groundwater recharge and discharge; storage of water for agriculture or industry	●	●	●	●	●	●		●
Pollution control and detoxification	retention, recovery, and removal of excess nutrients and pollutants	●	●	●	●	●	●		●
Erosion protection	retention of soils and prevention of structural change (such as coastal erosion, bank slumping, and so on)	●	●	●	●	?	●		●
Natural hazards	flood control; storm protection	●	●	●	●	●	●		●
Cultural									
Spiritual and inspirational	personal feelings and well-being; religious significance	●	●	●	●	●	●	●	●
Recreational	opportunities for tourism and recreational activities	●	●	●	●	●	●	●	●
Aesthetic	appreciation of natural features	●	●	●	●	●	●	●	●

Table 3.1. RELATIVE MAGNITUDE (PER UNIT AREA) OF ECOSYSTEM SERVICES DERIVED FROM DIFFERENT TYPES OF WETLAND ECOSYSTEMS (Derived from C19 Table 19.2, C20 Table 20.1) *(continued)*

Scale is low ●, medium ●, to high: ●; not known = ?; blank cells indicate that the service is not considered applicable to the wetland type. The information in the table represents expert opinion for a global average pattern for wetlands; there will be local and regional differences in relative magnitudes.

Services	Comments and Examples	Permanent and Temporary Rivers and Streams	Permanent Lakes, Reservoirs	Seasonal Lakes, Marshes, and Swamps, Including Floodplains	Forested Wetlands, Marshes, and Swamps, Including Floodplains	Alpine and Tundra Wetlands	Springs and Oases	Geothermal Wetlands	Underground Wetlands, Including Caves and Groundwater Systems
Cultural (continued)									
Educational	opportunities for formal and informal education and training	●	●	●	●	●	●	●	●
Supporting									
Biodiversity	habitats for resident or transient species	●	●	●	●	●	●	●	●
Soil formation	sediment retention and accumulation of organic matter	●	●	●	●	●	?	?	●
Nutrient cycling	storage, recycling, processing, and acquisition of nutrients	●	●	●	●	●	●	?	●
Pollination	support for pollinators	●	●	●	●	●	●	●	●
Services	Comments and Examples	Estuaries and Marshes	Mangroves	Lagoons, Including Salt Ponds	Intertidal Flats, Beaches, and Dunes	Kelp	Rock and Shell Reefs	Seagrass Beds	Coral Reefs
Coastal Wetlands									
Provisioning									
Food	production of fish, algae, and invertebrates	●	●	●	●	●	●	●	●
Fresh water	storage and retention of water; provision of water for irrigation and for drinking	●	●	●	●	●	●	●	●
Fiber, timber, fuel	production of timber, fuelwood, peat, fodder, aggregates	●	●	●	●	●	●	●	●
Biochemical products	extraction of materials from biota	●	●	●	●	●	●	●	●
Genetic materials	medicine; genes for resistance to plant pathogens, ornamental species, and so on	●	●	●	●	●	●	●	●

Table 3.1. RELATIVE MAGNITUDE (PER UNIT AREA) OF ECOSYSTEM SERVICES DERIVED FROM DIFFERENT TYPES OF WETLAND ECOSYSTEMS (Derived from C19 Table 19.2, C20 Table 20.1) *(continued)*

Scale is low ●, medium ●, to high: ●; not known = ?; blank cells indicate that the service is not considered applicable to the wetland type. The information in the table represents expert opinion for a global average pattern for wetlands; there will be local and regional differences in relative magnitudes.

Services	Comments and Examples	Estuaries and Marshes	Mangroves	Lagoons, Including Salt Ponds	Intertidal Flats, Beaches, and Dunes	Kelp	Rock and Shell Reefs	Seagrass Beds	Coral Reefs
Regulating									
Climate regulation	regulation of greenhouse gases, temperature, precipitation, and other climatic processes; chemical composition of the atmosphere	●	●	●	●		●	●	●
Biological regulation (C11.3)	resistance of species invasions; regulating interactions between different trophic levels; preserving functional diversity and interactions	●	●	●	●		●		●
Hydrological regimes	groundwater recharge/discharge; storage of water for agriculture or industry	●		●					
Pollution control and detoxification	retention, recovery, and removal of excess nutrients and pollutants	●	●	●		?	●	●	●
Erosion protection	retention of soils	●	●	●				●	●
Natural hazards	flood control; storm protection	●	●	●	●	●	●	●	●
Cultural									
Spiritual and inspirational	personal feelings and well-being	●	●	●	●	●	●	●	●
Recreational	opportunities for tourism and recreational activities	●	●	●	●	●			●
Aesthetic	appreciation of natural features	●	●	●	●				●
Educational	opportunities for formal and informal education and training	●	●	●	●		●		●
Supporting									
Biodiversity	habitats for resident or transient species	●	●	●	●	●	●	●	●
Soil formation	sediment retention and accumulation of organic matter	●	●	●	●				
Nutrient cycling	storage, recycling, processing, and acquisition of nutrients	●	●	●	●	●	●		●

(C19.2.1)). Many estuaries, intertidal flats, beaches, dunes, and coral reefs also have spiritual, aesthetic, and recreational values. Most coastal wetlands play a role in delivering supporting services as well, such as nutrient cycling and soil formation. Coastal areas, including coastal wetlands, coastal river floodplains, and coastal vegetation, all play an important role in reducing the impacts of floodwaters produced by coastal storm events (C16.1.1).

Wetlands provide an important service by treating and detoxifying a variety of waste products (C15.7.5). Water flowing through a wetland area may be considerably cleaner upon its exit from the wetland. Some wetlands have been found to reduce the concentration of nitrate by more than 80%. Some artificially constructed wetlands have been developed specifically to treat nitrogen-rich sewage effluents. Metals and many organic compounds may be adsorbed to the sediments (that is, accumulated on their surface) in the wetlands. The relatively slow passage of water through wetlands provides time for pathogens to lose their viability or be consumed by other organisms in the ecosystem. However, wetlands can become “hotspots” of contamination—wastes can build up to concentrations high enough to have detrimental effects on wetland functions. Unfortunately, the threshold between where loadings are tolerated and where they will do damage to wetlands is not easily determined.

Wetlands are important tourism destinations because of their aesthetic value and the high diversity of the animal and plant life they contain (C19.2, C19.3.2, C20.2.6). In some locations, tourism plays a major part in supporting rural economies, although there are often great disparities between access to and involvement in such activities. Recreational fishing can generate considerable income: some 35–45 million people take part in recreational fishing (inland and saltwater) in the United States, spending a total of \$24–37 billion each year on their hobby. Reefs support high diversity that in turn supports a thriving and valuable recreational diving industry. For example, much of the economic value of coral reefs—with net benefits estimated at nearly \$30 billion each year—is generated from nature-based tourism and diving. The demand from tourists for biologically rich sites to visit increases the value of intrinsically linked habitats, such as mangroves and seagrass beds. Temperate bays, semi-enclosed seas, and estuaries can generate tourism revenues of similar orders of magnitude. The negative effects of recreation and tourism are particularly noticeable when they introduce inequities and do not support and develop local economies, and especially where the resources that support the recreation and tourism are degraded.

Wetlands play an important role in the regulation of global climate by sequestering and releasing significant amounts of carbon (C20.2.4). Inland water systems play two critical but contrasting roles in mitigating the effects of climate change: the regulation of greenhouse gases (especially carbon dioxide) and the physical buffering of climate change impacts. Inland water systems have been identified as significant storehouses (sinks) of carbon as well as sources of carbon dioxide (for instance, boreal peatlands), as net sources of carbon sequestration in sediments, and as transporters of carbon to the sea. Although covering only an estimated 3–4% of the world’s land area, peatlands are estimated to hold 540 gigatons of carbon, representing about 1.5% of the total estimated global carbon storage and about 25–30% of that contained in terrestrial vegetation and soils. Inland waters also contribute to the regulation of local climate.

Wetlands provide many nonmarketed and marketed benefits to people, and the total economic value of unconverted wetlands is often greater than that of converted wetlands (medium certainty) (C19.3.2, C20.2). There are many examples of the economic value of intact wetlands exceeding that of converted or otherwise altered wetlands. (See Box 3.1.) Estimates for the global economic importance of wetlands are highly variable, with an upper value of \$15 trillion. Figures such as these are strongly disputed on methodological grounds by many economists, who point to limitations in the methods and urge careful consideration of the assumptions made. Regardless of the ongoing debate

Box 3.1. TWO EXAMPLES OF THE COSTS AND BENEFITS OF RETAINING OR CONVERTING NATURAL COASTAL AND INLAND WETLANDS (C5 Box 5.2)

Draining freshwater marshes for agriculture (Canada): Draining freshwater marshes in one of Canada’s most productive agricultural areas yielded net private benefits, but in large part this was only because of provision of substantial drainage subsidies. When the social benefits of retaining wetlands, arising from sustainable hunting, angling, and trapping, are calculated, however, they greatly exceeded agricultural gains. For all three marsh types considered, the net present value was higher when the wetlands remained intact (average for three wetland types of approximately \$5,800 compared with the total economic value of a converted wetland of \$2,400 per hectare).

Conversion of a mangrove system to aquaculture (Thailand): Although conversion for aquaculture made sense in terms of short-term private benefits, it did not once external costs were factored in. The global benefits of carbon sequestration were considered to be similar in intact and degraded systems. However, the substantial social benefits associated with the original mangrove cover (from timber, charcoal, non-timber forest products, offshore fisheries, and storm protection) fell to almost zero following conversion. Summing all measured services, the total economic value of intact mangroves was a minimum of \$1,000 and possibly as high as \$36,000 per hectare, while that of shrimp farming was about \$200 per hectare.

about the means of calculating the economic value of wetlands, it is now well established that they are valuable and deliver many services for people. This does not mean that conversion of wetlands is never economically justified, but it illustrates the fact that many of the economic and social benefits of wetlands have not been taken into account by decision-makers.

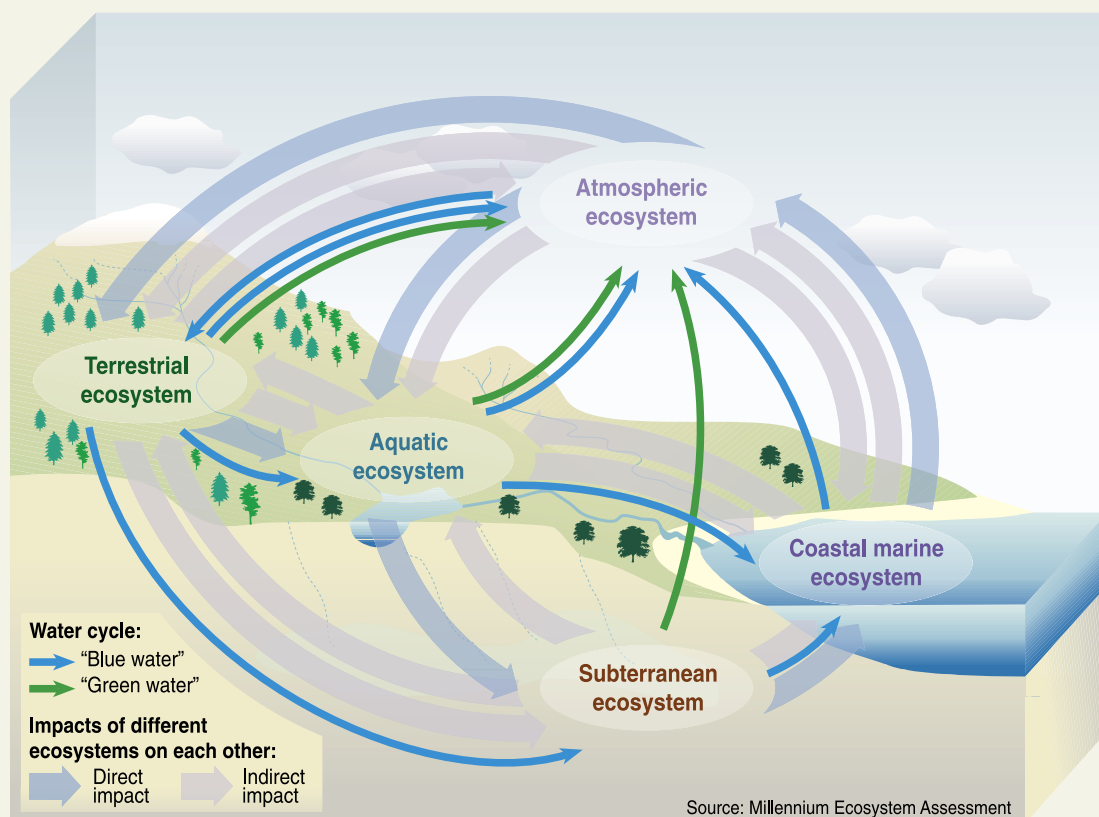
The declining condition of wetlands has placed their ecosystem services and the people who depend on them at increasing risk (C7.2, C7.4, C8.3, SG7). Humans now withdraw about 3,600 cubic kilometers of water a year from inland wetlands—a substantial fraction of the available global continental runoff (C7.2). Global freshwater use has been increasing at about 20% per decade from 1960 to 2000 and is estimated to continue to increase by 10% by 2010. In river basins in arid or populous regions, the rate of water use can be much higher. In addition, supplies of fresh water in many parts of the world continue to be polluted. Pollution of inland wetlands by inorganic nitrogen has doubled globally since 1960 and has increased more than tenfold in many industrialized parts of the world. Many pollutants are long-lived and can be transformed into compounds whose behaviors, synergistic interactions, and impacts are for the most part unknown. As a consequence of pollution, the capacity of many wetlands to provide clean and reliable sources of water has been reduced.

Water scarcity and declining access to fresh water is a globally significant and accelerating problem for 1–2 billion people worldwide, leading to reductions in food production, human health, and economic development (C7.2). With population growth and the overexploitation and contamination of water resources, the gap between available water and water demand is increasing in many parts of the world. Scarcity of water will affect all businesses either directly or indirectly, just as increases in the price of petroleum affect the state of the global economy (*Business and Industry Synthesis*). Governments will be called on to allocate supplies and adjudicate water rights.

The Synergistic Role of Wetlands and the Global Water (Hydrological) Cycle

Both inland and coastal wetlands have a significant influence on the water (hydrological) cycle and hence the supply of water for people and the many uses they make of it, including for irrigation, energy, and transport. The water cycle is the movement of water between all parts of Earth in its different forms (vapor, liquid, and solid) and throughout the broader biophysical environment (atmospheric, marine, terrestrial, aquatic, and subterranean). (See Figure 3.1.) Water resources, via water itself, are linked to all aspects of this broader environment. Two components of the water

Figure 3.1. INTERRELATIONSHIPS AMONG ENVIRONMENTAL COMPONENTS OF GLOBAL WATER CYCLE, INCLUDING CYCLING OF “GREEN WATER” AND “BLUE WATER” (Derived from C7 Box 7.1)





cycle are generally recognized: “blue water” is all water that is controlled by physical processes, including evaporation, and “green water” is water that is influenced by biological processes such as evapotranspiration by vegetation.

The global water cycle plays a fundamental role in supporting both inland and coastal wetlands, while at the same time wetlands have a significant influence on the water cycle itself (C7.2, C19.2.3, C20.2.1). Wetlands can either increase or decrease particular components of the water cycle. The interrelationship between wetlands and the water cycle extends well into the coastal zone, with coastal wetlands being influenced by the inflow of fresh water from catchments as well as by the tides and other coastal/oceanic factors that in turn influence the freshwater aspects of the water cycle. Although there is insufficient information on wetland hydrology to fully meet the needs of decision-makers, there is a progressive decline in investments to generate new hydrological data or enhance the quality of existing information at global, national, and local levels, particularly in developing countries (C7.1.2).

It is well established that inland wetlands provide a wide array of hydrological services, but the nature and value of these is not consistent, and many are not well understood (C20.2.1). There are several long-standing generalizations about the hydrological services performed by wetlands, notably that they reduce floods (C16.2.1), promote groundwater recharge, and regulate river flows, specifically the augmentation of low flows (for instance, wetlands act as sponges that soak up water during wet periods and release it during dry ones). While there are numerous examples of wetlands, notably floodplains, where this does occur, there is increasing evidence that such generalizations are not applicable for all hydrological contexts or wetland types. Indeed, there are many instances where the opposite occurs: where wetlands reduce low flows, increase floods, or act as a barrier to groundwater recharge. This variation is not unexpected given the wide range of wetlands—from entirely groundwater-fed springs to large inland river floodplains. When divided into hydrologically similar types, however, services do tend toward greater consistency for some wetland types. (See Box 3.2.)

Maintenance of the key hydrological services performed by wetlands enables them to continue to deliver a wide range of critical and important regulatory and provisioning ecological services to humans (C20.2). Historically, it is *well established* that the maintenance, protection, and even restoration of wetlands have often been encouraged because of the manifold hydrological services they perform. However, while some of these hydrological services, such as water storage, flood attenuation, and the augmentation of dry-season flows, are likely to be seen as favorable for human well-being, others that are essential to maintain wetland ecological character (such as flooding and evaporation from wetland vegetation) may complicate water management efforts aimed at balancing differing needs between cities, navigation, agriculture, and wetlands.

Maintaining the hydrological regime of a wetland and its natural variability is necessary to maintain the ecological characteristics of the wetland, including its biodiversity (*high certainty*) (derived from C19.2, C20.2). (See Table 3.2.) Hydrological regime and topography are generally the most important determinants of the establishment and maintenance of specific types of wetland and wetland processes, creating the unique physicochemical conditions that make wetlands different from both deepwater aquatic systems and well-drained terrestrial systems. Hydrological conditions affect numerous abiotic factors, including nutrient availability, soil anerobiosis, and salinity in both coastal and inland wetlands, which in turn determine the biota that establish in a wetland. These biotic components can alter the hydrology and other physicochemical features of the wetland.

Wetlands such as floodplains, lakes, and reservoirs help to attenuate floods. Flood attenuation potential can be estimated by the “residence time” of water in rivers, lakes, reservoirs, and soils. Residence time is defined as the time taken for water falling

Box 3.2. HYDROLOGICAL SERVICES OF WETLANDS

Although the influence of a wetland on the hydrological cycle is site-specific, some general patterns found in assessments in North America and a smaller number of European assessments (and a very small number of assessments in Asia and South America) are described here (C7, C20).

Gross water balance: Wetlands evaporate more water than other land types, such as cultivated land, grassland, or forests. Around 65% of studies reviewed concluded that non-riverine wetlands reduce average annual flow in rivers. Some 25% of studies were neutral, and in only 10% did such wetlands increase flows. There appear to be no obvious distinctions among wetland sub-types or geographical regions in this regard.

Flow regulation: Inland wetlands are important water storage sites during wet periods and often provide a reserve of water during dry periods. However, there is strong evidence that some wetlands with high evapotranspiration rates reduce the flow of water in downstream rivers during dry periods. This is backed by overwhelming evidence that shows evaporation from wetlands to be higher than from non-wetland portions of the catchment during dry periods; there is no discernible difference for different wetland sub-types. In only 20% of cases examined did wetlands increase river flows during the dry season.

Flood-related services: Floodplain wetlands almost always reduce floods (and their peaks) or delay them. Many wetlands in the headwaters of river systems (such as bogs and river margins) probably perform a simi-

lar service. However, some headwater wetlands are known to increase flood peaks and generate flood flows. They often increase the immediate response of rivers to rainfall, due to a tendency to be saturated, generating higher volumes of flood flow even if the flood peak is not increased.

Pollution control and detoxification: The valuable role played by wetland plants and substrates in trapping sediments, nutrients, and pollutants is well established. Where erosion has increased as a consequence of wide-scale vegetation clearing, many shallow water bodies have trapped high levels of sediment that would otherwise be transported downstream and deposited in coastal areas or on nearby reefs. Vegetation along the edge of Lake Victoria, East Africa, was found to retain 60–92% of phosphorus. More generally, it is estimated that wetlands intercept more than 80% of nitrogen flowing from terrestrial systems (although figures vary due to temperature and size of the area) (C7.2.5, C12.2.3). In West Bengal, India, water hyacinth is used to remove heavy metals, and other aquatic plants remove grease and oil, enabling members of a fishers' cooperative to harvest one ton of fish per day from ponds that receive 23 million liters of polluted water daily from both industrial and domestic sources. However, excessive loads of domestic sewage or industrial effluent can degrade inland wetlands, with a loss of both biota and services (C20.1.1). The costs of reversing damages to waste-degraded ecosystems are typically large; in some cases, rehabilitation is effec-

tively impossible (CWG).

Groundwater services: Services delivered by groundwater are generally less well understood than those derived from surface waters. Many wetlands exist because they overlie impermeable soils or rocks and there is therefore little or no interaction with groundwater. However, numerous wetlands are groundwater-dependent and fed largely or wholly by groundwater, such as wetlands that form at springs, oases, and many lakes. In some instances, wetlands may promote less groundwater recharge than other land types. In other cases, such as floodplains overlying sandy soils (in West Africa and India, for example), recharge of the aquifer occurs during flooding. The direction of water movement between the wetland and the ground may change in the same wetland, such as in some peatlands in Madagascar and along many river reaches, depending on season and local hydrological conditions.

River flow and hydrological regime variability: These services vary greatly between different types of wetland and their localities. For instance, different headwater wetlands and peat bogs showed increases, decreases, or neutral effects on variability. Glaciers and snowmelt also contribute to flows and their variability and timing. While floodplains (such as the Okavango delta in Africa and the Barito floodplain in Indonesia) reduce flow variability, principally by reducing flood peaks, other wetlands (such as many headwater wetlands) serve to increase flow variability through both increasing flood peaks and reducing dry-season flows.

as precipitation to pass through a system: the longer the residence time, the larger the buffering capacity to attenuate peak flood events. Larger rivers (such as the Congo and the Amazon) have a greater attenuation capacity than smaller rivers. Nearly 2 billion people live in areas with a residence time of one year or less and are thus in areas of high flood risk with low attenuation potential. Most of these people live in northern South America, highly populated regions of northern India and Southeast Asia, Central Europe, and the southwest coast of Africa. Large and extreme flood events have high costs both in terms of human life and expenditure on mitigation and recovery measures (C16.2.2).

However, floods also play an important role in maintaining the productivity of wetlands (and agriculture in floodplains), since they transport dissolved or suspended sediments and nutrients to the floodplains. The presence of a natural flood regime thus contributes to the livelihoods of millions of people, particularly those who depend on floodplains for flood-recession agriculture and pasturage and for fish production (C20.2.1).

Table 3.2. EXAMPLES OF HYDROLOGICAL-ECOLOGICAL RELATIONSHIPS AT DIFFERENT RIVER FLOWS THAT SUPPORT ECOLOGICAL CHARACTER OF WETLANDS AND THEIR SERVICES (Derived from C19.2, C20.2)

Flow Component	Ecological Role
Low (base) flows <i>Normal level:</i>	<ul style="list-style-type: none"> provide adequate habitat space for aquatic organisms maintain suitable water temperatures, dissolved oxygen, and other chemical conditions, including salinity maintain water table levels in floodplain and plant soil moisture provide drinking water for terrestrial animals keep fish and amphibian eggs suspended enable passage of fish to feeding and spawning areas support hyporheic organisms (living in saturated sediments)
Low (base) flows <i>Drought level:</i>	<ul style="list-style-type: none"> enable recruitment of certain floodplain plants purge invasive, introduced species from aquatic and riparian communities concentrate prey into limited areas to the benefit of predators
Higher flows (small flood pulses)	<ul style="list-style-type: none"> shape physical character of river channel, including availability and heterogeneity of different biotopes (such as riffles, pools) and microhabitats restore normal water quality after prolonged low flows, flushing away waste products, pollutants, and proliferations of nuisance algae maintain suitable salinity conditions in estuaries prevent encroachment of riparian vegetation into the channel aerate eggs in spawning gravels, prevent siltation of cobble interstices determine size of river bed substrata (sand, gravel, cobble, boulder)
Large floods	<ul style="list-style-type: none"> provide fish migration and spawning cues provide new feeding opportunities for fish and waterbirds recharge floodplain water table maintain diversity in floodplain forest types through prolonged inundation (plant species have differing tolerances for flooding) and their natural regeneration processes control distribution and abundance of plants on floodplain trigger new phases of life cycles (such as insects) enable fish to spawn on floodplain, provide nursery area for juvenile fish deposit nutrients on floodplain maintain balance of species in aquatic and riparian communities create sites for recruitment of colonizing plants shape physical character and habitats of river channels and floodplain deposit substrata (gravel, cobble) in spawning areas flush organic materials (food) and woody debris (habitat structures) into channel purge invasive, introduced species from aquatic and riparian communities disburse seeds and fruits of riparian plants drive lateral movement of river channel, forming new habitats (secondary channels, oxbow lakes) provide plant seedlings with prolonged access to soil moisture drive floodplain productivity

5. Human Well-being

The loss and degradation of wetland ecosystem services harms the health and well-being of individuals and local communities and diminishes development prospects for all nations (C19.6, C20.6). The services provided by wetlands are vital for human well-being and poverty alleviation. The sustainable use and, where necessary, restoration of wetland ecosystem services can often help people meet basic needs for water, food, shelter, and good health. This is particularly true in dryland regions. (See Box 5.1.) As the human population has grown and urbanization has increased, more and more people rely on wetland services such as clean water or fisheries being delivered to them from some distance away through trade networks or the development of infrastructure for water transport. In both rural and urban areas, the poor are likely to suffer most when the availability and quality of water and food are reduced, whether due to failures in infrastructure and trade networks or to the demise of wetlands.

Degradation and loss have reduced the capacity of wetlands to provide sufficient amounts and quality of water (C7.3, C7.4, C19.2, C20.4). It is well established that maintenance of an adequate flow of good-quality water is needed to maintain the health of inland water systems, as well as estuaries and deltas. The reverse is also true: healthy inland water systems generate and maintain adequate flows of good-quality water (C20.6). Water engineering to facilitate use by humans has fragmented aquatic habitats, interfered with migration patterns of economically important fisheries, polluted receiving waters, and interfered with the capacity of inland water ecosystems to provide reliable, high-quality sources of water (C7.3). The degradation of inland water systems reduces the potential of these systems to mitigate the effects of pollutants through detoxification and waste processing and results in an overall reduction in human well-being (C20.6).

The provision of ecosystem services by coastal systems can be highly dependent on the condition of coastal freshwater wetlands (C19.2.1). Water quality in river systems plays a crucial role in the sustainability of coastal aquatic habitats, food webs, and commercial fisheries that serve as a major protein source for humans. The decline of traditional fisheries (due to commercial exploitation of coastal fisheries and damage to inland water ecosystems due to water extraction and diversion) can have severe negative nutritional consequences for poor artisanal fishers (C8.5, C19.2.3). Water quality degradation is usually most severe in areas where water is scarce, such as arid, semiarid, and dry subhumid regions, due to the reduced capacity for waste dilution (C20.4).

Inland Wetlands

The loss and degradation of inland waters and floodplains has reduced their natural ability to buffer or ameliorate the impacts of floods; this threatens the security of individuals and entire communities (C6.5.2, C16.4.2, C20.4.2, C20.6). Forested riparian wetlands adjacent to the Mississippi River in the United

Box 5.1. WETLANDS IN DRYLANDS: IMPACT OF CHANGES IN WETLAND SERVICES ON HUMAN WELL-BEING (Derived from C22.5.2)

Wetlands such as marshes and rivers that are found in drylands are particularly important for well-being due to the scarcity of water in these regions. The supply of water from these wetlands is essential for food production. Other key services delivered by wetlands in drylands include:

- nutrient cycling and primary production of water bodies;
- soil formation away from wetlands;
- provision of aquatic animals and plants as food;
- drinking water for people and for livestock using terrestrial forage;
- wild food plants and cultivated crops produced by lands surrounding water bodies and often affected by seasonal water receding and flooding;
- provision of fuelwood from the highly productive wetland edges;
- biochemicals from both aquatic and terrestrial species;
- climate regulation through evaporative cooling;
- water purification, especially by marshes;
- support of biodiversity, including species that spend most of the time away from the dryland wetlands but for which these wetlands are critical for their survival, such as migratory birds; and
- cultural services—recreational, spiritual, and religious.

The large-scale appropriation of river, lake, and marsh water for dryland irrigation by diversion canals and dams along with marsh reclamation for dryland agricultural development, directly expressed in wetland shrinkage, leads to the degradation or loss of most of the services provided by wetlands in drylands. It also diminishes services provided by other ecosystems, since dams and reduced river flow diminish sediment load and decrease nutrient output to downstream water bodies.

States had the capacity to store about 60 days of river discharge. With the removal of the wetlands through canalization, construction of levees, and draining, the remaining wetlands have a storage capacity of less than 12 days discharge—an 80% reduction in flood storage capacity. The extensive loss of these wetlands was an important factor contributing to the severity and damage of the 1993 flood in the Mississippi Basin (C16.1.1). The majority of large floods have occurred in Asia during the last few decades, but few countries have been free of damaging floods (C16.2.2). In Bangladesh, the inundation of more than half of the country is not uncommon—about two thirds of the country was inundated in the 1998 flood. The floods in Central Europe in August 2002 caused damage totaling nearly 15 billion euros. Floods (and droughts) typically affect the poorest people most severely, as they often live in vulnerable areas and have few financial resources for avoidance, mitigation, or adaptation (C20.6).

Coastal Wetlands

Resource overexploitation and coastal degradation have undermined subsistence use of coastal ecosystems, harming local communities as well as national economies (C19.6). For instance, the net economic benefit from coral reefs—including fisheries, coastal protection, tourism, and biodiversity values, which are currently worth some \$30 billion annually—will be diminished from ever-accelerating coastal degradation. Many coastal communities, especially in poorer developing countries, are trapped in a vicious cycle of poverty, resource depletion, and further impoverishment. This phenomenon is not unique to communities dependent on coral reefs, but it is noteworthy that once coral reefs are destroyed, restoration is extremely difficult, and costs brought about by loss of services such as coastal protection continue to be incurred for long periods.

Even when people are made aware of the importance of coastal ecosystems, they still may not be able to stop the kinds of activities that destroy or degrade these areas unless alternative resources or livelihoods are made available to them (C19.6). For instance, boat builders of the coastal and island communities of East Africa have little choice but to remove mangrove from key nursery habitats, which actually support the very fisheries on which their boat-building industry is based. Few alternative materials for boats exist except when conservation projects have expressly built in alternatives and training on how to use them. In areas in which resource extraction is moving beyond ecologically sustainable limits or in which the removal of the resource causes major physical changes to the habitat, the search for alternatives is particularly crucial.

Wetlands and Human Health

The continued degradation of wetlands, and more specifically the continued decline in water quantity and quality, will result in further impoverishment of human health (*high certainty*), especially for vulnerable people in developing countries, where technological fixes and alternatives are not as readily available (C7, C20.6, R16). The burden of disease from inadequate water, sanitation, and hygiene totals 1.7 million deaths and results in the loss of at least 54 million healthy life years annually. Some 1.1 billion people lack access to clean drinking water, and more than 2.6 billion lack access to sanitation (C7.ES). Globally, the economic cost of the pollution of coastal waters is estimated to be \$16 billion annually, mainly due to human health impacts (C19.3.1).

Although largely eliminated in wealthier nations, water-related diseases are among the most common causes of illness and death, affecting mainly the poor in developing countries (C20.6). Human health is closely linked to safe drinking water and sanitation; degraded and polluted inland waters are very likely to lead to human illness and death (C7.4.5, C20.6). Water-related diseases that are exacerbated by the degradation of inland waters include those caused by the ingestion of water contaminated by human or animal feces or urine containing pathogenic bacteria or viruses, including cholera, typhoid, amoebic and bacillary dysentery, and other diarrheal diseases; diseases passed on by intermediate hosts such as aquatic snails or insects that breed in aquatic ecosystems, including dracunculiasis, schistosomiasis, and other helminthes, as well as dengue, filariasis, malaria, onchocerciasis, trypanosomiasis, and yellow fever; and diseases that occur when there is insufficient clean water for washing and basic hygiene or when there is contact with contaminated water, including scabies, trachoma, typhus and flea, and lice and tick-borne diseases.

Large dam construction has been associated with outbreaks of several different diseases (C14.2.1, C14 Box 14.1), and small dams are likely to have an equal or greater impact on human health because there is usually a high degree of water contact with people and animals. Intense transmission of diseases such as schistosomiasis, onchocerciasis, malaria, lymphatic filariasis, and dracunculosis is associated with small dams in many African countries, including Cameroon, Kenya, Ghana, Mali, Rwanda, and Zambia (C14.2.1). Tropical rice irrigation systems have also been linked to vector-borne diseases such as malaria and Japanese encephalitis.

Some waterborne pollutants (chemical and microbiological) have a major effect on human health; some chemical pollutants accumulate in the food chain to the point where they harm people (C20.6). Many countries now experience problems with elevated levels of nitrates in groundwater from the large-scale use of organic and inorganic fertilizers. Excess nitrate in drinking water has been linked to methemoglobin anemia in infants, the so-called blue baby syndrome. Arsenicosis, the effect of arsenic



poisoning when drinking arsenic-rich water over a long period, is also known and is a particularly severe problem in Bangladesh and Western Bengal, where some 35–77 million inhabitants are exposed to excessively high levels in water drawn from wells. On the whole, though, it is still difficult to quantify the cumulative effects of long-term exposure to a variety of chemicals.

Pollution puts coastal inhabitants at great risk—directly by affecting human health and indirectly by degrading the resource base on which many people depend. Poor sanitation affects not only slum dwellers but others as well (C19.6). South Asian waters are highly polluted, partly as a result of the 825 million people who lack basic sanitation services. Pathogens are spread more quickly and reach greater numbers of people in coastal ecosystems that have become degraded (C14.2.1). Chronic exposure to heavy metals and other bioaccumulating pollutants may not cause death in large numbers of people, but the cumulative effect can lead to reproductive failure and significantly decreased well-being. Food security is also greatly compromised in degraded coastal ecosystems. In addition, evidence exists from wildlife studies that humans are at risk from a num-

ber of chemicals that mimic or block the natural functioning of hormones, interfering with natural body processes, including normal sexual development (C20.5.6).

While preservation of ecosystems can sometimes prevent the emergence or spread of disease, trade-offs do sometimes exist between the maintenance of undisturbed ecosystems and risks of human disease (C14.1.3). Malaria control efforts, for example, which relied heavily on the insecticide DDT and the draining of marshes, caused enormous damage to wetland and other ecosystems but did often reduce the prevalence of the disease. Such trade-offs also have an important temporal aspect. For example, draining wetlands can reduce mosquito breeding sites for immediate benefit, but the wetland services of filtering water, detoxifying wastes, or providing species habitat will be lost.