A

TERM PAPER ON

GLOBAL ECOSYSTEM FOR NURTURING WATER RESOURCES AND INNOVATIVE HANDLING OF WATER RESOURCES

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ABSTRACT

This report examines global ecosystems as a driving force impacting the water resources. The report begins with a description of the current state of global ecosystems and water resources, depicted through a series of key elements and their complex interactions and interdependencies. It identifies major impacts on the current state. It then extracts major trends and projections for future states from available global scenarios. The table of possible developments is provided, detailing events, time factors, positive and negative impacts on water resources, low probability developments and principal sources of information. Causal links are established between this driver and the other nine water drivers. Lastly, critical uncertainties and future research needs are identified. Driver elements analyzed in this report include: 1) Value of ecosystem services; 2) Freshwater resources (*e.g.*, wetlands); 3) Extreme climate/water‐related events (floods and droughts); 4) Biodiversity and invasive alien species; 5) Changes in land use (deforestation); 6) Changes in water availability, use and productivity, including groundwater overdraft; 7) Changes in water quality (*e.g.*, eutrophication).

INTRODUCTION

 ECOSYSTEM

  An ecosystem is a dynamic complex of plant, animal and microorganism communities and the  nonliving  environment  interacting  as  a  functional  unit.  Humans  are  an  integral  part  of  ecosystems. The Millennium Ecosystem Assessment defines ecosystem services as  benefits provided to people, comprising:

1. Provisioning services, i.e., the products obtained from  ecosystems,  including  fresh  water,  food,  fuel,  fiber,  biochemical  and  genetic  resources.
2. Regulating  services,  i.e.,  the  benefits  obtained  from  the  regulation  of  ecosystem  processes,  including  climate  regulation,  air  quality  maintenance,  regulation  of  hydrological  flows,  water  purification, human disease and pest control, pollination, coastal protection, flood and erosion  control.
3. Cultural services, i.e., the nonmaterial benefits obtained from ecosystems through  spirital enrichment, cognitive development, reflection, recreation and aesthetic experiences.
4. Supporting services, necessary for the production of other services, e.g., oxygen production, soil  formation, nutrient storage, recycling, processing and acquisition
5. The ability of any particular aquatic ecosystem to supply the range of services listed above  depends upon a variety of factors, e.g., the type of ecosystem, the presence of key species,  management interventions, the location of human communities, the surrounding climate and  topography. Few sites have the capacity to provide all of the above services. Generally, the more  biologically diverse an ecosystem is, the greater the range of services that can be derived from it  (MA, 2005).  Current decision making processes often ignore or underestimate the value of ecosystem  services. There are two paradigms of value:

1) The anthropocentric (utilitarian) concept is based on the principle of humans’ preference  satisfaction  (welfare).  Ecosystem  services  have  value  to  societies  because  people  directly  or  indirectly derive utility from their use (use values). Value is often ascribed to knowing that a  resource exists even if people never use that resource directly (non‐use or existence values), e.g.,  the deeply held historical, national, ethical, religious and spiritual values ascribed to ecosystems.

 2)  The  nonutilitarian  paradigm  holds  that  an  ecosystem  can  have  intrinsic  value  irrespective  of  its  contribution  to  human  well‐being.  Intrinsic  value  may  complement  or  counterbalance considerations of utilitarian value (Alcamo et al., 2005).    Well‐documented impacts of human activities on ecosystem services at a variety of scales  include changes in the number and distribution of species (Chapin et al., 2000; Higgins et al., 2002;  Sala et al., 2000), and the quality and quantity of fresh water (Brinson and Malvarez, 2002).     For certain ecosystem services, monetary values are estimated.2 Conversely, ecological  degradation results in economic losses. Coastal erosion from altered currents and sediment loads  can be caused by changes in coastal and upstream land use. The beaches largely disappear in areas  where new ports are built, resulting in substantial tourism income losses. Societal consequences of  altered biodiversity are also measured.

3     MA (2005) reports that the degradation of lakes, rivers, marshes and groundwater systems  is more rapid than that of other ecosystems. The status of freshwater species is deteriorating  faster than those of other ecosystems. Direct drivers of degradation of freshwater ecosystem  services include: infrastructure development, land conversion, water withdrawal, eutrophication,  pollution, overexploitation and the introduction of exotic species (Mayers et al., 2009). UNEP  (2009a) provides a review of water security and ecosystem services case studies and lessons  learned about habitat rehabilitation, pollution control and integrated watershed management.

 WATER RESOURCES

Less than 3% of the global total water resources is represented by freshwater and less than  1% of that (less than 0.01% of total water) occurs in the Earth’s liquid surface freshwater. The  remainder represents ice caps or groundwater. The small fraction of liquid surface freshwater  hosts an extraordinary level of biodiversity supported through a range of freshwater ecosystem  types:  1)  running  waters,  2)  standing  waters  and  3)  areas  of  transient  water  availability.  Freshwater ecosystems include: permanent and temporary rivers and streams; permanent lakes,  reservoirs; seasonal lakes, marshes and swamps, including floodplains; forested, alpine and tundra  wetlands; springs and oases; groundwater systems and geothermal wetlands (Mayers et al., 2009).    The volume of water in rivers and streams is only a fraction of the water in the entire  hydrosphere, but often this water constitutes the most accessible and important water resource  (WWDR3, 2003). Uneven global distribution of precipitation and runoff influence the distribution  of  river  networks.  Asia  and  Latin  America  each  contribute  approximately  30%  of  the  world  freshwater discharged into the ocean, North America contributes 17, Africa 10, Europe 7, and  Australasia 2% (Fekete et al., 1999). There are several published inventories of rivers, listing the  major river systems with their drainage area, length and average runoff (e.g., Shiklomanov, 1997).  The variability between estimates can be explained by different definitions regarding the extent of  a river system and different time periods or locations for the measurement.    There are 5‐15 million lakes across the globe (WWDR3, 2003) and approximately 10,000  lakes have a surface area over 1 km2. Only about 15‐20 existing lakes in the world are older than 1  million years (LakeNet, 2003). A disproportional share of large lakes, with a surface area over 500  km2, is found in North America, where glacial scouring created many depressions in which lakes  have formed. The International Lake Environment Committee (ILEC) maintains a database of over  500 lakes worldwide, with some physiographic, biological and socioeconomic information.    The definition of inland wetlands adopted by the Convention on Wetlands (Ramsar, Iran,  1971) covers all wetland types, including artificial wetlands, and encompasses permanent and  temporary riverine, lacustrine and palustrine systems, above ground and underground systems  (karst  and  cave),  freshwater,  brackish  and  saline  systems  (Ramsar  Classification  System  for  Wetland Type in the Annex to Resolution VII.11). A Global Review of Wetland Resources and  Priorities for Wetland Inventory (GRoWI, Finlayson & Spiers, 1999) estimated the global extent of  wetlands including coastal wetlands in some countries, at 1,276‐1,279 million hectares (ha).4  Revenga and Kura (2003) offer some reasons for the incompleteness of global wetland inventories,  notably inconsistent interpretations of definitions, difficulty defining the boundaries, limitation of  maps and remote sensing products.

During the past hundred years, the groundwater portion of the water cycle was subjected  to massive changes, as humans learned to dig or drill wells and abstract groundwater using pumps.  Groundwater  serves  as  a  water  shortage  buffer  during  short‐term  climate  variations  and  is  important to adaptation strategies. Groundwater mining from fossil aquifers is often the only  reliable means of obtaining water.     These groundwater resources are increasingly being used for agricultural, industrial and  domestic water supplies, although they are almost never recharged.  Changing land use and water  infrastructure also greatly modify groundwater regimes, with groundwater pumping from deep  aquifers now a worldwide phenomenon. In many instances, groundwater is pumped with no  understanding of its source or its annual recharge, and therefore of how much may be used  sustainably. Heavy groundwater pumping has led to unsustainable conditions. Stresses result in: 1)  Falling water levels; 2) Degraded groundwater aquifers; 3) Increased salinization; 4) Chemical and  microbiological  pollution;  5)  Desiccated  wetlands;  6)  Dewatered  rock  sequences;  7)  Land  subsidence. Use of groundwater for irrigated agriculture increased enormously in the past 50  years. Some 70% of global groundwater abstraction is now estimated to be used in irrigation.  Pollution of shallow aquifers became widespread four or five decades ago and triggered water  quality protection measures in many countries. Groundwater abstractions also contributed to the  development of rural economies.

LITERATURE REVIEW

**What is an ecosystem?**

An ecosystem is a natural environment and includes the flora (plants) and fauna (animals) that live and interact within that environment. Flora, fauna and bacteria are the biotic or **living components** of the ecosystem. Ecosystems are dependent on the following abiotic or **non-living components**:

* climate - the temperature and amount of rainfall are very important in determining which species can survive in the ecosystem
* **soil** - the soil type is important as this provides nutrients that will support different plants
* **water** - the amount of water available in an ecosystem will determine which plants and animals can be supported

The biotic parts of the ecosystem, which include bacteria, flora and fauna, have a complex relationship with the abiotic components - changing one will lead to a change in the other.

**Energy flows**

Energy flows through an ecosystem in a number of food chains. Plants act as producers at the start of all food chains, making food from the process of photosynthesis. Herbivores then eat the plants - these are the first consumers. Herbivores are then eaten by carnivores - the second consumers.



Food chains inter connect in an ecosystem to form a complex food web.

Humans and ecosystems share the same water In the catchment the rainfall is shared between nature and human society and between terrestrial and aquatic system. This is therefore, a unit in which a balance between man and nature can be carried out. All the rain falling inside that water divide constitutes the water resource shared by all the water-dependent activities there, Figure 1. After reaching the land surface the rainwater is partitioned into the green water vapour flow supporting the terrestrial ecosystems and the blue water liquid flow supporting the aquatic ecosystems and accessible for human use. The green water flow system reflects the water consumption by forests, grasslands and rainfed croplands. It sustains the terrestrial ecosystems in general and in particular rainfed crop production. The blue water moves as blue water flow from uphill to downhill, from land to water systems where it is accessible for societal use. By withdrawals water is “harvested” to support water-dependent human activities and carried to cities and to industries. After use it goes back to the water system as a return flow of wastewater loaded with pollutants, unless far-reaching wastewater treatment has been carried out. Blue water is also withdrawn to support irrigation. During use part of that water – the consumptive use – will turn into green water flow while the surplus (nonconsumed part) forms a return flow of blue water. The return flow is often loaded with leached agrochemicals and soil nutrients causing eutrophication in the river water and the coastal waters where it empties.



**SOME WATER DEPENDENT ECOSYSTEM SERVICES**

 The water cycle A more successful coping with the complex roles of water in the life support system should begin by paying larger attention to the water cycle in its role as the bloodstream of the biosphere , i.e., take a water-cycle-based approach to human interaction with the natural system. First of all, through its physical, chemical and biological involvement, water has absolutely fundamental balancing functions in the water cycle. It dissipates solar energy variations in space and time through three main process properties with mutually balancing component processes: – physical ones through the interaction between evaporation and condensation of major importance for the redistribution of energy over the planet – chemical ones through the interaction between crystallization and dissolution of fundamental importance for the redistribution of soluble substances over the planet – biological ones through the interaction between the water molecule splitting as the first step in the photosynthesis process and the later re-assemblage through respiration. The liberated hydrogen forms cellulose, in the process liberating oxygen.

Key functions and linkages Ecosystem services are of decisive importance for the functioning of the life-support system. Some ecological services are evident, others have remained mentally hidden. By a systematic approach they can be structured as follows: – physical services such as phosphorous absorption in the soil; erosion and sedimentation of silt; interception of rainfall; facilitating rainwater infiltration into the soil – chemical services such as oxygen production and carbon dioxide uptake in the photosynthesis process; denitrification; nutrient release through biodegradation – biological services like photosynthesis, pollination, seed dispersal, pest control, production of biomass, and macropore creation in the soil.

Sources: Ripl (1995), Daily (1997), FAO (2000)

TERRESTRIAL ECOSYSTEMS

The terrestrial ecosystems play a fundamental role in the runoff generation process since they consume huge amounts of green water, in fact two thirds of the continental precipitation

The photosynthesis process involves a consumptive use of water that is climate dependent. Water is one of the two raw materials in the process with carbon dioxide being the other. The process starts by the splitting of the water molecule followed by a second biochemical reaction where the freed hydrogen reacts with carbon dioxide from the air, forming sugar molecules that constitute the basic building blocks of plant biomass (Waterlow et al., Eds, 1998). However, when opening the stomata in the leaves to take in carbon dioxide the plant looses water by diffusion and the lost water is replaced through a water flow up the plant from the roots.

Landscape ecosystems may be quite different in character with a main distinction between grasslands and forests and in terms of characteristic vegetation with dominating species shifting with climate.

TERRESTRIAL ECOSYSTEMS CONSUME WATER

Terrestrial ecosystems basically feed on infiltrated water. Seen on a global scale they consume two thirds of the precipitation over the continents: – croplands (including weeds and periphery)6800 km3 /yr – temperate and tropical grasslands15100 – temperate and tropical forests, woodlands40000 – bogs, fens, swamps and marshes1400 – tundra and desert 5700 – other systems2 000

Altogether7 1000

These 71,000 km3 /yr constitutes the total green water flow from the continents, i.e., continental evapotranspiration. Figure 4 visualizes the continental water partitioning showing the fundamental importance for the blue water flow of the green water flows involved in consumptive water use by terrestrial ecosystems including crop production. It also puts in proportion the tiny relative scale of water use that has been the focus of past water management and was discussed by the World Water Commission. The overall water withdrawals were estimated to 3900 km3 /yr out of which 2600 is consumptive use and the remaining 1300 constitutes the return flow.

Sources: Rockström et al., (1999), Cosgrove and Rijsberman (2000)

**FLOODS AND DROUGHTS**

Extreme climate/water‐related events can have positive and negative impacts on ecosystems and their services. They recharge natural ecosystems, providing more abundant water for food production, health and sanitation. But extreme water‐related events also destroy lives and property. Adikari and Yoshitani (2009) analyze water‐related disaster events between 1980 and 2006.**5** The factors that lead to increased water‐related disasters include: natural pressures, *e.g.*, climate variability; management pressures, *e.g.*, lack of appropriate organizational systems and inappropriate land management; and social pressures, *e.g.*, escalation of population and settlements in high‐risk areas (particularly for poor people). Flooding is broadly defined to include both excess water caused by rainstorms that subsequently leads rivers to flood (spill over their banks), and severe coastal storms or cyclones that can lead to excess water through largely tidal surges (Cosgrove and Rijsberman, 2000). The moisture‐holding capacity of the atmosphere has been increasing at a rate of about 7% per 1°C of warming, creating the potential for heavier precipitation. There have likely been increases in the number of heavy precipitation events in many land regions, consistent with a warming climate and **5** Numbers of floods and windstorms increase drastically from 1997 to 2006 (factor of 2 and 1.5, respectively), but other types of disasters do not increase significantly in this period. Drought is severe at the beginning of the 1980’s and gains momentum again during the late 1990’s and afterwards. The numbers of landslides and waterborne epidemics are highest during 1998–2000 and then decrease. Waves and surges increase between 1980 and 2006. In general, water related disaster fatalities follow a decreasing trend, but the fatalities record has occasional peaks: droughts, during the period 1983–1985; windstorms, 1989–1991; waves and surges, 2004–2006. Global estimates of water-related economic losses show an increasing trend, the main contributors in descending order being windstorms, floods and droughts; the rest of the water-related disasters are insignificant, but underestimated (Adikari and Yoshitani, 2009). the observed increase in atmospheric water vapor, even where total precipitation has declined. Some people rely on floods for irrigation and natural fertilization, but disruption, devastation of human lives and infrastructure are common. Among the regions devastated by floods in the period 2001‐2010 were Southern China, Haiti, India, Indonesia, U.S., Mexico, South Eastern Europe and most recently Portugal. In developing countries extreme floods can result in many deaths, while in developed countries extreme floods cause material damage in the billions and tens of billions of dollars. Van Lanen *et al*. (2007) define drought as a sustained and regionally extensive occurrence of below average natural water availability. The main causes are low precipitation and high evaporation rates. In regions with a cold climate, temperatures below zero can also give rise to a winter drought. Drought is characterized as a deviation from normal climate and hydrology, which is reflected in precipitation, soil water, groundwater and streamflow. Droughts have a substantial impact on the ecosystem and agriculture of the affected region. Climate change is expected to influence precipitation, temperature and potential evapotranspiration and to influence occurrence and severity of droughts. But it is difficult to disentangle the impacts of climate change from those of other human influences, *e.g.*, engineered effects, land use changes and multidecadal climate variability. More intense droughts, affecting more people and linked to higher temperatures and decreased precipitation have been observed in the 21st century (Zhang *et al*., 2007). Burke *et al*. (2006) assess meteorological drought in the Hadley Centre global climate model using the Palmer Drought Severity Index (PDSI). On average, the limiting PDSI values for extreme, severe and moderate drought are −4.3, −3.3, and −2.0, respectively. The land surface in drought increased by the beginning of the 21st century for all three types of drought, from 1% to 3% for the extreme droughts, from 5% to 10% for the severe droughts, and from 20% to 28% for the moderate droughts.

**. DEFORESTATION**

Deforestation is the clearance of naturally occurring forests by logging and burning Disregard or ignorance of intrinsic value, lack of ascribed value, lax forest management anddeficient environmental law are some of the factors that allow deforestation to occur on a largescale. In many countries, deforestation is an ongoing issue that is causing extinction, changes toclimatic conditions, desertification and displacement of indigenous people (FAO, 2005).

Deforestation also significantly impacts the water cycle:

1) It reduces the content of water in the soil, groundwater and atmospheric moisture. Trees extract groundwater through their roots and release it into the atmosphere. When part of a forest is removed, the trees no longer evaporate away this water, resulting in a much drier climate.

2) It reduces soil cohesion, which results in erosion, flooding and landslides. Vegetation litter, stems and trunks slow down runoff. Roots create macropores in the soil that increase infiltration of water.

Asian carp have been found in the Illinois River, which connects the Mississippi River to Lake Michigan (USA). Two species of Asian carp (the bighead and silver carp) were imported by catfish farmers in the 1970’s to remove algae and suspended matter out of their ponds. During large floods in the early 1990’s, catfish farm ponds overflowed their banks, and the Asian carp were released into local waterways in the Mississippi River basin. They can weigh up to 100 pounds, and can grow to a length of more than four feet. They are well-suited to the climate of the Great Lakes region, which is similar to their native Asian habitats. Due to their large size and rapid rate of reproduction, these fish can disrupt the food chain that supports the native fish and pose a significant risk to the Great Lakes Ecosystem. Additionally, silver carp can leap several feet out of the water when disturbed by boat propellers, possibly causing damage to boats and injuries to boat operators and fishermen. To prevent the carp from entering the Great Lakes, USEPA and other authorities are working to install and maintain a permanent electric barrier between the fish and Lake Michigan (USEPA, 2004a).

Water hyacinth (*Eichhornia crassipes*) became invasive in many tropical and sub-tropical inland waters. Indigenous to the upper Amazon basin, it was spread throughout much of the planet for use as an ornamental plant beginning in the mid-19th century. By 1900, it spread to every continent except Europe. Today, the plant has a pan-tropical distribution.

It quickly extends its range throughout rivers and lakes in the tropics, clogging waterways and infrastructure, reducing light and oxygen in freshwater systems, and causing changes in water chemistry and species assemblages (Hill *et al*., 1997).

Dinoflagellates are protists, mostly marine plankton, which sometimes bloom in concentrations of more than a million cells per milliliter. Certain species produce neurotoxins (*e.g.*, saxitoxin, a powerful paralytic), which kill fish and accumulate in filter feeders, *e.g.*, shellfish, which in turn cause poisoning in people. Their rapid and copious reproduction due to the abundant nutrients in the water can result in the red tide phenomenon.

Trees or derived charcoal are used or sold for fuel or as a commodity. Cleared land is used as pasture for livestock, plantations of commodities and settlements. The removal of trees without sufficient reforestation results in damage to habitat, biodiversity loss and aridity. Deforestation has adverse impacts on biosequestration of atmospheric carbon dioxide.

3) It lessens the landscape’s capacity to intercept, retain and transpire precipitation. Instead of trapping precipitation, which then percolates to groundwater systems, deforested areas become sources of surface water runoff, which moves much faster than subsurface flows. That quicker transport of surface water can translate into flash flooding and more localized floods than would occur with the forest cover.

4) It contributes to decreased evapotranspiration, which lessens atmospheric moisture which can affect precipitation levels downwind from the deforested area, as water is not recycled to downwind forests, but is lost in runoff and returns directly to the oceans. According to the FAO Global Forest Resource Assessment (FRA 2005), forests cover 30% of the total land area. The total forest area in 2005 is just under 4 billion ha, corresponding to an average of 0.62 ha per capita. But the area of forest is unevenly distributed: 64 countries with a combined population of 2 billion have less than 0.1 ha of forest per capita. The ten most forest rich countries account for two‐thirds of the total forest area. Seven countries or territories have no forest at all, and an additional 57 have forest on less than 10% of their total land area.

**WATER AVAILABILITY, USE AND PRODUCTIVITY**

Water availability is critical for the maintenance of flora, fauna, freshwater systems and human activities. Water is needed for forests and wetlands, which in turn recharge aquifers, store runoff and regulate pollution by processing organic waste (Johnson *et al.*, 2001). Sufficient in stream water availability can help temper water pollution through the dilution of contaminants in the watercourse. Extreme changes in ecosystems may occur if water available for environmental uses falls below a certain threshold. There is a growing interest in understanding environmental demands for water. Environmental flows refer to the quality, quantity and timing of water flows required to protect an ecosystem, enable ecologically sustainable development and water resource utilization. The Nature Conservancy developed the following tools for environmental flow management: 1) Ecological Limits of Hydrologic Alteration**12** (ELOHA); 2) Ecologically Sustainable Water Management(ESWM); and 3) Indicators of Hydrologic Alteration(IHA). The possible trade off between water for nature and water for food production can be a contentious issue, as demonstrated during the 2nd World Water Forum in The Hague (2000). Participants in the “Water for Food” theme stressed the need for slow growth in water consumption in agriculture, while the “Water for Nature” theme called for significant reallocation of water from agriculture to environmental uses.

ELOHA is a scientifically robust and flexible framework for assessing environmental flow needs across large regions (states, provinces, major river basins or entire countries), aimed at understanding the ecological ramifications of human induced alterations in river flows. Information gathered through ELOHA allows water managers and stakeholders to develop environmental flow targets for rivers without requiring detailed, site-specific hydrologic or biological information for each river.

ESWM is a six step framework that determines how to meet human water needs by storing, diverting and releasing water in a manner that either sustains or restores a river’s ecological integrity.

IHA is a free software program developed by Nature Conservancy, which provides information for developing environmental flow recommendations and understanding the impacts of human activities on water flows. IHA displays statistical information about water flow changes and trends in multiple formats, *e.g.*, comparing the flow in a particular river between pre-dam and post-dam periods.

The total rainfall on the Earth’s land surfaces amounts to 110,000 cubic kilometers (km3). Rain replenishes blue water sources, *i.e.*, rivers, lakes, *etc*, and green water, *i.e.*, soil moisture. About 39% of rain contributes to blue water, supporting biodiversity, fisheries and aquatic ecosystems; 56% of green water is evapotranspired by landscape uses that support bioenergy, forest products, livestock grazing lands and biodiversity; 4.5% is evapotranspired by rainfed agriculture supporting crops and livestock; total evapotranspiration by irrigated agriculture is 2% of rain, of which 30% is directly from rain (green water) and the remainder from irrigation (blue water). Blue water withdrawals for irrigation, industry and municipal use represent 9% of total blue water. Cities and industries return more than 90% of their withdrawals to blue water, but the return flows are often of lower quality (Molden, 2007).

Only a small fraction of the total available water is accessible by humans. Therefore, it is more useful to consider total water withdrawn for human use. Groundwater/Surface‐Water Maximum Allowable Water Withdrawals (G/S MAWW) are actual water withdrawals, which are constrained by allowable water withdrawal for surface water and groundwater. MAWW are limited by infrastructure constraints, *e.g.*, physical diversion structures and pumping capacities, and policy constraints, *e.g.*, the amount of water which must be left in‐stream for environmental purposes. Of the total water withdrawn for human uses, withdrawals for agriculture represent 70%, those for industry 20%, and for municipal use about 10%. Shiklomanov (1999) presents tables of the dynamics of water use by continents and by economic sectors. Between 1950 and 1995, agricultural uses for water more than doubled (Cosgrove and Rijsberman, 2000; Shiklomanov, 1999). Sixty years ago, the world population was smaller, less wealthy, consumed fewer calories, ate less meat and required less water to produce their food. When agricultural activities change the quality, quantity and timing of water flows to support food provision, the ecosystems’ capacity to provide other services is reduced. Regulating services are primarily affected: pollination, biological pest control, flood retention capacity, changes in microclimate regulation, the loss of biodiversity and habitats (Molden, 2007). The development of dams and irrigation systems has significant environmental and human resettlement costs, *e.g.*, 48 million people were displaced by dam projects. In addition, agricultural expansion caused an estimated 56‐65% of the available wetlands in Europe and North America to disappear. Globally, wetland loss is 26%, and still intensifying in many regions.

Agricultural water withdrawal is largely attributed to irrigation. The key environmental issues for rivers related to unsustainable agriculture are: excessive water depletion, water quality reduction, waterlogging (60–80 million ha of irrigated lands are affected), salinization (20–30 million ha irrigated lands severely affected) and loss of ecosystem services (FAO, 1996). River downstream effects are temperature changes, depleted fish stock, effects on wetland, reduction in silt and water quality. The upstream effects are siltation, salinization and deforestation. Many countries and basins currently exploit their groundwater reserves at a rate substantially exceeding recharge. Overdraft occurs when pumping rates exceed the rate of natural recharge. Unsustainable groundwater use is often associated with irrigation, and can lead to both

water scarcity and water quality problems. Postel (1999) draws on several sources to estimate total annual global groundwater overdraft at 163 km3. The threshold at which localized groundwater overdraft occurs at the whole‐basin level can be set at 0.55. The key impacts which result from overdraft are: increasing lifts and costs from the lowered water table, subsiding land (sometimes irreversibly damaging the aquifer) and degrading water quality (including saline intrusion and arsenic). Water productivity is largely determined by crop yield in the agricultural sector, which dominates water use. Relatively small gains can be achieved by trending towards more beneficial water consumption. The greatest benefit comes from having a stable climate with adequate rainfall. Water productivity increased by at least 100% between 1961 and 2001, mainly due to increases in crop yields. Irrigated rice yields doubled and rainfed wheat yields rose by 160%.

Globally, FAO (2003) estimated that water needs for food per capita halved between 1961 and 2001. A 10% increase in water productivity equals current domestic water consumption, therefore investing in agricultural water management is an attractive strategy for freeing water for other purposes. The water productivity of rice is significantly lower than that of other cereals, ranging from 0.15‐0.60 kilograms per cubic meter (kg/m3), while that of other cereals ranges from 0.20‐ 2.40 kg/m3. The average water productivity of other cereals in the developed world is 1.0 kg/m3 while in the developing world it is 0.56 kg/m3 (Rosegrant *et al.*, 2002).

In many developing countries, industrial production and hence the sectoral use of water grow fast, putting increasing pressure on scarce water resources. The relationship between industrial water withdrawal and industrial growth is not linear, as technological advances lead to water savings and water reuse in industry. Hence industrial water withdrawals in many developed countries have flattened off, while industrial water consumption (which is only a fraction of the total water withdrawal) continues to grow.

In terms of domestic water use, delivery of safe water and sanitation are critical. Withdrawals for domestic and industrial uses grew four‐fold between 1950 and 1995 (Cosgrove and Rijsberman, 2000; Shiklomanov, 1999). There is much promise in the ongoing developments for desalination technology, but today it contributes only 0.02% of global water withdrawals and perhaps 1% of drinking water (Martindale and Gleick, 2001). It is mostly limited to coastal regions.

Three key issues are: high energy costs, concentrate disposal and high capital costs. Poverty is directly associated with lack of access to safe drinking water, sanitation and water‐related disease. Global sanitation coverage rose from 49% in 1990 to 58% in 2002 (WHO, 2004).Many people still access water and sanitation the same way their ancestors did thousands of years ago: 1 billion people lack access to improved water supply and 2.6 billion lack access to improved sanitation, resulting in water related disease. There are four classes of water-related disease: 1) Waterborne, for which water is the agent of transmission, caused by pathogens transmitted from excreta to water to humans, *e.g.*, cholera, hepatitis A and E; 2) Water-based, from hosts that either live in water or require water for part of their life cycle, *e.g.*, schistosomiasis spreads in regions where irrigation and dam projects produce habitats that favor the host snails; 3) Water-washed, caused by water scarcity where people cannot wash themselves, their clothes or homes regularly, *e.g.*, trachoma; and 4) Water related insect vectors, *e.g.*, malaria, onchocerciasis (UNEP, 2010). Water, sanitation and hygiene risk factors contribute annually to over 2 million deaths from diarrhea (cholera, typhoid) and over 1 million deaths from malaria.

The focus here is on water availability, use, efficiency and productivity development guided by the following indicators. Water availability indicates the volume of water theoretically exploitable. Water withdrawals indicate the volume used by society to fulfill its domestic, industrial and agricultural needs. Water productivity indicates water availability for uses other than agriculture. The criticality ratio is an indicator of water scarcity stress at the basin level and the intensity of human water use. Water stress is defined as the long‐term average annual withdrawals to availability ratio (Alcamo and Henrichs, 2002).**32** The change in water stress is an indirect indicator of the ability of a freshwater ecosystem to deliver ecosystem services. Return flows roughly indicate the magnitude of wastewater discharged into the receiving water in a river basin.

Rosegrant *et al.* (2002) discuss three scenarios projecting the likely water and food outcomes to 2025: the business‐as‐usual (BAU), crisis (CRI) and sustainability (SUS) scenarios.**33** Under BAU, total global water withdrawal in 2025 is projected to increase 22% above 1995 levels to 4,772 km3. This is consistent with other recent projections to 2025 including: Alcamo *et al.* (1998) medium scenario of 4,580 cubic km3, Seckler *et al.* (1998) business‐as‐usual scenario of 4,569 km3 and Shiklomanov (1999) forecast of 4,966 km3 (excluding reservoir evaporation). The Global Orchestration scenario shows strong economic growth coupled with an increase in population, which leads to a worldwide increase in withdrawals of around 40% by 2050. For OECD, MENA and FSU only slight increases in withdrawals are predicted, because economic and population growth are compensated by improving water efficiency. By 2050, TechnoGarden experiences strong structural changes in the domestic and industrial sectors and improvements in the efficiency of water use in all sectors, which lead to a net decrease in water withdrawals. Adapting Mosaic and Order from Strength do not have the largest economic growth, but by 2050,

Water stress is severe if the ratio is greater than 0.4; medium for ratios between 0.2 and 0.4; and low for ratios below 0.2. Alcamo and Henrichs (2002) identify critical regions in which water resources have higher sensitivity to global change than other regions, using an increase in water stress as a measure of watershed sensitivity. Stress increases when water withdrawals increase or water availability decreases. The extent of computed critical regions depends upon the scenario and the set of criteria for determining critical regions. Scenarios considered are: Markets First, Policy First, Security First and Sustainability First. Certain regions appear to be critical under all scenarios, *i.e.*, central Mexico, the Middle East, large parts of the Indian subcontinent, and the northern coast of Africa. Oki *et al.* (2001) derive annual water availability from annual runoff estimated by land surface models using total runoff integrating pathways. The total population under water stress estimated for 1995 is consistent with earlier estimates. This number is highly dependent upon assumptions about the volume of water from upstream of a region, which is considered “available” water within the region. Therefore, it is necessary to evaluate the upstream regional water quality and the real consumption of water resources, as well as the accessibility of water.

CONCLUSION

It follows from the above discussion that freshwater management and the management of ecosystem dynamics have to be integrated. This is equivalent to finding ways and means to merge water management, land use management, and ecosystem management (terrestrial as well as aquatic) within a socio-ecohydrological catchment management – with full awareness of the different ethical and political dilemmas involved. Since land use and terrestrial ecosystems are green-water related while societal water needs and aquatic ecosystems are blue-water related, and the blue and green water flow branches are the result of the partitioning of incoming precipitation, the ultimate resource is the precipitation over the catchment.

The changes with which we have to learn to live without destroying the capacity of the ecosystems to provide life support involve two basic categories of anthropogenous manipulations change of water components in the landscape and change of land/vegetation. Both types of manipulations will produce water-related side effects on both water flow components and blue/green water partitioning. Both of these represent water determinants of ecosystems and therefore, will generate higher order ecological change. Finally, water flows through the landscape are involved in linking upstream and downstream activities and ecosystems in the catchment. The approach has to be land/water integration in a catchment-based ecosystem approach (GWP , 2000).

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