Chapter 7

Healthy freshwater ecosystems: an imperative for human development and resilience

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Introduction | Fresh water is vital to human life and wellbeing. Along with food and shelter, it forms our most basic need. So vital, in fact, that access to drinking water is commonly considered a fundamental right for all humanity. Healthy, functioning freshwater ecosystems provide reliable and quality water flows upon which these basic human needs depend. Energy, food and health – all indispensable to human development – rely on the water services provided by natural ecosystems. Freshwater ecosystems, such as wetlands and rivers, also provide crucial regulating services, such as water purification, flood mitigation and the treatment of human and industrial wastes. Now, more than ever, we must incorporate the value of water-related environmental services in our water management decisions. Eradicating poverty and hunger among the billions living in deprivation today and those in the future will depend fundamentally on water security – for both people and ecosystems.

Water is central to the functioning and resilience of the biosphere. Its availability and variability strongly influences the diversity and distribution of biomes and habitats that harbour the wealth of plant and animal life on Earth. Water of specific quantity and quality is required to preserve the state and stability of ecosystems and build their resilience to localised disturbance and to global change. It mediates the persistence of ecosystem types, their composition and function, and facilitates the migration of species and habitats as key environmental conditions such as temperature, rainfall, and soil moisture change.

Water's central role in the biosphere has long implied that several of the most important challenges confronting human development are related to fresh water (e.g., Falkenmark, 1990). This has been true for decades and will only intensify without a change in the course of human water use. For too long, conventional approaches to water planning have focused narrowly on economic productivity, largely ignoring the costs of overdrawing water from ecosystems or disrupting natural flow regimes with hard infrastructure. If we are serious about meeting human development objectives for the coming century, the way we plan and manage water resources must change.

Humanity's freshwater footprint | Water provision for economic growth provides unquestioned benefits that too often come at significant but unquantified costs to ecosystems and biodiversity (Vörösmarty et al., 2010). Humans change the dynamics of the water cycle through damming and diversions, through water withdrawals for energy, agriculture, industry, and domestic use, and through return flows of altered quality, quantity and variability. Reservoirs intercept more than 40 per cent of global river discharge (Vörösmarty et al., 2003, Lehner et al., 2011) and more than 50 per cent of large river systems are affected by dams (Nilsson et al., 2005, Lehner et al., 2011). Fragmenting and degrading freshwater ecosystems results in a reinforcing cycle of decline, as ecosystem damage in turn reduces the quantity, reliability, and quality of water flows, weakens storm and flooding protection, wastewater treatment, fish production, and other ecosystem services. In several regions of the planet, direct human impacts on the water cycle are of the same order of magnitude or even exceed the impacts expected for moderate levels of climate change (+2°C) (Haddeland et al., 2014).

Freshwater species and ecosystems are disproportionately threatened by human activities due to both the magnitude of disturbance and their exceptional richness as a

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habitat for plants and animals. Over 10,000 fish species live in fresh water, approximately 45 per cent of global fish diversity (IUCN, 2014). Together, freshwater endemic fish, amphibians, reptiles and mammals constitute as much as one third of all vertebrate species (Dudgeon et al., 2006). Yet surface freshwater habitats contain only around 0.01 per cent of the world's water and cover only about 0.8 per cent of the Earth's surface (Gleick, 1996). Of some 25,000 freshwater plant and animal species assessed for the IUCN Red List, almost one third are threatened with extinction, over 200 are already extinct, and their rate of loss is higher than either marine or terrestrial species (IUCN, 2014). Extinction rates rival those of previous transitions between geological epochs like the Pleistocene-to-Holocene (Meybeck, 2003); suggesting, based on a similar exponential rise in human pressures on other key parameters that regulate the stability of the Earth system (e.g., nutrient loading and climate change), that humanity has entered a new geological epoch: the Anthropocene (Crutzen 2002, Steffen et al., 2007, Zalasiewicz et al., 2008)

Freshwater ecosystem resilience | While improved water management is needed to meet human development goals, it is also required to provide protection from the uncertainties of a changing planet. Both people and ecosystems are vulnerable to environmental changes or shocks, like floods and droughts. Floods displace people from their homes and livelihoods. Droughts damage both natural wetlands and human agriculture. Wetlands can provide natural buffers to flood waters, but only if they are allowed to thrive, which requires that some water be allocated to sustain their function. Similarly, it is easier to withstand droughts if a system is not already stressed. Allocating adequate water flows to ecosystems during periods of stasis adds stability and adaptability during times of stress. This concept is known as water resilience (Rockström et al., 2014). Resilient ecosystems handle shocks without being damaged beyond repair. Excessive changes to ecosystem structure and function, stress, and simplification of natural complexity has the potential to push functionally intact freshwater ecosystems beyond the bounds of resilience (Baron et al., 2002).

Freshwater systems are directly threatened by human activities and stand to be further impacted by climate change. Climate change will not only exacerbate water scarcity in many parts of the world, it will also increase the variability of rainfall patterns (IPCC, 2014). This makes the availability of fresh water even more unpredictable, further complicating its allocation between increasingly stressed, competing sectors such as agriculture, energy and domestic use.

As more and more water is allocated to human use, less becomes available for ecosystems. In the increasingly unpredictable planetary conditions of the Anthropocene, it is more important than ever to ensure that human activities operate within safe boundaries of Earth system change (Rockström et al., 2009). Human development within the safe operating space of these boundaries offers a better chance of preserving a desired stable environmental state of the Earth system, thus providing resilience – the ability to absorb and respond to shocks without fundamentally altering biophysical, social, and economic systems. Building resilience is an urgent social and economic issue, one that communities across the globe must focus on as shocks and stresses become more frequent (Rodin, 2014). Exceeding these boundaries risks pushing the Earth into an even more volatile and unpredictable state (Steffen et al., 2015) and humans to ever more dire conditions.

This concept is equally applicable for natural systems such as a water basin: freshwater systems are defined by key attributes that also constitute a “boundary” (Rockström et al., 2014). Flow regime, sediment and organic matter inputs, thermal and light characteristics, chemical and nutrient characteristics, and biotic assemblages are defining attributes of freshwater ecosystems (Poff et al., 1997, Baron et al., 2002). Their natural ranges of variation are critical to maintaining the integrity and dynamic potential of aquatic ecosystems (Baron et al., 2002).

When water use drives river basins below minimum thresholds for these attributes, freshwater ecosystems become more unstable and unpredictable, and less resilient to change. Once a boundary is transgressed, freshwater ecosystems may change rapidly to a new stable condition that is very difficult to restore to previous natural conditions (Holling, 1973, Scheffer et al., 1993). Fisheries collapse and eutrophication from nutrient inputs are two examples of potentially irreversible freshwater ecosystem change.

The ecological consequences that result from depriving freshwater aquatic ecosystems of adequate water quantity, timing, and quality often become apparent only after they begin to interfere with societal uses of freshwater (Baron et al., 2002). Without reliable water supplies, freshwater ecosystems are prone to damage from shocks, with potentially grave consequences for the communities and industries that depend on them.

Human development and water Management decision-making | Water and human development are inseparable. People need water for sustenance and for basic sanitation and hygiene. Water is a key input to both food and energy production, and waterways provide a means of transferring people, food and energy from place to place. The amount and variability of water availability affects economic growth (Brown et al., 2014, Hall et al., 2014). As such, water management to preserve freshwater ecosystem productivity and resilience as well as ecosystems is a prerequisite for human development, and fundamental to attaining the Sustainable Development Goals. However, improving water management requires a substantial shift in how decisions are currently made in the water sector.


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Currently, some 1.6 billion people live in river basins with severe water stress. Under business as usual, that number is expected to increase to 3.9 billion by 2050, or over 40 per cent of the world’s projected population (OECD, 2012). Under current population and economic growth trends, by 2030 global water demand will exceed available supply by 40 percent (The 2030 Water Resources Group, 2009).

Agriculture is currently by far the largest user of water, responsible for nearly 70 per cent of fresh water withdrawals from rivers, lakes and water tables globally (FAO, 2014). However, the majority of additional water withdrawals by 2050 are expected to come primarily from manufacturing, electricity, and domestic use (OECD, 2012). A 2014 survey of 302 companies in the Global 500 index found that 82 per cent of the energy sector is exposed to water risk while 77 per cent of consumer industries that include food and beverage companies are affected (CDP, 2014).

Growing recognition of the vital threats to water for economic growth and development and the increasing costs of water-related hazards will drive major new initiatives and investments to mitigate these concerns. As a result there is an important opportunity to rethink current approaches to decision-making for fresh water use. Most industrialised settings utilise constructed infrastructure and policy approaches that rest primarily on traditional cost-benefit analyses. These conventional paradigms for water management, enshrined in institutional planning guidance and engineering education, have delivered water benefits and protection from hydrological hazards to human society for centuries, but they are no longer suitable to chart the future of fresh water management. New approaches are needed that build on sound traditional engineering planning but redirect the objectives to a focus on building resilience to changing conditions for both services and ecosystems (Brown, 2010). The transition to adaptive approaches to sustainability embedded in dynamic, variable ecosystems will prove to be a critical intellectual shift for humans this century (Matthews and Boltz, 2012).

Redirecting the efforts to provide water benefits to society beyond traditional approaches will not be easy. Yet there is a strong case for doing so. As illustrated in the previous section, withdrawing more water from ecosystems to meet human demand can actually make water availability more unpredictable and exacerbate water scarcity, undermining water resilience. Unless the water needs of freshwater ecosystems are incorporated into decision-making, it is difficult to envision how human development will be anything but negative for ecosystems. Economic-based decision-making could help spur greater efficiency in water use, but will not necessarily lead to benefits for ecosystems. One can envision a scenario where water savings from the agricultural sector flow to the energy sector or urban centres, with none of the saved water returning to ecosystems. Without due consideration for ecosystems, the human development-led agenda will lead to greater use of water, with negative consequences for freshwater ecosystems and, ultimately, for all humanity.

A path forward: freshwater ecosystem management for resilience | Sustaining and restoring ecosystems will require reducing or limiting water withdrawals in many river basins, preventing the ill-conceived construction of new dams that cause fragmentation and are not suited for adaptation to future climate and water regimes (e.g., Ansar et al., 2014, Poff and Matthews, 2013), and treating polluted water from cities and agriculture. The establishment of measurable thresholds in freshwater use and ecosystem change is vital to changing the contemporary decision-making processes that continue to lead to ecological degradation. The challenge is how to integrate the threshold concept in the context of disaggregated, local and largely political decision-making processes. Current approaches to water planning do not adequately account for the costs of overdrawing water from river basins or of disrupting natural flow regimes with hard infrastructure. These costs can be significant, particularly to the extent that they undermine a water basin's ability to adapt and respond to changing environmental conditions (Meng et al., 2014). In the long run, degrading freshwater ecosystems could actually prove more costly than implementing policies to protect them.

Recognising environmental objectives in their own right was promoted in perhaps the most influential water planning initiative in academia, the Harvard Water Program (Reuss, 2003). This program was initiated in response to the recognition that economic planning approaches used for US water projects did not reflect the national interest, which was broader than simple economic efficiency and must fundamentally include protecting the environment (Maass, 1962). The Harvard Water Program launched the field of water resources systems analysis and created multi-objective water planning which explicitly formalised the equal standing of economic and environmental objectives. Under current and future conditions of increasing freshwater stress, competing demand and ecological uncertainty, such principles of multi-objective, integrated planning are now an imperative (Brown et al., 2015).

Conclusion | Sound freshwater ecosystem management is central to human wellbeing. Water resilience is a prerequisite for human development, helping to protect and maintain the resilient ecosystems that people rely on for our most basic needs and for the success of our economies and society. Fresh water must now also be recognized as a key factor safeguarding natural capital and ecosystem services by providing water resilience. Moreover, global sustainability is now a prerequisite to achieve stable water supply at the local and regional scales. This means that investing in sustainable water use at the community, city or river basin scale cannot be done in isolation from a deeper understanding of global changes. Likewise, successful water management at the local level now depends on our ability to safeguard water resilience at the Earth system scale, i.e., ensuring that human development must take place within the safe operating space of a stable planet. This fundamentally changes the water resource management agenda – every scale of operation must relate to global dynamics. The time has come to stop framing issues of water security in terms of tradeoffs between human benefit and environmental benefit – they are interdependent. This requires a significant shift in the conventional paradigms of water management. Decision makers can no longer ignore the costs of overdrawing water from ecosystems or disrupting natural flow regimes with hard infrastructure. Rather, these costs must be internalised by promoting safe thresholds on water use and ecosystem alteration. Doing so will make freshwater ecosystems more resilient, giving us the best chance of meeting human development objectives.

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