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Aquatic Procedia 6 (2016) 99 – 105

Aquatic Procedia

www.elsevier.com/locate/procedia

World Water Week 2015, WWW 2015

People and fresh water ecosystems: pressures, responses and resilience

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Abstract

Freshwater ecosystems are central to the global water cycle, in local generation of freshwater flows, and the healthy functioning and resilience of other ecosystems. Freshwater security depends on healthy ecosystems. Current human threats to freshwater ecosystems include rapid infrastructure development and land-use change, inefficient water use and over-abstraction, and pollutants. These threats, combined with increasing demand for water resources, exacerbate the sustainable development challenge. By 2025, two-thirds of the world's population may be living in conditions of severe water stress. It is essential to find solutions that provide for the maintenance of freshwater ecosystems while meeting human needs. This paper examines responses to three pressures to freshwater ecosystems: declining ecosystem services, hydropower and urban development. It explores opportunities for improved decision-making and enhanced resilience including: better evaluation of trade-offs and interlinkages; improved monitoring; decision-making that incorporates long-term perspectives and risks; and the leveraging of crises to advance change.

Peer-review under responsibility of the Stockholm International Water Institute

Keywords: freshwater; ecosystem services; payment for ecosystem services; multidisciplinarity; hydropower; urban development; resilience

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Peer-review under responsibility of the Stockholm International Water Institute
doi:10.1016/j.aqpro.2016.06.012

1. Introduction and aims

Freshwater ecosystems including lakes, ponds, rivers, streams, springs and wetlands are home to approximately 126,000 species. In addition to being an important home for biodiversity, these aquatic ecosystems provide provisioning, supporting, regulating and cultural ecosystem services that underpin the health, livelihoods and well-being of billions of people (Aylward *et al.,* 2005). Despite their importance, freshwater ecosystems are some of the most heavily altered ecosystems on earth (Carpenter et al, 2011).

The shift to the Anthropocene, a rising population and climate change have all increased the threats to and demands on ecosystems (Vörösmarty *et al.*, 2010; Russi *et al.*, 2013). More specifically, these threats include:

- Agro-chemical runoff from agricultural and urban areas
- Loss of wetland area due to urban growth and agricultural expansion
- Overexploitation and pollution of ground water supplies for irrigation and drinking water
- Poorly planned and implemented dams
- Invasive species that kill off or reduce local biodiversity
- Poorly managed industrial and household pollution, affecting water resources and biodiversity.

The impacts of these threats are already being felt, and at increasing scales. Over 200 river basins, which are home to over 2.67 billion people, are experiencing annual states of severe water scarcity. Globally, wetlands are estimated to have declined by between 64 per cent and 71 per cent in the 20th century alone, with degradation continuing (Gardner *et al.,* 2015). Freshwater species have decreased by 50 per cent since 1970 and rivers are often deprived of flows or are heavily polluted (Gleick and Palaniappan, 2010). The Colorado, a principal river of the United States, suffers from invasive species, point source pollution and over-extraction (Kennedy *et al.,* 2013; Jones-Lepp *et al.,* 2012). In China, the Chinese Academy of Sciences estimates that 43 per cent of surface water is polluted beyond use (Liu and Yang, 2012) with one study finding that roughly 28,000 rivers have disappeared across the country in the last few decades – due in part to uncontrolled and unsustainable water extraction for industry and agriculture (Hsu and Miao, 2013). Meanwhile, Wang *et al.* (2011) highlight China's heavy reliance on irrigated agriculture, which has caused groundwater abstraction to increase from 10 km^3 per year in the 1950s to more than 100 km^3 per year by the 2000s. The over-extraction of groundwater in the Central Ganga Plain in India is also having significant social and environmental consequences (Ahmed *et al.,* 2014). These limited examples demonstrate the scale of the challenge, and the need for innovation, scientific support, and changes and improvements in behaviour, institutions and technologies governing the relationship between people and freshwater ecosystems.

For the earth to be a sustainable home for an estimated 9.7 billion people by 2050, and to cope with increasing demands for water, food, minerals, energy and fibre, we require a fundamental shift away from business as usual. This paper draws from presentations given at the 2015 Stockholm World Water Week workshop on Freshwater Ecosystems and Human Development organized by the CGIAR Research Program on Water, Land and Ecosystems (WLE), the International Union for Conservation of Nature, the Rockefeller Foundation and the Stockholm International Water Institute. The aim of this workshop was to explore the broad spectrum of benefits derived from ecosystems, the costs of human activity on these ecosystems, and the possible solutions and trade-offs associated with the sustainable management of ecosystems. This short paper explores three examples of potential threats and solutions for freshwater ecosystems as they relate to human development. First, it discusses advances in payment for ecosystem services (PES) as a potential solution to protect freshwater ecosystems. Second, it looks at the challenges and solutions for ecosystem management in urban areas. And third, it analyzes the threats and opportunities of hydropower development. It should be noted that this paper does not provide a complete list of the tools, approaches and challenges covered in the workshop, nor is it an attempt to provide a comprehensive review of the extensive literature available on freshwater ecosystems and human development (*c.f.* Aylward *et al.,* 2005).

2. Payment for ecosystem services

Payment for ecosystem services, along with varying non-structural, demand-side management approaches that target behaviour change, has evolved over the last few decades to become an effective way to manage natural resources and especially freshwater (Pagiola *et al.,* 2002; Sachs, 2015). PES schemes have been criticized for their commodification of natural capital and for failing to adequately account for the full value of ecosystems in complex systems. A number of successful examples exist, however, where strong enabling conditions and supporting governance frameworks have been developed (Salzman, 2005).

Agriculture remains one of the largest contributors to nonpoint source (NPS) pollution, causing significant impact on lakes and rivers around the world (Conway and Pretty, 2013). PES schemes offer opportunities to reduce NPS pollution, especially N or P runoff. To overcome the challenge of measuring nutrient losses from fields, Winsten (2015) has developed a tool to model losses at the farm and watershed levels to trigger incentive payments. This approach, when applied to case studies in Vermont and Iowa, has reduced P loss by 0.269 kg and 0.988 kg respectively per hectare per year.

Cassin *et al.* (2015) have developed a framework for assessing the multiple values provided by watersheds and freshwater ecosystems. This framework applies a holistic approach to identifying beneficiaries, and the most valuable ecosystem services in watersheds to be evaluated, in a variety of ways including through scientific and traditional knowledge and data. When the framework is applied to different development scenarios, it is possible to see how benefits and costs are distributed, and how to improve decision-making and demand-side management to enhance freshwater ecosystem services. Water funds that create opportunities for downstream users to pay upstream users to protect the ecosystems and water used downstream have also shown promise in improving water management, ecosystem functions and livelihoods in Peru and Kenya (WLE, 2014; MINAM, 2014).

The US and Australia have experimented with the use of water markets to maintain or restore freshwater ecosystem services in over-allocated rivers and aquifers. This has met with some success when public and private organizations acquire water entitlements from irrigators to enhance environmental flows (Garrick *et al.,* 2009). The Columbia Basin Water Transactions Program is one prominent example of this trend. Since 2003, the programme has restored habitat for salmon by retiring or reducing irrigation diversions to increase instream flows in the Pacific Northwest US − enhancing stream flows by approximately 24 m^3 per second (CBWTP, 2014). However, these examples have only been possible with significant financial support and capacity building across multiple levels of government coupled with sustained engagement by a range of stakeholders in collaborative planning and decision-making, including with recreational, environmental and indigenous groups (Garrick, 2015).

Researchers from the CGIAR Research Program on Water, Land and Ecosystems have found that incorporating stakeholders' concerns and finding the right incentives, institutional mechanisms and monitoring regimes for effective PES schemes is important for their success, but also highly complex and resource intensive (Suhardiman *et al.,* 2013). This is especially true where stakeholders use freshwater in different ways, such as for recreation, as a key part of the supply chain for private-sector beverage companies, for agriculture or drinking water or for sanitation in cities and towns. In addition, PES requires competitive market structures, appropriate regulations and enforcement; otherwise, they can potentially be used as tools for strengthening state control over natural resources instead of helping to improve governance (*ibid*).

3. Urban areas and ecosystems

Urban populations are expected to grow from approximately 3.7 billion today to nearly 5 billion by 2030, accounting for 90 per cent of future population growth. This growth has the potential for profound negative impacts on ecosystems, with urban land cover increasing by 1.2 million km^2 (Seto *et al.,* 2012). Rapid and expansive land cover change will increase carbon emissions and destroy key habitat areas for biodiversity (*ibid*). In addition to terrestrial systems, this expansion of urban areas also represents a significant threat to freshwater ecosystems.

Effluent from wastewater treatment plants, for example, can represent up to 70 per cent of the flow of urban rivers, leading to increased nutrient loading and eutrophication (Brooks *et al.,* 2006; Gücker *et al.,* 2006). Anthropogenic litter represents another significant threat to urban ecosystems, especially with growing consumption patterns of a larger middle class (Hoellein *et al.,* 2014).

With increasing urbanization, peri-urban areas are hot spots of intensification but can also buffer the urban footprint. A recent study carried out by WLE and the International Water Management Institute (Thebo *et al.,* 2014) estimated that 456 million ha of farmland can be found within a 20 km radius of urban centres – an area about the size of the European Union. The authors also showed that the ratio of irrigated farmland to rainfed production is especially high closest to these cities. This reflects strong intensification, which is often driven by the informal sector and can result in uncontrolled trade-offs and challenges of intersectoral water competition, including groundwater over use (Molle and Berkoff, 2006; Foster and Vairavamoorthy, 2013) and food safety concerns due to poor sanitation and the use of polluted water for irrigation (Raschid-Sally and Jayakody, 2008).

Cissé *et al.* (2015) highlight the need to better understand the benefits wetlands accrue to urban freshwater ecosystems. These benefits include supporting diverse livelihoods, mitigating the impacts of flooding and providing a rich habitat for biodiversity. Preserving urban wetlands from encroachment and restoring degraded or lost wetlands will contribute to Sustainable Development Goal (SDG) 6 and a number targets including Target 14.2 on 'Sustainable management of marine and coastal ecosystems' and 15.1 on 'Protection, restoration and sustainable use of terrestrial and freshwater ecosystems'. Complementary to these findings, in India, the importance of ecosystem-based adaptation supported by strong institutional mechanisms and political will has been found as essential to effective integrated water resource management in cities (Kumar, 2015). Enormous opportunities for protecting freshwater ecosystems in urban areas through wetland management and ecosystem-based adaptation exist in both India and Africa. The Government of India, for example, has allocated USD 1.2 billion in the fiscal year 2014–15 to build 100 new 'smart cities', and Africa is home to thousands of wetlands within its 60 international river basins. These basins and wetlands are key providers of ecosystems services and are home to 77 per cent of the continent's population.

4. Hydropower

Hydropower produces approximately 16 per cent of the planet's electricity and is a rapidly growing industry (IHA, 2015). In 2014, 37.4 GW of new installed capacity were added, bringing the total installed capacity to 1,036 GW (IHA, 2015). Globally, hydropower is expected to double by 2050, bringing with it the construction of thousands of new dams (Zarfl 2015). In the Amazon River Basin, if the current trajectory of 277 planned dams is realized, there will be only three free-flowing tributaries in the next few decades (Castello and Macedo, 2015). The Mekong River Basin is also undergoing a rapid expansion with 91 hydropower dams planned, 39 under construction and 60 complete (GMDD, 2015; Matthews and Geheb, 2014).

Hydrological connectivity regulates the structure and function of global river systems. Ecosystem services provided by healthy connected rivers include water quality, climate and flow regulation, food and fibre production, and nutrient and carbon cycling. Small hydropower plants, between 10 and 50 MW, are often portrayed as having fewer and less severe environmental and social externalities than large hydropower plants. However, Kibler and Tullos' (2015) evaluation of the relative cumulative impacts of small and large hydropower plants in China's Nu River Basin, found that in some instances small dams can have greater cumulative biophysical impacts than large dams. This finding is important because small dams in the Mekong region, and elsewhere, are often not held to the same environmental protection standards as large dams. Dams in China, Thailand and Laos, for example, do not require full environmental impact assessments if their storage reservoirs or megawatt capacity is below certain thresholds (Gao, 2014). Importantly, however, according to Kibler and Tullos (2015), small dams can offer more manageable opportunities to mitigate impacts.

Whether large or small, hydropower associations and developers are attempting to respond to critics by making significant efforts towards sustainability; for example, the International Hydropower Association's 2015 World Hydropower Congress theme was 'advancing sustainable hydropower'. All energy development has trade-offs, however, and equitably sharing the benefits and trade-offs of hydropower in both local and transboundary contexts has proved a challenge for developers and governments. A significant proportion of the new hydropower being developed and planned around the world is driven by the private sector, and this brings its own challenges and opportunities. Apart from providing much-needed funding where state resources are scarce, private-sector developers often bring efficiencies and innovation to projects. However, they may also be more profit focused and, due to business norms, less transparent than state-funded projects. To ensure that the new era of hydropower currently being planned and constructed learns from the past, a change from business-as-usual approaches to dam development will be required. Environmental justice, nexus and political economy approaches can be important lenses to better understand the drivers and enablers of construction, who stands to win and lose from hydropower development over both the short and the long term, and to illuminate the benefits and costs of disrupting interconnected river and ecological systems (Zeitoun *et al.,* 2014; Matthews and Motta, 2015). Scientists must find better ways to communicate complex multidisciplinary research and influence decision-makers across both the private and public sector. Perspectives from ecology, freshwater science, social science including gender, economics and policy, and local knowledge are all needed to sustainably guide the design, location and operation of future dams.

5. Conclusions and recommendations

The challenge of protecting our freshwater ecosystems and ensuring that humans develop sustainably requires a diversity of natural capital (Guerry *et al.,* 2015). Ignoring the threats to our freshwater ecosystems will amplify risks to human development and ultimately undermine prosperity. A range of interdisciplinary solutions that encompass policy, science, governance and tools are required to manage the complex interconnected nature of ecosystems and human development (*c.f.* Ledford, 2015). Although its importance is already acknowledged, it must also be recognized that interdisciplinary research is multifaceted and often more time consuming than standard approaches. Finding ways to operationalize interdisciplinary thinking is another challenge, and there is need for more effective tools and approaches to help decision-makers balance trade-offs, manage and reduce systemic risks, and accommodate uncertainty, especially in a rapidly changing climate (Grafton *et al.,* in press).

The pressures and responses to declining freshwater ecosystems presented in this paper highlight critical areas where research can inform decisions and enhance resilience. Political will at all levels is also an essential factor that allows for multiple objectives to be included in policymaking. Capturing political windows of opportunity can provide leverage points to influence change. In resource management, these windows include disruptive and often serious events such as floods, droughts or shifts in governments. At the global level, the SDGs provide an opportunity to set a common framework and dialogue surrounding sustainable growth that demonstrates the linkages between human development and ecosystems and demonstrates the importance of freshwater from local to global scales

Solutions to protect and sustainably manage ecosystems include payment for ecosystem services, protecting or building natural infrastructure such as wetlands, and mitigating and better understanding the impacts and trade-offs of grey infrastructure including hydropower dams. To ensure that ecosystems are valued in decision-making, we must influence a wide range of decisions-makers. This includes farmers, who manage much of the world's water resources, and politicians and consumers who through their purchase power can shift companies to be more sustainable. Furthermore, it is essential that women, men, youth, disadvantaged groups and the environment all have a voice at the decision-making table.

Solutions must also incorporate the private sector as this will be essential for the scaling up and sustainability of tools and approaches. Businesses, supported by governments and researchers, need to account for and value natural capital within a systems approach. Finding more ways to engage the private sector is a key task for researchers. Effective monitoring, communication and engagement are also essential. As stated by Posner *et al.* (2016), when examining research surrounding ecosystem services, the legitimacy of knowledge is more important than its credibility for creating impact. In order to enhance legitimacy, researchers need to use more research-for-development approaches that engage decision-makers from the start of the research process and ensure transparency (*ibid*). As the importance of ecosystems becomes more widely recognized and their protection becomes more deeply incorporated into decision-making, there may be opportunities to shift our thinking away from environmental impact assessments towards environmental opportunity assessments.

Acknowledgements

Many thanks go to Dustin Garrick, Pay Drechsel, Matthew McCartney, two anonymous reviewers and the editors for their helpful comments and suggestions.

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