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Editorial

Introduction to the special issue: Understanding and linking the biophysical, socioeconomic and geopolitical effects of dams

1. Introduction

Dams have made important contributions to human development, and the benefits derived from them have been considerable (World Commission on Dams, 2000). With the rising global population and desire to increase quality of life, dams are prominently staged to deliver hydropower, irrigation and drinking water supplies, recreation, navigation, and many other resources to the growing planet. Further, the uncertainty of the future climate regime may mean that dams will play an increasingly important role in water resources. For example, it is predicted that drought-affected areas will likely increase in extent and flood risks will be augmented in response to increased frequency of heavy precipitation events (IPCC, 2007), the effects of both of which may be ameliorated by dams. Thus, the construction of new dams, while in decline in the United States since the 1970s (US Army Corps of Engineers, 1996), may see a renewed intensity both at home and abroad.

At the same time, dams are increasingly slated for removal, reflecting a growing concern over their adverse ecological, social, and economic impacts (Pejchar and Warner, 2001). Aging structures, which can pose a risk to public safety, are increasingly removed under new policies and funding sources to support removal projects (Heinz Center, 2002). Dam removal is also emerging as a promising option for restoring continuums and reconnecting habitats for migratory fish species, including anadromous salmon, that are federally listed as threatened or endangered in the United States (Gregory et al., 2002). However, there is a great deal of uncertainty about the consequences of dam removal (Aspen Institute, 2002; Hart et al., 2002), particularly the unknowns related to the extent, magnitude, and timing of physical and ecological outcomes (Heinz Center, 2002; Hart et al., 2002).

Thus, dams are a crucial issue for resource managers, scientists and policymakers. To advance the knowledge about and inform the management of dams, this special issue of the *Journal of Environmental Management* presents cutting-edge research in various academic disciplines and proposes new multi-disciplinary approaches for understanding and predicting how dams and dam removals affect societies and ecosystems. The goal of this collection is to offer guidance for and provoke conversations about the interdisciplinary nature of dams. The idea for the special issue was conceived at a symposium, held in April of 2007 at Skamania Lodge on the Columbia River in Washington State, USA, which brought together scientists and resource managers to discuss the effects of dams on social and ecological systems. Many of the authors whose work is included in this special issue participated in the symposium and shared with us the recognition that, while various scientific fields have developed their own specialized theories and methods for assessing the impacts of dams, no comprehensive effort to understand dams from a holistic, interdisciplinary perspective yet existed. The papers included in this special issue, which represent three key thematic areas (biophysical, socioeconomic, and geopolitical) associated with sustainable development (United Nations Committee on Economic Development, 1993) are a step toward achieving this goal.

In this brief introductory paper, we discuss the global distribution and significance of dams in today's world and discuss the three thematic areas included in this special issue.

2. Dams in historical and global context

Existing records indicate that dams were first built in Jordan around 4000 BCE. The earliest known dam remains, from the Sadd El-Kafara earthen dam in Egypt, are dated to 2600 BCE (Schnitter, 1994). Romans built the first concrete and mortar dams around 100 AD, followed by arch dam construction in Mesopotamia around 1280 AD. By the 1600s, the Spanish were leaders in dam construction, and they brought their knowledge and expertise with them to the New World, a milestone in the global spread of river regulation.

With rapid economic development, increasing demand for electrical power, and governmental support for large public works projects, dam construction reached its peak in the latter half of the 20th century. Current figures indicate that 50,000 large dams, which the International Commission on Large Dams defines as those greater than 15 m in height or having a storage capacity greater than 3 million cubic meters, exist in the world today (World Commission on Dams, 2000; Scudder, 2005). Dams are now a ubiquitous part of the landscape in many parts of the world; a digitally georeferenced database of all dams and reservoirs worldwide, which is being developed as part of an ongoing research effort, illustrates this ubiquitous and often dense distribution of dams and reservoirs (Fig. 1).

Among the large river basins of the world (those with a historical mean annual discharge of greater than 350 $m^3 s^{-1}$, of which there are 292), nearly one half (139 of 292) remain unfragmented by dams on their main channels (Fig. 2), and more than one-third (102 systems) remain unfragmented on both the main stem and major tributaries (Nilsson et al., 2005). At the continental scale,

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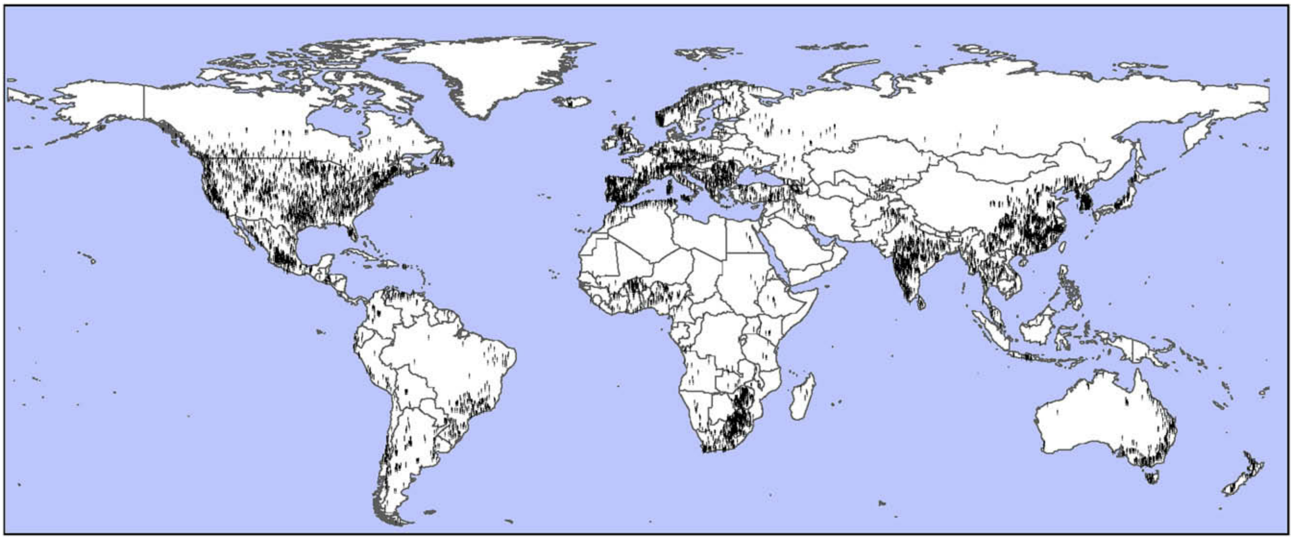

Fig. 1. Distribution of dams and reservoirs that have been digitally georeferenced as part of an ongoing collaborative development of a comprehensive global database on dams and reservoirs Lehner et al. (unpublished data).

North and Central America have the greatest number of unfragmented basins remaining (35), while the greatest proportion of free-flowing large river systems remains in Australasia (74%). North and Central America, along with Europe, feature heavily regulated river systems; 12 major river basins on these two continents have less than 25% of their main channel lengths remaining free-flowing.

Dams provide the opportunity to harness water for a variety of human uses, including irrigation, flood control, household and commercial consumption, recreation, and navigation. Human beings thus have the capability to heavily use—and sometimes seriously over-exploit—water resources. Of the world's 292 large river basins, there are at least six in which reservoir storage exceeds the annual discharge: Manicougan, Colorado, Volta, Tigris-Euphrates, Mae Khlong and Rio Negro (Nilsson et al., 2005). Another 14 major rivers are so heavily regulated that more than 50% of their annual flow is diverted for reservoir storage and use. Several of the world's great rivers, including the Colorado, the Nile, and the Yellow, no longer reach the sea year round.[1] Thus, the distribution of global dams is broad and the impacts of dams on the world's rivers are profound, demonstrating the critical need for understanding how biophysical, socioeconomic, and geopolitical impacts interact over time and space.

3. Thematic areas in the special issue

There is a rich literature on the effects of dams (see thematic reviews from World Commission on Dams) and case studies of dam removals are being reported at an increasing frequency (See *BioScience* special issue, 2002). We believe that the concepts and information on dam impacts represented in this literature are appropriately framed around the three themes (biophysical, socio-economic, and geopolitical) associated with environmental and social sustainability as defined by the 1992 United Nations Conference on Environment and Development (United Nations Committee on Economic Development, 1993). Contributors to this special issue have focused their scholarship on these three key thematic areas.

3.1. Biophysical

Dams affect biophysical systems primarily by altering the hydrograph of a river and by fragmenting river systems (Kotchen et al., 2006). These primary effects in turn impact sediment load and riverbed morphology (Yang et al., 2006); soil salinity and quality; species composition of riparian areas, including the proliferation of invasive species (Mumba and Thompson, 2005); the health and viability of aquatic biota (Kingsford, 2000); and water quality and disease burden in human populations (Lerer and Scudder, 1999).

To better understand these biophysical impacts and how to minimize them, Tullos (2009) evaluates how large dam impact minimization has both contributed to and benefited from the introduction and subsequent improvements in the Environmental Impact Assessment (EIA) process. In presenting an analysis of the EIA process for the Three Gorges Project (TGP) in China, this case study attempts to evaluate the feedback between the EIA, science, and policy. Results indicate that the availability, consistency, and uncertainty of scientific information limits the projection of environmental impacts, and that a lack of direct feedback between the EIA process and emerging science challenges the environmental sustainability of TGP post-construction. This work highlights important institutional changes that need to occur to improve the environmental sustainability of large dams, including the integration of scientific research and environmental compliance into the management strategies for dams.

Burke et al. (2009) apply a process-based, hierarchical framework to evaluate environmental impacts of dams on the Kootenai River in the United States. By investigating the relative effects of two dams and the operation strategies, including environmental flow releases, of those dams over time and space, these investigators were able to mechanistically describe and quantify environmental impacts of dams, simultaneously isolating and linking biophysical impacts of large dams. This framework is valuable for river managers around the world because it provides a powerful tool for assessing the operational impacts of dams on physical processes and consequent ecosystem function.

Schmitz et al. (2009) also linked physical and biological processes through investigations of a dam breach and removal in Montana. Using paleoflood hydrology, hydrologic modeling, and aerial photo interpretation, these investigators documented the corresponding channel and vegetation adjustments. This work

[1] At the other end of the flow regulation spectrum, reservoir storage in the Amazon–Orinoco is only about 3% of the mean annual discharge.

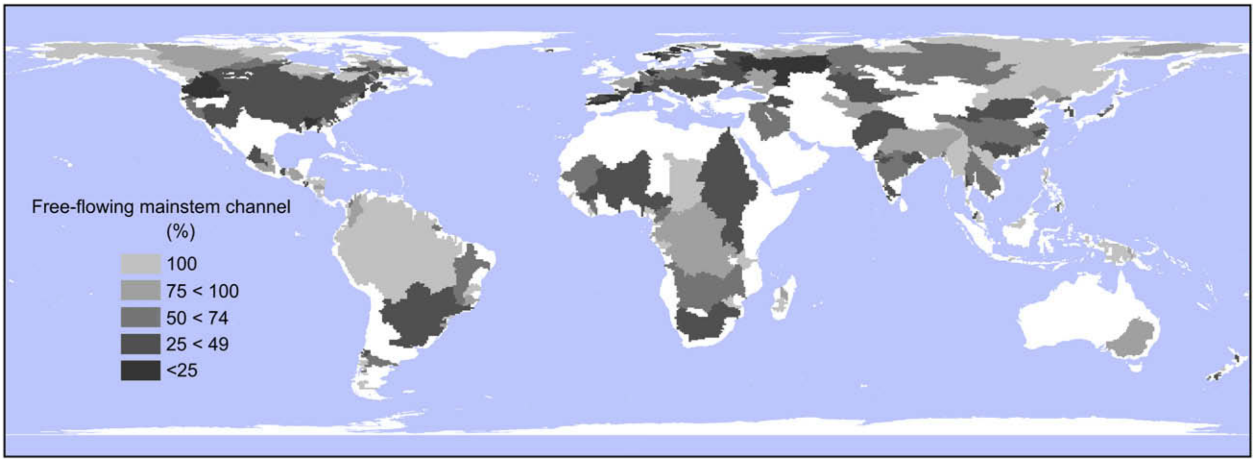

Fig. 2. Distribution of main stem fragmentation by dams among the world's 292 large river systems. White areas represent river systems excluded for size or lack of data.

demonstrates the utility of paleohydrology and aerial photography as tools for integrating biological and physical responses to dams and dam removals, providing a critical perspective on how these responses are integrated over time.

3.2. Socioeconomic

Because dam projects are often used as tools for development, their socio-economic impacts on human communities, both intentional and unintentional, can be substantial (Egre and Senecal, 2003). International interest in the socio-economic effects of dams is on the rise among scholars and policymakers, as evidenced by the growth of organizations such as the World Commission on Dams and the International Rivers Network. Socio-economic impacts of dams include migration and resettlement (Bartolome et al., 2000), changes in household size and structure (Lerer and Scudder, 1999), changes in employment and income-generating opportunities, alteration of access and use of land and water resources; changes in social networks and community integrity (Fuggle and Smith, 2000), and often a disruption of the psychosocial well being of displaced individuals (World Commission on Dams, 2000). Managing and mitigating the negative socio-economic impacts of dam construction is an important task since, as the World Commission on Dams noted in its seminal report, these effects are "spatially significant, locally disruptive, lasting, and often irreversible" (World Commission on Dams, 2000, p. 102).

The papers included in this thematic area address some of the complex human issues involved in dam construction and removal. Tilt et al. (2009) use the tool of social impact assessment to examine the effects on human communities from two recent large-scale, international dam projects: the Lesotho Highlands Water Project in Lesotho, southern Africa, and the Manwan Dam in China's upper Mekong basin. Their analysis suggests that social impact assessment should be used as a tool not simply to evaluate or predict dam impacts, but also to facilitate the participation of key stakeholders in the decision-making processes related to dam design, siting, and construction.

Both Bohlen and Lewis (2009) and Wyrick et al. (2009) focus their attention on the socio-economic impacts of dam removal, a practice that is seeing an increasing trend in the United States (Heinz Center 2002). Wyrick et al. (2009) discovered important concerns among residents living adjacent to several small dams scheduled for removal in New Jersey. Although these dams presented a safety hazard and structural repairs would be prohibitively expensive, residents voiced a number of concerns about removing the dams, including the potential for aquatic habitat loss, impacts to wildlife, increased flooding risk, and declining property values. Using hydrological models, the researchers determined that dam removal would actually result in minimal effects on the hydrology and biology of the stream corridor. Their study points to a significant information gap between scientists, policymakers, and property owners.

Using geographic information systems (GIS) and hedonic property value analyses, Bohlen and Lewis (2009) examine the complex relationship between hydropower dam location and nearby residential property values on the Penobscot River in Maine, where a basin-wide restoration effort includes plans to remove two dams and decommission a third. Their analysis suggests that property values may be impacted by dam removal, but that this effect is mediated by a host of other variables. Consideration of the social and economic impacts of dam building or dam can complement studies of the ecological impacts of the practice. Ultimately, policymakers have to balance the perceived ecosystem and economic benefits associated with dam removal—including habitat restoration and benefits to migratory species—with other potential economic impacts on residents and communities.

3.3. Geopolitical

Geopolitical issues associated with dams range from the unequal and unfair distribution of costs and benefits (Bocking, 1998), to transboundary water concerns (Wolf, 2000), and public participation and governance. Reviews (Waterbury, 1979; McCully, 2001; Scudder, 2005; Wolf, 1994) of the geopolitics of dams emphasize the importance of hydropolitics, and problems often arise when politics are not considered equally with other factors associated with dam development (Okidi, 1987).

Meierotto (2009) examines the role of advocacy groups, including NGOs, in the decision-making processes behind large dams, with a focus on the Talo Dam in Mali. Significantly, much of this advocacy—both for and against the dam—came from transnational groups that were somewhat removed from the experiences of the people whose lives would be most affected by the project. Despite the current focus of most international development organizations on community-based participatory development, Meierotto's work reminds us of the complexities involved in achieving this goal.

McNally et al. (2009) analyze the roles of policy and institutions in hydropower development in China, which involves a complex array of state agencies and corporate entities. Using the ecological concepts of resilience and vulnerability, and adapting them for institutional analysis, they assess China's capacity for dealing with water resource management in a sustainable way. Their findings have implications not only for China's watersheds but also for transboundary rivers elsewhere.

Funding sources for large-scale infrastructure projects in the developing world are increasingly diffuse. McDonald et al. (2009) explore the role of Chinese funding and expertise in the construction of Sudan's Merowe Dam, one of Africa's largest dam projects. In contrast to the World Bank and other multilateral development organizations, Chinese dam builders have yet to adopt internationally accepted standards for assessing and mitigating the social and environmental costs of dam construction projects. The authors suggest that, given China's current involvement in dozens of large-scale dam projects worldwide, this has important implications for human rights, global finance, and environmental sustainability.

4. Toward a new synthesis

Clearly, these three themes do not act independently. For example, the biophysical impacts of dams often affect society by disrupting existing cultural and economic institutions (Goldsmith and Hildyard, 1986; Cernea, 1999; Scudder, 2005), and it is known that the most socially benign dams are those with the least environmental impacts (Ledec et al., 1997). As Ledec et al. suggest, "There exist various quantitative, easily calculated indicators which can be used to estimate the extent of adverse environmental and social impacts for any proposed hydroelectric project" (Ledec et al., 1997). However, natural and social scientists have traditionally worked independently to study how dam construction changes each of the three components. While useful data has been produced in these studies, this reductionist approach has not been sufficient for documenting the interconnected nature of biophysical, socioeconomic, and geopolitical effects. What is needed now is a collaborative, holistic approach to study the integrated effects of dams, particularly how the synergistic relationship among these three components impact river communities.

Such an approach is not a simple endeavor. While the impacts within each theme may be well-defined conceptually, many are not directly measurable. Across disciplines, we see differences in spatial scales (e.g. watershed vs. powershed vs. tradeshed), time scales for change (i.e. ecological change is slow relative to economic change), data types and availability, and indicators (e.g. values, covariance, and relevance), and organizations (i.e. individuals, formal and informal organizations, cultures, societies, and ecosystems). In an effort to simultaneously evaluate the biophysical, socioeconomic, and geopolitical costs and benefits of dams, Brown et al. (2009) present the Integrative Dam Assessment Modeling (IDAM) tool. The IDAM tool evaluates each of 27 different impacts (9 from each of the three thematic areas) of dam construction both objectively (e.g., flood protection) and subjectively (i.e., policymakers' valuation of said flood protection). By providing a visual representation of the various costs and benefits associated with two or more dams, the IDAM tool allows researchers to investigate basic questions regarding distribution of impacts and decision-makers to evaluate design and operation alternatives and to articulate priorities associated with a dam project, making the decision process about dams more informed and more transparent. Such a tool can be useful for developing recommendations as a collaborative and multi-disciplinary approach by which all three thematic areas (biophysical, socioeconomic, and geopolitical) are simultaneously judged.

In closing, decisions about dams potentially involve very high stakes, and can result in undesirable changes and outcomes that are irreversible or extremely difficult to reverse (Whitelaw and Macmullen, 2002). Current decision-making about dams often relies on incomplete, fragmented information from various scientific disciplines. By synthesizing existing knowledge, documenting new observations, and proposing new tools, we present this special issue as a collection of information to assist scientists, policymakers and resource managers as they assess the costs and benefits of dams across communities and ecosystems.

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