Pursuing Sustainability and Finding Profits: Integrated Planning at the System Level

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Abstract
The concept of sustainable hydropower has received a great deal of attention in recent years due to rising concerns about climate change and the hydropower industry's desire to improve its environmental and social performance. Several sustainable hydropower guidelines or frameworks have been developed, primarily directed at assessing or improving the design or operations of single hydropower dams. While project-scale improvements are important, we suggest that the greatest advances in sustainability can only be achieved at a system scale. Here we describe a system-level approach that integrates planning for hydropower, other water management sectors, and conservation of environmental and social resources. For already developed basins, such integrated planning can identify opportunities for restoring the ecological integrity of rivers with minimal reductions in power generation, or even increases in power generation. Within basins poised to undergo hydropower development, this integrated planning approach seeks to identify an optimal spatial arrangement of dams that achieves power generation targets while maintaining important environmental and social resources. Through this process, conservation is accomplished primarily through the protection of the most valuable sub-basins and reaches. In addition to providing meaningful conservation, we propose that this approach holds several benefits for hydropower proponents, including reduced controversy, risk, and operational constraints (e.g., environmental flow requirements) for individual projects that proceed through this framework. Further, these approaches can potentially yield outcomes that approach a standard that the public is increasingly demanding from hydropower—a renewable energy source that doesn't compromise important riverine values. We provide several case studies where integrated planning has yielded these multiple benefits, and use these cases to propose a framework for hydropower that is sustainable at the system scale.

Introduction
The environmental and social sustainability of hydropower is receiving increased scrutiny recently for several reasons. The growing awareness of the potential impacts from climate change has spurred a great deal of interest in low-carbon forms of energy, including renewables such as wind, solar, and geothermal. Hydropower's place among these renewable forms of energy is a matter of considerable debate, in part because of the often significant environmental and social impacts that hydropower dams can cause. These impacts have been documented by a variety of sources and were summarized in the World Commission on Dam's report, *Dams and Development* (WCD 2000). Dam-related impacts are a cause of concern because of the high rates of endangerment of aquatic species and habitats, which are considerably greater than those within terrestrial or marine ecosystems (Ricciardi and Rasmussen 1999, Richter et al. 1997) and because rivers and riverine wetlands provide significant ecosystem services to human communities throughout the world (Brauman et al. 2007, Costanza et al. 1997).

In response to these collective concerns, many organizations—both within and outside the hydropower industry—are now working to examine and define standards and policies for sustainable hydropower (Bratrich et al. 2004, International Hydropower Association (IHA) 2006). In this paper, we offer our perspectives on how the relative sustainability of hydropower projects—both existing and those yet built—can be improved. Our central theme is that sustainable hydropower *can only be assessed and pursued at large spatial scales*, such as a basin, region and/or energy system. First, the degree of impact of an individual project can only be meaningfully understood within the context of cumulative and aggregate impacts within the region or basin. Further, while some hydropower impacts can be minimized or mitigated at the scale of a single project, other important impacts cannot be minimized or mitigated at that site and must be offset elsewhere. Moreover, we suggest that adopting a large scale of assessment and implementation holds the potential for considerable benefits for developers of hydropower projects, including greater certainty during the review process, reduced constraints for project operation, and increased opportunity for innovative solutions that can improve profitability.

Environmental and social impacts of hydropower

The environmental and social impacts of hydropower projects have been described thoroughly elsewhere (Postel and Richter 2003, World Commission on Dams 2000) and thus we present only a brief review here. While impacts can be divided into environmental and social categories, these categories are highly intertwined. For example, the loss of floodplain inundation patterns affects both ecosystems and human communities dependant on floodplain fisheries. Here, we describe impacts affecting *connectivity, upstream resources,* and *downstream resources.*

1. Connectivity. Hydropower dams and reservoirs affect the downstream transport of sediment, wood and nutrients and disrupt the up- and downstream movement of organisms, including fish and invertebrates (March et al. 2003). Dams can either be complete barriers (e.g. the 168 m tall Grand Coulee Dam on the Columbia River blocks all fish passage) or partial barriers—dams with fish passage facilities can still exact considerable mortality on fish moving both up and downstream and/or may be impassable at some flow levels (National Research Council 1996). Further, some fish species, such as the extremely rare Mekong giant catfish, are unable to use fish ladders (Hogan et al. 2004). Declines in fish populations can negatively affect human communities, both up and downstream, that rely upon migratory fish for food.

2. Impacts to upstream resources. The impacts to upstream resources have often received the most attention in debates about dam development. The flowing, dynamic, and variable aquatic habitat of a length of river upstream of the dam is replaced by a flatwater reservoir that provides habitat features that favor a different biological community. The reservoirs behind large dams can inundate agricultural land, and natural ecosystems such as wetlands and forests. The displacement of human communities has been perhaps the most controversial impact of large dam development. Displacement by dams raises serious questions of equity as those displaced are often poor and lack political strength.

3. Impacts to downstream resources. While traditionally receiving less attention than the upstream resources affected by impoundment, dam impacts to downstream environmental resources are often far greater than the upstream impacts. Because human livelihoods and communities are often directly tied to functioning river ecosystems, these downstream environmental impacts can also have considerable social costs as well.

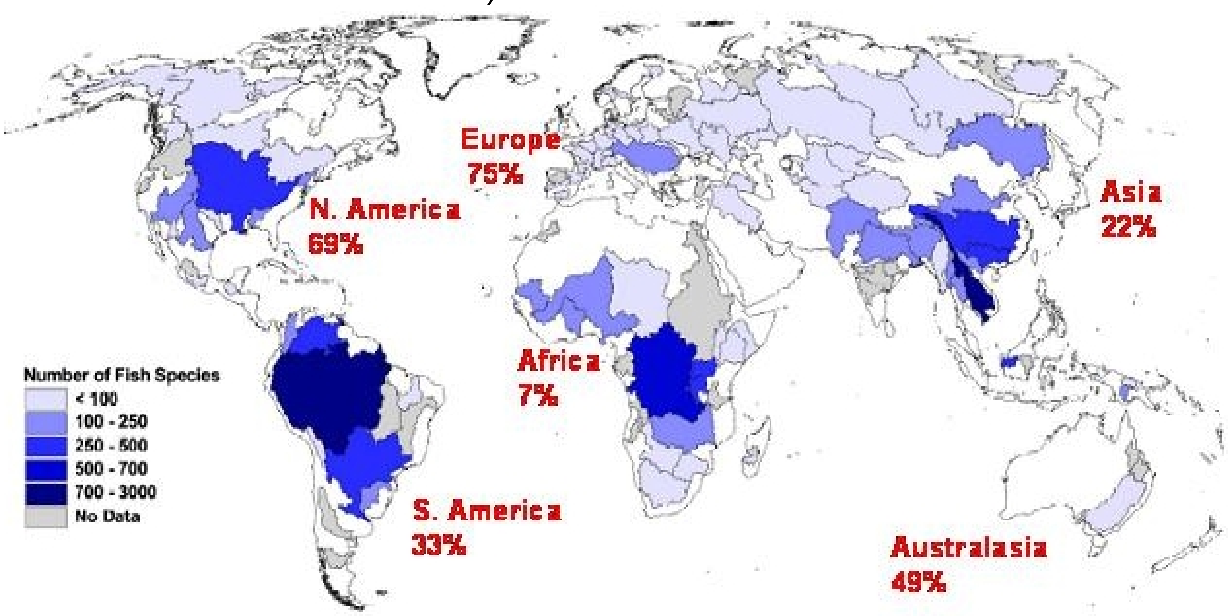
Large reservoirs can trap nearly all sediment, except for the smallest sizes, and even small reservoirs can trap much of the larger sediment in transport (e.g., cobbles and gravels). This disruption of sediment transport processes can lead to channel incision and isolation of the river from its floodplain (Ligon et al. 1995). Reservoirs can release water that differs markedly in terms of temperature and turbidity from the conditions under which native fish communities successfully feed, reproduce and avoid predators.

Reservoirs capable of storing a large volume of water can significantly alter the flow regime downstream of a dam. The flow regime can be viewed as a ‘master variable’ that structures river ecosystems—affecting channel morphology, water quality, and ecological processes—and thus disruptions to the flow regime can have serious consequences for river ecosystems (Bunn and Arthington 2002). For example, fish behaviors for reproduction and migration are often triggered by changes in the flow regime, such as floods, and so dam-induced changes to the magnitude, timing, or frequency of flood events can therefore influence fish population dynamics and broader biotic community structure (Poff et al. 1997). Hydrological alteration, largely caused by dams, is one of the primary threats to freshwater ecosystems and their species (Postel and Richter 2003, Richter et al. 1997). Hydrological alteration also affects human communities that depend upon functioning ecosystems. For example, In the Mekong River basin, 55 million people depend upon floodplain fish as primary source of protein (Coates et al. 2003) and the productivity of this fishery is threatened by both hydrological alteration caused by dam construction and the barriers to migration that would reduce or prevent successful spawning.

Current and future distribution of hydropower

The extent to which regions have been developed for hydropower varies greatly across the world from Europe and North America, which have developed a relatively high proportion of potential hydropower, to regions that have developed a comparatively low proportion of hydropower potential, including South America, Asia and Africa (Figure 1). The regions that currently have developed a low proportion of hydropower—and therefore will be at the center of future hydropower development—tend to be those places with the most intact river ecosystems and highest aquatic biodiversity. These are also the regions where human communities tend to rely most directly on the services provided by functioning ecosystems. Indeed, much of the debate about hydropower development centers on rivers in Asia (Mekong, Salween, Yangtze), Latin America (Brazil), and Africa (Dudgeon 2000, Fearnside 2006, WWF-International). River basins within these regions contain the highest diversity of fish species in the world (Figure 1).

Figure 1. The proportion of economically feasible hydropower potential that has been developed (red percentages, estimates from the International Hydropower Association) and the distribution of fish species diversity within major river basins (from IUCN Water Resources eAtlas and World Resources Institute).



Approaches for defining sustainable hydropower

The size of a project, usually defined by generation capacity, has often been used as a simple criterion for differentiating sustainable or 'low impact' hydropower from non-sustainable or high impact hydropower (Frey and Linke 2002). For example, in the United States, Renewable Portfolio Standards (RPS), which mandate that a certain proportion of power purchased within a given area be from renewable sources, sometimes include small hydropower (e.g., facilities with less than a 20 MW capacity) as an eligible renewable source along with wind, solar, and geothermal. The rationale for inclusion of small hydropower is often that it is less environmentally damaging than large hydropower (State Environmental Resource Center 2004).

However, the cumulative effect of multiple small hydropower projects could be more environmentally damaging (and potentially produce less energy) than a single large hydropower project (Frey and Linke 2002). Most debate has centered on large dams, but small and medium size dams are extremely common, are being rapidly built and receive less scrutiny than large dams (Anderson et al. 2006). A single small dam in a critical part of a river basin could individually have a large impact—and an extremely large impact per unit of energy produced—and the cumulative effect of numerous small projects can certainly be considerable.

Numerous frameworks or policies are currently available to provide guidance on the sustainability of individual hydropower projects and the hydropower development process. We briefly review a few of these below:

1. World Commission on Dams. The World Commission on Dams (WCD) report, *Dams and Development* (2000), received a great deal of attention and was hailed as a landmark achievement (Postel and Richter 2003). The most important conclusions of the WCD report are summarized in a set of five core values and seven strategic priorities. "Dams and Development" does not provide directly applicable criteria and standards for evaluating actual dam projects or programs, and it was not necessarily intended to provide this level of operational detail. The International Rivers Network suggested that dams that passed through a "WCD-compliant process" could be considered sustainable (McCully and Wong 2004), and some entities have linked compliance with the World Commission on Dams to project approval, such as the EU Directive linking Clean Development Mechanism carbon certificate market with the European Trading Scheme.

2. Dam siting criteria. The WCD report includes some guidance on site selection criteria, including preference for tributary locations over the mainstem of large rivers (to minimize connectivity impacts) and the avoidance of areas that are of particular importance for biodiversity or cultural resources. In a report for the World Bank, Ledec and Quintero (2003) provide 13 indicators to compare and rank alternative sites for hydropower projects. This report emphasizes that good site selection is by far the best "mitigation" strategy for dam development: minimizing significant harms through good site selection greatly reduces the responsibility of mitigating harms through dam operations.

3. Systems to certify sustainable hydropower. There are two primary systems in place to certify sustainable hydropower. Certification provides a recognized status to providers and consumers of energy and can be a component of a green market for energy. In Europe, a "Green Hydropower" approach provides the basis for certification under the Nature Made label. In the United States, the Low Impact Hydropower Institute (LIHI) certifies sustainable hydropower projects. Both of these certification systems are primarily intended to assess existing projects.

4. The International Hydropower Association's Sustainability Guidelines and Assessment Protocol. In 2003, the International Hydropower Association (IHA) released Sustainability Guidelines, which provide broad guidance on social and environmental sustainability, suggestions for a general process for selecting and locating sites, a list of impacts to consider, and suggestions for design and management practices to address those issues. The Sustainability Assessment Protocol was developed to "assist IHA members in assessing performance against criteria described in the IHA *Sustainability Guidelines."* In other words, the Protocol provides an applied instrument for assessment of project performance relative to the principles articulated by the Guidelines.

A framework for improving the sustainability of hydropower

The reports, policies, and frameworks reviewed above provide a great deal of guidance on improving the sustainability of hydropower dams, including both existing and future dams and ranging from individual projects to large-scale planning. Here we synthesize this guidance along with insights from other fields, including the science of environmental flows, conservation planning, and Integrated Water Resources Management (IWRM) to provide a proposed framework for how hydropower can increase its environmental and social sustainability. The main points of this section include:

1. There are significant opportunities to improve the environmental performance of individual projects and these are worth exploring and implementing (Richter and Thomas 2007). However, the most promising gains for improving sustainability—whether addressing current dams, future dams, or a combination thereof—lies with approaches that consider resources, impacts, and solutions at a *system scale* (e.g., a large river basin, a region, an energy grid).
2. Comprehensive and integrated planning, in some form or another, is supported by most of the recent frameworks proposed for sustainable hydropower (International Energy Agency 2000, International Hydropower Association (IHA) 2004, World Commission on Dams 2000). We describe a framework for integrating conservation science and planning with hydropower planning in a manner that is iterative, flexible, responsive to changing conditions, and is calibrated to the level of resources and data available for a set of decisions.
3. Although hydropower proponents and developers may view system-scale planning as onerous, we suggest that this approach actually will produce multiple benefits for hydropower developers and funders, including greater certainty, lower controversy, reduced operational constraints, streamlined review, preferential access to financing, and access to carbon-offset markets and mechanisms. Integrated planning that includes other water management sectors may even result in projects with greater profitability than those produced through less comprehensive planning processes (see Yangtze case study).

<u>Project-level sustainability: opportunities and limitations</u>

Opportunities to improve project sustainability and the importance of dam design

Although in this paper we discuss limitations to project-scale approaches and emphasize the importance of system-level comprehensive planning, project-level sustainability does have a critical role to play. First, there are already 45,000 large dams in the world and many of these dams have impacts on cultural and environmental resources that will need to be mitigated. Although we suggest that the most complete restoration solutions will come through system-scale analysis and implementation, much of this future mitigation and restoration will be achieved through improvements to the design and operations of individual dams. Second, even with comprehensive planning for future dams, improving the performance of individual dams will still be essential. Some proportion of future dams undoubtedly will be sited in locations where protection of local resources (e.g., the flow regime below the river) will still be an important component of the project's mitigation obligation

Numerous opportunities exist to improve the sustainability of individual projects and a thorough review is beyond the scope of this paper. Strategies to improve project sustainability include implementing environmental flows through modifying dam releases (Postel and Richter 2003, Richter and Thomas 2007, Tharme 2003) and adding or improving fish passage facilities. However, as described below, there are often significant limitations to the extent to which individual projects can be improved. These limitations emphasize the importance of dam design. Characteristics of a dam's design, such as turbine size and release capacity, frequently constrain the implementation of environmental flows. Therefore, it is imperative that the compatibility of dam design and operational objectives be assessed early in the design process. It is much easier to adjust the design of the dam to accommodate environmental flow releases than to try to address it after the dam has been constructed. Additionally, innovative designs may allow dams to provide more natural flow regimes with less sacrifice in terms of generation and revenue. The ability for innovative designs to facilitate more natural flow regimes has received some attention but is clearly deserving of greater research and development. For example, variably sized turbines may allow hydropower dams to operate more efficiently over a wider range of discharges (Balciunas and Zdankus 2007), thereby improving the downstream flow regime with less diminution of generation and revenue. Other important design considerations include oversizing outlet capacity and multiple-level outlets that can provide greater management flexibility for water quality and temperature.

Limitations to seeking sustainability at the scale of single projects
Although great improvements to environmental performance can be made through dam design and environmental flow releases, a number of important impacts from dams cannot be mitigated effectively at the dam site, particularly those that affect connectivity. Techniques for passing sediment through a reservoir, or mitigating downstream effects of sediment capture, are very difficult and expensive and require ongoing management (Kondolf et al. 1996), although Chinese engineers and others are currently investing heavily in research in sediment passage techniques.

Similarly, fish passage poses significant challenges for successful on-site mitigation. As discussed above, many important fish species do not use fish ladders and even for those species that do, dam passage can impose stress and increase mortality of migrating populations (Pelicice and Agostinho 2008).

Unique ecological or cultural resources that are inundated essentially cannot be replaced or mitigated for and thus such resources are most effectively addressed during the planning stage, before an individual project and location have been selected (Ledec and Quintero 2003). Finally, free-flowing rivers, in and of themselves, are unique resources and obviously the loss of this unique value cannot be mitigated for on the reach affected by a new dam. Conservation of free-flowing rivers, vis-à-vis hydropower development, can only come through a process of comprehensive planning (WWF-International 2006).

To illustrate the limited capacity to assess and pursue sustainability at the project scale we provide a conceptual example. Imagine a large hydropower dam that has been well-designed and operated in a manner that would achieve very high marks from a scoring system such as the IHA Protocol. The dam did not displace any human communities and provides a downstream flow regime that largely mimics natural variability. The dam's primary environmental impact is that it prevents access to spawning grounds for a rare sturgeon.

However, three other spawning sites exist. Should this dam be considered environmentally sustainable? Whether it is depends on circumstances completely outside the project area. The question cannot be answered without knowing the status of these three other spawning sites. Indeed, projects may be planned or going forward that will impact these sites. A dam that contributes to the loss of an irreplaceable resource cannot be consistent with the label 'sustainable.' Beyond changing its location, the most effective way for the dam in question to demonstrate its sustainability is to link its development to the meaningful protection of a sufficient amount of the irreplaceable spawning habitat. Perhaps there would need to be mitigation payments to a fund to secure permanent protection for the other areas. While this may be difficult for a single project to undertake, such regional-scale mitigation can occur within a system-scale planning process.

Pursuing sustainability at the system scale

We suggest a conceptual approach that seeks to maximize the environmental and social sustainability of hydropower development within a basin or region. The approach relies heavily on comprehensive and integrative planning, encompasses broad geographic scales, integrates several water management and energy sectors, and infuses traditional development planning with new approaches for regional planning and identification of freshwater priorities (Higgins 2003). Much of this approach has been proposed by, or is consistent with, existing schemes to improve the sustainability of hydropower, including the World Commission on Dams and the IHA's Sustainability Guidelines.

The heart of this approach is planning that simultaneously addresses objectives for water and power and for the maintenance of important environmental and social resources, and that seeks some optimal design between these objectives. A key concept is that this approach leads to an effective regional conservation strategy and links individual project development to implementation of that strategy. As described below, this regional approach to project mitigation may offer significant benefits and efficiencies for project operation.

Much has been done in the area of comprehensive integrated planning for water resource development. The concepts of Integrated Water Resources Management (IWRM) and Integrated River Basin Planning (IRBP) have become common in the lexicon of water planners. Strategic Environmental Assessments (SEA), regional energy planning and needs assessments are supported in numerous documents and policies for sustainable hydropower, including those of WCD and IHA. The kind of comprehensive and integrative planning that we suggest is not different in kind from those formal approaches. Where such planning processes are underway, hydropower developers and environmentalists should take advantage of them to pursue truly integrative outcomes.

These complex processes are generally conducted by government agencies and are beyond the reach of individual hydropower developers. Due to their considerable potential benefits of integration and efficiency, we suggest that hydropower developers encourage, support and contribute to processes such as IWRM and SEA where possible. However, the absence or slowness of such processes should not preclude hydropower planning that is comprehensive, integrative and conducted at a system scale. In the absence of effective formal planning processes, there is a real need for pragmatic and efficient processes that nevertheless are comprehensive in geographic scope and integrative across different water management sectors

The first step toward system-scale hydropower planning entails drawing fully on existing information resources and formal planning processes already complete or in progress. However, where information gaps exist, an integrative hydropower planning process must seek