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.

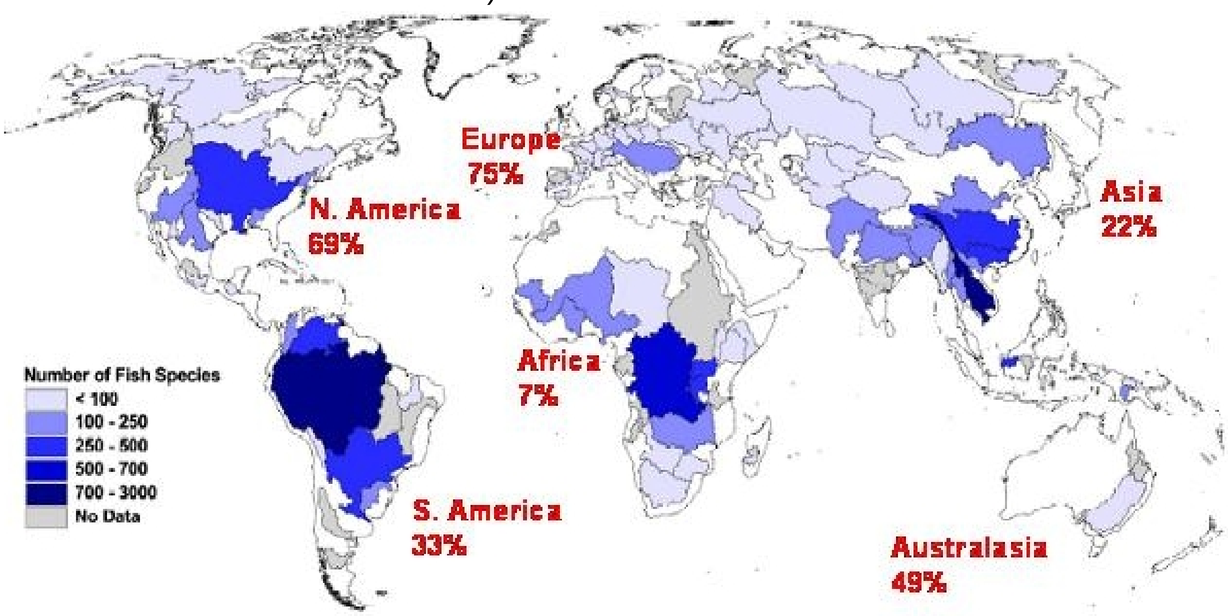
Large reservoirs can trap nearly all sediment, except for the smallest sizes, and even small reservoirs can trap much of the larger sediment in transport (e.g., cobbles and gravels). This disruption of sediment transport processes can lead to channel incision and isolation of the river from its floodplain (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.

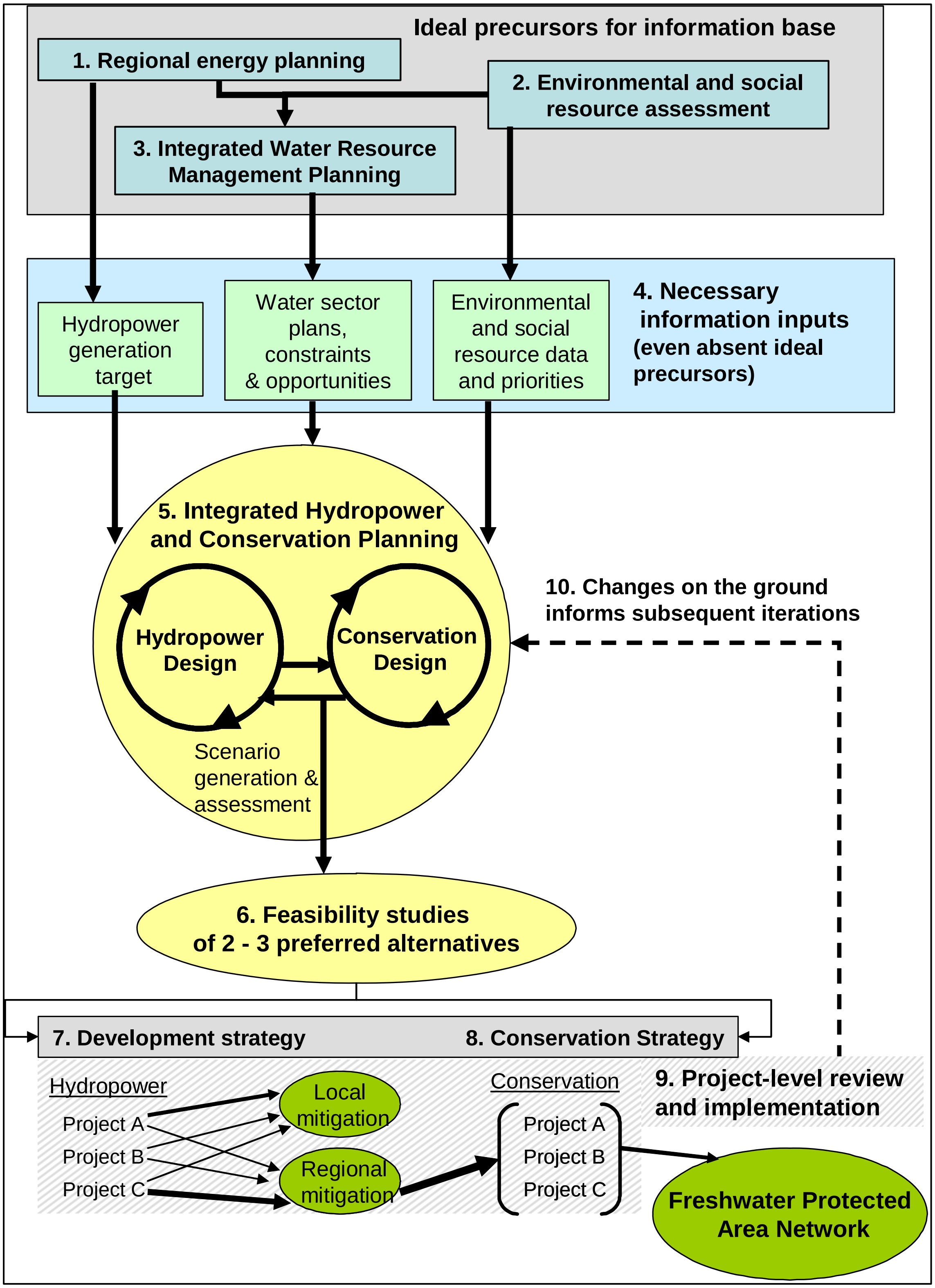
These complex processes are generally conducted by government agencies and are beyond the reach of individual hydropower developers. Due to their considerable potential benefits of integration and efficiency, we suggest that hydropower developers encourage, support and contribute to processes such as 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 to generate appropriate levels of information to characterize (1) energy needs, (2) water sector constraints and opportunities, and (3) environmental and social resources. A formal IWRM ought to reveal potential synergies within multipurpose projects or opportunities for specialized projects such as pumped storage. Absent a formal IWRM, any integrative hydropower planning process should seek to identify such opportunities and synergies through dialogue with other water management sectors (see Yangtze case study). Similarly, an ideal hydropower planning process would draw upon a state-of-the-art ecoregional assessment of environmental and social resources. If such data and analyses do not exist, expert workshops can allow a rough synthesis of known areas of high priority for protection.

The system-scale hydropower process is designed to produce two interacting strategies: a hydropower strategy and a conservation strategy. The strategies are developed through iterative comparisons of the tradeoffs of various hydropower and conservation scenarios, with the selection of two or three alternatives for more detailed analysis. The hydropower strategy will include a set of projects that are prioritized for development and a framework for linking project development to implementation of the conservation strategy. This would include identification of areas to be protected and mechanisms for regional conservation funding. Both strategies will contain essential information to inform and streamline project-level review. The scope of decisions produced by the integrated planning process, such as the number and location of prioritized projects, should be calibrated to the quantity and quality of information available for decision making. For example, a process that draws upon a high-quality IWRM plan can make more confident decisions about both the hydropower and conservation strategies for the long term. Conversely, a process based on a coarser and more rapid information sources should be restricted to the clearest, “no-regret” choices for both hydropower sites and sites important for biodiversity conservation. And as long as the process is understood to be iterative in nature, coarse initial decisions will not close the door to more detailed and sophisticated planning. Subsequent iterations will lead to more mature hydropower and development strategies. Indeed, project-level review and implementation (both hydropower and conservation) will produce more information and funding for further studies as well as lead to new realities on the ground. These new realities and sources of information then inform subsequent iterations of the planning process.

Even a rough first iteration of comprehensive and integrated planning will necessarily involve multiple stakeholders and will likely require governmental sponsorship. It might still stretch the reach of individual project proponents. But the leadership from stakeholders is essential to catalyzing any planning. The default of no system-wide planning at all carries too high costs for both efficient project implementation and environmental and social resources. The lost opportunities on all sides are simply too great, as illustrated in the subsequent case studies. These concepts are illustrated in Figure 2 below. The accompanying Box 1 provides a step-by-step description of the proposed process.

Figure 2. System-scale hydropower and conservation planning (see Box 1)



Box 1.
Ideal precursors for information base (1-3)
1. Regional energy planning, including a needs assessment, realistic forecasts and conservation and efficiency options. Produces a *hydropower generation target.*
2. Environmental and social resource assessment focuses on key resources likely to be impacted by hydropower development. Fields to be addressed include human communities and livelihoods, land use, ecological communities and habitats, species distributions, migratory fish, hydrology, sediment, and linkages between flow regime and river processes and ecosystem services. Produces *resource data and priorities.*
3. Integrated Water Resource Management (IWRM) Planning is a process to ensure the sustainable and equitable development and management of water resources. Potentially, IWRM can address conflicts and synergies between various water sectors—flood control, water supply, and hydropower—and the maintenance of environmental and social resources. Both of the above processes—regional energy planning and environmental and social resource assessment—will contribute to an IWRM process. Where present, IWRM can provide an important and integrative knowledge foundation to support *integrated hydropower and conservation planning* by providing *water sector plans, constraints and opportunities.* See the Yangtze case study for an example of an opportunity provided by integrating planning for hydropower, flood control and floodplain management.
4. Necessary information inputs. The three processes above produce necessary information for the *integrated hydropower and conservation planning.* However, these processes may not formally exist and integrated planning cannot wait for these precursors to develop. In the absence of these ideal precursors, the integrated planning must undertake alternative processes to produce acceptable information inputs of a *hydropower generation target, resource data and priorities,* and *water sector plans, constraints and opportunities.*
5. Integrated hydropower and conservation planning proceeds in an iterative manner to compare the economic, social, and environmental tradeoffs of various infrastructure designs and conservation designs. Two or three preferred alternative scenarios, appearing likely to meet hydropower and conservation objectives, should emerge from this process.
6. Feasibility studies are then conducted to subject each of the preferred alternative scenarios to more rigorous review and analysis. Two interacting strategies emerge from the feasibility studies.
7 – 9. A **development strategy** and a **conservation strategy** provide an overarching framework for **project-level review and strategy implementation** (the review, development and operation of individual projects and the design, implementation and management of mitigation measures, including a freshwater protected area network). The development strategy includes a set of prioritized projects. Much of the information required for project-level review will have been generated during *integrated hydropower planning* and the *feasibility studies.* For example, these strategies will provide the information required to develop the mitigation requirements for each individual project. Mitigation requirements will be a balance of *local mitigation* (e.g., fish passage, environmental flows) and *regional mitigation*. The amount and proportion dedicated to either local or regional mitigation will vary by project based on location and impact, as indicated by the size of arrows in the figure. Meeting the *regional mitigation* requirements will likely require financial contributions toward the completion of the regional conservation strategy. Thus, individual projects interact with regional scales in two ways: first, the prioritized set of projects is selected through a regional analysis of tradeoffs and, second, the development of each project is directly linked to the implementation of a regional conservation strategy.
10. These initial steps allow a set of projects to go forward and contribute to the fulfillment of an initial conservation strategy. The review and implementation of these hydropower and conservation projects and strategies will result in **changed conditions on the ground** as well as **new information that will inform subsequent iterations** of the *integrated hydropower planning process.*

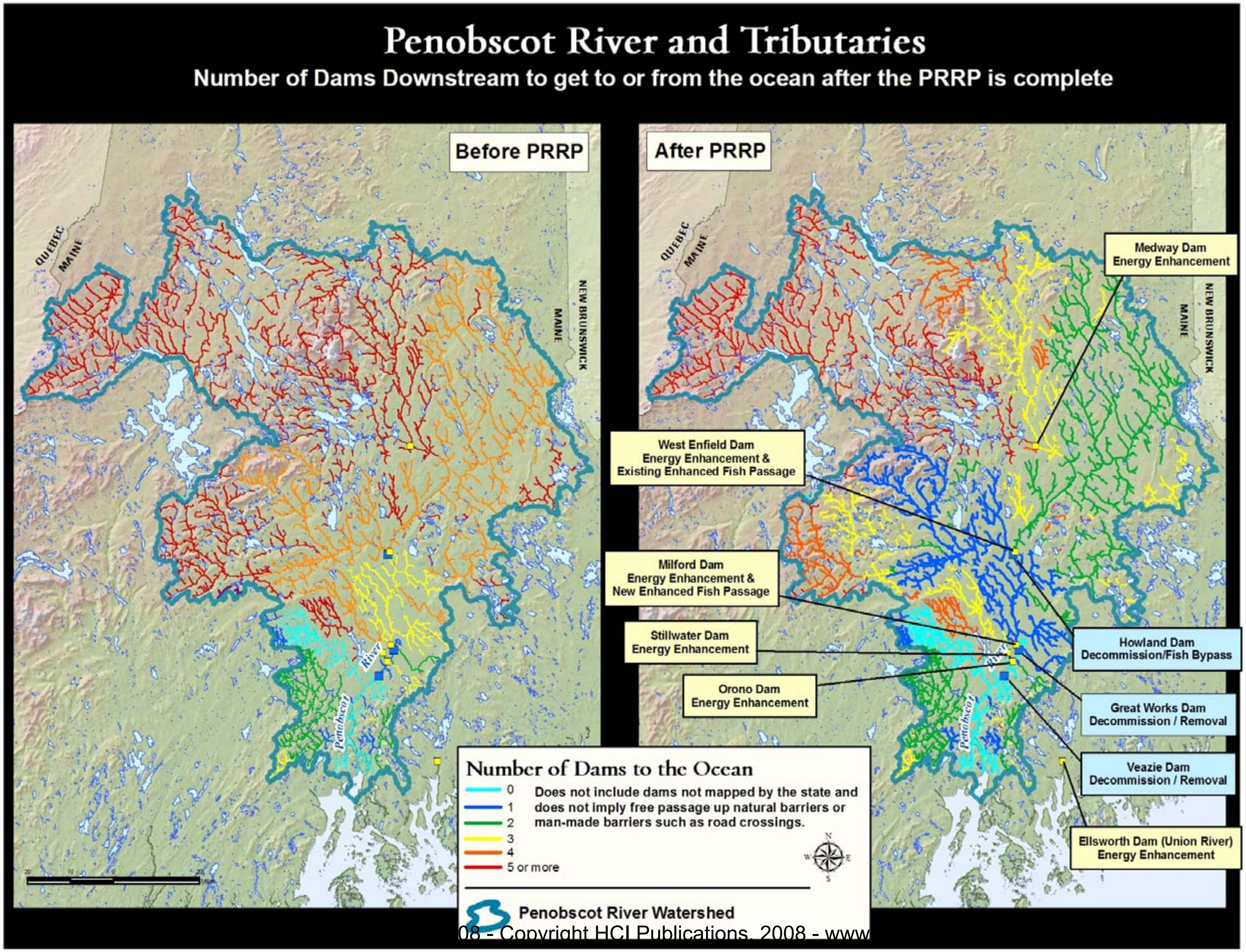
<u>System-scale sustainability in the Penobscot River Basin</u>
The Penobscot, Maine's longest river, supports twelve fish species that migrate between river and ocean habitats to complete their life cycle, but dams on the mainstem and major tributaries have prevented these populations from accessing the majority of the basin for more than a century (Figure 3). A diverse group of entities—including a power company, conservation organizations, and state, federal and tribal agencies—recently brokered the Penobscot River Restoration Project ('the Project'). The Project will dramatically increase migratory fish access within the Basin, through dam decommissioning and retrofitting, with a minimal loss of power generation. The Project illustrates how pursuing sustainable hydropower at large spatial scales can facilitate much more fundamental solutions for both energy and environmental resources than can be achieved at the scale of a single dam

The Project achieved innovative solutions because it examined energy production options across multiple hydropower facilities within the basin and ecological resources across thousands of river kilometers. This multi-dam, basin wide perspective revealed that energy production from the mainstem dams resulted in significant ecological impacts, in the form of migration barriers, whereas dams on tributaries could potentially produce equivalent amounts of power with far lesser impacts on migration access. Thus, the Project's solution was to reallocate power generation to sites where it could be produced with lower ecological costs: three dams on critical mainstem habitat will be decommissioned and the loss of generation will be offset by increased generation on tributary dams. To further improve migratory fish access, state-of-the-art fish passage facilities will be added to the remaining dams on the lower mainstem and as well as other dams that will continue to generate power under the agreement (Figure 3).

The agreement was forged between the energy utility Pennsylvania Power and Light, the Federal Energy Regulatory Commission (FERC) and other government agencies, and the Penobscot River Restoration Trust (PRRT). The PRRT is membership organization composed of the Penobscot Indian Nation, The Nature Conservancy, Trout Unlimited, The Atlantic Salmon Federation, American Rivers, The Natural Resources Council of Maine, and Maine Audubon Society. Because PPL was relicensing all of their dams within the basin at one time, the FERC relicensing process allowed for a holistic solution that encompassed all of FLP dams in the basin at once. The PRRT holds an Option Agreement with PPL to acquire three dams and associated hydroelectric facilities on the Penobscot River. The acquired dams will then be removed after environmental reviews have been completed.

As a result of this project, total generation capacity in the basin will be reduced by less than 4% (well within annual variability of generation). Accompanying this small loss in generation capacity will be a river basin that is transformed in terms of its environmental resources. Due to removal of the two most downstream dams on the mainstem and improved fish passage at other dams, migratory fish will have access to thousands of kilometers of additional habitat. Federal biologists estimate that, upon project completion the Penobscot alewife run could increase from 12,000 to several million, with shad increasing from near zero to 1.5 million annually. Dam removal will restore essentially all historic habitat for shortnose sturgeon, tomcod, rainbow smelt and Atlantic sturgeon. Finally, the project will restore 52% of historical habitat for the endangered Atlantic salmon with one dam passage and 80% with two dam passages. The Penobscot basin currently supports approximately 75% of the U.S. population of this recreationally and culturally important species. Biologists estimate that the additional habitat could allow the Penobscot salmon population to increase from less than 1,000 today to a self-sustaining run in the 10,000-12,000 range. This case illustrates several important concepts.

Figure 3. Fish passage scenarios before and after the Penobscot River Restoration Project. Reaches and tributaries are color-coded to represent how many dams lie between them and the ocean. A key feature of the Project is providing state-of-the-art fish passage at the mainstem dams that will remain after project completion.



First, by considering a broad spatial scale, this restoration project could mitigate impacts, such as fish passage, that are difficult or impossible to address at the scale of a single dam. The regional approach allowed for dams to be decommissioned, greatly expanding access for migratory fish, with minimal loss of generation capacity. Rather than being an incremental improvement on a reach of river, as can be accomplished through the reoperation of a single dam, this restoration project represents a transformative change in the ecological processes of an entire basin. Though the Penobscot case concerns dams that are centuries old, this process provides insights for comprehensive planning of future hydropower development. Upon completion, the future spatial arrangement and operation of dams in the Penobscot will provide essentially equivalent power generation as did the previous arrangement and operation. However, the future spatial arrangement will generate this power while providing a river environment that supports fish populations that will have the potential to approach historical (pre-dam) levels, whereas the previous arrangement resulted in a river with dramatically reduced fish populations. This is the objective of the comprehensive planning process described above: to direct hydropower development toward a spatial arrangement and operation of dams that is consistent with the maintenance of important ecological and cultural resources.

<u>The potential for integrating hydropower planning with floodplain management and ecoregional priorities in the Yangtze River basin</u>

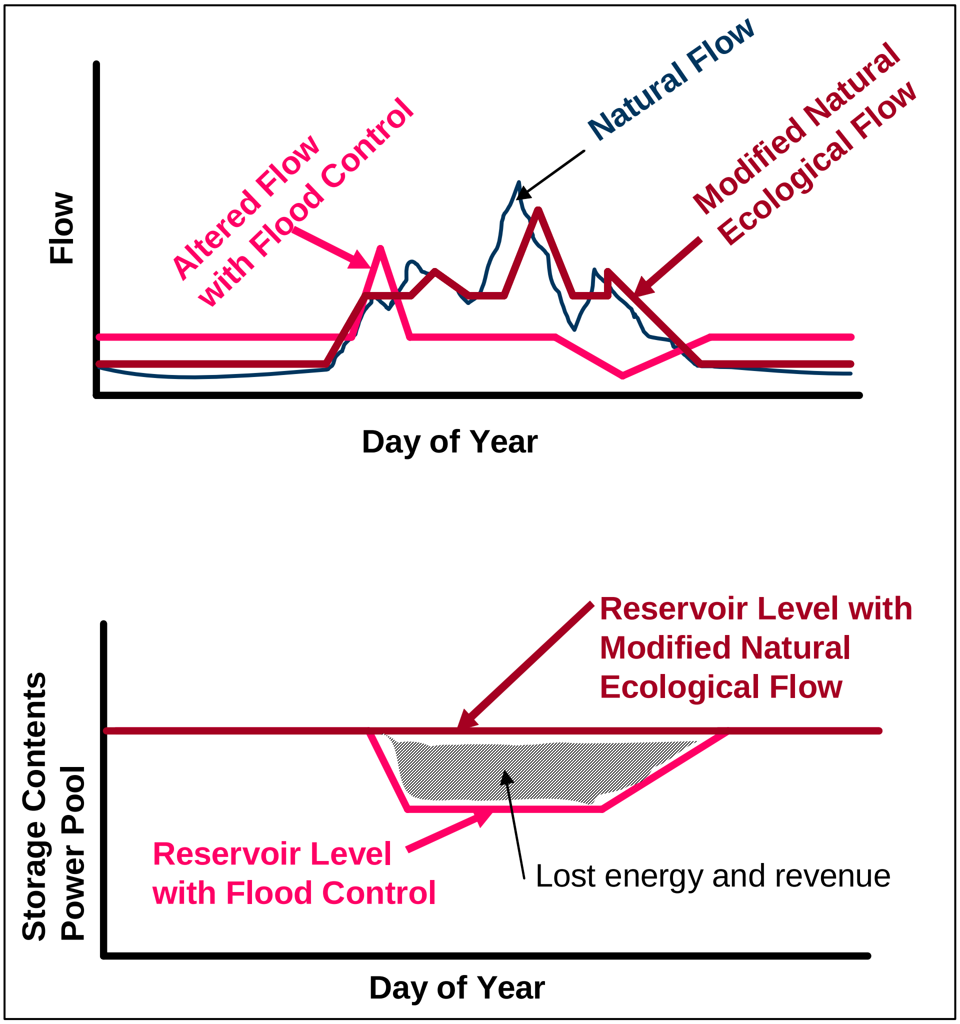
The growth of hydropower in China is fueled by its rapidly growing economy and associated energy demand. Concerns about air pollution and climate change provide further incentive to increase hydropower production. China's Three Gorges Power Corporation (CTGPC) is currently planning and building a new set of dams on the upper mainstem of the Yangtze River, known as the Jinsha Jiang, that will have a collective generating capacity (36,000MW) nearly twice that of its namesake project. A cascade of eight more dams, including a controversial dam at Tiger Leaping Gorge, with a collective capacity of 20,000MW are being planned further upstream on the Jinsha Jiang by the Jinshajiang Hydropower Development Corporation. In addition, numerous small and middle-sized dams are being planned throughout the Upper Yangtze River Basin, covering virtually every major river and tributary segment.

Cumulatively, these planned developments present a tremendous threat to the ecological values of the Upper Yangtze River Basin, a region with high levels of biodiversity and endemism. For example, the Yangtze River basin supports 350 species of fish including 140 endemic species. Millions of people rely on protein from Yangtze River fish, and these fisheries largely depend on a functioning river ecosystem. Fisheries and other environmental resources in the Yangtze Basin will be impacted both by the dams acting as barriers to fish migration and by changes in the flow regime and sediment transport. The intense conflict between harnessing the Yangtze's energy potential and maintaining its ecosystem services and unique biodiversity suggests a strong need for comprehensive and integrated hydropower planning. Here we illustrate two components of the planning process described above: (1) integrated water resource management that considers hydropower, flood control, floodplain management, and environmental flows to find solutions; and (2) integrating regional conservation planning into hydropower planning to ensure that biologically high-value and representative portions of the basin's rivers remain protected and free-flowing.

Integrated water resource planning and reservoir operations.

The natural flow regime of the Upper Yangtze River Basin is driven by a summer monsoonal weather pattern that, along with snowmelt from the Himalayan plateau, results in 60% or more of the flow occurring during three or four summer months. The summer high flows coincide with the period of greatest energy demand in CTGPC's market area, south and east China. Because flood risk has typically dominated water management planning in the Yangtze Basin, the proposed dams have been planned to include substantial storage space for flood control operations during the summer monsoon months. This flood control obligation will exacerbate the disruptions to the natural hydrograph caused by hydropower generation. Flows will likely be increased in May and June, as the flood pool is being evacuated, and flows will decrease when the power pool is being refilled in October after the flood control season (Figure 4). Thus the inclusion of flood-control operations will make it much harder for the planned dams to operate in a manner that broadly follows natural seasonal patterns.

Figure 4. Alternative operation scenarios for future dams on the Upper Yangtze.



In addition to ecological concerns, the flood-control operations will significantly diminish hydropower production during the summertime period of high demand. This will reduce revenue from the dams and the lost energy potential will have to be made up by additional thermal power plants or hydropower dams, entailing further environmental costs. These economic and ecological conflicts suggest that alternative operating scenarios should be considered thoroughly. Generating alternative scenarios requires simultaneous assessment of multiple resources and sectors including hydropower, environmental resources and biodiversity, ecosystem services such as fisheries, reservoir flood management, and flood risk in the downstream floodplain. Therefore, achieving a more optimal allocation between these resources requires comprehensive and basin-scale planning.

Because the summertime high flows and high energy demand occur simultaneously, a modified ‘run-of-river’ operation could be adopted to provide somewhat natural-like flow patterns downstream of the dam cascade (Figure 4). Although this run-of-river approach provides environmental flow and hydropower benefits, achieving it would require a reduction in reservoir flood-control operations. But flood management can be addressed in numerous ways beyond reservoir storage of flood peaks. A current plan is emerging that would allocate a portion of the increased hydropower revenue from the run-of-river operations (relative to proposed operations with significant flood control) to create a floodplain management fund. The floodplain management fund would support various structural and non-structural management actions in the floodplain to reduce downstream flood risk. These actions may include increased flood storage and conveyance on the floodplain, in the form of flood bypasses, as well as improved flood warning and evacuation systems, and flood insurance. This approach has two major advantages over traditional reservoir-based flood control. First, while flood control in the reservoirs would exacerbate the degradation of the river ecosystem of the Yangtze downstream, the floodplain management approach will result in considerable restoration of floodplain habitats. Second, the reservoir-based flood management would have been designed for a range of flood levels, and downstream communities would be vulnerable to floods larger than those the system was designed to manage (e.g., hundreds of thousands of people live in flood bypasses intended to be used during very large floods). By improving many aspects of floodplain management, the new proposed approach will actually *reduce* overall flood risks because, while the reservoirs will provide little reduction in flood risk from very large floods, the floodplain management approach will reduce risks across the full range of flood magnitudes.

To implement this comprehensive approach, numerous studies must be conducted and challenges overcome. However, the solution proposed here suggests that comprehensive planning—integrating multi-sector water management planning with biological resources and downstream floodplain management—can yield solutions that result in net gains for hydropower, river ecosystems and ecosystem services, and flood risk.

Hydropower planning and regional conservation planning

Challenges for sustainable hydropower in the Yangtze basin go beyond the four Jinsha Jiang dams. In addition to these, there are more than 50 large dams proposed on tributaries throughout the upper Yangtze Basin, and hundreds more medium to small dams proposed. If implemented in an uncoordinated manner, this proliferation of hydropower projects will cause profound impacts to the environmental and social resources of the basin. Coordinated, comprehensive planning will be required to provide a framework for this future development that will lead to a spatial arrangement of dams that will both provide a large increment of new power capacity *and* maintain and protect the most important environmental and social resources. The conceptual approach described in this paper can potentially provide such a framework, within which dam development sites are prioritized in terms of their impact and mitigation strategies are targeted at the basin scale to achieve the greatest conservation benefit (e.g., the ecological sustainability of areas important for freshwater biodiversity).

Chinese agencies have been working with The Nature Conservancy to refine and implement a method for a biodiversity assessment to develop a vision for conservation success across China, building on methods that have been implemented globally over the past decade (Groves et al. 2002, Groves 2003, Higgins 2003, Higgins and Esselman 2006) (Figure 5). A pilot project for the Upper Yangtze basin has recently been completed. This project involved the development and mapping of information on freshwater biodiversity, ecosystem patterns and processes, and impacts to the condition of freshwater resources throughout the Upper Yangtze basin (above Three Gorges Dam). The assessment resulted in a first iteration "blueprint" -- a map of a possible mosaic of areas of biodiversity significance that, taken as a whole, could give a reasonable degree of protection and sustain the freshwater ecosystems and the biodiversity that comprise the sub-basin. The "blueprint" took into account, at a preliminary level, existing and planned hydropower projects, and it attempted to reach a spatial "optimal" freshwater conservation design through "capturing" representation of the diversity of ecosystems and endangered species in areas with the least current impacts and future threats, and maintaining connectivity. Because of the limited information on planned and proposed dams, the "blueprint" has to be considered preliminary. What is possible by working with Chinese agencies in a trial and error, back and forth process is the design of an integrated development and ecosystem protection plan that will best optimize hydropower generation, minimize flood risk, and maximize conservation and ecosystem services outcomes. The hydropower output can be expected to be nearly as large as the sum of the currently proposed individual projects (if not greater when considering integrated hydropower and flood risk management). A large amount of ecosystem protection can be accomplished at well-selected sites with only a small amount, if any, of loss of hydropower capacity. In the Yangtze, in particular, a few of the mega projects currently under construction or in advanced planning will overwhelm the amount of capacity to be foregone in areas that are important for biodiversity conservation.

Figure 5. A potential portfolio of priority areas of biodiversity significance for the Upper Yangtze Basin.

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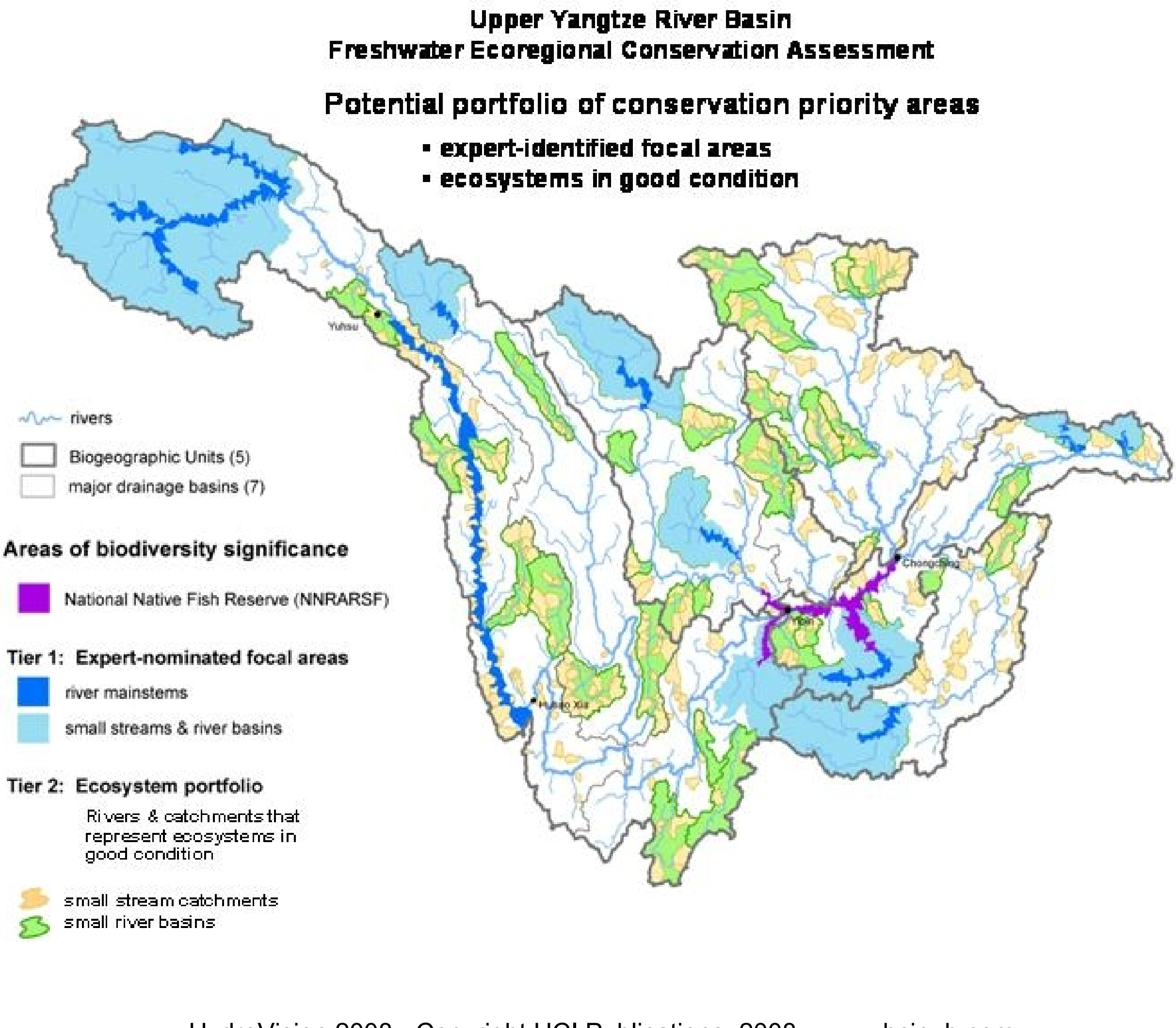

It must be acknowledged that some of the proposed projects may be located in very high-priority conservation areas, and that those projects should not be built. The project proponents may feel that there is some inequity in comprehensive planning that results in designating some projects as “winners” and some as “losers.” Such perceived inequity does often attend to large scale land use or development planning. But the comprehensive plan can address this. The opportunity to protect certain ecological functions and ecosystems at specified high-priority locations is actually an opportunity for the developers of those projects that are going to be built to mitigate their impact – and to do so efficiently. The concept of comprehensive planning and mitigation should involve mitigation payments, by projects to be built, into a basin-wide fund that will be used for compensation for no-build commitments in areas critical for conservation, in addition to other direct mitigation of environmental impacts such as floodplain management.

In the case of the Upper Yangtze, literally hundreds of small hydro projects are being promoted jointly by local governments and private developers. Their primary motivation is to get a dedicated source of revenue for the local government. Their combined energy capacity is relatively insignificant at China’s macro level. If, for example, 50 small projects were to be foregone, each with an average capacity of 20 MW, that would amount to 1000 MW (or 1 GW). While this may seem significant in isolation, it represents a small part, about 2%, of the immediately planned capacity of large projects in the Upper Yangtze. And that large project capacity could itself be upsized by more than 2% if environmental constraints, and particularly, flood control constraints, could be eased. The affected local governments could actually be paid not to develop projects and instead implement and manage conservation areas.

Such a comprehensive plan may seem to be beyond the immediate reach of individual project proponents but its advantages are clear. Generally, we think of such planning as a government function and ultimately it must be. But governments are much more likely to respond to such opportunities if industry takes a lead role. The Yangtze River Basin Commission (Changjiang Water Resources Committee or CWRC) has a project in process right now to reevaluate its 2003 water development plan for the whole Yangtze, and it has a golden opportunity to work with industry and NGO’s to reach for an optimal development and conservation plan.

Conclusions: Advantages of systems level approach

The benefits to environmental and social resources of integrated, system-scale planning are clear: greater probability of avoiding the most damaging projects, improved ability to address cumulative effects, and a framework for linking project development to the implementation of a comprehensive regional conservation plan. These benefits can go a long way toward fulfilling the promise of sustainable hydropower.

We suggest that the benefits of system-scale planning to hydropower proponents are equally significant and include:

1. Integrated water resources management may achieve more economically optimal outcomes, such as the increased hydropower revenue that could be produced from Yangtze mainstem dams if their flood-control obligations are reduced in favor of floodplain management improvements.
2. Projects that are developed through an integrated system-scale process are likely to have less controversy and uncertainty and, therefore, represent lower risk for developers and funders. A reduction in risk may be a considerable advantage for hydropower projects. These projects will also likely have more streamlined project-level review, because many of the issues will have been identified and avoided or addressed at higher levels of planning.

3. Projects developed through this process may have fewer operational constraints because a (potentially significant) portion of their mitigation obligation will be accomplished through contribution to regional scale mitigation. This balancing of local and regional mitigation has the potential to produce more efficient outcomes, in terms of both project operations and conservation.
4. If system-scale processes can lead to better outcomes, then the hydropower industry will receive positive public recognition and be much better positioned to advance hydropower as a source of renewable and sustainable energy in the global market.

In this paper we have described a flexible, iterative, and comprehensive process for integrating hydropower and conservation planning at the system scale. Although the proposed process is intentionally pragmatic—to improve projects that are already going forward and to inform short-term development and conservation decisions—we caution that the decisions made under this process should be calibrated to the level of information available. Where such information is rudimentary, decisions should focus on the clearest, "no regrets" options with the understanding that subsequent iterations will draw upon improved information and can make more extensive decisions. We do not present this process as a substitute for the WCD Principles or IWRM or SEAs. Indeed, these comprehensive planning processes are critical for hydropower to realize its potential as a sustainable energy source.

A number of conservation organizations, river basin authorities, development banks, and representatives of the hydropower industry are currently advancing various portions of the integrated process proposed here. However, the evolution of system-scale processes that are both practical and effective will require a greater scale of implementation and refinement. In 2007, US$20 billion was invested worldwide in large hydropower dams (www.waterpowermagazine.com, Mar 10, 2008). If even 1/10 of 1% of that investment was directed at integrated, system-scale planning, US$20 million per year would be available to support comprehensive processes that could greatly improve both the efficiency and the environmental and social sustainability of hydropower projects.

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