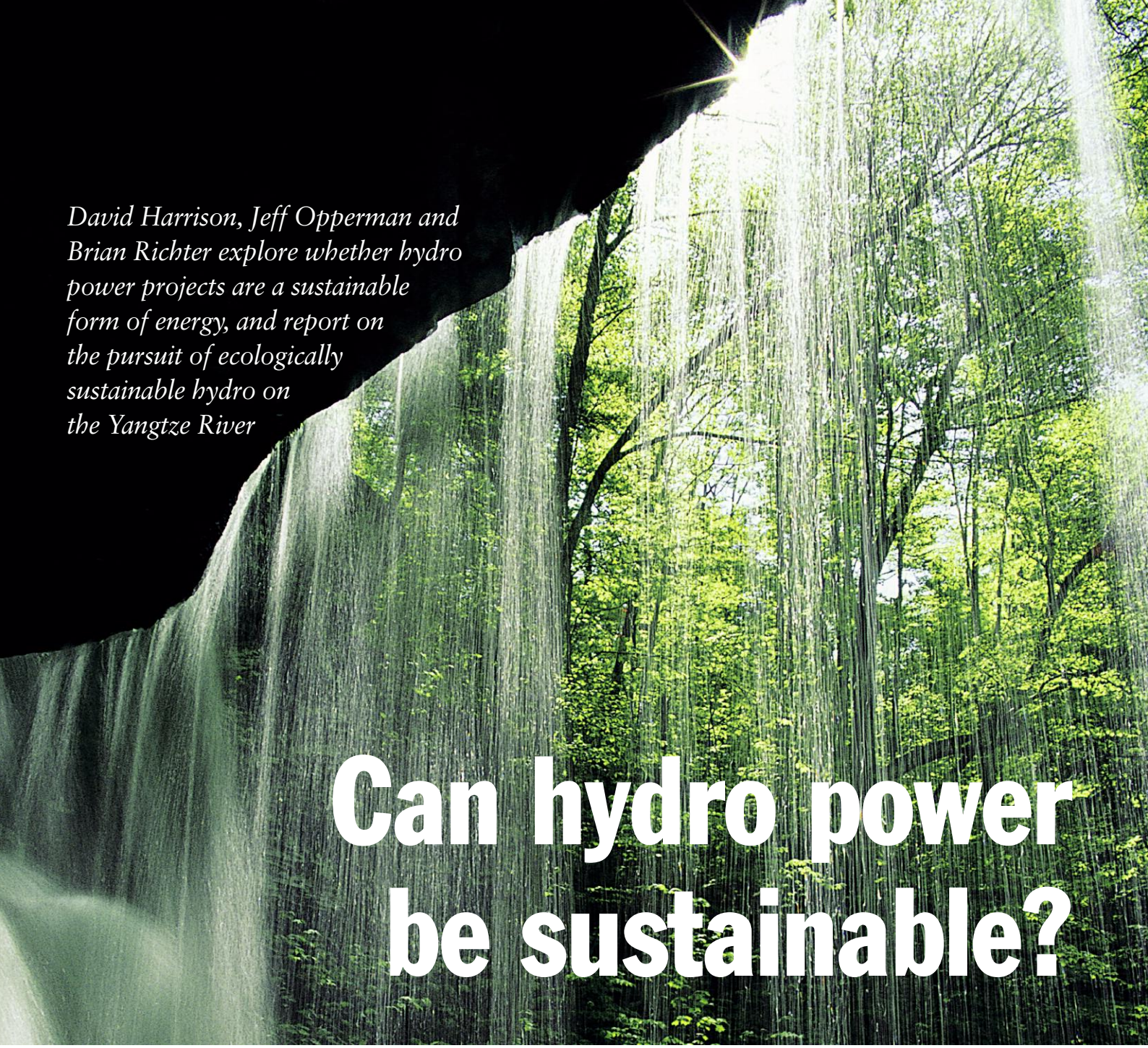


David Harrison, Jeff Opperman and Brian Richter explore whether hydro power projects are a sustainable form of energy, and report on the pursuit of ecologically sustainable hydro on the Yangtze River

Can hydro power be sustainable?

WITH Three Gorges dam rapidly nearing completion[1], China Three Gorges Power Corporation (CTGPC) has announced it is building a new set of dams to rival its massive and controversial namesake project. The first two of four tall dams to be located upriver from Three Gorges are now under construction on the upper mainstem of the Yangtze, known as the Jinsha Jiang. These four dams are planned to collectively provide a capacity of 36,000MW – two times the original design capacity of Three Gorges.[2]

Eight more dams, including a controversial dam at Tiger Leaping Gorge, are being planned further upstream on the Jinsha Jiang by the Jinshajiang Hydropower Development Corporation, a joint venture between Huaneng, Huadian and Yunnan Provincial Power Companies. The first of these dams, Jinganqiao, is now under construction. This eight-dam cascade will produce something on the order of 20,000MW of capacity.

In addition, other dam development companies are planning and constructing many more dams in the Upper Yangtze River Basin. The Ertan Hydropower Development Company is completing a very high dam at Jingping I (305m high, 3600MW) and is moving ahead with the interconnecting head race tunnels to Jingping II (4800MW). These, together with the existing Ertan dam (240m high, 3300MW) are among the first wave of projects in an ambitious proposal by Ertan Company for a 21 dam river development plan for the Yalong Jiang, a major tributary to the Upper Yangtze. Total capacity of this system would be 25,000MW.[3]

Yet another 20 or more large dams are being planned on the Minjiang and Dadu He, tributaries of the Jinsha Jiang. Throughout the Upper Yangtze River Basin, numerous small and middle-sized dams are being planned, covering virtually every major river and tributary segment.

The cumulative effect of all this development presents a monumental threat to the ecological values of the Upper Yangtze River Basin, which is well known among ecologists for its high level of biological productivity and richness of species, including hundreds of plants and animals (including fish) found nowhere else in the

1 The removal of the cofferdam this past winter signaled the completion of the main concrete structure. Nine of the power units are operating; work is ongoing on the nine main units on the right side, leading to the completion of the originally plowed 18,000MW of nameplate capacity.

2 Work is now underway on the right bank underground power house which will take the total nameplate capacity to around 22,000MW.

3 See IWP&DC magazine, May 2007 p. 20, Moving Through Mountains.

world. In this context, the question of the sustainability of hydro power being developed in the Upper Yangtze River Basin takes on a very large dimension.

Dams and the environment

Hydro power is increasingly being promoted as a renewable source of energy with low emissions of greenhouse gases, capable of being produced at a scale necessary to meet pressing energy demands with current technology. With heightened global concern about energy security and climate impacts, hydro power is extremely attractive. In rapidly developing countries such as China, the availability of immense hydroelectric resources is seemingly irresistible. With its strong economic growth being highly dependent on reliable electrical energy, and with its severe problems with air pollution, China will almost certainly build a large increment of new hydro power.

However, hydro power doesn't come without significant environmental costs. In general, freshwater ecosystems and species are among the most highly threatened in the world. Environmental concerns about dams typically center on their blockage of fish migrations or their upstream impacts, such as the inundation of habitats and the displacement of human communities. However, dams can cause serious downstream impacts as well. Although the public generally thinks of threats to aquatic organisms solely in terms of water quality, hydrological alteration – the modification of downstream water flow regimes caused by dams and infrastructure – is one of the primary causes of the degradation of freshwater ecosystems worldwide. The basic life histories of freshwater organisms – how, where and when they reproduce and grow – have evolved in response to natural flow variations such as seasonal high flows and natural drought periods. When these natural flows are highly altered, populations of freshwater species can plummet or even be driven to extinction.

Hydro power dams typically alter flow regimes by reducing daily flow rates in the high flow season when storing floodwaters for later use, including eliminating small floods. Hydro power dams also artificially augment natural low flows in the dry season, when stored water is released for power generation. In some instances, dam releases can cause non-natural high flows at the wrong time of year. The extreme fluctuations in flow due to peaking operations can also exert tremendous stress on the habitats that support fish and other aquatic species. In addition to changes in the flow regime, dams can heavily modify water temperatures and the downstream transport of sediment, further impacting river ecosystems.

All of these environmental impacts can have serious implications for downstream plant and animal communities, as well as human communities dependent upon the goods and services provided by properly functioning river ecosystems.[4] Unfortunately, hydro power's global track record of managing such environmental and social impacts and assuring equitable distribution of social benefits has been less than stellar. So the occasional generality thrown out by the most vigorous proponents, that hydro is 'environmentally friendly', calls for a more careful analysis. The reality is that hydro power can potentially cause serious environmental and social disruption if not planned and operated carefully.

Although hydro power has an important role to play in reducing poverty and meeting energy needs without exacerbating climate change, the alleviation of one environmental problem should not aggravate another. It is possible to aspire to a higher standard – hydro power that is carefully planned and operated so as to get as much energy benefit as possible within boundaries consistent with the protection of natural freshwater ecosystems and their valuable social benefits. Some hydro schemes do better at this than others. Some hydro power could be considered sustainable; some hydro power should not.

Sustainable issues

Is hydro power a sustainable form of energy generation? The question defies a simple answer, in part due to multiple definitions of 'sustainable.' However, it is an extremely important question. Hundreds of large hydro power dams are planned in coming decades, in part due to growing demand for energy sources with lower greenhouse gas emissions. Where these dams are located - and how they are designed and operated - will have enormous implications for the sustainability of river ecosystems, aquatic biodiversity, and human communities dependent upon ecosystem services.

Thus, it is how this future development unfolds that will largely answer the question of whether hydro power is sustainable in multiple dimensions. That is to say, hydro power is not *a priori* either sustainable or unsustainable. Rather, its relative sustainability will be determined by myriad considerations of system-level and project-level planning, design, operation, and mitigation. In this article we explore these considerations, focusing on a region projected to undergo rapid development of hydro power resources. Here we use the commonly cited definition of the Bruntland Commission which defines as sustainable those activities that 'meet the needs of the present without compromising the ability of future generations to meet their own needs', considering economic, social, and environmental aspects.

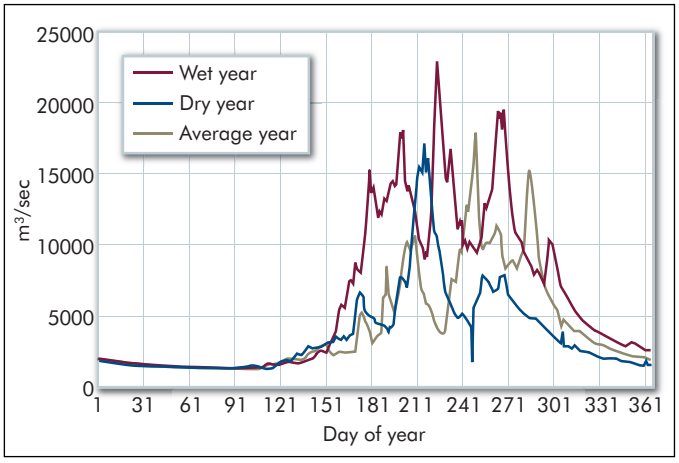


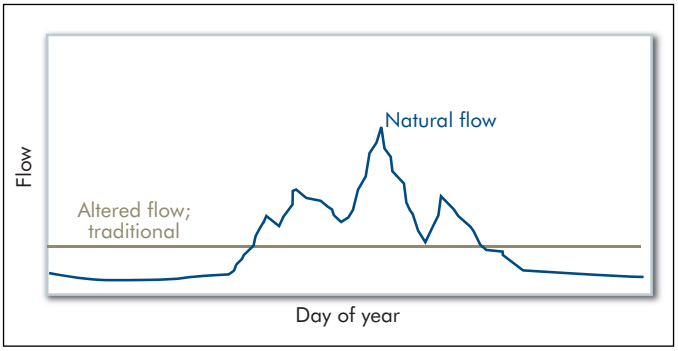
Figure 1: The natural flow regime of the Upper Yangtze River Basin

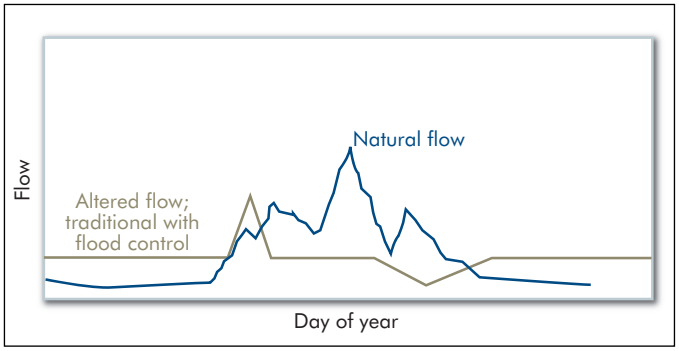
The elusive nature of sustainability

Much has been written about 'sustainable development' to the point that some critics have abandoned it as an intangible and unquantifiable platitude, and therefore of little use in real-world natural resource management. This is a serious mistake. Instead, the challenge of defining sustainable development in practical terms must require a much deeper inquiry into each development sector. Indeed, the goal of being fully 'sustainable' will remain aspirational in value. No hydro power project is likely to be 100% sustainable; all projects must be viewed as more or less sustainable. The quest to improve their sustainability will be ongoing.

To address the concerns described above and guide the pursuit of sustainability, several entities have developed policies that articulate 'sustainable hydro power,' including Green Hydro in Switzerland and the Low Impact Hydropower Institute in the US, in addition to guidance on sustainability presented in the World Commission on Dams report. Recently, the International Hydropower Association has developed Sustainability Guidelines and a Sustainability Assessment Protocol. Collectively, these documents describe specific measures for hydro power planning and operation that can be used to evaluate the sustainability of a hydro project or programme. Below we apply many of the principles embedded within these documents to describe how hydro power development in the Upper Yangtze River Basin can move higher on

4 For a thorough discussion of the impacts of dams on rivers, see *Postel, S., and B. Richter. 2003. Rivers for Life: Managing Water for People and Nature. Island Press, Washington, DC.*





From left to right: Figure 2: Year round flows and firm energy production; Figure 3: Flow regime and flood control operations

the sustainability yardstick. Many of the problems and potential solutions we describe for the Yangtze Basin will apply to other parts of the world likely to undergo development of hydro resources.

Pursuing sustainability in the Upper Yangtze

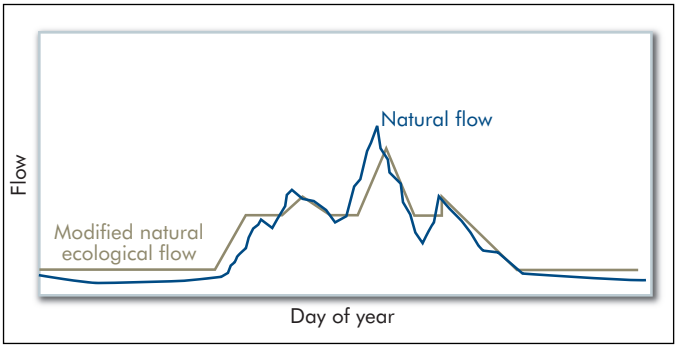
The four Jinsha Jiang dams being planned and built by CTGPC provide a tangible opportunity to improve the sustainability of a cascade of hydro power dams. They could be designed and operated in a very traditional mode, without consideration of downstream impacts. Or, as we propose, they could be planned and operated in a manner responsive to environmental and social requirements. Here we describe an operating regime for the Jinsha Jiang dams that would not only maintain downstream ecosystems, but would provide economic advantages to CTGPC and to China.

The natural flow regime of the Upper Yangtze River Basin is driven by a summer monsoonal weather pattern, with 60% or more of the flow occurring during three or four summer months as shown in Figure 1. This is also the time of year of the greatest energy demand in south and east China, the market areas for CTPC energy.

If traditional hydro power operating concepts were applied, the large reservoirs would store high flows during the summer monsoon season, and then release the stored water as river flows begin to drop in the fall. This scenario results in relatively constant year-round flows and relatively constant firm energy production, and produces the 'flat line' scenario depicted in Figure 2 as 'Altered Flow Traditional'.

Flood risk has typically dominated water management planning in the Yangtze basin, and, therefore, the proposed dams are planned to include substantial storage space for flood control operations during the summer monsoon months. This complicates the likely picture for the downstream flow regime. Resulting operations would involve an increase in flow in May and June, as the flood pool is being evacuated, and decrease in flow when the power pool is being refilled in October after the flood control season, depicted in Figure 3 ('traditional with flood control'). This alteration of the flow regime's natural patterns and variability will likely have serious impacts on the Yangtze's important and imperiled fish populations, as well as other aspects of the river ecosystem.

Figure 4: A modified 'run-of-river' operation could be adopted to provide 'natural-like' flow patterns downstream of the dam cascade



The fact that these dams are planned to be multipurpose is not surprising; it has become traditional in water development around the world to try to make hydro power projects into multipurpose projects. Some amount of flood control is very often planned into what are primarily hydroelectric facilities. But sometimes, and certainly in the case of the Upper Yangtze dams, this exacts a considerable cost. Providing flood control storage means the power pool must be drawn down to provide flood capture space at the very time the capacity is most needed to supply the regional energy demand. This is a direct compromise in the hydro power benefits being sought, not only in revenue, but in energy production. A 25% reduction in operating head to create flood control capacity could mean another dam must be built – or another coal-fired thermal electric plant.

These economic and ecological conflicts suggest that alternative operating scenarios should be considered thoroughly. 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, as illustrated in Figure 4.

However, achieving this run-of-river approach would require a reduction in flood storage space. But flood management can be addressed in numerous ways beyond reservoir storage of flood peaks. An alternative for managing flood risks should be put on the table for examination alongside hydro power operation considerations. What if the differential hydro power revenue gained from eliminating flood control storage in the reservoirs could be utilised for restoring flood storage capacity and insuring against flood risks in the flood plain?

Comprehensive planning

This leads to a very important general concept. Evaluating the sustainability of a single project is difficult, if not impossible, without considering a broader system-level context. A system-level approach holds great potential for improving not only the environmental and social sustainability of hydro power, but may also provide considerable economic benefits.

A system level approach requires the integration of multiple layers of information and planning, cutting across disciplines and sectors. For example, as we described above, the reallocation of flood-control space within the Yangtze dams may potentially improve both hydro revenue and environmental flows. These synergies can only be identified through integrated basin planning – planning and analysis that integrates hydro power with flood control operations and floodplain management. Additional operational flexibility may be revealed by further expanding the scope of planning to include the whole system of energy demand and generation with which the proposed dams will interact.

The need for integrated basin planning and management is illustrated by potential conflicts between flood control and hydro power

throughout the Upper Yangtze River Basin. It is now apparent that the ubiquitous prescription of flood control storage in the numerous dams in the basin would be extremely problematic for other water management objectives. There is so much flood control capacity planned – between 105-112Bm^3 among all the large reservoirs – that the reservoirs could seldom if ever be refilled to full power pool capacity following the summer flood control season. There is simply not enough water available under current hydrology and climate. The basin as a whole has an average annual runoff of 480Bm^3 per year; October has about 45Bm^3 on average. In dry months there may not be enough to refill even Three Gorges Reservoir, 22Bm^3, if it must wait until after September to start refilling. Just which projects would have the priority right to refill from scarce physical supplies in the fall of each year has not been reconciled. Integrated basin planning, including floodplain management in addition to water management, can likely identify better alternatives. For example, flood storage could be reduced, and a portion of the consequent higher hydro power revenues could be dedicated to reducing flood risks in the floodplain.

In addition to identifying more optimal water management strategies, integrated basin planning can also be used to improve the environmental sustainability of a hydro power system. Within a basin or region undergoing development for hydro, a systems-level approach can allow various interests to work together towards a more optimal spatial arrangement of dams. The integrated basin planning described above – encompassing hydro power, water supplies and flood risk reduction – can be combined with detailed assessments of environmental and social resources. This process can identify those sub-basins or river reaches that have the greatest ecological and social values, and thus should receive greater protection, and those basins or river reaches in which hydro power development will have relatively lower impacts. Achieving this more optimal spatial arrangement of dams has obvious benefits for the maintenance of social and environmental values.

What may be less obvious is that such planning also holds benefits for hydro power proponents. This integrated planning approach may reduce controversy and risk during the development of projects that are selected through this process. Further, by pursuing conservation of resources through the spatial arrangement of dams, the dams that are built may have reduced environmental constraints on their operation.

In the Upper Yangtze River Basin, The Nature Conservancy, in collaboration with China's National Development and Reform Commission and State Environmental Protection Agency, has developed an ecological 'blueprint' that classifies freshwater ecosystems and identifies high-priority conservation areas (Figure 5). This blueprint can be overlain with dam development proposals to look for a best fit – what set of dams with what operating plans will give the most energy at the most needed times, and what arrangement of protected areas will maintain freshwater ecosystem services and representative freshwater biodiversity?

Developers or proponents of individual hydroelectric projects cannot by themselves drive meaningful system-wide planning, even if they see some opportunity for their own projects. This responsibility falls on governments, national or regional. Multiple projects and multiple water and energy management functions need to be considered simultaneously. The system-level planning described above can potentially be achieved within a comprehensive Strategic Environmental Assessment (SEA), increasingly called for by the World Bank and others.

In China, recent legislation has provided for what is called a 'Plan Environmental Assessment' (PEA). Although the PEA may contain many of the same elements, it appears to less comprehensive than a true SEA and may be more advisory than compulsory in controlling final development decisions. Meanwhile, the Comprehensive Plan for Water Development in the Yangtze River is being reviewed and revised by the Yangtze River Basin Commission (known as Chianjiang Water Resources Commission or CWRC in China). This, together with a comprehensive PEA, may provide a realistic surrogate for a Yangtze River basin-wide SEA.

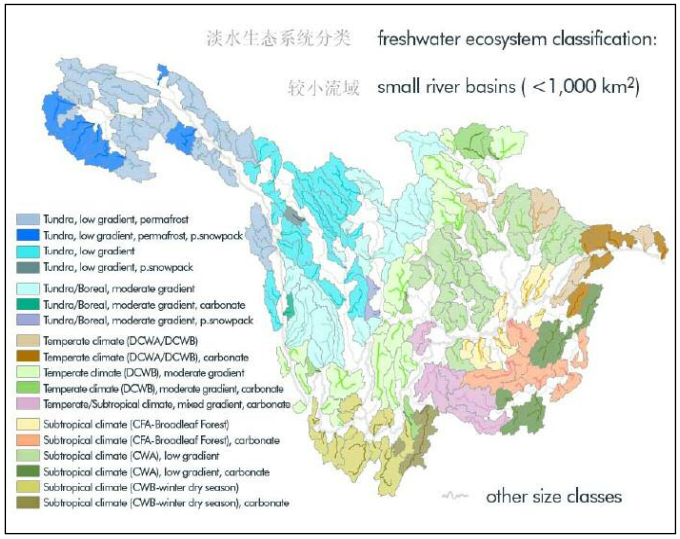


Figure 5: An ecological 'blueprint' has been developed that maps freshwater conservation targets and high-priority conservation areas.

Conclusions

Conditions in the Yangtze provide some optimism that China can develop the basin's hydro power resources in a manner compatible with maintaining its unique environmental resources. The CTGPC has expressed a willingness to review the design and operation of the four Jinsha Jiang dams and its scientists, along with the CWRC Scientific Institute, The Nature Conservancy, and numerous other experts, have been participating in a process to develop environmental flow recommendations for the upper Yangtze. As we describe here, we believe there is great potential for an environmental flow regime that both protects the river ecosystem and provides even greater hydro power generation than is currently anticipated.

However, true environmental sustainability on the Yangtze River will require more than environmental flows. This strategy must be augmented with protection of important free-flowing reaches and tributaries. As a first step, Chinese agencies are planning a nationally designated Upper Yangtze River Native Fish Reserve downstream from the four dams and upstream of the Three Gorges reservoir. The ecological blueprint should be used to identify additional important areas for protection.

Moving hydro power development in the Yangtze toward greater sustainability will require the integration of all the important processes described above, including comprehensive planning across sectors, environmental flow regimes, and using ecological blueprints to designate protected areas. Until all the hydro power developers, water managers, and other stakeholders come together to provide leadership for a true system-wide plan, real sustainability may remain an elusive and immeasurable goal. The Yangtze basin has the primary components in place to pursue such comprehensive planning: an ecological blueprint, a process for defining environmental flows, national-level leadership from NDRC Energy Bureau and SEPA, and a collaborative relationship between CTGPC, CWRC, The Nature Conservancy, World Wildlife Fund, and others. We acknowledge that forging all these components into a comprehensive planning process will require overcoming significant challenges; achieving sustainable outcomes confronts yet larger challenges. The Yangtze is immense in its scale and economic, ecological and cultural value. If those working in the Yangtze can overcome these challenges, the basin can serve as a remarkable model for sustainable hydro power planning and development. IWP&DC

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