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Assessing the influence of environmental impact assessments on science and policy: An analysis of the Three Gorges Project

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A R T I C L E I N F O

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A B S T R A C T

The need to understand and minimize negative environmental outcomes associated with large dams has both contributed to and benefited from the introduction and subsequent improvements in the Environmental Impact Assessment (EIA) process. However, several limitations in the EIA process remain, including those associated with the uncertainty and significance of impact projections. These limitations are directly related to the feedback between science and policy, with information gaps in scientific understanding discovered through the EIA process contributing valuable recommendations on critical focus areas for prioritizing and funding research within the fields of ecological conservation and river engineering.

This paper presents an analysis of the EIA process for the Three Gorges Project (TGP) in China as a case study for evaluating this feedback between the EIA and science and policy. For one of the best-studied public development projects in the world, this paper presents an investigation into whether patterns exist between the scientific interest (via number of publications) in environmental impacts and (a) the identification of impacts as uncertain or priority by the EIA, (b) decisions or political events associated with the dam, and (c) impact type. This analysis includes the compilation of literature on TGP, characterization of ecosystem interactions and responses to TGP through a hierarchy of impacts, coding of EIA impacts as "uncertain" impacts that require additional study and "priority" impacts that have particularly high significance, mapping of an event chronology to relate policies, institutional changes, and decisions about TGP as "events" that could influence the focus and intensity of scientific investigation, and analysis of the number of publications by impact type and order within the impact hierarchy. From these analyses, it appears that the availability and consistency of scientific information limit the accuracy of environmental impact projections. These analyses also suggest a lack of direct feedback between the EIA process and emerging science, as indicated by the failure of literature to focus on issues related to the design and management of TGP, ultimately challenging the environmental sustainability of the project. While the EIA process has enormous potential for improving both the basic sciences and the planning and sustainability of hydrodevelopment, important institutional changes need to occur for this potential to be realized. This paper concludes with recommendations about those institutional changes needed to improve the feedback between the science and policy, and ultimately the environmental sustainability, of large dams.

1. Introduction

1.1. Environmental impacts of large dams

Large dams offer society many benefits but simultaneously impose adverse, and often irreversible, impacts on the environment (World Commission on Dams, 2000). Dams fragment river systems, causing multilevel effects throughout the aquatic ecosystem in several ways. By interrupting the longitudinal connectivity of rivers, dams interrupt the migration of aquatic organisms and alter their life cycles (Andersson et al., 2000; Jansson et al., 2000; Morita et al., 2000; Dynesius and Nilsson, 1994; Dudgeon, 2000). The trapping of sediment and nutrients behind dams promotes downstream erosion, impairs habitat-building processes (Gosselink et al., 1974; Kondolf, 1997), and forces changes in the aquatic food chain (Humborg et al., 2000). Dams also modify temperature regimes both within the reservoir and downstream, thereby affecting the reproduction and composition of aquatic communities (Clarkson and

Abbreviations: TGP, Three Gorges Project; EIA, Environmental impact assessment; CIDA, Canadian International Development Agency; CYJV, Canadian Yangtze Joint Venture; SEA, Strategic Environmental Assessment.

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Childs, 2000; Walks et al., 2000). Other environmental effects include changes in flooding and hydrology patterns (Poff et al., 1997; Junk et al., 1989), landslide and earthquake occurrences (Edmonds, 1991), loss of biodiversity (McAllister et al., 2000), and changes to aquatic and terrestrial flora and fauna (see Kingsford, 2000 for review). Large dams impact the environment both directly and indirectly through various mechanisms that are well described in the literature (see for example, Li et al., 1987; Pfleiger and Grace, 1987; McCully, 1996; Friedman and Auble, 1999; Hughes and Parmalee, 1999; Aparicio et al., 2000; Jansson et al., 2000; Penczak and Kruk, 2000; Sharma, 2001).

To characterize and minimize environmental effects associated with proposed projects, environmental impact assessments (EIAs) have become a fundamental component of the planning process for large dams (IAIA, 1999). In the United States (US), the history of EIAs is tied to decades of industrial development and consequent environmental degradation. Regulatory protection of the environment in the US emerged largely through litigation. For example, the 1965 Scenic Hudson Preservation Conference versus Federal Power Commission suit demonstrated the judicial process as a way by which the public could use the legal system to enforce environmental laws. The US EIA process was created in 1969 with the passage of the National Environmental Policy Act (NEPA), which mandated assessment of the environmental outcomes of development projects. The EIA process was quickly adopted by governments and legislatures around world, including Japan (1972), Hong Kong (1972), Canada (1973), Australia (1974), the Philippines (1977), Taiwan (1979) and the People's Republic of China (1979) (Gilpin, 1995).

Some form of environmental assessment is now required in most developed countries and many developing countries. Numerous texts and guidance documents are available worldwide on the subject (World Bank, 1991; Canter, 1996; Petts, 1999; Glasson et al., 2005). The World Commission on Environment and Development's Brundtland Report (Brundtland, 1987) emphasized the importance of public scrutiny and consensus as part of the EIA process, promoting global responsibility for protecting the human and natural environment. In 1992, the United Nations Conference on Environment and Development in Rio devoted Principle 17 of their Declaration on Environment and Development to EIA as part of a larger call to relate human and environmental well being. Since its initiation in 1969, the EIA process has changed and expanded its scope, from basic characterization of a limited number of impacts to more current Strategic Environmental Assessments (SEAs) that evaluate direct and indirect impacts and address consequences of those impacts (Therivel, 2004).

One important component of EIA through time has been the uncertainties related to impact projections, which may either serve an important role in the design and assessment process (De Jonghe, 1992) for dams, or limit the utility of the EIA to influence project outcomes (Sadler et al., 2000). Uncertainty in predicting the significance and extent of environmental impacts arise from insufficient and/or inaccurate baseline information, unexpected changes in project plans, oversimplification in monitoring and modeling efforts (Glasson et al., 2005), and a failure to accurately assess causality (Perdicoúlis and Glasson, 2006). Failure to address these uncertainties is due in part to limitations on time and resources for scientific study, which Boxer (1988) reported would result in underestimation of negative impacts of a project.

An EIA lacking in time and resources for full scientific investigation can lead to a flawed assessment, thereby weakening the role of the EIA process as a platform for guiding the policy making and engineering for large development projects such as dams. However, this situation is different from one where the EIA, while thorough, is inconclusive. Whereas an EIA that is not fully developed given the available science is indicative of a failed process, an EIA that identifies scientific uncertainties leads the way for the EIA process to play a direct role in guiding the science, decision-making, and engineering design to improve the sustainability of large development projects. Issues identified in the EIA as "Needs for Further Study", for example, can inform the allocation of resources for impact assessment and mitigation (Clarke, 2000). However, it is more often the case that the influence of the EIA process on impact minimization is weakened by the information gaps, providing inadequate guidance for modifying designs, particularly when projects have limited flexibility in the timeline and budget.

To evaluate the role that EIAs can play in informing the science, design, and and policy of large dams, this paper presents an analysis of the literature on the Three Gorges Project (TGP) on the Yangtze River in China. This analysis was performed to compare initial documents of the TGP-EIA process with independent scientific assessments to investigate which issues were addressed in each. I sought to identify patterns in the number of peer-reviewed publications over time and across environmental impact types, using the impacts identified in the 1988 feasibility study by the Canadian Yangtze Joint Venture (CYJV) as the baseline EIA document. This analysis includes (1) the compilation of literature on TGP, (2) a characterization of ecosystem interactions and responses to TGP through a hierarchy of impacts, and (3) a coding of CYJV impacts as "uncertain" impacts that require additional study versus "priority" impacts that have particularly high significance, and (4) an event chronology to relate policies, institutional changes, and decisions about TGP as events that could influence the focus and intensity of scientific investigation.

This paper first introduces the background and EIA process for TGP and then reviews the projected environmental impacts and initial observations following construction. The relationships between the priority and uncertain impacts, impact types within the hierarchy, TGP decision and reporting events, and the literature that followed the 1988 CYJV feasibility study, referenced herein as (CYJV pp.), are then illustrated. The paper concludes with reflections on the science and policy of EIA in large dam development.

2. Three Gorges Project, China

The Yangtze River drains 1.8 million square kilometers of agricultural and industrial terrain reaching from northern Tibet to Shanghai where it empties into the East China Sea. With a total mainstem length of 6300 km, it is the third largest river in the world and the largest river in China in terms of length and water flow. As the river flows east through the Daba mountains, it encounters a narrow constriction at the Three Gorges of Qutang, Wu, and Xiling (or Sanxia). The entire Yangtze valley is important nationally and globally, supporting approximately one-third of China's population (Vemula et al., 2004) and substantial agricultural (70% of nation's rice) and industrial (40% of total output) production for China (Ryder and Barber, 1990). Further, the Yangtze River is China's treasure house of freshwater aquatic resources. The Yangtze basin, which comprises the mainstem, tributaries and connecting lakes and reservoirs, is rich in aquatic resources and has been listed in the Global Ecoregion 200 by the World Wildlife Fund (WWF) for priority conservation (Fu et al., 2003).

The Yangtze River is also responsible for some of China's worst natural disasters (Yin and Li, 2001). Major catastrophic floods occurring over the last century on the Yangtze include those in 1911, 1931, 1935, and 1954, resulting in the deaths of over 300,000 people (Jackson and Sleigh, 2000). A 200-year flood event in 1954 resulted in the death of 30,000 and the displacement of over one million people. In 1981, another flood resulted in the death of nearly 3000 people. As recently as 1998, flooding in the Yangtze caused over 4000 deaths, inundated 25 million hectares of cropland, and cost in excess of US $36 billion in damages to property and infrastructure (Abramovitz, 2001), providing part of the justification for the TGP.

The proposal for damming the TGP first came in 1919 from Dr. Sun Yat-sen, a founder of the People's Republic. For the following 60 years, plans for the 175 m high structure took shape. Construction began on the concrete gravity dam in 1993. With the closure of the structure in 2003, a 600 km long reservoir was formed upstream of the dam. To date, the TGP is the largest (Chen et al., 2001), most expensive (Qing, 1998), and most powerful (Lu, 1994) water project ever built in the world. It comprises a dam, two powerhouses, and navigation facilities. Fifteen years of construction and US $25 billion have moved the project towards its three objectives: (1) flood protection for over 10 million downstream floodplain residents, (2) over 20,000 MW of hydropower generation, and (3) improved navigation.

While the benefits of TGP are indeed substantial, the environmental impacts of TGP on the Yangtze River ecosystems cannot be neglected (Du, 1999; Yangtze Valley Water Resources Protection Bureau, MWR and NEPA, 1999; Chen, 2004; Huang, 2004). Given the enormous size of the dam as well as its strategic position at 1830 km upstream from the mouth of the Yangtze River, environmental impacts affect a wide range of river-related ecosystem components, among them hydrology, water quality, sediment regime, geology, and both the terrestrial and aquatic flora and fauna, including humans. Located in an exceptionally important conservation area (Park et al., 2003), TGP is set to affect the rich biodiversity of the Yangtze river (Wu et al., 2005) and the endangered status of 25 fish species within its basin.

Efforts to protect such areas now fall under the relatively recent EIA process in China (Ziyun, 1986; Chen et al., 2007), which requires the consultation and application of various policies and laws, including State Environment Protection Act (SEPA – 1979), Water Pollution Prevention and Control Law (1984), and Environmental Impact Assessment Law (2003) for major development projects. While Chinese law does require completion of an EIA prior to construction, the penalty for non-compliance is completion of a post-construction assessment. This leniency of EIA regulation and enforcement in China has resulted in a high failure rate in protecting the environment (Wang, 2007a,b). The EIA experience is similar to other environmental regulations in China, the enforcement of which has been estimated at only 10% (Gu, 2005a,b).

Following the questionable success rate of this strategy at protecting the environment, the policy and practice of environmental regulation in China are undergoing rapid change, as illustrated by recent interagency meetings organized by central governmental agencies (HWCC, 2007), the increasing public criticism of large development projects, and the organization of public interest groups in China. In 2004, SEPA suspended work on 30 projects nationwide, including TGP, to evaluate environmental assessments (Gu, 2005a,b). In 2005 alone, SEPA minister Zhou Shengxian reported 51,000 disputes over environmental pollution (Wang, 2007a,b), while Chinese environmental authorities report having received written and personal requests from 597,000 petitioners regarding environmental protection and rights in only four years (Chinese Academy of Environmental Planning, 2005). Community groups, ranging from local alliances to formal Non-Governmental Organizations, such as the Center for Legal Assistance to Pollution Victims and the Chongqing Green Volunteers Federation, are facilitating the regulatory disputes and advocating the rights of people and the environment in China with increasing frequency and intensity. These examples demonstrate how the policy and public awareness of environmental impacts are changing in China, with TGP-EIA both benefiting from, and contributing to, the elevated status of environmental issues on China's national agenda over the past decade (Heggelund, 2006).

The TGP-EIA process began when a preliminary feasibility study was commissioned (1983) and published (1985) by the Yangtze Valley Planning Office (YVPO), an agency of the Ministry of Water Resources and Electric Power. A second, more comprehensive feasibility report was later commissioned in 1986 and published in 1988 through the CYJV, a collaboration between China's Ministry of Water Resources and Electric Power and the Canadian International Development Agency (CIDA). This 10-volume, US $14 million study, hereafter referred to as the CYJV study, was based largely on the 1985 YVPO environmental assessment, reporting on the extent to which environmental and social impacts of the TGP affected its feasibility. This study, which was a fundamental document of the EIA process for TGP, concluded that environmental impacts would "not affect the overall environmental feasibility [of the project] and may indeed enhance the environment" (CYJV vol. 1; 16–12). By the end of 1991, the Three Gorges Dam Approval Committee and Ministry of Water Resources reviewed and approved the CYJV study. In January 1992, a state-appointed Approval Commission concluded that the CYJV study documented the benefits and costs associated with TGP in sufficient detail. After further review, SEPA accepted the CYJV study findings, emphasizing the importance of implementing recommended measures for limiting environmental impacts, while concluding that "environmental issues do not affect the feasibility of the project" (Changjiang Water Resources Commission, 2007).

The following review evaluates the 1988 CYJV study[1] as the baseline EIA document. The CYJV study mapped the Yangtze River into three primary impact zones: (1) the reservoir area, (2) the middle and lower reach region located between Sandouping dam and Jiangyin in Jiangsu Province, and (3) the estuary region located from Jiangyin in Jiangsu Province to river mouth and coastal area (Fig. 1). For this analysis, the environmental outcomes of TGP as described in the CYJV study have been remapped into a hierarchy of first, second, and third order impacts (Fig. 2) based on existing typologies (World Commission on Dams, 2000; Jorde et al., 2008) to illustrate their interactions, link impacts across the orders to investigate causality, and describe their coverage in the scientific literature.

2.1. Projected and realized impacts of TGP

Even in a very well-studied project such as TGP, information gaps exist. In this analysis, I utilize these gaps as an opportunity to investigate the relationships between science and the EIA to evaluate how scientific focus influences the projection of physical and biological impacts. In this regard, three questions were addressed:

1. How do decisions, documents, and recommendations that define the EIA process influence the number and type of scientific investigations on the dam impacts?
2. Does the classification of an impact as "uncertain" or "high priority" influence scientific attention?
3. Does scientific interest follow certain types of impacts? More broadly, what is the role of EIAs for driving the science of conservation, ecological and physical models, and environmental engineering?

An examination of these questions in the context of the CYJV study and the literature that it and the TGP project have spawned can help shape our understanding of the links between science and policy in EIA of large dams. An event chronology (Fig. 3) maps this literature by its timing and volume to explore the first question.

[1] The entire 10-volume CYJV study, obtained directly from CIDA, was reviewed as the basis for this analysis.

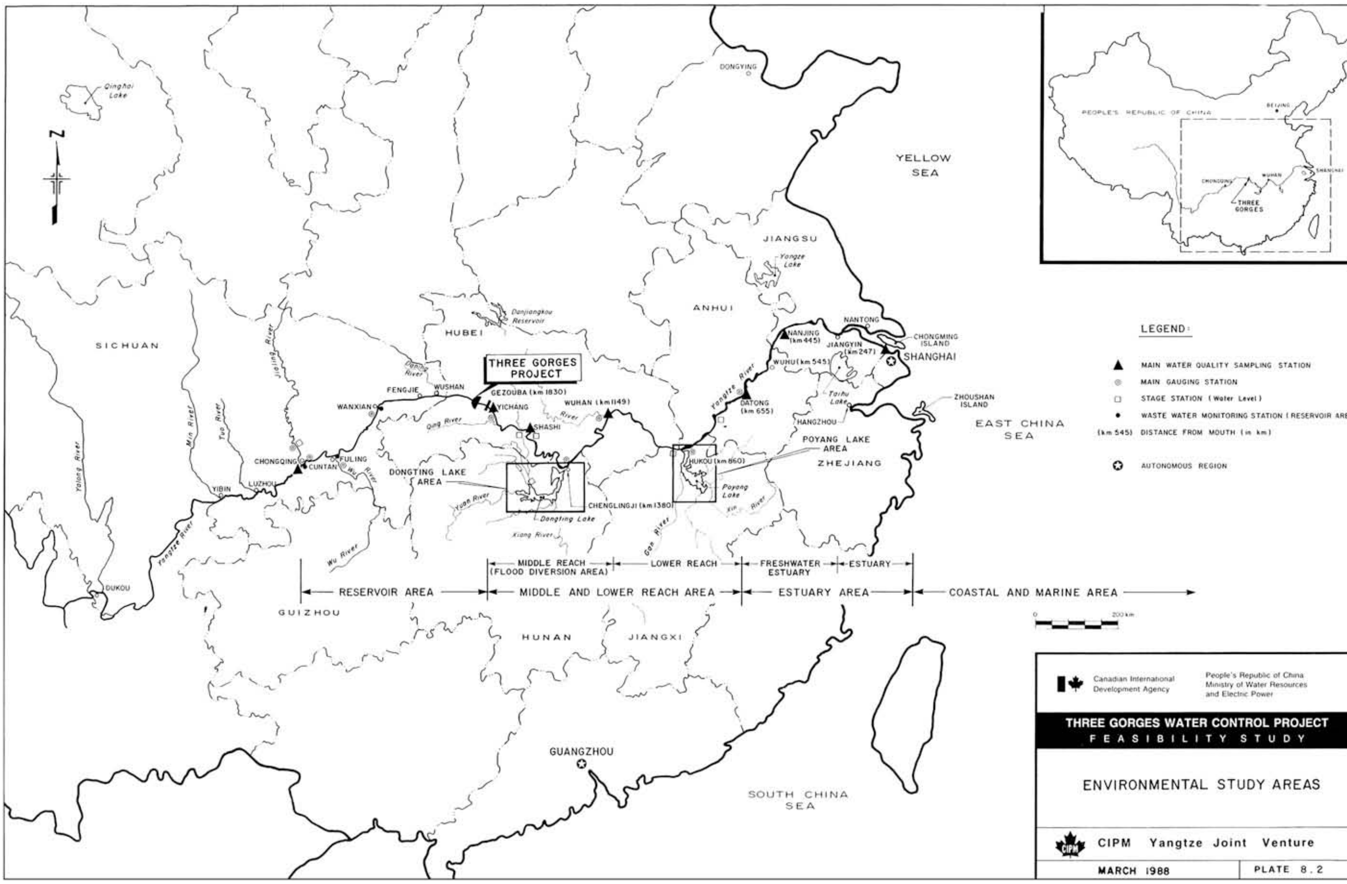

Fig. 1. CYJV environmental study areas map. Three impact areas were mapped, including the reservoir reach and three reaches below the dam. The tributaries surrounding and above the reservoir were not included in the study area because they were "not expected to affect the engineering feasibility of TGP" (CYJV; 1–4). Reprinted with permission from CIDA.

Coding of impacts (Fig. 4) illustrates scientific coverage on issues by impact types, priorities, and uncertainties to address the latter two questions. It is important to note that with only five years of evidence currently available in the literature on environmental impacts since the closure of TGP reservoir in 2003, any references to observed impacts are very preliminary. Because environmental outcomes of the project are expected to change over time and with changing operation and management strategies, a comprehensive analysis of environmental impacts of TGP may never be realized (Wang, 2003).

2.2. A hierarchy of impacts at TGP

According to established typologies (World Commission on Dams, 2000; Jorde et al., 2008), first order impacts include the primary effects that are directly associated with physical, chemical, and geomorphological consequences of dams and reservoir operation, including hydrology, climate, sediment, and water quality. The second order impacts include those related to primary changes in the ecosystem, such as habitat quality or quantity and primary productivity of algae and plankton. Third order impacts characterize the cumulative effects associated with first and second order impacts on the river system, including changes in the richness and distribution of aquatic and terrestrial plants and animals (Fig. 2).

Scientific coverage of these impacts is not uniform across the orders. Despite TGP being one of the best-studied modern dam development projects, the CYJV study noted critical gaps in knowledge regarding its impacts (CYJV, 9-32). Specifically, CYJV identified a critical need for further study of several second and third order environmental issues, particularly those related to the habitats and fate of Chinese Sturgeon, Yangtze Sturgeon, Chinese dolphin, and the Siberian crane (CYJV, 9–26). This finding supports the assertion that the techniques for predicting dam impacts on the physical environment (e.g., hydrology, sedimentation, water quality) appear to have advanced with the evolution of the EIA, while projecting impacts on the flora and fauna (e.g., genetic resources, significance of change on species and habitat) has not progressed at the same rate (Sadler et al., 2000).

2.2.1. First and second order impacts

2.2.1.1. Hydrology. With the impoundment of the Yangtze River, several hydrological changes have been acknowledged in the CYJV study and the literature. Among the reported hydrologic impacts is the inundation of 26 upstream tributaries that account for 21–33% of the reservoir surface area (CYJV, 6–14) as well as the mainstem of the Yangtze River, causing a velocity decrease by at least a factor of five (CYJV, 4–20). Further details of these impacts are available in the literature, including confirmation that the inundation resulted in lower velocities and sedimentation (Liu and Zuo, 1987), as well as increased evaporation of water from the increased surface area of the reservoir (Jackson and Sleigh, 2000).

Because reservoir operation at TGP is prescribed by the project objectives of flood control, power generation, and navigation (CYJV, 4–24), the reservoir water level was predicted to vary widely, from 15 to 30 m over the course of a year and up to several meters within a day (CYJV, 6–15). Further, water levels were projected to fluctuate in a cycle opposite from natural conditions, with lower levels during the summer and higher levels in the winter (CYJV, 6–15).

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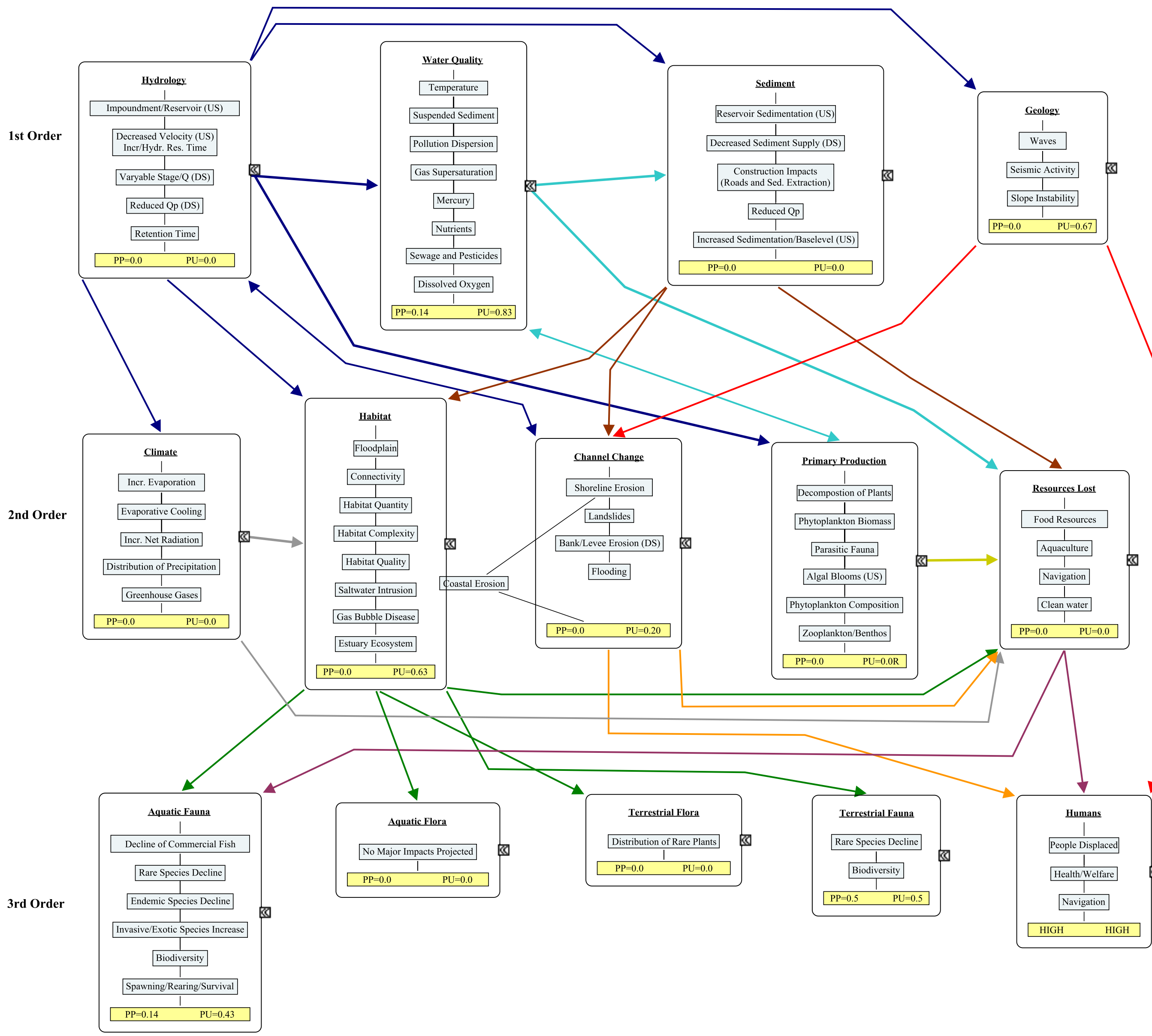

Fig. 2. Hierarchy and interactions of Three Gorges impacts. Primary changes in first order impacts translate into cumulative effects across the second and third orders. Only impacts considered in the CYJV study and the reviewed literature were included in this figure. PP indicates the proportion of the impacts in this category reported in the CYJV study to be "priority" impacts, whereas PU indicates the proportion of the impacts reported by CYJV as "uncertain. "

Downstream effects of this hydrologic modification were predicted to affect water levels in the mainstem and potentially the two largest freshwater lakes in China, Poyang and Dongting Lakes (CYJV, 6–15), the latter of which is home to 41 globally-significant aquatic and terrestrial organisms (Gui, 2007). The greatest reductions in discharge were projected to occur in October, when flows were estimated to be reduced by two-thirds of the pre-dam flows (CYJV, 6–26). Upstream of the dam, inundation of the reservoir area fragments habitat as people and wildlife are resettled. This secondary impact creates landbridges and issues of genetic diversity and intensified population densities as people and wildlife move to higher elevation areas (Wu et al., 2003).

Other secondary impacts associated with hydrologic changes reflect local and regional changes in climate. Climate modifications associated with TGP were projected to be minimal, occurring only locally within the reservoir region, and to be well within existing background variability (CYJV, 6–31). However, Miller et al. (2005) reported that preliminary changes in evaporation, evaporative cooling, and net radiation have already been detected in the reservoir area. Wu et al. (2006) simulated and observed increased precipitation in the region around TGP, specifically between the Daba and Qinling mountains, while precipitation was reduced within the TGP reservoir area following the closing of the dam's gates. The impact of flooding biomass and the resulting generation of methane from decomposing vegetation and organic materials, a potential source of greenhouse gasses (Palmieri et al., 2001; St. Louis et al., 2000), was not addressed in the CYJV study nor in the literature available on TGP at this time.

Hydrologic changes also result in changes in the microbial community structure as secondary and cumulative impacts. Observed community changes in the estuary and the East China Sea after the TGP gates closed in 2003 are attributable in part to the sudden decrease in runoff and related changes in temperature and salinity (Shan et al., 2005; Jiao et al., 2007). Similarly, phytoplankton abundance and biomass, negatively correlated to discharge in the mainstem of the Yangtze downstream of the dam, have been shown

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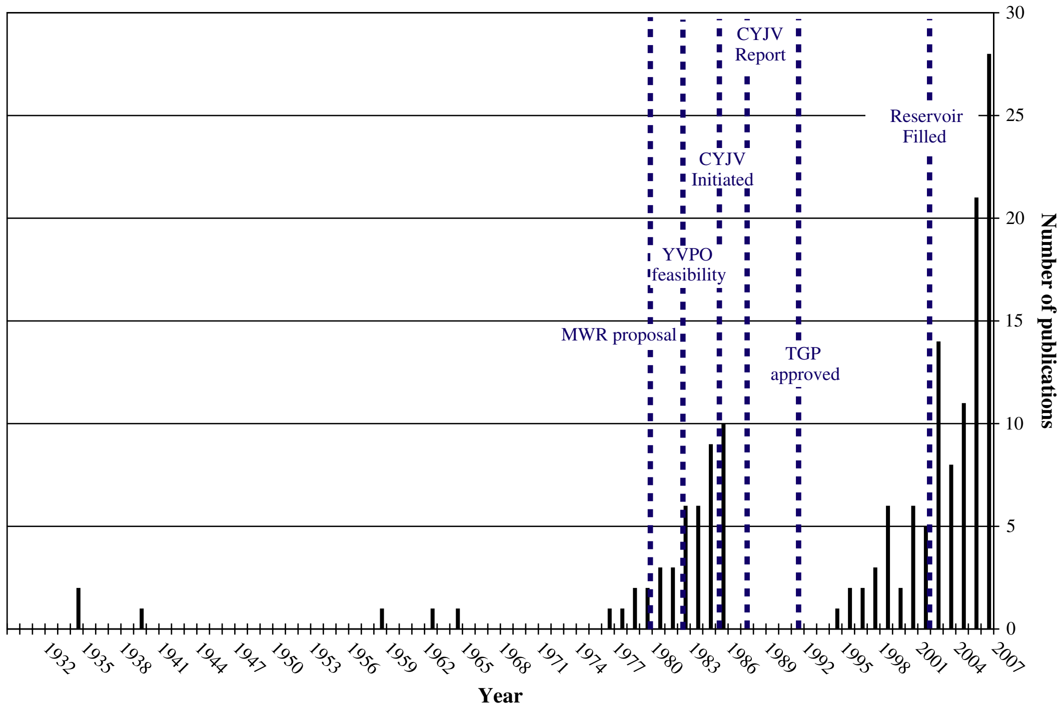

Fig. 3. Number of Three Gorges publications by year. Events are coded as "MWR Proposal" – Chinese Ministry of Water Resources (MWR) formally submitted the TGP proposal to the Chinese State Council for approval, "CYJV initiated" – following the recommendation of the State Council, the CYJV study was commissioned. "CYJV Report" – CYJV feasibility study completed. In June of 2003, the reservoir at TGP was formed, "Reservoir filled".

to decrease with the decrease in TGP discharge (Zeng et al., 2007a). Downstream hydrologic modifications were also projected to lead to an increase in the distribution of the snail host (*Oncomelania hupensis*) and thus occurrence of a blood fluke (*Schistosoma japonica*) (Xing-jian et al., 1999; Zheng et al., 2002). However, this prediction has been dismissed by some due to the steep shorelines that provide little habitat for the snail (Jobin, 2005). Upstream of the dam, occurrence of algal blooms within the TGP reservoir have been attributed to increases in residence time (Zeng et al., 2007b). Secondary impacts also extend to other parasitic fauna upstream of TGP, with the reservoir predicted to encourage the proliferation of a fish tapeworm (*Bothriocephalus acheilognathi*) (Morley, 2007).

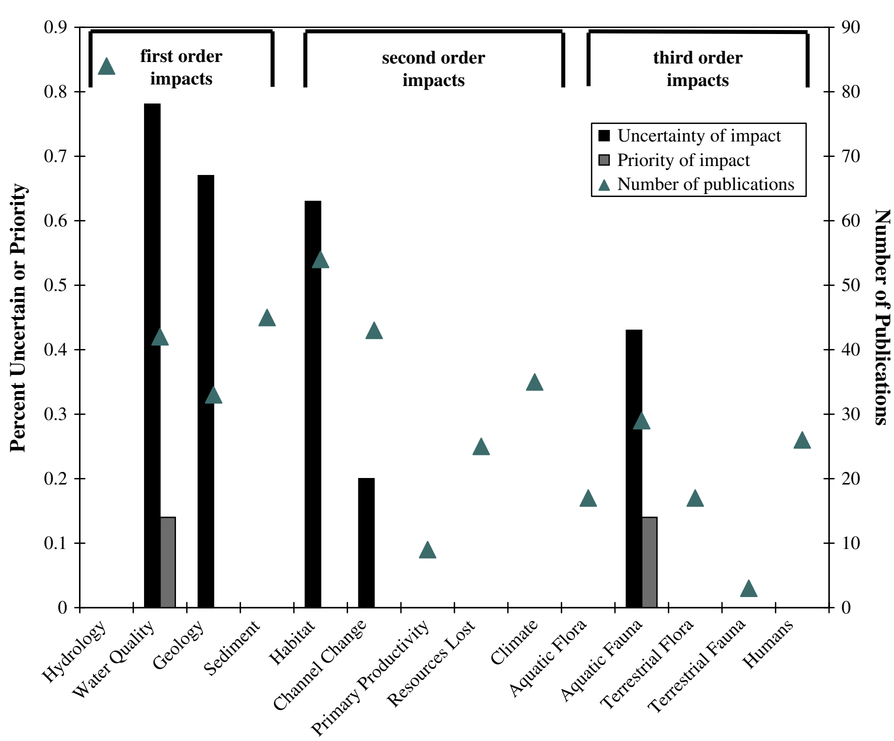

Fig. 4. Number of Three Gorges publications by subject. The number of publications for first, second, and third order impacts do not appear to be related to the CYJV study classification as uncertain or priority impacts.

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Secondary effects of modified hydrology also include changes in habitat, such as the submersion of sandbars that create eddies utilized by freshwater dolphins downstream of TGP as resting sites (Fearnside, 1988). While it has been reported that birds and mammals upstream of the dam would not be significantly affected by inundation due to their mobility (Xiao et al., 1999) and distribution in higher altitudes (Xiao et al., 1999; Lin et al., 2003), some evidence suggests that important habitats of terrestrial fauna may be by the changes in hydrology downstream of the dam. For example, the Poyang Lake Nature Reserve provides critical habitat to many unique and rare crane species, including the rare and endangered Siberian crane, of which 95% of the world's population overwinters at this reserve (CYJV, 6–99). The CYJV study does acknowledge that changes in hydrology could occur in this downstream lake. It recommends further study to evaluate the relationship between the mainstem Yangtze elevation and Poyang Lake (CYJV, 6-22) and acknowledges that the unknown impacts on the Siberian crane habitat constitute a critical environmental concern (CYJV, 6–106). In addition to the potential seasonal effects on the lake habitats downstream, filling of biodiverse side-channel habitats (Wang et al., 2005) and saltwater intrusion into the estuary may also occur (Chen et al., 2001) as a consequence of reduction of peak flows in the wet season.

Despite their expected significance on the ecosystem (Jackson and Sleigh, 2000), many of the secondary impacts of these reduced flood flows downstream in the wet season (summer and fall), as well as hourly and daily fluctuations in flow for hydropeaking during the dry season (winter and spring) and synergistic changes in water quality and sediment, were not well addressed in the CYJV study. For example, despite the substantial reduction in peak flows downstream, increased flooding of some areas below the dam could occur due to clearwater erosion and undercutting of the dikes along the Yangtze that protect cities from rising floodwater. This threat to dikes is the same mechanism by which the 1931 Yangtze flood caused so much damage (Fearnside, 1988). The CYJV study dismisses this impact, noting that general lowering of the downstream riverbed may occur but that revetments along the banks would prevent bank erosion (CYJV, 6–44). Similarly, while other second and third order impacts were identified in the CYJV study—e.g., the increased probability of upstream flooding due to increased base level from deposition of fine sediment at the upper delta of the reservoir (CYJV, 6–43; Maize, 1996), many were dismissed as insignificant and/or the significance internally contradicted by CYJV. This situation was partly a consequence of the difficulty in projecting second and third order impacts of large dams (World Commission on Dams, 2000) when baseline data are lacking (CYJV, 1988).

2.2.1.2. Geology. The scientific literature reports greater concern over geological impacts than was reported in the CYJV study. Erosion of reservoir shorelines caused by waves and fluctuating water levels and instability of slopes due to construction of roads and infrastructure are presented as the potential impacts of TGP by the CYJV study (CYJV, 6–37). The hundreds of known, existing landslides caused by deforestation, rural development, and underlying geology in the TGP region, some of which are in a state of active deformation (Chen and Cai, 1994; Liu et al., 2004), were predicted not to further destabilize with inundation at TGP (CYJV, 6–36). While the CYJV study did acknowledge that new landslides could occur around the reservoir area, it qualified its assessment by noting that landslides are a common feature of the Yangtze River valley and that the hazards are low, with impacts projected to fall primarily on navigation (CYJV, 6–36). Wu et al. (2001) confirm the low risk of landslides in the area, finding that landslide hazards cover an area of less than 5% of the total region, with secondary impacts not affecting the TGP but potentially affecting the navigation, highways, reservoir slopes, and building of cities and towns. These assessments of low hazard potential contrast with the work of Sheng and Liao (1997) who reported that the steep and unstable slopes of the Yangtze River valley, in addition to the land clearing and farming that further destabilizes the slopes, suggest a great potential for landslide hazards in the area impacted by the reservoir. A field study during the early 1980s by the Sichuan Provincial Geological Office found 203 landslide and mud-flow foundations in the reservoir area (Edmonds, 1992), which may have provided the foundation for a particularly large (approximately 20 million m3) landslide that later occurred in July 2003. Other investigators attribute this landslide, at least in part, to the filling of the reservoir at TGP (Dai et al., 2004; Wang et al., 2004). The debate over the influence of TGP on landslide hazards continues. In 2007, a smaller landslide in an area near the dam resulted in the death of one nearby worker, injury of another worker, and the disappearance of another two workers. The State-run Xinhua News Agency reported that no evidence exists to link the landslide to TGP (Chang, 2007).

Another geologic hazard of TGP is reservoir-induced seismicity, known to have caused earthquakes in India (Konya), China (Xinfeng Jiang/Hsingfengkiang), Zimbabwe (Kariba), and Greece (Kremasta) (Talwani, 1997). However, the CYJV study projected the TGP seismicity risk to be low following inundation (CYJV, 6–37). A similar assessment is supported by the work of Tan et al. (1997). However, Williams (1990b) noted substantial deficiencies in the CYJV study's geological assessment, including the underestimation of earthquake ground accelerations leading to an inadequate analysis of reservoir-induced seismicity. Zheng (1992) agreed, noting that over twenty earthquakes have been recorded in the reservoir area, with magnitudes over 4.75 on the Richter scale, with one measuring 6.5. Williams (1990b) has argued that the CYJV study finding of no impact was based on a record of insufficient data, with a resulting underestimation of the potential magnitude and/or frequency of these events. These critiques have preliminary support from the recent displacement (10–40 mm vertically, 5–10 mm horizontally) of the lithosphere crust following the reservoir impoundment at TGP (Du et al., 2005).

2.2.1.3. Water quality. The CYJV study examined water quality impacts, finding that while there was insufficient information existed to determine the significance of many water quality effects (e.g., temperature, suspended sediment, pollution dispersion) of TGP, none of these effects were likely to influence the feasibility of the project (CYJV, 6–68). The study did note potentially significant impacts of supersaturation below the dam, resulting in fish kills from gas bubble disease (CYJV, 6–22), as well as the presence of mercury in inundated soil and plants of the Yangtze basin, which would prohibit human consumption of fish (CYJV, 6–66). It suggested that both could be mitigated by monetary compensation, enhancement measures, and aquaculture production (CYJV, 6–22; 6–68). Not only does the scientific literature contradict these findings but the CYJV study contradicts itself. For example, CYJV reported that TGP would either have no effect on, or would reduce saltwater intrusion (CYJV, 6–23), but later reported that reduced flows could significantly increase saltwater intrusion (CYJV, 6–26). Early reports attempting to predict salinity effects found that while saltwater intrusion may not occur during the low-water season under the increased baseflow, it could occur in the wet season as the reservoir stores water and flows are reduced downstream (Liu and Zuo, 1987). More recent assessments found that saltwater intrusion was already increasing in the Yangtze estuary prior to closure of the dam at TGP (Xing et al., 2001), potentially influencing waterworks (Chen, 1998), water supply (Li and Shao, 1996), crop productivity (Shanzhong et al., 2007), and the estuary ecosystem (Zhu et al., 2006).

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Changes in flow and water quality appear to have already affected the microbial communities of the Yangtze mainstem and estuary. Since inundation of TGP in 2003, substantial algae blooms, predominantly dinoflagellates (*Peridiniopsis* spp.) and diatoms (*Cyclotella* spp.), have been observed, particularly during the spring dry season (Cai and Hu, 2006; Tang et al., 2006). At this stage, it is unclear whether changes in primary production are a response to declines in water quality or changes in flow regime. Cai and Hu (2006) report that overall water quality was not degraded in the TGP reservoir, due in part to the low retention time of water. However, a laboratory study of inundated reservoir soils found that they released substantial amounts of nitrogen and phosphorus to the overlying water upon submersion (Liu et al., 2004). Further, Gong et al. (2006) reported a substantial decrease in Si:N ratio at Datong downstream of TGP, accompanied by a 55% reduction in sediment loading and an 86% decline in primary productivity, which they explained by changes in nutrient supplies associated with the 2003 filling of TGP. While these data have been called into question due to the temporal and spatial coverage of the dataset (Yuan et al., 2007), other negative impacts regarding eutrophication in the tributaries upstream of TGP are predicted (Zhang et al., 2007) due to the decreased velocity from the impoundment.

Another water quality concern is that of methylmercury production, a central nervous system toxin (Clarkson, 1987). It is easily absorbed into the tissue of fish that may be consumed by humans, and subsequently result in mercury poisoning at modest consumption rates (USEPA, 2001). Newly-formed reservoirs are known sources of methylmercury to the aquatic food web (Kelly et al., 1997; Duchemin et al., 1995; Bodaly et al., 1997). While the CYJV study indicates that inorganic mercury is present in the sediment, soil, and vegetation in the area inundated by TGP (CYJV, 6–66), no attempt to analyze the risk to the ecosystem or to humans eating contaminate fish from reservoir sources was made because it was believed that the lost food resources for people could be replaced or mitigated by monetary compensation, enhancement measures, and aquaculture production (CYJV, 6–22; 6–68).

Other water quality impacts are relevant to this analysis of TGP but were given little attention in the feasibility study due to insufficient data. For example, changes in temperature were projected to reduce crop yields for those diverting the Yangtze River for irrigation (Fearnside, 1988). Further, over 10 million tons of industrial wastewater and domestic sewage are discharged into the Yangtze river and its tributaries each day upstream of TGP (Heming and Rees, 2000), in addition to the 28,000 tons of nitrogen and 80 tons of pesticides in annual agricultural runoff discharged into the river (CYJV, 6–47). These combined pollutants will accumulate in the reservoir, increasing potential for algal blooms and water quality impairment within the reservoir. As soils are flooded and submerged plants decompose, anoxic conditions created by algal blooms may further affect water quality by releasing soil-bound nutrients and pollutants (Gunnison et al., 1984). Unfortunately, the potential development of these impacts could not be thoroughly addressed because so ‘‘little water quality data [were] made available to CYJV’’ (CYJV, 6–51).

2.2.1.4. Sediment. The first order environmental impacts associated with changes in sediment regimes reported to affect the feasibility of TGP are those of reservoir sedimentation, deposition, and higher flood levels upstream of the reservoir, as well as degradation and possible river regime changes downstream of the dam. (CYJV, 6–43). Substantial scientific study of the Yangtze River sediment regime began in the 1950s and has continued (e.g., Gu et al., 1987; Gu and Douglas, 1989; Higgitt and Lu, 1996; Lu and Higgitt, 1998) with an entire 2001 issue of the journal *Geomorphology* dedicated to describing various features of the Yangtze river's sediment dynamics. Despite such extensive information on Yangtze sediment regime, some discrepancies are found between the CYJV study's predicted sediment impacts and reports in the literature. This difference in views is primarily related to the sedimentation rates estimated for the approximately 530 million tons of sediment entering the TGP reservoir every year. The CYJV study reported, with little noted uncertainty, estimates of sedimentation rates in the reservoir of 80% for the first 50–60 years, predicting that alternating deposition and erosion would occur to maintain 95% of live storage over the long-term (CYJV, 6–43). However, Luk and Whitney (1990) found that these rates underestimate sedimentation at TGP because some important factors were not considered, among them new sources from resettlement, land clearing, and reservoir shoreline erosion, as well as existing upstream sources on terrace floodplains that may be mobilized. Further, Williams (1990a) questioned several calculations in the CYJV study that could result in underestimating sedimentation, including those associated with the calculation of equilibrium slope, bed load of the Yangtze, and reservoir trap efficiency. Complicating the estimate of a Yangtze River sediment budget, China has begun working to reduce sediment volumes arriving at TGP, including acting on suggestions from the Yangtze Valley Planning Office to build more dams upstream to trap sediment (Luk and Whitney, 1990).

Regardless of the exact figures for sediment trapping at TGP, impacts associated with the modified sediment regime are expected to extend both upstream and downstream of the dam. Upstream of the dam, sedimentation is expected to extend into the mainstem and tributaries up to Chongqing (Liu and Zuo, 1987), likely affecting navigation at the upstream end of the reservoir (Fearnside, 1988) and potentially altering flood levels for upstream communities (Maize, 1996). Downstream of the dam, the sediment reduction is anticipated to have multiple effects. Channel erosion is predicted to increase and lead to deepening of the mainstem Yangtze, eventually reaching the lower stretches of the Yangtze's middle reaches (Liu and Zuo, 1987). While the CYJV study notes that this type of erosion may occur in some areas, it does not consider it to be significant (CYJV, 6–45). The CYJV study does acknowledge several negative impacts of sedimentation. It reports that the decline in sediment supply, estimated by Koshikawa et al. (2007) to be 23% for the first 50 years, could create a serious problem for the flood protection infrastructure and unprotected alluvial terraces due to redirection of flows (CYJV, 6–45). Sediment decrease and flow changes could also have second order impacts downstream of TGP on the preferred habitat of the Chinese dolphin. CYJV addresses this potential impact with the recommendation that ‘‘remedial measures to ensure conservation of prime habitat should be envisaged where deemed necessary’’ (CYJV, 6–45). The CYJV study also predicts that the reduction in sediment supply will have a small but long-term effect (i.e. centuries) on the sediment budget of the Yangtze estuary (CYJV, 6–45).

Since the TGP impoundment, downstream effects have already been observed, including a 65% reduction in sediment load in 2004 (Yang et al., 2006), one year after the dam was closed, and up to 25% reduction of net deposition in Lake Dongting downstream of TGP (Dai et al., 2005). This reduction in sediment discharge associated with TGP has been characterized as generating an ‘‘ecosystem disaster’’ for the inner shelf off the Yangtze River in the East China Sea (Changsheng et al., 2003). Drawing from their estimate of a 31% decrease in the supply of sediment to the estuary, Yang et al. (2007a,b) have found that the deltaic coast of the Yangtze River has already begun to recede and predict that coastal erosion will intensify with time. Others predict that changes in sediment supply, which acts as the primary driver of deposition and erosion in much of the Yangtze River, will lead to extensive erosion for the next 50 years, after which a balance of supply will be reached and erosion will be reduced (Yang et al., 2007c). These changes in erosion and deposition associated with coastal sediment dynamics define a secondary impact of TGP on estuary habitats, where the interannual and interdecadal growth rates of intertidal wetlands are strongly linked to the sediment supplied by the Yangtze River (Yang et al., 2005).

2.2.2. Third order, cumulative impacts

First order and second order impacts translate into third order, cumulative impacts that can result in substantial losses for aquatic and terrestrial organisms and the humans who live around and make use of the river system. The CYJV study predicted that the most critical of the third order impacts for TGP would fall on three rare and endangered aquatic species and their habitats—the Chinese dolphin, the Chinese sturgeon, the Yangtze sturgeon (CYJV, 6–95). Research studies extend these impacts to other fish species. For example, mathematical models predict that as many as six endemic fish species have a high probability of extinction, while the future of 14 other species is uncertain (Park et al., 2003).

2.2.2.1. Flora. The Three Gorges area is home to a number of important plants (Ye et al., 2001), which are likely to be impacted by construction, resettlement, and reservoir inundation. For aquatic flora, the CYJV study reported that river-system plants were already heavily modified due to agriculture, water diversions, and pollution (CYJV, 6–69), thus projecting a ''low magnitude of predicted effect and little proliferation'' (CYJV, 6–81). Morley (2007) also reported a low impact of TGP, finding a limited area for plant growth in the reservoir due to the steep shoreline and resulting narrow euphotic zones.

The CYJV study also argued that insufficient data existed on the distribution and abundance of rare plants in the terrestrial area around TGP (CYJV, 6–104). Since the CYJV study, Xiao et al. (1999) have found 47 plant species among the flora of the Three Gorges region that are listed as ''Rare and Endangered Plant Species Protected in China,'' with four species in Class I and 21 species in Class II under China's Wild Animal Protection Law (1989). On this point, the CYJV study has taken the position that the TGP will have no direct impact on natural vegetation because the region has already been so heavily impacted by historical and current anthropogenic activities (CYJV, 6–104). However, it has since been estimated that at least 34 local plant communities, including some found only in the reservoir area, will be partly or completely inundated (Chen et al., 1994; Huang, 2001). Among the rare and endangered plants distributed in the reservoir region, the geographic range of *Adiantum reniforme* var. *sinense*, a species of fern that is important both scientifically and culturally in China (Liu et al., 2007), is predicted to be partly submerged and will further decline due to damage by resettlement activities. A large proportion of the range for two subtropical fruits, *Litchi chinensis* Sonn. and *Dimocarpus longan* Lour, will be submerged by the reservoir. Among the specific native terrestrial plants in the reservoir region, *Myricaria laxiflora* was projected to be most affected by reservoir impoundment (Xiao et al., 1999) and is now extinct due to habitat loss (Liu et al., 2006).

2.2.2.2. Terrestrial fauna. The comprehensive impacts on the terrestrial fauna are not particularly well understood although acknowledged primary impacts include (1) inundation and modification of habitats, including low-altitude grasslands and grass farmlands, and (2) changes in the food web. The CYJV study specifically reported a priority concern for the Siberian crane at Poyang Lake Nature Reserve downstream of the dam. The study notes that hydrologic and sediment regime modifications could have unknown impacts for this endangered species (CYJV 6–106). Additionally, researchers express concern over the upstream flooding of the valley that is projected to result in over 100 mountaintops and ridges becoming landbridge islands (previously connected land areas isolated by flooding or rising sea levels) (Wu et al., 2003), potentially causing changes in vertebrate species diversity and dominance of non-endemic species (Cosson et al., 1999).

2.2.2.3. Aquatic fauna. The impacts of TGP are uncertain at several levels of the aquatic food web, from phytoplankton up through fish species. The CYJV study projected only small changes in zooplankton and benthos abundance and found that those increases would be of little significance to the fishery (CYJV, 6–81). However, substantial increases in phytoplankton biomass in response to the reduced velocities of the reservoir and increased transparency of streamflow released downstream have already been observed (Kuang et al., 2005; Xue et al., 2006). Some researchers argue that these changes in productivity of the channel will (1) impact water quality by increasing levels of eutrophication and (2) reduce Dissolved Oxygen (DO) levels, resulting in second order impacts, such as higher concentrations of toxins in the water, habitat loss, and reduction in food sources for fish (Xie, 2003; Fearnside, 1988). It is these second order impacts that drive adverse effects on the food web; TGP is predicted to negatively impact between 40 (Fu et al., 2003) and 80 fish species (Liu and Zuo, 1987). One indication of these changes in the food web is the increasing gradient of copepod density observed since the 2003 impoundment (Yao et al., 2007). Reports of change in the next level of the food web have been published as well. For example, there has been a shift in the density and composition of benthic macroinvertebrate communities in Xiangxi Bay of the Three Gorges Reservoir towards a dominance in oligochaetes in the two-year period after TGP's initial closure, presumably due to sedimentation in the bay (Shao et al., 2006a). Also at the mouth of the Yangtze, researchers at the National Taiwan Ocean University have reported an 86% reduction in the high productivity zone and a 55% reduction in sediment load, both attributable to a reduction in flows during the flooding season (Marshall, 2006). This study also reported a shift from silicaceous diatoms to flagellates in the Yangtze River estuary, a condition which will negatively impact the health of the fishery through flagellate depletion of oxygen, release of toxins, and reduced quality of food (Marshall, 2006). These impacts may relate to other changes in the food web, with observed shifts in fish community composition at Guanzhuangping Bay from historical species to more opportunistic species (Shao et al., 2006b). The CYJV study acknowledged the uncertainty of these impacts, asserting that since too little information is available, these types of estuarine impacts are unpredictable (CYJV, 6–94).

Prior to TGP, 172 species of fish resided in the reservoir region, 25 of which were caught commercially (Wegner, 1994), serving as an important food resource for the residents of the Yangtze River valley. Affecting these fish are important secondary impacts that include the possible detention of fry spawned in the upstream reaches in the reservoir, preventing them from reaching their rearing grounds in Dongting Lake which is connected to the Yangtze River downstream of TGP (Chen et al., 2002; Duan et al., 2002; Qiu et al., 2002). Huang (2001) has reported on the range of fishes in the middle and downstream areas of the Yangtze that will be narrowed due to decreases in fry supplementation from the affected upstream systems. Interestingly, the third order impact of losing an important migratory pathway is given as a primary reason for dismissing the impact of turbines on fish mortality (CYJV, 6–88). No literature since the release of the CYJV study has confirmed or denied this assertion. Another secondary impact is the effect of flooding on the existing aquaculture facilities, irrigation ponds, and rice fields, which combined are responsible for twenty times the annual production of the region's natural fisheries (Wegner, 1990). The CYJV study acknowledges that the consequences of losing these aquaculture facilities are serious (CYJV, 6–87), noting that these impacts should be addressed by further aquaculture development and production (CYJV, 6–88).

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While public release of data on centrally coordinated fisheries monitoring at TGP has been restricted until 2009, preliminary reports provide evidence of third order responses to TGP in the three years following initial closure, including 50–70% decreases in annual harvest of carp and up to 95% decrease in carp eggs and larval carp, both of which can be attributed to changes in temperature and hydrologic regimes (Xie et al., 2007).

The aquatic species most critically affected by TGP are those considered special, rare, or endangered, or those found only in the geographical region occupied by the Yangtze. The CYJV study found essentially no impact on some rare species, including the Chinese Paddlefish and Chinese Sucker (CYJV, 6–81) and discounted impacts on the Finless porpoise, finding that "because of the relatively wide range of this somewhat rare species and the minor changes in hydrology of the lower reaches and the estuary, no significant impact is anticipated" (CYJV, 6–81).

While the CYJV study dismissed impacts on the abovementioned rare aquatic species, it did acknowledge impacts on others. The fate of the Chinese dolphin, Chinese sturgeon, and Yangtze sturgeon are three of the primary five aquatic environmental issues not dismissed by the study (CYJV, 6–94). At the time of the CYJV study (1988), the Chinese dolphin (*Lipotes vexillifer*) was considered the rarest freshwater dolphin in the world, with only 200–300 individuals remaining. The impacts of TGP on the Chinese dolphins are indirect since this species is found only in the middle and lower reaches of the Yangtze below Yichang and rarely migrates into the Three Gorges area. The State Council Three Gorges Project Construction Committee (2004) suggested that the project could improve the fate of Chinese dolphin, by providing deeper water to escape accidental deaths and strandings and through improved management of the Yangtze fisheries. However, researchers warned that changes in downstream hydrology, degradation of the channel and aggradation of small island and sandbars, could potentially destroy resting areas and reserves (Fearnside, 1988; Perrin et al., 1989). The CYJV study acknowledged the potential severity of impacts on Chinese dolphins but noted that insufficient information existed to evaluate the magnitude of the impact (CYJV, 6–91) and recommended immediate implementation of monitoring studies and mitigation measures (CYJV, 6–94). Apparently such a program has either not been implemented or has not been successful because in late 2006, officials declared the species functionally extinct (Lovgren, 2006).

The fate of the Chinese sturgeon (*Acipenser sinensis*) is still unclear. A large, migratory fish, the sturgeon's range was limited in 1981 by the existing Gezhouba Dam downstream of TGP. The sturgeon has since spawned in the 10 km downstream of the Gezhouba dam. However, it was projected in the CYJV study that TGP created an additional third order impact on the spawning success of the sturgeon in response to flow reductions in October (CYJV, 6–90). Additionally, extraction of up to 13 million tons of sand and gravel for the construction of TGP may "coincide with key spawning grounds for the rare and endangered Chinese sturgeon" (CYJV, 6–44). While, insufficient information was available for the feasibility study authors to assess the significance of impacts on Chinese sturgeon (CYJV, 6–90), researchers (Xie, 2003) later predicted that the 41% reduction in discharge downstream of the dam would most likely destroy the remaining breeding grounds available to the sturgeon. Navigation noise from increased shipping and mortality due to a reduced supply in food resources have also been reported as potential impacts on sturgeon population viability (Edmonds, 1992).

2.2.2.5. Humans and the environment. Described in the CYJV study as "the most significant environmental issue of the project," the third order impacts on humans are primarily those associated with resettlement (CYJV 8, 9–26). With initial estimates of three quarters of a million people resettled (CYJV 8, 9–26), increasing to over 1.2 million people (Heming et al., 2001), the impacts are broad. Driven by deforestation and cultivation of steep slopes, land recontouring and water development projects, and increased densities of people in urban areas of up to double the national average (Yardley, 2007), these impacts could lead to increased surface runoff, wastewater discharges, and erosion. While these environmental impacts are difficult to measure, they may substantially add to the cumulative effects of TGP on the environment of the Yangtze River system.

2.3. Analysis of the impact projections and the literature

With the purpose of the EIA to both support policy and design considerations and to minimize environmental impacts (Petts, 1999), evidence of scientific focus on uncertain and priority impacts should be clear. To evaluate how impacts of TGP were considered as priorities to scientists and the funding agencies, a collection of literature on environmental impacts of TGP was compiled and reviewed. References for this literature search were identified through the bibliography of the 1988 CYJV study and through a search in several databases, undertaken using the keywords "Three Gorges" and "Dam." Electronic databases checked included Web of Science (1970–present), GeoRef (1985–present), Environmental Science & Pollution Management (1967–present), Aquatic Pollution & Environmental Quality (1990–present), Aquatic Sciences & Fisheries Abstracts (1978–present), EIS: Digests of Environmental Impact Statements (1985–present), and Water Resources Abstracts (1967–present). This literature analysis focused on articles published since the 1988 release of the CYJV study with relevance to environmental impacts. The papers were used to map the scientific interest in environmental impacts at TGP across time, impact types, and the CYJV study findings.

2.4. Environmental impacts and impact interactions at TGP

While Fig. 2 is not an exhaustive road map of all potential impacts at TGP, the hierarchical analysis includes and links those impacts treated in the reviewed literature. This analysis is valuable for investigating how uncertainty and priority translate across impacts and illustrates the interactions between higher and lower-order responses to TGP. For example, hydrologic impacts directly influence numerous other responses to TGP, including those of first, second, and third orders. While the CYJV study treated hydrologic impacts as having little uncertainty or priority, it considered some secondary impacts influenced by hydrology to be uncertain and/or priority. Among those affected by hydrology is habitat. The percentage of habitat impacts classified as uncertain is high (0.63), but the percentage of habitat impacts classified as priority is low (0.0). Habitat then influences impacts on aquatic fauna, which were classified as both priority (0.14) and uncertain (0.43) in the CYJV study. This dichotomy illustrates that inconsistencies exist in the knowledge about sources of uncertainty and in the prioritization of impacts. If hydrologic impacts were considered certain, but habitat impacts are uncertain, it could be concluded that habitat is influenced by other, unidentified drivers, that the links between hydrology and habitat are unclear, or else that the certainty of hydrologic impacts is not as great as stated. Similar inconsistencies exist with water quality impacts, noted as highly uncertain by the CYJV study, though secondary impacts associated with degradation of water quality, such as changes in primary productivity and resource availability, were not considered to be uncertain. These types of inconsistencies illustrate how uncertainty is not consistently translated across linked impacts in the EIA process and provide justification for linking the lower-order drivers of change (e.g., hydrology, water quality) to cumulative responses (e.g., aquatic fauna) to establish causality (Perdicoúlis and Glasson, 2006)

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in study impacts. This hierarchical analysis not only illustrates those links and thereby identifies areas for future study as part of the EIA process, it also emphasizes why a single disciplinary approach to impact assessment is incompatible with the environmental protection objectives of EIA.

2.5. Literature coverage of impacts across time and EIA decisions and reporting

An event chronology was constructed by overlaying a distribution of publications in each impact area over time (Fig. 3) with dates of important decisions and reports in the EIA process to illustrate the relationship between the EIA process and the number and focus of research publications. Numbers of publications increased in the years just before the Ministry of Water Resources formally proposed the TGP to the State Council in 1983 and continued to rise up through 1986 when the CYJV study was commissioned. For the next seven years, little literature was published on TGP, despite the release of the CYJV study in 1988. That pattern shifted again in 1995, two years after the TGP was formally approved by the State Council. With the reservoir closed in 2003, scientists are increasingly reporting initial responses of the Yangtze River environment to TGP. The findings of those studies, as discussed in the previous sections, indicate mixed and inconclusive impacts of the project. Disagreement between scientists and between scientists and state officials emphasizes the remaining uncertainty in impact significance, four years after the project closed the reservoir.

2.6. Literature coverage of impacts and findings of CYJV study

The uncertainty of impact projections appears to generally decrease with increasing order across the hierarchy (Fig. 4). While uncertainty in hydrologic and sediment impacts was considered low by the CYJV study, the uncertainty of other first order impacts, including water quality (0.83) and geology (0.67), was high relative to the impacts in the second (e.g., habitat at 0.63) and third orders (e.g., aquatic fauna at 0.43) with the greatest uncertainty.

The focus of research efforts does not tend to fall primarily on impacts that were classified in the CYJV study as uncertain or priority (Fig. 4). Instead, the studies appear to be distributed across impacts independent of prediction confidence and impact significance as stated in the CYJV study. For example, despite the lack of uncertainty in projections about hydrology, it was the best studied of all environmental impacts with 84 publications devoted to it. In contrast, the uncertain effects of TGP on habitat were the second most-cited of the impacts, a situation consistent with the high percentage of uncertain, but low priority, classification of habitat impacts in the CYJV study. In this latter case, scientific interest followed classification of uncertain, rather than priority, impacts. From the other cases, no relationship appears to exist between the classification of impacts by CYJV and the number of scientific publications. For example, the well-studied impacts on water quality and aquatic fauna received the highest number of priority classifications by CYJV but were also considered highly uncertain by CYJV. In contrast, several impacts across the three orders (e.g., sediment, climate, human environment) were relatively well cited in the literature despite not being noted as priority or uncertain impacts in the CYJV study. Other first and second order impacts (e.g., water quality, geology, channel change, aquatic fauna, lost resources) have been relatively well studied, with 40–50 publications each since 1988, across mixed levels of uncertainty and/or priority indicated by the CYJV.

With the exception of the secondary impacts on primary productivity, the least studied impacts primarily fell into the third order, represented by only 20% of the publications, whereas first order and second order were addressed by 44% and 36% of the literature, respectively. This lack of attention on the cumulative effects of TGP is consistent with what Brookes (1999) describes as the difficulties attributed to predicting flora, fauna, and other higher order impacts due to the multitude of interactions defining them (see Fig. 2).

This analysis leads one to question why scientific interest failed to follow uncertain and poorly understood, but important impacts: were hydrologic impacts more uncertain than the CYJV study indicated? Why was water quality not of greater interest to funding agencies and researchers? The lack of consistency between scientific focus of literature published since the 1988 CYJV study and the noted limitations of scientific information in that report make it difficult to conclude that the TGP-EIA process adequately informed the funding for and pursuit of questions related to informational gaps that should be uncovered by an EIA. Instead, it suggests that either the CYJV erroneously dismissed priority and/or uncertain impacts or that the scientific community failed to follow the CYJV identified needs for further study.

3. Implications for measuring dam impacts – linking science and policy

3.1. Limitations, uncertainty, and responsibility in the EIA process

The World Commission on Dams (2000) notes that the EIA process is often limited by five primary problems: (1) resistant attitudes, (2) insufficient structural integration of the EIA into policy/decision making, (3) insufficient scope of the EIA, (4) inadequate procedural assessments, and (5) poor technical quality of the EIA. EIAs are further limited in their function when performed too late into the planning and design of large dams to evaluate alternatives that include environmental objectives in the dam design and reservoir operation (e.g., the environmental flow component of the Mohale dam in Lesotho; World Commission on Dams, 2000). For one of the world's most widely studied large development projects, the TGP-EIA process could have provided an example of how science can move beyond these limitations to inform policy, design, and management of large dams. For example, given the relatively long time-frame of this project development, some studies were able to inform ecological mitigation recommendations, such as the recommendation that several large water releases be built into the operational schedule to stimulate fish reproduction during spawning season (Chao et al., 1987). However, it is unclear whether this mitigation strategy was implemented, as preliminary observations indicate success in stimulating reproduction appears is limited with the announcement of the Chinese dolphin as functionally extinct. The "long and hard road" ahead for environmental remediation at TGP, a recent warning voiced by a representative of the Chinese State Council (Yardley, 2007), reflects the limited success of the EIA in contributing to mitigation measures of the large project.

Some uncertainty in impact projection, and consequently environmental mitigation measures, of large dams is inevitable (World Commission on Dams, 2000). This uncertainty is driven by the different time and spatial scales over which the various impacts occur (Edmonds, 1992), a failure to thoroughly consider interdisciplinary links (Brown et al., this issue) and their cumulative effects (World Commission on Dams, 2000), and the acknowledged insufficient baseline study on the impacted river system (CYJV, 1988). Because scientific monitoring and study can be of substantial value in assessing and mitigating the environmental impacts of large dams (Wu et al., 2003), linking EIA findings to research priorities and funding should be viewed as a necessity. Steps towards improving the EIA process are primarily promoted through the coherence and commitment of the regulators and scientific

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funding agencies and can only occur if the EIA process is initiated early in the preliminary stages of planning.

For the integration of science and policy to be successful at protecting the environment, consideration of the hierarchy of impacts of dams across space and time is needed. For example, the hierarchical links between changes in hydrology and habitat are needed to understand the critical impacts of TGP on the spawning habitat of endangered Chinese sturgeon. With 98% of the historical habitat blocked by Gezhouba Dam in 1981, severe reductions in the remaining 2% of spawning areas downstream of Gezhouba was anticipated in response to the additional 40% reduction in flow associated with TGP (Xie, 2003). This cumulative effect of the hydrologic change translates across all three orders and emphasizes the need for broad spatial extents, particularly when considering the profound and synergistic effects of multiple dams on an ecosystem (World Commission on Dams, 2000).

Given the longitudinal connection of river systems and the fact that many rivers are already heavily impacted by man, the need to assess and relate new projects to existing developments for hierarchical, additive, and synergistic links is warranted (Wegner, 1990). Extending this principle, the strong links between social and environmental welfare (Ledec and Quintero, 2003) make social impacts relevant to the EIA process. For example, in the case of the TGP region, resettlement was considered the greatest threat to the environmental feasibility of TGP, potentially generating profound environmental impacts, such as increased erosion from deforestation and increased population density.

3.2. Opportunities through linking science and policy

While the CYJV study certainly has its limitations (see Ryder and Barber, 1990 for an excellent review), the availability and

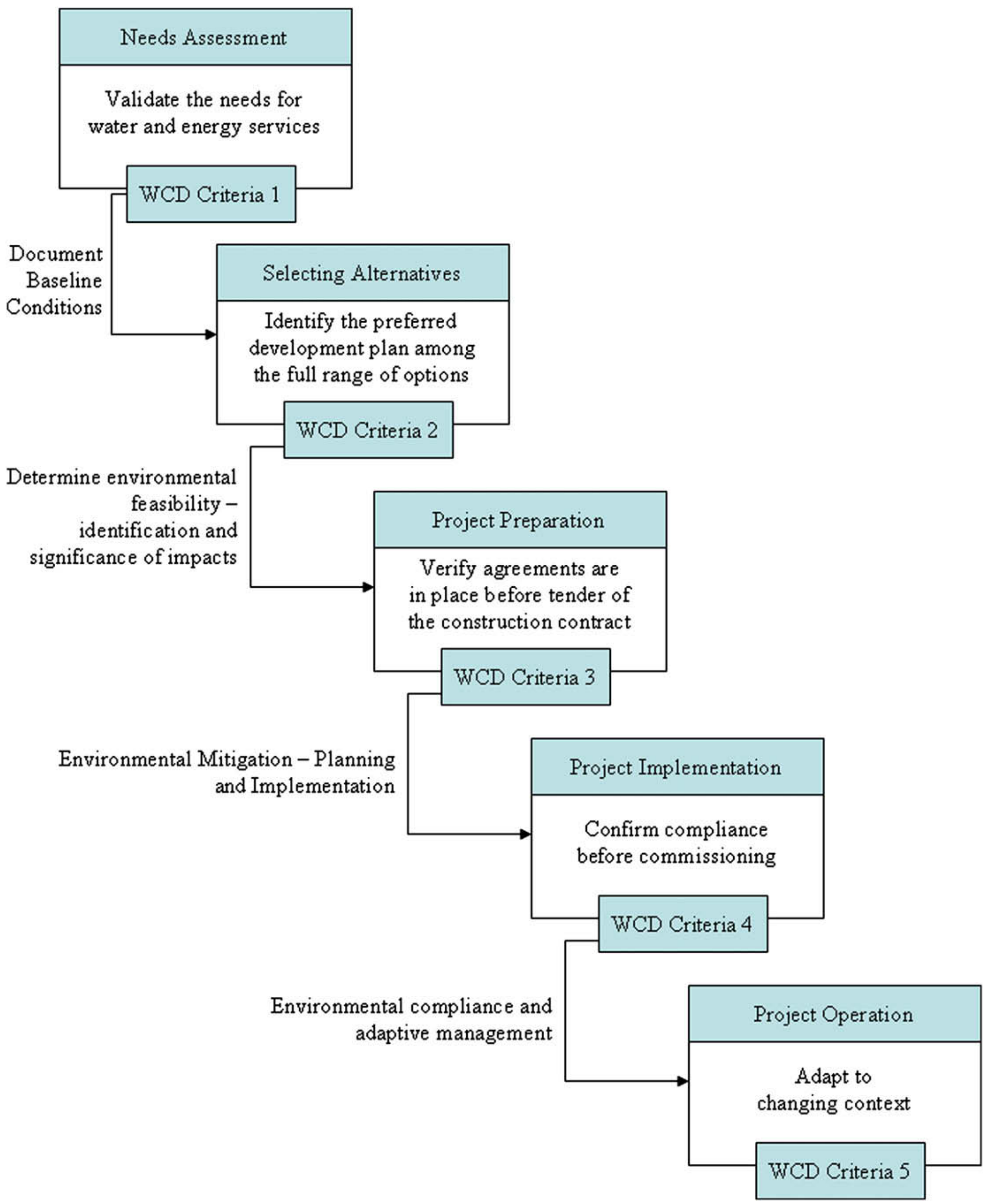

Fig. 5. Essential integration of publicly funded science with large dam planning. Arrows to illustrate the points at which publicly funded scientific investigation on environmental outcomes should support the planning and development process for large dams. Modified from the World Commission on Dams (2000).

consistency of scientific information and the lack of a more direct role for the science in guiding design and management of TGP ultimately challenged the TGP-EIA process. To overcome the gaps in scientific information important for implementing and evaluating conservation and management issues, changes in the planning process for large dams (Fig. 5) are needed. As integrated with the planning of large dams, the EIA becomes a dynamic and long-term effort to understand and minimize project impacts. In this context, the sources of impact uncertainty identified by EIA assessments offer opportunities for advancing the science and informing policy, design, and mitigation strategies of large dams. The analyses presented here illustrate why the interdependence of scientific investigation and EIA intent needs to be utilized to both guide and serve the assessment and design processes. This is critical because, like TGP, the realized impacts of large dams will vary depending on how the dam is ultimately managed (Shen and Xie, 2008). However, such an integration of science with policy will require establishing funding priorities that support these types of studies and should become a mandatory part of the planning process.

Thus, environmental monitoring of large dam projects serves two roles: (1) providing the fundamental work that informs understanding of dam impacts over time and space and (2) forming the basis for assessing environmental compliance. To fulfill these roles, the explicit integration of scientific investigation should be made for developing guidance on the environmental compliance and performance of large dams. On a practical level, this challenging integration will be influenced by environmental permits, legal agreements, and project scheduling and budgeting. Recently the World Bank moved in this direction with the Second Ertan Hydroelectric Project (Sichuan, China), by setting funding criteria on, among other things, conducting annual site visits during construction to investigate environmental conditions and interview local residents. This project, hailed as "China's first large hydroelectric project built in full compliance with international practice and yet in consideration of China's practical situations," (Yunhua, 2004) attempts a step forward in institutionalizing environmental compliance conditions in planning and funding of large dams (World Commission on Dams, 2000).

4. Conclusions

As climate change increases the potential for flooding and drought (IPCC, 2007) and the global demand for energy (Criqui and Kouvaritakisn, 2000) and water (Jobin, 1999) of a growing human population also increase, a surge in new large dam projects is likely to occur. However, without comprehensive investigation of the potential impacts of a major project, irreversible and unforeseen impacts to the environment will occur. For the EIA process to constructively support the minimization and mitigation of the environmental effects of large dams, the links between (a) hierarchical and interrelated impacts and (b) science and policy need to be to recognized and additional commitments of time and resources should be made to advance the science and sustainability of hydropower development.

A robust EIA process is essential in the assessment of large dam impacts. A project of the scope of TGP will be increasingly common in China and abroad. Several dams of similar height are already in various stages of planning and construction in Yunnan Province, China—for example, the Xiaowan Dam (292 m) on the Lancang River and the Song Ta (307 m) and Ma Ji (300 m) dams on the Nu River (Magee, 2006). While it is encouraging that research on dams in China has increased throughout the planning of TGP (Liu and Zuo, 1987), there are several lessons to be learned from the EIA process for the world's largest dam. This review has revealed discrepancies and omissions in impact significance and certainty that could have been reduced had systematically, and coherently planned, monitoring programs been implemented. As suggested by De Jongh for all development projects (1992), the EIA process for TGP would have benefited from the integration of a more formal and interdisciplinary approach for characterizing the uncertainty of impact projections.

To address the significance of projected impacts for a large project, an approach for considering risk would help focus research priorities. Various approaches already exist (Donnelly, 2006; ICOLD, 2005), including Potential Failure Mode Analysis (PFMA), which has been required under the Federal Energy Regulatory Commission (FERC) regulations on all hydropower facilities in the United States since 2002. Establishing causality across the hierarchy of impacts (see Perdicoúlis et al., 2007 for an excellent review) can also reduce uncertainty by providing linkages between impacts and their significance. By more thoroughly and transparently analyzing the uncertainty and significance of impacts, the CYJV study could have better guided research in a larger sense to further understanding and minimization of the negative consequences of large dams on people and the environment.

To be fair, the performance of EIAs both within China and around the world is continually improving and the increasing use of the EIA process has placed more emphasis on improving the identification of potential impacts. Whereas dams might be described as "threatening" should an EIA not be conducted, prepared too quickly, or offer no mitigation options (McAllister et al., 2000), the EIA process can potentially go a step further by playing a fundamental role in the design process as well as advancing the science and improving interdisciplinary communication of large dam impacts. Evaluation of the risk and uncertainty of environmental impacts should inform the process, both in spite of and in response to the enormous challenge of predicting the myriad integrated impacts of large dams.

However, without a policy that continuously integrates scientific findings into the dam planning and design process, the benefits of expanding environmental analysis are limited. Institutional and international policies regulating the EIA process also face criticism. Concerns regarding the responsibility of environmental assessment and performance of large dams include those regarding who should perform the impact assessments (Edmonds, 1992; Fearnside, 1988) and who should establish and enforce regulations and incentives for minimizing those impacts (Sadler et al., 2000). In response to these concerns, Strategic Environmental Assessment (SEA), adopted as part of the World Bank's Environmental strategy in 2001, offers some guidelines for integrating the EIA with policies and planning, simultaneously making the process more transparent and accessible to the public (World Bank, 2005).

However, recognition of the interdependence of science and policy is critical within any public process, including the SEA framework. In the case of large dams, science is needed to establish an understanding of the interactions between, the uncertainty around, and the significance of environmental impacts. Policy is needed both to fund scientific study and to enforce EIA recommendations throughout a long-term monitoring and environmental permitting process that is informed by the science before, during, and after dam construction. Only through the continued engagement of unbiased science throughout the planning, design, construction, and operation of dams can hydrodevelopment approach the sustainability necessary in the arriving era of water and energy instability.

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References

Abramovitz, J., 2001. Averting unnatural disasters. In: Brown, L.R. (Ed.), State of the World 2001. W.W. Norton & Company, New York.

Andersson, E., Nilsson, C., Johansson, M.E., 2000. Effects of river fragmentation on plant dispersal and riparian flora. Regulated Rivers: Research and Management 16, 83–89.

Aparicio, E., Vargas, M.J., Olmo, J.M., De Sostoa, A., 2000. Decline of native freshwater fishes in a Mediterranean watershed on the Iberian Peninsula: a quantitative assessment. Environmental Biology of Fishes 59, 11–19.

Bodaly, R.A., St. Louis, V.L., Paterson, M.J., Fudge, R.J.P., Hall, B.D., Rosenberg, D.M., Rudd, L.W.M., 1997. Bioaccumulation of mercury in the aquatic food chain in newly flooded areas. In: Sigel, H., Sigel, A. (Eds.), Mercury and Its Effects on Environment and Biology. Marcel Decker, New York, pp. 259–287.

Boxer, B., 1988. China's three Gorges dam: questions and prospects. The China Quarterly 113, 99.

Brookes, A., 1999. Environmental impact assessment for energy projects. In: Petts, V. (Ed.), Handbook of Environmental Impact Assessment, vol. 2. Blackwell Science, London, pp. 405–430.

Brown, P., Tullos, D., Tilt, B., Magee, D., Wolf, A. Modeling the costs and benefits of dam construction from a multidisciplinary perspective. Journal of Environmental Management, this issue.

Brundtland, G. (Ed.), 1987. Our Common Future: The World Commission on Environment and Development. Oxford University Press, Oxford.

Cai, Q.H., Hu, Z.Y., 2006. Studies on eutrophication problem and control strategy in the Three Gorges Reservoir. Acta Hydrobiologica Sinica 30, 7–11.

Canadian Yangtze Joint Venture (CYJV) 1988. Three Gorges Water Control Project Feasibility Study. Environment, vol. 8. Obtained from the Canadian International Development Agency (CIDA).

Canter, L.W., 1996. Environmental Impact Assessment, second ed. McGraw-Hill Inc., ISBN 0-07-114103-0, 660 pp

Chang, A., 2007. China: Three Gorges impact not that bad. Associated Press. Nov 22, 2007, Beijing, China. Three Gorges Project, Published online by the Chinese Ministry of Water Resources (MWR) 2004. Changjiang Water Resource Commission (CWRC) 1997. pp. 22.

Changjiang Water Resources Commission, 2007. China pledges more measures to ensure environmental protection in Three Gorges. http://www.river.gov.cn/detail/20071122/97100.asp?column=News (accessed 02/2008).

Changsheng, C., Jianrong, Z., Beardsley, R.C., Franks, P.J.S., 2003. Physical–biological sources for dense algal blooms near the Changjiang River. Geophysical Research Letters 30, 21–24.

Chao, W., Yu, Z., Xu, W., Deng, Z., Chai, M., 1987. A preliminary assessment of the impact of the Three Gorges Project on fish resources in the Changjiang River and review of ways of enhancing the resource. In: A Collection of Literature on the Environmental Impacts of the Three Gorges Project in the Changjiang River and Strategies for Mitigation. Science Publishing House, Beijing, pp. 2–20.

Chen, X., 1998. Changjiang Yangtze River Delta, China. Journal of Coastal Research 14, 838–858.

Chen, Z., Li, J., Shen, H., Wang, Z., 2001. Yangtze River of China: historical analysis of discharge variability and sediment flux. Geomorphology 41, 77–91.

Chen, D., Liu, S., Duan, X., Shi, W., Wang, B., 2002. On the dynamics of fishery resources of the Yangtze river and its management. Acta Hydrobiologica Sinica 26, 685–690.

Chen, Y., 2004. Effect of the Three Gorge Project on the sustainable development in the Yangtze River basin. Resources and Environment in the Yangtze Basin 13, 109–113.

Chen, D.J., Cai, Y.J., 1994. Monitoring and prediction of landslides and unstable cliffs in the Three-Gorges reservoir region, People's Republic of China. In: Proceedings of 7th International IAEG Congress, pp. 1383–1389.

Chen, W., Zhang, X., Liang, S., et al., 1994. Plants and Composite Agricultural Ecosystems of the Three Gorges Reservoir Region. Science Press, Beijing, PR China.

Chen, Q., Zhang, Y., Ekroos, A., 2007. Comparison of China's Environmental Impact Assessment (EIA) law with the European Union (EU) EIA directive. Environmental Monitoring and Assessment 132, 53–65.

Chinese Academy of Environmental Planning, 2005. Environmental Protection in China 1996–2005. http://www.caep.org.cn/english.

Clarke, C., 2000. Cross-Check Survey: Final Report, A WCD survey prepared as an input to the World Commission on Dams, Cape Town, www.dams.org.

Clarkson, T., 1987. Metal toxicity in the central nervous system. Environmental Health Perspectives 75, 59–64.

Clarkson, R.W., Childs, M.R., 2000. Temperature effects of hypolimnial-release dams on early life stages of Colorado River basin big-river fishes. Copeia, 402–412.

Cosson, J.F., Ringuet, S., Claessens, O., de Massary, J.C., Dalecky, A., Villiers, J.F., Granjon, L., Pons, J.M., 1999. Ecological changes in recent land-bridge islands in French Guiana, with emphasis on vertebrate communities. Biological Conservation 91, 213–222.

Criqui, P., Kouvaritakisn, N., 2000. World energy projections to 2030. International Journal of Global Energy Issues 14, 116–136.

Dai, F.C., Deng, J.H., Tham, L.G., Law, K.T., Lee, C.F., 2004. A large landslide in Zigui County, Three Gorges area. Canadian Geotechnical Journal 41, 1233–1240.

Dai, S.B., Yang, S.L., Zhu, J., Gao, A., Li, P., 2005. The role of Lake Dongting in regulating the sediment budget of the Yangtze River. Hydrology and Earth System Sciences 9 (6), 692–698.

De Jonghe, P., 1992. Uncertainty in EIA. In: Watharn (Ed.), Environmental Impact Assessment: Theory and Practice, pp. 62–82.

Donnelly, C.R., 2006. Safe and secure – risk based techniques for dam safety. International Water Power and Dam Construction, Wilmington Media Ltd., December 7.

Du, Z., 1999. Soil and water conservation and improving ecological environment in the Three Gorges reservoir area. Resources and Environment in the Yangtze Basin 8, 299–304.

Du, R.L., Qiao, X.J., Wang, Q., Xing, C.F., You, X.Z., 2005. Deformation in the Three Gorges Reservoir after the first impoundment determined by GPS measurements. Progress in Natural Science 15, 515–522.

Duan, X., Chen, D., Liu, S., Chi, C., Yang, R., 2002. Studies on status of fishery resources in the Three Gorges reservoir reaches of the Yangtze river. Acta Hydrobiologica Sinica 26, 605–611.

Duchemin, E., Lucotte, M., Canuel, R., Chamberland, A., 1995. Global Biogeochemical Cycles 9, 529.

Dudgeon, D., 2000. The ecology of tropical rivers and streams in relation to biodiversity and conservation. Annual Review of Ecology and Systematics 31, 239–263.

Dynesius, M., Nilsson, C., 1994. Fragmentation and flow regulation of river systems in the northern third of the World. Science 266, 753–762.

Edmonds, R.L., 1991. Global Ecological Biogeography Letters 1, 105. Summary report for environmental impact of Three Gorges Dam Project. Environment Evaluation Department and the Yangtze River Water Resources Reservation Research Institute 1996. The Chinese Academy of Sciences (in Chinese).

Edmonds, R.L., 1992. The Sanxia (Three Gorges) project: the environmental argument surrounding China's super dam. Global Ecology and Biogeography Letters 2, 105–125.

Fearnside, P.M., 1988. China's Three Gorges dam: fatal project or step toward modernization? World Development 16, 615–630.

Friedman, J.M., Auble, G.T., 1999. Mortality of riparian box elder from sediment mobilization and extended inundation. Regulated Rivers: Research and Management 15, 463–476.

Fu, C., Wu, J., Chen, J., Wu, Q., Lei, G., 2003. Freshwater fish biodiversity in the Yangtze River basin of China: patterns, threats and conservation. Biodiversity and Conservation 12, 1649–1685.

Gilpin, A., 1995. Environmental Impact Assessment (EIA): Cutting Edge for the Twenty-first Century. Cambridge University Press.

Glasson, J., Therivel, R., Chadwick, A., 2005. Introduction to Environmental Impact Assessment: Principles and Procedures, Process, Practice and Prospects, second ed. UCL Press, ISBN 1-85728-945-5, 496 pp.

Gong, G.C., Chang, J., Chiang, K.P., Hsiung, T.M., Hung, C.C., Duan, S.W., Codispoti, L.A., 2006. Reduction of primary production and changing of nutrient ratio in the East China Sea: effect of the Three Gorges Dam? Geophysical Research Letters 33, 7.

Gosselink, J.G., Odum, E.P., Pope, R.M., 1974. The Value of the Tidal Marsh. Louisiana State University, Center for Wetland Resources, Baton Rouge. Publication no. LSU-SG-74-03.

Gu, L., 2005a. China improves enforcement of environmental laws. http://www.chinese-embassy.org.uk/eng/zt/Features/t214565.htm# Embassy of the People's Republic of China in the United Kingdom of Great Britain and Northern Ireland, 09/29/2005 (accessed 02/2008).

Gu, H., Douglas, I., 1989. Spatial and temporal dynamics of land degradation and fluvial erosion in the middle and upper Yangtze River basin, China. Land Degradation and Rehabilitation 1, 217–235.

Gu, H., Ai, N.S., Ma, H., 1987. Sediment sources and trend of sedimentation in the Three Gorges reservoir area. In: Leading Group of the Three Gorges Project Ecology and Environment Research Project, Chinese Academy of Sciences Collected Papers on Ecological and Environmental Impact of the Three Gorges Project and Countermeasures. Science Press, Beijing, pp. 522–541 (in Chinese).

Gu, L., 2005b. China improves enforcement of environmental laws. http://www.chinese-embassy.org.uk/eng/zt/Features/t214565.htm> National Day Feature published by the Embassy of the People's Republic of China in the United Kingdom of Great Britain and Northern Ireland, 2005/09/29.

Gunnison, D., Brannon, J.M., Chen, R.L., Smith Jr., I., Sturgis, T.C., 1984. Richard B. Russell Dam and Reservoir: Potential Water Quality Effects of Initial Filling and Decomposition of Vegetation. Army Corps of Engineers Waterways Experiment Station, Vicksburg, Mississippi, 68 pp.

Haihe River Water Conservancy Comm. Commission (HWCC), 2007. MWR and SEPA Jointly Organize Examination of EIA of Water Resources Planning. www.hwcc.com.cn/newsdisplay/newsdisplay.asp?Id=165108 November.

Heggelund, G., 2006. Running into Dead Ends: Challenges in Researching the Three Gorges Dam. China Environment Forum. Woodrow Wilson International Center for Scholars, pp. 79–88.

Heming, L., Rees, P., 2000. Population displacement in the Three Gorges reservoir area of the Yangtze River, central China: relocation policies and migrant views. International Journal of Population Geography 6, 439–462.

Heming, L., Waley, P., Rees, P., 2001. Reservoir resettlement in China: past experience and the Three Gorges Dam. The Geographic Journal 167, 195–212.

Higgitt, D., Lu, X., 1996. Patterns of sediment yield in the Upper Yangtze Basin, China. In: Walling, D.E., Webb, B.W. (Eds.), Erosion and Sediment Yield: Global and Regional Perspectives (Proceedings of the Exeter Symposium) IAHS Publication, vol. 236. International Association of Hydrological Sciences, Wallingford, pp. 205–214.

Huang, Z., 2001. Biodiversity conservation for the Three Gorge Project. Biodiversity Science 9, 472–481.

Please cite this article in press as: Tullos, D., Assessing the influence of environmental impact assessments on science and policy: An analysis of the Three Gorges Project, Journal of Environmental Management (2008), doi:10.1016/j.jenvman.2008.07.031

Huang, Z., 2004. Eco-environmental Monitoring and Protection for the Three Gorges Project 2003. Three Gorges of China Press, Beijing.
Hughes, M.H., Parmalee, P.W., 1999. Prehistoric and modern freshwater mussel (Mollusca: Bivalvia: Unionidae) faunas of the Tennessee river: Alabama, Kentucky, and Tennessee. Regulated Rivers: Research and Management 15, 25–42.
Humborg, C., Conley, D.J., Rahm, L., Wulff, F., Cociasu, A., Ittekkot, V., 2000. Silicon retention in river basins: far-reaching effects on biogeochemistry and aquatic food webs in coastal marine environments. Ambio 29, 45–50.
ICOLD. 2005. Risk assessment in dam safety management. A Reconnaissance of Benefits, Methods and Current Applications. ICOLD Bulletin 130, Paris.
International Association for Impact Assessment in Cooperation with Institute of Environmental Assessment (IAIA), 1999. Principles of EIA Best Practice. IAIA International Headquarters, ND 58103, USA.
Intergovernmental Panel on Climate Change (IPCC), 2007. WGII – Impacts, Adaptation and Vulnerability, August, p. 938.
Jackson, S., Sleigh, A., 2000. Resettlement for China's three Gorges Dam: socio-economic impact and institutional tensions. Communist and Post-Communist Studies 33, 223–241.
Jansson, R., Nilsson, C., Dynesius, M., Andersson, E., 2000. Effects of river regulation on river-margin vegetation: a comparison of eight boreal rivers. Ecological Applications 10, 203–224.
Jiao, N.Z., Zhang, Y., Zeng, Y.H., Gardner, W.D., Mishonov, A.V., Richardson, M.J., Hong, N., Pan, D.L., Yan, X.H., Jo, Y.H., Chen, C.T.A., Wang, P.X., Chen, Y.T., Hong, H.S., Bai, Y., Chen, X.H., Huang, B.Q., Deng, H., Shi, Y., Yang, D.C., 2007. Ecological anomalies in the East China Sea: impacts of the three Gorges dam? Water Research 41, 1287–1293.
Jobin, W., 1999. Dams and Disease. Taylor and Francis, London.
Jobin, W., 2005. Health conscious: dams in China and Africa have been linked to positive health impacts in their local populations. International Water Power and Dam Construction 57, 10–13.
Jorde, K., Burke, M., Scheidt, N., Welcker, C., King, S., Borden, C., 2008. Reservoir operations, physical processes, and ecosystem losses. In: Habersack, H., Piéay, H., Rinaldi, M. (Eds.), Gravel-Bed Rivers VI: From Process Understanding to River Restoration. Elsevier, pp. 15,607–15,636.
Junk, W.J., Bayley, P.B., Sparks, R.E., 1989. The flood pulse concept in river floodplain systems. In: Dodge, D.P. (Ed.), Proceedings of the International Large River Symposium, Ottawa, Ontario (Canada), vol. 106. Department of Fisheries and Oceans, Canadian Special Publication of Fisheries and Aquatic Sciences, pp. 110–127.
Kelly, C.A., Rudd, J.W.M., Bodaly, R.A., et al., 1997. Increases in fluxes of greenhouse gases and methyl mercury following flooding of an experimental reservoir. Environmental Science Technologies 31, 1334–1344.
Kingsford, R.T., 2000. Ecological impacts of dams, water diversions and river management on floodplain wetlands in Australia. Austral Ecology 25, 109–127.
Kondolf, G.M., 1997. Hungry water: effects of dams and gravel mining on river channels. Environmental Management 21, 533–551.
Koshikawa, M.K., Takamatsu, T., Takada, J., Zhu, M.Y., Xu, B.H., Chen, Z.Y., Murakami, S., Xu, K.Q., Watanabe, M., 2007. Distributions of dissolved and particulate elements in the Yangtze estuary in 1997–2002: background data before the closure of the Three Gorges Dam. Estuarine Coastal and Shelf Science 71, 26–36.
Kuang, Q., Bi, Y., Zhou, G., Cai, Y., Hu, Z., 2005. Study on the phytoplankton in the Three Gorge reservoir before and after sluice and the protection of water quality. Acta Hydrobiologica Sinica 29, 353–358.
Ledec, G., Quintero, J.D., 2003. Good dams and bad dams: environmental criteria for site selection of hydroelectric projects. The World Bank Latin America and Caribbean Region Sustainable Development Working Paper, 16, p. 30.
Li, C., Shao, L., 1996. Review of impact between sea water and fresh water on the coastal zone – a case study from China. In: Groundwater Discharge in the Coastal Zone: Proceedings of an International Symposium, vol. 8, pp. 135–142.
Li, H., Schreck, C.B., Bond, C.E., Rexstad, E., 1987. Factors influencing changes in fish assemblages of Pacific Northwest streams. In: Matthews, W.J., Heins, D.C. (Eds.), Community and Evolutionary Ecology of North American Stream Fishes. University of Oklahoma Press, Norman, pp. 193–202.
Lin, Y.H., Su, H.L., Ma, Q., Xiao, W.F., 2003. Status and conservation of rare and threatened terrestrial vertebrate in the Three Gorges reservoir area. Scientia Silvae Sinicae 39, 100–109.
Liu, C., Zuo, D., 1987. Environmental issues of the Three Gorges Project, China. Regulated Rivers: Research and Management 1, 267–273.
Liu, J.G., Mason, P.J., Clerici, N., Chen, S., Davis, A., Miao, F., Deng, H., Liang, L., 2004. Landslide hazard assessment in the Three Gorges area of the Yangtze river using ASTER imagery: Zigui–Badong. Geomorphology 61, 171–187.
Liu, X., Gituru, R., Chen, L., 2007. Genetic variation in the endangered fern *Adiantum reniforme* var. *sinense* (Adiantaceae) in China. Annales Botanici Fennici 44, 23–32.
Liu, Y., Wang, Y., Huang, H., 2006. High inter-population genetic differentiation and unidirectional linear migration pattern in *Myricaria laxiflora*, an endemic riparian plant in the Three Gorges Valley of Yangtze River. American Journal of Botany 93, 206–215.
Lovgren, S., 2006. China's Rare River Dolphin Now Extinct, Experts Announce. National Geographic News, December 14.
Lu, Y., 1994. Three Gorges Project – A Progress Report. International Water Power and Dam Construction, pp. 20–23.
Lu, X., Higgitt, D., 1998. Recent changes of sediment yield in the upper Yangtze, China. Journal of Environmental Management 22, 697–709.
Luk, S., Whitney, J., 1990. Unresolved issues: perspectives from China. In: Damming the Three Gorges: What Dam Builders Don't Want You to Know. Earthscan, London.
Maize, K., 1996. China's three Gorges Dam: mammoth opportunities and risks. The Electricity Journal 5, 10–13.
Magee, D., 2006. Powershed politics: Yunnan hydropower under great western development. China Quarterly 185, 23–41.
Marshall, J., 2006. Three Gorges dam threatens vast fishery. New Scientist 2540 (February 25), 18.
McAllister, D., Craig, J., Davidson, N., Delany, S., Seddon, M., 2000. Biodiversity impacts of large dams. World Commission on Dams: Thematic Report. http://www.dams.org/thematic/tr21.htm.
McCully, P., 1996. Silenced Rivers. The Ecology and Politics of Large Dams. Zed Books, London.
Miller, N.L., Jin, J.M., Tsang, C.F., 2005. Local climate sensitivity of the Three Gorges Dam. Geophysical Research Letters 32, 16.
Morita, K., Yamamoto, S., Hoshino, N., 2000. Extreme life history change of white-spotted char (*Salvelinus leucomaenis*) after damming. Canadian Journal of Fisheries and Aquatic Sciences 57, 1300–1306.
Morley, N.J., 2007. Anthropogenic effects of reservoir construction on the parasite fauna of aquatic wildlife. Ecohealth 4, 374–383.
Palmieri, A., Shah, F., Dinari, A., 2001. Economics of reservoir sedimentation and sustainable management of dams. Journal of Environmental Management 61, 149–163.
Park, Y.S., Chang, J.B., Lek, S., Cao, W.X., Brosse, S., 2003. Conservation strategies for endemic fish species threatened by the Three Gorges Dam. Conservation Biology 17, 1748–1758.
Penczak, T., Kruk, A., 2000. Threatened obligatory riverine fishes in human modified Polish rivers. Ecology of Freshwater Fishes 9, 109–117.
Perdicoúlis, A., Glasson, J., 2006. Causal networks in EIA. Environmental Impact Assessment Review 26, 553–569.
Perdicoúlis, A., Hanusch, M., Kasperidus, H., Weiland, U., 2007. The handling of causality in SEA guidance. Environmental Impact Assessment Review 27, 176–187.
IUCN Species Survival Occasional Paper No. 3. In: Perrin, W., Brownell, R., Kaiya, Z., Jiankang, L. (Eds.), Biology and Conservation of the River Dolphins. IUCN, Gland, Switzerland.
Petts, J., 1999. Handbook of Environmental Impact Assessment. Blackwell Science Ltd, Oxford.
Poff, N.L., Allan, J.D., Bain, M.B., Karr, J.R., Prestegaard, K.L., Richter, B.D., Sparks, R.E., Stromberg, J.C., 1997. The natural flow regime. Bioscience 47, 769–784.
Pfleiger, W.L., Grace, T.B., 1987. Changes in the fish fauna of the lower Missouri river, 1940–1983. In: Matthews, W.J., Heins, D.C. (Eds.), Community and Evolutionary Ecology of North American Stream Fishes. University of Oklahoma Press, Norman, pp. 155–163.
Qing, D., 1998. The River Dragon Has Come! The Three Gorges Dam and the Fate of China's Yangtze River and Its People. M.E. Sharpe Inc., Armonk, NY, pp. 181.
Qiu, S.L., Liu, S.P., Huang, M.G., Chen, D.Q., Duan, X.B., 2002. Monitoring of spawning sites of four major Chinese carps in the middle section of Yangtze River. Acta Hydrobiologica Sinica 26, 716–718.
Ryder, G., Barber, M., 1990. Damming the Three Gorges: 1920–1993. In: Damming The Three Gorges: What Dam Builders Don't Want You To Know. Earthscan, London.
Sadler, B., Verocai, I., Vanclay, F., 2000. Environmental and Social Impact Assessment for Large Dams, Thematic Review V.2 prepared as an input to the World Commission on Dams, Cape Town, www.dams.org.
Shan, X.-J., Xian, W.-W., Wu, Y.-F., 2005. Dynamic changes in the ichthyoplankton community structure after the sluice of the Three-Gorges Dam. Zhongguo Haiyang Daxue Xuebao 35, 936–940.
Shanzhong, Q., Zulu, Z., Zhaopei, Z., Qiaoyu, G., Yan, Z., 2007. Saltwater intrusion in the Laizhou Gulf, Shandong Province, China: causes and its impact on coastal areas. AMBIO: A Journal of the Human Environment 36, 361–362.
Shao, M.L., Xie, Z.C., Ye, L., Cai, Q.H., 2006a. Changes in the benthic macroinvertebrates in Xiangxi Bay following dam closure to form the Three Gorges Reservoir. Journal of Freshwater Ecology 21, 717–719.
Shao, X.-Y., Li, D.-F., Cai, Q.-H., 2006b. The composition of the fish community in Xiangxi Bay and resources evaluation. Acta Hydrobiologica Sinica 30, 70–74.
Sharma, V.K., 2001. Post impoundment changes in river Beas after Pong Dam emergence. Applied Fisheries and Aquaculture 1, 9–12.
Shen, G., Xie, Z., 2008. Three Gorges Project: chance and challenge. Science 304, 681.
Sheng, J., Liao, A., 1997. Erosion control in South China. Catena 29, 211–221.
State Council Three Gorges Project Construction Committee, 2004. Small Three Gorges with the Reservoir Water Storage of the Three Gorges Project. http://www.3g.gov.cn/english/Small%20Three%20Gorges%20with%20the%20Reservoir.%20Water%20Storage%20of%20the%20Three%20Gorges%20Project.htm.
St. Louis, V.L.C., Kelly, C., Duchemin, E., Rudd, J., Rosenberg, D., 2000. Reservoir surfaces as sources of greenhouse gases to the atmosphere: a global estimate. Bioscience 50, 9.
Talwani, P., 1997. On the nature of reservoir-induced seismicity. Pure and Applied Geophysics 150, 473–492.
Tan, C.X., Sun, Y., Wang, R.J., Hu, D.G., 1997. Assessment and zonation of regional crustal stability in and around the dam region of the Three Gorges Project on the Yangtze River. Environmental Geology 32, 285–295.
Tang, H.B., Liu, G.X., Hu, Z.Y., 2006. Preliminary research on the algal bloom of Peridiniopsis sp. in Gaolan River of the Three Gorges Reservoir. Acta Hydrobiologica Sinica 30, 47–51.

Therivel, R., 2004. Strategic Environmental Assessment in Action. Earthscan, London.

USEPA, 2001. Water Quality Criterion for the Protection of Human Health: Methyl Mercury. National Service Center for Environmental Publications (NSCEP), pp. 303.

Vemula, V.G., Hamid, M.N., Kaplan, A., Phiromchai, S., Price, R., Lei, G., Yu, X. 2004. Development of an integrated river basin strategy in the Yangtze River basin. UNITAR Hiroshima Office for Asia and the Pacific, Series on Biodiversity, Kushiro, Japan, 29 November to 3 December 2004.

Wang, R.Z., 2003. Natural occurrence and backwater infection of C-4 plants in the vegetation of the Yangtze hydropower Three Gorges Project region. Photosynthetica 41, 43–48.

Wang, F., Zhang, Y., Huo, Z., Matsumoto, T., Huang, B., 2004. The July 14, 2003 Qianjiangping landslide, Three Gorges Reservoir, China. Landslides 1, 157–162.

Wang, S.J., Chen, Z.Y., Smith, D.G., 2005. Anastomosing river system along the subsiding middle Yangtze River basin, southern China. Catena 60, 147–163.

Wang, A., 2007a. Environmental protection in China: the role of law. China Dialogue, February 05, 2007. http://www.chinadialogue.net/homepage/show/single/en/745-Environmental-protection-in-China-the-role-of-law (accessed 02/2008).

Wegner, D.L., 1990. Three Gorges Reservoir: environmental impacts. In: Damming The Three Gorges: What Dam Builders Don't Want You To Know. Earthscan, London.

Wegner, D., 1994. Three Gorges Reservoir: Environmental Impacts Yangtze! Yangtze!. Earthscan.

Walks, D.J., Li, H.W., Reeves, G.H., 2000. Trout, summer flows, and irrigation canals: a study of habitat condition and trout populations within a complex system. In: Cowx, I.G. (Ed.), Management and Ecology of River Fisheries. Blackwell Science, London, pp. 115–125.

Wang, A., 2007b. Environmental Protection in China: the Role of the Law. China Dialogue.

Williams, P.B., 1990a. Sedimentation analysis. In: Damming The Three Gorges: What Dam Builders Don't Want You To Know. Earthscan, London.

Williams, P.B., 1990b. Dam safety analysis. In: Damming The Three Gorges: What Dam Builders Don't Want You To Know. Earthscan, London.

World Bank, 1991. Environmental Assessment Sourcebook, 3 vols.. Environment Department, The World Bank, Washington, D.C.

World Bank, 2005. Integrating Environmental Considerations in Policy Formulation: Lessons from Policy-Based SEA Experience. Report No. 32783 of the World Bank, Washington, D.C.

World Commission on Dams, 2000. Dams and Development. A New Framework for Decision Making: The Report of the World Commission on Dams. Earthscan Publications, London, England. http://www.dams.org/report.

Wu, J., Huang, J., Han, X., Xim, Z., Gao, X., 2005. Three-Gorges Dam – experiment in habitat fragmentation? Science 300, 1239–1240.

Wu, L., Qiang, Z., Zhihong, J., 2003. Three Gorges Dam affects regional precipitation. Geophysical Research Letters 33, 4.

Wu, S.R., Shi, L., Wang, R.J., Tan, C.X., Hu, D.G., Mei, Y.T., Xu, R.C., 2001. Zonation of the landslide hazards in the forereservoir region of the Three Gorges Project on the Yangtze River. Engineering Geology 59, 51–58.

Xiao, W., Li, J., Yu, C., 1999. Terrestrial Animal and Plant Ecology of the Three Gorge of Yangtze River. Public Press Of Southwest China Normal University, pp. 85–90.

Xie, P., 2003. Three-Gorges dam: risk to ancient fish. Science 302, 1149.

Xie, S.G., Li, Z.J., Liu, J.S., Xie, S.Q., Wang, H.Z., Murphy, B.R., 2007. Fisheries of the Yangtze river show immediate impacts of the three Gorges dam. Fisheries 32, 343–344.

Xing-jian, X., Xian-xiang, Y., Yu-hai, D., Gui-yang, Y., Liu-yan, C., Zheng-ming, S., 1999. Impact of environmental change and schistosomiasis transmission in the middle reaches of the Yangtze River following the Three Gorges construction project. Southeast Asian Journal of Tropical Medicine and Public Health 30, 549–555.

Xue, J.Z., Ye, L., Cai, Q.H., Liu, J.K., 2006. Variation of cladocerans from Maoping to Guizhou in the Three Gorges Reservoir before and after impoundment. Acta Hydrobiologica Sinica 30, 58–63.

Gui, X., 2007. Challenge and opportunities biodiversity conservation in Dongting lake. Forestry Department of Hunan Province.

Xing, C., Zong, Y., Zhang, E., Xu, J., Li, S., 2001. Human impacts on the Changjiang (Yangtze) river basin, China, with special reference to the impacts on the dry season water discharge into the sea. Geomorphology 41, 111–123.

Yang, S.L., Zhang, J., Zhu, J., Smith, J.P., Dai, S.B., Gao, A., Li, P., 2005. Impact of dams on Yangtze River sediment supply to the sea and delta intertidal wetland response. Journal of Geophysical Research Part F Earth Surfaces 110 (F3), 12.

Yang, S.L., Li, M., Dai, S.B., Liu, Z., Zhang, J., Ding, P.X., 2006. Drastic decrease in sediment supply from the Yangtze River and its challenge to coastal wetland management. Geophysical Research Letters 33, 4.

Yang, D.-G., Wei, Q.-W., Chen, X.-H., Liu, J.-Y., Zhu, Y.-J., Wang, K., 2007a. Hydrology status on the spawning ground of *Acipenser sinensis* below the Gezhouba Dam and its relation to the spawning run. Acta Ecologica Sinica 27, 862–869.

Yang, S.L., Zhang, J., Xu, X.J., 2007b. Influence of the Three Gorges Dam on downstream delivery of sediment and its environmental implications, Yangtze River. Geophysical Research Letters 34, 10.

Yang, S.L., Zhang, J., Dai, S.B., Li, M., Xu, X.J., 2007c. Effect of deposition and erosion within the main river channel and large lakes on sediment delivery to the estuary of the Yangtze River. Journal of Geophysical Research Part F Earth Surfaces, 1–13.

Yangtze Valley Water Resources Protection BureauMWR & NEPA, 1999. Questions and Answers on Environmental Issues for the Three Gorges Project. Science Press, Beijing, New York.

Yardley, J., 2007. Chinese Dam projects criticized for their hidden costs. New York Times.

Yao, J.-l., Xue, J.-z., Wang, D.-y., Cai, Q.-h., Huang, X.-f., Liu, J.-k., 2007. Seasonal variation and longitudinal distribution of copepods in the main river area of the Three Gorges Reservoir. Biodiversity Science 15, 300–305.

Ye, Q., Chen, S., Wang, S., 2001. The archaic and relict communities of rare and endangered plants in the Three Gorge area and its adjacent area. Journal of Plant Resources and Environment 10, 21–25.

Yin, H., Li, C., 2001. Human impact on floods and flood disasters on the Yangtze River. Geomorphology 41, 105–109.

Yuan, J., Hayden, L., Dagg, M., 2007. Comment on reduction of primary production and changing of nutrient ratio in the East China Sea: effect of the Three Gorges Dam? by Gwo-Ching Gong, et al. Geophysical Research Letters 34, L14609, doi:10.1029/2006GL029036.

Yunhua, C., 2004. Hydroelectric Exploitation and Sustainable Development of the Yalong River. UNHYDRO 2004, Beijing.

Zeng, H., Song, L.-r., Yu, Z.-g., Chen, H.T., 2007a. Preliminary study on algal blooms within the Three Gorges Reservoir. Changjiang Liuyu Ziyuan Yu Huanjing 16, 336–339.

Zeng, H., Song, L.R., Yu, Z.G., Chen, H.T., 2007b. Post-impoundment biomass and composition of phytoplankton in the Yangtze River. International Review of Hydrobiology 92, 267–280.

Zhang, S., Li, C.-m., Zheng, B.-h., Zhai, C.-z., Zheng, J., Zhang, Q., 2007. Trophic states and nutrient output of tributaries in Three Gorges Reservoir area. Huanjing Kexue 28, 500–505.

Zheng, J., Gu, X., Xu, Y., Ge, J., Yang, X., He, C., Tang, C., Cai, K., Jiang, Q., Liang, Y., Wang, T., Xu, X., Zhong, J., Yuan, H., Zhou, X., 2002. Relationship between the transmission of *Schistosomiasis japonica* and the construction of the Three Gorge Reservoir. Acta Tropica 82, 147–156.

Zheng, Z., 1992. Sanxia gongcheng yingxiang Zhongguo mingyun. Zhongyang Ribao (International Edition) 23153 (March 03).

Zhu, J., Ding, P., Zhang, L., Wu, H., Cao, H., 2006. Influence of the deep waterway project on the Changjiang estuary. In: Wolanski, E. (Ed.), The Environment in Asia Pacific Harbours, The Netherlands.

Ziyun, F., 1986. Environmental impact assessment in the Yangtze Valley. Ambio 15, 347–349.