STATE of KNOWLEDGE

Hydropower Environmental Mitigation Measures on the Lancang River

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Why is China developing hydropower on the Lancang River?

China's hydropower potential is the world's largest, with a gross theoretical hydropower potential of 694 GW[1] in installed capacity and 6.083 TW/year in electricity generation. In 2015, China accounted for 26% of global hydropower capacity alone (IHA, 2016). The nation has accelerated hydropower development since the 1980s to meet the increasing electricity demand that accompanies its rapidly growing economy. At the same time, large HydroPower Projects (HPPs) have contributed to flood control, irrigation, and rural/urban water supply. In recent years, hydropower development has been seen by the government as an important way to reduce China's heavy reliance on fossil fuels, achieve its emissions reduction targets, and increasing resilience to climatic change.

The Lancang River (the upper part of the Mekong River located in China) is a key Chinese hydropower base and was a priority area in its national hydropower planning before 2016. HPPs on the mainstream of the Lancang are multipurpose projects, with electricity generation, flood control, water supply, and navigation improvement as their primary purposes (Hennig et al., 2013). Hydropower is a key industry of Yunnan Province and contributed 7.36% of the provincial GDP in 2014 (Yunnan Provincial Bureau of Statistics, 2015). HPPs on the Lancang River improved the flood control standard of Jinghong City from a 50-year to a 100-year recurrence interval. Small HPPs have been developed to improve rural electrification and replace fuel wood exploitation in remote mountainous areas. The global Clean Development Mechanism market made many small HPPs financially attractive (Hennig et al., 2013).

Conclusion: *Chinese HPPs on the Lancang River have been developed for electricity generation, flood control, water supply, and navigation improvement. Hydropower was expected to play an increasingly important role in developing a low carbon economy and increasing resilience to climate change in China.*

The Lancang River Basin and Hydropower Basics

The Lancang River is the upper portion of the approximately 4,880 km long Mekong River. Its source is on Mt. Guozongmucha in Zaduo County, Qinghai Province, China. Over the next 2,000 km or so, the elevation of the river drops about 4,900 m. The Lancang drains an area of 167,487 km^2 and has a mean annual discharge of 2,180 cubic metres per second (m^3/s) (Zhou and Guan, 2001). The mean annual runoff of the Lancang River is approximately 64 km^3, about 13.5% of the total discharge of the Mekong (475 km^3) (Zhao et al., 2000; Adamson et al., 2009).

The Lancang River is rich in hydropower resources. The 4th National Survey of Hydropower Resources (in China) estimated that its total theoretical hydropower potential is 35.9 GW, and that its exploitable installed capacity is 34.8 GW (Li and Shi, 2006; Yuan, 2010). Hydropower development on the Lancang River was first planned in the 1950s (Zhao et al., 2000). In 1986, construction of the first HPP on the Lancang – the Manwan – commenced. . There are now five hydropower projects on the middle and lower reaches of the river that had started operation by 2016: the Gongguoqiao, the Xiaowan, the Dachaoshan, the Nuozhadu, and the Jinghong. The total installed capacity of all existing projects is 15.6 GW, and holding back 42.4 km^3 of water (Table 1). There are seven hydropower projects on the upper reaches of the river in Yunnan that are currently under construction or site preparation: the Gushui, the Wunonglong, the Lidi, the Tuoba, the Huangdeng, the Dahuaqiao, and the Miaowei (Table 1). The total installed capacity of these projects is just 8.8 GW. An additional eight HPPs may be constructed on the upper Xizang (Tibet) section in the future, along with the Ganlanba a little further down: the

1 - One way in which electricity is measured is in watts. 1,000 watts is equal to one kilowatt (KW); a million KW is equal to one gigawatt (GW); and 1,000 GW is equivalent to one terawatt (TWh). In 2013, the average Chinese person used 3,762 KW a year (World Bank, 2016).

Cege, the Yuelong, the Kagong, the Banda, the Rumei, the Bangduo, the Guxue, and the Quzika (Huang 2013; Fan 2015). The Mengsong, the last planned dam on the lower segment, was cancelled out of consideration for fish migration (Kang et al., 2009a; He et al., 2014). Over the past three decades, dam construction has advanced rapidly. Huaneng Lancang River Hydropower Co. Ltd. ('HydroLancang') holds the concession for hydropower on the Lancang, and is responsible for developing and operating all of these, except for the Dachaoshan.

According to the latest survey of small-scale hydropower in China, there are 782 small hydropower projects (installed capacity not exceeding 50MW) planned on the tributaries of the Lancang and 374 projects completed or under construction (NSRH, 2008). In addition to small hydropower projects, a great number of medium and small reservoirs were constructed in the Lancang River basin (Yunnan Provincial Department of Water Resources and Yunnan Provincial Bureau of Statistics, 2013). Most of small hydropower projects are developed and operated by private owners.

On the Lancang , hydropower projects with large reservoirs are usually considered multipurpose projects, designed to meet social demands of water supply, flood control, electricity, navigation, aquaculture, and tourism. Providing these services, however, generally requires that dam operations change the natural flow regime of a river and will affect river ecosystems (Poff et al., 1997; Postel and Richter, 2003). Negative impacts can, however, be mitigated and managed to some extent, and rivers can be managed to address human needs and activities.

Name	Installed Capacity (MW)	Dam Height (m)	Total Storage (km^3)	Status
Gushui	2,600	245	1.54	Under site preparation
Wunonglong	990	133.5	0.65	Under construction
Lidi	420	63	0.10	Under construction
Tuoba	1,250	140	1.04	Under site preparation
Huangdeng	1,900	203	1.51	Under construction
Dahuaqiao	900	106	0.29	Under construction
Miaowei	1,400	131.3	0.66	Under construction
Gongguoqiao	900	130	0.51	Completed (2012)
Xiaowan	4,200	292	15.1	Completed (2010)
Manwan	1,550	132	1.06	Completed (Phase 1 in 1995, Phase 2 in 2007)
Dachaoshan	1,350	120.5	0.88	Completed (2003)
Nuozhadu	5,850	261.5	23.7	Completed (2012)
Jinghong	1,750	110	1.14	Completed (2009)

Table 1.Hydropower projects in operation, construction and site preparation on the mainstream of Lancang River

What are ecosystem services?

Ecosystem Services (ESS) are "the combined actions of the species and physical processes in an ecosystem that perform functions of value to society" (Walker and Salt, 2014). Ecosystems provide humanity with four key services (WLE, 2014):

Provisioning services: these are goods that can be directly consumed, and include food, water, raw materials, such as fibre and biofuel, and genetic, medicinal and ornamental resources.

Regulating services: these comprise the regulation of climate, air quality, nutrient cycles and water flows; moderation of extreme events; treatment of waste, including water purification; preventing erosion; maintaining soil fertility; pollination; and biological controls, such as pests and diseases.

Habitat services: these maintain the life cycles of animals and plants, and the quality and quantity of suitable habitat, e.g., vegetation that enables the natural selection of species to maintain a diverse gene-pool, or which serves as a source for pollinators and or natural pest control agents. These types of habitats benefit people primarily by maintaining biodiversity, which is necessary for other types of service provided by ecosystems.

Cultural services: these are the aesthetic, recreational and tourism, inspirational, spiritual, cognitive development and mental health services provided by ecosystems.

For a specific ESS, the impacts of hydropower projects may be varied. Dams can, for example, benefit society by regulating floods (Hearnshaw et al., 2010); but the lack of flood and high flows can also cause negative impacts to ESS (Postel and Richter, 2003). The impacts of hydropower on fisheries, water quality, and erosion controlcan also be problematic (Hearnshaw et al., 2010).

The negative impacts of hydropower on river ecosystems should be identified and assessed in Environmental Impact Assessments (EIAs) and Strategic Environmental Assessments (SEAs). Negative impacts should be addressed by employing measures to avoid, reduce, or compensate for the impacts.

Addressing the impacts of HPP development

Hydropower projects impact ecosystem services. They may affect the whole ecosystem or a specific component within it. When considering a development intervention, environmental managers will typically consider three approaches to addressing impacts on the environment and ecosystem services: avoidance, mitigation, and compensation.

Avoidance: these types of measures are taken to avoid creating negative impacts from the outset of HPP development, such as careful spatial or temporal placement of infrastructure. Avoidance is often the easiest, cheapest and most effective way to reduce potential negative impacts, but it requires ESS to be considered in the early stages of a project.

Mitigation: if avoidance is not employed, or cannot be, the mitigation seeks to diminish the magnitude and scope of negative impacts. For instance, dams commonly affect fish populations, so developers might include fish passage into the design to try and reduce the negative impact of the dam on fish populations. Mitigation will not, however, remove negative impacts completely. Mitigation might also address cultural and economic concerns.

Compensation: if forest is lost due to reservoir inundation, new forest might be planted elsewhere to compensate. Similarly, if a dam affects fisheries, other tributaries might be set aside for fishery conservation purposes, on which no dams may be built. Compensation, therefore, seeks to address ecosystem losses in one place by conserving and/or enhancing these ecosystem features elsewhere. 'Compensation' is also routinely employed as a strategy in the resettlement of communities affected by a development intervention, and often involves replacing the lost assets of people affected by hydropower development or paying them an equivalent value.

China has been known to employ avoidance measures in the development of HPP on the Lancang mainstream. For example, the Guonian HPP was cancelled due to the proximity of the dam site to the Mingyong Glacier, a unique and much valued natural feature. The height of Wunonglong dam was reduced to avoid impacts on the Three Parallel Rivers of Yunnan Protected Area, a UNESCO World Heritage site (Wang, 2015). So too, the height of the Gushui was reduced to avoid inundation of the salt fields in the Naxi Ethnic Town that are a cultural site with a thousand-year-old history (Wang, 2015). The Mengsong HPP was cancelled to protect routes for four long-distance migratory fish species, since the dam would have prevented them from reaching two tributary habitats off the lower Lancang River.

Mitigation efforts are more common in the HPP development of the Lancang. The function of the Ganlanba HPP was changed from electricity generation to that of a re-regulating reservoir to reduce water level fluctuation caused by the unsteady flow release from the Jinghong HPP. In this way, water level fluctuations could be controlled in order to allow for navigation of the river (Xinhua News, 2011; Huang, 2013).

The dams in the middle and lower reaches of the Lancang River have constructed very close together, so that individual dams were constructed at the tail end of the reservoir of the dam immediately below it. There is, therefore, no 'free flowing' river along this stretch of the river. On the upper reaches of the Lancang, however, the dams have been spaced further apart to enable free-running water between dams and reservoirs, so as to support fisheries functions. The length of river reaches with unaltered hydraulic conditions in Xizang and Yunnan on the Lancang upstream are 32.5km and 77.9km, respectively. If the length of the river from the Ganlanba HPP to the China–Myanmar border (81 km) is included, then the total length of river with unaltered hydraulic conditions is about 190km on the Lancang mainstream (Zhao et al., 2013). How these efforts have affected fish habitat and biodiversity needs to be further evaluated.

Table 2 summarises the variety of measures to avoid, minimize or compensate for the adverse impacts of hydropower on ESS on the Lancang. In many cases, these efforts have been costly. Environmental protection measures at the Gongguoqiao HPP cost RMB 137 million (ca. US$21.1 million); at Xiaowan HPP, they cost RMB 406 million (ca. US$62.5 million), accounting for 1.8% and 1.2% of total construction investment respectively (MEP, 2015a, 2015b). The investment in environmental protection at the Nuozhadu HPP was estimated to be a billion RMB (ca. US$153.9 million), and the cost of a structure to reduce the temperature change of water released from the reservoir was 240 million RMB (ca. US$36.9 million) (Yunnan News, 2012).

In addition to these measures, environmental monitoring and management plans have been developed.

Conclusion: *To address negative impacts to ecosystem and other services, hydropower developers will consider avoidance, mitigation and/or compensation measures. Chinese hydropower developers do practice some avoidance measures to preserve some ecosystem services, and to protect culturally significant features. Mitigation and compensation measures have also been used to diminish the negative impacts if hydropower development on ecosystems.*

Are mitigation measures effective for minimising hydrological changes?

HPP operations on the Lancang River change the magnitude, timing, duration, frequency and rate of river flows (Chen et al., 2014; Lu et al., 2014). In accordance with the requirements of their EIAs, Gongguoqiao and Xiaowan HPPs release 168 m^3/s and 269 m^3/s respectively in the dry season, to ensure that channels downstream are not left without water (MEP, 2015a, 2015b). The Jinghong HPP controls its rate of release at below 300m^3/hour, so that the water level at the outlet does not fluctuate by more than a metre per hour. The minimum flow release is generally acceptable after mitigation, but the changes to flow processes (timing, duration, frequency and rate) could be further addressed by improving the operation of the HPPs (Chen et al., 2014; Li and Zhao, 2016).

Environmental Impact	Mitigation Measures	Project or Region
Downstream hydrological changes	Management of water releases	All HPPs (environmental flow release); Xiaowan, Nuozhadu (flood peak reduction and low flow augmentation in dry season).
Low temperature water release	Selective water intake	Huangdeng, Nuozhadu
Deterioration of water quality	Water pollution control Forest clearing in the reservoir	All HPP reservoirs.
Reservoir sedimentation	Operation of storing clear and releasing muddy water; watershed soil erosion control	Xiaowan, Manwan, Dachaoshan, Nuozhadu (storing clear and releasing muddy); construction sites and watershed (erosion control).
Flooding of natural habitats	Fish habitat compensation; fish nature reserve	Jidu River at Miaowei (dam removal and fish habitat restoration); Luosuo (Buyuan) River, Nanla River downstream of Jinghong (rare and endemic fish nature reserve); eight tributaries for fish habitat preservation.
Fish and other aquatic life	Management of water releases; fish passage facilities; fish hatcheries and release; fishing regulation	Ganlanba (fish ladder); Wunonglong, Huangdeng, Dahuaqiao (fish lift), Wunonglong, Lidi, Tuoba, Huangdeng, Dahuaqiao, Miaowei (fish attraction barge); Huangdeng, Gongguoqiao, Nuozhadu (fish hatcheries and release), Gongguoqiao, Nuozhadu (fish netting and transport).
Greenhouse gases	Forest clearing in the reservoir	All reservoirs of the HPPs
Loss of terrestrial vegetation	Transplantation of valuable and rare plants	Lidi, Xiaowan, Nuozhadu, Jinghong,
Loss of terrestrial wildlife	Wildlife rescue	Nuozhadu, Xiaowan

Table 2. Environmental Impacts and Mitigation Options for HPPs on the Lancang River

Fan and colleagues (2015) argue that the Lancang dams have led to a decline in the amount of water passing through the river system during the flood season; a decrease in sediment loads; and to declines in water quality within China's borders. Combined, these have negatively impacted the Lancang's aquatic ecology. These difficulties do not, however, cross China's southern borders into the lower Mekong, where the dams have only had small unfavourable effects on downstream environments and ecosystems.

Before 2010, HPPs on the Lancang River caused only modest changes to the hydrology of the Lower Mekong. Just south of the China-Thai border is the monitoring station of Chiang Saen, which recorded relatively modest flow changes as a result of the dams (-15% to 9%) (Lu et al., 2014). The initial filling of hydropower reservoirs on the Lancang River was associated with a moderate reduction in the extreme low flows (Lu et al., 2014). There were also changes to the magnitude, timing, and duration of flows (water levels increase in the dry season and decrease in the wet season), but the frequency and rate of water level changes increased significantly due to HPPs on the Lancang River (Cochrane et al., 2014).

Since 2011, however, Räsänen and his colleagues (2017) have found that Chinese hydropower operations have modified river discharge considerably, with the largest changes being observed in 2014, when Chinese hydropower operations caused exceptionally high dry season flows and low wet season flows in northern Thailand. In this year, dry season flows reached record highs of two to three times the long-term average. During the same year, wet season flows reached record low levels and were roughly two thirds of the long-term average. These changes in flow were observed over 2,000 km downstream in Cambodia, where the 2014 dry season flows increased by half.

These changes can have economic benefits. For instance, water levels at Chiang Saen are now high enough during the dry season to allow large cargo ships to pass through the port (National News Bureau of Thailand, 2015). Furthermore, in the spring of 2016, HPPs on the Lancang River released extra water in an effort to alleviate downstream drought conditions attributed to El Niño.

Conclusion: *Minimum flow requirements were generally met after mitigation of hydropower operations, but the changes of flow processes (frequency and rate) were not adequately mitigated. Extreme low flow and flow fluctuation should be addressed by improving the operations of HPPs on the Lancang River.*

Can mitigation measures effectively minimize the changes to water quality and temperature, and the greenhouse gas emissions?

The damming of rivers has the potential to diminish water quality due to the reduced oxygenation and dilution of pollutants by relatively stagnant flows, flooding of biomass, and reservoir stratification. Despite the presence of reservoirs along the Lancang, the Yunnan Province Environmental Quality Communiqué of 2014 showed that water quality on the mainstream (including the gauge at the Chinese border) was good (YEPD, 2014), indicating no water quality degradation on the main stem of the Lancang River after HPP operation. Furthermore, the joint operation of dams had cumulatively positive impacts on water quality of waters immediately below the dams, but no impacts on waters further downstream (Wei et al., 2009). In addition, because of limited industrial and domestic pollution in the Lancang River basin, water quality can remain good and stable after hydropower operation has begun.

'Reservoir stratification' refers to different layers in a reservoir defined by temperature. In reservoirs, the temperature differences can be considerable, which causes a reduction in the penetration of oxygen from surface layers to deeper layers (Elçi, 2008; Thornton et al., 1996). Monitoring data at Xiaowan HPP indicates that its reservoir is steadily stratifying and that the temperature of the water released is between 0 and 5.2°C lower than normal in summer, and 0.8-1.2°C higher than normal in winter (MEP, 2015b). At the Nuozhadu HPP, HydroLancang invested heavily in a structure to minimize low water temperature releases in summer, and other structures that would allow the water temperature to be increased by up to 4.3°C (Gao et al., 2013). Monitoring data and reports are not, however, currently available to analyse the effectiveness of this expensive structure.

Carbon dioxide and methane emissions are emerging issues in hydropower as a result of decaying biomass at the bottom of reservoirs (Galy-Lacauxet al., 1997; Gile, 2006). Due to forests being cleared before filling a reservoir, climatic characteristics and topographical conditions in the Lancang River basin, the greenhouse gases (GHG) emissions from its reservoirs are quite low. Monitoring results indicate that the Xiaowan, the Manwan and the Nuozhadu emit the equivalent of 1.48, 8.40, and 3.20 CO^2 per kilowatt hour gross emission, respectively. On a per kilowatt basis, the GHG emissions values at these three reservoirs are considerably lower than that of many tropical reservoirs (Yang et al., 2014), and are less than 1% that of fossil fuel-run electricity generation facilities (CAE Project Team, 2015).

Conclusion: *Due to the natural conditions and mitigation measures, water quality degradation and large GHG emissions are not observed on the Lancang River. The effectiveness of expensive water temperature mitigation structures needs to be analysed with future monitoring data.*

How does mitigation address sediment loads?

Sediments are critical to the ecological productivity of the Mekong system as a whole. It is not known how much sediment the river system generates, though the figure of 165 million metric tonnes of sediments a year is sometimes used. It is not known either how these sediments are distributed. The biggest source of sediments was (i.e. before the Lancang dams) the Lancang, generating an estimated 90 – 100 million metric tonnes a year (Sarkkula et al., 2010), 50-60% of the sediments in the Mekong system as a whole. The Lancang dams trap large quantities of sediment that originate in Yunnan. Fu and He (2007) have estimated that the Manwan HPP traps some 60.48% of the sediment that flows into it, and that the Gongguoqiao, the Dachaoshan and the Jinghong dams trap around 30.23%, 66.05% and 63.50% respectively. Based on field data, it was estimated that 54.2% of the total volume of the Manwan Reservoir was consumed by sediment after 12 years of operation (Mei et al., 2006). Cumulatively, the Lancang dams are estimated to trap more than 90% of the sediments that flow into them (Kummu et al., 2010; Kondolf et al., 2014).

It is not necessarily clear how these sediment reductions impact downstream environments. Lu and Siew (2006) have shown that the impacts of these reductions are only significant at the first gauging station (Chiang Saen) below China. Sediment levels in areas located along the middle of the river have remained stable or even increased after the construction of the Manwan. Research results by Fu and colleagues (2007) and Liu and colleagues (2013) confirm these findings. The picture is further complicated by other variables that also affect sediment levels. Darby and his colleagues (2016) show that the suspended load to the Mekong Delta has declined by between 42.4 - 62.8 million tonnes between 1981 and 2005, of which 25.9 - 40.1 million tonnes is due to changes in cyclone activity.

Other research, however, predicts that dams and associated reservoirs will trap increasingly larger proportions of sediment in the future, including those on the Lancang (Kummu et al., 2010; Kondolf et al., 2014). In the absence of detailed studies, however, it is not known how rapidly this will occur, or how these impacts will be distributed throughout the system.

Conclusion: *Mitigation measurs to address the impact of HPPs on sediment loads are currently designed to manage sediment deposition in reservoirs. These are not designed to address possible downstream (and transboundary impacts), perhaps because current evidence shows no definite relationship between Lancang dams and downstream sediment loads; and because other drivers currently impact sediment levels much more significantly than do HPPs.*

Can fish habitat and community-compensation measures offset the impacts of hydropower projects on fisheries?

Constructing dams on the mainstream Lancang blocks fish migration and changes fish habitats from fast-flowing rivers to stagnant reservoirs. Biodiversity and populations of fish in the middle and lower Lancang River have decreased mainly due to hydropower operation (Li et al., 2013; Kang et al., 2009a; Zheng et al., 2013). Along the Manwan HPP reach, there were 61 fish species (including reaches upstream and downstream the dam) before dam construction, including 47 endemic species. In 2008, the number of fish species and endemic fish species dropped to 31 and 16, respectively (Yu et al., 2011). Fish investigations after reservoir creation at Gongguoqiao and Xiaowan HPPs showed that fish populations were dominated by species adapting to slow-moving or standing water. Before impoundment, there was a more diverse mix of fish species adapting to both slow moving and fast moving waters (MEP, 2015a; 2015b).

Artificial fish hatch-and-release programmes of both endangered and endemic species have been implemented at Nuozhadu and Gongguoqiao HPPs and will be implemented at the Huangdeng project (Huang, 2013). The effects of the fish hatch-and-release programmes at the HPPs on the Lancang River have not been documented. The Jidu River – a tributary of the Upper Lancang - is a spawning and rearing area for several endemic fish species. Four cascade hydropower stations were planned on the Jidu River, and the first one was constructed in 2010. In order to re-connect the tributary to the mainstream and compensate for the fish habitat, HydroLancang spent 140 million RMB (approximately US$ 21.5 million) to purchase and then to remove a 12.6 MW hydropower station on the tributary in 2012. After dam removal, the number of fish species in the downstream section (from the dam to 3 km downstream) increased significantly from three (two endemic) in 2011 to 17 (ten endemic) in 2013; and the number of species 1 km upstream of the dam increased from four (one endemic) in 2011 to seven (two endemic) in 2013 (Ding, 2015). This initiative helped conserve biodiversity and population of fish species as a compensation measure for losses on the main stem.

The capture records of four long-distance migratory fishes between the Lancang and the Mekong indicate those fish species that migrate upstream migrate only as far as Jinghong, but the populations have been in decline since 1970 for a variety of reasons (Kang, 2013; Yang et al., 2007). The Luosuo and Nanla Rivers are two critical habitats for migratory fish from the Mekong River (Yang et al., 2007; Kang et al., 2009b). The cancelation of the Mengsong Dam for fish habitat conservation on the Luosuo and Nanla rivers has been beneficial for fish migration from the Mekong River. As such, dams on the Lancang River are currently unlikely to be blocking fish migration routes from the Lower Mekong River.

Conclusion: *Mainly as a result of hydropower operation, biodiversity and endemic fish populations have been significantly affected on the Lancang. No data are currently available to assess how effective fish hatch-and-release programs have been for the river's ecology. Fish habitat restoration on tributary rivers can compensate for fish biodiversity loss to some extent, but the impacts on fish biodiversity and population should be further evaluated.*

How effective are mitigation measures for terrestrial vegetation and wildlife?

Along the middle and lower reaches of the Lancang, inundation by reservoirs and water level variations have caused a loss of, or reduced the complexity of, riparian vegetation (Li et al., 2012). If the scope of study is expanded to 20 km of either side of the river, it was found that vegetation quantity and diversity declined during dam construction, and then increased after project operation began (Liu et al., 2015). It is thought that this latter outcome arises because of the moderating effect that large reservoirs have on local climatic conditions (Liu et al., 2015). Transplanting of valuable and rare plants and wildlife rescue were undertaken at HPPs on the Lancang River. The effects of these measures on biodiversity and population of terrestrial vegetation and wildlife have yet to be documented.

Conclusion: *No data are currently available to understand the effectiveness of the mitigation measures for terrestrial vegetation and wildlife.*

How were the environmental mitigation measures determined?

Hydropower development can be generally divided into five phases in China: river basin hydropower planning; pre-feasibility studies; feasibility studies; construction; and operation. The processes of environmental management of HPPs corresponds to these five phases: Strategic Environment Assessment (SEA) of hydropower planning; project preliminary Environment Impact Assessment (EIA); project EIA and environmental design; environment protection implementation; and post-project environmental monitoring and impact assessment. The SEA of hydropower planning evaluates the environmental impacts of a hydropower development plan in a river basin, and may propose modification to the plan for environmental reasons. The EIA evaluates the environmental impacts of a specific hydropower project and propose avoidance, mitigation or compensation measures.

At each phase mentioned above, relevant technical documents are supposed to be reviewed and approved before proceeding to the next phase. Environmental management agencies will review and approve the SEA report,EIA report, and environmental design. The Environmental Protection Law of China requires that the design, construction and operation of appropriate mitigation measures should be synchronised with the design, construction and operation of a new HPP. Once the construction of the HPP is completed, environmental inspection and approval by environmental administrations are required to ensure the mitigation measures are in place. The environmental assessment of HPPs on major rivers or with an installed capacity of over 250 MW are reviewed and approved by the Ministry of Environmental Protection (MEP). The Lancang River is one of China's major rivers, so the SEA, EIA, and inspection and acceptance of HPPs on mainstream Lancang are all reviewed and approved by the MEP. This ensures that the HPPs on the mainstream Lancang comply strictly with relevant requirements and meet high standards. Since 2016, a post-project EIA has also been required to examine the actual impacts of the project and effectiveness of mitigation measures, and then further improve or modify the mitigation measures. It has been proposed that existing HPPs completed before 2016 shall also be required to implement this post-project EIA.

Prior to 2006, the environmental assessment of small HPPs was managed by the municipal environmental department in Yunnan Province. Standards were lower, and less strictly applied, than for Lancang mainstream HPPS. This resulted in a variety of environmental problems, including construction without environmental assessment, low standards of in-stream flow, harmful alteration, and disruption or destruction of fish habitat and fish communities. Since 2006, the environmental assessment of small HPPs must be reviewed and approved by the Environmental Protection Department of Yunnan Province. In 2016, Yunnan provincial government halted new development of, and upgrades to, medium and small HPPs (installed capacity up to 250MW) in consideration of economic and environmental issues.

Conclusion: *The SEAs and EIAs of HPPs on the Lancang River propose measures to avoid, mitigate, and compensate for negative environmental impacts. The Ministry of Environmental Protection of China reviews and approves SEAs, EIAs, and mitigation measures, and supervises the design, construction and operation of appropriate mitigation measures, synchronised with the design, construction and operation of HPPs on the Lancang River mainstream.*

How is the environmental management of HPPs on the Lancang River evolving?

Environmental assessment and mitigation/compensation measures of HPPs on the Lancang mainstream have been gradually improving over the last decades. Environmental protection measures for the Manwan HPP, the first dam on the Lancang, were relatively simple. Since 2010, HydroLancang has improved mitigation and compensation measures for the conservation of fish habitat and communities, including fish habitat restoration and fish passage proposed or implemented after 2010 at Huangdeng, Miaowei and Ganlanba HPPs.

The enhancement of policy and standards for environmental impacts of HPPs are crucial for improving the environmental management of hydropower development on the Lancang River. In 2006, the MEP issued EIA guidelines for HPPs on for in-stream flow, low temperature water releases, and fish passage (EIA Department of the MEP, 2006). In 2011, the MEP proposed the principle of "ecological protection as the first priority with overall consideration, appropriate development and ensuring the bottom line" during hydropower development (Wu, 2011). In 2012, the MEP issued the policy to “Further Enhance the Environmental Protection of Hydropower Development”. Fish habitat compensation at tributaries, fish hatcheries and release, fish passage, and operational improvement for environmental purposes were highlighted in the specific requirements (MEP, 2012).

The MEP required the post-project environmental impact assessment should be conducted for Gongguoqiao, Xiaowan, and Jinghong 3-5 years after these were commissioned. HydroLancang is planning to integrate and improve existing monitoring systems at watershed scale for managing the impacts of the Lancang dam cascade. Post-project monitoring and assessment will provide a better basis for understanding project-ecosystem interactions on the Lancang River, and for further protection of its ecosystem.

Conclusion: *Environmental management of HPPs on the Lancang River has been gradually improving over time. The improvement of awareness and knowledge, government and public concerns, and policy and standards for managing environmental impacts of hydropower projects are crucial drivers for improving environmental management of HPPs in China.*

Are there any gaps in environmental management of HPPs compared to international best practice?

Compared with international best practice, the environmental mitigation measures implemented by HPPs in China are still being trialled and developed in terms of management mechanisms and technical capacities. Experience and capability should be improved, especially with respect to the conservation of fish habitat and communities (Yu, 2016). The monitoring and assessment of a variety of fish conservation efforts are still relatively poor at HPPs on the Lancang River. Environmental flow implementation should not only maintain minimum flows, but also restore flow regime patterns. Standards and requirements are not specified for fish conservation measures. The mitigation and compensation measures should be further optimized at the scale of the watershed. Necessity and feasibility of new mitigation or compensation measures should be studied and implemented for existing projects in the future.

The transboundary environmental impacts of Chinese hydropower has become one of many focal points of public attention in the region and around the world, and knowledge sharing should be improved between China and the lower Mekong countries (Grumbine et al., 2012; McNally et al., 2009). The dialogue, communication and collaboration among hydropower operators, scientists, and communities should be strengthened to improve the sustainability performance of HPPs on the Lancang River. China can also share its experience and lessons on hydropower development and environmental issues with Mekong countries for addressing critical environmental challenges.

Conclusion: *Gaps still exist between international best practice and the environmental management of HPPs on the Lancang River. The effectiveness of monitoring and assessment, environmental flow implementation, fish conservation, and adaptive management are key points of potential improvement to meet the government's requirements and public expectations. The knowledge sharing around the environmental management of HPPs should be addressed by strengthening dialogue, communication and collaboration among China and Mekong countries.*

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