

# Environmental and Human Impacts of Lancang-Mekong Mainstem and Tributary Dams on China, Laos, Thailand, Myanmar, Cambodia, and Vietnam

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## Abstract

The Lancang-Mekong River in China, Laos, Thailand, Myanmar, Cambodia, and Vietnam is the soul and heart of mainland Southeast Asia. Over 60 million people depend on the river and its tributaries for food, transportation, water, and other necessities of life. The river supports one of the world's most diverse fisheries, second only to Brazil's Amazon River. Lancang-Mekong and tributaries are already heavily dammed primarily in China, Laos, Thailand, and Cambodia, with many more dams planned or under construction. Dams can worsen the impact of periodic droughts in the Lancang-Mekong basin and block the river's "pulse effect" that spreads water and nutrients needed for fishing and farming onto the floodplains and delta. The headwaters of the Lancang are in China and its waters are considered a national resource. China regards the Lancang, Yangtze and Yellow rivers as a free resource rather than a shared resource. The primary difference between these rivers is the Lancang flows from China into and through other countries and not directly into a sea or ocean. China and Myanmar have not joined the Mekong River Commission (MRC) as full members but have been Dialogue Partners since 1996. Over the past thirty years, China's Lancang policies and actions have reflected its national resource interests. China has actively engaged with individual trans-boundary countries at various levels including environmental, conservation, and economic agreements. The primary objective of this study is to assess the environmental and human impacts of all Lancang-Mekong mainstem and tributary dams and the plans by many countries for more hydropower utilizing the potential of the river as the continent's energy lifeline. Future dams

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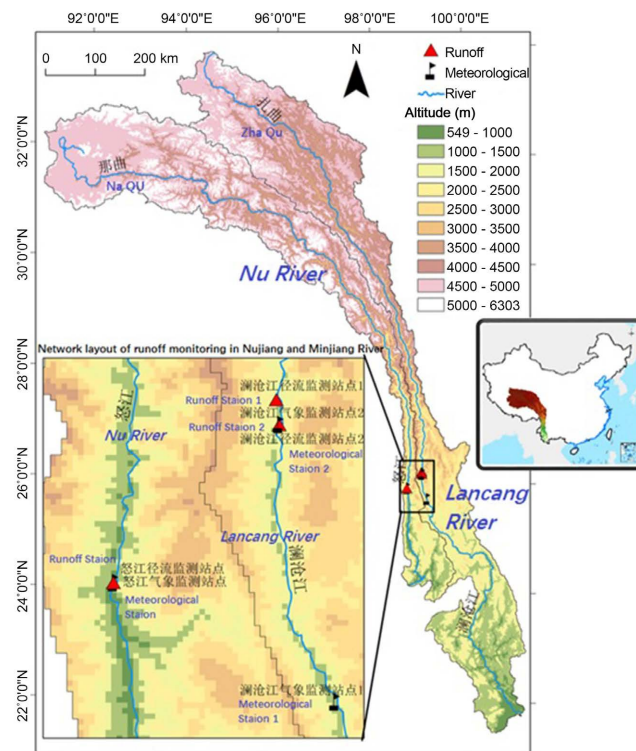
need to include fish ladders and navigation locks to reduce the environmental impacts on fish populations, natural resources, navigation, and livelihoods. Strengthening of international collaboration via the MRC or by individual or multiple country agreements to address Lancang-Mekong's sustainable transboundary development goals is recommended. When new Lancang-Mekong and tributary dams are built within any of the transboundary watershed countries, additional communities will need to be resettled. Significant environmental and human impacts are observed. Steps will have to be taken by all the concerned countries to prevent these problems and to ensure that people's livelihoods are restored after resettlement.

## Keywords

Lancang-Mekong River, Dams, Human Activities, Environmental Impacts

## 1. Introduction

The Lancang-Mekong is a transboundary river in Southeast Asia (**Figure 1**). It is the world's twelfth-longest river and the seventh-longest in Asia. The river has an estimated length of 4350 km and drains an area of 795,000 km<sup>2</sup>, discharging 475 km<sup>3</sup> of water annually [1]. Originating from the Qinghai-Xizang Plateau, the river flows through the Hengduan Longitudinal Valley (**Figure 2**) and Yunnan-Guizhou Plateau. In terms of inland fishery production, the river has an essential role.



**Figure 1.** Lancang and Nu Rivers in China. Photo Credit: eforchina.env.dtu.dk.



**Figure 2.** Grassland in Lancang River valley in China. Photo Credit: Encyclopedia of Britannica.

Then the Lancang-Mekong meets the China-Myanmar border and flows about 10 km along the border (**Figure 3**) until it reaches the tripoint of China, Myanmar, and Laos (**Figure 1**). From there it flows southwest and forms the border of Myanmar and Laos for about 100 km until it arrives at the tripoint of Myanmar, Laos, and Thailand [2]. This is also the confluence between the Ruak River (which follows the Thai-Myanmar border) and the Mekong. The area of this tripoint is sometimes termed the Golden Triangle, although the term also refers to the much larger area of those three countries notorious as a drug-producing region.



**Figure 3.** Lancang River twisting through the mountains. Photo Credit: International Rivers Network.

The Lancang-Mekong Basin is frequently divided into two parts: the “*upper Lancang-Mekong basin*” comprising those parts of the basin in Tibet, Yunnan, and eastern Myanmar, and the “*lower Mekong basin*” from Yunnan downstream from China to the South China Sea (also referred to in Vietnam as the East Sea) [3]. From where it rises to its mouth, the greatest drop in the Mekong occurs in the upper Mekong basin, a stretch of some 2200 km. Then, it enters the lower basin where the borders of Thailand, Laos, China, and Myanmar come together in the Golden Triangle.

The elevation of the Qinghai-Xizang Plateau during the Tertiary period was an important factor in the genesis of the southwest monsoon and the dominant climatic control influencing the hydrology of the Lancang-Mekong Basin [4]. The physical and geographical conditions of the river basin are basically like the Nu River Basin, and the spatial and temporal distribution of floods have many common characteristics and basic laws within China. Lancang-Mekong is already heavily dammed, with many more dams planned and under construction (Figures 4-8). China has already built eleven cascade dams on the Lancang-Mekong mainstem (Figure 9) since 1995 [5]. As of November 2016, China has five more under construction, and another 11 planned or proposed. Laos has two dams under construction on the mainstem (Figure 10), and another seven planned or proposed; Cambodia has two planned or proposed. The Mekong is the fastest-growing large river hydropower construction basin globally [6]. The scheme is expected to change the river’s natural flood-drought cycle and block the transport of sediments, affecting ecosystems and livelihoods (Figure 11) [7].



**Figure 4.** The Xiaowan Dam on the Lancang River. Photo Credit: Danish Ministry of Foreign Affairs.



**Figure 5.** Nuozhadu Dam on the Lancang River. Photo Credit: Encyclopedia of Britannica.



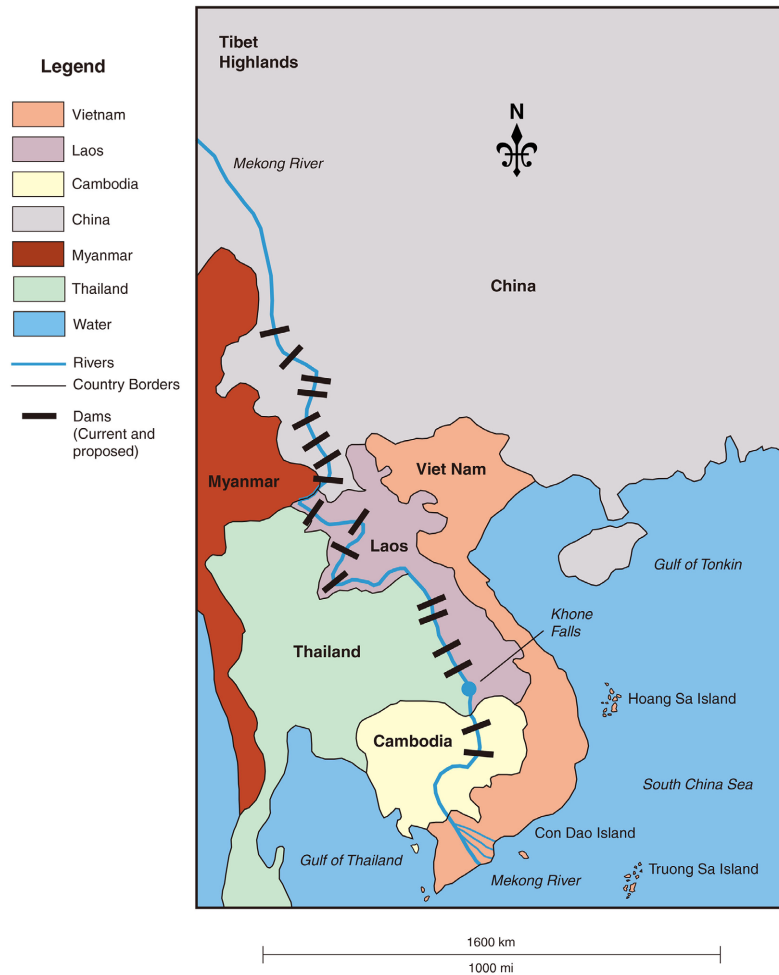
**Figure 6.** Jinghong Dam on the Lancang River. Photo Credit: Danish Ministry of Foreign Affairs.



**Figure 7.** The Jinghong Reservoir above the dam. Photo Credit: Encyclopedia of Britannica.



**Figure 8.** Wunonglong Dam on Lancang River. Photo Credit: Danish Ministry of Foreign Affairs.



**Figure 9.** Existing and proposed dams on the Lancang-Mekong River mainstem by China, Lao People's Democratic Republic, and Cambodia. Map by Mic Greenberg. Published with the permission of the Editor of Open Journal of Soil Science.



**Figure 10.** The location of all the current and proposed dams on the Lancang-Mekong mainstream. Photo Credit: Wikipedia.



**Figure 11.** Urbanization of the Lancang-Mekong River wider floodplain. Photo Credit: In the Public Domain.

Located south of the Three Rivers Area [8], this highland and plateau area in China is still relatively elevated (2000 - 3000 m above sea level), transitioning to mid- and lowland reaches as the Lancang-Mekong flows down a steep gradient, broadening as it goes. Small tributary catchments drain into the river from both sides of the mainstem.

The upper Lancang basin [9] makes up 24% of the total area and contributes 15% - 20% of the water that flows into the Lancang-Mekong River. The catchment here is steep (Figure 12) and narrow with soil erosion being a major problem with 50% of the sediment in the river coming from the upper basin (Figure 13).



**Figure 12.** Limestone cliffs. Limestone caves and cliffs tower over the Mekong River. The flood of 2008 reached the top of the stairs to a cave that tourists frequently visit and covered more than three-quarters of the cave opening. Published with the permission of the Editor of Open Journal of Soil Science.



**Figure 13.** Limited flow on the Lancang-Mekong River. Photo Credit: New York Times.

In Yunnan Province of China, the river and its tributaries are confined by

narrow (Figure 14), deep gorges (Figure 15). The tributary river systems in this part of the basin are small. Only 14 have catchment areas that exceed 1000 km<sup>2</sup>, however, there is a significant loss of forest cover due to demand for natural resources [9] [10]. South of Yunnan, in Simao and Xishuangbanna Prefectures, the river changes as the valley opens out, the floodplain becomes wider (Figure 11), and the river becomes wider and slower (Figure 16).



**Figure 14.** Lancang River canyon. Photo Credit: In public domain.



**Figure 15.** Narrow valley along the Lancang River. Photo Credit: In public domain.

The elevation of the Qinghai-Xizang Plateau during the Tertiary period was an important factor in the genesis of the southwest monsoon [11] and is the dominant climatic control influencing the hydrology of the Lancang-Mekong Basin. Understanding the nature and timing of the elevation of Tibet (and the Central Highlands of Vietnam) therefore helps explain the provenance of sediment reaching the Tonle Sap Lake and the Mekong Delta today. Studies of the provenance of sediments in the Mekong Delta reveal a major switch in the source of sediments about eight million years ago (Ma) [12]. From 36 to 8 Ma the bulk (76%) of the sediments deposited in the delta came from erosion of the bedrock in the Three

Rivers Area [13]. From 8 Ma to the present, the contribution from the Three Rivers Area fell to 40%, while that from the Central Highlands rose from 11% to 51%. One reason for the sediment reduction from the Three Rivers area was the construction of mainstem and tributary dams on the Lancang-Mekong in all six transboundary countries. One of the most striking conclusions of provenance studies is the small contribution of sediment from the other parts of the Lancang-Mekong basin, notably the Khorat Plateau, the uplands of northern Laos and northern Thailand, and the mountain ranges south of the Three Rivers area.



**Figure 16.** Long Boats and cave. Published with the permission of the Editor of Open Journal of Soil Science.

The primary objective of this study is to assess the environmental and human impacts of Lancang-Mekong mainstem and tributary dams and the plans for more to utilize the hydropower potential of the river as the continent's energy lifeline. Strengthening of international collaboration, via environmental, conservation, and economic agreements between individual and multiple transboundary countries, to address Lancang-Mekong's sustainable development goals is encouraged. When additional dams are built within China, Laos, Thailand, and Cambodia,

additional communities will need to be resettled and could suffer from a lack of adequate compensation, problems with food security, and increased incidence of disease. Steps will have to be taken to prevent these problems and to ensure that people livelihoods are restored after resettlement.

## 2. Lancang-Mekong Natural Resources

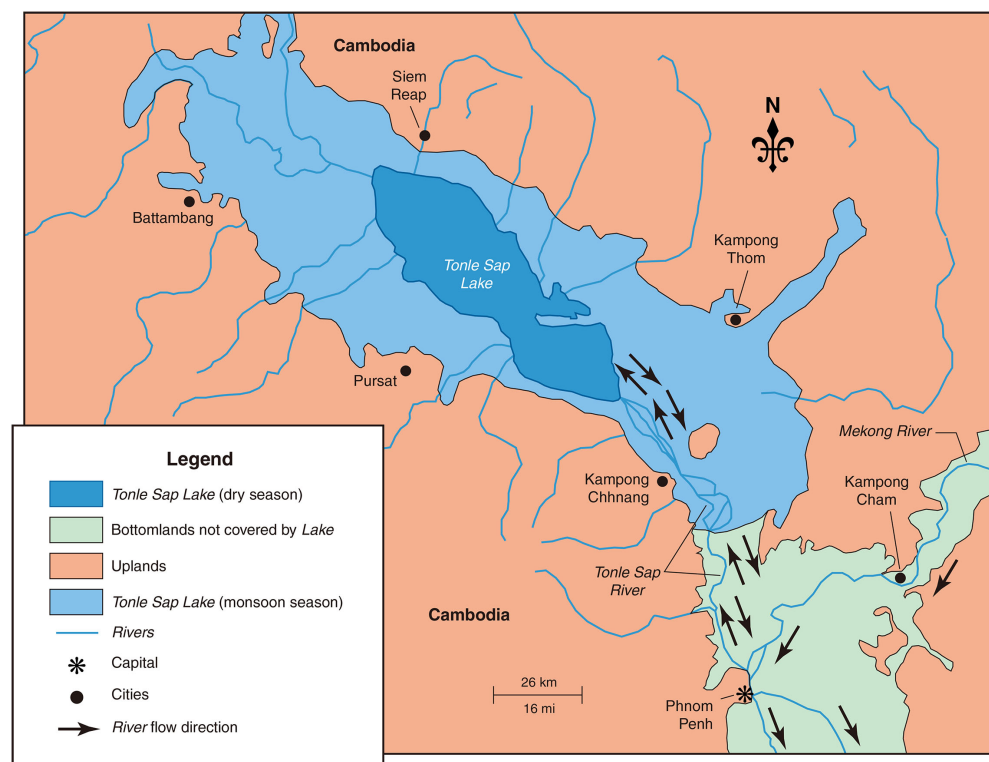
### 2.1. Geology, Soils, Erosion and Sedimentation

Olson and Morton [14] reported the “*Early Quaternary and older alluvial deposits reveal the tectonic and sea-level adjustments, fold and fault lines, subsidence, and uplifts that characterize the evolving Lancang-Mekong River. About 40 million years ago, its precursor drained into the sea near where the Red River now flows just south of Hanoi, Vietnam. Over time, earthquakes and volcanic activity of the Himalayas altered the mountain drainage southward via steep gorges that appeared about 13 million years ago, and by 8 million years ago formed the present courses of three rivers: the Mekong, Yangtze, and Yellow Rivers, which run in parallel sutures [12] [15]. Below this area was a wide inland sea during the Upper Mesozoic. The Mekong River at that time likely flowed directly south and to the west of the Korat Upland, joining what has become the Chao Phraya River in Thailand [15]. There is evidence that subsidence in the Tonle Sap basin of Cambodia, perhaps during the last 12,000 years, drew the Mekong River eastward and away from its former Chao Phraya connection and the Tonle Sap basin. The modern-day Mekong River carries a large supply of fluvially transported fine sediments and sands that originated in the Tibetan and Himalayan mountain regions and have been mediated over time by glaciation, precipitation, and evapotranspiration. The Mekong River channel has several distinct hydro morphological reaches as it flows south. In some places, the channel is straight, in other locations, it becomes sinuous with high radius bends as it follows bedrock-carved fault lines and tectonic lineaments. As the bedrock-walled single channel flows into alluvial lowlands, the channel meanders with low-radius bends. When the single alluvial channel at high flows takes a shortcut across the neck of a bend, the river becomes braided and divided, creating islands and multiple channels with water levels that vary with the season*” [14]. It is worth emphasizing that the tectonic features and local geology significantly shape the Mekong River basin which constitutes a substantial water asset in Southeast Asia in particular.

From Vientiane to the Mun River confluence, natural levees composed of silt and clay about 8 to 10 m high line both riverbanks, evidence of historical overtopping. However, the topping of these levees is not common today [16]. Many wetlands beyond the levees are artificially drained for rice paddies, corn (*Zea mays* L.), vegetables, and other crops. Where the riverbanks are not steep, they are cultivated for flood recession agriculture, that is, planted according to the river level as it transitions from wet to dry season. The riverbed in this reach is fine sand with occasional outcrops of fluvial pebble beds with about 30 to 50 cm of organic-rich or black inorganic silts [16]. Cretaceous volcanic activity occurred throughout

southern Laos, and eruptions of basalts in the Miocene and Quaternary were widespread. The modern-day Mekong River near Muang Khong is locally controlled by basalt outcrops and fault patterns that give rise to the spectacular Si-phandone (4000 islands) and Khone Falls on the Lao-Cambodia border [16]. The river in this reach has bedrock anastomosed channels overlain by alluvial deposits. This means that the river flows are separated by many large islands about 5 to 10 m above the low water mark that sustain mature vegetation and are stable or may migrate slowly from bank erosion.

Cambodia's parent material, hydrologic, and physiographic features are the products of tectonic, erosional, and other geological processes [14] [16]. The Mekong River basin lowlands, the Cambodian plains, and the Mekong delta are constituted primarily of Quaternary and Holocene river alluvium. The Great Lake of Cambodia, Tonle Sap Lake (Figure 17), and its alluvial and lacustrine floodplains occupy a geological depression during the Upper Mesozoic was a wide inland sea. Extending over 44% of Cambodia's total land area, the Tonle Sap basin was formed as the sea retreated and connected to the Mekong River system in the last 17,000 years [16]. The Tonle Sap Lake itself is only about 5000 to 10,000 years old. A bedrock ridge near Kampong Cham prevents the 120 km long and 35 km wide permanent lake from fully draining.



**Figure 17.** The Tonle Sap Lake and River reverse their flow in the monsoon season when the Mekong River floods and backs up into the Tonle Sap River and Lake. With the onset of the dry season, the floodwaters recede, and the Tonle Sap flow changes direction and flows into the Mekong River as it travels southward to the South China Seas. Map by Mic Greenberg. Published with the permission of the Editor of Open Journal of Soil Science.

Cambodia is entirely within the tropics and has a 443 km coastline along the Gulf of Thailand (**Figure 18**). The age and general origins of Cambodian soils can be categorized into three distinctly different groupings: 1) regions that retained their original parent material, such as the Cardamom and Central Annamite mountains, 2) regions that are covered by ancient alluvial or colluvial plains; and 3) regions that presently receive annual alluvial sediments, such as the Tonle Sap bottomlands [17]. The central plain includes Tonle Sap Lake and River and the upstream reaches of the Mekong River delta [18]. The margins of the low-lying central plains are transitional plains consisting of Old Alluvium that rise 200 m above sea level and are thinly forested. North of these plains from east to west is a sandstone escarpment stretching 320 km.



**Figure 18.** The Great Lake of Cambodia (the Tonle Sap Lake) and the Mekong River are valuable water resources for Cambodia in Southeast Asia. Map by Mic Greenberg. Published with the permission of the Editor of Open Journal of Soil Science.

Sediments deposited on Tonle Sap Lake plain contain marine animal and vegetation materials suggesting the ancient South China Sea once came that far inland. Analyses of soil and geologic cores collected near Angkor Borei, downstream of where the Tonle Sap and Mekong rivers currently confluence reveal sediments that were deposited in the presence of tides, salt marshes, and mangrove swamps [19].

Predominantly, Cambodia's soils are sandy and low in nutrients. The red-soil regions (Oxisols and Ultisols) grow commercial crops such as cotton (*Gossypium herbaceum*), tobacco (*Nicotina tabacum*), rice, and wheat (*Triticum aestivum*), and perennial tree crops like rubber (*Hevea brasiliensis*) and coconut (*Cocos nucifera*). The Mekong River during the annual wet season carries rich alluvial sediments that are deposited on its floodplains (Figure 17). These floodwaters improve the central plain soil fertility and provide natural irrigation for rice cultivation. Highlands are forested high plateaus and mountains that rise above the plains. The Kravanh and Damreh mountains form a highland region between Tonle Sap Lake and Gulf of Thailand.

The Cambodian Mekong floodplain is a large low-lying area 800 km from north to south and 600 km with an elevation of less than 100 m through which the Mekong River flows to the South China (East) Sea (Figure 18). Sediment deposits at Phnom Penh are about 30 m thick. Upstream, the Mekong River is northeast from Phnom Penh to Kampong Cham and then turns north to Kratie where bedrock falls block boat traffic during the dry season.

Tonle Sap Lake and River and the Mekong River dominate the Cambodian landscape. The Mekong River arises out of the Plateau of Tibet and dissects Cambodia on its way to the South China (East) Sea [14]. It runs approximately 510 km through Cambodia from the Khone Falls in Laos to the Vietnam border (Figure 19). Tonle Sap River, a tributary of the Mekong River is 120 km long during the dry season and connects Tonle Sap Lake to the Mekong near Phnom Penh (Figure 18). This unique and complex hydrological system is strongly influenced by the Asian monsoon season. A freshwater lake with a rather flat bottom, it is quite shallow during the dry season and seldom exceeds 3.3 m. However, during the wet season, the lake can reach a depth of 8 to 10 m [20].



**Figure 19.** Khone Falls on the Mekong River and on border of Cambodia and Laos. Photo Credit: Basile Morin.

The Mekong River floods during the rainy season (mid-May to early October) and water backs up into the Tonle Sap River and flows into Tonle Sap Lake (**Figure 17**). Flooding and reverse flows extend the dry season lake (120 km long by 35 km wide) into its floodplain and create a wet season lake (250 km long and 100 km wide). In the dry season Tonle Sap River and Lake surface areas cover 3100 km<sup>2</sup> to 7800 km<sup>2</sup> and during the wet season expand to cover more than 24,605 km<sup>2</sup>. During the wet season, the volume of the Tonle Sap Lake expands from 10 km<sup>3</sup> to 80 km<sup>3</sup> [18].

This 200% - 300% increase in Tonle Sap Lake's size and 800% increase in water volume effectively covers the western section of Tonle Sap River and shortens the river length by approximately 65 km during the monsoon season. The lake and river have a natural levee between the permanent lake and surrounding floodplains. Floodplain vegetation has low diversity consisting of rice fields, and seasonally inundated forests, and plant communities are well adapted to the regularity of the flood cycle [18]. Homes along the lake and river (**Figure 20**) are either built on stilts or part of floating villages (**Figure 21**) to protect them from seasonal water levels which can increase the river and lake depths to 10 m.

With the onset of the monsoon season, inflow starts in May/June when the Mekong River begins to flood and back up into the river and lake. Maximum rates of flow peak around 10,000 m<sup>3</sup> per sec from August through October and are amplified by upland run-off and wet season precipitation. In November, the rain stops, and the Mekong River levels drop. Once the Mekong River depth falls below the flooded Tonle Sap and surrounding wetlands levels, the river waters reverse their flow and begin draining south again into the Mekong River. Thus, the Tonle Sap River flows northwest for 6 months a year into the Tonle Sap Lake (**Figure 17**) and then for 6 months flows in the opposite direction (southeast) into the Mekong River that flows south into the Mekong Delta (**Figure 18**) [5].



**Figure 20.** Homes on the Mekong Riverbank. Published with the permission of the Editor of Open Journal of Soil Science.



**Figure 21.** The floating villages on the upper 65 km of Tonle Sap River and in Tonle Sap Lake are homes to fisheries: men, women, and children who make their livings catching, processing, and marketing fish, reptiles, frogs, and other amphibians, insects, and aquatic vegetation. Published with the permission of the Editor of Open Journal of Soil Science.

As the dry season advances, the river and lake become shallow making navigation on the river and lake increasingly difficult. Only shallow drafting boats enable traffic between Phnom Penh and Siem Reap to continue and would not be possible without the outflow from Tonle Sap Lake. As the water levels drop, the lake turbidity increases when winds kick up the shallow lake and re-suspend sediments [18]. River and lake nutrient concentrations have similar patterns throughout the year, with both nitrogen and phosphorus peaking in May as water levels increase. This suggests that river water is not diluting or increasing lake nutrient levels.

The water hyacinths during the dry season on the Tonle Sap River reproduce quickly and wrap on the boat propellers (Figure 22) requiring the engines to be reversed periodically to clear the propellers. Boat propellers often hit the soft alluvial sediments and spray a combination of water and dark sediment into the air behind the speedboat (Figure 23), a reminder of how shallow Tonle Sap Lake and River become in the dry season. The alluvial sediments and nutrient-rich waters of Tonle Sap Lake nurture hundreds of fish species from newly hatched fry to large giant fish [21]. The abundance of fish and other aquatic species provides food and livelihoods for “floating villages” (Figure 21), communities of houseboats anchored along the edges of Tonle Sap Lake and River.

The Mekong River supplies Tonle Sap Lake with water, fish, and sediments via the Tonle Sap River in the monsoon season. Unlike the Mississippi River where navigation dominates management decisions and keeping the channel deep is a priority, the Mekong River sediment is highly valued, and its annual transport has made Tonle Sap Lake one of the most highly productive fisheries in the world. The floodwaters bring nutrient-rich sediments into the large shallow, warm lake and offer ideal conditions for rapid growth of algae (*Phaeophyceae*). Algae is a

key food source in the aquatic ecosystem food web. Many commercially important fish species in the lake get their energy from algae growing on attached wet surfaces [18]. Flooding also rewets floodplain soils and releases mineralized nutrients to support algae growth to provide direct food sources for fish. Larger fish “*move into the floodplains and feed on terrestrial vegetation, fruits, detritus,*” insects, arthropods, and the fry of smaller fish [22].



**Figure 22.** A speedboat plows a path through water hyacinths that grow quickly during the dry season and by March of 2016 covered much of the open waters on the Tonle Sap River. Published with the permission of the Editor of Open Journal of Soil Science.



**Figure 23.** A speedboat carrying passengers from Phnom Penh to Siem Reap, a five-hour trip in the dry seasons, sits low in the water, and the propeller sprays black sediment and water from the shallow alluvial bottom of Tonle Sap Lake. Published with the permission of the Editor of Open Journal of Soil Science.

During the dry season, sediments are re-suspended, and the nutrients feed a surge in algae growth providing food to fish and invertebrates. If the lake was permanently at the 10 m flood season depth, sediment attached to phosphorous and other nutrients would settle to the bottom of the lake, reducing algal access to nutrients and the light that shallow waters provide for fast growth. This internal nutrient cycling is critical to lake and floodplain productivity.

Much of the sediment in Tonle Sap Lake naturally occurs. However, increased population and development rates seem to add to lake sedimentation through bank erosion and run-off where vegetation has been removed. Local people who live along the banks and floating villages (**Figure 21**) are anecdotally observing some areas of the lake becoming shallower. Research efforts are needed to document sedimentation sources and system rates and causes of change. Although lake sediments support a thriving fish industry, an increase in river and lake sedimentation had the potential to shut down dry season navigation between the capital and regional centers by making the shallow lake even less deep over time.

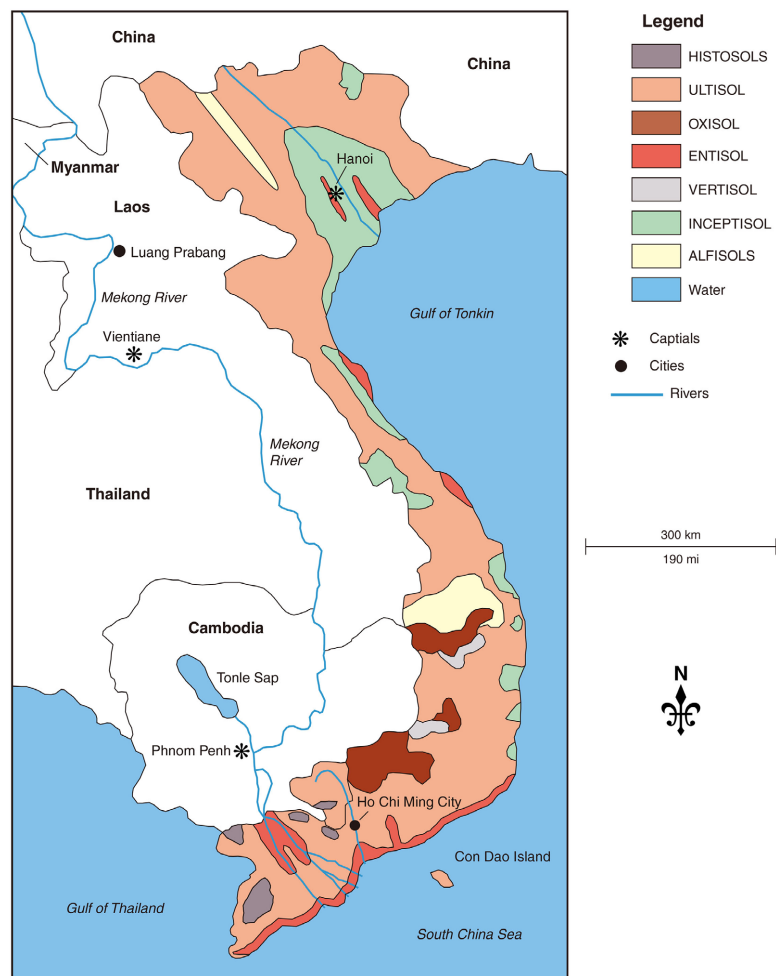
The last glacial period ended 19,000 years ago when sea levels rose 4.5 m above present levels. At that time shoreline of the South China Sea almost reached modern-day Phnom Penh. The present river morphology of the Mekong Delta developed during the last 6000 to 10,000 years [23]. During this period, the delta advanced 200 km over the continental shelf of the South China Sea (from present-day Phnom Penh to about the current shoreline) and covered more than 62,000 km<sup>2</sup> during the development of the Mekong Delta it was sheltered from wave action and built through fluvial and tidal process [16]. About 3500 BC the delta advance rate dropped to 17-18 m per year after it was built and extended beyond the embayment. The coastal shore was subject to wave action and marine currents which deflected deposition southeast towards Ca Mau Peninsula a more recent feature of the Mekong Delta.

The soils of the Delta (**Figure 18**) [24] [25] are alluvial from the Mekong River (**Figure 24**) and (**Figure 25**) and its tributaries including Tonle Sap River. The soils are formed in recent alluvium. The temperature in the tropics makes it difficult to retain SOC stock if the area is drained and aerated. The Mekong River has changed course many times, much like the Mississippi River, due to the low flat topography. And riverbanks of unconsolidated sediments that are highly erodible. During early geological times, the Mekong River discharged into the Red River [26] [27] near current Hanoi, Vietnam. Later it flowed into what is known as the Chao Playa River in Thailand and then into the Gulf of Thailand south of the modern city of Bangkok [14] [15]. During the Holocene history of the Mekong Delta the Mekong River discharged into both the Gulf of Thailand and the South China Sea. A paleo-channel located in the western part of the Delta, in the Reeds Plain and north of Camau Peninsula, was once the pathway to the Gulf of Thailand [17]. Presently the Mekong River only flows into the South China Sea. The Mekong River has two main channels (Mekong and Bassac) (**Figure 19**) that drain into the South China Sea.

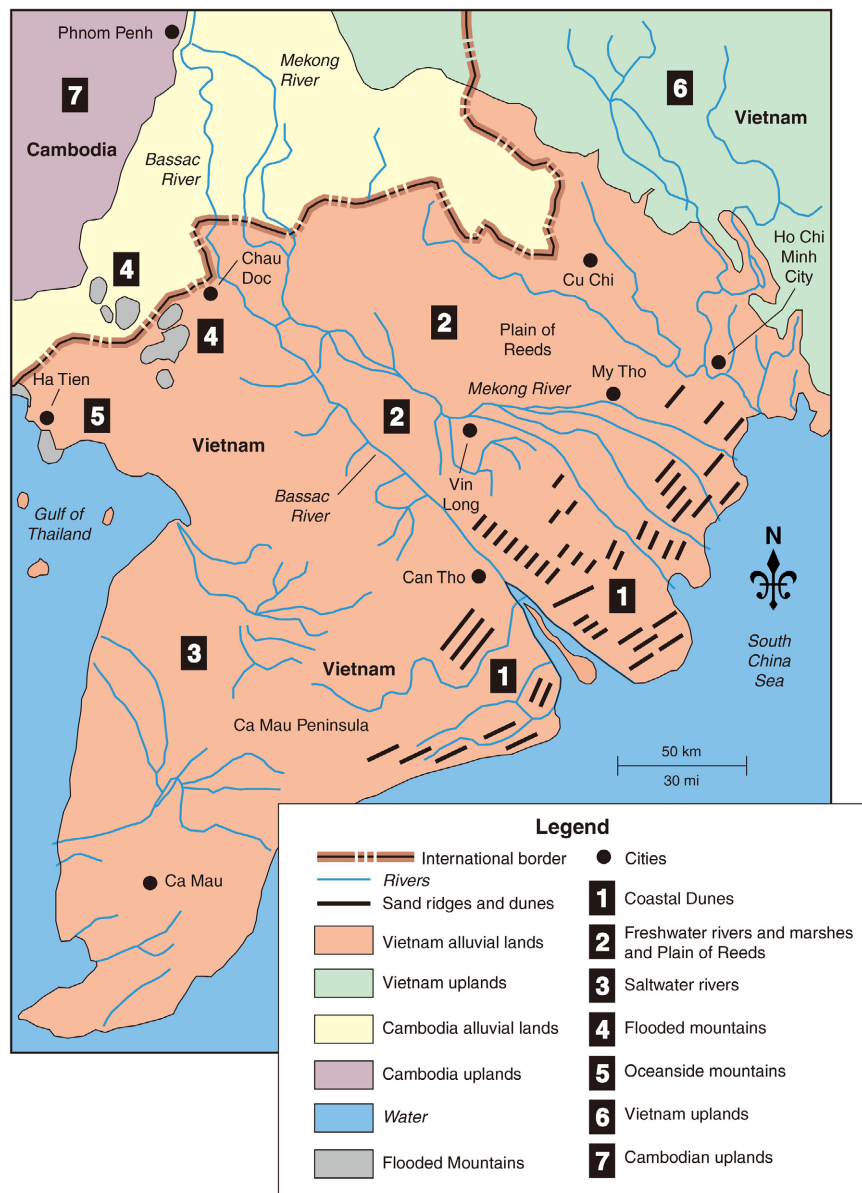
## 2.2. Protected Areas

### 2.2.1. Three-River Source National Nature Reserve (Sanjiangyuan)

The Sanjiangyuan National Nature Reserve (or Three-River Headwaters) is the largest nature reserve in China and the most concentrated reserve of living creatures in high-altitude localities. It is also the highest natural wetland in China and the origin of the Yangtse River, the Yellow River, and the Lancang-Mekong River. This reserve is in south Qinghai Province the hinterland section of the Qinghai-Xizang Plateau. For many years, the Qinghai-Xizang Plateau was called “*Virgin Land*”. However, due to nature and human activities, its ecological system gradually degraded and the Three-River Source area in its hinterland also gets influenced. Thus, a Nature Reserve was set up to protect its eco-system and the wetlands, provide favorable living habitats for its wild animals, and preserve its original physiognomy and unique natural scenery. This reserve was officially launched on August 19, 2000. In January 2003, it was upgraded, to the state level, by the State Council.



**Figure 24.** A soil map of Vietnam. Adapted from FAO/UNESCO preliminary definitions legend and correlation. Table of the soil map of the world. World soil resources report no. 12. Rome 1964. Reprinted with the permission of the Editor of the Open Journal of Soil Science. OJSS 7: 34-35. Map by Mic Greenberg. Published with the permission of the Editor of Open Journal of Soil Science.



**Figure 25.** Mekong River landscape map. Map created by Mic Greenberg. Re-published with copyright permission from Managing Editor of Journal of Environmental Protection.

### 2.2.2. Three Parallel Rivers of Yunnan Protected Areas, a UNESCO World Heritage Site

The headwaters of the Mekong in Zadoi County, Qinghai, China, are protected in Sanjiangyuan National Nature Reserve [7]. The name Sanjiangyuan means “*the sources of the Three Rivers*”. The reserve also includes the headwaters of the Yellow River and the Yangtze. The section of the river flowing through deep gorges in Yunnan Province is part of the Three Parallel Rivers of Yunnan Protected Areas, a UNESCO World Heritage Site. The Three Parallel Rivers of Yunnan Protected areas represent a landscape of river gorges and high mountains. The areas contain the watershed areas of the Yangtze (Jinsha), Mekong (Lancang), and Salween (Nujiang) rivers and glaciated peaks over 6000 m altitude. It also has

significant geological value, being the “*collision point*” of tectonic plates and holding landforms such as alpine karst and alpine Danxia.

## 2.3. Environmental Issues

### 2.3.1. Impacts of Climate Change on Sustainable Development Goals

Liu *et al.* [4] found “*The Lancang-Mekong River (LMR) is an important trans-boundary river that originates from the Qinghai-Xizang Plateau China and flows through six nations before draining into the South China Sea. Knowledge about the past and future changes in climate and water for this basin is critical to support regional sustainable development. A comprehensive review of the scientific progress that has been made to understand the impact of changing climate and water systems. A discussion of outstanding challenges and future research opportunities is needed. The existing literature suggested that: 1) The warming rate in the Lancang-Mekong River Basin (LMRB) is higher than the mean global warming rate, and it is higher in its upper portion, the Lancang River Basin (LRB), than in its lower portion, the Mekong River Basin (MRB); 2) Historical precipitation had increased over the LMRB, particularly from 1981 to 2010, as the wet season became wetter in the entire basin, while the dry season became wetter in the LRB but drier in the MRB; 3) In the past, streamflow increased in the LRB but slightly decreased in the MRB, and increases in streamflow are projected for the future in the LMRB; and 4) historical streamflow increased in the dry season but decreased in the wet season from 1960 to 2010, while a slight increase is projected during the wet season. Four research directions are identified as follows: 1) investigation of the impacts of dams on river flow and local communities; 2) implementation of a novel water-energy-food-ecology (WEFE) nexus; 3) integration of groundwater and human health management with water resource assessment and management; and 4) strengthening of transboundary collaboration to address sustainable development goals (SDGs). To cope with and overcome these serious challenges, international collaborations among governments, scientists, and the public, are critically important. Such collaborations must generate new knowledge based on an interdisciplinary ‘web’ model, instead of a disciplinary ‘tree’ model, to play a key role in moving toward achieving SDGs in the LMRB” [4].*

Drought is linked to a changing climate and dozens of hydroelectric dams are damaging the Mekong ecosystem [28]-[30]. When the dry season ends and the monsoon season floods begin, the effects of Lancang-Mekong dams on flood pulse dynamics over the entire Lower Mekong are significant [31]-[34].

### 2.3.2. Pollution

Sewage treatment is rudimentary in towns and urban areas throughout much of the Lancang-Mekong’s length, such as Vientiane in Laos and Kunming in China. Water pollution impacts the river’s ecological integrity as a result.

Much of the 8.3 billion tons of plastic present on the globe [35] and making its way to the oceans. Ninety percent of ocean plastic is flushed into the sea by just 10 rivers. The Lancang-Mekong is one of them [36]. Lancang-Mekong has one of

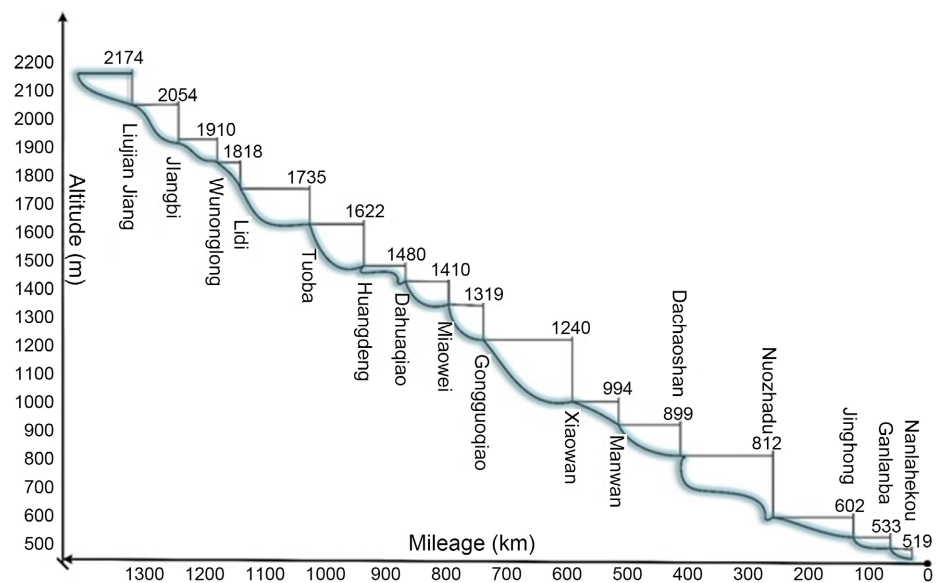
the highest microplastics pollution levels in a river. They occur as pellets for cleaning and care products, as intermediate production in plastic production, or from fragmentation of plastic debris. They contribute to “*great garbage patches*” in oceans. Microplastics are ingested by many organisms, from baleen whales to protozoa. Approximately 80% of the marine plastic comes from rivers including the Lancang-Mekong. Billions of plastic items can be ingested by organisms which has a negative effect on the organism’s health and may enter the food chain [36].

A growing number of academics, Non-Governmental Organization (NGOs), and scientists have urged the international community and the Mekong River Commission to reduce the use of hydropower over long-term sustainability concerns [37]. Some scholars have urged an immediate moratorium on new construction of hydropower projects and a shift to solar and other forms of renewable energy, which are becoming more competitive and faster to install [38].

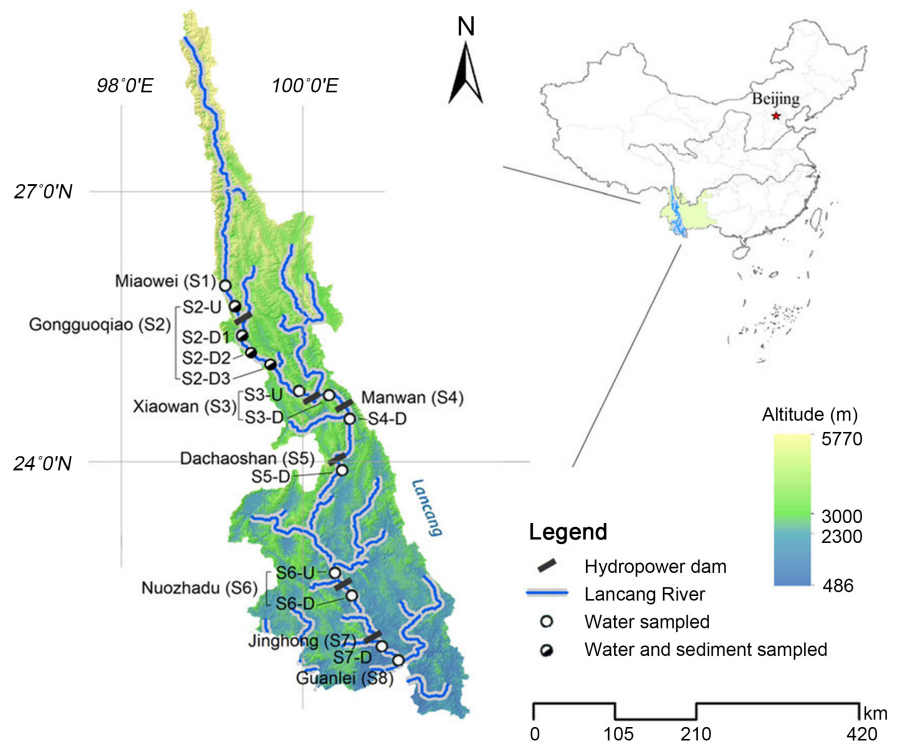
### 3. Discussion

#### 3.1. Environmental and Human Impacts of Lancang-Mekong Dams in China

China’s construction of dams (Figure 26) and a navigation channel along the upper reaches of the Lancang threaten the ecosystem. Development of an 8-dam cascade (Figures 4-8) is already underway [3]. Two dams are completed with three currently under construction in 2019 (Figure 9) and (Figure 10). These dams will drastically change the rivers’ natural flood-drought cycle and block the transport of sediment (Figure 27), affecting the downstream ecosystems and the livelihoods of millions living downstream in Laos, Myanmar, Thailand, Cambodia, and Vietnam. Impacts on fisheries and water levels have already been recorded along the Thailand-Laos border.



**Figure 26.** Longitudinal Profile of Lancang River. Cascade Development Phot Credit: Peter Bauer-Gottvein.



**Figure 27.** Overview and detailed map of the Lancang River basin and distribution of sampling sites. Photo Credit: ResearchGate.net.

The dam construction in China has proceeded with little consultation with China's neighbors to the south and limited assessment of the dam's likely impacts on the river ecosystem and the people. Near the Three Parallel Rivers World Heritage Site more dams are planned [3]. In July of 2004, it was reported in a Xinhua media outlet that pre-feasibility studies were underway for a 7-dam cascade (**Figure 10**).

Communities resettled after Manwan and Dachaoshan dam construction have suffered from a lack of sufficient compensation, problems with food security, and increased incidence of disease. Steps have been taken to address these problems, but more is required to ensure that people's livelihoods are restored.

The leading developer is Yunnan Huaneng Lancangjiang Hydropower Company Ltd, a subsidiary of one of China's largest independent power producers, Huaneng Power International. The China Development Bank, which is government-run, is expected to provide most of the funds for the Upper Lancang dams. Over the past three decades Laos and China's Mekong actions and policies have impacted the Lower Mekong Basin and what happens in the Lower Mekong Basin [39] [40]. In Laos, there are two dams on the Upper Mekong which are greater than the Chinese mainstream dams in the Lancang course [41]. Kondolf *et al.* [42] summarized the regional policies for Delta region.

The Stimpson Report [39] [40] is based on imagery collected by Eyes on Earth, an organization using satellite imagery to monitor climate developments. The report relies on satellite imagery to assess precipitation and can be criticized for its

inaccuracies and for overlooking areas with negative precipitation anomalies. The findings are concerning, coming after a succession of droughts in the past two decades that have wreaked havoc throughout the Lower Mekong Basin. Crops have failed on several occasions, and there have been very particular worries in the Mekong Delta, where regional authorities have called for a declaration of emergency because of drought conditions in 2019. This disturbing situation has been magnified by the reduction in the flow of sediment down the river, sediment retained by China's 11 Mekong dams (*total in 2019*) (**Figure 10**). The effect of the two Laos Upper Mekong main stem and tributary dams was not included in the analysis [41] [42]. There is consistent evidence that fish stocks in the Mekong have been declining in circumstances in which fish provides the vital contribution of animal protein to the diet of populations in the region.

The Stimson report [39] and [40] noted “*While drought ravaged the lower Mekong Basin in 2019, there was above-average rainfall and snowmelt in China and the flow from these events was nearly all retained in China's dams*”. It was important for China to fill the reservoirs during the monsoon season so that there would be sufficient water to generate hydroelectric power during the dry season and maintain river flow. Dams are just one factor in the reduced river flow during the dry season. Other factors that reduce the river flow include reduced precipitation, increased evaporation driven by higher temperatures and stronger solar radiation. The increased in solar radiation in this region is attributed to reduced cloud formation, caused by intensifying high pressure weather system characterized by sinking air. Furthermore, evaporation is enhanced by higher temperatures which reduce air humidity. Climate change, evidenced by increasingly frequent and intense droughts and heatwaves in Indochina, leads to water shortages and electricity outages in central Thailand and northern Vietnam, areas outside the Mekong River Basin.

Reactions to the Stimson report [40] ranged widely. As expected, civil society groups seized on the Stimson revelations to call for action to change Chinese policies in the future. However, in 2020, the Mekong River Commission, consisting of countries which are located along the Mekong River and chartered to protect the Mekong River, called into question the validity of data released by Eyes on Earth [39] [40] and suggested the need for further study before any conclusions are reached. The Global Times and the Bangkok Post have reported Chinese studies suggesting that the dams China has built on the Mekong play a vital role during the wet (monsoon) season (reduce flooding on the Upper Mekong) and appear to ignore what happened during the dry season [38].

However, the Stimson report [39] [40] seems to overlook the many regional environmental issues stemming from local actions which do not relate to Cascade dams. For example, indiscriminate fishery in Tonle Sap, extensive number of dykes in the delta, sand mining in the Delta, extensive number of tributary dams in 3S basin, preventing fishery migration between this region and lower and upper regions. The Chinese cascades has had a negative influence on the lower Mekong, but the current situation is because of basin-scale and regional scale anthropogenic

stressors not just the Lancang region [41] [42].

### 3.2. Environmental and Human Impact in Laos

1) The Lancang-Mekong River is one of the world's most diverse and unique large rivers, and its flood pulse drives an extensive and productive ecological system. However, the capacity of the Mekong River basin to sustain fishery resources and upland and riverbank agriculture that provide food security and livelihoods for the people of Lao People's Democratic Republic (PDR) is strained by competing economic, ecological, and political interests. Development projects, such as dam construction on the Mekong River and tributaries to support a booming hydropower industry, are bringing great change to ecological, agricultural, and cultural systems in this region. The Laotian government has built many small "pocket" dams along tributaries and has proposed eight or more large dams on the Mekong main stem to meet energy needs for economic growth and to increase export revenues. Traditional fishing and agricultural systems are affected when dams submerge narrow floodplains and disrupt the timing and volume of river flows. As a result, dam building on the Mekong River main stem has become a source of uncertainty and unease in local river communities and has led to geographic and national unrest and conflicts [14].

Sustainable development of the Mekong River will need an integrated approach of technologies and active engagement of farmers and fishers in information exchanges and decisions to ensure the transition is beneficial to people and the river basin. There is little doubt that hydroelectricity is a key resource in providing needed energy, modernization, and economic vitality to Southeast Asia. The question is, how can the Mekong River resources be well utilized to realize the goals of many without compromising the river's capacity to continue to meet the needs of the region into the future? Dams are only one of many threats to the sustainability and resilience of the river. A changing climate, deforestation of uplands, and irrigation needs of a growing population are other difficult issues the governments and peoples of the region must address. As a transboundary river, management decisions by one country inevitably reverberate throughout Southeast Asia. The Mekong River Commission (MRC) is a critical institution that all Southeast Asia countries must respect and re-empower to negotiate and balance the many competing interests. One of the MRC's major tasks will be to mitigate the negative impacts of dam building while realizing the benefits.

#### 2) Mekong River Commission Headquarters in Vientiane, Laos

The MRC, headquartered in Vientiane, Laos PDR, is an inter-governmental body working to facilitate cooperation on the sustainable development and management of the Mekong River Basin. Its members are Cambodia, Lao PDR, Thailand, and Vietnam. The MRC acts as a platform for water diplomacy and regional cooperation through which the Member Countries share the benefits of common water resources and address transboundary challenges in the basin, despite diverging national interests. The commission also serves as a knowledge hub that promotes evidence-based policymaking. It provides technical assistance and

develops practical tools to help its Member Countries make informed decisions.

The MRC [43] mission statement suggests “MRC was created when Cambodia, Lao PDR, Thailand, and Vietnam signed the Agreement on Cooperation for Sustainable Development of the Mekong River Basin, known as the Mekong Agreement, on 5 April 1995. The Member Countries agreed to cooperate in areas such as fisheries, flood control, irrigation, hydropower, and navigation. China and Myanmar, through which the upper reaches of the Mekong River flow, have been Dialogue Partners of the MRC since 1996.”

“The MRC facilitates dialogue and negotiation on water resources management among governments, the private sector, civil society, and other relevant stakeholders. It plays an active role as a neutral facilitator seeking to strike a balance between national and basin-wide interests, between the countries, and between development needs and environmental sustainability.”

“The MRC Secretariat Office is hosted in Vientiane, Lao PDR, while Phnom Penh, Cambodia is home to its Regional Flood Management and Mitigation Centre. The secretariat, responsible for the commission’s daily operations, has more than 60 professional and support staff. It reports to the MRC Joint Committee, the main management body of the MRC.”

“The MRC Joint Committee sets direction and priorities in collaboration with the Member Countries’ National Mekong Committees and through consultation with the MRC’s Development Partners and stakeholders. The MRC Council is the highest decision-making body in the MRC. It makes decisions on all policy-related matters concerning implementation, including organizational policies, basin-wide strategies and plans, strategic cooperation partnerships, and resolution of differences. The MRC is funded by its Member Countries and Development Partners, currently including Australia, Belgium, European Union, Finland, France, Germany, Japan, Luxembourg, the Netherlands, Sweden, Switzerland, United States, and the World Bank.”

“The Mekong Agreement provides the foundation for the MRC to support basin-wide planning processes, based on principles of integrated water resources management. The commission looks across all sectors to meet multiple objectives, including sustaining fisheries, fostering sustainable hydropower, identifying opportunities for irrigated agriculture, maintaining the freedom of navigation, improving flood and drought management, and preserving important ecosystems. Its goal is to promote and coordinate sustainable development and management of water and related resources of the Mekong River Basin for the countries’ mutual benefit and the people’s well-being” [43].

### **3) Laos Environment and Human Impacts**

Predictable seasonal flooding from the Southeast Asia monsoon and the local geology of the river influences the channel platform and sedimentation patterns that enable riverbank vegetables and rice (*Oryza sativa* L.) cultivation to follow receding wet season floodwaters (Figure 28). Riverboats move farm products from fields to homes and markets (Figure 29), and tourists to scenic destinations until the dry season makes the river too shallow to travel. The Mekong River also

provides habitat for a large variety of fish species, the rare Irrawaddy dolphin (*Orcaella brevirostris*), and several other endangered species. The challenge for the people of Laos and its government is to modernize their country, developing energy resources in ways that improve health and well-being and ensure livelihoods while protecting abundant and diverse fish resources and ecologies of this large river system and the unique cultures it represents.



**Figure 28.** As the wet-season floodwaters recede, gardens and crops are planted on the Lancang-Mekong riverbanks and benefit from the residual soil moisture during the dry season. This photo was taken in March of 2016 at the height of the dry season. Published with the permission of the Editor of Open Journal of Soil Science.



**Figure 29.** Night markets in Laos on the Lancang-Mekong River. Published with the permission of the Editor of Open Journal of Soil Science.

The Mekong River is a major trade route between western China and Southeast Asia notwithstanding the extreme seasonal variations in flow and the presence of rapids and waterfalls. Volumes of goods shipped decreased by more than 50% during the June to January dry season [23]. Despite dangerous rock outcrops in the river, trade volumes are expected to increase from 8% to 11% annually. New facilities are planned for Chiang Saen Port, Thailand, where over 300 vessels fly Chinese flags [40]. The Mekong River is used to ship goods and produce between Thailand and Vientiane. In Laos, 50 to 100 vessels are operated for regional trade. The main cargo includes timber, construction materials, and agricultural products. There is a large tourist trade in the region, and long boats (Figure 17) take tourists on river cruises to view limestone caves in the cliffs (Figure 14) with stops at villages that weave silk and cotton fabrics and rugs. The Golden Triangle, where Lao PDR, Myanmar, and Thailand meet, is northwest of Luang Prabang on the Lancang-Mekong.

The more than 500 known species of Mekong River fish have sustained millions of people through droughts, deluges, and even the genocidal Cambodian regime of Pol Pot. Fish are grilled, fried, or boiled; wrapped in palm leaves; garnished with ant eggs; or simply mixed into a wooden bowl with rice. In addition to being used fresh, fish are preserved by drying and pickling. The main fishing seasons are March through April and November through December, with women catching smaller fish and the men catching the giant fish. Fish production is a central part of river communities' social and economic activities ranging from managing fisheries to fish processing and marketing. Many kinds of crops are grown on the banks of the Mekong River and its tributaries and within narrow floodplains. Flood recession agriculture is practiced extensively to cope with annual wet-season flooding and dry-season conditions. This type of farming uses the residual soil moisture stored in the soil profile after the rainy season flooding. Sedimentation of fine-grained materials under a seasonal flooding environment develop clayey soils (e.g., Vertisols, Fluvisols, Gleysols, and Camisols) with high water retention [44] [45], which allows cropping during the dry season as river water levels drop. Laotian farmers plant vegetables, melons, rice, corn, peanuts (*Arachis hypogaea*), and other crops on sloping riverbanks (Figure 28) for family use and local markets. The predictability of the wet season flooding, and the onset of the dry season reduces risks of crop loss and enables farmers to match specific crops and flood-tolerant varieties to the river stage and bank location as the flooding recedes. Flood recession farming has been practiced for generations along the Mekong River, and the local knowledge of which crops and varieties perform best under specific practices is specific to each village and its location within the reach. Vegetable plots are also found in the valleys of tributaries near small mountain villages and cities, such as Luang Prabang, Laos. These plots must be irrigated daily during the dry season to ensure productivity and are watered manually. Several tributaries have small pocket dams that are used for irrigation, fisheries, and hydroelectricity (Figure 30). Laotian farmers and fishers supplement their food and incomes by raising cows, pigs, buffalo, and small animals such as ducks, geese,

and chickens. Wild mushrooms, bamboo, and herbs are also gathered by women and children for family use and village markets (Figure 29). The Mekong River valley in China is famous for rubber tree (*Hevea brasiliensis*) plantations, and the plantations have spread into Laos, Myanmar, and Vietnam. The mountain slopes and valleys are often cleared and farmed. The northern Lao highlands, with 30% to 60% slopes, are planted with pineapples (*Ananas comosus*) and other tree crops including teak (*Tectona grandis*) and rubber trees (Figure 31).



**Figure 30.** Hydroelectric power is produced from a small dam on a Mekong River tributary in the northern Lao People's Democratic Republic highlands. The reservoir behind the dams is used as a fishery and for irrigation. Published with the permission of the Editor of Open Journal of Soil Science.



**Figure 31.** Rubber trees grow in a plantation near a Hmong village south of Luang Prabang, Lao People's Democratic Republic. Published with the permission of the Editor of Open Journal of Soil Science.

Currently, there are about 60 small pocket dams on the Mekong tributaries (**Figure 30**) that are used for electricity and irrigation, but they do not appreciably alter the consistent flow of the Mekong River [46] or provide sufficient energy to meet Lao domestic and export demands.

PDR on the Mekong main stem, almost all designed for hydropower generation rather than water extraction for irrigation [46] or to improve navigation since they will not have mechanisms for boats to lock through. Xayaburi Dam and the Don Sahong Dam are the first two under construction. These dams will increase dry season water availability (via the reservoirs behind the dams) and potentially reduce wet season flows.

The implications for people who derive their livelihoods from fishing and riverbank agriculture as well as resettlement of villages flooded from the dam reservoirs are great concerns to local communities. Many claim they have not had access to accurate information during the dam planning and construction stages and lack knowledge about dam impacts on their fishing grounds and farmlands. Further, few local people have been asked to share their knowledge, perspectives, or recommendations on resettlement, training needs, and dam impacts on their community. Many are fearful about reduced fish catches, loss of farmland, reduced family income, patterns of river travel, compensation for loss of land and homes, and loss of their traditional ways of life [47].

The 1995 establishment of the MRC was intended to implement a four-country agreement (Lao PDR, Thailand, Cambodia, and Vietnam) of cooperation to achieve sustainable development and conserve water and related resources of the Mekong River basin. It is no small task for the MRC to provide governance and negotiate ecological, social, economic, and political balance across countries when it has no legally binding authority [18]. In 2010, an environmental assessment sponsored by MRC called for a 10-year moratorium on the construction of main stem dams, citing the devastating effects on regional food supplies and the likelihood of irreversible environmental damage. The 10 to 11 main stem dams proposed by Laos and Cambodia have undercut the power of the MRC.

Many are concerned that the Xayaburi Hydropower Dam (**Figure 32**) could cause irreversible and long-term ecological damage to a river that feeds millions of people, force the resettlement of 2100, directly affect 202,000 people who use the Mekong bottomlands to produce food, and may push endangered fish, such as Mekong giant catfish, to extinction. A village next to the dam site will be covered by reservoir water. It is being moved out of the valley upstream where new housing is being built. Downriver another village must also be moved out of the river canyon. Villagers have been promised new homes built of cinder blocks and wood in the new location. The villagers are poor and live off the fish and rice that they grow in the Mekong bottomlands. Their main traditional crop, rice, is not suited to upland soils where the village is being relocated. Traditional fishing areas upstream will be covered by the reservoir water, and villagers must learn new ways of fishing. The potential impacts of the reservoir and dam on downstream Mekong River fish populations are not well understood.



**Figure 32.** Xayaburi dam in Laos. Photo Credit: Mekongeye.

The defining characteristics of the Mekong River today are “*its single, smooth, and regular flood peak and the consistent size and regularity of that peak*” [46]. The people of this region and the ecology of the river are highly tuned to this regularity. The loss of this predictability with the construction of dams on the mainstem is the single greatest concern of those who earn their living from the river and those who value its unique ecology. How will dam management of floodwaters and release of water during the dry season affect the river hydrology, habitats, and species that live there? Will the water releases be consistent and predictable so fishers and farmers can effectively adapt? If water is held in pools behind the dams, will there be sufficient water for downstream users? There are many unknowns about the resilience of the Mekong River if one dam, two dams, or many dams are built across the mainstem. The loss of riverbank and floodplain farmland will be substantial for both relocated villages and villages along the new reservoir that must learn new skills in upland regions that have very little topsoil and are not suited to cultivated cropping systems. The new dam-reservoir ecological system may change fish species and abundance, fishing techniques, and uses of river resources (panning for gold, harvesting riverweed, and big shrimp) [48]. The greatest impacts of Mekong mainstem dam building to date are on fishers and farmers and the psychological fear that comes from a lack of information that limits capacities to adapt. Villagers are not fully involved in the dam planning or construction stages, are not informed, or invited to be part of the process, and as a result, are very frightened and afraid [47]. They do not trust developers and are worried about where they will live and how they will provide for their families. Without accurate details on the dam planning and building process and its potential impacts on the river, it is difficult for them to learn new ways, adapt, and prepare for a changed situation. Sustainable development of the Mekong River will need an integrated approach of technologies and active engagement of farmers and fishers in information exchanges and decisions to ensure the transition is beneficial to people and the river basin. There is little doubt that hydroelectricity is a

key resource in providing needed energy, modernization, and economic vitality to Southeast Asia. The question is, how can the Mekong River resources be well utilized to realize the goals of many without compromising the river's capacity to continue to meet the needs of the region into the future? Dams are only one of many threats to the sustainability and resilience of the river. A changing climate, deforestation of uplands, and irrigation needs of a growing population are other difficult issues the governments and peoples of the region must address. As a transboundary river, management decisions by one country inevitably reverberate throughout Southeast Asia. The MRC is a critical institution that all Southeast Asia countries must respect and re-empower to negotiate and balance the many competing interests. One of the MRC's major tasks will be to mitigate the negative impacts of dam building while realizing the economic benefits.

### **3.3. Environmental and Human Impacts of Lancang-Mekong Dams in Myanmar**

Smith [49] found *“In an energy-hungry age on the continent, the rivers share another distinction, as wellsprings of financial temptation for the struggling countries that rely on their flow, Laos, and Myanmar (Burma). Both countries are grappling with decisions on whether to build massive hydropower dams on the two significant rivers. The projects could put fragile ecology and associated livelihoods at risk, but the dams could help the two countries reap billions of dollars by exporting the megawatts to China and Thailand, two neighbors with rapidly growing energy demand”*.

*“For now, it looks like the two nations are taking different paths. In Laos, the government appears to be going ahead with the \$3.8 billion Xayaburi dam on the Mekong River despite opposition by environmental groups, some international donors, and some neighboring countries. In Myanmar, meanwhile, the government shocked many observers when it announced it would suspend work on the \$3.6 billion Myitsone dam project on the Irrawaddy River. The decision came without notice to its Chinese partner, and just weeks after Myanmar's power minister was adamant the project would go forward. Some observers both within and outside Myanmar are skeptical the suspension will hold”*.

*“Energy demand has been rising exponentially as the region becomes more prosperous. The money could transform the poorly developed economies of Laos and Myanmar, although many worry the revenues would just enrich the elite. Scientists and environmentalists are concerned the dams will displace thousands of people, and damage river ecology and the livelihoods of people along the river. They are concerned the dams will lead to additional projects that could have even more devastating impacts. The dams on the upper Mekong and the Mekong's tributaries are already triggering changes in river flows” [49]*.

### **3.4. Environmental and Human Impacts of Lancang-Mekong Dams in Thailand**

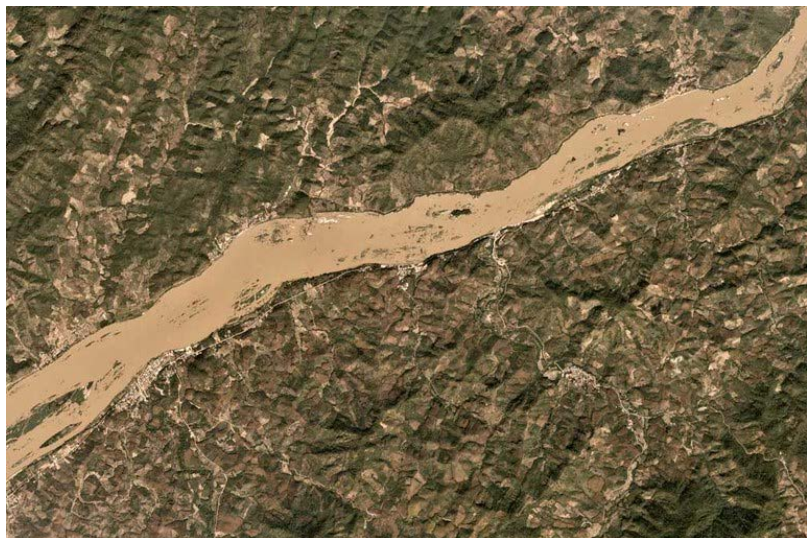
The Mekong is one of the world's most biodiverse river basins with more than

1100 species of fish. As the world's largest inland fishery, the river is a vital food source for the 70 million people in Laos, Thailand, Cambodia, and Vietnam who live in its basin. But the river's normal flow (Figure 33) (Figure 34) over the last three years has been among the lowest ever recorded, with 2020 being the lowest on record (Figure 35), according to the analysis of MRC data by the Washington-based Stimson Center's Mekong Dam Monitor project [40].

The MRC Commission is an intergovernmental organization that works with the governments of the four Mekong basin countries to jointly manage the shared water resources and the sustainable development of the Mekong. The Thai Mekong People's Network from Eight Provinces group represents people who live along the Mekong River in eight Thai provinces, including areas on the border with Laos, and face transboundary environmental impacts from the Xayaburi Dam hydropower project, Laos' first dam on the Lower Mekong River.



**Figure 33.** Drought lowered the Mekong River water level in Thailand. Photo Credit: Mekongeye.



**Figure 34.** Full Mekong River in Thailand in January 2019. Photo Credit: Planet Labs with RFA analysis.



**Figure 35.** Dry Mekong River in Thailand in January 2022. Photo Credit: Planet Labs with RFA analysis.

Laotians and Thais who depend on the Mekong River for life's necessities—food, water, income—fear the mighty waterway may be drying up. They say climate change may be a factor in recent droughts in the region but believe the direct cause of their troubles are the many dams China and Laos have built upstream that siphon off water for agricultural and other uses before it reaches them. Experts [37] [38] [47] say the dams make the impact of periodic droughts in the Mekong basin worse and rob the river of the “*pulse effect*” that spreads water and nutrients that support fisheries and farming. Dams can also mitigate future droughts and droughts are thought to be caused by climate change rather than because of dams. In Thailand, the Planned Lao dam raises additional concerns.

The Xayaburi Dam and the Don Sahong Dam were the first two of Laos' Mekong mainstem dams and were completed in 2020. Three others are in the planning or early construction stages as the government looks to generate revenue by selling the electricity from its hydropower projects to its neighbors, especially Thailand.

Laos has 78 dams in operation and has signed memoranda of understanding for 246 other hydroelectric projects, despite uncertainty about Thailand's willingness to purchase the electricity they generate. China operates 11 mega-dams on the river, with at least two more planned.

A Laos official [40] who works closely with the MRC told RFA that the water levels of the Mekong depend on the amount of water released by China. “*When there is little water coming down from the north, the lower region will have less water,*” he said. “*Sometimes, there is too much water in the north, so a lot of water is released. That's why sometimes, the lower Mekong River region is dry and sometimes flooded.*” Recent reports by the MRC and by the Mekong Dam Monitor [40] say the main driver of drought in the Mekong basin is lack of rainfall during the wet season, said Brian Eyler, head of the Stimson Center's Southeast

Asia Program and the Energy, Water, and Sustainability Program. Eyster [40] said “*We have determined that by and large, throughout these last three years of low flow, most dams in the Mekong basin operated the same way as they operated in previous years of high or normal flow*”.

On the Lower Mekong, fewer fish are being caught and some days water levels are so low people can walk from one shore to the other [47]. With more dams planned in Laos to generate electricity for export, Thai farmers and fishermen fear the worst is yet to come. An Pich Hatda, head of the MRC Secretariat, said in a press release [47] “*The drought has been affecting agricultural production and the fishery industry as well as putting more pressure on livelihoods of those who live along and depend on the Mekong River. It’s also been threatening the ecosystem of the river. Therefore, aggressive cooperation is important, from China and all MRC members to tackle this problem*”.

A representative from the Network of Community Organization Council of Seven Northeastern Provinces, a Thai group representing people who live along the Mekong, emphasized the need for residential input into the Lower Mekong sustainable development.

The U.S. and five lower Mekong nations (Laos, Myanmar, Thailand, Cambodia, and Vietnam) launched the partnership in September 2020 as a new multilateral cooperation framework. A partnership representative said [47] “*In the last five years, our Mekong River has had a lot of problems with the water becoming clear [because of the] lack of sediment and food for aquatic species. The water level is down by more than half, and the river is flooded during the dry season and dry in the wet season. It’s not normal. The water turns blue, affecting the ecosystem, natural resources, the environment, and the fish population.*”

### 3.5. Environmental and Human Impact in Cambodia

The ancient Angkor civilization (Figure 36) (ninth to fourteenth century AD) developed complex canals and pond irrigation systems (Figure 37) to water inland rice fields as well as bred floating rice on Tonle Sap Lake (Figure 38).

In June 2020, the FAO’s annual State of the World Fisheries and Aquaculture report ranked the Mekong Basin as the world’s most productive freshwater fishery, accounting for over 15% of global fresh fish catch [25]. The WWF Researchers estimate that the contribution is higher, approximately twenty-five percent of the world’s freshwater catch. This massive inland fishery is critical to the food security of millions living in Cambodia, Laos, Thailand, and Vietnam and is fed by the Mekong River’s natural flow cycle. Each year the flooding pulse drives water from the Mekong up through a tributary at Phnom Penh, expanding Tonle Sap Lake (Figure 17) area in Cambodia to more than 3 times its dry season size and containing 8 times more water. The Tonle Sap Lake, a unique World feature, is the foundation for the Mekong River’s extensive fishery. The annual expansion produces an annual 50-ton fish catch in the lake. The lake contributes to the Lower Mekong fish population and the nutrient plume in the South China Sea. It releases

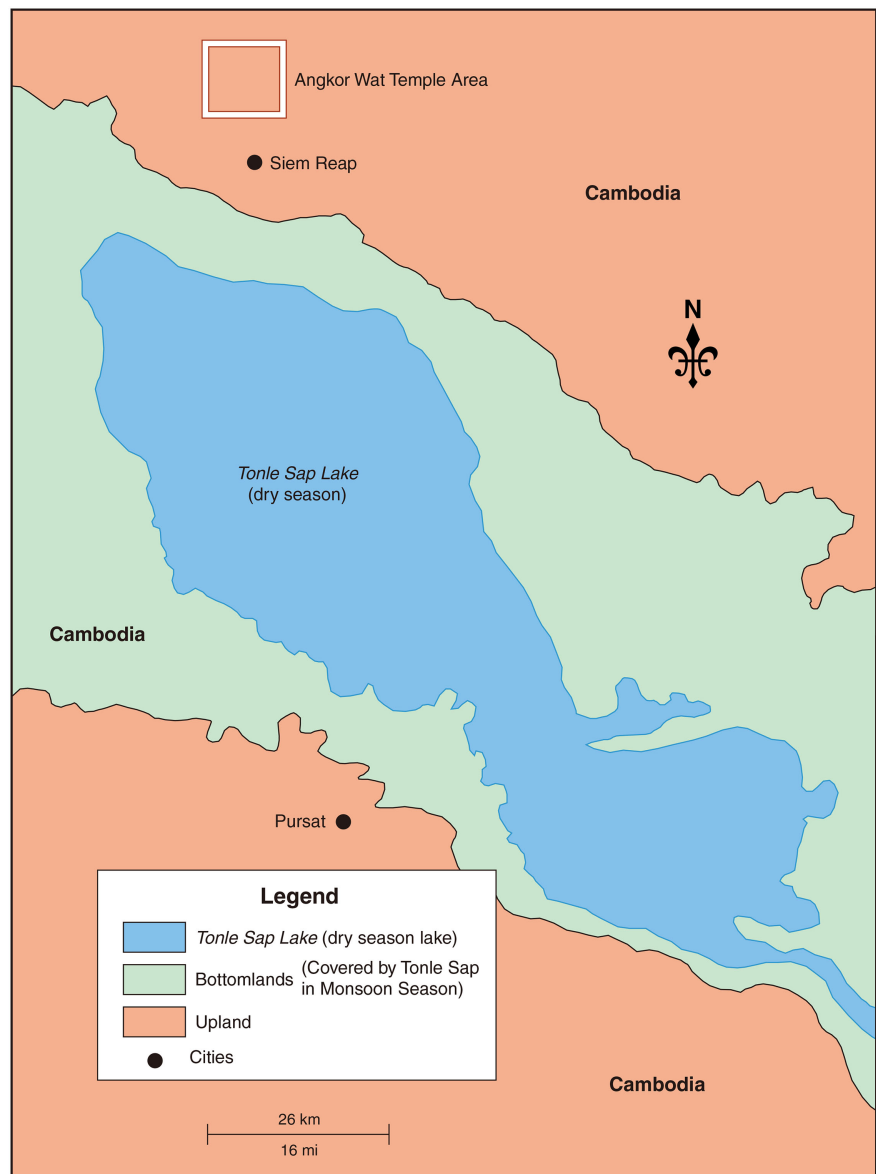
migratory fish through the entire Mekong Basin if not impeded by dams on the mainstem or tributaries. The Mekong flood pulse is also critical to riverbank agriculture which supports the livelihoods of millions of people who live along the banks of the river and its tributaries. Floods also deposit nutrients and sediment across the Mekong floodplains.



**Figure 36.** Tree roots growing over the Ta Phroh Temple, part of the elaborate 163 ha religious complex at Angkor Wat (near modern day Siem Reap), built by the Khmer Empire (802 to 1500 AD). Published with the permission of the Editor of Open Journal of Soil Science.



**Figure 37.** Angkor Wat Temple buildings with ponds. Published with the permission of the Editor of Open Journal of Soil Science.



**Figure 38.** Tonle Sap map showing the location of Siem Reap, the Angkor Wat Temple area and the Tonle Sap Lake. Map by Mic Greenberg. Published with the permission of the Editor of Open Journal of Soil Science.

### 3.6. Environmental and Human Impact in Vietnam

The delta coastal region and the Mekong River distributaries have fostered local and international commerce and trade for thousands of years. Today, the upper Lancang-Mekong River in China is controlled by dams and reservoirs that have altered navigation patterns and the flow of water and sediment to the Mekong Delta. Further south, Laos is constructing a hydroelectric dam and planning more [24]. Sediment and associated nutrients shape the morphology of the Mekong Delta and influence livelihoods dependent on fisheries and annually flooded rice fields [50]. Data on sediment flows are limited, but it has been estimated that the total sediment load is as much as  $120 \text{ mt y}^{-1}$  with half coming from the Lancang

catchment in China. However, creation of dams and huge reservoirs on the Mekong mainstem seems to reduce the sediment delivery to the delta. Since 1994, up to 11 mainstem dams have been proposed on the lower Mekong River in Laos and Cambodia. Xayaburi was the first of dam to be submitted to the MRC, is a proposed 32 m high, 1260 MW dam located 150 km downstream from Luang Prabang.

Member countries concerned about changes in the river pulse and downriver effects on sediment distribution and water quality have requested additional environmental and human impact studies be undertaken. Navigation upriver from the South China Sea is blocked by Khone Falls just above Kratie near the Cambodia-Laos border (**Figure 39**). Many barges loaded with military ordnances during the 1970s Indochina wars were sunk in Cambodian sections of the Mekong River. These unexploded ordnances created problems for future bridge construction, navigation, irrigation systems, and local fishermen. By 2013, Cambodian volunteers were trained with support from the Office of Weapons Removal and Abatement, the US State Department, Bureau of Political-Military Affairs to conduct underwater explosive removal [51]. Container traffic at Phnom Penh port and general cargo through Can Tho port (Vietnam) increased steadily until the 2009 global financial crisis. The construction of a new deepwater port at Cai Mep in Vietnam allows ships with a 15.2 m draft to be loaded. Now Cai Mep can handle the largest container ships in the world, and these ships travel directly to Europe and the United States carrying raw and finished products from Southeast Asia.



**Figure 39.** Khone Falls Xayaburi dam view from river. Photo Credit: Kittipoon Khamsri.

If all the proposed dams are built, almost half of the lower Mekong River water could be captured in reservoirs, and the river's seasonal flow is considerably altered [14]. Further, these reservoirs will trap much of the nutrient-rich sediment that now fertilizes delta fields and feeds fish throughout the entire Mekong River and Delta system. The rich sediment deposited in the delta during the monsoon season is important to agricultural production, and even the fishing grounds in the South China Sea will be less productive without sufficient sediment. The Vietnamese boats that fish in the productive plume of the South China Sea catch more than 446,000 t·y<sup>-1</sup> each year [21] [52]. The Mekong River is not alone in these environmental challenges. The deltas of the Mississippi, Yangtze, Nile, and Red River of Vietnam [27] are also experiencing loss of wetlands, flood disasters, poor water quality, reduced soil capacity to filter and absorb excess agricultural nutrients and other pollutants, and the need to increase food production for expanding populations [53]. Historical perspectives, new science and technologies,

and public and political efforts are critical if the deltas of the present and future are to ensure an environment habitable for human well-being and strong agricultural productivity while strategically conserving wetland ecologies.

The rapid growth of hydropower dams (**Figure 10**), agricultural specialization and intensification, global markets, and urban industrialization have benefited cities and industrial zones far from the rural places that are the source of resources used to modernize. And much too frequently these projects leave rural people and their communities only marginally better off and often worse off [54]. Many of these modernization and development efforts threaten not only the Mekong natural resource base but also millions of small-scale farmers and fishers that are the underpinning of regional food systems and food security [55] [56]. Of particular concern is the ecological degradation of the Mekong region's water and soil resources, pesticide and industrial pollution, salinity incursions from sea level rise, changes in river flows and sedimentation brought on by dam construction and water diversion and increasing conflicts among interest groups and geographies along the river [18] [57]. The development discourse, in search of solutions to economic progress often undervalues the rural people resources that is needed to take SE Asia into the 21st Century. Rural outmigration to urban places has not been a pathway to prosperity. Rather data show rural people who remain in rural areas in SE Asia are more likely to be food secure and more likely to escape poverty than those who move to cities [57]. Rural household occupational multiplicity offers flexibility and resilience under social and technological change, drought, flooding, social conflict, and economic ups-and-downturns [58] [59]. This diversity in livelihood strategies can strengthen capacities to be more food secure and accumulate sufficient resources to take advantage of opportunities. How can development projects build on rural cultural worldviews and their knowledge and experiences with river and floodplain systems of agriculture and fisheries? How can household livelihood goals be achieved while encouraging adoption of innovative technologies that support better management of the Mekong landscape [60]? It is important to understand the Mekong farmer's current role in the food system and their future potential in protecting and managing the soil and water resources of the main stem river, tributaries, and floodplains.

In this paper, we explore the connection Mekong farmers and fishers have with their water and soil resources; and how the geography and physical characteristics of the region affect livelihoods, income, and food security, and shape cultural worldviews. We ask, what are the resources and policies rural people need to strengthen their livelihood strategies so they can thrive, provide food for themselves and urban populations, and ensure the environmental integrity of the Mekong basin for future generations? Initially, livelihood and income diversification concepts are applied to the Mekong farmers and fishermen. Then, the biophysical nature and diversity of the Mekong River Basin are presented considering the resources they provide to rural people who live there. This is followed by a discussion of two modernization efforts intended to bring economic prosperity to

individual countries and the region: agricultural specialization and intensification and hydropower infrastructure. Examples, based on the geography of the Mekong River and its are offered to illustrate the intimate and dependent individual and social relationships. These relationships are formed by occupations that are in daily contact with the riverine environment. Lastly, the impacts and potential solutions for mitigating the collision between modernization and rural livelihoods rooted in the natural environment and a culture that builds on past knowledge and experiences are discussed.

Olson [61] found that “*Land subsidence and rising sea levels (Figure 40) could result in 40% of the Mekong Delta being covered by the South China Sea within the next few decades. The impact of groundwater withdrawal, in the SE Asia mega deltas of Ganges-Brahmaputra Delta, Jakarta Delta, Chao Phraya Delta, and Mekong Delta, is a major reason these deltas are sinking. There are lessons to be learned from failures and successful remediation efforts in other mega deltas as Vietnam policymakers seek to address Mekong Delta subsidence. Without significant Vietnam government remediation and mitigation efforts, land subsidence in the Mekong Delta will continue. Land subsidence has occurred in the Mekong Delta because of the retention of sediments behind the China and Laos dams on the main stem of the Mekong River, reduced flooding peaks, climate change, sea level rise, storm surges, and flooding.*



**Figure 40.** Picture of subsided and flooded fields from adjacent drainage ditches, waterways, and Mekong River tributary. Photo Credit: Wikipedia.

*In addition, subsidence has been exacerbated by compaction, groundwater extraction for shrimp ponds, rice paddies, and the household and drinking water needs of approximately 20 million people living on the Mekong Delta in Vietnam and Cambodia. The Mekong Delta shorelines are eroding (Figure 41) and significant land areas, including wetlands, are becoming open water. The wetlands and*

land mass are also subsiding because of the reduction in sediment deposition. Large dams on the mainstem of the Mekong River in China and Laos have reduced peak flows and reduced sediment loads in the lower Mekong River. Population and industrial growth have increased groundwater extraction and saltwater intrusion as the delta subsides leading to consolidation and reduction in the current plumes flowing into the South China Sea. The primary objective is to identify mitigation efforts used in other sinking Southeast Asia deltas and make remediation recommendations for the Mekong Delta.



**Figure 41.** Vietnam subsidence and shore erosion along the Mekong River. The house is falling into the river. Photo Credit: Courtesy of DTi News.

Promising mitigation approaches are injecting river water deep into the underlying alluvial sediments, returning the sediments trapped in China and Laos reservoirs to the Mekong River mainstem, increasing the Mekong River flooding peaks, and construction of sea and floodwalls, dikes, polders, and levees. The addition of Mekong River sediments to build up existing floodplains, the reduction of coastal shoreline erosion, the planting of mangroves and the protection of urban and agricultural areas from being covered by the South China Sea are strategies that could help remediate land subsidence in the Mekong Delta” [61].

### 3.7. Dam Construction Impact on the Mekong Delta Subsidence

Olson [61] found “The Mekong River discharges 457 km<sup>3</sup> of fresh water annually from a 795,000 km<sup>2</sup> watershed area. Historically, discharge volume and flood timing have been highly predictable and concentrated in regular wet season peaks [23] [62]. The wet season or monsoon begins when warm moist winds from the ocean blow eastward over Cambodia, Thailand, Lao PDR, and Vietnam. The onset of flood season usually occurs near the end of June each year and lasts about 130 days. The start and end of the annual flood occur within two weeks with little

variation. The dry season onset begins in late November. As moisture-laden winds encounter the mountains of Lao, the left-bank (eastern) Mekong tributaries receive high amounts of monsoon rainfall. The 14 tributaries in northern Laos all drain into the Mekong River (Figure 1), including the 447 km Nam Ou River longest tributary river in Lao. Runoff from Laos tributaries of the Mekong is the source of major wet season flooding, discharge, and sediment load [63]. The longest single tributary of the Mekong is the 673 km Mun River of northern Thailand. Despite its length, the Mun River contributes very little to the Mekong's discharge and sediment load since the river drains a dry, flat region. The Mekong Delta, with 20 million people, is subsiding at the rate of 1.6 cm per year [46]. The Mekong Delta is one of the world's major rice exporters. Delta plains have low bearing strength and soils are soft and easily compressed. These plains are usually held up above sea level by fresh groundwater that flows through the pores of sediment deposits. When those resources are extracted, such as in the Mekong Delta, the sediment compresses, the land shrinks, and the surface is lowered.

Southern Vietnam includes the Saigon River (Figure 17) and (Figure 18) and Delta and the Mekong Delta (Figure 16) and both deltas are sinking because of land subsidence caused by excessive pumping of groundwater for shrimp ponds, rice paddies and to meet the drinking water and household needs of 20 million Vietnamese living in the Mekong Delta. The entire delta is sinking up to 10 times faster than the China Sea is rising. This groundwater extraction problem is aggravated by sand removal since the sand is no longer being replenished. The mitigation solution, to excessive sand extraction, is to ensure more replacement sediment is deposited on the floodplains. With the construction of the China and Laos dams on the mainstem of the Mekong River and tributaries, that is no longer possible. In addition, the creation of polders, earthen levees, dikes, polders, and flood or sea walls reduced the sediment deposition on the Mekong Delta floodplains' [61].

#### 4. Summary

The high gradient of physical, chemical, and biological processes along the mainstem Lancang-Mekong River provides a variety of habitats that support some of the world's most diverse aquatic and terrestrial communities as well as many critically rare, endangered, and endemic species.

China has made Yunnan Province its "Southern Gateway" and the hub of its transportation corridors and energy-water nexus in Southeast Asia by incorporating the Greater Mekong Subregion into its "Belt and Road Initiative" [17]. China's Lancang River (Upper Mekong) hydropower development generates costs and benefits for downstream countries. China dominates the Greater Mekong Subregion through institutional development, technological expertise, and financial investment; yet, despite asymmetrical power relationships, China's Mekong neighbors guard their sovereignty and maintain substantial bargaining power. China is most successful when it embraces the "preferences" it shares with them. An

ongoing debate undermines Beijing's dominance among China's stakeholders, who contest the developmental model versus the environmental sustainability model, as a means of "environmental protection."

The latest reports from the Lower Mekong Basin are cause for growing concern for future drought years and the effect it would have Laos [14], Thailand, Cambodia [24] and Vietnam [25]-[27]. In 2019, the "normal" reversal of the Tonle Sap tributary at Phnom Penh [24] and flowing back-up into the Great Lake, has not occurred. In the Great Lake itself, the low levels of water have had a negative impact on fish catches, with fishermen reporting some of the smallest catches in years.

The prospect of future droughts comes with an assurance that river resource management will be conducted under terms of an agreement between multiple countries, ensuring fair water resource distribution. Power trade between Lancang-Mekong watershed nations has significantly improved power supplies, help nations address spikes in power usage. Despite ongoing challenges with power shortages, the construction of hydroelectric dams is seen as a solution to substitute coal fired power plants. These dams are expected to supply clean energy and reduce carbon emission, mitigating global warming effects.

Morton and Olson [26] suggested "*The farmers and fishers of the Mekong River and its tributaries can bring their knowledge of the past forward to manage and adapt to changes in the pulses of the river and their livelihoods. But they need resources, training, and public policies that build on their knowledge and skills and remove barriers to successful adaptation. They need social, political, and economic signals that reaffirm their value and contributions to the well-being of their communities and society. Development projects and the modernization of this region, as currently envisioned, are threats to the food security and incomes of rural people, as well as their communities and ways of life. Mitigating the collision of modernization with the cultural traditions and practices of farming and fishing that have sustained more than 2/3 of the population for centuries requires an understanding of these occupations as sources of livelihood and community. New technologies do not by themselves transform nations, rather it is the way people respond to technologies and use them to achieve individual and societal goals. This tension is reflected in the two distinct views Laotian farmers expressed-some wholeheartedly embracing new technologies and others more cautiously selecting technologies congruent with their traditional world views. The entire continuum of these approaches is viable and valuable in bringing change and meeting social goals of economic prosperity and improved quality of life.*

*Agricultural intensification, large dams, roads, bridges, and other infrastructure have been proven technologically to expand agricultural yields and outputs, generate power, and provide a return on investment. However, the social and environmental results of modernization often leave many behind. The Mekong River and adjacent lands are where the poorest people in SE Asia live with an average annual income of less from US\$ 2000. They make their living from agriculture in*

*the floodplains and fishing from the banks of their rivers. China and Laos are mountainous countries, and the fertile soils are in the narrow floodplains. Dams flood fertile lowlands and resettling rural people in uplands means the soils are different, often less fertile, and not well suited to rice and vegetable crops they are familiar with. They will need to learn new agricultural practices, and different fishing strategies (river versus lake) and use different fishing equipment. This kind of change takes time and personal resources that people often don't have. River-bank fishing and recession agriculture provide food, income, and cultural continuity. Resettlement in many instances means reduced food security and movement to a cash economy where they must pay for electricity, water, and food not grown from a very limited household income”.*

*“The Mekong River presents a huge opportunity for hydropower that can modernize China, Lao PDR, and Cambodia and provide a needed infusion of external dollars to build the infrastructure necessary to grow their economies. The United Nations Sustainable Development 2013 agenda to address poverty and hunger depends on rural transformations that increase the number of people living above the poverty line [56]. Critical in this effort is not just the economic number assigned the boundary between poverty and non-poverty but careful attention to economic and non-economic aspects of rural livelihoods that ensure household self-reliance. In the rush to modernize, profitable markets can lead to a concentration of food production in large commercial farms, large processors, and retailers, leaving smallholders behind. To ensure that small-scale producers participate fully in meeting the food demand, policy measures are needed to reduce barriers limiting their access to inputs, foster the adoption of environmentally sustainable technologies and approaches, increase access to credit and markets, facility mechanization and agricultural extension outreach and strengthen land tenure rights” [56].*

*“The tensions among different sectors and how river resources (water, floodplain soils, wetlands and backwaters and adjacent upland) are valued are not unique to the Mekong River and its tributaries but can be seen globally. The Mekong River Basin is experiencing many of the same social, economic, and biophysical challenges associated with human settlement patterns, industrialization, climate change, and political viewpoints. In the United States, the US Army Corps of Engineers (USACE) has authority and oversight (via leadership on Mississippi River Commission) to manage flooding and balance the various social values of large and smaller river resources: navigation, agriculture, industrial uses, drinking water, and river ecosystems [64]. The Mekong River Basin has similar challenges, but as a transboundary river has six countries with many more than six different goals and needs for the resource. The MRC is a new governance structure, created to coordinate and ensure the river is protected for future uses as well as current. However, it is only as powerful as the countries that fund it to give respect and authority to its rules and regulations, even if they don't agree with them always. This is a difficult governance challenge which must be worked through if the*

*Mekong River is to serve these many competing needs effectively and sustainably”.*

*“The challenge is to build on rural people’s knowledge, rethink the scale of development to bring these valuable resources and biophysical forward into the future in ways that address rural needs and the region’s quality of life. Large-scale agricultural intensification and dam infrastructure and water diversion, unchecked will reduce small-scale land holdings and farmers and fisher’s capacities to provide daily food for their own consumption and surplus produce and fish for household incomes”.*

*“The effect of dams on the seasonal pulse of the Mekong, fish diversity and abundance, and downriver impacts on water availability are just beginning to be understood and need significant and systematic research and investments on the interacting effects among river systems and livelihoods. Guerry et al. [65] call for the development of solid evidence linking decisions to impacts on natural resources and ecosystem services and human well-being. Closing the gap in fundamental interdisciplinary sciences of river ecosystems and social-human sciences will enable the development of knowledge, tools, and practices and will go a long way in helping farmers and fishers realign their livelihoods to provide economic and social well-being. It will be critical that development and management efforts recognize, value, and invest in rural people’s roles in producing a stable, affordable food system and managing the integrity of river ecosystems upon which future prosperity depends. Interventions are needed to prevent degradation of the Mekong Basin soil and water resources from large-scale agricultural intensification, water diversion, and overbuilding and locating of hydropower dams which are threats to sediment and nutrient delivery, fresh water supplies, peak flows on the Mekong and Tonle Sap rivers, salt-water intrusion in the Mekong Delta, fish spawning, land subsidence in the Mekong delta, small-scale land holdings and farmer and fishers capacities to provide daily food for their rural family consumption and to feed SE Asia’s and the world’s growing urban and rural populations” [26].*

The unique, symbiotic relationship between Tonle Sap Lake and River and the Mekong River is a natural wonder of the world. Concerns about dams blocking annual upstream fish migration, submergence of critical fisheries’ breeding habitat, and changes in the flood pulse that supplies nutrients and sediments into Tonle Sap Lake are legitimate and critical issues [18]. These are issues that don’t just affect Cambodian fishers and farmers but also impact the food security of urban people throughout Southeast Asia. There is not much known or understood about the ecological systems of the Mekong River and how they interact with Tonle Sap River and Lake systems. The Mekong River Commission, the voluntary transboundary governance body for the Mekong River; World Bank; countries along the Mekong River; and other international agencies have supported biophysical research over the last few years, but much more is needed to guide good management decisions. Further, biophysical knowledge must be integrated with

social science research findings on local knowledge about these ecological systems, perspectives on dam locations and impacts on villages, and the adaptive capacities of riparian communities. Local communities have deep knowledge of the river and lake ecosystem and have adapted to the seasonal rhythms of their waters. They can continue to successfully adapt if given the opportunity and tools. This is a human resource that can help government and private industries find workable, politically, and socially acceptable solutions to the energy crisis Cambodia faces, food security, and the long-term sustainability of Tonle Sap Lake and River ecological systems.

Significant Mekong Delta land areas and wetlands in Vietnam are being lost each year because of coastal shoreline erosion. The wetlands and land mass are also subsiding because of the sediment deposition reduction caused by dams on the mainstem of the Mekong River, groundwater extraction, salt-water intrusion, and consolidation, reduced sediment loads in the lower Mekong River, and reduction in the current plumes flowing into the South China Sea. The loss of sediments from China, Laos, and perhaps future Cambodia dams needs to be addressed. The trapped sediment behind these huge reservoir dams needs to be dredged and transported over the dams and returned to the mainstem of the Mekong River to flow to the Mekong Delta. This process needs to be repeated at each dam site in China and Laos. In addition, artificial recharge is needed to restore the piezometric heads of the multi-aquifers system. The mangrove forests along the South China Sea need to be restored. Without sediment additions over time, the Mekong Delta will continue to sink into the South China Sea.

## 5. Conclusion

The primary objective of this study was to assess the environmental and human impacts of Lancang-Mekong mainstem and tributary dams and the plans for more hydropower utilizing the river's potential as the continent's energy lifeline. Strengthening of international collaboration to address Lancang-Mekong's sustainable transboundary development goals is encouraged. Future dams need to include fish ladders and navigation locks to reduce the environmental impacts on fish populations, natural resources, navigation, and livelihoods. When new Lancang-Mekong and tributary dams are built within the transboundary watershed additional communities will need to be resettled and could suffer from lack of adequate compensation, problems with food security, and an increased incidence of disease. Relevant steps need to be taken to prevent these problems and to ensure that people's livelihoods are restored after resettlement. Dams are only one of many threats to the sustainability and resilience of the river. A changing climate, deforestation of uplands, and irrigation needs of a growing population are other difficult issues the governments and peoples of the region must address. As a transboundary river, management decisions by one country inevitably reverberate throughout Southeast Asia. The MRC is a critical institution that all Southeast Asia transboundary countries must respect and re-empower to negotiate and

balance the many competing interests. One of the MRC's major tasks will be to mitigate the negative impacts of dam building while realizing the economic benefits. For large-scale development reasons, the construction of dams is necessary. However, the relevant protection of the ecosystem must be considered during all decision-making. Above all, all associated decision-making must consider both the sustainability of the projects and that of the ecosystem. Therefore, the reasonable achievement of such a goal is a challenge that requires proper integrated planning and studies.

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## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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