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Impacts of dams on lowland agriculture in the Mekong River catchment

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Preface

This is a literature review of statistic data and research published in scientific articles and governmental- and nongovernmental organization reports. It was carried out during the spring semester of 2011.

I would like to give a special thank you to Mr. Anders Thurén who assisted me in the process of getting in touch with the MRC. I also thank my supervisor Ulrik Mårtensson for the valuable feedback given.

Abstract

The Mekong River catchment on the Indochinese peninsula in Southeast Asia is currently one of the world's most active regions in terms of hydropower planning and development. In recent decades China has launched a hydropower plan comprising eight large dams on the main stream river in the upper part of the catchment. Three dams have already been built and now also the countries in the lower basin, Laos, Cambodia and Vietnam have joined the pursuit with great visions. The hydropower expansion may well add to welfare and reduced poverty in especially Laos and Cambodia. However, it might also bring about negative consequences for the people living downstream practicing agriculture on the lowlands adjacent to the river. The purpose of the thesis is to describe if and how agriculture in the lower part of the catchment area is influenced by the impacts of upper catchment dam building. The focal area is the lowland agriculture, i.e. the cultivated floodplains of Laos, Cambodia and the delta in Vietnam. The agricultural practices on the floodplain and in the delta that is said to be impacted by the dam building are rice, riverbank agriculture and aquaculture. Dams in the upper Mekong River were accused for regulating the flows and trapping nutrient-rich sediment. The potential effects of this would e.g. be decline in agricultural productivity and loss of agricultural land. The conclusions are that extended dam development chiefly on the mainstream of the basin will have future negative impact on floodplain agriculture. The most important consequences are the reductions in dry season water flows and trapped sediments. However, up to now there is no definite measurable impact that can be attributed to the dams. Therefore it is important to continue measurements and assessments.

Keywords: physical geography · Mekong River Catchment · dam building · floodplain agriculture · sediment delivery · floods

Sammanfattning

På den Indokinesiska halvön ligger Mekongflodens avrinningsområde. De senaste årtiondena har Kina, som innehar den nordligaste delen av flodbassängen, startat ett omfattande vattenkraftsprojekt på flodens huvudfåra. Åtta mycket stora dammar är planerade varav tre redan är byggda. Länderna som ligger nedströms från Kina, nämligen Laos, Kambodja och Vietnam har på senare tid också beslutat att bygga ut vattenkraften ordentligt. Laos och Kambodja rankas som några av världens fattigaste länder, export av den genererade elen skulle därför kunna bidra till ekonomisk tillväxt och minskad fattigdom. Emellertid så kan dessa dammar även medföra negativa konsekvenser för bönderna som brukar jorden på flodslätterna nedströms de stora dammarna. Syftet med denna litteraturstudie är att undersöka hur och om jordbruket i den nedre delen av avrinningsområdet påverkas av dammbygge i den övre delen av flodbassängen. Studien fokuserar på de brukade flodslätterna i Laos och Kambodja samt floddeltat i Vietnam. Det spås att av det jordbruk som bedrivs här kommer risodlingar, jordbruk på flodbankar samt fisk- och skaldjursodlingar påverkas negativt av dammarna. Klimatet här domineras av monsunsäsonger med en regnsäsong och en torrperiod. En av de största nackdelarna med dammarna sägs vara att de reglerar vattenflöden under torrperioden vilket skulle orsaka vattenbrist samt oväntade översvämningar som förstör jordbruksmarken. Dessutom ska dammarna enligt uppgift stoppa upp stora mängder med sediment som floden annars för med sig. Detta sediment är mycket näringsrikt och är en förutsättning för framförallt det småskaliga jordbruket. Dessa effekter skulle minska avkastningen och förstöra brukbart land. Studiens slutsats är att den snabbt ökande expansionen av vattenkraftsdammar, främst på huvudfåran, kommer att påverka jordbruket negativt. De värsta effekterna är uppstoppade sediment och minskade vattenflöden under torrperioden. Fast än så länge så finns det bara indikationer på att detta skulle ha hänt. Därför är det viktigt att fortsätta med undersökningar och analyser för att kunna övervaka utvecklingen och förhoppningsvis kunna förhindra att jordbruket blir utsatt.

Nyckelord: naturgeografi · Mekongflodens avrinningsområde · dammbygge ·
flodslättsjordbruk · sediment · översvämningar

List of abbreviations

Cumec	Cubic meters per second
GIS	Geographic Information System
LMB	Lower Mekong Basin
MD	Mekong Delta
Mm ³	Mega cubic meters
MRB	Mekong River Basin
MRC	Mekong River Commission
Mt	Metric tonnes
MW	Megawatt
NGO	Non-Governmental Organization
PBMA	Period Between March and April
SSC	Suspended Sediment Concentration
SSL	Suspended Sediment Load
UMB	Upper Mekong Basin
UN	United Nations

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Introduction

The Mekong River is the longest Southeast Asian river extending over one of the world's largest catchment areas, covering a big part of the Indochinese peninsula (IMC, 1987). The riparian countries of the Mekong river basin are, in a northwest to southeast gradient: China, Burma, Laos, Thailand, Cambodia and Vietnam (see figure 1). Within this area 65 million people live and depend on the river and have adapted their way of life to the river regime that is regulated by the Asian monsoon (Nesbitt, 2005). The main source of income is agriculture and in order to maintain this livelihood, both at industrial and subsistence scale, water availability is essential (MRC, 2003). Rice along with fish production are the two most important food sources, two types of agriculture that highly depends on the hydrology and nutrient rich suspended sediment load of the river (Nesbitt, 2005). Population predictions point at an increase to over 80 million by 2030, an expansion that will add further dependence on river water flow and quality.

However, the last two decades concerns have been raised because of the Chinese construction of dams in the upper part of the catchment (Campbell, 2009, Roberts, 2001, Xue et al., 2011). Three dams are already in operation and the rates at which new and larger dams are constructed troubles the people that are living downstream. There is an ongoing debate whether these dams have adverse ecological and hydrological consequences or not. Mass media and the public opinion in the downstream countries hold the Chinese dams responsible for the severity of recent floods and that there has been a change in dry season water flows. Also, when the catchment area was troubled by a severe drought with low flows and negative social impacts during 2003 and 2004, many blamed the dams (Lu and Siew, 2006). General worries of the governments of the lower basin concern water quantities and flows while NGO's and local groups are mainly troubled by water fluctuations and river bank collapse (MRC, 2010).

Since this became a hot topic, a lot of research has been made and many articles have been published on the issue. The publications touch upon problems such as the environmental, ecological and hydrological consequences. But, how agriculture in turn is affected by the changes has not been highlighted as much yet.

This thesis will therefore try to identify and summarize the potential and actual effects on agriculture caused by upstream reservoir construction. The specific aim is to describe if and how agriculture in the lower part of the catchment area is influenced by the impacts that upper catchment dam building has on hydrology and the dynamics and delivery of nutritious sediment load. Focus will be on the lowland agriculture, i.e. the cultivated floodplains in Laos, Cambodia and the delta in Vietnam.

Dams are not only being planned and built in China, recently both Laos and Cambodia (and Vietnam to a certain extent) have set out with grand visions of hydropower development on the Mekong mainstream and tributaries. The intention of this thesis is for that reason to identify the potential effect of these lower catchment dams as well.

Background

Introduction to the area

The Mekong River basin is normally divided into three parts: The upper basin (often called Upper Mekong Basin, UMB), the lower basin (often called Lower Mekong Basin, LMB) and the delta (Adamson et al., 2009). The upper basin comprises the Chinese part, where the river is called “Lancang Jiang”, which makes up one fourth of the total catchment area. More downstream, basically at the Laotian border, the lower basin) begins. It covers the major part of the catchment area (77 %) and continues down towards southern Cambodia. Further down in the catchment the delta stretches out, reaching from Pnom Penh (capital of Cambodia) and into Vietnam.

The geophysical properties of the catchment, covering an area of almost 800,000 km², are in the north (the upper basin) dominated by the Himalayan orography of the Tibetan plateau (Adamson et al., 2009). The typical traits of this setting are rocky and steep sloping narrow river valleys (Gupta, 2009). This character remains as the river crosses the border to Laos, with the mountainous northeastern part (“the left-bank tropical tributaries”) where rains provide much of the annual runoff. The elevation decreases progressively just as the gorges get wider. Eventually, in central to southern Laos the river valley broadens into the lowlands of Cambodia, here the floodplain stretches out. From there the river crosses the flat terrain surrounded by elevated highland areas to the east (“Korat Upland” in Thailand and “Cardamom and Elephant Hills”, bordering Cambodia and Thailand) and to the west (“Annamite Mountains” in Vietnam) (see figure 1). At the end of the river, in southwestern Cambodia and Vietnam, the delta is situated. It is one of the world’s largest with a vast network of distributary channels, of which the main ones are bounded by levees.

Although there is an ongoing economic growth in the countries, poverty is a critical issue especially in Cambodia and Laos, regarded to be the poorest in the world (Kirby and Mainuddin, 2009). A substantial part of the poor people in the lower Mekong catchment area is settled on the floodplains. Here they have cultivated the land for thousands of years, learning to cope with climate and the seasonal flooding features of the river (Yoshimura et al., 2009, Acreman, 2000). The main occupation is still agriculture (see specific section below), both at the large industrial scale and at a local scale. The poor local people often have no other options of livelihood than agriculture, making them quite susceptible to changes in the natural resources on which they depend. Studies point out that agriculture plays a decisive role when it comes to reducing poverty and improving economic development (WB, 2005, Irz X, 2000).

Historically, the river has been renowned for its unspoiled nature, without much regulation (Adamson et al., 2009). However, this nomination is today questionable, because of the basin wide dam plans. The 65 million people living in the basin are expected to increase to above 82 millions in as little as 20 years. This is one of the reasons that the governments and stakeholders refer to, defending the dam development. More detailed information on this topic will be provided further on in this thesis.

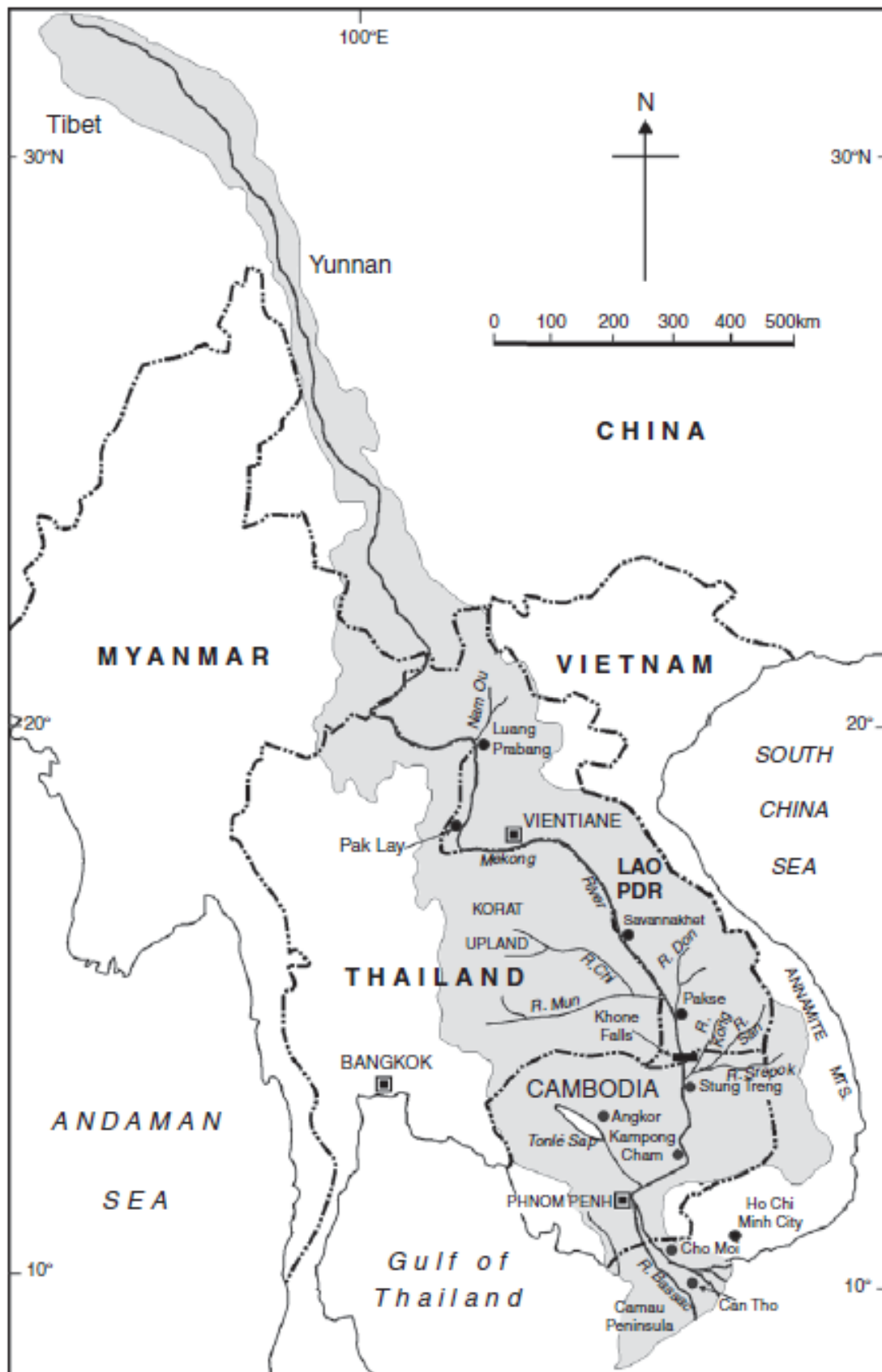


Figure 1. Map showing the location of the Mekong River catchment on the Indochinese peninsula. The grey part indicate the MRB and the countries within the basin. Source: Gupta (2009). Courtesy of Dr. Avijit Gupta and Dr. Ian C. Campbell, reprinted with permission.

Climate

The climate in the Mekong River basin is humid and tropical (MRC, 2010, Xue et al., 2011). Dominated by the Northeast and the Southwest monsoon, the seasons are clearly defined by changes in rainfall. During summer a strong low pressure is located above the relatively warm Asian continent and the Indochinese peninsula where the Mekong basin is located. Warm and moist air flows into the peninsula from the Indian Ocean and thereby the wet season commences. Conversely, in winter a large and shallow high pressure develops over the continent, associated with very dry air masses which indicate the dry season. The wet season, governed by the SW monsoon, lasts for seven months between mid-May and October. Regarding the dry season, under the regime of the NE monsoon it usually stretches from November to mid-March.

The beginning and end of the Southwest monsoon in terms of precipitation is very predictable at a regional scale (MRC, 2010). In contrast, the dates of the average beginning and end of the monsoon do not coincide among different spatial stations. The reason for this may be that October and November, when the monsoon usually ends, is the time of year when tropical storms are most likely to occur. Research has proven that there are no indications of an alteration in the regional beginning and end of the Southwest monsoon as part of a climate change.

The mean annual rainfall pattern is distributed along an east-west gradient with maximum means as high as 3,200 mm/year in eastern Laos, whereas minimum below 1000 mm/year occur in Thailand (Kite, 2001). 90 % of the annual rainfall is received during the wet season. Total amounts may however vary quite a lot since often only parts of the basin are affected by storms associated with intense tropical depressions (MRC, 2010). Regardless of this fact, the MRC (2010) put together annual rainfall data from the period 1980 to 2004 in order to get a general overview of the recent years in the LMB. The data was plotted as deviations from the mean, thus displaying an annual rainfall anomaly. The outcome showed a dipping trend from 1980 towards the dry peak in the early nineties. The very dry phase with strong rainfall reductions lasted for several years, until 1995 when the trend turned towards normal conditions. Annual rainfall continued to increase to a very wet phase between 199 and 2002, after which it declined to average and below.

The mean temperature range from the coldest to the warmest month is relatively uniform for the whole catchment area, around 5 degrees Celsius. The coldest means are experienced in the elevated area in the northeastern part. Maximum temperatures at sea level reach 35° C, whereas the minimum goes down to 15° C.

The Mekong River Commission

The transboundary nature of the Mekong River implies that political, economic, and environmental changes and questions are a concern of all the involved countries (Kummu and Varis, 2007). In terms of the subject of this thesis it means that reservoir development in one country is a current issue for the other countries as well. In 1995, The Mekong River

Commission (MRC) was founded to be an informative and mediating organ between the countries of the LMB regarding these matters. The funding agreement was signed by Cambodia, Laos, Thailand and Vietnam. Up to now, China has not yet joined the MRC (Roberts, 2001).

The MRC aspires to assure cooperation between member countries and a sustainable development for the communities that use the river to maintain their livelihood (Terra, 2011). It is also an institute of research that aims to survey the status of the hydrology, environment, societies etc.

Criticism against the functioning and working procedures of the MRC has been raised as a consequence of the recent dam controversy. The critics claim that it is hard to see MRC as an “international river basin organization’ capable of protecting the river from severe ecological damage or responding to the diverse needs and interests of people in the basin” (Terra, 2011). Further statements do not credit the efficiency in resolving LMB conflicts, even though the organization is annually aided with millions of dollars. One of the examples referred to is the issue concerning the downstream impacts of damming in China. One of the leading NGO’s in the area, Terra¹, stress the unwillingness/inability to respond to the concerns of the people and civil groups. This rests upon the problem that MRC only strives to be responsible for the member states but not the people, according to Terra. But most importantly, they claim that the member countries have neglected the signed agreement of 1995 by pushing for more dams to be constructed.

Dam building

The MRB is presently one of the world’s hydropower hotspots, in comparison to other great basins in the world, it is placed ninth in terms of dams planned (MRC, 2010, WWF, 2007). The pursuit for rapid economic growth and reduced poverty in China and other countries in the Indochinese peninsula is the main driving force behind this recent explosion in cascade-like reservoir development (Kummu and Varis, 2007, Li and He, 2008). The predominant purpose for the construction of dams in the Mekong basin is hydropower generation and it is likely to be the objective the forthcoming decades (Campbell, 2009).

This kind of basin wide project is however not the first in the history of the MRB (Hortle, 2009). In the beginning of the 1960s the UN presented the “Mekong Project” with visions of economic development. The project focused on the realization of dams on the Mekong mainstream and tributaries, these would support the economy by providing hydroelectricity, irrigation, flooding control etc. When the second Indochina War broke out in 1964 (lasted until 1973) these plans were interrupted and practically no dams were built under the following Khmer Rouge regime (1973-1979).

¹ Terra (= Towards Ecological Recovery an Regional Alliance) works to promote ecological and environmental issues and support local communities of the LMB.

Upper basin

In the beginning of the 80s, China commenced what would be the existing hydropower plan on the Lancang Jiang River (Li and He, 2008). Eight dams were planned and the first project started in the early 90s (see figure 2). By 1993 the Manwan dam was completed. In 2001 the second dam was built on the river, called Daochaoshan. They are situated on the main stream in the upper part of the Lancang Jiang basin. By 1995 and 2003 respectively they were fully operational.

In the upper Lancang Jiang part of the river basin China has plans on extending the hydropower industry to a generation of more than 15,000 MW (Walling, 2009). As a comparison the Dachaosan, Manwan, and Xiaowan dams generate 1,350 MW, 1,500 MW, and 4,200 MW respectively. Recently, in 2010 the much greater Xiaowan dam was enclosed upstream of the two earlier mentioned. By 2013 another great dam is to be completed, namely the Nuozhadu located more to the south. In comparison to the two “older” dams these two new ones are huge even by world standards, in order of total storage the Xiaowan is about 15 times larger and the Nuozhadu as much as 24 times larger (see table 1). Kummu and Varis (2007) estimated the theoretical trap efficiencies of sediment for the dams (i.e. the percentage of sediment trapped by the dam), also presented in table 1. At present the Three Gorges Dam on the Yangtze River in China, completed in 2006, is by far the largest dam in the world with a total storage of 39.3 km³ and a current generation of 18,000 MW (Britannica, 2011).

Critics say that after the construction of the Manwan dam China did not consult the downstream countries (Roberts, 2001, Mastny, 2003). Neither was the newer projects informed until very late. Furthermore, now that three dams are constructed it is by some claimed that the downstream countries still are not always told when water will be released.

Table 1. List of the eight dams included in the Chinese hydropower plans. Figure are presented on commissioning year, total storage and estimated trap efficiency of sediments. Source: Kummu and Varis (2007) and Lu and Siew (2006).

Name	Commissioning year	Total storage (Mm3)	Estimated trap efficiency (%)
Manwan	1993	920	68
Dachaosan	2003	880	66
Xiaowan	2010	15,130	92
Jinghong	2012	1,040	66
Nuozhadu	2017	24,670	92
Ganlanba	N/A	N/A	N/A
Gongguoqiao	N/A	510	61
Mengsong	N/A	N/A	N/A

Lower basin

Lately, China is not alone in planning for a large hydropower development (MRC, 2010). Strive for rapid economic growth in the LMB during the latest decades has brought about a steadily increasing energy demand. This has been one of the main triggers behind the increased interest in the hydropower potential in the lower basin. In 2004 many smaller

hydropower and irrigation dams had already been built on the Mekong tributaries in Laos and Vietnam. Plans exist on development of both types of dams, many of the hydroelectric ones funded by Chinese stakeholders.

Large scale hydropower expansion is prepared in the tributary basins of the 3Ss (Sekong, Sesan, and Sre Pok) that covers parts of Laos, Cambodia and Vietnam (Xue et al., 2011). Much of this area, the largest sub-basin in the MRB, constitutes the “left-bank tropical tributaries” that dominate the flood runoff, mentioned in “Hydrology” below (ADB, 2006, Xue et al., 2011). The biggest dam constructed here so far is the Yali Falls in Vietnam which was completed on the Sesan River in 1999.

Eleven new dams are proposed on the lower part of the Mekong mainstream, see figure 2, nine of them in Laos and the remaining two in Cambodia (MRC, 2010). Laos will mainly construct hydropower dams in order to be able to sell the electricity to wealthier countries like Thailand. The implementation and economic sustainability of these plans has been realized by the regulative Chinese dam flows (more information provided further down). These dams are relatively small in comparison to the Lancang Jiang cascade, but are still large by international definition (over 6 meters high) (Wong et al., 2007). The heights range from 6 to 40 m, while in China they are 67 to 248 meters. Nonetheless, due to the flat topography of the floodplain, many of these dams will inundate much greater areas than the upstream counterparts.



Figure 2. A schematic sketching of the MRB and the main stream hydropower dams that were existing, under construction and planned in the year of 2008. Source: Lee (2008). Courtesy of Terra, reprinted with permission.

Hydrology

The Mekong river, the world's 10th greatest in terms of discharge (for specific figures for the Mekong River, see table 2), originates from the Tibetan plateau in China at approximately 5000 meters above sea level, wherefrom it flows southwards through Burma, Laos, Cambodia and Vietnam (Prathumratana et al., 2008, MRC, 2010). The main river stream is supported by numerous tributaries in a great river basin that extends over these countries. This vast catchment eventually debouches into the South China Sea in the delta of Vietnam (WRI, 2003).

Table 2. Source: Adamson et al. (2009)

Mekong river catchment hydrology facts	
Total Length	4,880 km
Total catchment area	795,000 km ²
Annual runoff (to sea)	475 km ³

The shape of the river basin is quite narrow in the upper stretches and it is not until it leaves the elevated northern mountain complex that the catchment progressively gets wider (Adamson et al., 2009). For this reason it does not have a dendritic form like most catchments do. Instead the widest part is located more to the south, just north of the delta to be more specific (MRC, 2005). Due to these features the catchment is divided into the three parts mentioned earlier, namely the upper basin, the lower basin and the delta. One of the most important hydrological features of the southern LMB is the Tonle Sap Lake which is the largest freshwater body in Southeast Asia. The special characteristic of this lake is that it changes the seasonal flow of water in the adjacent basin, rendered by the extremely low height gradients (Kite, 2001). During the dry season the Tonle Sap water level decreases and flows out to the Mekong River through the Tonle Sap River. Conversely, when the flooding season arrive the water table of the Mekong River rise to a higher level than in the lake and thereby cause a backflow of river water into the Tonle Sap. This feature provides a relief of the flooding in the wet season and an aid to irrigation in the dry season.

As a typical large tropical monsoonal river the Mekong River is characterized by a massive discharge of water during the very regular wet season and a discharge below the annual mean during the dry season, see figure 3 (Adamson et al., 2009). The flooding season occurs, on average, from late June until early November with the peak in August/September. Not only the annually returning date, but also the size and the distinctiveness are very regular for the flood peak. At the other extreme, the daily minimum discharge during the dry season most often occurs in early April. The time periods in between the two seasons are called transition seasons. The first transition season starts when the water discharge is doubled and ends as the wet season commences when the discharge exceeds the annual mean at that specific station. Similarly, when the discharge drops below the annual mean the second transition season begins and continues until the discharge drops to low flow conditions that defines the dry season.

These highly regular features of the Mekong River are practically the same at all sites of the stream even though the hydrology is dominated by different flows throughout the basin. Furthermore, the temporal homogeneity brings about a precisely adapted biology and a river

system sensitive to changes, primarily anthropogenic that will be brought up further down in the thesis.

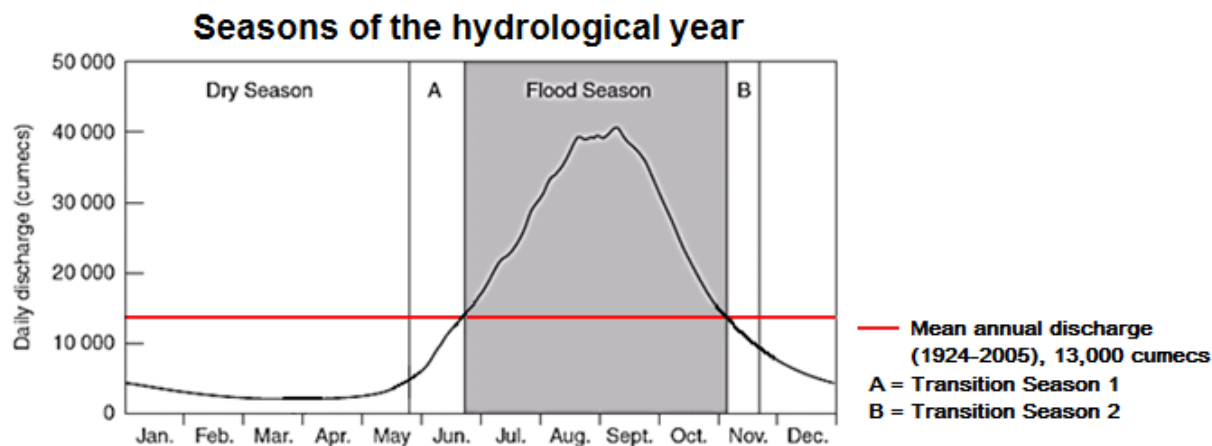


Figure 3. Diagram showing the four seasons of the hydrological year in the MRB. The red line indicate the mean annual discharge for the whole basin, given in cumecs². Modified from Adamson et al. (2009).

Two major sources of outflow dominate the Mekong river basin; the Tibetan plateau in the UMB and the left-bank tropical tributaries of northeastern Laos in the LMB (Adamson et al., 2009). The northern Tibetan discharge of snowmelt governs the runoff in the upper part of the basin with >75 % and >50 % (exemplified figures from Vientiane, Laos) of the water during dry- and wet season respectively. However, there is a fairly large variation in the runoff contribution from year to year.

When the river continues southward, the Tibetan runoff contribution decreases gradually (Adamson et al., 2009). Reaching Cambodia the left-bank tropical tributaries of Laos, receiving the majority of its rainfall from the monsoon, surpass Tibet in water contribution. I.e. at Kratie, Cambodia the Tibetan discharge stand for about 40 % during dry season but only 15-20 % during wet season (Adamson et al., 2009). On the Mekong river catchment as a whole, the total annual discharge from China is 16 %, with much of the remaining greater volume originating from the left-bank tropical tributaries (Adamson et al., 2009, Roberts, 2001).

As stated, the floods of the wet season reappear practically at the same time each year (Adamson et al., 2009). When it comes to large floods, they are normally brought about by tropical cyclones and violent tropical storms. With 18 % of the average flood volume, the left-bank Laotian tributaries are the predominant contributors of flooding in the lower Mekong basin.

The discharge of the Mekong River fluctuates at an interdecadal time scale. An example of this fluctuation was presented by Campbell (2009). This study employed data of mean dry season discharge during the 20th century. It was demonstrated that, at Vientiane, between the middle of the 1940s and the middle of the 1960s the discharge fluctuated very much. The

² Cumec stand for cubic metres per second.

discharge decreased from the 40s (ca 1350 cumecs) until the extreme dip in the 50s (ca 1050 cumecs), after which it increased again in the 60s (1250 cumecs). The same variation could be seen between the other decades as well, but the fluctuation was not as extreme.

Sediment load

The magnitude of transported suspended sediment, transported by the runoff, is critical to the status of e.g. the downstream agriculture and erosion (Wang et al., 2011). Therefore it is important to survey the magnitude of the sediment load to investigate the status and fluctuations of the sediment yield. Among the important influences on the magnitude is dam construction (Walling, 2006).

Sediment load is usually divided into the coarser bed load and the fine textured suspended load, where the latter one is more easily measured due to its abundance and accessibility (Campbell, 2009). The common understanding is that the bed load comprises around 10 % of the total load. The suspended sediment load (SSL) is susceptible to climate change and anthropogenic activities. For example, clearing of forests for agricultural expansion increases the erosion and consequently the SSL while reduced rainfall and damming results in a decrease of this load (Walling, 2006). An increase in sediment loads can cause a reduction in dam storage capacity because of sedimentation and siltation (Campbell, 2009). Furthermore, it may diminish the transportability and boost the turbidity of the river water. A decrease of sediment loads could therefore be beneficial for damming purposes but on the other hand it can be devastating to agriculture. This is due to the fact that smaller amount of sediment bring less nutrients to lakes, floodplains and deltas downstream. Moreover, a smaller sediment delivery could in the deltas lead to recession, erosion and river bank collapse (Roberts, 2001).

In addition to variations in the amount of sediment load the “quality” is also an important key factor. The quality is defined by the geochemical composition (nutrient and contamination content) and the grain size, which is very important for the agriculture. However this is not within the focus of this thesis. Concerning the composition of the suspended sediment load in the MRB, it is agreed upon that silt is the major component (Ahlgren and Hessel 1996; Wolanski and Nguyen 2005). Moreover, the clay content is also substantial in the major part of the catchment.

Owing to the fact that the Mekong still is one of the world’s most pristine great rivers (Kummu and Varis, 2007), it should discharge relatively small sediment loads (Campbell, 2009). This in comparison to other great rivers in Southeast Asia such as Chao Phraya, Brahmaputra, Ganges, Indus, Irrawady, the Pearl River, the Red River, Yangtze and the Yellow River. It is difficult to estimate SSLs of great rivers like these without involving a lot of questionable data, due to rapidly changing sediment loads and unavailable or unreliable statistics. Notwithstanding, Campbell (2009) made an attempt by comparing these large rivers with a long term estimate of mean annual suspended sediment yields, measured in tonnes per year. The data used belonged to time series in the middle and latter parts of the 20th century, prior to the dam constructions. Campbell (2009) found that the Mekong basin should be

considered as small in terms of SSL in relation to the other great rivers. The reason for this is that a large part of the river basin is situated in gently sloping to flat areas that do not contribute with as much sediment as hilly areas do.

Thanks to the relatively unregulated nature of the river, until quite recently, the sediment deposits are suggested to have been relatively constant for 3000 years. Lately (the past 50 years or so), the relative large increase of human/infrastructure development is likely to have caused changes in the sediment load. This possibility will be treated in the part about changes in the sediment load.

Sediment regime

The interannual variability in the sediment load delivery is important to consider when measuring the effects of dam building. Measurements can provide information on whether the trend is part of a natural fluctuation or influenced by the dams (Campbell 2009). As mentioned earlier, limitations in data availability and quality makes comparisons between river basins difficult, particularly modeling of sediment loads at different locations in the catchments. In order to minimize the influence of inter-annual variations in sediment load caused by land use changes and dams, only measurements from areas with as stable land use conditions as possible were included. The Campbell study computed the inter-annual variation coefficient for the Mekong to be between 25-35 %, which is, when comparing to a global study of sediment discharge variability conducted by Walling and Kleo (1979), to be considered as relatively low. The regular flood season and monsoonal climate regime was by Campbell (2009) said to be the reason for the low interannual variability. Yet, lately the Mekong has experienced some dry years with small annual runoffs and sediment loads. This could indicate an increase in climate variability.

Due to the topographical character of the basin, approximately 50 % of the sediments originate from the upstream Chinese parts (Roberts 2001), which is also confirmed by Harden and Sundborg (1992) that found that the tributaries downstream contribute with relatively low amounts of sediments. The deposition of sediments is naturally also increasing downstream, due to reduced water velocity (Campbell, 2009).

Soils

Alluvial deposited soils dominate the floodplains and delta of the LMB (MRC, 2010). The deposition of nutrient rich alluvial sediment occurs during the flood season and hence improves and maintains soil fertility. Amount estimations are about 79 million tonnes of deposited nutrient rich sediment that reaches the delta. Otherwise, the soil types are typically acidic sandy clay loams (Acrisols) with low nutrient content due to low content of organic matter and low Cation Exchange Capacities (CECs)³ (Nesbitt, 2005). In addition they fix phosphorus and may contain levels of aluminum that can be hazardous to plants under

³ Cation Exchange Capacity refers to the fertility of a soil, the higher CEC the more cations could be “hold” by the soil at a specific pH value. For example, a high CEC means that the soil can hold more nutritious basic cations and that it has a higher ability to neutralize acids.

aerobic conditions. Moreover, the physical properties of the sandy loams make them prone to crusting which cause short-term waterlogging after the first rain/irrigation. In the delta the soil classes are the same but generally with higher fertility. These features of the alluvial plain soils make them highly suitable for rice cultivation and recession agriculture.

The soils of the delta contain a lot of salt due to the natural process of salinity intrusion (Roberts, 2001). This process occurs when salt sea water in the distributary channels penetrates the soils and contaminates the ground water. The agricultural practices here are adapted to these natural conditions, for more information see subsequent section.

Agriculture

The cultivation types that are influenced by dam building are presented in this section. The agriculture in the LMB is dominated by rice production, and so it this is the most affected land use type (Nesbitt, 2005). Other types of affected land uses are riverbank market gardening and fish farming through aquaculture.

In the lower basin of the Mekong River catchment area the predominant occupation is agriculture which employs between 65-85 % of the total labor force in Laos, Cambodia and Vietnam (MRC, 2010). Almost half of the total area in the lower Mekong basin constitutes of land characterized by gentle slopes and floodplains (Nesbitt, 2005), areas within the scope of this thesis. On these flatter floodplains adjacent to the river more than 64 % is covered by agricultural land. In comparison to upland farming the lowland version is normally more intense (MRC, 2010). As the demand increases in proportion to the population expansion, more land is annexed (Nesbitt, 2005). The agricultural pressure and dependence on river water is also rising in accordance to the demand. By 2005, around 80 to 90 % of the total water abstractions in the lower basin are for agrarian purposes.

Rice

The staple crop has been rice for thousands of years, which is not surprising since the floodplains of the LMB are excellent for rice cultivation (Nesbitt, 2005). The ultimate element of this suitability is determined by the flooding pattern of the monsoonal climate with the huge amounts of rain it brings. Unlike many other crops rice tolerates temporal waterlogging and, a typical feature of this ecosystem. Another unfavorable factor for most plants is the fairly high dominance of the acidic sandy loams (described above). Luckily for the producer, when the flooding season arrives it saturates the soils with water, creating anaerobic conditions which increases the pH, reduces the toxic levels of aluminum and makes the phosphorus available.

This is one of the reasons why rice is the dominating crop on the floodplains and will continue to remain that way in the foreseeable future (Nesbitt, 2005). Other reasons are the rice-eating tradition and the well-developed market. Subsistence farmers cannot afford to irrigate their crops to a large extent, nor can they afford to buy fertilizers. This explains why around 80 % of the production of rice still is dependent on the access to river water, the silty sediment and the nutrients it brings along during flood season (Roberts, 2001).

The kind of rice that grows in water, with the only supply from the natural flooding regime, is called rain-fed lowland or paddy rice, see figure 4 (MRC, 2010) (Nesbitt, 2005). However, long time logging conditions they cannot tolerate. The seeds are usually sown by the start of the wet season in May-June and are ready to be harvested from October on. It is the most common practice of rice cultivation and constitutes the bulk of the annual harvest. There are two more types of rice that also grow on the paddies of the Mekong floodplain; deepwater- and irrigated rice. The definition of deepwater rice is a water depth of more than 50 cm and if the growing parts of the plant float on the surface at water level maximums, it is called “floating rice”. Deepwater rice does not require much maintenance but since the farmers consider them as a high-risk crop they are not very common. In many cases they have shifted to dry season rice crops or newly bred HYVs (High Yielding Varieties) where rainfall is sufficient.



Table 3. Rice cultivation types and their percental part of the rice farming in Laos and Cambodia. Source: MRC (2010)

Type	Cambodia (%)	Laos (%)
Irrigated rice	11	12
Rainfed lowland rice	84	67
Deepwater rice	3	0

Figure 4. Paddy field. Source: USAID Bangladesh, reprinted with permission.

Another land use type for cultivating rice is called dry-season flood recession (Fox and Ledgerwood, 1999). It takes advantage of the sediment deposits of nutritious silt that arrives during the floods. As the name reveals it is grown upon these fertile soils in the dry season, the time when it constitute the major land use. The receding flood water is stored in smaller natural (channels, canals and depressions) and artificial reservoirs, to be released as irrigation later (MRC, 2010). Farmers in the LMB usually choose to grow dry-season flood recession rice if possible since yields are higher compared to the other varieties, thanks to the nutrient rich soil.

In the Mekong delta of Vietnam, two types of dry season crops are cultivated where floods are common (Nesbitt, 2005). Both fully- and partly irrigated rice is primarily grown all the year round. In contrast to the floodplain areas of Cambodia and Laos where irrigation is sparse, rain-fed rice crops are rare in the MD. In the LMB as a whole figures from MRC indicate that “over 4 million ha of wet season rice receives some form of supplemental irrigation”, estimating the total areal of wet season rice to be “well over 10 million ha”.

One typical rice type grown in the delta is the Vietnamese version of the profitable Thai “jasmine rice” (Roberts, 2001). This type is adapted to saline soils and to irrigate these paddies the farmers take advantage of the riverine floods that is diverted into the fields by means of tidal hydropower.

Riverbank market gardening

This is another important practice of agriculture that is either part of a farm cultivating other crops or it exists alone as a great “riverbank truck gardening” (Khmer: “Chamkar”, Lao: “Kaset rim fang menam”) (Roberts, 2001). Riverbank market gardening involves a wide range of cash and/or subsistence crops that are cultivated, as the name reveals, on the riverbanks and islands of the Mekong mainstream. The cultivation includes typical cash crops such as tobacco (see figure 5), corn, watermelon and soy bean.



Figure 5. Tobacco crops on a riverbank market garden in the LMB. Source: Terra (2007). Courtesy of Terra, reprinted with permission.

Further crops are for instance: aquatic/semi aquatic plants like water mimosa and lotus, medicinal herbs and orchards of mango and citrus fruits. Practically no fertilizers or pesticides are needed in this farming. In order to be able to practice riverbank truck gardening, the river water level must fluctuate throughout the year. The receding river water provides exposed river banks with fertile soil and the oncoming river water adds the required natural irrigation and a certain amount of annual deposited silt, much like for flood recession rice (Lazarus, 2006).

Aquaculture

In the LMB, aquaculture is an important financial income especially for rural communities and is one of the increasing agricultural practices (Phillips, 2002). A few large scale farms exist but the greater part of the production is generated by the individual households that use the yield both for own consumption and for selling.

Aquaculture adjacent to the LMB mainstream and tributaries involve fish and shellfish breeding (mostly shrimp in the delta) in three main ways: i) in ponds ii) in rice fields iii) in cages or demarcated areas (Hortle, 2009). In the delta the greater part of the production is harvested. Additional land used for aquaculture here includes ponds and tidal flats. All year round supply of water from the canal systems and the smooth topography in this area are good conditions for intensive production. Generally, aquaculture occurs at a household scale all over the LMB, whereas it is commercial in the Vietnam delta (MRC, 2010) (though by

percent, in the LMB, household cultures are most common as well) (Hortle, 2007). The dominance of aquaculture in the delta is demonstrated in table 4, in terms of land under cultivation.

Table 4. Extension of different aquaculture practices in selected countries of the LMB. “N/A” signifies that figures are not available. Rural small scale practice may be underestimated to some extent. (Source : Phillips (2002)).

	Pond aquaculture (ha)	Cage aquaculture (ha)	Rice-fish aquaculture (ha)
Cambodia	315	14	N/A
Laos	5,150	N/A	1,896
Vietnam (delta)	51,264	39	79,750

Normally, fishes are bred in polycultures combining several indigenous and exotic species (MRC 2002). Among the most common fish species are: river catfish (*Pangasianodon hypophthalmus*), silver barb (*Barbodes gonionotus*), and common carp (*Cyprinus carpio*). In addition, there are also several species of prawn. 15 % of the land use in the delta is devoted to aquaculture, of which 75 % constitutes shrimp farming (Truong et al., 2008).

As stated, seafood aquaculture combined with rice is common but this is also valid for the combination of aquaculture and riverbank market gardening, where snails, shrimps, crabs and fish are bred.

Changes and possible damming impacts on agriculture

The agriculture is by the critics said to be negatively influenced by the changes in hydrology and the sediment load/delivery that upstream dams create (Roberts, 2001, Mastny, 2003, Adamson et al., 2009). A summarize of the articles, research and analyses that debates and proves whether this is true or not and if there really has been a change in the hydrology and/or sediment load/delivery is given below.

Possible impacts by damming

Changes in the hydrology

Dams in the UMB

Whether the main stream dams in China are changing the dry-season hydrology by reservoir storage has been a controversial topic. In 2004 The South East Asia Rivers Network (SEARIN⁴) urged the countries involved in the hydropower development to start surveillance and work according to the framework and recommendations of the World Commission on Dams (SEARIN, 2004). The underlying cause of this was their conclusion on the negative impact that dams bring along. The Manwan dam was said to be responsible for a 25 % decrease in the mean annual minimum amount of water flowing past the border to Laos as well as an overall reduction in the mean annual minimum discharge trend. Pornrattanaphan (2004) revealed that the annual mean of minimum discharge had decreased with 25 % (183 m³/second) comparing pre-dam and post-dam data series from Chiang Saen at the northernmost Thai-Lao border. This implies that there has been a lowering of downstream water volumes in general. The emergence in abnormally large rapid water flux was also attributed as a post-Manwan dam effect.

MRC presented in 2005 research that indicated no proof of a systematic alteration in the dry season flow in the lower basin (gauging stations were located at Kratie, Cambodia and Vientiane, Lao PDR). This report used data measurements of average daily minimum discharge on an annual 90 days-sequence from 1960 to 2004. Furthermore, Campbell (2007) showed that downstream the decreased flow pattern during the 2003-2004 drought had nothing to do with dam water trapping in China. Rather the rainfall scarcity in the lower basin was to blame since the low flows were more severe downstream than upstream, close to the dams. Another study confirmed that the overall influence of the Manwan dam on the Mekong mainstream in China was confined to the very adjacent downstream part of the river (Lu and Siew, 2006).

Propagators of the beneficial consequences with hydropower dams often promote the so called “multi-purpose aspect” (Roberts, 2001). First and foremost they provide electricity that can contribute to the country’s welfare either by own consumption or by exporting. Beneficial effects, thanks to the increased dry season flow, may also be less salt intrusion in the delta that

⁴ SEARIN is an NGO established by academics and activists that work to educate and support local communities affected environmentally and socially by large dams.

is favorable for rice cultivation and aquaculture (Kummu and Varis, 2007). Higher discharge during the dry season will also offer more water for irrigation. Another positive aspect that is broadcasted is the “flood and drought security” by managing water releases. Roberts (2001) confirmed that the Chinese hydropower dams really can offer flood and drought security. However, to lessen floods, conditions must be ideal and the discharge moderate/normal if it is going to work properly. The major drawback resides upon the fundamental fact that they in all cases primarily are built for storing water to generate electricity. Therefore the aim is always to keep the reservoir pretty full, and in order to save water to the dry season water is “stacked up” in the wet season. However when an unexpected big flood arrives the dam is too full and has to let it through. To be on the safe side, engineers often release some of the stored water as well. Hence this instead leads to an aggravation of the flood downstream.

Li and He (2008) identified three major issues that fuel the friction between two parties in this dam dispute. The first aspect concerns the lack of a well-structured quantitative data measurement that covers the whole catchment. Secondly, the collected data and information is discontinuous. Lastly, but of uttermost importance, they stress the absence of a well-developed transboundary dialogue among the countries in the lower basin and China in the upper basin.

To assist the lack of quantitative data, Li and He (2008) therefore undertook a comparative water level study of three Lancang Jiang mainstream sites. All of them exist at rocky reaches that are not affected by changes in the dam outflow. One (Jiuzhou) is situated upstream of the two dams constructed at the time of investigation, namely Manwan and Dachaoshan. The second one (Gajiu) is located in between these two dams and the third one (Yunjinghong) downstream. The study sites were compared at different time scales (wet period, dry period and the period between March and April, PBMA) regarding water level and the possible response to cascade development. The period between March and April was chosen owing to the fact that the lowest flows usually occur at that time, as stated in the “hydrology” section above.

They asserted a general idea of the trend in the water level to be influenced by climate variability, whereas the interdecadal and annual variations of the same are affected by human activities like dam building. Results on the mean annual water levels in the PBMA, wet and dry season showed a significantly increasing trend at upstream and downstream of the dams. According to their asserted idea, this change was attributed to climate change (for more info on this see below on “Other factors that could influence the change in hydrology and sediment load”). During the time that the two dams were constructed same results were found for the variations in interdecadal, interannual and wet season mean water levels. This implies no effect from anthropogenic activities such as dam building.

On the other hand, between and downstream of the dams the interdecadal annual mean show that the water level have been raised in the PBMA period, whereas upstream the water level has decreased. The authors concluded that the flow is to some extent dam regulated in the dry

season, referring to these trends. Still, in general the downstream appearances of the dam-induced alterations are relatively strong at hourly to daily timescales, but not at the scale of wet season and annual means.

According to Roberts (2001), the two enormous dams Xiaowan and Nuozhadu will be really hazardous to areas downstream if really big floods come along. The dams contain capacity of five years of floods and if a really big flood arrives, as much water as possible has got to be released quickly. If the dam would break, contrary to all expectations, not only years of stored water will rush downstream but also the really big flood. Even though the likeliness of this scenario is small, it would not happen without the dam.

With regard to droughts, these big dams could fuel coping difficulties for farmers downstream, as they take years to fill up (Roberts, 2001). Of the areas in the LMB, the Cambodian floodplains and the Mekong delta are two areas expected to be susceptible to droughts caused by regulated river flows. Anticipated driving forces are floods that don't reach down south, have enough volume, duration or extent.

The MD is shown to be affected by salinity intrusion during the dry season as a result of flow regulation by dams in the UMB (Hoa et al., 2007, Roberts, 2001, Syvitski et al., 2005). Though salt intrusion is a natural phenomenon in the delta the reduced wet season flows and their consequential flushing reduction may well aggravate the salinity in the paddy soils and pose implications to agriculture, according to Roberts (2001) and Adamson et al. (2009). But salt intrusion is also likely to be caused on floodplain soils upstream from the delta, which are not adapted and therefore will experience worse degradation from the salinization and alkalization. Prathumratana et al. (2008) exemplifies that it would lead to less farmable areas, crop and yield losses.

A numerical model was used to forecast the height and duration of the floods in the delta in connection with e.g. upstream flows and engineered structures (Hoa et al., 2007). The model combined statistical and numerical modeling and GIS. The result predicted, among other things, that dams upstream of the MD will shortly after their completion result in less flooding in the delta due to decreased river flood peaks. According to the model, the lower flood peaks will lead to a siltation, raising the channel bed by 2 m which will increase the amount of water flooding out on the plains of the delta. This process, when the downstream flowing river water is obstructed by the higher riverbed is called a back water effect and the flooding is caused by tidal pumping⁵. Thus Hoa et al. (2007), supported by Syvitski et al. (2005), concluded that in a matter of 30 years, the siltation of the Mekong Estuary due to upstream dams will boost greater floods.

Roberts (2001) asserted few benefits and severe negative impacts of the upstream hydropower scheme in Cambodia and Vietnam, inter alia on agriculture. One of the cultivation practices vulnerable is the flood recession rice paddies of the floodplain. As mentioned before, this

⁵ The basis for tidal pumping is amplification of the tidal current and associated turbulence through topographic effects. Tidal currents are periodic and move water onto and off the shelf in a regular way.

practice is highly dependent on the regular floods that provide silt, nutrients and nonetheless water. Riverbank truck gardening is also vulnerable to changes in the flow (Roberts, 2001). The regulatory flows of the dams will devastate or even eliminate this kind of farming since they may lessen the difference between high and low water levels. Just as flood recession rice it is dependent on the deposition of silt. The combined effects will probably result in harsh conditions and even elimination of this farming type with consequential negative impacts on the local household economy.

In 2008 the two existing dams could not be proven to have had a noticeable impact on the flood/wet season discharges (Hori, 2000, Podger et al., 2004). Adamson et al. (2009) claim that, up to now there is not sufficient evidence supporting that dams would alter the hydrology of neither the wet- nor the dry season flows. But they agree, along with many researchers, on the fact that the hydropower construction boom will eventually affect the river flows, changing the wet- and the dry season flows (Adamson et al., 2009, Podger et al., 2004).

Dams in the LMB

So far, few articles have been published regarding the impacts of the dams in the LMB. Many dams exist on the tributaries but the most of them are so small that they have not attracted any scientific research. But the biggest dam in the LMB, the Yali Falls dam in Vietnam with a Mekong tributary catchment shared with Cambodia, actually has undergone scientific scrutiny (Wyatt and Baird, 2007).

Negative consequences for the farmers emerged already in 1996, before the dam was built (Wyatt and Baird, 2007). The diversion dam that was constructed to facilitate the building of the main dam had caused infrequent flooding that destroyed crops. More was to come after the dam was completed, namely unusually large, rapid and erratic flood peaks during wet season that also caused crop losses. Impact studies partly blame the water regulation of the Yali Falls dam for this.

Particularly vulnerable to the water flow changes by the dam have shown to be riverbank agriculture, but rice fields has also been hit. The fluctuating water levels have caused erosion and scouring. Even in the dry season months abnormally high and rapid flows unrelated to potentially unusual rainfall have been reported which inhibits the practice and harvest. The unpredictable nature of water levels makes the usual and habitual sowing and harvesting patterns more or less of no use. Accordingly, tens of thousands villagers along the Sesan River in Vietnam and Cambodia has suffered from ruined agriculture (Middleton, 2011).

Changes in the sediment load/delivery

Upper basin

A lot of possible negative impacts has been discussed in the ongoing debate, some of them reasonable and well-founded and others not. Kummu and Varis (2007) states that the Lancang River dams definitely will result in some positive impacts, in addition to the ones mentioned in the section on “Changes in the hydrology” the navigability of the river is improved when

dams are constructed. The big dams would facilitate boat traffic where it was hazardous before by releasing water when too low (Hori, 2000). But this brings along negative consequences for the agricultural land downstream (Roberts, 2001). Water quality would deteriorate due to the pollution from heavy shipping affecting the crops and aquatic organisms negatively. The planned channelization for the sake of better navigability (even though it is not a direct cause of the dams) would also lead to severe consequences for farmers. It will increase water speeds and hence decrease the erosion resistance of river banks. In this way, main stream runoffs will get faster both during dry and wet season and may thereby cause worse floods and droughts, respectively. As a result, the agriculturally productive seasons gets shorter.

A definite weakness of the sediment load data involves the measurement consistency (Campbell, 2009). One of the cases concerns the upper Chinese catchment area. Though data was collected on a continuous basis from the mid-sixties until the late eighties, after 1990 the measurements stopped. The existing data (from the Jinghong station) from the time period until 1990 points at a clear trend (statistically significant with $P < 0.01$) of increasing yearly sediment loads, from 60 Mt to 115 Mt. At the same time the annual runoff show a very weak (not statistically sign.) dipping trend. These phenomenons have been attributed to the rapid population expansion during the eighties and the land cover change and water abstraction that it brought about (You, 1999).

In 2006 a report claimed that China's soil conservation policies on reducing erosion and sediment discharge had decreased the annual yield since the year 2000 (Fu et al., 2008). However this was firmly questioned by Campbell (2009) since no analysis can be made without any proper sediment load data. Furthermore, the opposition meant that the dam development after 1990 could be responsible for the decrease.

Even though the two first dams constructed, Manwan and Daochaosan, are small in comparison to others in the world estimations point toward considerable amounts trapped sediments (Kummu and Varis, 2007). These estimations were based on surveys carried out by the Chinese authorities and showed that the reservoirs are trapping around 80 Mt sediment/year (Campbell, 2009). This is a relatively big amount that most probably will have a lowering effect on the sediment load of the Lancang Jiang River. But as mentioned further data on sediment loads downstream of these dams is not available and thus preclude detailed investigations.

Despite this fact one could look for indications of reductions downstream, which Fu et al. (2008) did. This was done at 401(Jinghong) and 746 km (Chiang Saen) south of the Manwan and Daochaosan dams. This study demonstrates evidence of a significant reduction in suspended sediment concentrations (SSC) as from the construction of the Manwan and later on, the Daochaosan. It is hard to say if the low yields of 2003 (since water flows were lower, so was the SSL) are due to this, they are more likely to be caused by the lower annual water runoff. Nevertheless the plot (figure 6) displays a clear dipping trend from the late eighties until 2003, with an approximate mean concentration decrease of 50 %.

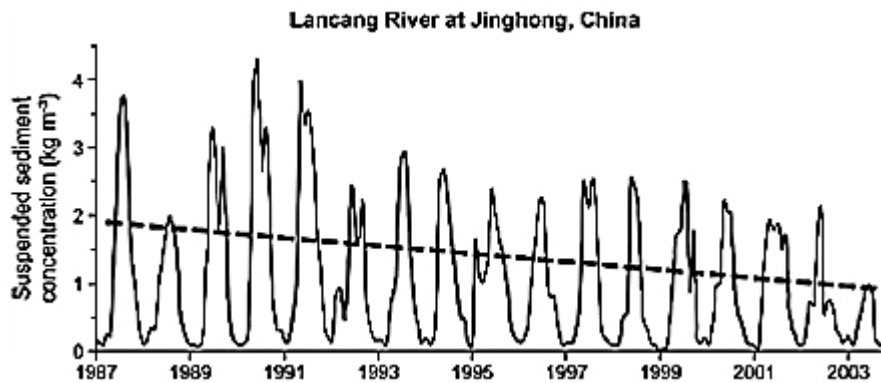


Figure 6. Graph showing fluctuations and trend in suspended sediment concentration at Jighong, Lancang Jiang River in China. Adapted from Walling (2009).

This impact is expected to be even more significant with proceeding construction of new dams (Campbell, 2009). Solely the fact that the future dams are bigger and hence trap more sediment will contribute to lower the annual rates. Besides this, a bigger part of the Lancang Jiang basin will be blocked as the new dams are planned throughout the whole area. This makes it even harder for the suspended sediment to flow on to the southern countries. By 2008 the Manwan will fill up and not trap sediment anymore, according to a study (Guo et al., 2007). So is the case for the Daochaosan dam in about 30 years but this will most probably not happen since the Xiaowan dam, completed upstream in 2010, is much bigger. The Xiaowan dam will in other words prolong the filling up of the dams downstream. The same research presents a lot of expected percental losses. Among these, the most interesting and exceptional is the prediction of a 95 % eventual reduction of the natural sediment input to the Mekong River.

In 2002, the International Rivers Network assessed that the Xiaowan dam will eventually trap 35 % of the SSL that is essential for nourishing the downstream floodplain agriculture (IRN, 2002). More alarmingly, the study by Kummu and Varis (2007) presented values ascribing the Lancang dams to trap 94 % of the SSL transported from the upper basin. The effects of more bed and bank erosion will be felt all the way down to Pakse in Cambodia. Kondolf (1997) explains that the dams release high energy water “hungry” for sediment which will cause erosion and scouring.

Lower basin

Proof of influence from the increasing population on the sediment load in the 1980s is not as apparent in the lower basin, i.e. the ascendant trend is not that strong (Walling, 2009). As for the upper basin the availability of reliable data is restricting further analysis.

From the construction of the Chinese dams in the early nineties and further on the interest on examining changes in sediment concentration has arisen. Both Saito et al. (2007) as well as Kummu and Varis (2007) agree upon the fact that there has been a major reduction. For instance, the Manwan dam is said to have decreased the annual sediment load at Pakse, Cambodia and Luang Prabang, Laos (both from ca 133 to 106 Mt per year). However the low

sediment load of 2003 cannot be linked to the construction and commissioning of the Manwan dam, but to the particularly low water runoff this year.

As touched upon, in the upper basin there are problems with lacking data as from 1990. In contrast the lower basin lacks consistent data series from the previous decades. At one of the common gauging stations in Pakse this is the case, where data between 1963 and 1998 is absent. Criticism against the presented values in the section above has been raised since they are based on data collected for water quality by the MRC. The reason behind this is that Campbell (2009) consider the measurement to be unreliable because of the shallow sampling depth (0.3). According to Campbell (2009), the samplings should have been made at greater depth since concentrations are known to be higher here. Therefore the data that Saito et al. (2007) and Kummur and Varis (2007) used could be based on underestimations of the actual mean sediment concentration.

In the study by Fu et al. (2008), the SSC at Chiang Saen was estimated to dip quite fast from 1987 until 1996 when it increased again, see the plot in figure 7. The possibility of misleading data due to the time series which originated from the MRC water quality survey was noted by the authors, in the same way as Campbell (2009) did. Their suspicion can be true since Lu and Siew (2006) got statistically significant results demonstrating a decrease in sediment flux at Chiang Saen, possibly related to Manwan dam sedimentation.

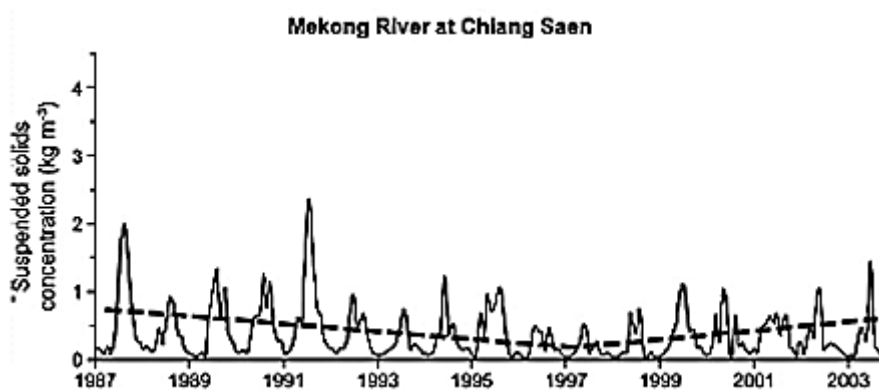


Figure 7. Graph showing fluctuations and trend in suspended sediment concentration at Chiang Saen, Mekong River in Thailand. Adapted from Walling (2009).

According to MRC's (2010) State of the Basin report, there was a major reduction in sediment concentration post 1993 due to the completion of the Manwan dam. But Campbell (2009) refer to the plot in the report by Fu et al. (figure 6) where there is no sign of a rapid decrease in 1993. On the contrary, it is claimed that the Mekong River has experienced a relative stable yearly sediment load since the 1960s. Employing data from four common gauging stations⁶, sediment loads were compared between data from 1961 and a recent year. Recognizing the interannual variability of water discharge, the recent year with the most similar discharge to 1961 was chosen for comparison at each of the stations. The results

⁶ Chiang Saen (Thailand), Luang Prabang (Cambodia), Mukdahan (Thailand) and Pakse (Laos).

showed that there was a 30-40 % increase at the two Thai stations which are both bordering Laos.

These results are explained to be the effect of increased land clearance and intensification on the tributaries of the Lao Mekong River (Campbell 2009). On the other hand, at the other two stations, in Pakse and Luang Prabang, sediment concentrations have remained practically the same. The balancing effect between major land use change and intensification in the eighties, which increase sediment yields, and the dam development in the nineties that reduces these yields could explain the relatively unchanged results.

Lu and Siew (2006) proved in their report that sediment flux has declined in the LMB, causing a number of implications. Completion of the Lancang Jiang would exacerbate these conditions and lead to deprivation supply of nutrient-rich sediments and lowered productivity (Campbell, 2007, Lu and Siew, 2006, Saito et al., 2007). The blocking of sediments and the disrupted flooding pattern makes the timing of crop planting harder for the farmers (Mastny, 2003).

A paper concentrating on the Mekong delta in Vietnam reveals that the basin has a “buffering capacity” to changes (Ta et al., 2002). The paper demonstrates the small change in sediment input to delta throughout the past 3,000 years. Campbell (2009) still recognize that the cascade of more and bigger dams in the upper basin, and also in the lower, are very likely to cause great reductions of the sediment load. Syvitski et al. (2005) claim that coastal wave-caused erosion in the delta will increase and affect the agriculture. This is because of the reduced floods in the wet season that deposit the suspended sediment in the delta channels rather than carrying it out to the coast. Thus the protection of the coastline against erosion will be reduced. This poses a threat to the long term stability of the delta (Saito et al., 2007, Campbell, 2007). Agriculture in the upper MD is predicted to be stricken by higher soil concentrations of acid sulfates in the topsoil. These are usually flushed away by the floods, but if they decrease in size the acid sulfates accumulated in the dry season will remain in the soil and hinder farming.

That aquaculture should be affected can be read in some studies (Li and He, 2008). But specific studies on how this kind of agriculture could not be found. However, the agricultural impacts may also affect aquaculture, especially the influence of reduced nutrient-rich SSL and increased pollution from boat traffic since the water is used to fill the fish reservoirs (Roberts, 2001).

Other factors that could influence the change in hydrology and sediment load

The results from the analyses of possible changes in the sections above sometimes ascribe increasing population etc. for observed alterations in hydrology and sediment delivery. This aspect and others are thus also considerable. The following paragraphs will therefore summarize the other possible anthropogenic influences, apart from dams.

Anthropogenic climate change

The potential influence of the anthropogenic climate change on the hydrology is likely to be demonstrated by two different factors: i) the retreating ice sheets in the Tibetan Plateau, the origin of the Mekong River and ii) changes in the monsoon affecting the left-bank tropical tributaries in Laos (Adamson et al., 2009).

At present, some 95 % of the glaciers throughout the world are decreasing because of global warming (Adamson et al., 2009). The rate is gradually increasing due to the feedback effect that emerge as the temperature increase causes ice to melt, exposing the bare ground which will enhance the warming even more. The Tibetan Plateau in the Himalayas is no exception, Adamson et al. (2009) stress the particular vulnerability to human induced climate change of this region. Large climate change impacts on Himalayan glaciers occur at the seasonal scale according to Singh and Bengtsson (2004). Thus the change in water availability will be most obvious during the dry season. This would cause adverse effects on the agriculture since this is the time of year when water is most needed. The water flows of the dry season is probably more likely to be stricken more severely owing to the fact that the low flows are to a greater extent dependent on the glacial meltwater (Adamson et al., 2009, Challinor et al., 2006). Like the section on hydrology above explains, during the dry season 75 % and 40 % of the flow at Vientiane and Kratie is received from the glacial meltwater.

The climate of the Indochinese peninsula is highly governed by the monsoon (MRC, 2010). The pattern and intensity of the southwest monsoon is depending on the temperature difference between land and ocean. The Tibetan plateau plays a major part in this pattern and intensity both thermally and mechanically (by orographic heaving etc.). Melting snow and retreating ice may therefore unsettle the south western monsoon and bring about changes in the starting dates of the monsoon and intensified rains (Wu and Zhang, 1998). Yet, Kripalani and Kulkarni (2001), supported by Adamson et al. (2009), are of the opinion that “there appears to be no systematic climate change”. They refer to their examination of seasonal rainfall data using time series covering the summer monsoon months, June to September, from 1881 to 1998. But they (Kripalani and Kulkarni) agree with other authors on the probability of a future intensification of the southwestern monsoon due to climate change, causing up to 14 % more rainfall, more intense floods and tropical storms as well as varying starting dates (Turner et al., 2007, Adamson et al., 2009, Wu and Zhang, 1998). This would make it more complicated to distinguish the impacts of dams and climate change.

Numerical modeling carried out by Hoa et al. (2007) resulted in a predicted increase of flooding in the Mekong River delta as an effect of increased sea levels, induced by anthropogenic global warming.

Land use change

Hydrology and sediment load are vulnerable to human activities that convert one type of land use into another (Walling, 2009). One of the most deteriorating land use changes is, and have since the early sixties been, clearance of forest in favor of e.g. agricultural land. The impact on hydrology caused by this kind of activity can be divided into two categories (Adamson et

al., 2009). Firstly, the evapotranspiration decreases and thereby increases the total water runoff. Secondly, as a result of the lower water holding capacity of the cleared land the runoff will decrease during dry season and increase during wet season (MRC, 2005, Adamson et al., 2009). Thus the seasonal hydrology pattern will be modified.

Still, there are no explicit proofs of such an effect on the hydrology of the river basin. Adamson et al. (2009) presents data that expresses the complicatedness when it comes to separating any trend caused by land use change from the normal flow fluctuations. The common opinion of affected people is though that the ever escalating rate of deforestation is to blame for the high occurrence and severity of recent flash floods. Interestingly, comparing flash floods from 1970 to 2003, the results show that 67 % of them occurred in the nineties and further on (MRC, 2008). A report from 2006 questions this common opinion and states that there are scant indications of any obvious changes in the hydrological pattern (Adamson, 2006). Between 1960 and 2004 Adamson (2006) concluded that there is no statistically significant shift in the average size of flow.

Land deforestation and other deteriorating land use changes will affect sediment load and delivery too (Walling, 2009). These activities expose bare ground without any protecting vegetation cover or root system. Consequently water runoffs will cause more erosion that increases the SSL of the river.

Irrigation

Adamson et al. (2009) divides the human impacts on hydrology by direct and indirect impacts. The main, and basically the only one of certain importance, direct impact is irrigation. Agriculture is naturally the greatest purpose, to which most of the water is acquired during dry season. The current needs for maintaining agricultural productivity has been calculated by simulating a flow period of 20 years (1980-99) (Haddeland et al., 2006). The simulation showed that 13.4 km³ is needed for irrigation each year implying 2.3 % of the basin outflow of water to sea. Actual water use was estimated to cause a 2.1 % decrease of the streamflow. This decrease is however small in comparison to other great rivers such as the Colorado river where 37 % of the water is consumed by agriculture. Still, it should be clear that most of the water extraction for irrigation occurs during the dry season when the river flow is lower which will cause a more noticeable effect. MRC (2010) provides data from Pnom Penh (Cambodia) on river water abstraction that unravels 60 %, 45 % and 40 % reductions of flow in February, March and April respectively.

According to Podger et al. (2004) the construction of dams will contribute to raise the dry-season flows thanks to the managed water releases and thereby reduce the impact of water diversion for irrigation purposes.

Summary and Discussion

The common and apparent conclusion among most researchers is that the hydrology has not yet been significantly altered by the influence of the Chinese dams. A lot of authors present and stress the potential effects that the dams will cause on the hydrology and in turn floodplain agriculture. But the greater part of the research carried out indicate that these changes in water flow has not yet occurred and thereby the impact on agriculture cannot be determined.

As one of the world greatest catchments with massive runoffs each year it is difficult to estimate relatively small changes in the Mekong River hydrology. Taking into account the interdecadal fluctuations in discharge and the lack of continuous data and research an evaluation gets complicated.

Research carried out in the delta showed more proof of an impact on agriculture. More extreme saline intrusion was attributed to the UMB dam regulations. Hence there is actually evidence of a decreased low flows. Modeling also predicted that the delta will suffer from increased future flooding. However the recent low flows during the dry years in 2003-2004 that caused a lot of anxiousness among the downstream farmers can probably not be attributed to the Chinese dams. At least not exclusively, as mentioned there are a number of other factors that influence the hydrology. The likely explanation is that climate change, all the human activities including reservoir construction and water regulation is responsible. Thus, dams in the UMB could not yet be determined to impact the agriculture in the LMB upstream of the delta.

Most of the summarized articles and reports of this thesis concern mainstream dams which mean that these dams will bring along the worst implications for agriculture. In summary it is agreed upon the fact that if the dams planned (mainly on the mainstream) are realized throughout the basin, water flow will change in wet and dry season. This will cause hardship for the downstream agriculture, especially at subsistence scale, that highly depends on the regularity of these flows. Not least the dams will be largest here (on the main stream) and block/store much greater amounts of sediment and water.

Regarding the sediment load transported downstream, inconsistent measurements preclude the analysis to some extent. For some reason the Chinese collection of sediment data suddenly stopped after 1990 in Lancang Jiang. Even so, studies carried out by independent scientists show a clear dipping trend in suspended SSCs downstream of the Manwan and Daochaosan dams. As far downstream as Chiang Saen no change could be detected though it can be possible that land use changes and other activities may mask the changes. Though, models foresee that the future much bigger dams will trap even more sediment and hence deprive the farming land from nutritious sediment. Evidence of drops in sediment concentrations in the LMB is not that strong. Moreover there is a scarcity of available and reliable data. But with

the construction of the LMB mainstream dams this impact will be even more significant for floodplain and delta cultivation.

Overall, the three cultivation practices (rice, riverbank farming and aquaculture) thought to be affected by dams are most probably going to be influenced to some extent. Aquaculture is the one of them for which least research has been done concerning dam consequences. But since water is used for all practices, a decline in quality and nutrition as well as increased flooding and erosion will in all probability disturb aquaculture as well.

This raises the demand (at least in the author's opinion) for thorough and continuous research not only on changes in sediment yield, hydrology etc. but with more focus on the actual consequences for agriculture. Many reports have predicted the "agricultural scenario" but it is of uttermost importance that proof or disproof is set out before it could be too late. As a matter of fact, studies from other catchments in the world have already proven the impacts of dams on agriculture. For example on the Sokoto River in Nigeria the Bakolori Dam, completed in 1978, had adverse impacts on agriculture (Adams, 1993). The agriculture on the floodplains downstream was impacted by e.g. reduced and delayed floods.

Another agricultural impact that occurs immediately upstream of a constructed reservoir is the inundation of farmable land. Since the thesis brings up consequences for farmers living downstream of dams this impact is not included. But eventually, when big dams are completed in the LMB lowland agriculture areas will be inundated and the farmers will have to resettle.

Although not touched upon, it is quite evident that ground water tapping may be an opportunity when river water supply is unreliable. This may be useful during the dry season when the low flows might become even more unpredictable because of dam regulations. Roberts (2001) however mean that attempts risk several problems. It may lead to alkalinization, salinization and arsenic contaminated groundwater (which happened in Bangladesh). In summary all these issues will acquire large costs, overshadowing the benefits of tapping.

The positive impacts that dams bring also involve potential drawbacks as stated in the text. Regulating the dam releases always involves a compromise between need for hydropower, navigability and agriculture (and also irrigation to some extent but the focal dams in this thesis are mostly hydroelectric). The location of the present mainstream dams, in China, will put the Chinese in charge of all the downstream flowing water. Since the predominant purpose of the dams was to generate hydropower, it will always remain most important. Navigability is also likely to be of high interest for the Chinese commercial sector that has lobbied for a navigable river all the way up to China, so that export and import is facilitated. In this way the agriculture in the LMB has to face the fact of being neglected in favor of economic interests in the UMB.

For this reason, China's absence among the MRC member countries is the main drawback for the mainstream countries. Of concern is also that the realization of many planned LMB dams

is aided by Chinese funders that most probably will expect eventual economic benefit. This might not prioritize the needs of the downstream locals. Still, the economic growth in the especially Laos and Cambodia is needed in order to alleviate poverty. Furthermore, hydropower is also one of the “clean energy sources” that do not emit carbon dioxide when it is running (even though transport, construction etc. does) and therefore a better option.

The dialogue between upper and lower Mekong countries is the way to go. Lately China has participated at MRC conventions and this may indicate future understandings and agreements. The hydropower potential is high in the MRB and will bring welfare but it cannot occur at the potential expense of lowland agriculture. A dialogue among the parties could hopefully result in sustainable dam plans that will consider both the requirements of lowland cultivation and the national economic growth.

Part of the initial aim was to find out if the dams have had an obvious impact on the agricultural production. However, this turned out to be difficult facing the fact that there is not much reliable data on this, at least not to be found in public documents. Intentions to calculate or estimate these quantitative changes must take into account that the production is steadily increasing and gaining more land for farming. Problems on distinguishing the newly adopted land from the old may therefore emerge. Additionally, the agricultural practices are getting more intensified. Even though some agricultural land could have been degraded due to upstream dams, an intensified and more effective crop technique on the land that still exists could produce higher yields than the time before the degradation. An interpreter without specific local information and knowledge could hence be deceived to think that the dams have not impacted the yield. Bearing these implications in mind, to try to estimate a possible change would be too time consuming for a thesis of this extent. Still, it could be interesting to include in a further study.

Conclusions

A continued development of dam construction will affect the hydrology and nutrient-rich sediment transport at an increasing rate, especially due to the numerous dams planned downstream. Floodplain and delta agriculture will in turn be negatively influenced, most severe are the possible reductions of low flow. The poor subsistence farmers will be the most unfortunate in these matters. Among the dams, the future main stream dams are of greatest concern. It is however hard to distinguish any evidence so far due to the interdecadal variation of the river water flow and hydrology and the scarcity of good quality data. Decrease in sediment yield is though more precise. In addition, the vastness of the river basin and the fact that most dams were constructed quite recently contribute to the difficulty of distinguishing any negative influences. Nevertheless, it is important that further surveillance is carried out on a regular basis in order to deduce possible changes in the trend.

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