

Exploring Tonle Sap Futures

Baseline results from hydrological and livelihood analyses

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*This is a report of on-going research under the 'Exploring Tonle Sap Futures' study, and presents the status of the research as of December 2011: for updated information, please contact the authors.
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SYNTHESIS: CHANGING TONLE SAP

The Tonle Sap Lake Area forms a critically important economic, social and environmental resource for the entire Cambodia. Over 1.7 million people live in the lake and its floodplains¹, while up to half of Cambodia's population is estimated to benefit directly or indirectly from the lake's resources both in terms of livelihoods and food security. Population in the area is, however, growing, and **the Tonle Sap is –similarly to entire Cambodia– seeing exceptionally large age groups of young people (born in the 1990s) entering into the work force.** Given the dominance of agriculture and the already heavy pressure on the area's natural resources, the Tonle Sap's future depends very much on what kinds of livelihood sources these young people will, and are able to, move to.

At the same time, the livelihood structure of the Tonle Sap area is diversifying, with increasing amount of people transferring from traditional, agriculture-based livelihoods to more modern sources of income, and the provincial capitals –Siem Reap and Phnom Penh in particular– attracting more and more migrants from the rural areas. **The Tonle Sap area is, however, developing unevenly,** and great differences are visible both between different provinces as well as between urban and rural areas. Worryingly, the disparities between the rural and urban areas are increasing in many fronts (e.g. education), suggesting possibility for social and political tensions.

Also the ecology and natural resources of the area is likely to change in the future, as the lake-floodplain system is predicted to feel increasing negative impacts due to human interactions, in particular through intensive hydropower development in the upper parts of the Mekong River Basin. In fact, the **Tonle Sap Lake area can be considered as the most vulnerable area to the changes caused by the current hydropower development plans in the Mekong**². At the same time, the climate change is estimated to cause new kinds of changes to the lake-floodplain system. Consequently, the area's future includes many uncertainties, and will depend on both external driving forces –including changes in the Tonle Sap's hydrology and related impacts to fisheries and agriculture– as well as on internal changes in the socio-economic setting of the area.

This report presents the first tentative findings from the two research components (hydrology and livelihoods) of the 'Exploring Tonle Sap Futures' study. Before heading to the actual report, however, this synthesis aims to provide a general introduction to the area in terms of its hydrology, main natural resources and livelihoods.

¹ The Tonle Sap area is in this study defined to be the area between National Roads 5 and 6, including a 3-kilometer buffer beyond the roads (to include households on both sides of the road). The area doesn't include the Tonle Sap River, as the area is separated from the river with a line located east from Kampong Chhnang and Kampong Thom (see Figure 14).

² See e.g. Hall & Bouapao (2010), who in their study done for the MRC conclude that people living in Cambodia / Tonle Sap are (out of the four Lower Mekong countries) the most vulnerable in terms of baseline vulnerability, exceptionally deeply dependent on fish, and have very low resilience to major environmental (and other) changes.

Unique hydrology

The Tonle Sap Lake is known for its extraordinary flood pulse system, which is closely connected to –and dominated by– the Mekong River³. The lake is connected to the Mekong through 120 km long Tonle Sap River, with the two rivers meeting in the Cambodian capital Phnom Penh. During the southwest monsoon, the water level in the Mekong River rises faster than that in the lake, and as a result part of the floodwaters runs to the Tonle Sap River. This causes the entire river to reverse its flow back towards the Tonle Sap Lake, which is a hydrological phenomenon unique for the river of this size even globally.

As a result, the Tonle Sap Lake loses its only outlet, and the flood waters extend to large floodplain areas surrounding the lake: the average surface area of the lake rises from around 3'000 km² during the dry season to a maximum of up to 14'500 km² (MRC 2005; MRCS/WUP-FIN 2007a). The variation of the lake's water level is equally stunning, ranging from less than two metres during the dry season to over 10 metres during the wet season (MRC 2005; MRCS/WUP-FIN 2007a).

The Mekong floods don't affect only the water quantity in the Tonle Sap Lake, but have an enormous (positive) impact to water quality as well. For the suspended sediment flux from the Mekong to the Tonle Sap is massive⁴, and provides a major nutrient boost for the lake-floodplain system, including both fisheries and agriculture.

The Tonle Sap is thus a very exceptional lake, as the impacts of any environmental change – whether due to climate change, hydropower development or other drivers– are felt as a combination of changes in its own basin and that of the Mekong River. The actual 'impact basin' of the Tonle Sap Lake is thus not merely the lake basin (86'000 km²), but the entire Mekong River Basin upstream from the Tonle Sap (680'000 km²). This, naturally, makes the assessment of potential impacts to the area a particular challenge, and also makes the management of the lake area very much a regional issue as well (Keskinen et al. 2010). Several different impact assessments have been carried out in the region to estimate the predicted hydrological changes (Annex A), but several uncertainties still remain.

³ Out of the total average inflow to the Tonle Sap Lake (79.0 km³), more than half (57%) originates from the Mekong River either as inflow through the Tonle Sap River (52%) or as overland flow (5%), with the share of the Tonle Sap's own tributaries being around 30% and that of precipitation some 13% (MRCS/WUP-FIN 2007).

⁴ The average annual suspended sediment flux into the Tonle Sap system from the Mekong is around 5.1 million tonnes/year, with the lake's tributaries contributing an additional 2.0 million tonnes/year. As the annual outflow of the sediments from the lake back to Mekong is around 1.4 million tonnes/year, around 80% of the sediment the Tonle Sap system receives from the Mekong River and tributaries –meaning stunning 5.7 million tonnes per year– is stored in the lake and its floodplain (MRC/IKMP 2010).

Flood pulse under threat: what happens to fish production and agriculture?

The flood pulse⁵ is a major driving force for the productivity of Tonle Sap ecosystem, including the immense fish production of the lake system (Kummu et al. 2006, MRCS/WUP-FIN 2007, Lamberts 2008, MRC/IKMP 2010). In addition, the suspended solids flux from the Mekong to the Tonle Sap provides an important nutrient boost –particularly phosphorus⁶– for the agricultural fields located in the Tonle Sap floodplains (MRC/IKMP 2010).

The Tonle Sap flood pulse can thus be seen to have two interlinked characters: quantitative (water levels, including the timing and duration of the different phases of flood pulse), and qualitative (water quality, including the suspended solids flux). While the characteristics of the flood pulse differ between the years, the seasonal variation of the Tonle Sap's water volume and level is generally rather regular (Lamberts 2006, MRCS/WUP-FIN 2007, MRC/IKMP 2010).

The worrying news is that the planned hydropower dams and other development in the Mekong River Basin (both mainstream and tributaries) are estimated to cause dramatic changes to the flood pulse, and consequently to both fisheries and agriculture in the Tonle Sap. According to MRC/IKMP (2010), the current hydropower plans alone would result in 50% or more decrease in the Tonle Sap primary productivity in large areas of the lake proper and in the floodplains. Such a change would naturally have a significant impact on the Tonle Sap fisheries as well. In addition, the dams would also result in sediment trapping that is estimated to decrease the amount of bioavailable phosphorus input to the Cambodian floodplains and Delta by 10'000-18'000 tonnes per year, thus having a negative effect also on agricultural production.

The critical role of Tonle Sap fisheries

Thanks to the flood pulse system, the Tonle Sap's fish production has been significant already for centuries, creating the foundation for local livelihoods and food security. While the share of fishing as the main occupation is rather small (4.5% of workforce in Tonle Sap area, meaning around 40'000 people), fishing forms also critical secondary and tertiary activity and plenty of people get their livelihood from fishing-related industries. The fish also forms a critical component of the national food security, as up to 80% of all animal protein consumption in Cambodia comes from fish and other aquatic animals (Hortle 2007). This is a proportion that is considerably higher than in most countries of the world, making Cambodia particularly dependent on its fisheries.

⁵ Ecosystems that experience fluctuations between terrestrial and aquatic states, such as the Tonle Sap ecosystem, are called pulsing ecosystems, and hydrology of such systems can be described with term 'flood pulse' (Kummu et al. 2006). Organisms of the two phases exchange energy and nutrients: the terrestrial organisms use the stranded aquatic material and the nutrients released by the aquatic organisms during decomposition (Kummu et al. 2006). Likewise, energy and nutrients become accessible for the aquatic organisms when terrestrial habitats are flooded and large amounts of inorganic and organic matter of the terrestrial phase are transferred into the water body (Lamberts 2008, MRC/IKMP 2010).

⁶ The water samples taken by MRC/IKMP (2010) indicate that the Mekong's flood waters entering the Tonle Sap system have rather constant level of bioavailable phosphorus in the bound to the sediment particles, with values varying between 31 - 42% of the total phosphorus. The sediment particles are thus carrying an important part of biologically available phosphorus to the Tonle Sap, in addition to the orthophosphate dissolved in the water.

In addition to crucial nutritional value, fish is socially and economically very important (Van Zalinge et al. 2000; Baran 2005; EIC 2007). Establishing the total economic value of fish catches is difficult due to lack of reliable, long-term data⁷, and the exclusion of the subsistence fish catch from the monetary estimates is likely to lead underestimations (Van Zalinge et al. 2000). Nevertheless, the value of Cambodia's annual inland fish production (290'000-430'000 tons) at a landing site has been estimated to be between US\$150 and US\$200 million per year (Van Zalinge et al. 2000). This value is estimated to increase in the processing and marketing chain to somewhere between US\$250 to US\$600 million (Van Zalienge et al. 2000; EIC 2007). In comparison, the total monetary gross value of paddy rice in Cambodia has been estimated to be between US\$500-600 million (EIC 2007).

Due to large amount of migratory fish species, the Tonle Sap system is crucial also for the fisheries of the entire Mekong River system. The Mekong's fisheries is probably the most abundant freshwater fisheries in the world, with hundreds of fish species and approximately 2.6 million tonnes harvested annually from the Lower Mekong Basin alone (Poulsen et al. 2002; Sverdrup-Jensen 2002; Coates et al. 2003; Hortle 2007, MRC 2010b). The economic value of the Mekong fisheries is equally remarkable, with the current estimates of the first-sale value being around US\$ 2-3 billion per year (Dugan 2008).

Socio-economic setting: exceptionally large age groups entering the work force

There are currently (as of March 2008) around 1.7 million people living in the 1'555 villages of the Tonle Sap area (see definition above). The average population growth from 1998 and 2008 was 14%, but the differences within the area were also remarkable, with the fastest population growth occurring in urban areas and particularly in Siem Reap.

In terms of age structure, the biggest age groups in the Tonle Sap –similarly to entire Cambodia– are the 10-14 years old (214'400 people) and 15-19 years old (217'800 people), which are clearly bigger than any other age groups. Consequently, within next 5-10 years the Tonle Sap area will see a large amount of young people entering the work force. The Tonle Sap area and Cambodia thus see a possibility for the so-called demographic dividend, where a rising proportion of working age people leads to increased economic growth (Ross 2004, Keskinen 2008). This requires, however, right kind of context that provides meaningful sources of employment: otherwise the increase in workforce can also lead to accelerating environmental and social problems when more people try to rely on same natural resources.

A great majority of the people (~90%) in the Tonle Sap area live in the verges of the floodplain close to the National Roads 5 and 6. In general, people living closer to the National Roads are in many ways in a better situation than the ones living closest to the Tonle Sap Lake. The people

⁷ Indeed, it is important to note that due to the lack of reliable, long-term data, the estimates on fish and fisheries in the Mekong Region remain sketchy, and the reliability of fisheries statistics can be questioned in many areas, including the Tonle Sap Lake (Lamberts 2006). The role of fisheries in supporting the economy and the livelihoods has also been frequently downplayed in the national and regional development plans, particularly in those related to hydropower development (Friend et al. 2009).

living close to the lake (or in the lake in the floating villages) are generally poorer, less educated, have fewer livelihood options, do not own agricultural land and depend strongly on common property resources such as water bodies and flooded forests for their livelihood (Keskinen 2003, 2006; Nuorteva 2009; Annex D). Also ethnic issues are important, as many of the floating villages are inhabited by ethnic Vietnamese whose status remains unclear.

Urban areas act clearly as the 'engines of change' in the area, with Siem Reap playing a particularly important role in that. Urban areas attract both seasonal and permanent migrants, and the livelihood sources in urban areas are clearly more diverse –and much less dependent on natural resources– than in rural areas. Also the education level is better in urban than rural areas, and this difference seems just to be increasing: the education level has between 1998 and 2008 increased more rapidly in urban than rural areas, with the education level in some rural areas (particularly close to the lake) even getting worse.

Livelihoods: close connection to the lake-floodplain system

The livelihood setting of the Tonle Sap area is as exceptional as its flood pulsing system. While people living in the lake and its floodplains have adapted to the huge seasonal variation of lake's water level, they are also deeply dependent on the resources that lake and its floodplains provide, including agricultural products as well as fish and other aquatic animals and plants (Evans et al 2004; Keskinen 2006; Chhun 2010; Hall & Bouapao 2010; MRC 2010b). Consequently, the Tonle Sap flood pulse can be seen as a major driving force for the area's livelihoods as well.

In terms of main livelihood source, there are clear differences between the different areas in the lake-floodplain. Fishing forms the main source of livelihood in the areas closest to the lake, and the area is thus called 'Fishing Zone' in this study (Figure 15). Rice cultivation and other agricultural activities form, however, by far the most important source of livelihood in other rural areas, and the area is thus called 'Agricultural Zone'. Secondary occupations –including fishing– form an important supplement for the main occupations, particularly during the seasons when the involvement in the main occupation is less intensive. In urban areas (in essence the six provincial capitals and few bigger district towns, which are called 'Urban Zone') the livelihood sources are much more diverse, and their dependency on natural resources and the Tonle Sap is much less.

While agriculture remains clearly as the area's main livelihood source (61% of the total work force in 2008, compared to 66% in 1998), there are signs for increasing livelihood diversification. According to the Population Census 2008, the six biggest livelihood sectors⁸ in Tonle Sap in 2008 were agriculture (61%), wholesale and retail trade (11.5%), fishing (4.5%), construction (3.7%), transport, storage & communication (3.5%) and manufacturing (3.4%). Most rapidly growing livelihood sector in the Tonle Sap was construction, which increased from 1% in 1998 to 4% in 2008: this resembles the national trend, although bit more slowly. Other increasing (although still

⁸ In Census, these are referred to as 'Industry sectors', but in reality they represent livelihood sources in general.

minor) livelihood sectors include other service activities, hotels and restaurants, and real estate, renting and business activities.

It should be noted, however, that the three livelihood zones used in this study differ greatly in terms of the amount of people: a great majority of the people (~1 million) lives in 1'158 villages of Agricultural Zone, while around third of the people (~600'000) lives in 311 villages of Urban Zone. This makes Fishing Zone clearly the smallest, with some 5% (~85'000) of the total amount of the people living in the Tonle Sap area.

Uncertain future: what drives the change in Tonle Sap?

The future of the Tonle Sap depends from both environmental and socio-economic changes. Environmentally, critical will be the estimated changes (largely due to external impacts from Mekong hydropower development) in the flood pulse that drives the high fisheries productivity – and thanks to huge sediment flux also enhances agricultural output– of the lake-floodplain system. At the same time there are also several livelihood-related factors that are crucial for the future development of the Tonle Sap, most of them being very much internal and therefore also partly dependent on the policies on how the area is being managed and developed.

Due to its unique flood pulse system, immense aquatic production and people's strong dependence on water-related natural resources, the Tonle Sap is most likely the most vulnerable area to major changes in water quantity and quality of the Mekong River (see e.g. Kummu & Sarkkula 2008; Lamberts 2008, MRC 2010b, MRC/IKMP 2010). As discussed above, the current plans for water development in the basin –particularly in form of large-scale hydropower dams– are estimated to cause remarkable hydrological and ecological changes to the lake system. These changes are expected to impact negatively both the fish production and agricultural productivity, having thus wide-reaching social and economic consequences that threaten the livelihoods of the poorest groups in particular (MRCS/WUP-FIN 2007; Chhun 2010; Hall & Bouapao 2010; Nuorteva et al. 2010; MRC 2010b; MRC/IKMP 2010). In addition to potential upstream impacts, the Tonle Sap floodplains are also under pressure from more local developments, including plans for large-scale irrigation structures, which are likely to have impacts on the flood pulse as well (Evans et al. 2005; Baran et al. 2007; Keskinen et al. 2007).

At the same time the Tonle Sap is also changing both socially and economically, although the pace is very different in different areas. While agriculture remains clearly as the area's main livelihood source, there are signs for increasing livelihood diversification, particularly in urban areas. Despite these changes towards more modern sources of livelihoods, majority of the people in the Tonle Sap remain deeply dependent on water-related natural resources –agricultural land, fisheries and wetland resources– for their livelihoods and food security. In addition, due to population growth, the actual amount of people involved in both agriculture and fishing actually increased by more than 140'000 people between 1998 and 2008⁹, suggesting increased pressure on agricultural land

⁹ The amount of people involved in agriculture increased from year 1998 to year 2008 by 130'000 people and in fishing by 10'700 people. For more information, see Annex D.

and indicating that more and more people are actually dependent on the Tonle Sap's natural resources¹⁰. At the same time the resilience of the people living in the Tonle Sap floodplains towards stress and shocks related their livelihoods seems to be rather limited, with the poorest being particularly weak in responding to both sudden and long-term negative impacts (Hall & Bouapao 2010; Nuorteva et al. 2010).

When noting that (as of 2008) two exceptionally large age groups i.e. 10-14 years old and 15-19 years old are entering the workforce between now and 2020, the area's deep dependency on natural resources seems particularly worrying. Given that the area of agricultural land is relatively limited (and partly concentrating on fewer hands) and the amount of fish seems to be decreasing, the increased amount of young people entering the workforce is likely to put the area's already stretched natural resources under increasing pressure. This growing resource scarcity may lead to environmental but also social and economic tensions.

In sum, the people living in the Tonle Sap are still dependent on natural resources for their livelihoods, and this doesn't seem to be changing very fast. On the other hand the urban areas are changing –and developing– at very different rate, with more diverse livelihood structure and increased amount of migrants from the surrounding rural areas. Siem Reap in particular is changing very rapidly, thanks largely to its booming tourism industry. Consequently, it is obvious that the predicted changes in the Tonle Sap flood pulse will have a negative impact on the area's natural resources as well as people. How serious these impacts will be in the different areas is, however, unclear, and will depend very much on the changes in the socio-economic setting and, therefore, also on the government policies applied for the area.

¹⁰ Increasing pressure towards natural resources was also visible in the regional surveys done by MRC's Social Impact Monitoring / Vulnerability Analysis (SIMVA). The study (Hall & Bouapao 2010: xx) concluded that "there has been a significant decline in fish catch over the five years prior to the interview. One third reported 'much less' fish than five years ago, with the greatest changes reported for the mainstream and the Tonle Sap and the lowest for paddies, ponds and canals. Over a third (38%) reported the absence of certain species that they used to catch 5 to 10 years ago."

NEW FINDINGS FROM THIS STUDY: What we didn't know before?

The on-going 'Exploring Tonle Sap Futures' study aims to deepen the understanding of the Tonle Sap Lake area, including its unique hydrology, key natural resources (fisheries, agriculture) and livelihoods.

While building on the existing information from these aspects, the study also aims to produce new knowledge on several issues that can be considered important for future planning and management of the Tonle Sap area.

Given that our two research components focus on hydrology and livelihoods, the most relevant new forms of knowledge produced in this study include:

- Hydrology
 - The impacts of water development and climate change on flood pulse have so far been analysed separately: in this study their impacts will be simulated also together, allowing more comprehensive understanding of their combined impacts
 - Developing and applying up-to-date hydrological and hydrodynamic modelling tools with most recent input data
- Livelihoods
 - Using for the first time the socio-economic data from the Population Census 2008 (includes all Cambodian villages and households) specifically in the Tonle Sap
→ A comprehensive, quantitative picture of the current livelihoods setting
 - Using the sets of two different socio-economic surveys (Census 1998 and 2008, CSES 2004 and 2007) to allow a simple trend analysis of selected s-e indicators
→ Enables us to understand how the socio-economic setting in the area is changing
 - Applying the data above in the 18 sub-areas of the Tonle Sap (divided according to provinces and livelihoods zones) and presenting it visually in maps

Plenty of this new information is already presented in this Baseline Report, but more is yet to come: next few months will result in more detailed analysis of the cumulative scenarios of Tonle Sap hydrology (combined impacts of water development and climate change) as well as a comparison between the results of our quantitative socio-economic data and the more qualitative data available from the household surveys.

Please note that the findings presented in this report are tentative, and we therefore welcome all comments and corrections to them.

INTRODUCTION TO THE STUDY

The Exploring Tonle Sap Futures study represents one of the five localised case studies of the 'Exploring Mekong Region Futures' project (<http://www.csiro.au/science/MekongFutures.html>), which is led by The Commonwealth Scientific and Industrial Research Organisation (CSIRO). The Exploring Tonle Sap Futures study focuses on the Cambodia's Tonle Sap Lake area. The study is implemented by a consortium consisting of Aalto University, 100Gen Ltd., Hatfield Consultants Partnership and Institute of Technology of Cambodia, complemented with work by EIA Ltd. and VU University Amsterdam. The partners of the Tonle Sap study are the Tonle Sap Authority (TSA) and the Supreme National Economic Council (SNEC).

The regional Mekong Futures project aims to improve community livelihoods and well-being in the Mekong Region by evaluating and producing combined quantitative and qualitative research that will inform decisions and investment directions for the sustainable production, distribution, and use of energy, food and water. The Mekong Futures project will conduct a series of alternative futures workshops at both regional and local scales, providing a systematic, participatory framework to reveal local development scenarios reflective of participants' values, knowledge and future visions. Subsequent workshops will refine the initial set of scenarios, informed and supported by specific and relevant research themes identified in the workshops.

The Tonle Sap study focuses on the interactions between livelihoods and the Tonle Sap's unique water resources. Majority of the Tonle Sap livelihoods are dependent on the Tonle Sap's aquatic environment, and any changes in Tonle Sap's water resources are therefore likely to influence the status of local livelihoods. Hydropower development in the Mekong River is considered to be among key factors in any future development of the Tonle Sap region, largely due to the expected negative impacts that hydropower development would have for the Tonle Sap flood pulse and, in particular, the immense fish production of the lake.

A central part of the Exploring Tonle Sap Futures study will be two Research Components focusing on water resources and livelihoods. The main aim of the Research Component on water ('Hydrological analysis') is to model the possible impacts of regional & local changes to the Tonle Sap flood pulse that drives the aquatic ecosystem productivity. The Research Component on livelihoods ('Livelihood analysis') aims to analyse current social and economic setting and trends in the Tonle Sap area, building on spatial analysis of key socio-economic databases from the area.

This report presents the baseline results of both research components under the headings 'Hydrological analysis' and 'Livelihood analysis'. The results are intended to serve as an input to the scenario workshop process of our study as well as to feed into other planning processes of our partners, namely the Tonle Sap Authority (TSA) and the Supreme National Economic Council (SNEC). In addition, we hope that our research findings help to facilitate also more general discussion about the current situation and possible futures for the Tonle Sap area.

HYDROLOGICAL ANALYSIS

SUMMARY

- Flood pulse is the key driver for Tonle Sap high ecosystem productivity, including the Tonle Sap system's immense fish production.
- It is important to understand the possible future changes on the flood pulse as such changes are likely to have significant impacts on the area's livelihoods that are largely dependent on the water-related ecosystems.
- The flood pulse is directly dependent on the water levels in the Mekong mainstream. Therefore, it is crucial to understand the future impacts in different scales: A) Mekong Basin, B) Tonle Sap catchment, and C) Tonle Sap Lake and its floodplain
- As part of our on-going research, we will assess the following three scenarios:
 - 1) Water development scenario,
 - 2) Climate change scenario,
 - 3) Cumulative scenario (including water development and climate change)
- Preliminary findings indicate that the cumulative impacts of climate change and hydropower operation will significantly impact on the flood pulse (delayed, shorter, and smaller flood; reduced floodplain area due to higher dry season water levels, etc.) and thus have negative impact on ecosystem productivity.

The main aim of the hydrological analysis is to assess the possible impacts of basin-wide & local changes on the Tonle Sap flood pulse. This is done with the help of detail and state-of-art mathematical models. The assessment is concentrating on two main drivers on hydrology: human development actions (mainly hydropower development, but including also other water development) and climate change. Those are estimated to be the two key driving factors for future hydrology alterations.

Although the study area focuses to the Tonle Sap Lake and its floodplains, it is also necessary to understand the basin-wide changes in the entire Mekong system, as the flood pulse is directly dependent on the Mekong mainstream flow regime. Consequently, the hydrological analysis also includes three scales of analysis, ranging from Mekong River Basin to the Tonle Sap Lake.

Approach and methods

To understand the future hydrological scenarios for the Tonle Sap Lake, we established two mathematical models. The first one is VMod hydrological model that has been applied for the whole Mekong basin. With VMod we are able to simulate the cumulative impacts of development and climate change on flow regime.

The VMod model is further linked to detail EIA 3D floodplain model from Kratie downstream. With the EIA 3D model we can simulate the impacts of basin-wide and local cumulative changes on the Tonle Sap flood pulse.

For climate change scenarios, we downscaled five global climate change models (GCMs), two scenarios in each, for the whole Mekong Basin. For development scenario, we used MRC hydropower database to estimate the future development in the hydropower field. For the local development scenario, we are relying on Cambodian national plans for hydropower and irrigation development in the Tonle Sap tributaries and within the floodplain.

Our analysis in relation to other assessments

Our assessment is not the first one that is done in the Tonle Sap Lake to explore the impact of development or climate change on hydrology. It does, however, extend and increase significantly the understanding of the future changes in water resources due to these two drivers.

While the previous studies have concentrated on analysing the future impacts on Tonle Sap flood pulse solely on either development plans or climate change (see Annex A), our study will assess the cumulative impacts of both of them, i.e. how much they will alter the hydrology together. Hoanh et al. (2009) studied the impact of climate change and development on Mekong mainstream discharges and inundation area in the LMB floodplain. They did not, however, analyse in details the implications on Tonle Sap and further, they used only one global circulation model to simulate climate change (Hoanh et al. 2009).

Our model system aims also to be more transparent, robust, and physically based compared to the previous ones used in other basin-wide assessments. The main assessments done in the Mekong have been listed and briefly described in Annex A. For more detail information of many of the assessments, see: Keskinen and Kummu (2010) and Johnston and Kummu (2011).

At this point it is worth of asking, why do we need several models to assess the impacts of future changes on hydrology? As the hydrological changes are extremely important both socially and economically, we believe that it is important that the model results provide as reliable and correct picture of the potential changes as possible. Using multiple models results in a set of impact range that can provide a more consistent –and reliable– picture of the actual expected impacts of planned water development, and also point out the areas still requiring further research. Also, there is already an example for such a process, as the climate change estimates of the

Intergovernmental Panel on Climate Change (IPCC) are put together through similar, comparative process.

Study area and the analysis scales

Our study area is the Tonle Sap Lake and its floodplains. However, the lake's hydrology is interconnected with the Tonle Sap catchment (90,000 km²) and Mekong River Basin (795,000 km²). Therefore, in order to understand the potential future changes for lake's hydrology, we needed first to analyse the Mekong basin-wide hydrological scenarios. Therefore, we are assessing the driving factors in three analysis scales: a) Mekong Basin, b) Tonle Sap Catchment, and c) Tonle Sap Lake and its floodplains (Figure 1).

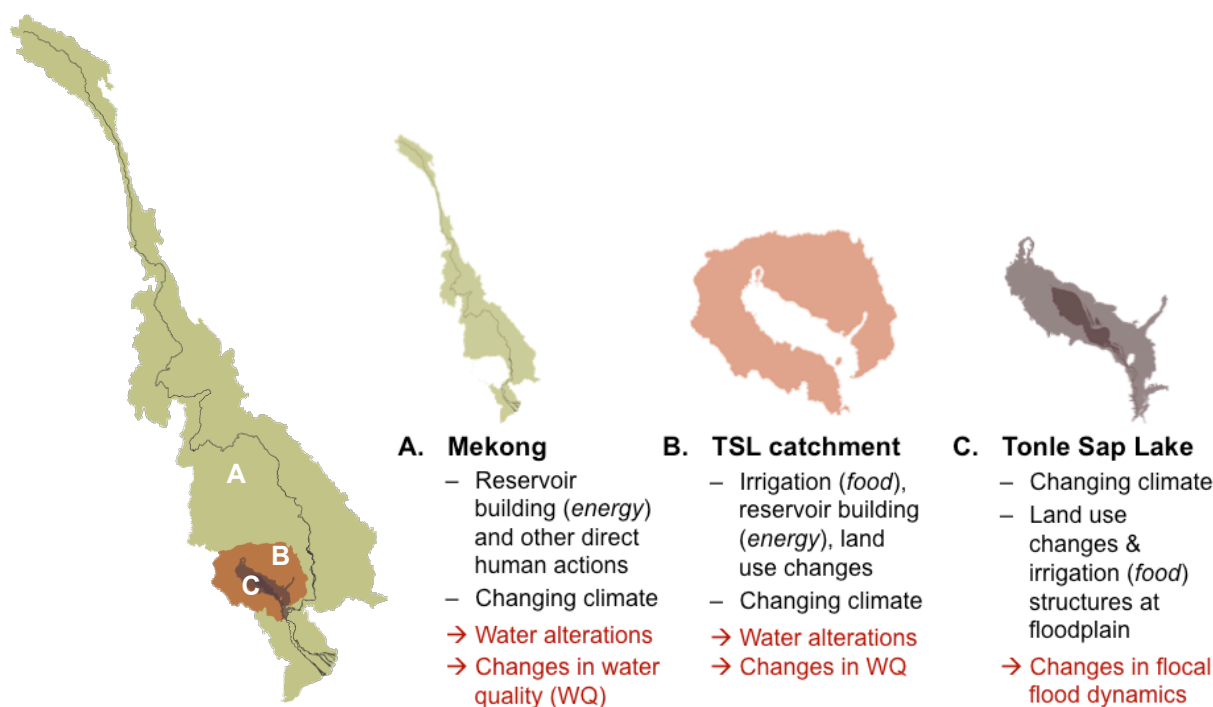


Figure 1. The geographical scales of hydrological analysis and the drivers of change: A. Mekong Basin, B. Tonle Sap catchment, and C. Tonle Sap Lake and its floodplain

Baseline results: hydrological analysis

Tonle Sap floodpulse

The Tonle Sap Lake is argued to be one of the most productive inland aquatic ecosystems in the world. The key driving force for the high productivity is the annual flood pulse, originating from the monsoon driven climate, together with the large floodplain and natural vegetation over there, such as flooded gallery forest (Lamberts 2006). The Tonle Sap system is characterised by notable seasonal differences in water level and surface area as illustrated in Figure 2 (Kummu & Sarkkula 2008). The timing of the flooding is, however, rather stable (Figure 2), as the peak date has

historically been within couple of weeks during early October. And although the water level during the peak flood varies significantly (6.5 – 10.4 m above mean sea level), the dry season water level is within tens of centimetres (around 1.3-1.5 m amsl). The floodplain vegetation needs the dry period and thus, it is important part of the lake’s ecosystem that the water level decreases every year to the same level.

More than half of the annual inflow to the Tonle Sap Lake originates from the Mekong mainstream, and water level in the lake is closely linked to the one in the Mekong mainstream. Thus, flow alterations in the mainstream would have direct impacts on the Tonle Sap water levels and hydrology as well. Recent research has shown that the relatively small rises in the dry season lake water level would permanently inundate disproportionately large areas of floodplain (Kummu and Sarkkula 2008), rendering it inaccessible to floodplain vegetation and eroding the productivity basis of the ecosystem by reducing the inundated area, and duration and amplitude of flooding (Lamberts 2008). The lake extension would thus cause permanent submersion; in essence destruction of considerable areas of the gallery forest surrounding the lake (Kummu and Sarkkula, 2008).

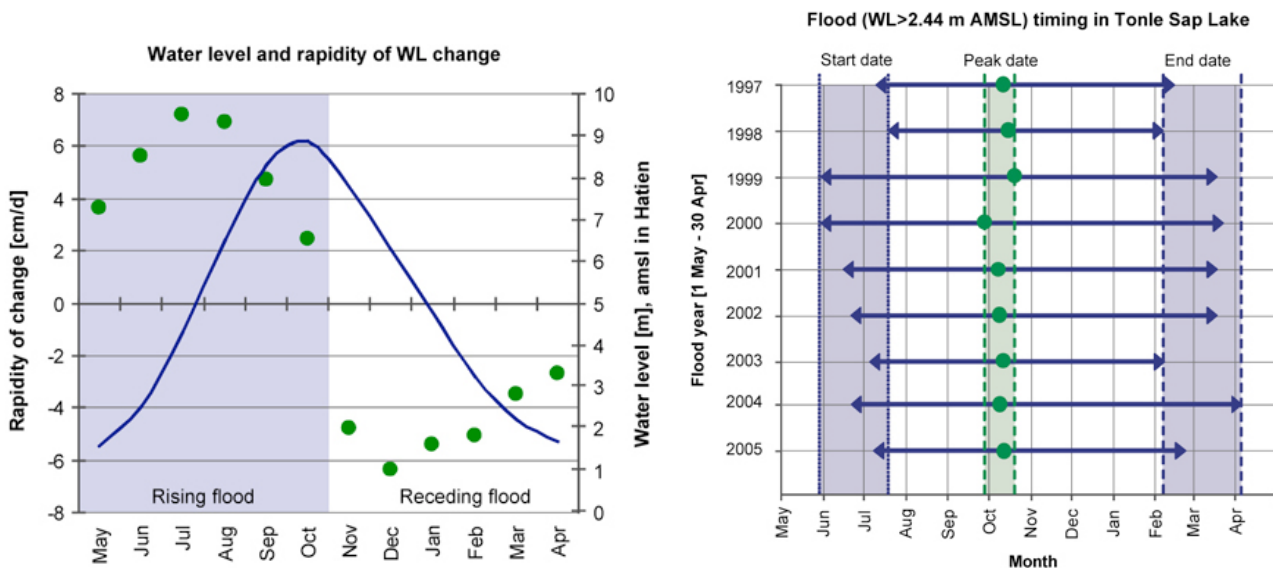


Figure 2. Tonle Sap floodpulse characteristics. Average water level (WL) and rapidity of WL change (left); and flood timing (right).

The flood pulse is thus mainly driven by the Mekong mainstream water levels throughout the year. Consequently, it is important to understand the basin-wide hydrological changes in the future to be able to simulate the possible changes to Tonle Sap flooding. The Tonle Sap catchment has also important contribution to the lake’s flooding particularly during the dry season, while the local actions in the floodplain may have significant role in local flooding and productivity.

Basinwide modelling: Mekong River Basin

The model grid for the Mekong River Basin was constructed using the following data:

- Digital elevation model (SRTM 90m)
- Land use (Global Land Cover 2000, 25m gridded data)
- Soil data (FAO soil map of the world, 1 km resolution)
- Mekong river catchment boundary (Mekong River Commission, 1:50'000 vector data)
- River bed and lake shore data (Mekong River Commission, 1:50'000 vector data)
- River cross section data for Mekong river main channel (Mekong River Commission)

From that data we constructed a 5 km resolution grid for the model (Figure 3). We used altogether 151 precipitation and 61 temperature measurement locations for the VMod hydrological model (Figure 3). Data was available for years 1981-2005.

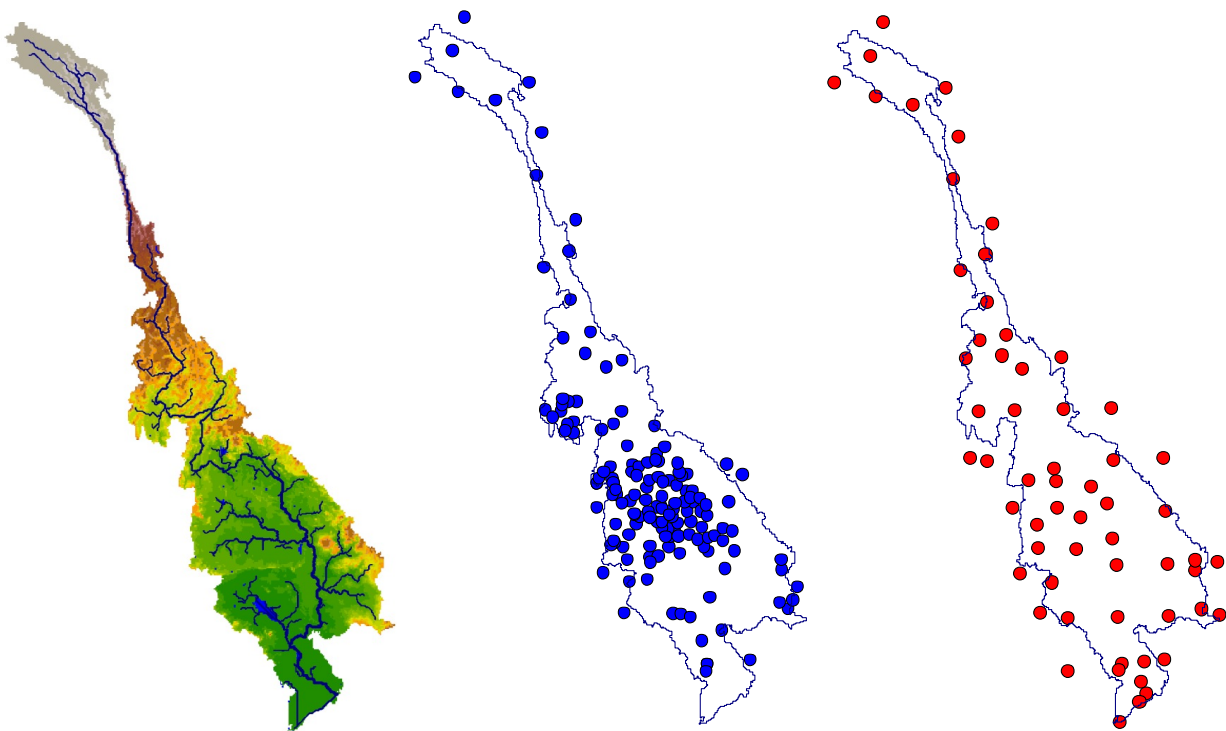
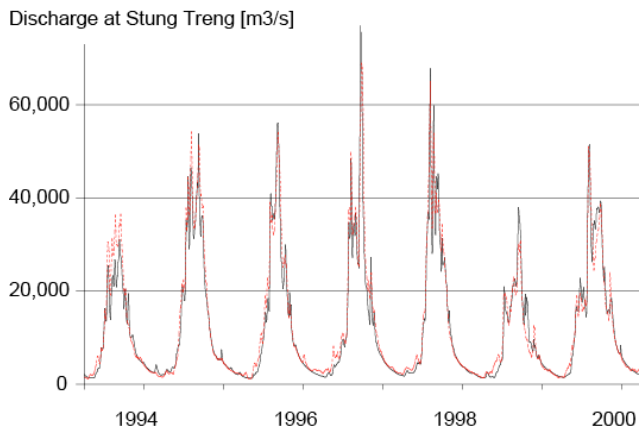


Figure 3: The model setup for the Mekong Basin: Elevation model and river network (left), precipitation points (blue; middle), temperature points (red; right).

The model was calibrated manually by using the observed discharge for the period of 1981-1992, by comparing the model results to measured flow at the Mekong mainstream Stung Treng measurement station. The verification period was 1994-2002. Stung Treng was selected for calibration instead of Kratie based on data quality considerations. The results for verification period are presented in Figure 4. In general the agreement between modelled and observed discharges is very good (calibration $r^2=0.922$; verification $r^2=0.941$) (Table 1).

A: Daily discharge; measured vs computed



B: Monthly average discharge; meas. vs comp.

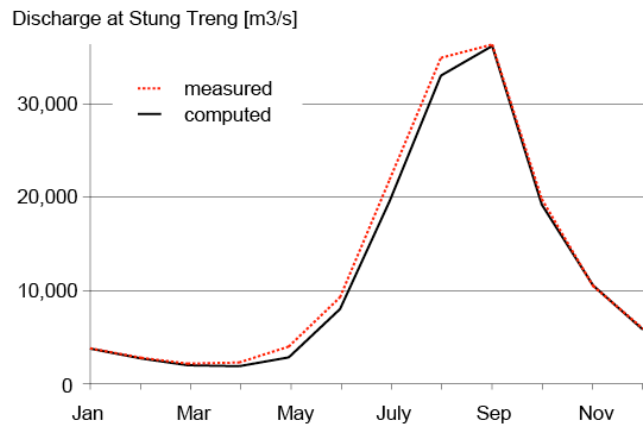


Figure 4: Verification results at Stung Treng. A. Daily computed vs. measured flows: $r^2=0.941$; computed flow vs. measured flow ratio: 0.95. B. Monthly average measured vs. computed flow.

Table 1. Goodness of fit coefficients and ratio of cumulative discharge volumes for calibration and verification periods.

Location	Calibration		Verification	
	R^2	comp /meas	R^2	comp /meas
Chiang Saen	0.827	0.94	0.779	1.05
Vientiane	0.872	1.06	0.808	1.13
Nakhom Phanom	0.819	1.12	0.933	0.93
Mukdahan	0.878	1.05	0.926	1.01
Pakse	0.925	0.98	0.928	0.96
Stung Treng	0.922	1.01	0.941	0.95

Our baseline period of the hydrological analysis was selected to be 1982-1992 with natural conditions what come to the hydropower. This period and assumptions are comparable to other studies (e.g. ADB 2004; World Bank 2004; Hoanh et al 2009). The baseline results of the model are very well in line with the measured discharges (Table 1) and thus, it is feasible to use the model for future scenarios.

Tonle Sap floodpulse modelling

Lower Mekong basin model (LMB) is a hydrodynamic model simulating the flooding of Lower Mekong Basin downward from Kratie. The LMB resides mostly in Cambodia and Vietnam and includes lake Tonle Sap, the Plain of Reeds and Mekong delta (Figure 5). Main aim of the model is the simulation of Tonle Sap Lake water levels. The LMB flood model is a gridded 3-dimensional hydrodynamic model and has a resolution of 1 km. The model takes into account bottom topography, incoming flows at the northern model boundary and Lake Tonle Sap basin, water level at the model southern boundary, water levels inside the model area and bottom friction.

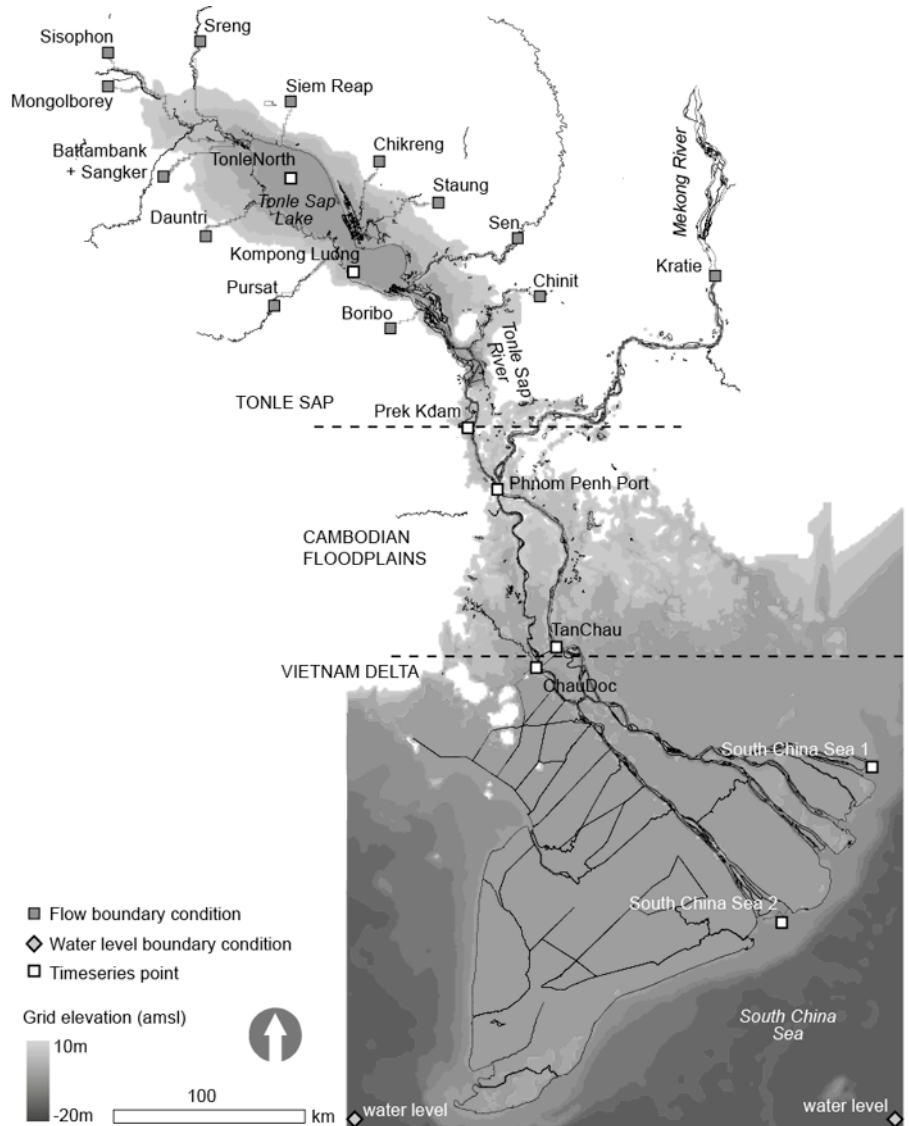


Figure 5. Model setup for the LMB hydrodynamic model with boundary conditions (modified from Västilä et al 2010).

As input data the LMB model requires incoming flows at Kratie and Tonle Sap Basin, and the water level at the South China Sea near Mekong Delta. For calibration of the model the incoming flows were taken from the measurement data, and for scenario runs from the 5km resolution VMod model of the upper basin (see previous section). The water level at the bottom boundary (i.e. South China Sea) was taken from 5-year period of water level measurements, and extrapolated from that to whole simulation period. The model was calibrated to measurements during years 1997-2000 by adjusting bottom friction for the whole model area and water depths at the main rivers. The latter can be seen as partial correction of an error induced by the coarse model grid size (1km) and 2D flow computation method.

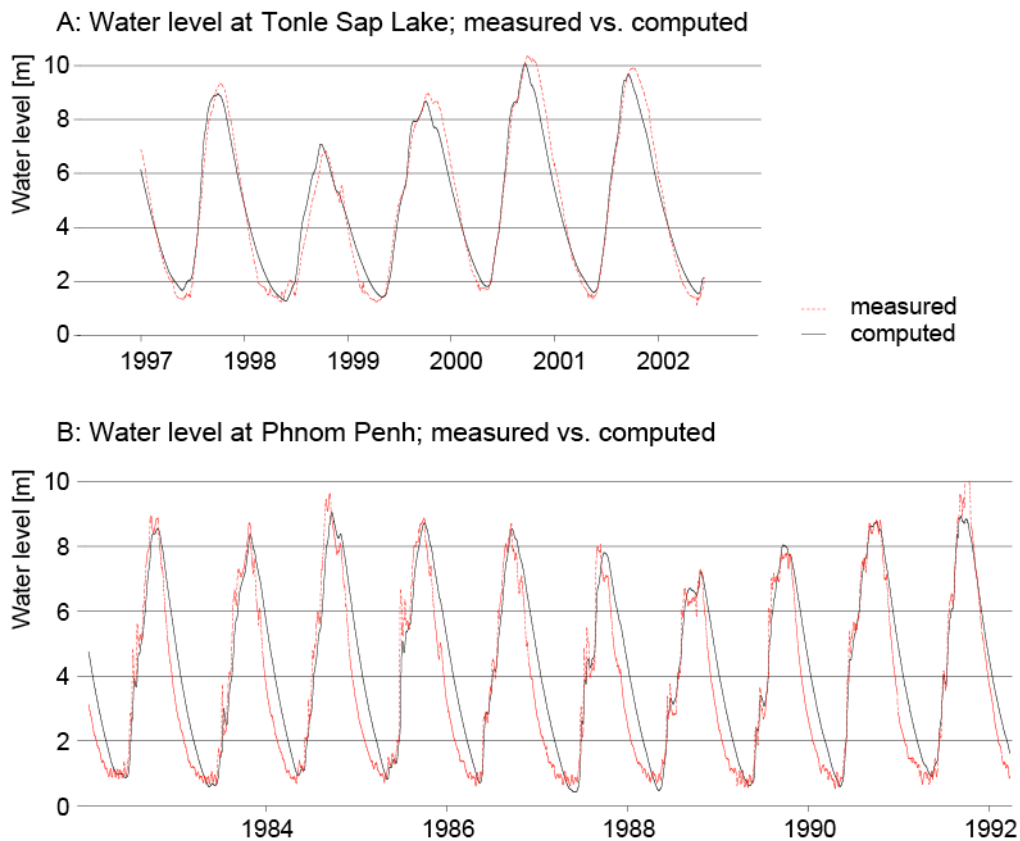


Figure 6. Measured and computed water levels of LMB model. A: Tonle Sap (Kampong Luong); B: Phnom Penh.

The model performed in general very well in the verification points (Kampong Luong at Tonle Sap Lake and Phnom Penh Port at Tonle Sap River) as illustrated in Figure 6. The verification results thus justify using the model baseline (1982-1992) as the natural condition of the lake flood pulse and that the model can be used to simulate the future scenarios in the lake.

Local development in the floodplain of the Tonle Sap Lake

Irrigation for rice cultivation is among the most important development activities in the Tonle Sap floodplain. Several reservoirs have been built in the floodplain between National Roads 5 and 6, while hydropower dams are built and planned to the several tributary rivers of Tonle Sap Lake (Evans et al. 2005; Baran et al. 2007; Keskinen et al. 2007: see also Table 2). Some irrigation reservoirs are submerged during the wet season and some are not. The reservoirs were built to store floodwaters towards the dry season, and thus also to reduce water withdrawals from the Tonle Sap Lake and other water bodies. The stored water is usually used to irrigate paddy fields around the reservoir, with irrigable area being usually around twice as much as the reservoir area.

Table 2. Statistics on different kinds of 'built structures' (roads, bridges, irrigation structures, dams) in the entire Tonle Sap catchment, as of 2006. Source: Baran et al. (2007).

Province	Area (km ²) flooded by medium floods	Land structures		Hydrological structures			Fishing structures	
		Length of roads (km)	Number of bridges	Length of embankments and dykes (km)	Area of reservoirs (km ²)	Number of dams	Area (km ²) of irrigation schemes	Length of fish fences (km)
Stung Treng	0	42	17	0	0	0	0	
Oddar Meanchey	31	800	106	7	9	2	32	
Preah Vihear	0	603	138	25	1	10	0	
Banteay Meanchey	1348	970	118	245	16	23	236	
Siem Reap	2825	1161	158	587	28	0	615	45
Battambang	3332	1144	187	300	13	0	1507	77
Kampong Thom	3626	1102	99	163	43	2	462	
Kratie	269	401	36	8	0	1	0	
Pailin	0	148	14	0	0	0	0	
Pursat	1612	996	242	81	0	0	334	
Kampong Chhnang	1964	543	87	255	0	0	64	
Kampong Cham	1642	478	53	265	2	0	193	
Kampong Speu	0	109	6	14	0	0	24	
Kandal	506	272	50	108	0	0	60	
TOTAL	17156	8932	1311	2064	111	38	3526	124

In order to understand the scale and current status of irrigation reservoir development in the Tonle Sap floodplain, the Exploring Tonle Sap Futures study analysed the location, shape and area of the reservoirs in two provinces where the construction of the reservoirs have been active, namely Kampong Thom and Siem Reap. The reservoir locations were extracted from GoogleEarth, with most of the satellite photos taken in 2009. Based on this data, around 240 ring dike reservoirs were found in the floodplain areas of the two provinces: 135 reservoirs in Kampong Thom and 93 reservoirs in Siem Reap (Annex B). Areas of the reservoirs range from 0.3 km² to 3 km², with an average of about 1 km².

While reservoirs have been actively built in the Tonle Sap floodplain, most of them have been constructed without official permits and their future is therefore unclear. Already now, number of reservoirs (around 30) has been demolished, and several other reservations (around 80) may be demolished. Possible reasons for demolitions (in addition to the fact that many of the reservoirs are illegal) include potentially negative impact to Tonle Sap hydrology and/or ecosystem as well as opposition by the local people.

Basin-wide scenario set-ups

In this section, the settings for basin-wide hydrological scenarios are briefly described for climate change scenarios as well as for water development scenarios.

Climate change scenarios

We used the above-described weather data, i.e. 151 precipitation and 61 temperature measurement locations, to downscale five global circulation models (GCMs) for the Mekong Basin. The models were selected based on their performance for the Mekong Region climate during their baseline period as described in Cai et al. (2009) and Eastham et al. (2008). The climate models and scenarios are shown in Table 3.

For each GCM we used two SRES (Special Report on Emissions Scenarios) scenarios (A1b, B1). Both scenarios are characterized by rapid economic growth and population rising to 9 billion by 2050. A1b scenario expects global average surface warming between 1.4-6.4 °C until 2100. The B1 scenario expects more environmental focused growth with global average warming between 1.1-2.9 °C.

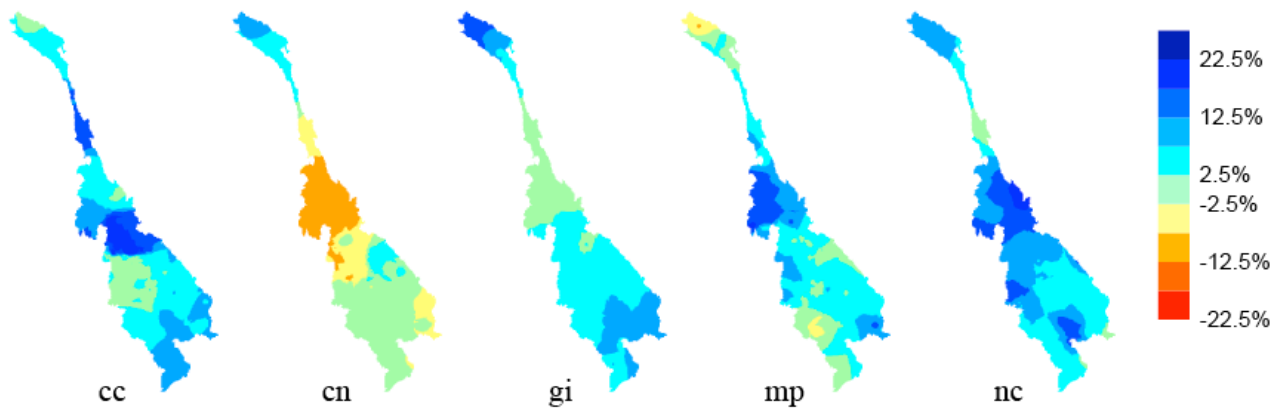
Table 3. Used Global Circulation Models (GCMs).

Climate model	CO ₂ Scenario	Abbreviation	Data period	Model resolution
CCCMA_CGCM3.1	A1b, B1	ccA, ccB	1850-2300	3.75° x 3.75°
CNRM_CM3	A1b, B1	cnA, cnB	1860-2299	2.8° x 2.8°
GISS_AOM	A1b, B1	giA, giB	1850-2100	3° x 4°
MPI_ECHAM5	A1b, B1	mpA, mpB	1860-2200	1.9° x 1.9°
NCAR_CCSM3	A1b, B1	ncA, ncB	1870-2099	1.4° x 1.4°

We analysed the climate change impacts during the period of 2032-2042. Areal precipitation in the climate change -scenarios was compared to baseline precipitation by summing the precipitation data from the whole simulation time, and computing the difference to baseline result. Change in precipitation of the cc-scenario compared to baseline in percentages, computed as $[(cc - baseline) / baseline * 100]$ for each climate change scenario, is shown in Figure 7 in for A1b scenarios. As can be seen from the results, there is no clear agreement between the different models on how the precipitation will behave. This is well in line with the current literature that concludes that the GCMs disagree whether monsoon precipitation will rise or fall (e.g. Ashfaq et al., 2009). On the average, the precipitation will increase by 3.5% in the A1b scenarios, and by 2.9% in the B1 scenarios. The largest increases are predicted by the CCCMA and NCAR models, and the smallest increases by the CNRM-model (Figure 7).

The different models agree that temperature rises, the rise is between 0.91 and 2.39 °C in the A1b scenario. The temperature rise in the B1 scenario is somewhat less. The large scale area distribution of the temperature change is similar in all the models: the temperature rises most in the northern and southernmost parts of the catchment while in the middle of the catchment the temperature rise is smaller (Figure 7).

A: Projected changes in annual precipitation [%] under A1b scenario



B: Projected daily maximum temperature changes [C°] under A1b scenario

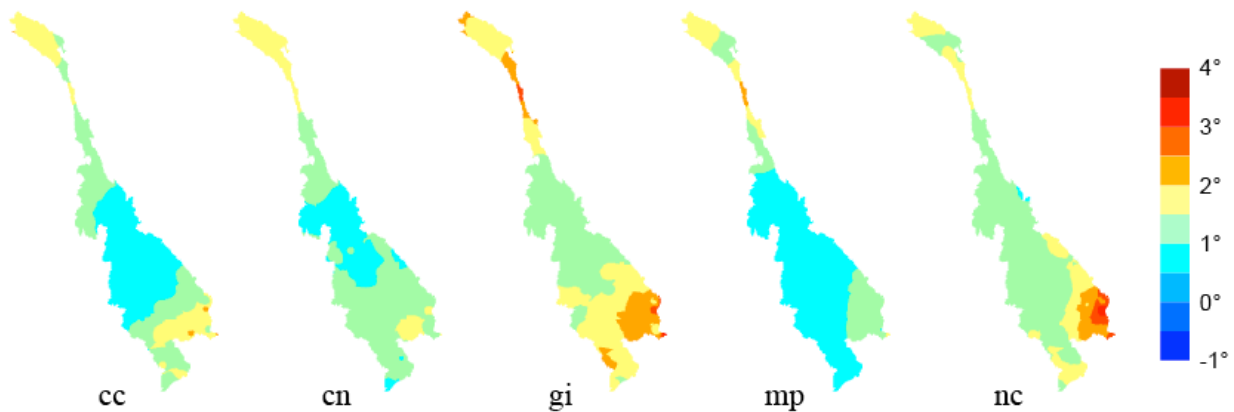


Figure 7. Climate change predictions in the Mekong under A1b. A: Average change in yearly precipitation (%) under A1b scenario of five models. The change correspondences to relative difference between years 2032-2042 and 1982-1992. B: Average change in yearly maximum temperature (°C) under A1b scenario. The change correspondences to absolute difference between years 2032-2042 and 1982-1992. Note: the GCM model abbreviations are spelt out in Table 3.

Water development scenarios

The Mekong Region is experiencing very rapid population growth and economic development. This is associated with increase in demand for and development of water resources (Johnston and Kummu 2011). All countries in the region have ambitious plans for development and significant water-related infrastructure has already been built, or is under construction, in major tributaries and upper reaches of the mainstream (King et al. 2007; MRC 2008). Developments include:

- Construction of dams and reservoirs for hydropower or irrigation
- Withdrawals for irrigation, domestic and industrial use
- Deforestation and other land use changes (including urbanization)
- Inter- and intra-basin diversions
- Construction of roads, embankments, levees and bank protection works

Figure 8 shows the main proposed dams based on MRC data (MRC 2009). The active storage capacity of the Mekong reservoirs may increase from around present 5 km³ to over 100 km³ if all the planned dams are constructed (Kummu et al. 2010). If the dams will be managed as expected (i.e. with economically most advantageous way), this would lead to significant modification and reallocation of flows from wet to dry season. Our development scenario includes the dams from MRC database (MRC-BDP2 2009), resulting altogether 126 reservoirs.

The reservoir locations were taken from the MRC database, and were additionally checked against the MRC hydropower project location map. Due to comparably large grid size of the model, inaccuracies in the model river network, and sparse precipitation data the reservoir inflow data may be biased, so that the average inflow to the reservoir may be larger or smaller than the inflows estimated elsewhere. When the sum of reservoir active volume is compared to mainstream discharges at Stung Treng, the sum corresponds to 96 days of average discharge, or 602 days of driest month discharge, or 34 days of wettest month discharge.

To define reservoir operation, a linear programming optimisation was used to define monthly outflows for all reservoirs. The target of the objective function was to maximise yearly outflow from the reservoir through hydropower turbines, using the reservoir active storage, estimated monthly inflows, minimum outflow and optimal outflow from the reservoir as parameters.

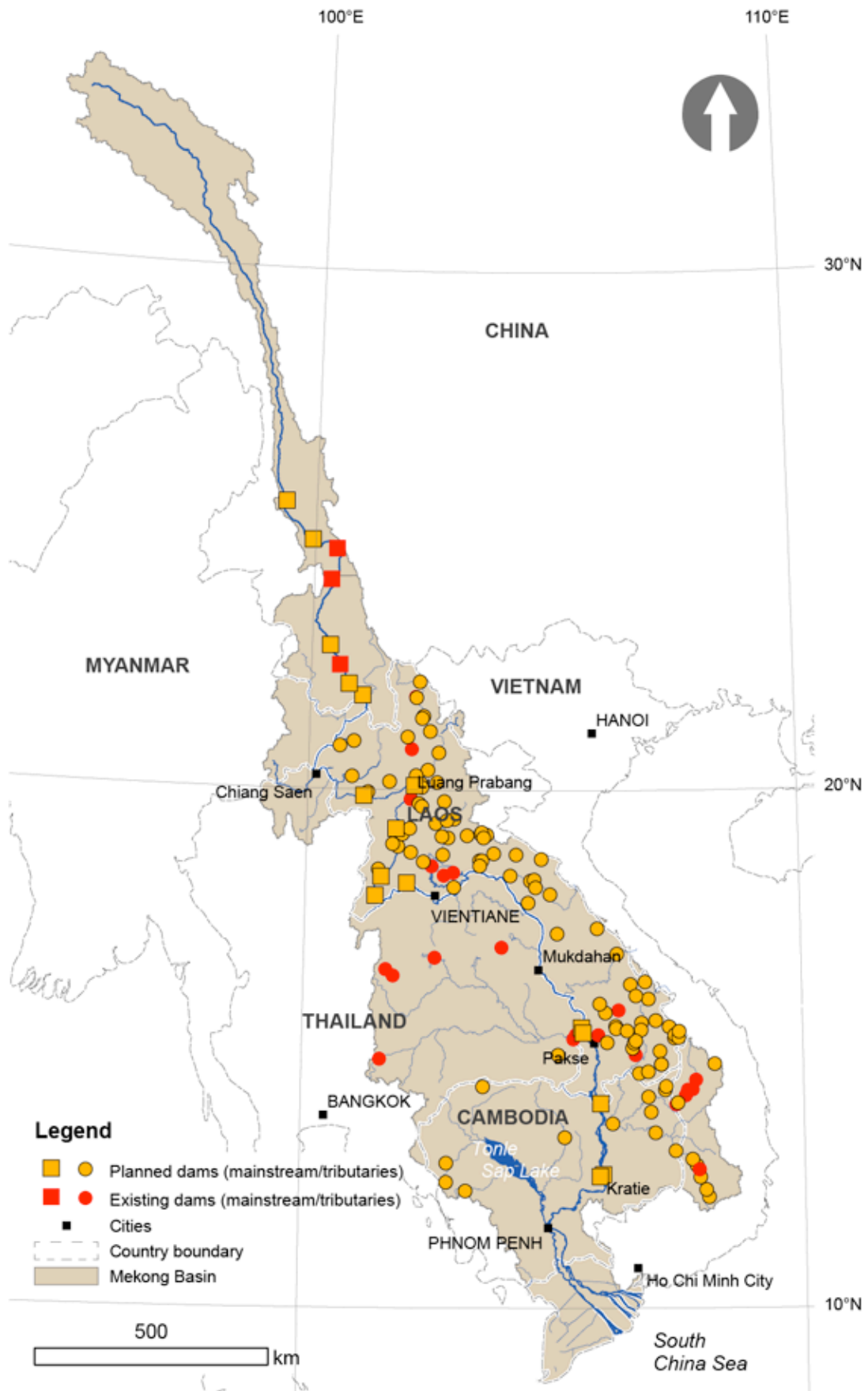


Figure 8. Existing and planned dams in the Mekong River Basin, with mainstream dams marked with boxes and tributary dams with circles (modified from Johnston & Kumm 2011).

Mekong basin-wide scenario results

Here the preliminary results of the basin-wide scenario results are presented. Please note that the results are not final and should thus be read and interpreted with special care. For the same reason, all comments regarding the scenario results are most welcome.

Climate change scenarios

The monthly average discharges at Kratie for different climate change scenarios are shown in Figure 9 (see also Annex C for tabulated information). Similarly to precipitation predictions, there seems to be no clear agreement on the direction of discharge change caused by the change of climate. Dry season discharges stay mostly same as for the baseline period, but wet season discharges increase or decrease depending on the scenario. The average of all scenarios show increasing discharges, where the largest increase is at the later half of the wet season in September and October. The average increase is modest 3.1%, but individual model show increases up to 12.5%.

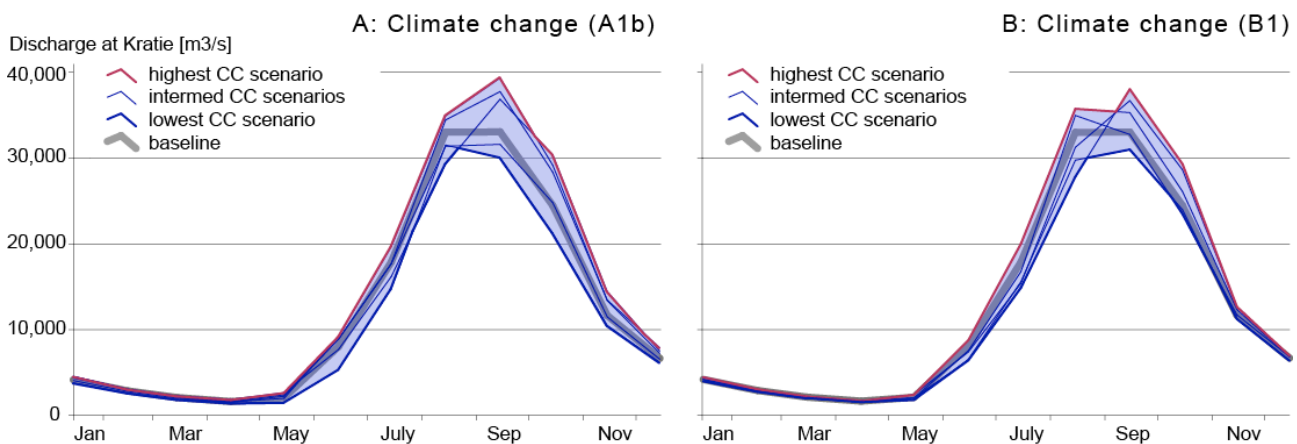


Figure 9. Monthly average flows in Kratie under climate change scenario for period of 2032-2042 A: A1b scenario; B: B1 scenario. The envelope represents the area limited by minimum and maximum of scenario flows for each month. Baseline represents the natural situation during the period 1982-1992.

Water development scenario

Under the development scenario, dry season flow increased significantly (Figure 10). The flood will be delayed several weeks from the normal while the end date will not change significantly. This would result in shorter flooding period. Flood peak will be, in average, lower than today (Figure 10). The largest decrease in flows is in the middle of wet season in August. Flow at the flood peak month September decreases by 9%. Also the amplitude of monthly flows during wet season decreases. Further, the flood would be significantly delayed.

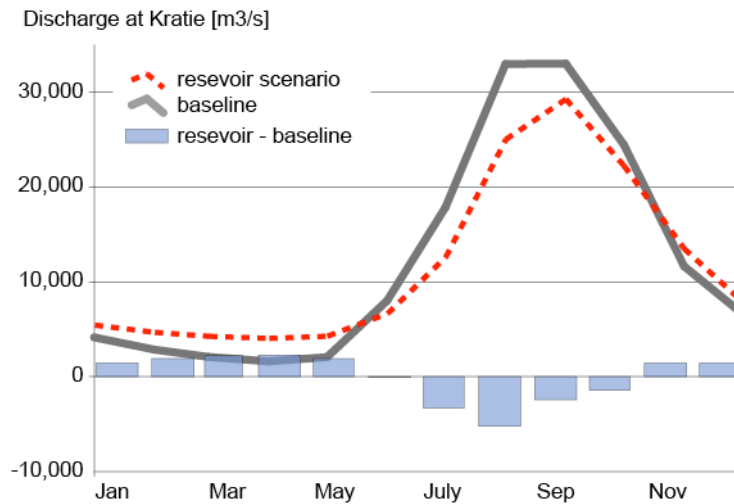


Figure 10. Monthly average flows (01.04.1982-31.3.1992) at Kratie under the development scenario and baseline. The bars represent the discharge difference between baseline and scenario.

Cumulative scenario

In the scenario where development impacts were modelled under the climate change conditions (Figure 11), the envelope of potential changes due to hydropower operation moved drastically lower compared to the climate change scenario alone (Figure 9). The cumulative impacts on dry season flow are similar to the development scenario impacts (Figure 10), as climate change does not impact heavily on that (Figure 9). The flood seems to delay in all the scenarios and flooding time will be shorter. There are, however, large differences between the climate scenarios for potential impacts on flooding amplitude. The two extremes in the projected climate change scenarios are very different. While the highest average monthly discharge under the lowest scenario is around 25,000 m³/s, in the highest scenarios is at the current level, approximately 32,000 m³/s (Figure 11).

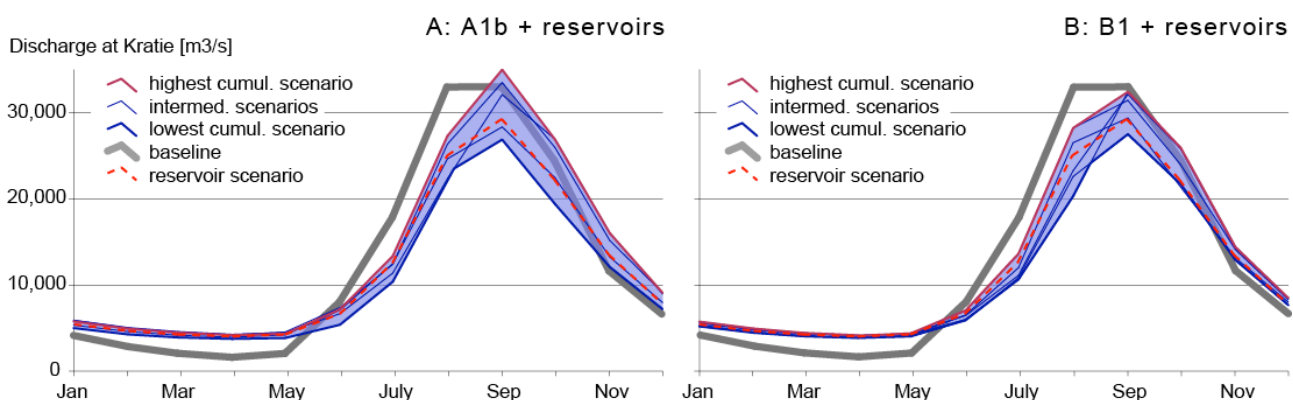


Figure 11. Results of the cumulative impacts of climate change and development on year 2032-2042. A: A1b climate change scenario and development; B: B1 climate change scenario and development. The red dashed line represents the development scenario alone and baseline refers to the period of 1982-1992. The envelope represents the area limited by minimum and maximum of scenario flows for each month.

Tonle Sap scenario results

The analysis of the implications of the scenarios for the Tonle Sap hydrology is currently on-going, and is expected to be finalised at the latest before the Fourth Tonle Sap Futures Workshop (planned for Spring 2012).

The basin-wide results, however, already indicate to significant changes in Tonle Sap flood pulse and thus impacts on aquatic ecosystems and productivity of the lake. The cumulative results of climate change and development indicate higher dry season water levels, delayed flood, lower flood peak and shorter flooding period. These all would lead to reductions in ecosystem productivity, as the floodplain would be smaller and the flooding time would be shorter. This is illustrated in Figure 12 (the estimations are based on previous study by Kummu and Sarkkula 2008). On the other hand, the reduced inundated area might provide additional opportunities for agriculture on the upper most parts of the current floodplain and increased dry season water level might increase the navigation opportunities.

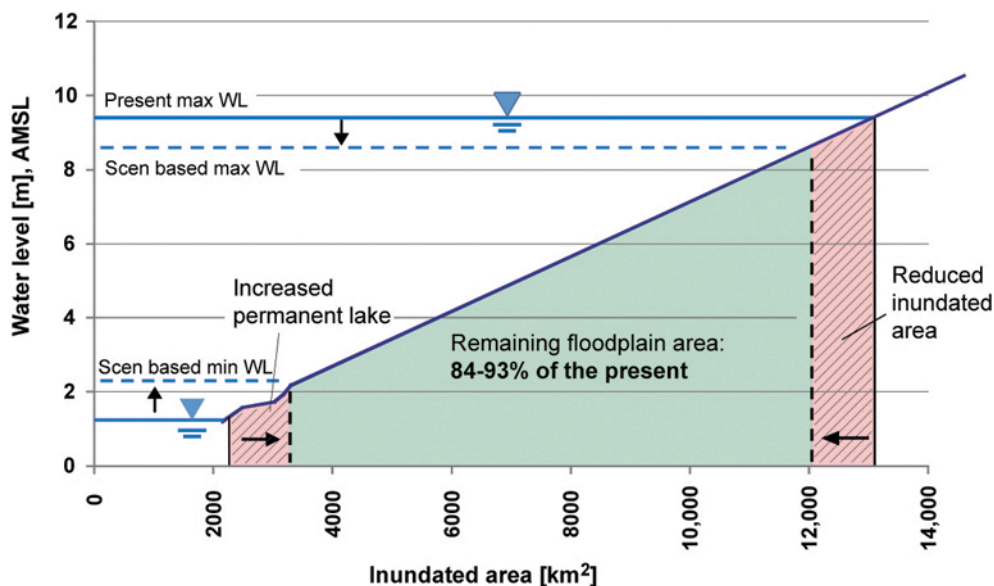


Figure 12. Impact of flow alterations on Tonle Sap floodplain, after Kummu and Sarkkula (2008).

On top of the hydrological changes, Kummu et al (2010) simulate that there will be drastic decline of suspended sediments in the future due to sediment trapping by reservoirs, should the hydropower development take place as planned in the basin. Kummu et al (2010) estimate that over 60% of the sediment would be trapped by upstream reservoirs. This would mean significant cut to the nutrients entering to the lake from the Mekong mainstream and thus have high negative impact also on the productivity of the lake's ecosystem (see also MRC/IKMP 2010).

Discussion

In this report, we have set up the baseline for our hydrological scenario work, including basic information about the current hydrology of the Tonle Sap system. The scenario settings were described, and the preliminary results for the basin-wide scenarios were presented and the possible implication on Tonle Sap briefly discussed. The work continues and final scenario simulations are planned to be finalised by the end of year 2011 and will therefore be ready for the fourth Tonle Sap Futures Workshop. We aim also to draw also broader conclusions on ecosystem productivity changes and so on, i.e. go beyond the hydrographs.

Our preliminary findings of development scenario are in line with the other studies (ADB 2004; World Bank 2004; Hoanh et al 2009; MRC/IKMP 2010), although the magnitude of change varies between the studies. More detailed comparison will be done within few months.

Our climate change scenarios show much less variability compared to the climate change study done by Eastham et al. (2008). They estimate rather significant increase on wet season runoff while our results indicate that climate change may either increase the flows or decrease them. It should be noted that Eastham et al (2008) did not use downscaled climate scenarios or observed timeseries for precipitation but relied on global scale data on both. Further, their hydrological model was rather simple water balance model. Thus, their results can be considered to be rather rough. We believe that our flow estimations for future climate are closer to the current understanding of future climate impacts in the Mekong, as we used observed ground station for model forcing, downscaled climate change scenarios and more detail hydrological model to run the simulations. Further, our findings are well in line with the general findings in Asia monsoon area (e.g. Ashfaq et al., 2009).

Finally, it is good to note that although the study concentrates on the hydrological impacts of hydropower development and climate change, we also aim to consider later on other development actions as well as natural climate variability, at least at the discussion level.

LIVELIHOOD ANALYSIS

SUMMARY

- The livelihood analysis presents the current situation (as of 2008) as well as the most important trends for key social and economic indicators in the Tonle Sap area.
- The analysis results are presented primarily in maps, with the available socio-economic data being aggregated and visualized for 18 sub-areas in the Tonle Sap
 - Tonle Sap area is divided based on administration (6 provinces) as well as on so-called livelihood zones (fishing, agriculture, urban). Study area is located between National Roads 5 and 6, including a 3 km buffer beyond the roads.
- In 2008, there were 1'707'090 people living in the study area, with around 5% living in Fishing Zone, 60% in Agricultural Zone and 35% in Urban Zone. There were altogether 1555 villages in the study area, with great majority (1244) being rural.
- Remarkable in demography is the dominance of the youth: 15 to 19 year-olds are the biggest age group and they are just about to enter the work force, seeking for employment in both rural and urban areas.
- Main livelihood sectors are still agriculture and fishing, but some minor sectors have grown rapidly between 1998 and 2008. These include construction, hotels and restaurants, manufacturing, and real estate & renting & business activities.
- Detailed examination between sub-areas reveals differences across the Tonle Sap: Siem Reap and Battambang saw biggest changes in many ways (population growth, migration, involvement in agriculture and fishing). Also the changes in livelihood sources differ greatly between the provinces and livelihood zones.

Approach and methods

The Research Component on livelihoods looks at the current status and past trends of selected social and economic indicators in the Tonle Sap area, with a focus on the main livelihood sources. This is done through spatial analysis of different socio-economic databases, most importantly from the Population Census 1998 and 2008.

The availability of two similar databases from different years (Census 1998 and 2008) allows a very simple trend analysis of past livelihood trends in the area, providing some insights into the dynamics of the socio-economic system in the Tonle Sap. Consequently, most of the livelihood-

related data is presented in two ways: the present situation (as of 2008) as well as the change from year 1998 and 2008 in both actual amount and in role / proportion (Figure 13). According to our knowledge, this is the first socio-economic analysis done specifically in the Tonle Sap area using the data from Population Census 2008. Even more importantly, we are not familiar with any other study in entire Cambodia that would have utilised both Census 1998 and Census 2008 to recognise socio-economic trends.

A special attention is paid on the visualization of the analysis results in different kinds of maps and tables, to facilitate a smooth linkage to the scenario workshop process.

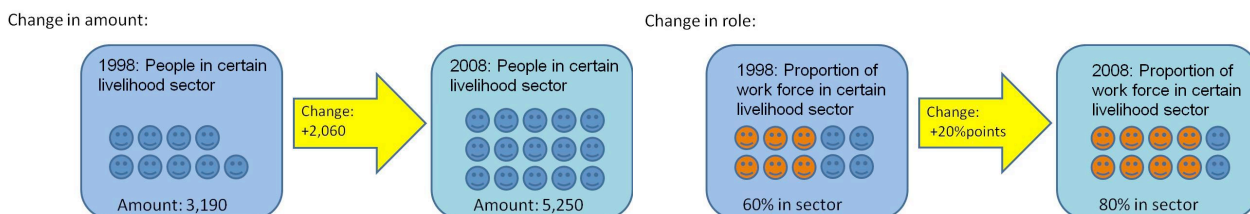


Figure 13. Example of the methodology for livelihood analysis. Change in both the absolute amounts and the proportion of work force were examined.

Study area and the units of analysis

The Tonle Sap area can be defined in different ways, and for example the Tonle Sap Authority (TSA) is currently finalizing its own definition for the Tonle Sap as an administrative area. For the purposes of this study, the Tonle Sap area is defined to consist of the Tonle Sap Lake and its floodplain, not including the area around the Tonle Sap River. The area covers parts of six different provinces, namely Kampong Chhnang, Kampong Thom, Pursat, Siem Reap, Battambang and Banteay Meanchey. The general characteristics of the study area are:

- The area within National Road 5 and 6, including a 3-km buffer beyond the roads (to include villages located on both sides of the National Roads).
- In the east side of the lake, the area is cut by a line that separates the lake floodplain from the Tonle Sap River floodplain (Figure 14).
- Based on the village location map of National Census of Cambodia, all villages within the above-mentioned borders were included in the analysis¹¹

¹¹ The village locations represent the location in 2006, as defined by the National Institute of Statistics (NIS). The location of the floating villages in this data seems to be indicative, and is usually marked on the border of province and the dry season lake area.

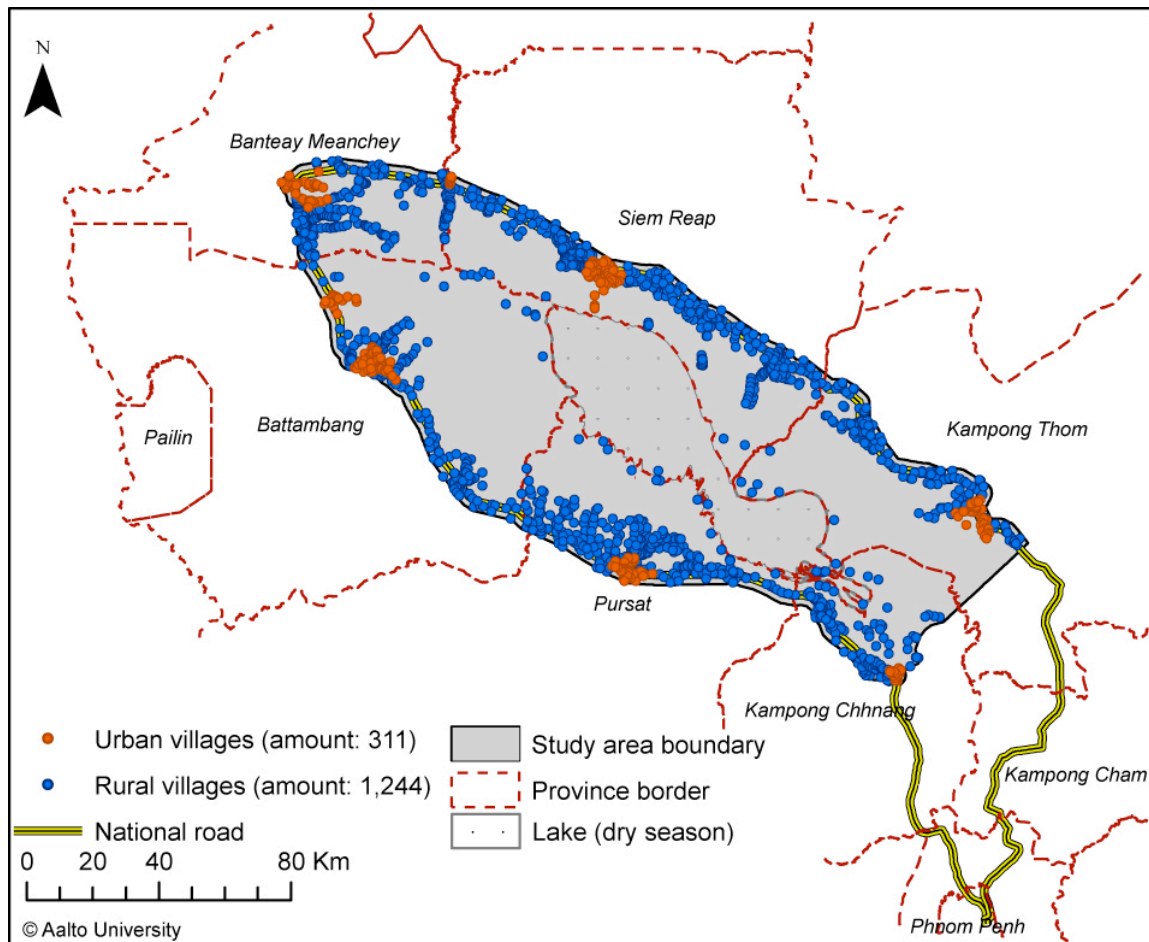


Figure 14. Villages within the study area, with rural villages in blue and urban villages in red.

For the purposes of the livelihood analysis, the study area was further defined based on so-called livelihood zones as well as on the administrative boundaries (six provinces). The definition of the livelihood zones (also called topographic zones) was based on the definition provided by Keskinen (2003), consisting of three zones having their own specific characteristics in terms of livelihood, hydrology and ecology:

- Fishing area (0–6 m above sea level)
- Agricultural area (6 m – national roads)
- Urban area (villages defined as urban in Census 1998 and in 2008)

Even though the names of the three zones represent the main livelihood sources for each zone, it should be acknowledged that the livelihood sources have generally become more diversified in the study area and also within the zones. In addition, the livelihood zones used in this study differ greatly in terms of the amount of people: a great majority of the people (~1 million) lives in 1'158 villages of Agricultural Zone, while around third of the people (~600'000) lives in 311 villages of Urban Zone. This makes Fishing Zone clearly the smallest, with some 5% (~85'000) of the total amount of the people living in the Tonle Sap area.

When combined, the livelihood zones and administrative boundaries create altogether 18 separate sub-areas that are visualized in Figure 15 below (for simplification and easier visualization the urban zone is marked with circles scaled according to the population). Table 4 shows the general population and village information for the study area.

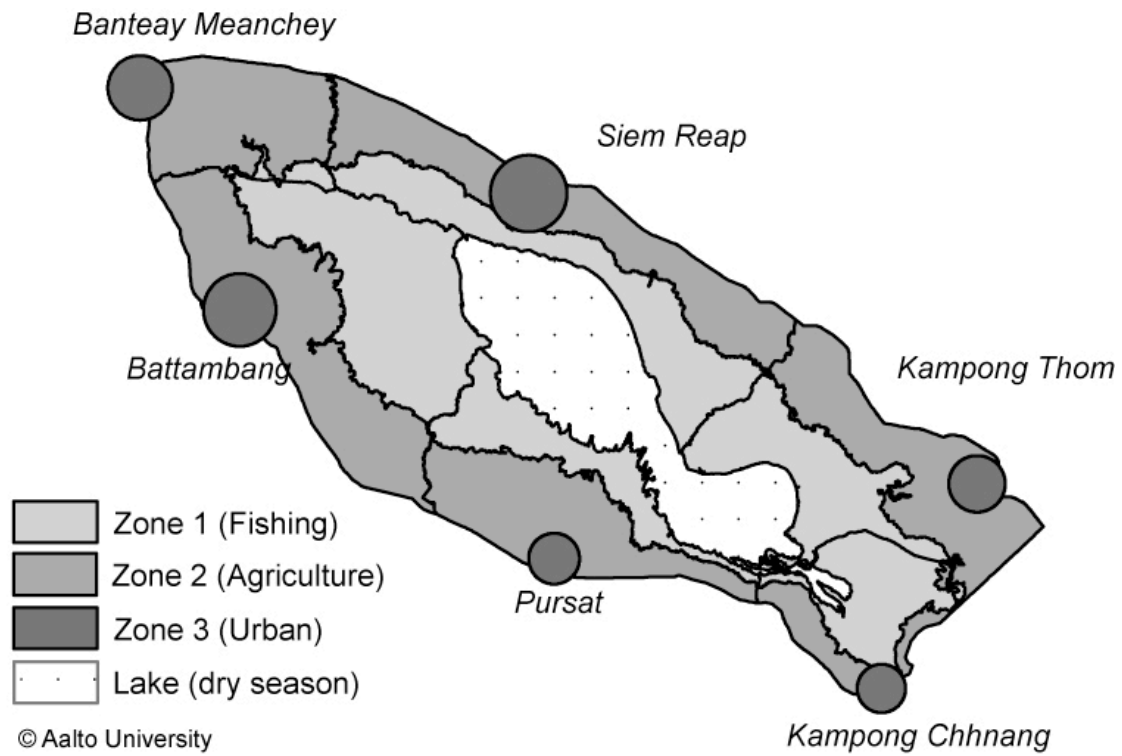


Figure 15. Visualization of the zoning and sub-area division for the study area.

Table 4. Population and village information for the three livelihood zones.

	Fishing zone (1)	Agricultural zone (2)	Urban zone (3)	Total
Population	84 490 (5%)	1 028 970 (60%)	593 630 (35%)	1 707 090
Villages	86	1 158	311	1 555
Average village size	982	889	1909	1098
Average HH size	5,1	4,8	5,0	4,9

Baseline results: Tonle Sap livelihoods

General socio-economic setting

There are currently (as of March 2008) around 1.7 million people living in the 1'555 villages of the Tonle Sap area. The average population growth from 1998 and 2008 was 14%, but the differences within the area were also remarkable, with the fastest population growth occurring in urban areas and particularly in Siem Reap.

In terms of age structure, the biggest age groups in the Tonle Sap are (as of 2008) the 10-14 years old (214'400 people) and 15-19 years old (217'800 people), which are clearly bigger than any other age groups, including those just before and after them¹². The situation is similar in entire Cambodia¹³. The Tonle Sap area is thus seeing a large amount of young people entering the work force just now as well as within next 5 to 10 years. Consequently, the Tonle Sap area and Cambodia have a possibility for the so-called demographic dividend, where a rising proportion of working age people leads to increased economic growth (Ross 2004, Keskinen 2008). This requires, however, right kind of context that provides meaningful sources of employment: otherwise the increase in workforce can also lead to accelerating environmental and social problems when more people try to rely on the same amount of natural resources.

A great majority of the people (~90%) in the Tonle Sap area live in the verges of the floodplain close to the National Roads 5 and 6. In general, people living closer to the National Roads are in many ways in a better situation than the ones living closest to the Tonle Sap Lake. The people living close to the lake are generally poorer, less educated, have fewer livelihood options, do not own agricultural land and depend strongly on common property resources such as water bodies and flooded forests for their livelihood (Keskinen 2003, 2006; Annex D). Also ethnic issues are important, as many of the floating villages are inhabited by ethnic Vietnamese whose status remains unclear (Annex D).

Urban areas act clearly as the 'engines of change' in the area, with Siem Reap playing a particularly important role in that. Urban areas attract both seasonal and permanent migrants, and the livelihood sources in urban areas are clearly more diverse –and much less dependent on natural resources– than in rural areas. Also the education level is better in urban than rural areas, and this difference seems just to be increasing: the education level has between 1998 and 2008 increased more rapidly in urban than rural areas, with the education level in some rural areas (particularly close to the lake) even getting worse.

¹² In 2008, there were 183'346 people in age group 5-9 years old, and 183'706 people in age group 20-24 years old.

¹³ In entire Cambodia there are (as of 2008) 1'670'000 people in the age group 10-14 years, and 1'620'000 people in the age group 15-19 years, compared to e.g. 1'470'000 in age group 5-9 years and 1'370'000 in age group 20-24 years.

Livelihood setting

The livelihood setting of the Tonle Sap area is as exceptional as its flood pulsing system. While people living in the lake and its floodplains have adapted to the huge seasonal variation of lake's water level, they are also deeply dependent on the resources that lake and its floodplains provide, including agricultural products as well as fish and other aquatic animals and plants (Keskinen 2006; MRC 2010b). This is exemplified in a simplified way by Figure 16, which shows how seasonal changes in the level of livelihood of four Tonle Sap villages seem to be following the flood pulse (there are naturally other factors impacting the level of livelihoods as well, and flood pulse may explain only partly its seasonal variation). For these reasons, the Tonle Sap flood pulse is among the major driving force for the area's livelihoods as well.

At the same time the studies indicate that the resilience of people living in the rural areas of the Tonle Sap towards stress and shocks related to their livelihoods is weak, with the resilience of the poorest being particularly weak (Nuorteva 2009; Chhun 2010; Hall Bouapao 2010; Nuorteva et al. 2010). This suggests that any major negative changes in the availability and access to the natural resources in the area is likely to have remarkable social and economic impacts, with the poorest being particularly hard-hit.

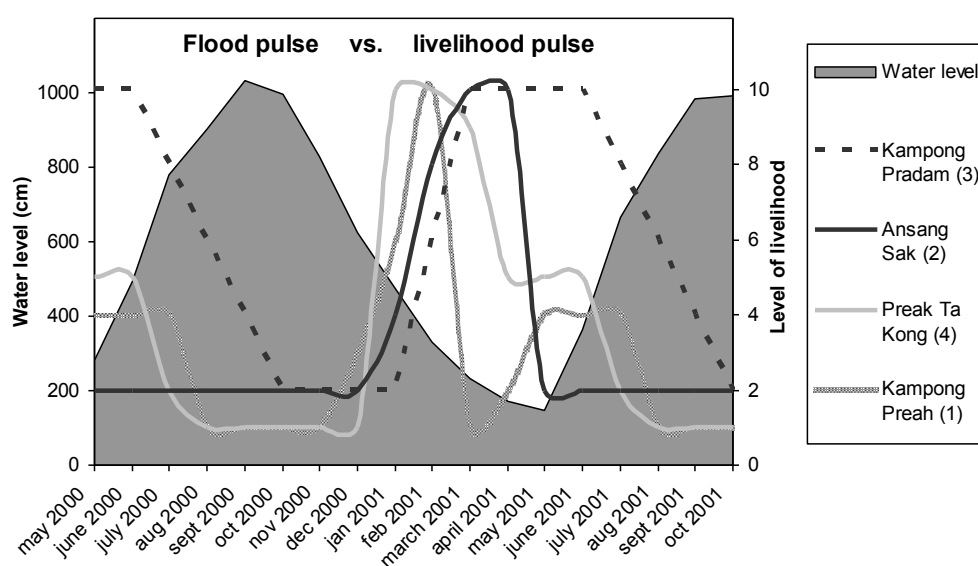


Figure 16. A simplified visualisation of the seasonal variation of the flood pulse and the 'livelihood pulse' in the Tonle Sap. The flood pulse is indicated in dark grey with seasonal variation of water level, while the four lines for 'livelihood pulses' show the seasonal variation in the level of livelihood, as defined by the villagers in four villages in different parts of the Tonle Sap area. Source: Keskinen (2006).

In terms of main livelihood sources, there are clear differences between the different areas in the lake-floodplain. Fishing forms the main source of livelihood in the areas closest to the lake, and the area is thus called 'Fishing Zone' in this study. Rice cultivation and other agricultural activities form, however, by far the most important source of livelihood in other rural areas, and the area is thus called 'Agricultural Zone'. Secondary occupations –including fishing– form an important supplement for the main occupations in all rural zones, particularly during the seasons when the

involvement in the main occupation is less intensive. In urban areas (in essence the six provincial capitals and few bigger district towns, which are called 'Urban Zone') the livelihood sources are much more diverse, and the role of secondary occupations is generally less important.

While agriculture remains clearly as the area's main livelihood source (61% of the total work force in 2008, compared to 66% in 1998), there are signs for increasing livelihood diversification. According to the Population Census 2008, the five biggest livelihood sectors in Tonle Sap in 2008 were agriculture (61%), wholesale and retail trade (11.5%), fishing (4.5%), construction (3.7%), and transport, storage & communication (3.5%). Most rapidly growing livelihood sector in the Tonle Sap was construction, which increased from 1% in 1998 to 4% in 2008: this resembles the national trend, although bit more slowly. Other increasing (although still minor) livelihood sectors include manufacturing (3.4%), other service activities (2.5%), hotels and restaurants (1.8%) and real estate, renting and business activities (1.1%).

Annex D presents the baseline results for several social and economic indicators (as derived from the analysis of Census 1998 and 2008 data) for the Tonle Sap area, divided into different sub-areas. The general social characteristics regarding population, age, education and migration are presented first. After that, the main livelihood sectors in the study area are examined, followed by growing as well as most relevant decreasing livelihood sectors. Finally, the livelihood activity and land ownership results from Cambodia Socioeconomic Survey (CSES) from years 2004 and 2007 are summarised.

Some interesting findings from the data presented in Annex D are summarised below:

- **Demographic changes across sub-areas**

- Population growth rapid particularly in Siem Reap
- 15-19 year-olds are the biggest age group, with the 10-14 years old being almost as big: both of these groups are just entering the work force
- Positive trends in education and literacy, except for some negative changes in Fishing Zone i.e. in the villages closest to the lake
- Siem Reap received the most migrants, half of which were from other provinces and in search of employment.

- **Changes in economically active population and industry sectors**

- Siem Reap and Battambang (especially Agricultural Zone) have the majority of the work force in Tonle Sap
- The livelihood diversity has increased since 1998, when looking at the distribution of work force in livelihood sectors.
- Some livelihood sectors (albeit still minor in 2008) have grown rapidly during the past 10 years, including construction, hotels and restaurants, manufacture, and real estate & renting.

- **Agriculture and fishing are still clearly the most important livelihood sectors, but their share from total work force is slowly decreasing.**
 - The proportion of agriculture from total work force is declining (from 66% in 1998 to 61% in 2008), but the absolute amount of people within the sector has increased by 130,000 people.
 - The proportion of fishing from total work force for entire study area has slightly decreased, but a more detailed level examination reveals increases in both share of work force and absolute quantity in Zone 1, especially in Battambang where the proportion of work force in fishing sector grew from 72% to 86%.
- **CSES socioeconomic surveys from 2004 and 2007 provide more detailed information about livelihood activities and land ownership.**
 - According to CSES data, collecting forest products was the most common and fastest growing additional livelihood activity in rural households, together with raising livestock and catching fish or shrimp.
 - The share of collecting or hunting food increased clearly between 2004 and 2007.
 - In urban households, the most common livelihood activities were raising livestock, running a business and collecting forest products.

Discussion

The livelihood analysis of the ‘Exploring Tonle Sap Futures’ study has so far focused on the quantitative analysis of the recent socio-economic databases, most importantly Population Census 1998 and 2008. The reason for such a focus is that –according to our knowledge– this is the first socio-economic analysis done specifically in the Tonle Sap area using the data from the recent Population Census 2008. Even more importantly, we are not familiar with any other study in entire Cambodia that would have utilised both Census 1998 and Census 2008 to recognise some (rudimentary) socio-economic trends. Consequently, we hope that our findings will be beneficial for our partners, and will also activate discussion about the methods used as well as findings achieved for the Tonle Sap.

Parallel to this quantitative analysis, a household survey of selected livelihood-related indicators and preferences was carried out. The household survey provides an important additional insight into the Tonle Sap area, including interesting, qualitative information about the different livelihood options and preferences. A logical next step is thus a comparison of the quantitative data presented in this report (particularly in Annex D) with the findings of the household survey: this process will be started in the Third Tonle Sap Futures Workshop, where the findings from both analyses is presented. In addition, our livelihood analysis would also benefit from more thorough

comparison of other recent livelihood studies from the Tonle Sap area (e.g. Nuorteva 2009; Chhun 2010; Hall & Bouapao 2010): any information on such studies is thus most appreciated.

It is also important to acknowledge some limitations or challenges entailed in the livelihood analysis presented in this report. The current definition of the study area excludes most of the Tonle Sap River area, which is intimately connected to, and dependent on, the Tonle Sap system. Consequently, the information presented in this report can be seen to underestimate the role and importance of the entire Tonle Sap area, with the underestimation being particularly major in relation to fishing¹⁴.

¹⁴ Other forms of uncertainties are related to the quality of the socio-economic data used in the analysis. There have for example been changes in the villages of the study area between 1998 and 2008, as new villages have emerged and some villages might have been reclassified from rural to urban or vice versa. Such changes naturally cause some inconsistencies with the sub-area division, but they are not considered to produce major uncertainty in the actual results. Additional challenges include e.g. the definition of different livelihood sectors. For example in the case of fishing, it was not possible to extract fishing-related trade or fish processing from the Census database: the figures presented for fishing and related activities are therefore partly underestimated.

NEXT STEPS

This report and its annexes have presented the methods, study areas and current research findings of the two Research Components of the Exploring Tonle Sap Futures study, namely Hydrological analysis and Livelihood analysis. By doing that, we hope that we have been able to establish both hydrological baseline and livelihood baseline for the Tonle Sap area.

Considerable amount of our analysis builds on methods and information that have not been previously applied in such a way for the Tonle Sap area (see the text box in page 12). Consequently, we hope that our research findings provide new insights to the area, and also act as useful inputs for the discussion about the possible future development paths for the Tonle Sap area.

In addition, the research findings aim to facilitate the on-going scenario workshop process of the Exploring Mekong Region Futures. The workshop process is implemented in close collaboration with CSIRO, TSA and SNEC, and it forms a central part of the entire Exploring Tonle Sap Futures study. The findings presented in this report were discussed in the Third Tonle Sap Futures Workshop that was organised 30.11-2.12.2011 in Kampong Chhnang.

In the Third Tonle Sap Futures Workshop, the research findings were presented under following three main categories:

- 1) Current characteristics of the Tonle Sap area both in terms of hydrology and social & economic issues ('BASELINE/STATUS QUO')
- 2) Key social and economic trends (including key livelihoods) in the Tonle Sap area, as derived from our socio-economic database analyses ('LIVELIHOOD TRENDS')
- 3) Preliminary findings on possible future hydrological changes in the Tonle Sap flood pulse, caused by both development plans (Mekong hydropower etc.) and climate change ('POSSIBLE HYDROLOGICAL CHANGES')

In addition, a natural –and very important– next step would be to combine the results from hydrological and livelihood analyses to understand what kind of livelihoods implications the predicted hydrological changes will have. This is, however, not an easy process, as major uncertainties and knowledge gaps exist particularly in terms of how different natural resources – such as fish and other aquatic animals, wetlands and agricultural land– will respond to changing hydrological conditions (including both quantitative and qualitative changes).

In addition, linking the three entities (hydrological changes, ecosystem / natural resource responses, livelihood impacts) is not an easy undertaking due to large amount of interconnections between the different variations (for more discussion, see: MRCS/WUP-FIN 2007, pages 108-113).

Yet, we are eager to try to create such linkages, and have already included in the synthesis of this report some key interconnections. We also aim to provide more detailed discussion on these interconnections for the Fourth Tonle Sap Futures workshop.

More importantly, however, we see that the on-going scenario workshops process –with the huge amount of local and regional expertise included– will be very helpful in this regard, and we hope that the workshops will also provide a useful forum to discuss the interconnections between Tonle Sap flood pulse, its natural resources, and people living in the area.

We welcome all comments regarding the research findings and ideas presented in this report. Please send your comments to Marko Keskinen and Matti Kummu (firstname.lastname@aalto.fi).

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ANNEXES

ANNEX A: Selected basin-wide assessments of water development and climate change impacts

ANNEX B: Reservoir development in the Tonle Sap floodplain

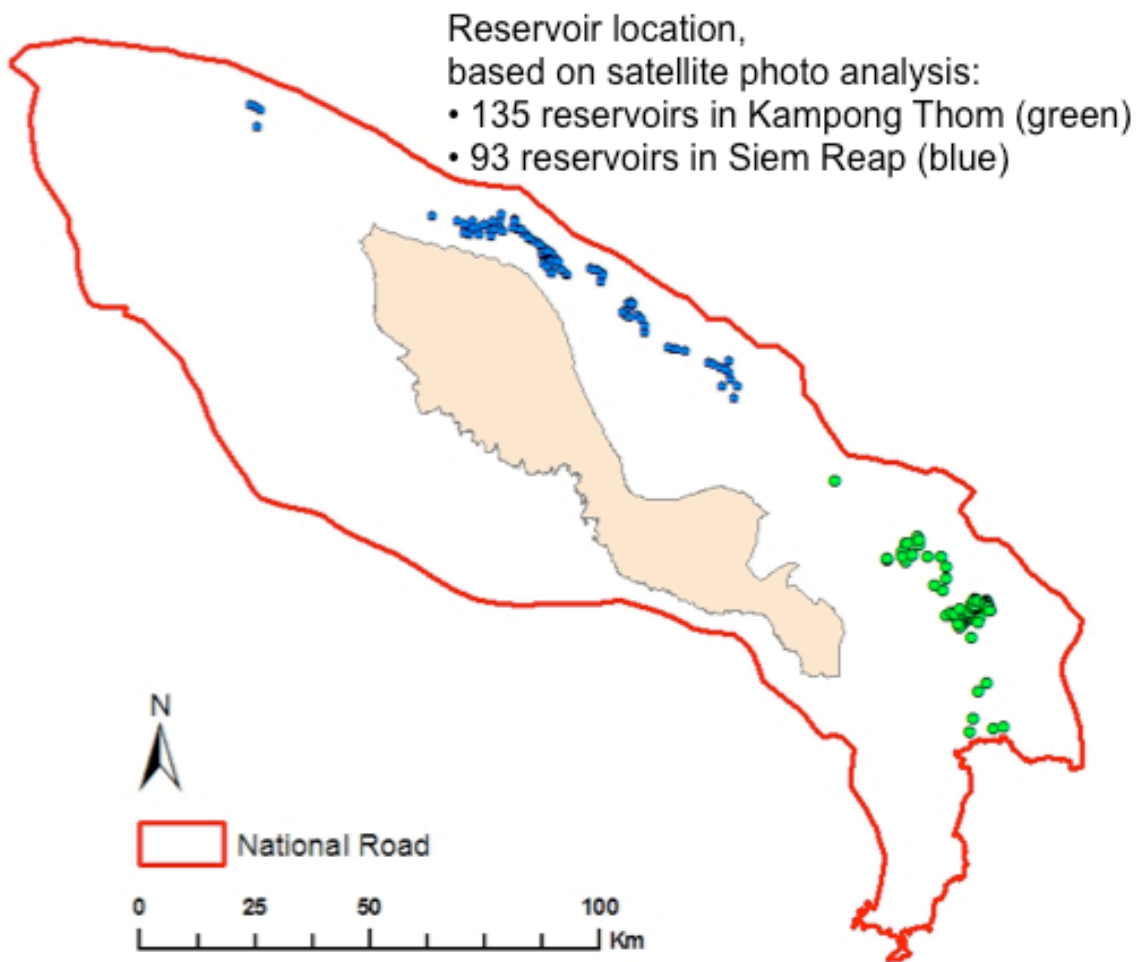
ANNEX C: Climate change impact on discharge

ANNEX D: General socio-economic characteristics for the Tonle Sap

ANNEX A: Selected basin-wide assessments of water development and climate change impacts in the Mekong

Assessment	Setup	Spatial scales	Assessed impacts	Main findings
World Bank synthesis based on MRC Decision Support Framework DSF (World Bank 2004)	MRC's DSF model suite related analyses	LMB hydrology LMB floodplain hydrodynamics	Development	Large hydropower potential with relatively small impacts, maintenance of fisheries production requires special attention
Basin-wide cumulative impact assessment as part of the Nam Thuon 2 impact assessment study (ADB 2004)	Hydrological models (Mike Basin, Mike 11) related analyses	Basin-wide hydrology LMB floodplain hydrodynamics	Development	Significant hydrological changes bringing both positive (flood prevention, delta support) and negative impacts (fisheries, Tonle Sap system).
MRC Integrated Basin Flow Management (MRC 2006)	Expert panel review combined with modelling (MRC's DSF)	LMB hydrology LMB floodplain hydrodynamics	Development	Substantial room for water development with significant economic benefits. But remarkable negative impacts to fish and the Tonle Sap system.
MRC Lower Mekong Modelling Project (MRC/WUP-FIN 2007)	Modelling (EIA models) complemented with environmental and social analyses	LMB floodplain hydrodynamics	Development	Remarkable negative impacts particularly to fisheries and floodplains. Distribution of the benefits and costs most likely very unequal.
Eastham et al. (2008)	Basic water balance modelling	Basin wide hydrology	Climate change	Rough estimates only. According to those, climate change has rather large impact on the basin's hydrology. The range of change is, however, large.
MRC Strategic Environmental Assessment of mainstream dams (ICEM 2010)	Synthesis of existing modelling and assessment work	Various	Development (and climate change in some extent, but not cumulative assessment)	Hydropower brings benefits, but also significant negative impacts. Due to serious risks and uncertainties the report recommends 10-year moratorium on mainstream dams.
MRC Basin Development Plan assessment (MRC 2010a)	MRC's DSF model suite additional assessments	LMB hydrology LMB floodplain hydrology	Development and climate change	Economic benefits significant, but also negative impacts particularly on fisheries. The more intensive the development, the more uneven the distribution of both benefits and risks.
Västilä et al. (2010)	VIC basin-wide model for hydrology; EIA model for the floodplain	Basin-wide hydrology LMB floodplain hydrodynamics	Climate change	Increase of the modelled annual average, average low (February–July) and average high (August–January) water levels in the LMB floodplains. Flood duration might also increase.
This study	EIA model suite (applied before in WUP-FIN and MRC IWRM work)	Basin-wide hydrology LMB floodplain hydrodynamics	Development and climate change	To be finalised

ANNEX B: Reservoir development in the Tonle Sap floodplain



ANNEX C: Climate change impact on discharge

Table C1: Average change in precipitation, maximum and minimum temperatures, and discharges in Kratie and Chiang Saen, scenario years 2032-2042 compared to baseline 1982-1992.

Scenario	Prec. %	Tmax °C	TMin °C	Discharge Kratie %	Discharge C.Saen %
ccA	7.8 %	1.09	0.72	12.5	7.4
cnA	-2.5 %	1.20	0.80	-11.3	-13.5
giA	5.2 %	1.65	1.10	-1.7	-2.9
mpA	5.6 %	0.93	0.62	6.2	9.1
ncA	8.6 %	1.41	0.96	10.0	13.6
avgA	4.9 %	1.26	0.84	3.1	2.7
ccB	5.8 %	0.86	0.59	7.2	3.5
cnB	1.2 %	0.85	0.57	-0.7	-9.7
giB	1.4 %	1.58	1.04	-7.6	-4.1
mpB	3.7 %	0.68	0.44	1.2	-2.2
ncB	4.7 %	1.05	0.72	3.3	-3.5
avgB	3.4 %	1.00	0.67	0.7	-3.2

ANNEX D: General socio-economic characteristics for the Tonle Sap

The annex is available by request.