USAID Mekong Adaptation and Resilience to Climate Change (USAID Mekong ARCC)

Climate Change in the Lower Mekong Basin

An Analysis of Economic Values at Risk

July 2014

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TABLE OF CONTENTS

TABLES AND FIGURES

EXECUTIVE SUMMARY

Through a five year project funded by the United States Agency for International Development (USAID), Development Alternatives Inc. (DAI) is conducting research on the environmental, economic, and social effects of climate change in the Lower Mekong Basin (LMB) and assisting highly exposed and vulnerable rural populations in ecologically sensitive areas to increase their ability to adapt. A central objective of the USAID Mekong Adaptation and Resilience to Climate Change (USAID Mekong ARCC) project is to bridge the knowledge gap between high-level science and on-the-ground community responses. DAI has partnered with the International Centre for Environmental Management (ICEM) and World Resources Institute (WRI) to implement the USAID Mekong ARCC project.

A key role of WRI is providing economic analysis support for the USAID Mekong ARCC, including analysis of the likely consequences of climate change. This report presents some preliminary results. The economic impacts of climate change in LMB are expected to be wide-ranging, significant, and mostly negative. Of most concern are significant reductions in the yield of crops, fish, and non-timber forest products critical for livelihoods of over 60 million people, damages associated with floods and sea level rise, and an increase in the incidence and severity of climate-related disease. Understanding the potential magnitude of these impacts over time is critical for making wise investments in appropriate adaptation measures, but the range of uncertainty in climate models downscaled to any particular region remains too great for reliable estimates. These, in turn, lead to significant differences in estimates of economic losses (e.g. Tol 2012; Heal and Milner 2013).

The Values at Risk Approach

As a result of these uncertainties, a more tractable, and more reliable approach to understanding the economic consequences of climate change in any one particular region may be to simply understand the existing economic value of resources at risk rather than projecting into the future exactly how the value of that resource will change over decades given complex interactions across multiple economic sectors. Such a values-at-risk (VAR) approach can still make use of climate models downscaled to a particular region, country, or province to identify at-risk economic resources that are likely to be affected but without pinning predictions of economic costs on any particular level of impact or timing of impact. As such, in the VAR framework, there is less emphasis on sophisticated modeling of the various dimensions of climate change as it unfolds and the interactions between them and more emphasis on understanding the existing economic values of resources that are reasonably well known to be at risk given likely changes in temperature, rainfall patterns, and sea level rise.

This report presents preliminary VAR estimates for key resources expected to be impacted by climate change in the LMB. These include rural and urban infrastructure, worker productivity, crop production, hydroelectric power, and ecosystem services. To generate VAR estimates for each of these resources WRI utilized the climate modeling of USAID Mekong ARCC's Climate Change Impact and Adaptation Study for the LMB (hereafter referred to as *"Climate Study"*) used by ICEM to identify the geographic regions likely to be impacted by increases in flooding, drought, temperature extremes and sea level rise then applied existing methods local data sources to generate VAR estimates. For example, the USAID Mekong ARCC Climate Study team identified areas likely to be newly inundated by river flooding and sea level rise in the Tonle Sap and Vietnam Delta portions of the LMB (Carew-Reid et al. 2013). Within these geographic areas, WRI estimated the existing value of both rural and urban infrastructure in these areas using FAO data and regional studies of exposed infrastructure assets (Figure 1). WRI used the Climate Study modeling of temperature extremes in combination with province-specific data on workers in outdoor occupations to identify worker productivity at greatest risk from heat stress (Figure 2). As another example, WRI used the Climate Study modeling to identify ecozones expected to be exposed to new flooding, sea level rise, or extreme temperatures. Using the results of ecosystem service valuation studies from across the region (e.g. Brander and Eppink 2012) WRI then tallied the annual ecosystem service values at risk in these areas (Figure 3). This generalized approach was applied to each of the five key resources addressed by the study.

Key Results

Table A below presents each of the mean annual VAR estimates for each of the five resources. All told, our analysis of five resource types suggests the minimum annual values at risk in the LMB are roughly US$16 billion per year. Worker productivity ranks as the most significant value at risk, accounting for more than half of the total, which is similar to findings of other regional assessments, such as the recent Climate Vulnerability Monitor (CVM) report (DARA 2012a).

We also corroborate CVM and other regional assessments (e.g. World Bank 2010; Costanza et al. 2011; Nicholls et al. 2008) that suggest there are significant values at risk for agriculture, infrastructure in coastal zone, and ecosystem services. Few other studies have attempted to quantify climate-related costs associated with hydro-electric power production. Our VAR analysis suggests that a more in-depth analysis of impacts to hydro-electric power is worth investigating, given that the value of production from just the few facilities located in areas at risk from increased evaporation and drought top US$434 million per year.

Table A: Summary of Minimum Annual Values at Risk

Excluding Infrastructure Assets (same as Table 9)

Values at risk component	Mean VAR- ($2013-mil)
Non-agricultural infrastructure services	$3,426.67
Worker productivity	$8,370.67
Crop production	$2,545.75
Hydro-electric power generation	$434.17
Ecosystem services	$1,240.85
Totals	$16,018.11

To put these values into perspective, the US$16.02 billion annual VAR translates into roughly 7% to 30% of rural GDP in the LMB (PPP adjusted, Table B). If the US$18 billion of at risk infrastructure is included, this range increases to 14% to 61%. Typically, economists distinguish between impacts to capital assets like infrastructure and the annual service they generate (like crop production) and don't add the two together. But either way, the analysis indicates that climate change represents a profound risk to the economy of the LMB—one that warrants a more careful and robust analysis of that risk as well as alignment of adaptation strategies to reduce that risk where possible.

Table B: Minimum Annual Values at Risk – Share of Rural GDP (same as Table 10)

Country	Mean VAR- no infrastructure (% rural GDP per capita)	Mean VAR- w/ infrastructure (% rural GDP per capita)
Cambodia	29.01%	61.27%
Lao PDR	23.63%	49.92%
Thailand	6.72%	14.19%
Vietnam	18.77%	39.64%

The magnitude of these values at risk in the LMB justify significant investments in adaptation measures such as workplace heat assessments and protection measures, eco-resilient cropping techniques, and green infrastructure for storm surge protection.

Policy Implications

While the VAR approach does not generate precise estimates of how climate change costs will unfold over time or where such costs are likely to manifest at a fine spatial scale, it nonetheless provides useful information to guide policy choices. There are three general uses of a VAR assessment: (1) in setting priorities for adaptation investments; (2) to provide a preliminary test of cost effectiveness of these investments, and (3) to help inform planning and land use decisions to avoid unnecessary exposure to climate risks. LMB countries should invest in VAR assessments to achieve these policy goals. A robust VAR for each LMB country could help identify strategies that are missing or not getting the attention they deserve.

For example, adaptation strategies to reduce the economic costs of lost worker productivity were surveyed by Nilsson and Kjellstrom (2010) and include measures such as guidelines for workplace heat assessment and protection, strengthening national health systems to respond to the specific needs of working populations, and changes in work practices such as increased rest periods. Cambodia's current climate adaptation strategy (MOE 2006) does not incorporate these or any other measures related to worker productivity and so a VAR assessment can help make the case as to why such interventions are an economic imperative.

Next Steps

This report presents a rough, first pass at VAR for the LMB largely to demonstrate the approach. Data underlying the values at risk estimates were based on publically available information that is often aggregated up to broad geographic regions (i.e. the value of crop production is averaged country-wide) and so are limited in their accuracy and scope. A more rigorous assessment could include, for example, original valuation studies of ecosystem services at risk in particular places based on actual use patterns by local communities, such as the Gerrard (2004) assessment of ecosystem services provided by the That Luan Marsh. Vulnerabilities to hydroelectric facilities could be informed by better data on the likely increase in upstream irrigation demands in portions of the LMB that will be affected by an increase in agricultural drought months. Effects on worker productivity could be better refined through analysis of how various heat stresses related disorders are already being manifested in multiple outdoor occupations, not just agriculture and construction. The magnitude of values at risk quantified in this rough first cut suggests that additional research along these lines could be of great worth in informing the scale and scope of adaptation programs in the years ahead.

IN BRIEF

- The economic impacts of climate change in the Lower Mekong Basin (LMB) are expected to be wide-ranging, significant, and mostly negative. Of most concern are significant reductions in the yield of crops, fish, and non-timber forest products critical for livelihoods of over 60 million people, damages associated with floods and sea level rise, and an increase in the incidence and severity of climate-related disease.

- Understanding the potential magnitude of these impacts over time is critical for making wise investments in appropriate adaptation measures, but the range of uncertainty in climate models downscaled to any particular region remains too great for reliable estimates.

- What is less uncertain is the existing economic value of resources in areas modeled to be at greatest risk from changes in temperature, rainfall, and sea level. An assessment of existing values at risk (VAR) rather than complex forecasts of economic costs over decades strikes an appropriate balance between using climate models for what they are good at, and not using them where they are less reliable.

- Here, we present a preliminary VAR analysis for the LMB based on climate change modeling completed by a team of researchers at the International Centre for Environmental Management (ICEM).

- Using this VAR approach, we estimate the annual value of infrastructure services, worker productivity, agricultural output, hydroelectric power, and ecosystem services at risk from climate change in the LMB to be at least US$16 billion per year. In addition, we estimate the value of infrastructure assets at risk in areas expected to be inundated more frequently or permanently to be at least US$18 billion. Combined, this represents a per capita risk of US$564, or up to 61% of rural GDP per capita in the LMB.

- The magnitude of these values at risk in the LMB justify significant investments in adaptation measures such as workplace heat assessments and protection measures, eco-resilient cropping techniques, and green infrastructure for storm surge protection.

- This report demonstrates how a VAR assessment can help inform policy in three important ways: (1) by helping to set adaptation priorities based on level of economic risk; (2) by providing a preliminary indication of the cost effectiveness of adaptation measures, and (3) by helping to steer land use and infrastructure decisions away from high risk activities.

- LMB countries should invest in VAR assessments to achieve these policy goals. This report provides a rough template for doing so based on publicly available data. A more complete and robust VAR would rely on more site specific information such as original valuation studies for ecosystem services at risk, or surveys to generate more precise estimates of the number of workers in both formal and informal sectors potentially exposed to a greater incidence and severity of heat stress.

1.0 OVERVIEW

The LMB is widely recognized as a region highly vulnerable to the impacts of climate change. The fourth assessment of the Intergovernmental Panel and Climate Change (IPCC) synthesized current scientific understanding of the impacts of climate change on water resources (Bates et al., 2008). The assessment indicated that the mega-deltas of the big river basins in Asia are considered particularly vulnerable because of the combination of flooding, sea level rise and large populations living there (MRC 2011). Many of the impacts anticipated by IPCC can be expected to affect the LMB.

As part of the early phase of the USAID Mekong ARCC project, ICEM took the lead in producing the scientific evidence base for identifying highly vulnerable and valuable agricultural and natural systems assets in the LMB, defining adaptation options and priorities, guiding the selection of focal areas for enhancing existing adaptation and demonstrating and testing new adaptation strategies. The USAID Mekong ARCC's Climate Change Impact and Adaptation Study for the Lower Mekong Basin, released in November 2013, relied in part on downscaling global climate models to the LMB in order to describe impacts on key livelihood sectors of the LMB including agriculture, capture fisheries and aquaculture, livestock, natural systems, and health and rural infrastructure (Carew-Reid et al. 2013). The USAID Mekong ARCC Climate Study generated a wealth of quantitative data that can be incorporated into a complementary assessment of economic impacts—one that assigns dollar values to resources at greatest risk.

WRI, as part of its role in providing economic analysis support for the USAID Mekong ARCC, has completed a preliminary values at risk (VAR) analysis to fill this role. This report presents our results, which are not based on detailed scenarios of economic impacts over time, but on a more tractable approach that considers existing economic values at risk based on USAID Mekong ARCC's forecasts of changes in the pattern of temperature, rainfall, and flooding in the LMB at a province level. The findings presented here are not a substitute for more rigorous, and more detailed economic impact assessments that should be commissioned by affected governments and completed with appropriate teams of researchers across multiple disciplines.[1] Instead, the WRI analysis presented here provides a rough sense of the likely magnitude of economic values at risk implied by the Climate Study data in order to inform the selection of cost-effective adaptation options to reduce that risk.

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[1] An example of a fully developed, robust assessment of the economics of climate change is provided by the PESTA II (Projection of Economic Impacts of Climate Change) project of the European Commission. The PESTA II project involved two core institutes of the EC's Joint Research Center and six teams representing different expertise areas. Description available online at: http://peseta.jrc.ec.europa.eu/.

2.0 ECONOMICS IMPACTS OF CLIMATE CHANGE IN THE LMB – EXISTING STUDIES

In recent years, concerns over the economic impacts of climate change have provided the impetus for a rapidly proliferating body of assessments at the international, regional, national and local levels that attempt to predict the overall magnitude of damage and its distribution amongst nations and economic sectors. These assessments are helpful in understanding the overall magnitude of economic damages anticipated in the LMB and identifying the sectors at greatest risk. But they also help illustrate the vast uncertainties involved in precise economic modeling of climate change, and thus help make the case for the VAR approach presented in this report.

As an example of studies that report the overall magnitude of expected damage, the new Climate Vulnerability Monitor (CVM) report estimates human and economic impacts of climate change and the carbon economy for 184 countries in 2010 and 2030, across 34 indicators (DARA 2012a). CVM estimates a net economic cost of nearly US$364 billion annually by 2030 for the four LMB countries. Losses in labor productivity are by far expected to be the most significant net cost, followed by costs associated with sea level rise and negative impacts on agriculture and fishery sectors (Table 1).

Table 1: Annual Net Climate Change Costs for LMB Countries by 2030 (US$ Millions PPP Adjusted)

Impact types	Cambodia	Lao PDR	Thailand	Vietnam	Total
Environmental disasters					
Drought	$60	$5	$200	$350	$615
Floods and landslides	$200	$15	$1,000	$2,000	$3,215
Storms	-	-$35	-$35	-$75	-$145
Wildfires	-	-	-	-	-
Subtotal:	$260	-$15	$1,165	$2,275	$3,685
Habitat change					
Biodiversity	$450	$300	$2,500	$750	$4,000
Desertification	-	-$1	-$650	-$850	-$1501
Heating and cooling	$500	$250	$3,000	$3,750	$7,500
Labor productivity	$9,250	$4,750	$150,000	$85,000	$249,000
Sea-level rise	$1,750	-	$6,750	$40,000	$46,750
Water	-$150	-$750	-$2,250	-$1,000	-$4,150
Subtotal:	$11,800	$4,549	$159,350	$127,650	$303,349
Industry stress					
Agriculture	$1,500	$1,000	$10,000	$6,000	$18,500
Fisheries	$3,000	$150	$8,500	$25,000	$36,650
Forestry	$150	$100	$1,500	$20	$1,770
Hydro energy	-	-	-$60	-$300	-$360
Tourism	-	-	-	-	-
Transport	-	-	-	-	-
Subtotal:	$4,650	$1,250	$19,940	$30,720	$56,560
Climate Impacts Total:	$16,710	$5,784	$180,455	$160,645	$363,594

Source: Dara. 2012b. Climate Vulnerability Model, 2nd Edition.

Additional regional and country studies corroborate some of CVM's predictions. In Vietnam, and as part of its global Economics of Adaptation to Climate Change (EACC) project, the World Bank has published quantitative estimates of economic impacts to agriculture, real GDP, real consumption and aquaculture that are similar in magnitude (World Bank 2010).

Potential costs to urban and coastal infrastructure in LMB countries have been addressed in a handful of studies. As another example, and as part of an assessment of 136 major port cities around the world, Nicholls et al. (2008) quantified the anticipated increase in annual exposure of economic assets to a 1 in 100 year surge-induced flood event with climate change by the 2070s, assuming no new defenses. Estimates were made for 136 port cities including three in LMB countries—Bangkok, Hai Phong, and Ho Chi Minh City. The increase in exposed economic assets from a 2005 baseline year was estimated, respectively, to be US$1,079 billion, US$323 billion, and US$626 billion.

While all these studies and the sophisticated climate models on which they rely indicate the potential for enormous economic consequences, by their very nature they are not particularly useful in predicting where and when the most significant impacts are likely to occur or their magnitude at anything other than at the scale of broad geographic regions and broad macro-economic sectors. Within the LMB, for example, there are some crops and provinces where agricultural productivity may increase, but others where it will decline. Hydro-energy may be adversely affected by reduced dry season runoff or in areas where rainfall will become more erratic, but benefit by greater flows in aggregate basin-wide (Eastham et al. 2008). Reporting net, aggregate impacts across the region is then of limited value to decision about where and when to invest in appropriate adaptation at a fine scale.

3.0 A VALUES-AT-RISK APPROACH FOR DEALING WITH MODEL UNCERTAINTY

There are vast uncertainties in underlying climate models. These, in turn, lead to significant differences in estimates of economic losses. As an illustration, Tol (2012) completed a meta-analysis of studies that predicted total economic impact of climate change. Even within a relatively small subset (14) of studies that modeled a 2.5°C increase in temperature there was enormous variation. Taken together, these studies predict a loss of output of −0.7% of GDP, but have a standard deviation of 1.2% of GDP. In other words, the range of variation is nearly twice the average value, making that average value almost meaningless. As noted by Heal and Milner (2013) "[e]mpirical uncertainties arise from our inability to predict the evolution of the global economy (how rich we will be), the future costs of CO_2 abatement (which technologies will be available), how damaging climate change will be to future economies, and how we will adapt to its effects. All of these factors are crucial inputs to designing 'optimal' climate policies, yet the tools we use to forecast them are educated guesses at best."

As a result of these uncertainties, a more tractable and more reliable approach to understanding the economic consequences of climate change in any one particular region may be to simply understand the existing economic value of resources at risk rather than projecting into the future exactly how the value of that resource will change across multiple climate models. Such a "values-at-risk" approach can still make use of climate models downscaled to a particular region, country, or province to identify at-risk economic resources that are likely to be affected but without pinning predictions of economic costs on any particular level of impact or timing of impact. As such, in the VAR framework, there is less emphasis on sophisticated modeling of the various dimensions of climate change as it unfolds and the interactions between them and more emphasis on understanding the existing economic values of resources that are reasonably well known to be at risk given likely changes in temperature, rainfall patterns, and sea level rise. Nicholls et al. (2008) demonstrated this in their study of economic assets at risk from a 1-in-100 year surge-induced flood event at port cities around the world.

Limiting consideration to existing economic values at risk also obviates the need to make often heroic assumptions about future patterns of land use, economic growth, trade, technology, level of adaptation or any other factor used in more complicated economic impact models. Instead, the methodology involves developing a limited number of scenarios about how much of the asset base in question is at risk. As an example, as part of the University of Oxford's Stranded Assets program, Caldecott et al. (2013) set out three scenarios to test to what extent declining natural capital, climate change, and other environmental stresses could place the stock of invested capital in agriculture at risk globally. The report found a one-in-20 chance the world's farmland assets and agricultural capital stock could lose between US$4.4 trillion and US$8 trillion in a single year.

While it could be argued that the information presented in a values-at-risk approach may be much less useful to decision making about adaptation investments in particular places for particular resources, it nonetheless provides at least a good first cut at the overall magnitude of potential damages (i.e. millions or billions) and thus helps decision makers begin to plan ahead for leveraging a commensurate level of resources needed to effectively reduce risk.

3.1 VALUES-AT-RISK ANALYSIS FOR THE LMB

To demonstrate the feasibility of this approach for the LMB, we used the climate study results of downscaled climate models and country-specific economic data to develop values at risk in five categories of economic resources—built infrastructure, worker productivity, crops, hydroelectric generation and ecosystem services. Within the LMB and Asian region in general, existing studies confirm that climate change is likely to pose significant risks to each of these economic resource categories (e.g. Dara 2012b; World Bank 2010; Nicholls et al. 2008). While there are many other cost categories to consider—public health, for example—they are beyond the limited scope of this analysis, which is based on information generated by the Climate Study modeling. Moreover, throughout, we report minimum values at risk that represent only those values that we can reasonably approximate given available data. As a result, actual values at risk may be substantially higher.

3.1.1 Built infrastructure

Throughout the LMB, the existing network of roads, bridges, communication lines, structures, irrigation systems, permanent crop and livestock areas, energy systems and other components of the built environment are at risk from climate change through a number of channels. In addition to the more obvious impacts associated with flooding and damage from severe storms, increased temperatures are likely to stress built infrastructure and require more frequent repair or replacement. Increases in rainfall and humidity are likely to foster mold, termites, and other damaging agents (Snow and Prasad 2011). Pinpointing if and where these impacts will occur and their magnitude is beyond the reach of climate modeling, but what is apparent is that most if not all of the existing built infrastructure in the LMB will be exposed to at least some level of increased risk.

To get a sense of the minimum values at risk in the LMB we confined the scope of our analysis to the areas with the greatest likelihood of increased flooding with climate change and an expected sea level rise of 0.3 meters. In their modeling, the Climate Study produced a number of flooding scenarios that considered the annual area flooded to depths of 0.2, 0.5 and 1.0 meters under average flooding, 1-in-100 year floods, and 1-in-100 year floods with an extreme typhoon in the Tonle Sap and Mekong delta portions of the LMB in Vietnam and Cambodia. The remainder of the LMB was not modeled, and so this analysis is limited to just these areas and thus probably represents a considerable underestimate.

Each of the Climate Study flooding scenarios was also analyzed with respect to existing (baseline) conditions and those expected with climate change. To be conservative in our estimates and to make the analysis tractable, we limited our analysis to only the scenario in which lands would be flooded “on average” to a depth of 0.5 meters with a 0.3-meter sea level rise. Using the Climate Study spatial data layers for this scenario, we calculated the difference between the area of existing (baseline average) flooding and area of new flooding under the scenario. In our calculations, we also differentiated between rural and urban areas.[2] Under this flooding scenario, a total of 356,583 hectares of newly flooded rural lands and 5,715 hectares of existing[3] and newly flooded urban lands are anticipated (Tables 2 and 3).

With respect to infrastructure at risk in these areas, there are two important distinctions to make. The first is between the capital stock at risk and the annual flow of goods and services generated by that stock. So, for example, irrigation canals, seeds, livestock pens, fish ponds and the like are the capital stocks used by the agricultural sector that produce an annual flow of meat, fish, and crops. In cities, the capital stock consists of buildings, offices, factories, ports and such and produces a wide variety of goods and services across multiple economic sectors. In the VAR framework, it is important to value both capital stocks and flows. The second important distinction is between rural and urban infrastructure. Obviously, they differ drastically and thus ought to be differentiated in the analysis.

To assign a minimum value at risk for infrastructure in newly flooded rural areas, we began with Food and Agriculture Organization's (FAO) periodic assessments of net agricultural capital stocks for Vietnam and Cambodia.[4] FAO's net capital stock includes land improvements, livestock, plantation crops, machinery, structures and other assets used in agricultural production. We updated FAO's 2007 data for Vietnam and Cambodia to current (2013) dollars using country-specific inflation indices, and then accounted for net capital stock additions during the 2007 to 2012 period in two separate ways.

The first used annual country-level statistics on gross capital formation published by Mundi.[5] The total value of gross capital formation during the 2007 to 2013 period was then multiplied by the agricultural share of GDP as an approximation of net capital formation for this sector. The second approach was to assume a rather low, but defensible rate of net capital stock formation in agriculture of 1% per year based on estimates by Anriquez et al. (2009). This provided a high and low range for the total value of the agricultural capital stocks in the two countries. We then divided these stock estimates by FAO's latest estimates of the area of land in agricultural production and the area of land in permanent crops and livestock to get a range of per-hectare capital stock figures.[6] This generated low (US$1,659), medium (US$5,668) and high (US$8,525) per hectare values.[7] The mean value was US$5,284 per hectare.

The final step was simply to multiply the low, medium, high and mean per-hectare capital stock estimates by the amount of new rural flooding anticipated for each province. The results appear below

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[2] For urban areas, we relied on Natural Earth Data, 1:10m scale urban areas, derived from Schneider, A., M. A. Friedl, D. K. McIver, and C. E. Woodcock (2003). Mapping urban areas by fusing multiple sources of coarse resolution remotely sensed data. *Photogrammetric Engineering and Remote Sensing*, Volume 69, pages 1377-1386. Downloaded from naturalearthdata.com on 6 Aug 2013.

[3] The reasons for including existing flooded areas in urban land uses are discussed below.

[4] The relevant FAO data portal is available online here: http://faostat3.fao.org/faostat-gateway/go/to/download/I/CS/E. Although there are other infrastructure elements in these rural areas, FAO's data provides a good approximation given the very high percentage of economic activity in these areas represented by agricultural.

[5] Mundi publishes annual figures for a wide range of economic indicators, including gross capital formation. Data is available online at: http://www.indexmundi.com/facts/.

[6] The area of agricultural production is the total area devoted to crops and livestock regardless of intensity or permanence. The area in permanent crops/ livestock is smaller, and represents the more intensively and regularly used lands.

[7] Dividing the low total agricultural capital stock figures by area of agricultural production yielded the low per hectare estimate used in our analysis (US$1,659). Dividing the high capital stock figure with the area of permanent crops/livestock yielded the high per hectare estimate of US$8,525. Dividing the high capital stock figure by the larger area of agricultural production yielded the medium estimate of US$5,668 per hectare.

in Table 2. As indicated in Table 2, the total value of rural infrastructure at risk using these methods ranges between US$4.9 to US$16.4 billion, with the vast majority of the stock at risk in the Ca Mau, Kien Giang and Ben Tre provinces in Vietnam where additional climate change induced inundation is expected to be the most widespread.

For the value of urban infrastructure at risk, we used a different approach since there are no publically available sources of data that directly measure the value of the urban capital stock. Here, we followed the general approach of Nicholls et al. (2008). In their analysis, they make the case for a formula that approximates the value of capital assets in urban areas to be roughly five times the value of GDP per capita times the population of the area in question.

Table 2: Minimum Value of Rural Infrastructure at Risk from New Flooding

Tonle Sap and Vietnam Delta Regions (Flood scenario of .5m and sea level rise of .3m)

Country	Province	Newly flooded area (ha)	VAR-lo ($2013-mil)	VAR-med ($2013-mil)	VAR-hi ($2013-mil)	VAR-mean ($2013-mil)
Cambodia	Banteay Meanchey	280	$0.46	$1.59	$2.39	$1.48
	Battambang	272	$0.45	$1.54	$2.32	$1.44
	Kampong Cham	184	$0.31	$1.04	$1.57	$0.97
	Kampong Chhnang	130	$0.22	$0.74	$1.11	$0.69
	Kampong Speu	0	$0.00	$0.00	$0.00	$0.00
	Kampong Thom	396	$0.66	$2.24	$3.38	$2.09
	Kampot	1,191	$1.98	$6.75	$10.15	$6.29
	Kandal	1,662	$2.76	$9.42	$14.17	$8.78
	Kratie	4	$0.01	$0.02	$0.03	$0.02
	Phnom Penh	55	$0.07	$0.25	$0.38	$0.23
	Prey Veng	984	$1.63	$5.58	$8.39	$5.20
	Pursat	136	$0.23	$0.77	$1.16	$0.72
	Siemreap	128	$0.21	$0.73	$1.09	$0.68
	Takeo	1198	$1.99	$6.79	$10.21	$6.33
	Cambodia subtotal:	6,609	$10.96	$37.46	$56.34	$34.92
Vietnam	An Giang	1,427	$20.00	$49.95	$67.27	$45.74
	Bac Lieu	20,311	$284.72	$710.90	$957.50	$651.04
	Ben Tre	43,497	$609.73	$1,522.43	$2,050.53	$1,394.23
	Ca Mau	136,122	$1,908.13	$4,764.38	$6,417.04	$4,363.18
	Can Tho	3,283	$46.02	$114.91	$154.77	$105.23
	Dong Thap	7,452	$104.46	$260.83	$351.30	$238.86
	Hau Giang	9,203	$129.01	$322.11	$433.85	$294.99
	Kien Giang	89,885	$1,259.99	$3,146.05	$4,237.34	$2,881.13
	Long An	33	$0.46	$1.16	$1.56	$1.06
	Soc Trang	1,801	$25.25	$63.04	$84.90	$57.73
	Tien Giang	24,124	$338.17	$844.36	$1,137.25	$773.26
	Tra Vinh	4,916	$68.91	$172.06	$231.75	$157.57
	Vinh Long	4,670	$65.46	$163.45	$220.15	$149.69
	Vietnam subtotal:	346,724	$4,860.32	$12,135.62	$16,345.21	$11,113.71
	Grand total:	353,333	$4,871.28	$12,173.08	$16,401.54	$11,148.63

To estimate the urban population, we used recent population density estimates for Phnom Penh, and multiplied this figure by the area of urban lands in the LMB exposed to both baseline and new flooding to a depth of 0.5 meters with a 0.3-meter sea level rise. The reason for including baseline area is the fact that climate changes will likely cause both an increase in the intensity and frequency of floods in areas already exposed, as well as increased exposure for areas not now being flooded. And in contrast with rural areas, where adaptation to regular flooding is already built into the management of agricultural lands, in urban areas, there has been little success to date in reducing exposure in areas already prone to flooding let alone areas expected to flood for the first time with rising seas and more intense rainfall events. Methods for deriving the relevant urban GDP per capita values are discussed below. By multiplying these values by five—following the Nichols (2008) methodology—and then multiplying by the urban area at risk we estimate that the minimum value of urban infrastructure at risk in four LMB provinces—Kandal, Phnom Penh, Can Tho and Vinh Long—to be nearly US$6.7 billion (Table 3).

In terms of the annual flow of goods and services generated by infrastructure at risk, we again relied on a general methodology developed by Nicholls et al. (2008). Their methodology was to assume that the annual value of services generated by infrastructure was best approximated by per-capita GDP multiplied by the population in a given area. Per capita GDP, however, varies considerably between urban and rural areas, and the magnitude of this GDP gap has been studied in at least one LMB country—Cambodia (World Bank 2009). The analysis found that the urban/ rural income gap was approximately 2.39:1, and so we used this figure to derive estimates for rural (US$1,822) and urban (US$4,355) GDP per capita for our analysis.[8] We aggregated the flood areas from Cambodia and Vietnam into a single region to simplify the analysis, and so these figures represent rural and urban GDP per capita estimates for the aggregated region as a whole.

Table 3: Minimum Value of Urban Infrastructure at Risk from Flooding

Tonle Sap and Vietnam Delta Regions (Flood scenario of 0.5m depth and sea level rise of 0.3m)

Country	Province	Urban area at risk (hectares)	Exposed population	Infrastructure value at risk ($2013-mil)
Cambodia	Kandal	824	44,150	$961.36
	Phnom Penh	2,683	143,755	$3,130.27
Vietnam	Can Tho	1,772	94,944	$2,067.40
	Vinh Long	436	23,361	$508.68
	Totals:	5,715	306,210	$6,667.71

The resulting annual urban and rural GDP at risk was calculated by multiplying the per capita figures by current population estimates for these two areas within the anticipated flood zones in each province. For the urban area at risk, we estimated population by using a population density figure of 54 persons per hectare from Phnom Penh and applied this to the total area of urbanized lands by province at risk from both baseline and new floods. For rural areas, we used province level population density figures updated to 2013, multiplied these by the area in newly flooded zones, and then backed out the urban population estimate.[9]

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[8] The derivation was made by assuming that the country-level average per capita GDP represents a weighted average between rural and urban GDPs per capita. The formula was then solved for the respective rural/urban values using weights implied by the World Bank (2009) study.

[9] LandScan (2007)™ High Resolution global Population Data Set copyrighted by UT-Battelle, LLC, operator of Oak Ridge National Laboratory under Contract No. DE-AC05-00OR22725 with the United States Department of Energy. The 2007 figures were updated to 2013 based on mean growth rates for the two countries over the past five years.

A complicating factor in this analysis is the potential for double counting the value of agricultural output at risk, which is discussed below in Section 3.1.3. To exclude this, we simply multiplied the mean agricultural share of GDP for Cambodia and Vietnam to the rural GDP at risk estimate and then subtracted this amount from the total. The results of this analysis are shown in Table 4 and Figure 1. We estimate the minimum annual value of infrastructure services at risk from increased flooding in the Tonle Sap and Vietnam Delta portion of the LMB to be over US$4.2 billion. Of this, at least US$3.43 billion is attributable to non-agricultural services.

To reiterate, these values are for just two portions of the LMB. Values for the entire LMB can be expected to be considerably greater. While it may be reasonable to extrapolate these findings to arrive at estimates for the entire LMB, we hesitate to do so given the spatially explicit nature of the underlying flooding risk.

Table 4: Minimum Value of Annual Infrastructure Services at Risk from Flooding

Tonle Sap and Vietnam Delta Regions (Flood scenario of 0.5m depth and sea level rise of 0.3m)

Infrastructure services category	Values at risk ($2013-mil)
Urban infrastructure services at risk	$1,333.54
Rural infrastructure services at risk	$2,911.16
Total infrastructure services at risk	$4,244.70
Less agricultural share at risk in rural areas	-$1,192.76
Total non-agricultural services at risk	$3,426.67

3.1.2 Worker Productivity

One of the most significant economic impacts predicted with climate change is a reduction in worker productivity, especially for the portion of the workforce engaged in outdoor occupations such as agriculture, forestry, fishing and construction. In CVM's assessment for LMB countries, lost productivity accounted for 80% of the economic impacts anticipated. Workers in outdoor industries are likely to be exposed to a greater incidence and severity of health disorders including heat rash, transient heat fatigue, heat syncope, heat cramps, heat exhaustion, and heat stroke (Roy et al. 2011). These disorders, in turn, are likely to reduce work performance and hours worked and increase accident rates. Globally, it is predicted that climate change and increased humidity may reduce labor productivity by 20% by 2050 (Dunne et al. 2013).

To estimate the minimum value of worker productivity at risk in the LMB, we began with the Climate Study downscaled modeling of anticipated temperature change. Climate threat modeling undertaken for the Climate Study shows that annual average daily maximum temperatures will increase by between 7% to 16 % or 1.6°C to 4.1°C, with the most significant increases taking place in the Srepok, Se Kong and Sesan river basins (Carew-Reid et al. 2013, p. 87). We obtained the relevant spatial data, aggregated these data up to the province level, estimated a mean change value for each, and assigned a worker productivity loss figure based on the range reported by Dunne et al. (2013). Provinces were grouped into three tranches: (a) low temperature change and worker productivity losses of no more than 10%; (b) moderate temperature changes and worker productivity losses from 11% to 15%; and (c) high temperature increases and worker productivity losses up to 20%.

We then calculated the size of the workforce in each province in two major outdoor sectors—agriculture and construction—through a series of calculations based on updated population figures, demographics, labor force, unemployment rates and employment shares.[10] It was not possible from publically available data to include estimates for other outdoor sectors, and so again it is important to reiterate that the values at risk calculated here are conservative.

The next step involved valuing annual worker productivity in each sector. The annual value of worker product for each sector was calculated by dividing that sector's contribution to national GDP by the size of the workforce in that sector.[11] For agriculture, this generated a range of US$928 to US$2,759 per worker per year. For construction, this generated a range of US$1,627 to US$2,373 per worker per year. The portion of this product at risk was then calculated on a province-by-province basis using assigned productivity loss values of 10%, 15%, or 20% depending on the degree of temperature increase anticipated. Average annual values at risk per worker are reported in Table 5.

With these values in hand, the value of worker productivity at risk for the two sectors was then calculated on a province by province basis by multiplying the per worker loss estimates by the number of exposed workers in each sector. The province level at risk values estimates were then added up country by country.

The results appear in Table 5 and spatially in Figure 2. As indicated by Table 5, publically available data suggest that there are 33.2 million workers in the agricultural sector in the LMB provinces included in our analysis, and over 2.2 million in the construction sector. The value of each worker's product at risk from ranges from US$140 to US$374 per worker per year. For the agricultural sector, this translates into an annual value at risk of over US$7.7 billion. For the construction sector, this implies an annual value at risk of over US$666 million. The total—nearly US$8.4 billion per year—is a conservative estimate because many other outdoor occupations were not measured.[12]

Table 5: Minimum Value of Worker Productivity at Risk in the LMB

(Limited to agricultural and construction workers)

Country	Workforce exposed		Annual value at risk – per worker ($2013)		Annual value at risk by sector ($2013-mil)		Total ($2013-mil)
	Ag	Cons	Ag	Cons	Ag	Cons	
Cambodia	7,471,421	242,087	$202.77	$261.58	$1,515.00	$63.33	$1,578.32
Lao PDR	3,377,144	212,259	$140.85	$303.46	$475.66	$64.41	$540.01
Thailand	11,757,320	889,987	$332.28	$241.40	$3,906.76	$214.85	$4,121.61
Vietnam	10,600,458	866,097	$170.47	$373.66	$1,807.11	$323.63	$2,130.73
Totals	33,206,343	2,210,430			$7,704.53	$666.22	$8,370.67

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[10] Macro-economic and labor force statistics were obtained from Mundi. Employment shares were obtained at the province level for agriculture from MRC (2003). Employment shares for construction were obtained from Vietnam's General Statistics Office, Thailand's Sector Activities Department, and for Cambodia from Niraula and Kusayanagi (2005). The construction share for Lao PDR was averaged across these three.

[11] See note 10 for a list of sources on which these calculations were based.

[12] As identified by Roy et al. (2011), these include rickshaw pullers, traffic police, outdoor professional athletes, street vendors, housewives, and but/taxi/auto drivers.

3.1.3 Crop Production

Throughout the LMB, anticipated changes in temperature and rainfall are likely to have a significant impact on agricultural production. These impacts can be both beneficial and adverse, because for any given crop, the area of land suitable for growing that crop can either expand or contract. The USAID Mekong ARCC Climate Study team modeled suitability implications for eight major crops grown in the LMB—rain fed rice, irrigated rice, maize, cassava, soya, sugar, rubber and coffee robusta. For each the team modeled both positive and negative shifts in the suitable land base on a province-by-province basis and with respect to major biomes. As an example, the team found that for rubber, climate change would probably increase the suitability of growing lands by 5,500 square kilometers in the high elevation moist broadleaf forest zone in northern Thailand, but decrease suitability by 7,000 square kilometers across five forest types in the Chi Mun basin (Carew-Reid et al. 2013, p. 114). The team also modeled anticipated changes in yield for rainfed rice (+4.6 to -4.8 tons/ha) and maize (-3.13 to -12.09 tons/ha) and identified which crops were most vulnerable to increased temperature, precipitation, and increased storms and flooding within eight distinct "hotspot" provinces (Carew-Reid et al. 2013, pp. 116–118).[13] These provinces include: Chiang Rai – Thailand, Sakon Nakhon – Thailand, Khammouan – Lao PDR, Champasak – Lao PDR, Mondul Kiri – Cambodia, Kampong Thom – Cambodia, Gia Lai – Vietnam, Kien Giang –Vietnam.

Anticipated effects on suitability and yields for key crops have also been discussed in other regional climate impacts assessments. These studies also show a high degree of variability in response crop-to-crop, basin-to-basin. For example, climate modeling completed by Vietnam's Ministry of Natural Resources and Environment predicts a net decline in million metric tons (mmt) annual production for paddy rice (-3.4 to -6.7 mmt), maize (-0.6 to -1.1 mmt), cassava (-0.6 to -2.6 mmt), sugar cane (-1.4 to -3.7 mmt), coffee (-0.1 to -0.4 mmt) and vegetables (-0.9 to -3.1 mmt).[14] In contrast, Eastham et al. (2008) predict a net increase in overall productivity of yields throughout the LMB basin but with significant declines for some crops in some basins.

The wide variation in predicated crop responses underscores the value of a VAR approach. In the VAR framework, our focus is not on figuring out what net changes in production over the long run may be, but on the existing value of production in areas likely to be at greatest risk. For existing production areas, two risk factors are of particular importance. The first is the negative shifts in suitability as modeled by the USAID Mekong ARCC Climate Study team. With increases in temperature and rainfall, crops currently grown on lands that are likely to become less suitable for future production, will be stressed and less productive because they will be forced outside of their "comfort zones," meaning the areas where species and ecosystems experience the most suitable growing conditions based on the range and timing of temperature and rainfall (Carew-Reid et al. 2013, p. 29)

The second risk factor is deeper, more frequent, and more extensive inundation from flooding and sea level rise. For example, Eastham et al. (2008) note that, "deep and prolonged submersion of paddy rice adversely affects plant growth. High yielding varieties are more susceptible to flood damage than most traditional varieties." For the Mekong River Delta, it has been estimated that about 590,000 hectares of

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[13] Within the Climate Study modeling framework, climate change hotspots are areas of the basin projected to experience the greatest change in any one climate or hydrological parameter representing a threat or opportunity for existing farming and natural ecosystems.

[14] As reported by the World Bank (2010).

rice area could be lost due to inundation and saline intrusion, affecting over 13% of rice production in the region (IBRD 2010).

To produce a VAR assessment for crops, we used the USAID Mekong ARCC's Climate Study geospatial data on existing and projected areas of crop suitability and production to compare changes due to climate change crop-by-crop in hot spot provinces. For each crop and province, we calculated the area of cropland now producing that is at risk from a negative shift in suitability. To this we added the amount of cropland that is likely to be newly flooded in both hot spot and non-hot spot provinces[15] based on the flooding scenarios described in Section 3.1.1, above. In terms of the total existing cropland at risk, rainfed rice is by far the most exposed at 488,472 hectares (ha) per year, followed by rubber (124,100 ha), maize (123,806 ha) and coffee robusta (104,075 ha). Next, we estimated the annual yield for each crop. We developed a range of yields based on data from the USAID Mekong ARCC project and data provided by FAOSTAT. The final step was to estimate the existing value of this production at risk using producer price information available from FAOSTAT and Mundi, updated to 2013 dollars.[16]

The results are reported in Table 6. For each crop, the low values-at-risk figures represent the total existing cropland area at risk multiplied by the lower yield estimates and then the low end of the price range. Vice versa for the high VAR estimates. Our analysis indicates that minimum values at risk for eight crops considered in the Climate Study modeling total $1 billion to $4 billion each year. Taken together, rubber and rainfed rice account for roughly 60% of these values at risk, while soya and sugar represent well less than 1% of the total values at risk.

Table 6: Minimum Annual Value of Crop Production at Risk in the LMB

	Existing production area (ha) at risk from			Yield assumptions (tonnes/ha)		Value Range ($2013-mil)	
Crop	Suitability	Flooding	Total	Low	High	Low	High
Rainfed rice	422,363	66,109	488,472	1.90	3.10	$283.47	$1,565.78
Irrigated rice	0	46,260	46,260	2.97	5.54	$41.96	$265.00
Maize	118,693	5,113	123,806	2.24	5.17	$49.96	$239.67
Cassava	80,882	4,255	85,137	17.73	23.87	$222.55	$585.57
Soya	5,890	406	6,296	1.47	1.96	$4.47	$10.57
Sugar	0	2,024	2,024	51.52	74.23	$3.00	$4.74
Rubber	124,100	0	124,100	1.64	1.72	$322.02	$806.05
Coffee robusta	104,075	0	104,075	0.82	2.35	$137.86	$548.81
			980,170		**Totals**	$1,065.29	$4,026.20

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[15] The reason for including all provinces in the flooding impacts calculations and only hot spots in suitability is because the changes associated with the latter are less certain, but more likely in terms of livelihood impacts in the hot spot provinces while inundation risk is fairly certain basin-wide.

[16] FAOSTAT producer price information is available here: http://faostat3.fao.org/faostat-gateway/go/to/download/P/PP/E. All prices are in 2004-2006 average international dollar values. We updated these to US$2013 based on U.S. Federal Reserve inflation factors.

3.1.4 Hydroelectric Energy Production

Over the past ten years interest in hydropower has escalated in the LMB accompanied by increasing private sector investment in dams and other power infrastructure. Most Mekong River tributaries now have "cascades of dams in place or planned with some 71 projects expected to be operational by 2030" (ICEM 2010). Installed capacity is approximately 13 megawatts in Cambodia, 663 in Lao PDR, 3,422 in Thailand and 4,155 in Vietnam (ADB 2008). Currently, hydropower makes up roughly 5% of the energy produced in Cambodia and Thailand, but over 30% in Vietnam.[17] In Lao PDR, fuelwood and other traditional fuels still make up the vast majority of energy produced (Luukkanen et al. 2012).

As with other LMB resources, there is much uncertainty over the effects of climate change on the Mekong's existing network of dams and their power generation capacity. While modeling is almost unanimous in projecting an increase in mean annual flows overall, it is the timing of those flows, increased variation between dry and wet seasons, and increases in temperature and associated evaporation that challenge generation capacity. Of most concern is the potential reduction in reservoir levels during more frequent and extreme droughts, such as those that plagued the region in 2010.[18] The risk of droughts is greatest in the southern and eastern portions of the LMB. In contrast with provinces to the north and west, dry season precipitation and mean runoff is expected to decline in this region while temperature increases are expected to be the greatest (Eastham et al. 2008). The USAID Mekong ARCC Climate Study generally corroborates these findings, although the most pronounced increases in drought and temperature are expected for the southeastern portion of the LMB, in the 3S River Basin. As in other drier portions of Southeast Asia, a litany of adverse effects to hydropower can be anticipated including significantly lower dry season generation and pressure to increase minimum flows to meet downstream irrigation needs (ADB 2012).

To be conservative in our analysis of hydroelectric energy production at risk, we assumed that only those facilities that are located in tributary reaches that are predicted to experience significant increases in temperature and increases in agricultural drought conditions would be at risk from climate changes. To identify the facilities at risk, we used the USAID Mekong ARCC's modeled spatial data showing locations of projected increases in temperature and changes in agricultural drought months due to climate change (Carew-Reid et al. 2013, pp. 90, 95) and overlaid point locations for hydroelectric facilities obtained from the Consultative Group on International Agricultural Research.[19] We then identified facilities that were located in areas where temperature increases are expected to be the most significant (10%+) and where agricultural drought months were expected to increase. These criteria pointed to a total of 11 major facilities at risk (Table 7).

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[17] Obtained from the International Energy Agency's web portal at: http://www.iea.org/statistics/statisticssearch/.

[18] The LMB's hydroelectric resources were severely affected by the 2010 drought. See http://www.china.org.cn/environment/2010-03/27/content_19698549.htm for a summary of the drought's impacts.

[19] CGIAR Challenge Program on Water and Food, 2013. Dams Data Base for the Mekong. Vientiane, Lao PDR, CPWF.

Table 7: Minimum Annual Value of Hydroelectric Production at Risk

Facility	Country	Tributary	Capacity (MW)	Value at risk – lo ($2013-mil)	Value at risk – hi ($2013-mil)
Houay Ho	Lao PDR	Houayho, Xekong	150	$22.50	$43.99
Nam Kong 2	Lao PDR	Nam Kong	80	$12.00	$23.46
Nam Kong 3	Lao PDR	Nam Kong	40	$6.00	$11.73
O Chum 2	Cambodia	Lam Dom Noi	1	$0.15	$0.29
Sre Pok 4A	Vietnam	Sre Pok	64	$9.60	$18.77
Upper Kontum	Vietnam	Se San	210	$31.49	$61.59
Xe Kaman 3	Lao PDR	Houayho/Xekong	250	$37.49	$73.32
Xe Pian - Nam Noy	Lao PDR	Xe Pian	195	$29.24	$57.19
Xedone 2	Lao PDR	Xe Don	54	$8.10	$15.84
Xepian-Xenamnoy	Lao PDR	Xe Don	195	$29.24	$57.19
Yali	Vietnam	Se San	720	$107.98	$211.17
		Totals	1,959	$293.79	$574.54

For each facility, we then obtained data on installed capacity and applied one of two capacity factors[20] to estimate a range of annual production in megawatt hours (MWh).[21] The Mekong River Commission (2009) estimates that capacity factors for existing LMB facilities range from 0.4 to 0.6 and so we adopted these factors to represent our low and high production estimates. The final step was to apply a range of economic values to this annual production at risk. Here, we relied on two estimates for the economic value of power production: (1) MRC (2009), which reported a break-even tariff range of 4 to 6 cents per kilowatt hour (c/kwh) for dams of various sizes, and (2) the Maunsell and Lahmeyer (2003) estimate of 4.4 c/kwh as a reasonable break even competitive tariff for power pricing in Lao PDR. Updated to 2013 dollars, this yielded low (4.28 c/kwh) and high (5.58 c/kwh) bounds for our value range. Multiplying these values by annual power production at each facility yielded the lower and upper end VAR estimates.

The results of this analysis are shown in Table 7, below. For the eleven hydroelectric facilities that appear most at risk from temperature increases, reduced runoff, and an increase in agricultural drought months as modeled in the Climate Study, combined capacity is approximately 1,959 MW and the value of annual production ranges from US$294 to US$575 million. This value excludes the value of power production at facilities at risk from extreme flooding basin-wide (ADB 2012), or the value at risk in the many small-scale facilities for which data were not available. As such, the VAR estimates in Table 7 are conservative.

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[20] Capacity factors are simply the proportion of installed capacity used for power generation on an average annual basis.

[21] For facilities in Lao PDR, we relied on data provided by Sunlabob Renewable Energy, a Lao PDR-based company specializing in renewable energy and clean water solutions throughout the developing world. For facilities in Vietnam and Cambodia, we obtained installed capacity estimates from various project reports available online.

3.1.5 Ecosystem Services at Risk

In their natural state, forest, wetland, and grassland ecosystems throughout the LMB provide a wide array of goods and services of significant economic value. The Millennium Ecosystem Assessment developed the most widely used classification system for these ecosystem goods and services (MA 2005). According to the MA system, ecosystem services fall into four primary categories: (1) provisioning services, which describe the raw materials, food, and other economically significant products derived from health ecosystems; (2) regulating services, such as flood control and regulation of air quality; (3) supporting services, such as the maintenance of genetic diversity on which all agricultural crops ultimately rely, and (4) cultural services, including ecosystems role in supporting recreation, tourism, and cultural and religious practices.

It has been reported that roughly 80 per cent of the Greater Mekong's 300 million people depend directly on the goods and services its ecosystems provide (WWF 2013). Because of this, in the LMB, ecosystem services have exceptional economic values relative to ecosystem service values in areas where populations are less dependent. As one example, Gerrard (2004) completed a detailed ecosystem service assessment of the That Luan Marsh in Vientiane, Lao PDR. She calculated the value of the marsh in terms of its role in supporting rice cultivation, garden cultivation, aquaculture production, capture fisheries, non-fish wetland products, flood protection, and wastewater purification. She found the value of these ecosystem services to be roughly US$5 million per year, or US$2,500 per hectare. Globally, and in contrast, the median ecosystem service value of freshwater marshes is reported to be just US$145 per hectare (Schuyt and Brander 2004).

Economic analyses that fail to incorporate the value of ecosystem services in the LMB are likely to miss the mark by a wide margin. For example, in a recent re-analysis of several dam-building scenarios for the Mekong that incorporated ecosystem service values associated with lost fisheries and wetlands, Costanza et al. (2011) found that the net economic benefit of each scenario was substantially reduced. At a one percent discount rate (discounting puts future impacts in terms of today's dollars) for example, the benefits from dam building were reduced from positive US$33 billion to a negative US$274 billion because of the loss of critical ecosystem services. The magnitude of this change underscores the importance of accounting for ecosystem services in economic impact assessments, including those related to climate change.

Climate change poses a significant threat to both ecosystem services and the livelihoods that depend on them. Because of climate change, the LMB's natural ecosystems will be under increasing threat from inundation, drought, fires, infestations of exotic species, and isolation and fragmentation of habitat (WWF 2009). Climate change is also expected to directly affect biodiversity by causing shifts in species distributions "with potentially major effects on ecosystem structure, composition and processes" (Williams et al. 2007).

With so many wide-reaching impacts anticipated, defining the scope of a VAR analysis of ecosystem services is difficult. But to be consistent with the minimum values-at-risk methodology used in this study, in our analysis, we considered only the ecosystems of highest vulnerability as identified through the Climate Study spatial modeling analysis. The USAID Mekong ARCC Climate Study team concentrated their analysis on threats to non-timber forest products (NTFPs), crop wild relatives (CWR), and protected areas (PAs). Their modeling analysis identified eight ecozones in six provinces at moderate to high risk from a range of factors including temperature and precipitation extremes, water availability, salinity, sea level rise, drought, flooding and storms (Carew-Reid et al. 2013, p. 68; Meynall et al. 2013). Two factors—temperature and inundation—stand out as the most significant.

Usingthe Climate Study spatial data, we tallied the area of each ecozone at risk from either an increase in the annual area expected to be inundated by flooding and a sea level rise of 0.3 meters or adverse changes in temperature and associated impacts such as increased forest fires. The area of the ecozone at risk due to each of these factors is identified in Table 8. Inundation is a significant risk factor for more than 350,000 hectares of delta freshwater wetlands, delta mangroves, coastal wetlands, and swamp forests. Temperature and precipitation risk is a factor for over 3 million hectares, largely within the broadleaf forest zones of Mondulkiri and Khammouane where an increase in drying, high temperature extremes and fires is a major concern.

Assigning an annual value to the ecosystem services provided by these lands is a complex task, further complicated by a great degree of uncertainty. This is because so much of the actual value of ecosystem services on any one particular hectare depends on its level of use—it can be great, as with the That Luan Marsh, adjacent to a major urban area, or virtually non-existent, as in the remote corners of protected areas. Moreover, ecosystem service valuation studies vary widely in the number of ecosystem services considered in the valuation exercise. While some studies quantify the total economic value (TEV) of the ecosystem studied, others concentrate on a handful of services such as their value in producing food.

Fortunately, there have been dozens of studies conducted in the South and Southeastern Asian region and the LMB attempting to develop reliable estimates of ecosystem service values for many of the important ecosystems found here. The sheer number of studies completed helps smooth out variation and justify broad application of mean and median values. An extremely useful database of such studies was recently compiled by Brander and Eppink (2012). They compiled 787 separate value estimates drawn from 182 studies, many of which are directly relevant to our VAR analysis. Of particular importance are studies related to mangroves, wetlands, and swamp forests in the coastal zones and studies that address ecosystem service values of upland tropical forests.

For the former, we extracted 14 studies from the database that reported TEV estimates for coastal ecosystems at risk. After converting values in these studies to USD and updating them to 2013 dollars, the implied range was US$1,933 to US$2,280 per hectare. We adopted the low end of this range as our low value figure for the three delta ecosystems at risk as well as the Tonle Sap swamp forests. For upland forests, there were 69 relevant studies, 41 of which addressed forests in the LMB. For the larger set of 69 studies, the median value was US$133/ha. We adopted this figure as the upper end of the value range for the three broadleaf forest types. For the smaller set of 41 studies, the median value was much less—rough ly US$25/ha. We adopted this figure as the lower end of the value range for these same forest types.

For the remaining values, we incorporated figures from two additional sources. For the ecozones affected by inundation, we updated the Costanza et al. (2011) figures for flooded forests (US$3,636.44/ha), wetlands (US$3,584/ha), and grasslands (US$2,518.29) and applied these, respectively, to the upper end of the value range for delta swamp forest, coastal wetlands, and Tonle Sap swamps and lower floodplains. For upper floodplains and lakes, there were few relevant studies contained in the Brander and Eppink (2012) database, so we adopted the range contained in WWF's global assessment (Schuyt and Brander 2004). Updated values for freshwater marshes (US$197) and forested wetlands (US$279) were used as the lower and upper ends of the value range.

Applying these value ranges to the area of each ecozone at highest risk according to the Climate Study modeling generated the range of values at risk (VAR) indicated in Table 8, below. The spatial distribution of these values at risk is illustrated in Figure 3. The minimum VAR for these ecozones falls within the range of US$783 million to US$1.7 billion per year, with the highest VAR near the coast where mangroves, coastal swamp forests, and coastal wetlands could be inundated, eliminating their valuable role in supporting aquaculture, capture fisheries, and protecting near shore communities from dangerous storm surges.

Table 8: Minimum Annual Value of Ecosystem Services at Risk

Ecozone	Inundation risk (ha)	Temp-precip risk (ha)	Value range ($2013/ha)	VAR-lo ($2013-mil)	VAR-hi ($2013-mil)
Delta freshwater wetlands	30,716	-	$1,913-$3,584	$58.77	$110.10
Delta mangroves/coastal wetlands	158,724	-	$1,913-$3,584	$303.69	$569.93
Delta acidic swamp forest	158,456	-	$1,913-$3,636	$303.18	$576.22
Low-mid elevation moist broadleaf forest	168	1,223,900	$25-$133	$30.48	$162.31
Low-mid elevation dry broadleaf forest	692	1,341,800	$25-$133	$33.43	$178.01
High elevation moist broadleaf forest	-	269,600	$25-$133	$6.71	$35.75
Tonle Sap and lower floodplain	4,636	-	$1,933-$2,518	$8.87	$11.67
Upper floodplain wetland, lake	-	194,500	$197-$279	$38.24	$54.33
Totals	353,392	3,029,800		$783.37	$1,698.32

3.1.6 Total Minimum Values at Risk

Table 9 below aggregates each of the mean annual VAR estimates from Sections 3.1.1 to 3.1.5. All told, our analysis of five resource types suggests the minimum annual values at risk in the LMB are roughly US$16 billion per year. Worker productivity ranks as the most significant value at risk, accounting for more than half of the total, which is similar to findings of other regional assessments, such as the recent Climate Vulnerability Monitor (CVM) report (DARA 2012a). We also corroborate CVM and other regional assessments (e.g. World Bank 2010; Costanza et al. 2011; Nicholls et al. 2008) that suggest there are significant values at risk for agriculture, infrastructure in coastal zone, and ecosystem services. Few other studies have attempted to quantify climate-related costs associated with hydro-electric power production. Our VAR analysis suggests that a more in-depth analysis of impacts to hydro-electric power is worth investigating, given that the value of production from just the few facilities located in areas at risk from increased evaporation and drought top US$434 million per year.

Table 9: Summary of Minimum Annual Values at Risk

Values at risk component	Mean VAR- ($2013-mil)
Non-agricultural infrastructure services	$3,426.67
Worker productivity	$8,370.67
Crop production	$2,545.75
Hydro-electric power generation	$434.17
Ecosystem services	$1,240.85
Totals	$16,018.11

To put these values into perspective, the US$16.02 billion annual VAR translates into roughly 7% to 30% of rural GDP in the LMB (PPP adjusted, Table 10).[22] If the US$18 billion of at risk infrastructure is included, this range increases to 14% to 61%. Typically, economists distinguish between impacts to capital assets like infrastructure and the annual service they generate (like crop production) and don't add the two together. But either way, the analysis indicates that climate change represents a profound risk to the economy of the LMB—one that warrants a more careful and robust analysis of that risk as well as alignment of adaptation strategies to reduce that risk where possible.

Table 10: Minimum Annual Values at Risk – Share of Rural GDP

Country	Mean VAR- no infrastructure (% rural GDP per capita)	Mean VAR- w/ infrastructure (% rural GDP per capita)
Cambodia	29.01%	61.27%
Lao PDR	23.63%	49.92%
Thailand	6.72%	14.19%
Vietnam	18.77%	39.64%

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[22] Calculated by deflating the country-wide per capita GDP figures reported annually by Mundi to reflect the disparity between rural and urban GDP discussed in Section.

4.0 POLICY IMPLICATIONS

While the VAR approach does not generate precise estimates of how climate change costs will unfold over time or where such costs are likely to manifest at a fine spatial scale, it nonetheless provides useful information to guide policy choices. There are three general uses of a VAR assessment: (1) in setting priorities for adaptation investments; (2) to provide a preliminary test of cost effectiveness of these investments, and (3) to help inform planning and land use decisions to avoid unnecessary exposure to climate risks.

With respect to priorities, a VAR assessment can provide a ranking of climate risk in monetary terms and so help identify what strategies are likely to have the most significant effects in reducing long-term climate related costs. As a result of this preliminary assessment, we identified worker productivity, non-agricultural infrastructure services, and crop production as the three economic resources at greatest risk from climate change in the LMB, and so at very least regional governments ought to ensure that their adaptation portfolios include significant investments in these areas.

A more complete and robust VAR for each LMB country could help identify strategies that are missing or not getting the attention they deserve. For example, adaptation strategies to reduce the economic costs of lost worker productivity were surveyed by Nilsson and Kjellstrom (2010) and include measures such as guidelines for workplace heat assessment and protection, strengthening national health systems to respond to the specific needs of working populations, and changes in work practices such as increased rest periods. Cambodia's current climate adaptation strategy (MOE 2006) does not incorporate these or any other measures related to worker productivity and so a VAR assessment can help make the case as to why such interventions are an economic imperative.

With respect to cost-effectiveness, a VAR assessment can help determine to what extent planned adaptation strategies are economically justifiable. For example, there is considerable attention being given to the promotion of eco-resilient agricultural techniques in the LMB as a way to protect crops from the ill effects of significant changes in temperature and precipitation patterns. In areas with higher temperatures and less precipitation during dry season, these techniques may include reliance on more drought and heat tolerant varieties derived wild crop relatives. While there has been no comprehensive evaluation of what this adaptation strategy may look like or cost in the LMB, we can look to other regions for a general sense.

In the Sahel, for example, the World Bank has determined that the price tag for a range of agricultural adaptations such as sustainable land and water management practices in rainfed regions would be roughly US$28 billion, or US$187 - US$452 per hectare depending on whether the target area is mostly pastureland or cropland (Van Nieuwkoop and Goyal 2010). In the LMB, we determined that the minimum values at risk for cropland to range between US$1,087 and US$4,107 per hectare (Table 6) and so even if a Sahel-type program were implemented at two to five times the cost, our VAR assessment indicates that it has a high likelihood of being cost effective.

A second example comes from Vietnam. Here, the World Bank (2009) estimated the cost of implementing a package of adaptation options for agriculture in Vietnam that include research, development, extension services and expansion of irrigation. In 2013, the cost was US$6.86 billion total through 2050, or roughly US$185 million per year. In this report, we estimate the annual value of crop production at risk in the Central Vietnam portion of the LMB to range between US$294 million and US$1 billion[23], implying that if invested entirely within the LMB these adaptation funds could easily pay for themselves if the actual costs of climate change in Vietnam's agriculture sector are reasonably close to the VAR figures estimated here.

With respect to informing planning and land use decisions, a VAR assessment can help identify whether or not major infrastructure investments are still worthwhile after climate risks are taken into account. For example, a VAR assessment of could help temper overly optimistic estimates of the expected value of annual hydroelectricity generated by facilities planned in regions with anticipated increases in agricultural drought months, less rainfall overall, and significant temperature increases. Likewise, a VAR assessment can help quantify the economic risks associated with building out new urban infrastructure in areas with anticipated increases in freshwater flooding and sea level rise. In either case, the values at risk can be considered a category of cost not typically incorporated into benefit-cost analyses of these decisions.

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[23] To arrive at this figure, we backed out the Vietnam cropland area at risk from coastal inundation, since the World Bank did not cost out adaptation options here. We then applied the same yield and crop value data used for Table 6 to the Vietnam upland crop production area at risk from suitability changes (236,290 hectares).

5.0 CONCLUSIONS AND DIRECTIONS FOR FUTURE RESEARCH

In this study, we demonstrated the usefulness of a values-at-risk (VAR) approach to the economics of climate change. In the VAR framework, there is less emphasis on projecting economic costs into the future and more on quantifying the existing values of resources that are likely to be at risk. This approach uses modeling where it is more reliable—in suggesting what existing resources are likely to be at risk—rather than using it for a less reliable purpose in trying to predict the unfolding of costs over time in particular places and economic sectors. As such, the VAR approach capitalizes on using climate models where they are strongest.

To demonstrate the VAR approach in the LMB, we applied the Climate Study results of downscaled modeling of anticipated climate-related changes in the LMB and its impact on the values of resources at risk. As in other climate assessments worldwide, in Asia, and in the LMB coastal infrastructure, worker productivity, agricultural output, and ecosystem services were determined to be at high risk. We also determined that hydroelectric power generation could be adversely affected in portions of the LMB where higher temperatures, lower runoff, and greater evaporation rates could significantly reduce reservoir levels in the dry season.

Using this minimum VAR approach, we estimate that the annual value of infrastructure services, worker productivity, agricultural output, hydroelectric generating capacity, and ecosystem services at risk from climate change in the LMB to be at least US$16 billion per year. In addition, we estimate that the value of infrastructure assets at risk in areas expected to be inundated more frequently or permanently to be at least US$18 billion.

As governments consider investing in adaptation measures, these values can provide useful basis for comparison. For example, in the context of its Economics of Adaptation to Climate Change (EACC) Program, the International Bank for Reconstruction and Development has determined that the total annual costs of adaptation for all economic sectors in the East Asia and Pacific region likely fall into the US$17.7 to US$20.1 billion range (IBRD 2010). This translates into a cost of roughly US$0.56 per person. In contrast, in the LMB, the US$16 billion annual VAR estimated is roughly US$267 per person. So even if the actual climate change costs that manifest over the next few decades turn out to be a small fraction of the values at risk we identified, it implies that adaptation expenditures would still be well worth the investment.

This report presents a rough, first pass at VAR for the LMB largely to demonstrate the approach. Data underlying the values at risk estimates were based on publically available information that is often aggregated up to broad geographic regions (i.e. the value of crop production is averaged country-wide) and so are limited in their accuracy and scope. A more rigorous assessment could include, for example, original valuation studies of ecosystem services at risk in particular places based on actual use patterns by local communities, such as the Gerrard (2004) assessment of ecosystem services provided by the That Luan Marsh. Vulnerabilities to hydroelectric facilities could be informed by better data on the likely increase in upstream irrigation demands in portions of the LMB that will be affected by an increase in agricultural drought months. Effects on worker productivity could be better refined through analysis of how various heat stresses related disorders are already being manifested in multiple outdoor occupations, not just agriculture and construction. The magnitude of values at risk quantified in this rough first cut suggests that additional research along these lines could be of great worth in informing the scale and scope of adaptation programs in the years ahead.

Figure 1: Minimum Value of Infrastructure at Risk from Climate Change in the Tonle Sap and Vietnam Delta Regions

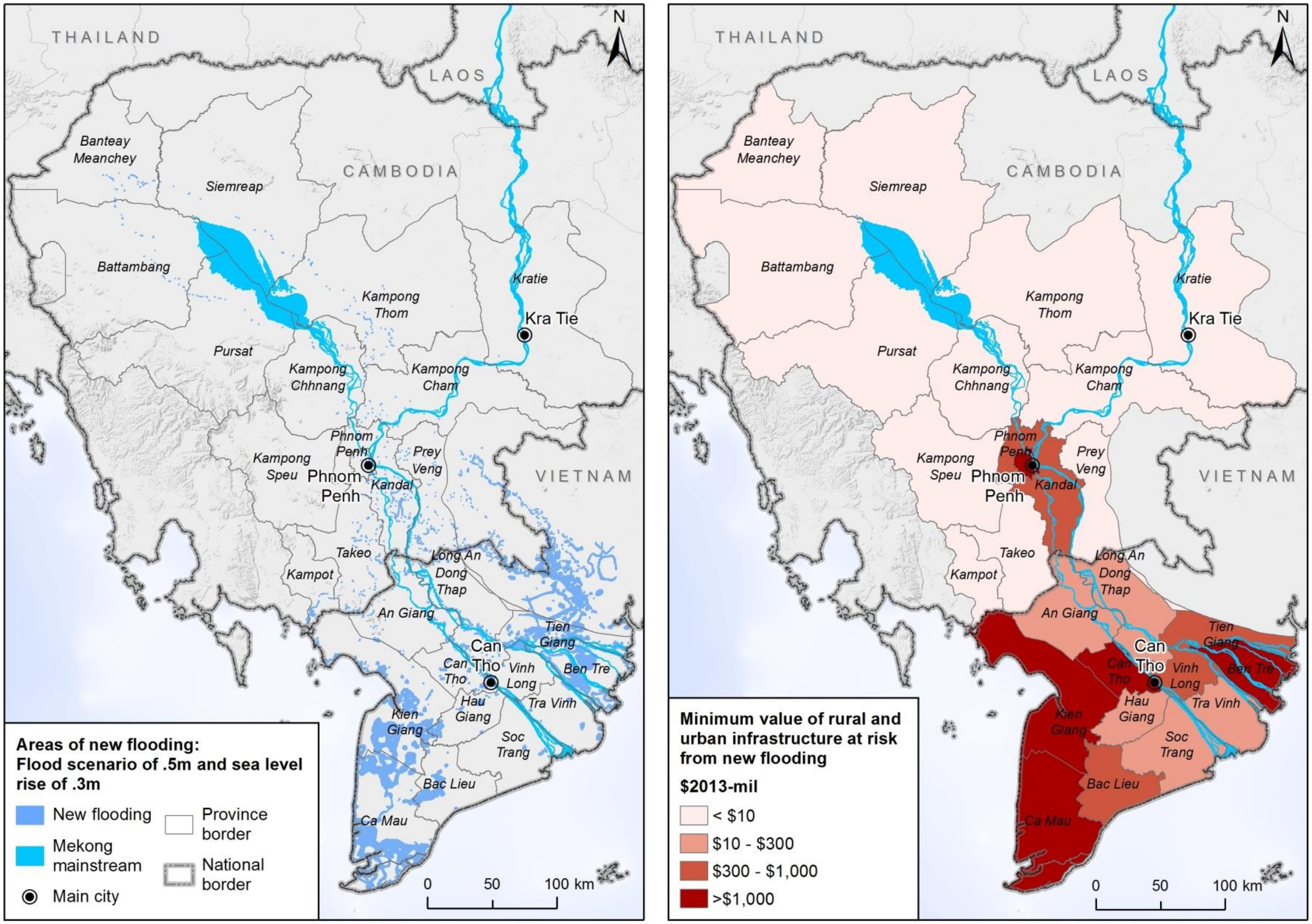


Figure 2: Minimum Value of Worker Productivity at Risk from Climate Change in the Lower Mekong Basin

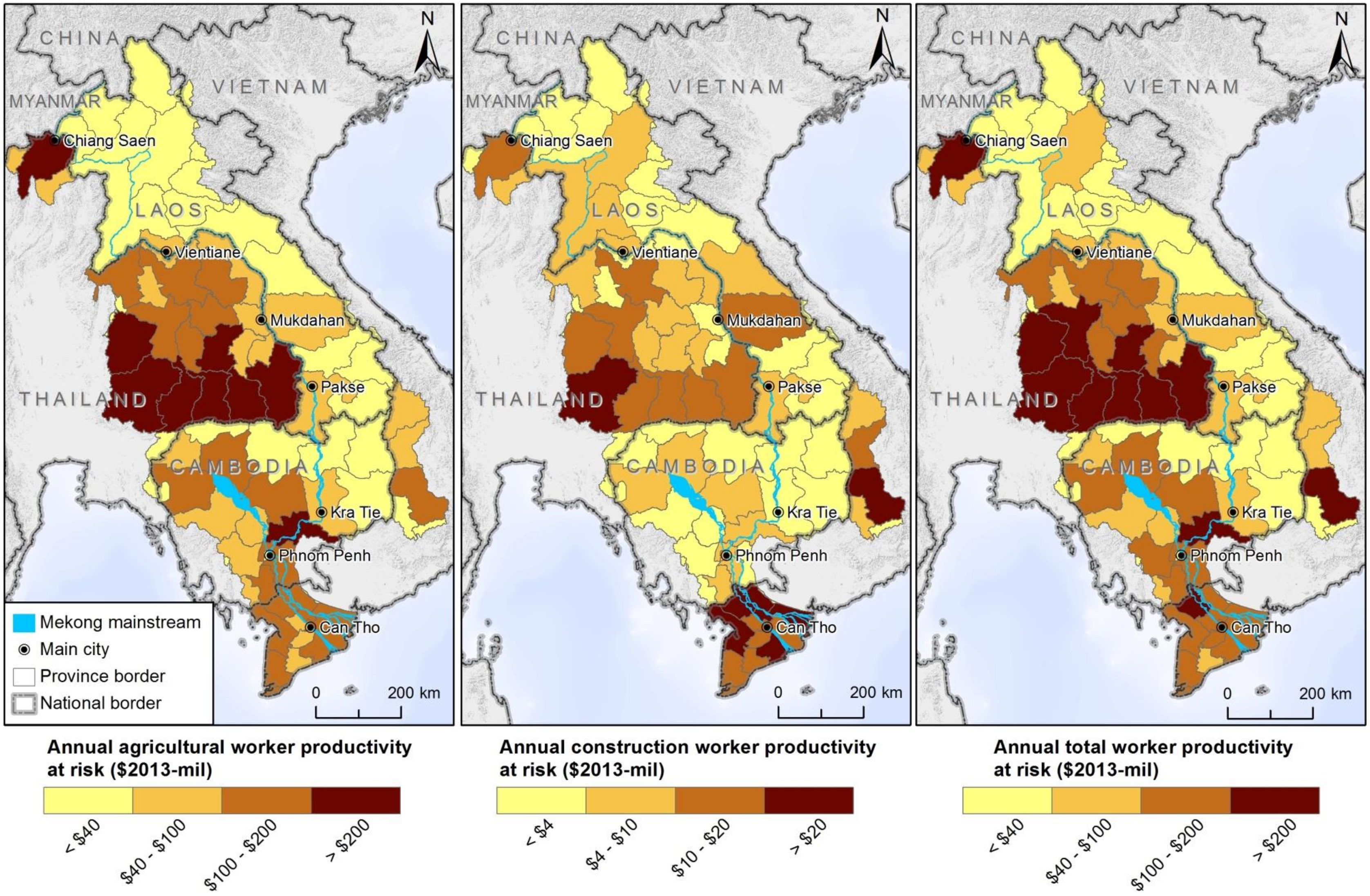
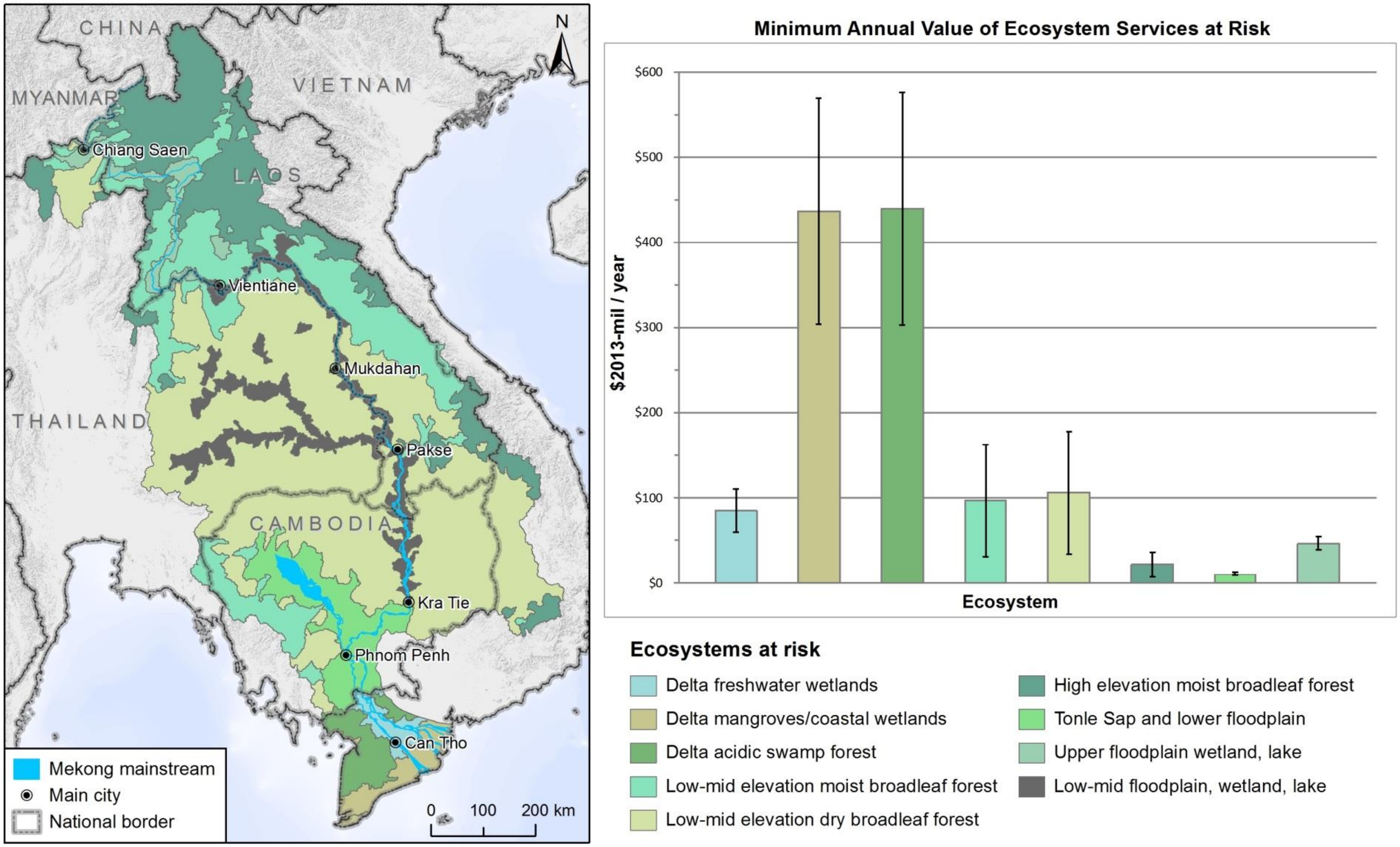


Figure 3: Minimum Value of Ecosystem Services at Risk from Climate Change in the Lower Mekong Basin



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