CPWF Project Report

Mekong Basin Focal Project: Synthesis Report

Project Number 58

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Program Preface:

The Challenge Program on Water and Food (CPWF) contributes to efforts of the international community to ensure global diversions of water to agriculture are maintained at the level of the year 2000. It is a multi-institutional research initiative that aims to increase the resilience of social and ecological systems through better water management for food production. Through its broad partnerships, it conducts research that leads to impact on the poor and to policy change.

The CPWF conducts action-oriented research in nine river basins in Africa, Asia and Latin America, focusing on crop water productivity, fisheries and aquatic ecosystems, community arrangements for sharing water, integrated river basin management, and institutions and policies for successful implementation of developments in the water-food-environment nexus.

Project Preface:

The Mekong Basin Focal Project aims were to assess water use, water productivity and water poverty in the basin, and analyse the opportunities and risks of change in water management that influences water poverty.

The main issue facing the Lower Mekong is not water availability (except for seasonally in certain areas such as northeast Thailand) but the impact of changed flows (which may result from dam or irrigation development or climate change) on ecology, fish production, access to water and food security. Poverty is generally decreasing in the Mekong, but the poorer people are not sharing in the improvements. Water governance and sharing of benefits is a key challenge for the Mekong.

CPWF Project Report series:

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EXECUTIVE SUMMARY

The Mekong River basin is one of the most dynamic, productive and diverse river basins in the world. Decades of civil strife have largely "saved" the basin from the disruption of natural flow patterns that has beset most major transboundary river systems in the world, where water impoundments and diversions have been more intensive. As a result, the Mekong basin, in relative terms, continues to enjoy exceptionally rich aquatic biodiversity and an exceptional reliance on the river's environmental services; fishing, farming and grazing, for peoples' livelihoods.

The key issues in the Mekong basin stem from the rising pressure on the natural resource base, resulting from the growing population, increasing development and resource use (especially hydropower and the growing demand for food). These pressures are leading to trade offs over resources between upstream and downstream interests, urban and rural areas, upland and low-land communities, sectors (notably between fisheries and hydropower), subsistence-based livelihoods and activities oriented towards industrialisation, and civil society interests and formal resource agencies. These tensions are likely to increase with the growing pressures and may be further exacerbated by climate change. These tensions will reinforce the perceptions of institutional failures and the demands for improved governance.

The specific objectives of the Basin Focal Project in the Mekong are to:

- Assess the current condition of water use within the basin in both biophysical and socio-economic dimensions. Water productivity and water poverty are the essential measures in this process.
- Analyse the opportunities and risks of change in water management that influences water poverty
- Identify appropriate research paths for promoting change, based on trend analysis, assessment of interventions and analysis of impact.
- Develop an integrated knowledge base to support change throughout and beyond the life of this program.
- Develop solution methods and outline solutions for the impact of water and agricultural interventions on poverty.

The work was organised into six work packages, and report is also structured into a chapter on each topic. These are:

1. Water Poverty Analysis
2. Analysis of Water Availability and Access
3. Analysis of Agricultural Water Productivity
4. Institutional Analysis
5. Intervention Analysis
6. Development and Application of the Knowledge Base

Key findings – poverty analysis

1. Poverty is decreasing in the Mekong basin, but the poorest households are not sharing the improvements.
2. There are common features across wealth ranking studies. This suggests that, in the absence of a detailed wealth ranking study, a common set of dimensions for measuring poverty can be adopted that is consistent with the way that knowledgeable local people view poverty.
3. The process by which aggregate poverty indicators are developed and applied is more important than the method used to generate them.
4. Aggregate poverty indicators should be used close to their source. They quickly become less useful as their application moves farther from the group that helped to construct them.

5. Paradoxically, the resilience of existing livelihood strategies blunts the apparent effectiveness of interventions.
6. A potentially fruitful goal for an intervention is to make targeted negative outcomes less likely while making targeted positive outcomes more likely. In a situation where variability and uncertainty are central, such an approach will support the build-up of livelihood assets over time, which helps make households and communities more resilient.
7. Livelihood activities are closely linked with water. Majority of villagers in water poor areas engage in crop farming, fishing or shrimp production in which water is considered as important element that constitute a good quality of life.
8. Common criteria for household's well-being defined by key informants in water poor areas agree well with seven broad categories of poverty criteria of the wealth ranking study (de la Rosa and Chadwick 2008) which are food security, land holding, shelter, livestock, productive assets, disposable income, and income and debt.
9. Problems of water are different area by area. It depends largely on hydrological conditions, environment and livelihoods of the communities. Water quantity problem such as flooding or water scarcity is obvious and occurs regularly, and therefore to some extent people have adapted themselves to it. For most of the water poor areas, quality of water seems to be a major issue causing significant impact to the livelihoods, food security, health and income of the poor (i.e. water pollution in the Tonle Sap lake, quality of groundwater in Northeast Thailand, and water salinisation and acidification in the Mekong Delta of Vietnam).
10. The rich and medium households with sufficient resources can better cope with water problems than the poor. Even some water problems are equally distributed to all families but often cause greater impact to the livelihoods of the poor than to the rich.
11. Large water infrastructure projects were considered less effective than smaller-scale interventions by farmers. For this reason, the extension of the electrical grid was seen as more useful than the creation of large irrigation schemes. However, to supply more electricity to larger area, more hydropower dams may need to be built. Hence, the farmer's preference for small interventions could cause a large intervention.
12. Cash crops irrigated with water from drill wells, canals and other water bodies provide many farmers with a reliable income, but profits are undermined by the high costs of fuel.
13. Fish ponds excavated in the rice paddies and supplied by water and fish naturally during the rainy season, provide a valuable and reliable source of nutrition and cash for farmers.
14. Rainwater harvesting provides much valued drinking water to virtually all households, but storage is not sufficient enough to see households through the dry season.
15. Several available options for interventions in water to improve livelihoods are of non-structural measure and so less expensive. A collaboration of various stakeholders is however crucial.

Key recommendations – poverty analysis

1. Carry out detailed wealth-ranking studies where possible. However, take advantage of the general outcomes of such studies. Criteria for wealth ranking can be transferred between sites with very different characteristics.
2. When carrying out a poverty mapping exercise, it is important to emphasize process and participation over data manipulation.

3. Build the application of poverty maps into the process used to generate them, so that the context and assumptions that lie behind the maps are clear to the people making use of them.
4. Continue to monitor the effectiveness of poverty mapping in targeting poverty interventions, including downstream impacts.
5. When designing water-related interventions to reduce water poverty, aim for changes that make incremental improvements more likely over time: these can have a significant cumulative effect. Project monitoring should reflect this long-term perspective.
6. Accompany water-related interventions with other interventions such as: compensation programs for distressed families during drought and flood; improved market access; and opportunities for alternative livelihoods.
7. Interventions that allow for a degree of local control and maintenance have a higher chance of success than large-scale projects that rely on the efforts and attention of people outside of the community for their success.
8. Financial and nutritional diversification is an important means of buffering shocks. The development of fish ponds is seen as particularly effective.
9. Water quality impacts in the Tonle Sap region require greater information and awareness, as well as strengthened capability and power of local leaders to manage pollution. Better waste collection and improved sanitation is also required.
10. A range of technical, structural and non-structural strategies in water management have been identified. Technical strategies include development of improved crop cultivars and improved sanitation and water supply. Structural strategies include access to electricity, storage of rainwater, and maintenance programmes for public water supply. Non-structural strategies include training programmes and improved awareness of public hygiene.
11. To better assess the water poverty and livelihoods basin-wide, a case study on this in the water poverty area of Lao PDR should be carried out.

Key Findings – water availability

1. A very simple spreadsheet model with few adjustable parameters has captured most of the runoff and river flow behaviour in the lower Mekong Basin. Obvious features such as the flow reversal of the Tonle Sap are modelled reasonably well. Less obvious features such as flow lags and local storages are also simulated reasonably well.
2. The main issue in the Mekong Basin is not water availability (except for seasonally in certain areas such as northeast Thailand) but the impact of changed flows on ecology, fish production, access to water and food security. Changes in the natural flow regime may alter the environment of fisheries in the Tonle Sap and elsewhere. Altered low flows may impact salinity intrusion in the delta, thus altering the balance of rice and shrimp production, which in turn may affect food security and incomes.
3. The impact of climate change, dam and irrigation development on water availability or flow is not great. The real issue, however, is the extent to which changes in flow will affect food production, the environment, floods and salinity intrusion in the delta.
4. The amount of water required for full irrigation development is small compared to the amount of water flowing to the sea. However, the impact of such development on the overall environment could be significant.
5. We found that deforestation and climate change, as formulated in these scenarios, altered runoff basin-wide at similar magnitudes, and also produced similar relative increases in unmet demand (i.e., reduced coverage of demand) for irrigated agriculture in several sub-basins where unmet demand is suggested to exist presently (as defined by the calibration period 1995-2002). These four sub-basins

include the Se Bang Hieng (16) and Se Done (17) tributary sub-basins in Lao, and the headwater sub-basins of the Se San (20) and Sre Pok (22) tributaries in Vietnam. Here, when the *Reference* development growth trajectory for each of the sub-basins is superimposed on either a climate change scenario or a deforestation scenario where grassland replaces forested areas, coverage of irrigation demand typically decreases by 5% or less during the dry season months up to 2026.

6. Deforestation altered to only a minor extent the cyclical fluctuations in the Tonle Sap Lake volume, an ecosystem dynamic on which many fishing-dependent livelihoods in the basin are based. For the grassland permutation of the deforestation scenarios, wet season peak volume increased by only about 1.5% by 2026, and dry season volume decreased by approximately 0.5%. Replacement of forest with the 'other' land cover induced larger changes in volume – increasing both wet season and dry season volumes by up to 5.5% and 0.5%, respectively, by 2026.

Key Recommendations – water availability

1. To develop policies and management practices for water, food and poverty, water availability (water resources, hydrology) should not be considered in isolation. Water availability is not the main issue in most places, but rather the impacts of changed availability and future demand on the environment, food production and poverty. Integrated analyses and integrated policy development should be undertaken. We will return to this in the sections on poverty and water productivity.
2. Again, while water availability is not a major issue in most places, management and governance of water is a major issue with the potential to affect food security, poverty and the environment, and should be considered in policy development. We will discuss this in the institutional analysis section.
3. There are water shortages in some part of the basin such as northeast Thailand. More integrated analysis is needed to formulate policy and management alternatives to minimize their adverse impacts on the environment and downstream.
4. The impact of climate change on flows, agricultural productivity, fisheries ecology, environment and sea level rise needs further works based on the 4th assessment report of the IPCC. The uncertainty related to climate change also warrants more analysis.

Key Findings – water productivity

1. Yield of rice, the dominant crop, varies from 1.0 to 5.0 ton/ha with the highest yield in the Delta region of Vietnam. The yield is lowest in north-east Thailand. However, in general, yield has increased over the years, and there appears to be scope for continuing increases.
2. The current rate of increase of both production and productivity of rice is considerably greater than is required to feed the expected extra population to 2050, suggesting that producing the food may not be the main challenge. Policies and institutions for distribution, and ensuring that the development is sustainable and has low environmental impact, will presumably be the main challenges.
3. As discussed in the water availability chapter, it would appear that the water demand of required increases in agricultural production is modest relative to the total volume of water in the Mekong. In addition, the water demand of the required increases may be mitigated by the strong increases in water productivity – more crop is being grown per drop now than a decade ago. Locally, especially in the drier NE Thailand, the impact of increases in demand, and the consequent demand for irrigation water, could be greater. While the hydrological impact overall is modest, the impact on the ecology and the environment is yet to be fully understood and could be significant.

4. The productivity of sugarcane is high in Thailand, presumably reflecting the use of greater inputs for a crop grown commercially (as opposed to for subsistence). This suggests that, in Thailand at least, better crop management with greater inputs can lead to higher yields. Again, policies and institutions for production and income distribution may be the main challenges.
5. There appears to be no growth (from 1993-2003) in livestock production in Laos, Thailand and Cambodia. In fact, the livestock density in terms of population declined. Production has increased in Vietnam since 2000 due to an increase in commercial poultry and pig farming.
6. There are major uncertainties in estimates of fisheries production and value in the Lower Mekong Basin. The uncertainties over production estimates make other conclusions tentative, but it appears that production from capture fisheries increased relatively little from about 1995 to 2005 in all four Lower Mekong countries.
7. Fisheries production is dominated by capture fisheries in Cambodia (where it is concentrated around the Tonle Sap and the Mekong), Laos and Thailand. In Vietnam, aquaculture dominates production, and is concentrated around the main rivers in the delta and along the coastal strip. Aquaculture in the delta is growing strongly, whereas capture fisheries appear not to be growing.
8. The value of fisheries in the Lower Mekong is, even if the unreliable lower catch-based estimates are used, at least as important as that of livestock. The consumption-based estimates lead to estimates of the value of fisheries as considerably greater than that of livestock.
9. It appears reasonable to suppose that in coming decades capture fisheries are unlikely to meet the projected growth in demand due to rising population.
10. The Lower Mekong fisheries face threats to production from changed water availability, quality, barriers to fish migration and overfishing. If the projected increase in demand is to be met, these threats must be managed such that developments do not reduce the production of fish, especially capture fish.
11. The future development of fisheries will be primarily determined by political choices - whether capture fisheries are managed sustainably; whether dams, diversions for irrigation or other developments are allowed in a way that impacts downstream fisheries; whether aquaculture grows unchecked and is allowed to pollute or endanger other fish stocks (through provision of feed).

Key Recommendations – water productivity

1. While there are many issues of detail in maintaining the increase in agricultural production (such as research and extension into fertiliser practices), in the main it appears that the sector will meet future demand. What is required is work on policies and institutions for distribution, and ensuring that the development is sustainable and has low environmental impact.
2. A particular case of the above is the potential to increase production by irrigation development. The environmental impact of such development must be better defined, as must the trade-offs of the benefit of irrigation development with the environmental and ecological costs. Work on policy and governance is urgently required on these questions.
3. There is a crucial need for more and better documented studies of fisheries production and consumption, especially on the impacts of changed flow regimes.
4. Work on policy and governance is urgently required to manage the threats to the production of capture fisheries.
5. Work on policy and governance is urgently required to manage the current and potential increases in production of aquaculture fisheries, and to ensure that its development is sustainable.
6. The manner in which the projected increase in demand (a near doubling) to 2050 can be met should be a key focus – capture fisheries won’t do it, so what policies

and practices will be put in place? Is current research really considering this question, or will it simply be left to the market to solve (with likely lack of attention to pollution and other aspects of sustainability)? Work on policy and governance is urgently required on these questions.

7. A particular issue in understanding the impacts of dams and irrigation development on fisheries production is the relationship between flow (both volume and timing – the latter is linked to spawning and migration timing) and the production of fish. A better understanding is required, and for more parts of the river system, so that the impact and trade-offs of development can be quantified.
8. The impact of climate change on agricultural, livestock and fisheries productivity should be further studied.

Key Findings – institutional analysis

1. There is a well developed literature on institutions and governance in water issues in the Mekong.
2. Political choices will govern the future development of the Mekong – it is not primarily limited by physical constraints such as cropland productivity and water availability.
3. Virtually all studies agree that greater public participation in decision making is required, though many add that other factors are necessary for full sharing of benefits. The other factors include strengthened laws and the espousal of public participation by local officials.
4. The Mekong River Agreement and the Mekong River Commission are too weak for debating and enforcing hard decisions, and must be strengthened if they are to have a leading role in basin-wide management.
5. Key actors who can solve the local water problems as perceived by the villagers are different, depending on the nature of the problems and resources and authorities required to take the actions.
6. The communities do not consider research organisations play any role in solving their problems but rather rely on the national government, local government, NGOs or themselves.
7. The government should support: diverse, small-scale, locally-driven projects that are designed and managed by the villagers.
8. State and provincial government were perceived more influential but less important to local villagers, because they are not easily reachable in times of immediate assistance.

Key Recommendations - institutional analysis

1. We echo the many calls in the literature for greater sharing of information, decisions and benefits. We also echo the calls for strengthening of the Mekong River Agreement and the Mekong River Commission, to a level where they provide true basin-wide rules and management.
2. There should be a clear and practical mechanism to allow the public be informed of and participate in planning and management of water and its related resources. Having the River Basin Organizations (RBOs) under the Integrated Water Resources Management (IWRM) concept undertaken by the four LMB countries' governments will be one promising option if their mandate and authority are clearly defined and the members of the RBOs well represent the groups and societies they belong, not influenced by other stronger groups. Since having the RBOs in the LMB countries is in an early stage, more studies on the current status and how to strengthen the institutional capacity of RBOs specifically for the Mekong countries should be carried out.

3. We think, however, that there should be studies on how the democratisation agenda might be accelerated. Action oriented research of the kind undertaken by ARCWIS in Australia should be undertaken more in the Mekong.
4. We also think that other information, such as that on fish and dams, should pose more starkly the difficult choices ahead. We are unaware, for example, of studies in the mainstream Mekong fish literature that point out the obvious fact that preservation of the capture fisheries (undoubtedly important as it is) appears most unlikely to sustainably feed the future populations.
5. To solve water problems and reduce the poverty, the integrated solutions and interdisciplinary participation involving the national government, local government and community-based organisations as well as villagers from planning to implementation should to be enhanced.
6. Since the state and provincial government are more influential but are not easily reachable in times of immediate assistance, the participation of local governmental sections particularly at village, commune and district levels need to be enhanced and their capacities need to be strengthened.

Key findings – analysis of interventions

1. Individual sub-catchments can be significantly affected by changes in irrigation, deforestation, climate change, and dam development. Of these possible drivers of hydrological change, none is clearly more significant than the others. However, some are more amenable to change, and the policy decisions that affect them operate at different scales.
2. Tonle Sap Lake and similar ecosystems are more likely to be affected by subtle changes in the inflow and outflow rates into the lake, and the consequent impact on fisheries, rather than by gross changes in volume or surface area due to climate change, increased irrigation, dam development, or deforestation.

Key recommendations - analysis of interventions

1. The following activities should be pursued jointly:
   a. Preparing mitigation strategies for the common problems that can arise in hot spot areas due to changes in hydrology. These strategies should be similar for a range of drivers.
   b. Engaging in policy at the global level (for climate), the regional level (for dam development), the national level (for irrigation), and the national and local level (for deforestation). All of these issues should be the subject of regional negotiations over the shared water resource.
2. The role of the inflows and outflows in affecting fisheries in Tonle Sap and similar lakes and wetlands should be a priority area of study.
3. Refine further the Bayesian livelihood model for the Tonle Sap lake area, where fisheries-based livelihoods predominate, to include the life cycle of fish in the lake, relationships of the lake surface area and accessible area to fishing, and incorporation of closed and open seasons for fishing.
4. Pursue research on the impact to livelihoods in hotspot areas due to dam development using scenario outputs and household level data obtained through the field case studies. For the Tonle Sap case study, the possible blocking of fish migration routes by dams should be considered in these analyses as well.
5. Since water quality is found to be a key water issue and has great impact to the livelihoods in many parts of the basin, it would be useful to further develop the WEAP model to capture the behavior (and changes) of water quality resulting from different development paths. The Bayesian livelihood models could also be modified to incorporate dependencies of both natural and financial assets on the quality of water (e.g. salinity levels of water for the Mekong Delta case study).

Key Findings - knowledge management

1. Main issue of water poverty data in the Lower Mekong Basin is not their availability but their spatial scale, sample size and way to define that data/indicator in each country. While a common set of indicators was compiled, for most of the indicators, national definitions differ to some degree. To interpret the study results over the LMB, it is important not to only know the data value but the nature and limitation of data collected and should be well understood.
2. The statistical offices in each country hold most of required data for the water poverty study but often publish up to a provincial level. Most of the data obtained through the MRC is available at a provincial level as well. Special requests of data have been made for the finer scale data and they were well responded by several concerned agencies. Significant time and efforts were spent on these.
3. Based on the results of the wealth ranking study, seven broad categories of poverty criteria were identified that appeared in many of the studies: food security, land holding, shelter, livestock, productive assets, disposable income, and income and debt. The income and debt data especially at a finer scale are considered as sensitive to the interviewee and therefore more difficult to obtain compared to other poverty related data. This indicator cannot be taken into the analysis and mapping.
4. Even two different methods (Bayesian model and median value methods) were used to define the water poverty area but final results are very similar. The Bayesian approach specifically addresses some of the criticisms leveled against aggregate poverty indicators, while the relative simplicity of the median value method recommends it as a useful tool for the rapid assessment of poverty indicators. The similarity of the outputs from the two methods suggested that for the purposes of the project, either approach would suffice.
5. WEAP, a user-friendly software tool that takes an integrated approach to water resources planning, has captured reasonably well for most of flow behaviour in the basin. With some adjustments of Kirby's water account applied in the key assumption function of WEAP, we could simulate the flows in the Tonle Sap River fairly well. WEAP was found useful to help determine the likely water-related changes and impacts of various basin-wide scenarios.

Key Recommendations - knowledge management

1. As stated in the rationale for having the IDIS, it is true that researchers need to spend significant time and efforts in gathering, managing and analyzing data are significant. Such data is usually located in different places, stored under different file formats, organized according to varying data structures and very often not documented. To help the researcher spend less time on data management and focus more on research and data analysis, it is important for the IDIS team to enhance its data bank in collaboration with the data contributors and communicate more with the wider research communities on an existence of the IDIS.
2. For the Mekong context, there is a great opportunity for the IDIS to enhance their databank through its collaboration with other Mekong data holding organizations (e.g. MRC and ADB). MRC is one of the Mekong BFP project partners and has its own data and information exchange and sharing policy (PDIES) being implemented under the Information and Knowledge Management Programme (IKMP). This might be a good channel for the IDIS team to start its consultation with the MRC.
3. Apart from data management, the tools developed and research products produced by all BFP projects should be managed by the BFP central knowledge team as well. It might be a case where the tools and materials developed by one project are suitable and can be applied to other BFP projects.
4. For the Mekong context, a lack of data from the upstream countries is often a limitation to a study on water related changes and impact of the basin-wide scenarios. There should be a mechanism to encourage an engagement of the researchers from the upstream countries for data and information exchange and sharing, probably through joint research projects or academic and policy fora.

1. INTRODUCTION

The Mekong River basin is one of the most dynamic, productive and diverse river basins in the world. Decades of civil strife have largely "saved" the basin from the disruption of natural flow patterns that has beset most major transboundary river systems in the world, where water impoundments and diversions have been more intensive. As a result, the Mekong basin, in relative terms, continues to enjoy exceptionally rich aquatic biodiversity and an exceptional reliance on the river's environmental services; fishing, farming and grazing, for peoples' livelihoods.

The pressure on the natural resource base, particularly water resources, has increased in recent decades and has resulted in new patterns of development within the six riparian countries. Whilst living standards have generally shown a marked improvement across the basin, there remain significant areas of poverty. Certain water resource interventions have assisted with the increasing living standards, whereas others have not realised their poverty-reduction objectives. The long deferred development of this basin has now given rise to ambitious plans by the six national governments for large scale hydropower and irrigation projects, particularly in the headwaters reaches, which may pose an increasing level of vulnerability for the poor in the basin, as well as the ecosystems on which they depend (SEI, 2002). Future plans along the Mekong, including the proposal to develop eight dams on the Lancang River (Upper Mekong, Yunnan, China), whilst having the potential to promote economic growth, are likely to have considerable negative impact on the environmental and livelihood security of downstream communities (Chapman and Daming, 1996; Daming et al., 2001; IRN, 2002). Basin level upstream-downstream linkages, where land and water-related decisions in one part of the basin impact other human and environmental uses elsewhere are difficult to address in water resources management, particularly in a transboundary system. Understanding the potential gains to be made in the productivity of water and the level of impact of these on poverty alleviation, and the integration of this understanding within adaptive governance structures is a key challenge.

1.1 Objectives of the Challenge Program for Water and Food (CPWF) and Basin Focal Projects (BFPs)

The CPWF is a global research-for-development program that seeks to contribute to achieving Millennium Development Goals by generating and applying knowledge on how to alleviate poverty and enhance food, health and environmental security through improvements in agricultural water management. The CPWF implements research in nine benchmark basins: Sao Francisco, Volta, Limpopo, Nile, Karkheh, Mekong, Indus-Ganges, Yellow river basins and the Andean system of basins.

The portfolio of Basin Focal Projects (BFP) is a major new initiative of CPWF, aimed at developing basin-wide analysis of the status of agricultural water use and the opportunities for poverty alleviation through specific improvements in the use of water in agriculture. The contribution of the Basin Focal Projects to the goal of CPWF is to articulate scientifically the extent of water-related issues influencing levels of poverty and to specify exactly how CPWF will enable significant and measurable impact, at basin and global scales on poverty, health and environment through improvements in water productivity and other aspects of agricultural water management.

The specific objectives of the Basin Focal Project in the Mekong are to:

- Assess the current condition of water use within the basin in both biophysical and socio-economic dimensions. Water productivity and water poverty are the essential measures in this process.
- Analyse the opportunities and risks of change in water management that influences water poverty
- Identify appropriate research paths for promoting change, based on trend analysis, assessment of interventions and analysis of impact.
- Develop an integrated knowledge base to support change throughout and beyond the life of this program.
- Develop solution methods and outline solutions for the impact of water and agricultural interventions on poverty.

The Mekong BFP is one of the four BFPs (the others are the Karkheh, Sao Francisco and Volta basins) commissioned in the first round in 2005. Based on the experience of these projects, the objectives of the BFPs for the remaining basins have been revised and detailed methodological guidelines have been developed. We will discuss at the end of the report, in conclusion, whether the objectives of the Mekong BFP remain relevant to the revised objectives and have been fulfilled.

1.2 Structure of the Work

CSIRO Land and Water was the lead agency to implement the project with collaboration from the Stockholm Environment Institute (SEI), the Mekong River Commission (MRC) and the Japan International Research Centre for Agricultural Sciences (JIRCAS). CSIRO has worked on basin water use, agricultural water productivity, fisheries productivity, institutional analysis and on intervention analysis. SEI concentrated on poverty and livelihood vulnerability studies, developed a WEAP (Water Evaluation and Planning) model for hydrological evaluation and contributed to institutional and intervention analysis. MRC initially supplied data to the other partners, organized stakeholder meetings and basin tours which helped the other partners to establish contact with the key actors in the basin, and at the later stage organized workshops and meetings. JIRCAS was responsible for remote sensing and land use change studies. After making a significant contribution to remote sensing studies in the project, JIRCAS withdrew from the study due to the transfer of the researcher assigned to this project to another position.

During the conduct of the study, the CPWF revised the methodological guidelines and, in particular, organised the work into 6 work packages. These are:

1. Water Poverty Analysis
2. Analysis of Water Availability and Access
3. Analysis of Agricultural Water Productivity
4. Institutional Analysis
5. Intervention Analysis
6. Development and Application of the Knowledge Base

Project responsibilities were not initially aligned in this manner. However, the original project responsibilities can be arranged in the new structure: SEI leads work package 1 and 5; CSIRO leads work packages 3 and 4; work packages 2 and 6 are shared though for accountability purposes CSIRO assumes lead responsibility.

1.3 Structure of the Report

Following this introductory chapter, Chapter 2 gives a brief description of the Mekong Basin and outlines the key issues in water, food and poverty. The main body of the report is in chapters 3 to 8, which is one chapter in turn for each of the work packages mentioned above. The report concludes with chapter 9 and references.

Our aim in this report is to focus on the outputs, key findings and recommendations. We do not give extensive descriptions of methods and results: details can be found in several other reports to the CPWF and in papers. These are all referred to in outputs sections in chapters 3 to 8, and summarised in the executive summary. In this report, we recapitulate the main elements of methods and results, sufficient to understand how we arrived at the key findings and recommendations. Each of chapters 3 to 8 has a section for key findings and another for key recommendations. The key findings and key recommendations are also summarised in the executive summary.

2. BRIEF DESCRIPTION OF THE MEKONG AND KEY ISSUES

2.1 Brief description of the Mekong

The Mekong Basin varies from high mountain plateau at its source; through tropical forested mountainous upper middle sections; densely settled, agricultural lower middle regions; to wide, flat irrigated floodplains of the Delta (Figure 2.1). The total area of the basin is 795,000 km^2, draining parts of the six countries: China, Myanmar, Laos, Thailand, Cambodia and Vietnam. The part of the basin in China and Myanmar are known as the Upper Mekong Basin, and the lower part as the Lower Mekong Basin.

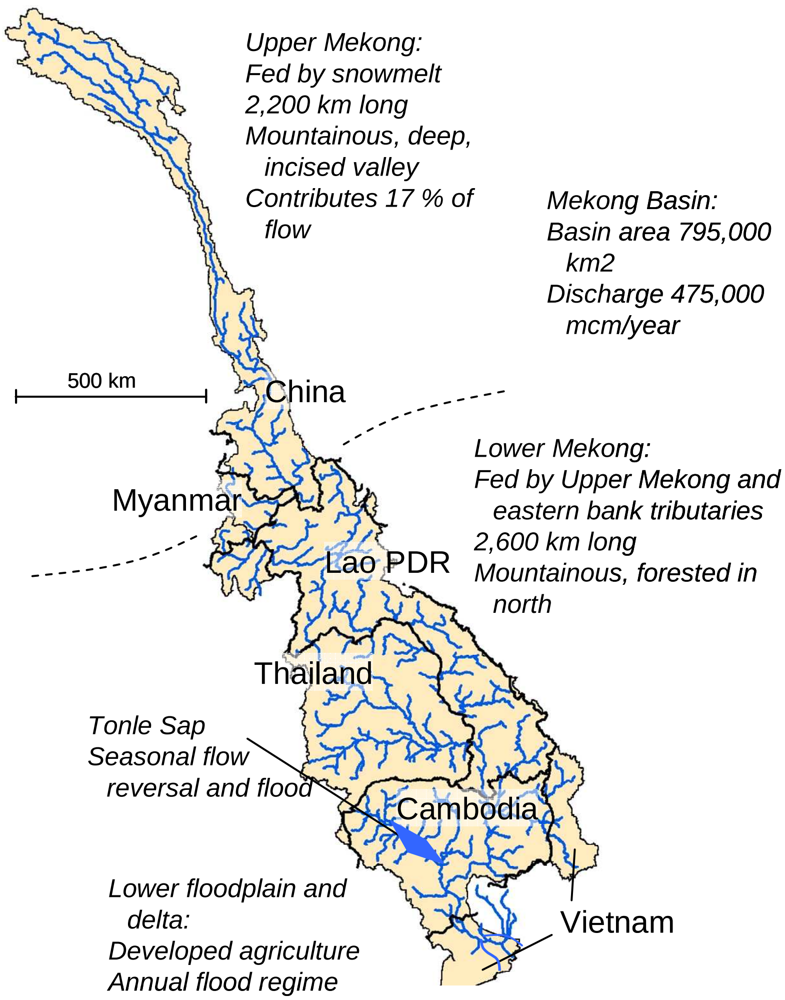


Figure 2.1 Mekong River Basin

The source of the Mekong is fed by snowmelt, though precipitation is much less than throughout the Lower Mekong (Figure 2.2). The Lower Mekong is fed by runoff, characterised by a pronounced wet and dry season. The peak flow from the Upper Mekong more or less coincides with the peak inflows from runoff into the Lower Mekong. Furthermore, the wet season affects the whole of Lower Mekong more or less simultaneously (Figure 2.2). The rainfall is greater in the eastern, mountainous regions of

Laos, from which the major portion of the runoff and flow is generated. The rainfall in NE Thailand is less, and the potential evapotranspiration (PET) somewhat greater than the rest of the basin, and this area contributes the smallest portion of the runoff and flow. In addition to the spatial variability of precipitation, there is considerable year-to-year variability (Figure 2.3).

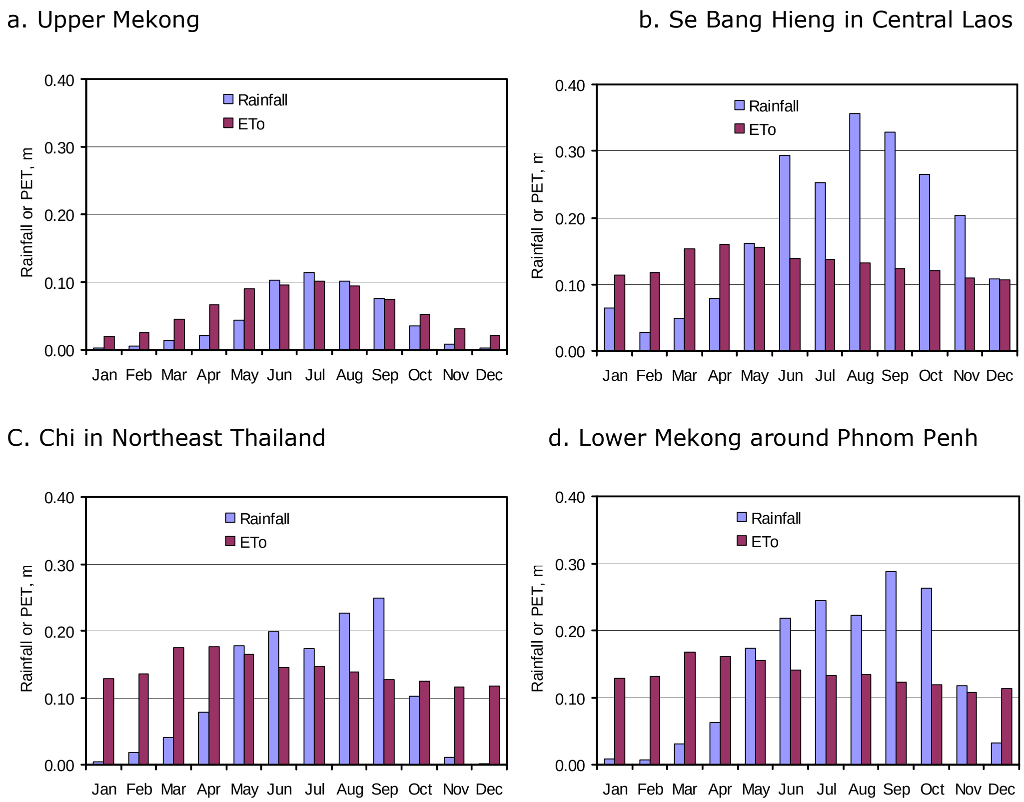


Figure 2.2 Monthly average rain and potential evapotranspiration in the Mekong Basin

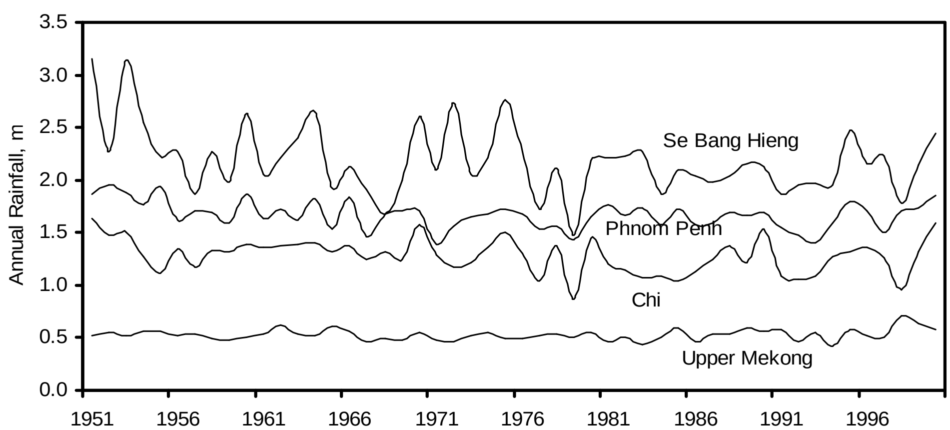


Figure 2.3 Annual rainfall 1951-2000

The rainfall is strongly seasonal. The dry season, from November to May, is particularly intense in NE Thailand, and the region suffers from seasonal water shortage. In the dry season, the river flow is modest, but increases many-fold in the wet season from June to October. At Chiang Saen, where the Mekong leaves the Upper Basin and enters the Lower Basin, the dry season flows are about 2,500 mcm/month and the peak wet season monthly flows vary from about 10,000 to about 20,000 mcm/month. At Phnom Penh, in southern Cambodia, the flows are about 6,000 to about 10,000 mcm/month in the dry season, and about 60,000 to 90,000 mcm/month at the peak of the wet season.

In the dry season, the Tonle Sap River drains the Tonle Sap (“Great Lake”) lake to the Mekong. In the wet season, the Mekong River rises above the level of the Tonle Sap River, and pushes water up the Tonle Sap River, reversing its flow for about five months of the year. The Tonle Sap swells greatly during this period, and there is a great production of fish. Annual production correlates with the magnitude of the annual flood (Baran et al., 2001). The flood pulse and fish production is less dramatic elsewhere, but is nevertheless important throughout much of the Lower Mekong, and the basin supports the third largest inland fishery in the world (after the Amazon and Bangladesh). It is the most important source of animal protein for millions of people, including many poor people (Hortle, 2007).

Agriculture, particularly rice production, is the dominant land use in northeast Thailand, central and southern Cambodia, and the delta region of Vietnam. There are smaller areas of cropping in Laos in the flatter areas near the Mekong and in the central highlands of Vietnam in the east of the basin. There is some irrigation in many of these areas, though the main area extensively developed for irrigation is in the delta (Mekong River Commission, 2003). Livestock production is also an important activity in the basin.

The Mekong River has one of the most diverse and abundant fisheries in the World (Mekong River Commission, 2003). The lower Mekong River system with its extensive associated floodplains and wetlands supports important inland fisheries (Baran et al., 2007). The fisheries are a major factor in the well being and livelihoods of the 60 million people of the basin (Mekong River Commission, 2005). Some 40 million people or two thirds of the basin’s population are involved in Mekong fisheries, at least part-time or seasonally. Not only do they derive their livelihood from fishery, they also depend on fish and other aquatic animals for food security (Mekong River Commission, 2003). Fish and other aquatic animals are the most important sources of animal protein, and thus a major support to food security, in particular of the rural population in the lower Mekong Basin (van Zalinge et al., 2003).

The basin is home to approximately 60 million inhabitants, most of whom are rural poor with livelihoods directly dependent on the availability of water for the production of food. Agriculture, along with fishing and forestry employs 85% of the people in the basin, many at subsistence level (MRC 2003). The pressure on the natural resource base, particularly water resources, has increased in recent decades and has resulted in new patterns of development within the six riparian countries. Whilst living standards have generally increased markedly across the basin, there remain significant areas of poverty.

2.2 Key Issues

Several studies have outlined key issues influencing development and livelihoods in the Mekong Basin (Badendoch, 2001; Hirsch and Cheong, 1996; Kaosa-ard and Dore, 2003; MRC, 2003; SEI, 2002; Öjendal, 2000). What is clear from these studies is that with rising pressure on the natural resource base, trade offs over resources can be seen between upstream and downstream interests, urban and rural areas, upland and low-land communities, sectors (notably between fisheries and hydropower), subsistence-based livelihoods and activities oriented towards industrialisation, and civil society interests and formal resource agencies. In order to improve the livelihoods in the Mekong, decision making requires some understanding of the origin and nature of these trade-offs so as to effectively resolve rising water-based competition. Here we describe four key water and natural resource issues in the basin.

2.2.1 Impacts of population growth and development

The population of the Mekong is expected to increase from the current 60 to more than 90 million (based on medium variant projection, UN Population Division, 2006), and the proportion of urban dwellers from about 20 % to about 40 %. Economic growth is around 4.5 % per annum. These three factors will drive great change in the Mekong.

Growth of urban and industrial centres: outside the Delta, other than Vientiane and Phnom Penh, current urban centres are small. By 2050, urban populations will increase from the current approximately 15 million to nearly 40 million, and many centres will grow in size dramatically. Together with industrial development, this will place demands on water supply and effluent disposal.

Changing land use and increasing irrigation: The increasing population and increasing food demand will create pressure for a continuing of expansion of irrigation. Irrigation in the delta has reached its potential but, according to some scenarios, expansion in Cambodia and Thailand could result in growth in annual diversions 15,000 mcm (World Bank, 2004). Deforestation is likely also to continue. Increasing diversions will result in reduced dry season flows, which may in turn result in greater saline intrusion in the Delta, jeopardising agricultural production.

Increasing energy demand and the development of hydropower dams: the rapid economic growth is accompanied by rising energy demand, especially in China, Thailand and Vietnam. The Mekong (and other SE Asian rivers such as the Salween), especially in China, Laos and the central highlands of Vietnam, is viewed as a large potential source of hydropower to meet this demand (Dore et al., 2007; Greacen and Palettu, 2007), though there is some debate over the accuracy of projected demand. The storage capacity of planned dams is in the order of 50,000 mcm (World Bank, 2004). Dam development will alter the timing and magnitude of flows, in particular flood peaks will decrease (World Bank, 2004), hence the seasonal expansion of the Tonle Sap and flooding of seasonal wetlands elsewhere in the basin will be reduced. This will in turn jeopardise fisheries production, since the production is correlated to the magnitude of the flood (eg Baran et al., 2001). Fish migration paths will be cut off, due to dams acting as a physical barrier, and refugia and spawning grounds for fish will be reduced. Again, this will jeopardise the fishery production. Furthermore, sediment trapping in completed hydropower dams in the upper Mekong has led to reduced sediment transport downstream leading to concerns that this will limit the supply of fresh nutrients for ecosystems and streams in the lower basin (Kummu and Varis, 2007).

2.2.2 Climate change

The impacts of climate change are expected to include increases of temperature of between 1° and 3° C, particularly from January to May, with the larger increases in the eastern highlands of the basin. The dry season is expected to lengthen and intensify, and the rainy season is expected to shorten and intensify, with dramatic increases in rainfall in the wettest months particularly in parts of Laos. Overall, however, only a modest increase in annual rainfall in most parts of the Mekong, though the upper Mekong in China is expected to receive somewhat less rain annually. Thus both seasonal water shortages and floods may be exacerbated, as may saltwater intrusion into the delta (Hoanh et al., 2003; Snidvongs et al. 2003; Chinvanno, 2004).

Rising temperatures will accelerate the melting of snow and ice in the Tibetan plateau, affecting the many large rivers that rise there and flow through south and east Asia. A short term impact could be greater floods, but the longer-term impact is likely to be a decline in flows. Concern is expressed that the Mekong will be amongst the rivers affected (Penning de Vries, 2006), but there appears to be no Mekong specific study on the likely magnitude of the impacts.

Sea level rise will adversely affect the delta, much of which would face inundation under the more extreme scenarios (Dasgupta, 2007; Wassmann et al. 2004). Even modest scenarios would lead to greater flooding risks and saltwater intrusion. More than one million people are expected to be affected by 2050 (Nicholls et al., 2007).

The anticipated changes to climate and hence flow are expected to affect agriculture and food production greatly. The longer dry season in many parts of the basin will reduce agricultural production. The overall effect will be to exacerbate the problems of supplying the increase in food demand with growing populations (Hoanh et al., 2003; Snidvongs et al. 2006).

2.2.3 Ecological sustainability

The natural environments of the Mekong provide livelihoods and ecological services for many, particularly the poor. Here we describe, by way of three contrasting examples, the importance of natural environments, and the potential impact associated with their loss.

Upland forests in Lao PDR: the uplands which form the greater part of Lao PDR are mountainous, forested and wet. They contribute about a third of the total runoff to the Mekong. They are home to about a third of the Lao population, many of whom traditionally practice shifting cultivation (Ducortieux et al., 2005). At low population densities, with long cultivation cycles, the practice is sustainable (Kleinman et al, 1995; also references cited in Ducortieux et al., 2005).

From the 1950s to the 1990s, increasing population density and government policies limiting access to land resulted in slash and burn cycles decreasing from 38 to 5 years, accompanied by loss of soil carbon, erosion and changes to weeds (Roder, 1997). Further land use policy changes in the 1990s have proved counterproductive for both forest protection and agricultural modernisation (Ducortieux et al., 2005).

The Songkhram: the Songkhram is in some ways like the Tonle Sap - an annual flood pulse with a reversing the flow component, and large fisheries productivity forming an important source of food for many poor people. It has recently been reviewed by Blake (2006). The catchment covers about 13,000 km2 in the north-east corner of NE Thailand, draining directly into the Mekong. Every year, floods inundate between 1000 and (for a one in 50 year event) 2000 km2. Reversing flow from the Mekong is an important component of the flood. The catchment contains the largest remaining area of natural forest and wetland within the Thai part of the Mekong, with about half the catchment being classified under some definitions as wetland, concentrated in the lower part.

The floods bring nutrients and sediments to the wetlands, flooding what may be the last seasonally-inundated forest remaining in Thailand. The region is important for its biodiversity, and the fishery is highly productive. In addition to the fish, other forest resources are important to local livelihoods.

There have long been plans to control the floods with various schemes include damming and diverting water for irrigation, and to convert remaining areas of natural vegetation to agricultural land. These are unlikely to control the floods, and may have undesirable downstream impacts, and will certainly involve loss of biodiversity, fish and other resources for local livelihoods.

The main rivers: the Mekong river itself is an important natural ecosystem. Key attributes include the physical form of the river, the flow regime and the water quality. Aspects of the physical form include deep pools, which form important refugia for fish during the low flow period of the year. Other structures (including rough, rocky stretches and rapids) are important for refugia, spawning and migration. In the high flow season, fish migrate long distances up and down the Mekong and into the tributaries. The flow regime acts as a signal for both migration and spawning. The water quality in the Mekong is characterised by the natural sediment and nutrient load it carries. This load is important in downstream areas as a food source and fertiliser to fish and flooded ecosystems.

These key attributes are all under threat: the physical form is threatened by blasting of rapids to increase ease of river transportation, and by dams in key parts of the river (with the proposed dam at the Khone Falls in Laos being a particularly contentious example); the flow regime is threatened by dams, diversions and by climate change; the water quality is threatened by dams which may act as sediment traps, and by agricultural, urban and industrial activities which may pollute the waters.

2.2.4 Poverty and resource access

There is widespread poverty in the Lower Mekong Region (Kristensen, 2001). The people in Cambodia and Lao PDR are among the poorest in the world. Also in the North-eastern part of Thailand and the provinces of Vietnam that are part of the basin, many people suffer from severe poverty. Poverty is closely related to access to cultivable land and appropriate amounts of water, as well as to fish (Kristensen, 2001; Chaudry and Juntopas, 2005). Chaudry and Juntopas (2005) describe the key factors governing poverty in the Mekong as:

- increasingly insecure tenure and rights of access of the poor to natural resources, such as land, forests and rivers.
- the predominance of subsistence based agricultural practices, particularly in rice production.
- a regional inland fisheries sector under increasing pressure from multiple sources.
- the eradication of upland farming systems upon which minority peoples depend.
- processes for hydropower and infrastructure development which adversely impact those with the least stake, or voice, in the national development 'project'.

Water and poverty are intricately linked in the Mekong region. Yet there is paucity of information on basin wide poverty and its linkage of poverty with land and water, particularly in the areas of Laos and Cambodia. Poverty is relatively well documented in the Mekong Delta of Vietnam and perhaps for the North-eastern part of Thailand though the majority of the poor people live in Cambodia and Lao PDR.

There have been some efforts for poverty reduction through various interventions such as aquaculture management (Van Brakel et al., undated; Haylor, 2001), forestry management (ADB, 2003), rice-shrimp farming (Brenan et al, 2002) etc in some areas of the basin. However, a comprehensive assessment of basin-wide poverty and their links with the water and land resources, their potential to alleviate poverty, their consequences on the biodiversity and natural environment are yet to be fully understood.

2.3 Implications for the Mekong Basin Focal Project

The Mekong contrasts with some other basins of the CPWF, where water shortage is often a key issue. Although the Mekong has areas (particularly northeast Thailand) which are short of water in the dry season, the basin as a whole is not short of water. In the basin, the issues are concerned with the access to and distribution equity in the resources in the basin, especially to the water and the fish resource. Development will alter the access and equity, with upstream-downstream tensions among countries and sectors. Furthermore, the issues are linked. Poverty may be alleviated through development and jobs – which in turn may be enhanced through the provision of hydroelectric power. Yet this form of development will reduce resources available to some downstream groups. What are the trade-offs? Are the gains worth the losses? Can the losers be compensated?

Dealing with these issues requires an integrated approach. Our approach is summarised in Figure 2.4. We started by understanding the water use account – how much water is there, where is it and what is it used for? How might these uses change with future events? From this we went on to examine the production of food and the way this is linked to the availability of water. At the same time, we assessed the level of poverty and vulnerability to change, through direct survey at targeted sites and through more general poverty mapping. Finally, we integrated these two strands of work through a modelling approach which deals with both the poverty and the water availability. It is this integration which enables a quantification of impacts due to development and other threats and opportunities. We briefly describe the elements of this approach, and our key findings resulting from its application, in the coming chapters.

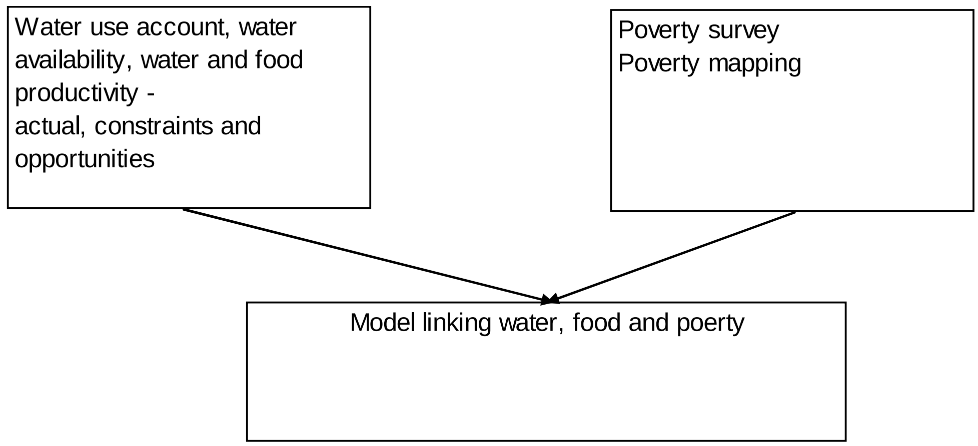


Figure 2.4 Integrated approach of dealing with basin issues

3. WATER POVERTY: DISTRIBUTION, LIVELIHOODS, AND VULNERABILITY

To achieve the ends of the Challenge Program on Water and Food (CPWF) and the associated Basin Focal Projects, effective approaches are required to identify those who are to benefit most readily from such efforts, elucidate critical water linkages that underpin secure livelihoods, and nurture capacity among the beneficiaries to advance and sustain those livelihoods with methods informed by knowledge of these linkages.

This chapter describes the work undertaken by the Mekong Basin Focal Project to analyze livelihoods and assess the extent of water poverty in the basin. The main outputs from this work are a set of poverty maps for the Lower Mekong Basin, field studies carried out as part of the project, and models of livelihood dynamics that were built on the analysis of field studies' results.

3.1 Literature

Despite the negative impact the Asian financial crisis (1997/98) had on the region, over the past 12 years (1992/93-2004/05) the poverty incidence has declined with reductions more pronounced in Vietnam (58% to 20%) and Thailand (23% to 10% for whole country, 40% to approx. 18% for its northeastern part) than in Lao PDR (46% to 33%) and Cambodia (39% to 35%). Despite the increase in export growth and a rise in the investment in the region, poverty remains widespread and socio-economic disparities continue to persist, as benefits and costs of development have not been shared equitably among the inhabitants. Within countries, socio-economic gaps persist and poverty is consistently higher in rural areas than in urban areas, with the highest incidence in remote, upland areas where ethnic communities live. Even in Thailand, the country with the fewest poor and with greater access to safe water and sanitation than in other lower Mekong basin countries, the poverty incidence in its rural area is significantly higher than in its urban area. Compared to the rest of Thailand, the northeastern part of Thailand (in the Mekong) has the greatest number of the poor and accounts about 60% of all poor in the country. [Source: various including ADB GMS Regional Cooperation Strategy and Program Update 2006; FAO Livestock Sector Report 2004; NESDB& TDRI works; and Mekong BFP works]

3.2 Conceptual framework

A conceptual framework was developed to help organize the several aspects of the work described in this chapter. The closely-related concepts of livelihoods and poverty are viewed through the lens of the DFID Sustainable Livelihoods framework, while within the broad topic of poverty, the special focus for the Mekong Basin Focal project is on water poverty. Both of these concepts – sustainable livelihoods and water poverty – are described in this section.

3.2.1 The Sustainable Livelihoods framework

The UK Department for International Development (DFID) devised a framework for assessing, monitoring, and analyzing livelihood systems called the Sustainable Livelihood (SL) framework (Carney 1998; Carney et al. 1999; DFID 2001). The framework is based on research carried out at the Institute of Development Studies at the University of Sussex (Scoones 1998; Chambers and Conway 1991) and takes as its starting point a definition of livelihoods provided by Chambers and Conway:

> A livelihood comprises the capabilities, assets (stores, resources, claims and access) and activities required for a means of living: a livelihood is sustainable which can cope with and recover from stress and shocks, maintain or enhance its capabilities and assets, and provide sustainable livelihood opportunities for the next generation; and which contributes net benefits to other livelihoods at the local and global levels and in the short and long term.

The particular framework that DFID developed is one way of organizing information about livelihoods. The livelihoods approach itself is more broad, and incorporates a variety of frameworks (Carney et al. 1999). The common core between the different frameworks is a focus on individual people's experience of development, in contrast to macroeconomic or institutional approaches. As formulated by DFID, the livelihood approach "put[s] people at the centre of development, thereby increasing the effectiveness of development assistance" (DFID 2001).

The DFID sustainable livelihoods framework is illustrated schematically in Figure 3.1. As shown in the figure, the five livelihood assets – physical, financial, human, natural, and social – are combined in livelihood strategies that generate livelihood outcomes that in turn affect the levels of assets. The levels of the assets influence and are influenced by policies, institutions, and processes that feed back into the vulnerability context, such as seasonal fluctuations and periodic shocks, which in turn interact with the livelihood assets.

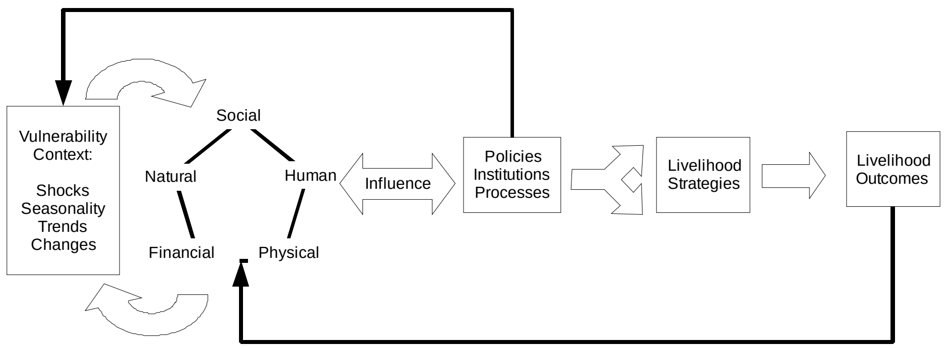


Figure 3.1 The Sustainable Livelihoods Framework (adapted from DFID 2001)

Development of DFID's Sustainable Livelihoods framework began in earnest in 1998. By 2002 a review of the framework could claim "considerable impact" both within and outside DFID, and point to a wide diversity of applications (Carney 2002). Since its inception it has formed the conceptual basis for books on development (e.g., Dalal-Clayton et al. 2003; Terbeck 2008; Baumgartner and Hogger 2004), country studies (e.g., Turton 2000; Winkels and Adger 2002; Luttrell et al. 2004), and sectoral studies (e.g., Allison and Ellis 2001; Adato and Meinzen-Dick 2002), among other applications.

Guidelines for applying the Sustainable Livelihoods framework are provided by the DFID Sustainable Livelihoods Guidance Sheets (DFID 2001), which detail how the framework is to be interpreted and the sort of field data that is required to inform the framework. DFID has specific goals for its own use of the framework, including – but not limited to – improved access to education and better nutrition; a more cohesive social environment; better access to infrastructure; more secure financial resources, and; an environment that supports multiple livelihood strategies. At the same time, they recognize that the framework has taken on a life of its own and applaud the various applications of the framework by other parties (Carney 2002).

3.2.2 Poverty and water poverty

There is more than one way to measure poverty. Citing Lok-Dessallien (1998), Cook and Gikuchi (2006) identify six distinct poverty concepts, including ones that focus on minimal needs (which leads to the use of an absolute poverty line), distribution (which leads to a relative poverty line), subjective definitions (which underpin participatory poverty assessment approaches), and structural definitions (which identify institutional factors that limit access or freedom of action). These definitions differ broadly on whether they focus on "means" or "ends" (Lok-Dessallien 1998). No approach is ideal, and all have hidden assumptions that may draw attention away from important features of real livelihoods. Poverty lines address the question of means, at the cost of ignoring institutional factors that may strongly influence the outcome. Generally, poverty lines are easier to measure and apply compared to other approaches.

Historically, means-focused indicators have used financial flows (income or expenditure) for defining poverty. More recently, asset-based indicators – that is, indicators of stocks – have seen increasing use (Carter and Barrett 2006). The benefit of an asset-based approach is that it provides an indication of resilience, and hence the risk of falling into poverty.

The Mekong Basin Focal Project uses subjective definitions of poverty drawn from a survey of wealth ranking exercises to identify poverty indicators, but then organizes those indicators using the Sustainable Livelihoods framework, which is an asset-based framework (Scoones 1998; Carney 1998; Carney et al. 1999; DFID 2001). In this sense, the approach taken for this project is a hybrid between means-focused and ends-focused poverty measures. In keeping with the focus on assets, the Mekong Basin Focal Project carried out a literature review of wealth ranking studies (de la Rosa and Chadwick 2008). Wealth ranking (Participation Website, accessed 2008) is a participatory approach in which the poverty situation of a community is viewed by looking at how community members or households are classified according to their wealth. Wealth ranking aims to draw out local knowledge and criteria from local reference groups or individuals (such as village leaders) who know the families living in a community (such as a village) and are in the position to make judgments about their poverty status. The ranking is based on the views of the community residents, who generate their own criteria with which to view and rank poverty or wealth.

Within the context of the CPWF, the specific focus is on water poverty, rather than on poverty in general. The Global Water Partnership (GWP) defines the water poor as those:

- whose natural livelihood base is persistently threatened by severe drought or flood;
- whose livelihood depends on the cultivation of food or gathering of natural products, and whose water source is not dependable or sufficient;
- whose natural livelihood base is subject to erosion, degradation, or state confiscation without due compensation;
- who lack access to productive land and water resources;
- who live far from a year-round supply of drinking water;
- who are obliged to expend greater than five per cent of household income on water;
- whose water supply is contaminated and who cannot afford to use, or have no access to, an alternate water source;
- who live in areas with high levels of water-associated disease without means of protection; and
- women and girls who spend hours a day collecting water, putting their security, education, productivity, and nutritional status at risk (Black and Hall 2004; Madar and Amarasinghe 2005).

The connection between this definition of water poverty and agricultural production – and hence its relevance to the CPWF – is clear (Cook and Gichuki 2006).

In contrast to the GWP approach to defining water poverty, which features a list of criteria for labeling a community or household as “water poor”, the Water Poverty Index approach (Sullivan 2002; Sullivan et al. 2003; Sullivan and Meigh 2003; Wallace et al. 2003) seeks to construct a single composite indicator that combines component indicators for water resources, access, productive use, capacity, and environmental impact. This is attractive for constructing water poverty maps, because only a handful of indicators can be effectively assessed by visually reviewing the maps, and aggregate indicators are all but essential. However, care is required when constructing the aggregate poverty indicators needed for poverty maps. Contemporary perspectives on poverty emphasize its multi-faceted nature, both regarding poverty in general (Henninger 1998; Baumann 2002; Sen 1983; Sen 1999) and water-related poverty specifically. An appropriate method for constructing aggregate poverty indicators must take into account the multidimensional nature of poverty, the insufficiency of the available data to reflect its true extent, and the importance of local context and judgment in assessing poverty. The aggregation process requires judgment and knowledge of the population whose poverty is being assessed, and is therefore best carried out through a participatory process (Molle and Mollinga 2003).

The Mekong Basin Focal Project uses aggregate indicators for mapping water poverty, while attempting to address at least some of the cautions regarding the use of such indicators. As discussed in detail later in this chapter, the aggregate poverty measures are designed to identify “hotspots” that have both high levels of poverty and significant water constraints. This definition of water poverty can be contrasted with other definitions, such as the WPI, in which only water-related poverty indicators are used. The premise is that livelihood strategies mediate the link between resource constraints (including water constraints) and outcomes, so that the link between water constraints and poverty is not direct. However, given the essential nature of water in sustaining livelihoods, the simultaneous appearance of water constraints and high levels of poverty is a strong indication that intervening to limit the impact of the water constraint can have a significant impact on poverty.

3.2.3 Mapping water poverty

Poverty maps can provide a rapid assessment of the distribution of poverty. The spatially-specific information that they provide can be assessed visually in order to test and extend one's understanding of the distribution of poverty, and also be used analytically with other spatially-explicit data sets to explore the correlates of poverty (Henninger 1998; Henninger and Snel 2002; Davis 2003). Ideally, poverty maps can be used as the basis for more transparent and participatory decision-making and to better target poverty-reduction interventions (Henninger and Snel 2002).

As discussed above, the approach taken for the Mekong Basin Focal Project is to construct aggregate poverty measures for creating poverty maps. Aggregate indicators can summarize an otherwise confusing mass of data. However, there are problems with aggregate poverty indicators, as argued eloquently by Molle and Mollinga (2003). In this section the critique of Molle and Mollinga is used to frame a discussion of previous work on poverty mapping, and aggregate poverty indicators.

Molle and Mollinga summarize the problems with poverty indicators as follows:

1. Inadequacies in the underlying data,
2. Arbitrariness of weights used in the aggregation process,
3. Incommensurability of value judgments and standpoints by those engaged in the aggregation process or affected by the use of the aggregated indicators,
4. Loss of information in the aggregation process.

They conclude,

> …indicators are socially constructed tools, "loaded" with particular development objectives and interests. Instead of looking for a general "best indicator", it would perhaps be possible to make the design of water indicators part of the water-resources development planning process. In this way, it becomes a tool or instrument for negotiation and alignment of the different objectives and interests of the participants.

With this critique in mind, we now turn to three examples of previous work: the Mekong River Commission's Social Atlas of the Lower Mekong Basin, the work of the Asian Development Bank for the Greater Mekong subregion, and the Water Poverty Index (WPI).

The Social Atlas of the Lower Mekong Basin (Hook et al. 2003) was commissioned by the Mekong River Commission. It provides a number of maps of key indicators at provincial level. Each map displays the spatial distribution of an indicator of social conditions across the Lower Mekong Basin, with the indicators and maps grouped into five themes: population, labor force, living standards, health, and education. Supplementary maps provide the environmental and infrastructural context for the social maps. Each indicator is presented on its own, and indicators are not combined into an overall aggregate indicator. Considering the critique of Molle and Molinga, the choice of indicators and the categories within which they were placed reflects a particular view of social needs and activities. However, the indicators and categories are broad and can be used for a variety of purposes. For a resource that is meant to be used widely, it is appropriate that no summary aggregate indicator was calculated.

The Asian Development Bank's (ADB) report on the economic overview for the Greater Mekong subregion (ADB 2004; ADB 2005) focuses on the indicators of greatest interest to the bank, namely macroeconomic indicators and indicators for measuring the outcomes of bank-funded investment projects. Standard indicators are used to measure poverty – national poverty lines – and development – the United Nations Development Programme's Human Development Indicator (HDI). From the point of view suggested by Molle and

Molinga's critique, the use of macroeconomic indicators and poverty line-based poverty measures reflect a vision of development that channels resources in particular directions. In particular, income or expenditure-based poverty lines are not well suited to capturing livelihood strategies of the poor that seek to buffer shocks by deploying a variety of assets, as suggested by the Sustainable Livelihoods framework. Similarly, the ADB's model of the interaction between interventions and outcomes focuses on the varieties of infrastructure that supports economic activity (ADB 2005), which takes into account physical and financial assets, but gives less focus to natural, human, and social assets. Despite these limitations, the indicators used by the ADB match the types of interventions that the bank has the capacity to undertake, and are likely to be useful for project monitoring. They are likely to be less effective in initial targeting of projects, since they miss potentially important aspects of the project context.

The WPI (Sullivan 2002; Sullivan et al. 2003 Sullivan and Meigh 2003; Wallace et al. 2003) is an aggregate indicator that combines indicators along five dimensions – resources, access, capacity, use, and environment. Indicators are chosen on a study-by-study basis. They are given a value from 0 to 100 and summed using application-specific weights to give an overall score from 0 to 100. The aggregate scores within each dimension are reported, as well as the overall score. Such a measure can, if used in the way that Molle and Molinga indicate, be of considerable use in a project. A potentially useful approach is to have stakeholders collaborate in defining the components of the indicator and then use the resulting indicator values as a prompt for discussions about possible interventions. The WPI loses its value the farther it gets from the context in which it was constructed. Despite claims that the WPI is transparent (Sullivan and Meigh 2003), the aggregation process unavoidably hides information. As with any aggregate indicator – including the ones developed for the Mekong Basin Focal Project – the farther the definition of the indicator is from its use, the less useful it is as a guide to action.

3.3 Poverty and vulnerability assessment of Lower Mekong countries

The Millennium Development Goals (MDG) to reduce extreme poverty by half by 2015 and to achieve significant improvements in health; education, environmental and livelihood conditions of the poorest present a big challenge. While the Goals are widely accepted, there is still a need for effective strategies on how best to target the poor and plan for the poverty reduction. Several studies on the poverty and vulnerability of the poor to several aspects have been carried out in the region recently.

3.3.1 Official poverty estimates - consumption or income as a measure of welfare

To measure poverty, all countries in the Lower Mekong Basin officially applied the income and consumption method where poverty lines are created (based on the consumption basket) and used as the baseline to compare monthly income or consumption per capita of the population in the area (Xaowanna 1999; Kakwani et al. 2001; Jitsuchon 2001; NESDB 2002; Andersson et al. 2006). The estimation of consumption and the construction of poverty line is complex, and the methodology employed varied between countries particularly with regard to the inclusion of non-food items (Hook et al. 2003)

The poverty estimates are primarily based on consumption as indicator of household welfare while non-consumption or non-income dimensions of welfare are also taken into account in many studies. This was explored by the construction of various vulnerability indices and maps that combine income and non-income indicators. The weights assigned to different dimensions are on ad hoc basis and imply value judgements on the relative importance of different dimensions of welfare.

3.3.2 Vulnerability to food insecurity index

Most relevant and pertinent relevant indicators that closely reflect food security concerns were selected to develop a new vulnerability index (WFP 2004). Considerable thought was attributed to the selection of an equal composition of indicators according to access, availability and utilization components of food systems in Laos, and in light of the various risk factors that cause rural subsistence based households to become vulnerable to food insecurity. The final selection of indicators include the following: rice production, crop diversity, access to forests and non-timber forest products, access to main roads and rivers, educated head of household, alongside the incidence of malaria and UXO risk. Alongside of a development of a new vulnerability index, a range of different risk overlays were developed to establish the districts potentially at risk to natural disasters, e.g. flood and drought, alongside other factors related to livelihoods, e.g. opium consumption. Once a selection of appropriate indicators was made, a comparative study of statistical data reduction techniques was undertaken to determine the most appropriate data processing method. Four different techniques were trialed and tested –in the final analysis the factor analysis technique was deemed the most appropriate technique to form an index of vulnerability. These results were compared to three historic analyses of poverty in Laos. Such comparisons yielded high correlations between poor and food insecure districts.

3.3.3 Vulnerability to natural disasters

Vulnerability analysis and mapping at commune level in Cambodia involves taking measures of human vulnerability, calculating estimates for these measures across the various geographic areas of the country, and creating maps to present the information visually. Vulnerability is anything that increases the likelihood of a person suffering disadvantage or deprivation of any kind. Cambodia has been repeatedly hit by natural disasters, particularly floods and droughts, over the last decade. Because many Cambodians depend upon subsistence agriculture for their livelihoods, they are particularly vulnerable to suffering hunger, poverty, or even the loss of life, when such disasters hit. This vulnerability has increased in recent years because of a series of almost consecutive annual disasters that have not allowed people the opportunity to recover from previous floods or droughts (MOP and WFP 2003).

To determine areas that should be priorities for flood related interventions, three issues are taken into account flood affected areas, rice dependency, and food security. The degrees to which each commune is affected by flood waters, dependent on rice production, and unable to produce enough food to feed itself during flood years are taken together to categorize communes into different levels of priority. These classifications essentially cover three different kinds of areas that are vulnerable to floods:

- The first priority group is severely affected by any kind of flood,
- the second group is only affected by the big central area floods, and
- the third group is only affected by flash flooding of the Mekong.

Thus, when a flood of a particular type hits the country, policymakers immediately know where to start prioritizing their relief efforts.

The issues analyzed were: drought affected areas, rice dependency, and food security. Data on precipitation and the Normalized Differential Vegetation Index (NDVI - a measure of the greenness of vegetation and a proxy for agricultural productivity) were used to identify drought-affected areas. Definitions for three levels of priority were again developed. First priority communes were defined as those with low precipitation and NDVI, high rice dependence, and food insecurity in 1998. These are communes where droughts are likely, and where they will have the worst consequences. Second priority communes have the same criteria as the first priority communes, but were not food insecure during the 1998 drought year. Third priority communes have low precipitation and NDVI, and are thus drought prone, but are neither highly rice dependent nor food insecure.

3.4 Mapping water poverty

3.4.1 Creating water poverty indicators for the Mekong Basin Focal Project

Aggregate poverty indicators were constructed for the purpose of constructing water poverty maps for the Mekong Basin Focal project. In any aggregation exercise, a number of component indicators are collected from data and combined in a weighting process to create the aggregate indicator. The most contentious issue when developing aggregate indicators is the assignment of weights. Weights inevitably involve both normative and positive judgments. A novel approach to assigning weights that is based on Bayesian statistical reasoning was developed for the Mekong Basin Focal project. This Bayesian method attempts to separate the normative and positive aspects of assigning weights, with the goal of reducing the arbitrariness of weight assignment. This new approach was accompanied by a parallel method for constructing indicators called the “median value” method in which all inputs are given equal weight. As discussed in a subsequent section, the two methods give similar results.

In both the median value and Bayesian methods, the focus is on relative poverty in the basin, rather than absolute poverty. As discussed previously in this chapter, the purpose is to identify hotspots that have both relatively high rates of poverty incidence and relatively high water constraints. For this purpose, data were collected that provide conventional poverty measures as well as water-specific poverty measures, with the choice of data being driven by the results of the wealth ranking study. The data and component indicators are discussed in the next section. In this section, the general features of the two approaches – the median value method and the Bayesian method – are described.

3.4.2 Median value method

In the median value method, any component indicator that has a value greater than the median across the basin (or across a country or sub-basin, for country-specific studies) is given a value of 1, otherwise it is given a value of 0. The median value is defined such that one-half the areas have a value less than or possibly equal to the median, while the other half have a value greater than the median. The aggregate indicator is constructed by summing the values for each indicator. The resulting assignment of hotspots was then subjected to expert review.

In this method, all component indicators are given equal weight. The method is straightforward and is well-matched to the definition of a hotspot, by giving special focus to those areas that score high on many indicators simultaneously. A possible weakness is that it may give "false positives" or "false negatives" for component indicators with highly skewed distributions. For example, suppose there is a situation in which 90% of the areas are unaffected by flood at all, whereas 5% have modest floods every few years, and a further 5% are strongly affected by floods nearly every year. The two groups that experience flooding will then be placed in the same category. This would give a false positive for the 5% with a small flood risk.

The role of the expert consultants is to identify possible false positives and false negatives, as well as to compensate for the use of spatially aggregate indicators.

3.4.3 Bayesian method

The Bayesian method is described in detail in an accompanying report (Kemp-Benedict 2008a). In this approach, the poverty and water-constraint indicators are taken to reflect an underlying reality that is captured by the levels of the five assets of the Sustainable Livelihoods framework.

Similarly to the median value method, in the Bayesian method the distribution of each parameter across the basin (or country, or sub-basin) is used to determine the status of a particular area. However, in contrast to the median value approach, which uses a binary "poverty/no poverty" definition, in the Bayesian approach an area is said to have a value of *high* for some indicator if it is in the top 25% of that indicator's distribution across the basin, *medium* if it is in the middle 50%, and *low* if it is in the lowest 25%. Similarly, the sustainable livelihood assets are assumed to be either high, medium, or low. The levels of the assets are not known from data, but the indicators are taken as evidence for the levels of those assets, in the following way. Each indicator is assumed to be the result of a combination of livelihood assets, and for each indicator the question is asked,

> What is the probability that this indicator will be high, medium, or low, given the levels of the livelihood assets?

Typically, each indicator will be affected by the levels of more than one asset. This can be represented as in Figure 3.2. As shown in the figure, each asset is linked to several indicators, and each indicator is a reflection of several of the assets. Any particular area will have specific values for all or most of the indicators. Given the network shown in Figure, and specifying the values for each of the indicators whose value is known, the probability distribution of the levels of the assets can be inferred, using Bayesian inference (Bayes 1763; Ben-Gal 2007; Cain 2001).

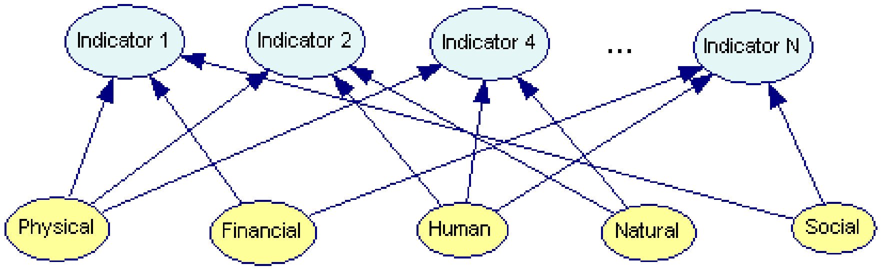


Figure 3.2 Schematic network for the Bayesian method

As a further step, an aggregate poverty indicator is computed as a combination of the assets. At present, equal weights are used for each of the livelihood assets when computing the aggregate poverty index. This is shown schematically in Figure 3.3. With this definition, once the value for each of the component indicators is specified, the poverty indicator can be calculated.

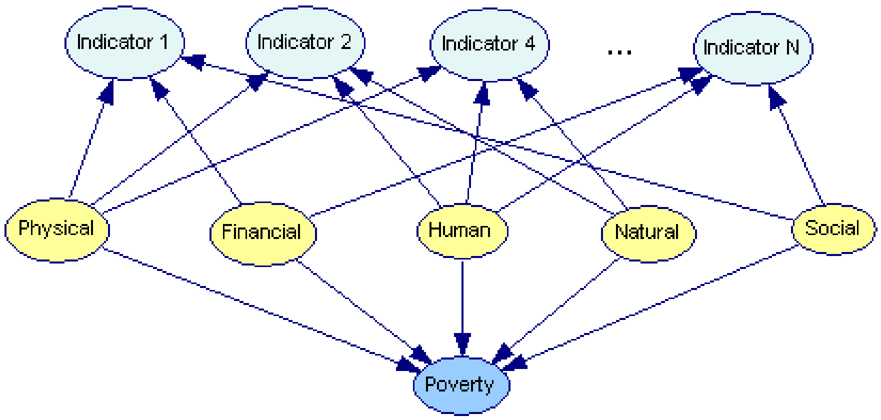


Figure 3.3 Aggregate poverty indicator for the Bayesian method

There are several theoretical benefits to the Bayesian aggregate poverty approach compared to other aggregation procedures. In particular, it addresses two of the items in Molle and Molinga's (2003) critique of aggregate indicators: the arbitrariness of weights and dealing with inconsistent underlying data.

Weights in the Bayesian method are assigned in a two-step process. The first step is in the choice of the Sustainable Livelihoods framework as a conceptual model for organizing indicators. The assignment of equal weights to each of the livelihood asset categories implicitly acknowledges that effective livelihood strategies can be constructed using a variety of combinations of assets, and that assets are to some degree substitutable when constructing strategies. The second step, as discussed in the background report (Kemp-Benedict 2008a), is an initial assignment of weights of evidence to the indicators. These weights are elicited from stakeholders when defining the network, and are subsequently refined by training the network with data.

The two-step process for assigning weights splits the task into a normative and a positive component. The normative component is the choice of conceptual framework. While informed by experience and previous theoretical work (Chambers and Conway 1991), the Sustainable Livelihoods framework takes a particular view of development and of livelihoods (Carney et al. 1999). In contrast, the second step when assigning weights asks for a positive assessment on the part of stakeholders and experts, in that they assess how much evidence each indicator provides about the state of the assets (Kemp-Benedict 2008c). This approach acknowledges that normative judgment is inescapable when choosing component indicators and aggregating them, but separates the normative aspect into a high-level explicit choice – the choice of framework – rather than being hidden in the detailed weighting.

The Bayesian method addresses data problems through the weighting of evidence. In conventional aggregation procedures, indicators are given weights based on the categories to which they are assigned. Aside from categorical weights, indicators are put on the same footing. With the Bayesian method, weights are assigned to indicators based on the amount of evidence they provide about the underlying state of affairs – taken to be the levels of the livelihood assets. In this way, lower quality data can be included in a consistent and defensible way, by giving them less weight in determining the indicator.

A further benefit, not explicitly addressing the concerns of Molle and Molinga, is that in the Bayesian approach, indicators do not need to be assigned to specific categories. Indicators rarely fit neatly into one or another category. For example, access to water reflects both water resources and financial resources. In the Bayesian approach, an indicator of access to water can be linked to both financial and natural assets.

The Bayesian methods shares with the median value method the weakness that highly skewed distributions can create false positives or false negatives when classifying indicators as high, medium, or low. A further weakness of the method in practice is that the method can be somewhat difficult to explain and justify to stakeholders.

3.4.4 Data and procedures

Based on the results of the wealth ranking study, seven broad categories of poverty criteria were identified that appeared in many of the studies: food security, land holding, shelter, livestock, productive assets, disposable income, and income and debt. Some of the indicators that have been collected are consistent with these broad categories of poverty criteria, while others focus specifically on water-related issues. These two indicator sub-sets will be referred to as "poverty indicators" and "water constraint indicators."

The poverty indicators are: the percentage of population without a motorcycle, without television, living in non-permanent housing, having no cow or buffalo, owning no land, and living below a consumption-based poverty line for food and basic necessities. The water constraint indicators are: the percentage of the population without a toilet or without safe water, the percentage of land area affected by flood, the annual malaria rate (per 1000) and the departure of net primary production (NPP) from a 10-year average, which represents the drought situation. These data were obtained from several concerned line agencies.[1]

While a common set of indicators was compiled, for most of the indicators, national definitions differ to some degree. Furthermore, while most are available at district level, in some cases indicators are only available at provincial level. In the case of the Food Insecurity indicator, which uses a food-based poverty line, differences are expected, and even welcome, as this indicator provides a measure of relative poverty within each country. Unfortunately, in addition to differences in living standards, the basic conceptions of what constitutes "basic necessities" differ from country to country, making this indicator problematic (MOP/WFP Poverty Estimates 2002; Kakwani et al. 2002; NESDB 2002; Minot and Baulch 2001). In spite of these difficulties, the indicator was retained as the best available indicator for this poverty category. In the construction of the poverty map, the indicators are treated as though they were comparable. The actual measures used for each of the indicators are shown in Tables 3.1 and 3.2. Indicators that are only available at provincial level, rather than district level, are indicated with an asterisk (*).

[1] Mekong River Commission; Japan International Research Center for Agricultural Sciences; World Food Program; World Health Organization; International Food Policy Research Institute; National Institute of Statistics of Cambodia; Ministry of Agriculture Forestry and Fisheries of Cambodia; Seila Program; National Statistics Center of Lao PDR; National Statistical Office of Thailand; and General Statistics Office of Vietnam.

Table 3.1 Poverty indicators at district level

Broad Category	Indicator	Cambodia	Lao PDR	Thailand	Vietnam
Food Security	Food Insecurity	People living below consumption based poverty line for food and basic necessities (%)*			
Land Holding	% With no land	Number of crop landless families compared to total households (%)	Sampling families without agricultural land ownership (%)	Number of villages that have a problem of no agricultural land ownership (%)	Sampling families without agricultural land ownership (%)
Shelter	% With non-permanent housing	Rural families living in thatched roof house (%)	Rural families with non-permanent roof house (%) – Bamboo, Grass, Others	Rural families living in non-permanent structure house (%)-with non-permanent materials or reused materials*	Families living in non-permanent structured house (%)-wooden or simple house
Livestock	% Without cow or buffalo	Rural families without cow or cattle (%)	Sampling families without cattle or buffalo (%)	Rural agricultural families without cattle or buffalo (%)	Sampling families without cow or buffalo (%)
Productive Assets	% Without motorcycle	Rural families without motorcycle estimated from number of motorcycles (%)	Sampling families without motorbike (%)	Rural families without motorbikes estimated from number of motorcycle (%)	Families without motorcycle (%)
Disposable Income	% Without television	Rural families without TV estimated from number of TVs (%)	Sampling families without TV (%)	Rural families without TV (%)	Families without TV (%)

* Indicator provided at provincial level, not district level (except Lao PDR).

Table 3.2 Water constraint indicators at district level

Broad Category	Indicator	Cambodia	Lao PDR	Thailand	Vietnam
Water Quantity	% Affected by flood	District area affected by flood in 2001-2002 (%)			
	% Departure of NPP from 10-year average	Net Primary Production (NPP) value in April 1992 and 1993 departure from long-term 10 years average value (%)			
Water Quality	% Without toilet	Rural families without estimated from number of latrines (%)	Rural families without proper toilet (%)- not modern or normal type or no toilet in house	Rural families without proper toilet in house (%) - pit toilet or no toilet*	Families living without proper toilet in house (no toilet or simple toilet) (%)
	Malaria rate	Malaria reported cases per 1000 people per year*			
Water Access	% Without safe water	Rural families without a communal tap, pump well or ring well, usable year round, within 150 m of their house (%)	Rural families without access to safe water (%)- or water from unprotected well, river, mountain, rain, or others	Rural families without tap water in the house (%)	Families without access to safe water (%)- rainy water or water from unprotected well

* Indicator provided at provincial level, not district level (except Lao PDR)

Poverty maps were constructed using these indicators with both the median value and Bayesian methods. Table 3.3 shows the weights adopted for the Bayesian method. Indicators that are only available at provincial level for most countries were given relatively low values for the information they provide (20% for food insecurity and 10% for malaria control).

The results of the median value poverty mapping study were submitted to expert review (Krittasudthacheewa and Kemp-Benedict 2008). Experts were asked to respond to the following questions:

1. What is your opinion/view on our study, which considers not only the food security but several indicators under other broad categories?
2. Are there any other indicators should have been considered in the study? If yes, please elaborate.
3. In relation to your knowledge and experience, do the final maps of the water poverty created on a basis of combination of various poverty and water constraint related indicators present well the potential water poverty hotspots in the region? If no, please elaborate.
4. Do you have any other comment or suggestion on the present study? If yes, please elaborate.

Table 3.3 Indicator weights for Bayesian aggregation method

Indicators	Capitals					
	Information	Human	Financial	Natural	Physical	Social
Motorcycle	25%		10		5	
TV	10%		10		1	
Permanent house	75%	2	10		2	4
Cow	50%		10	7		
Land	50%		8	10		
Food security	20%	8	10	7	2	5
Toilet	25%		10		10	
Piped water	20%		10		10	2
Affected by flood	20%			10	7	
Malaria control	10%	7		7	10	5
NPP	25%	8		10		8
Poverty	100%	10	10	10	10	10

While generally expressing support for the approach, the expert reviewers also offered suggestions for improvement. This included some comments on the overall approach, including:

- The importance of maintaining some connection with national poverty reduction strategies. It was pointed out that the indicators should be chosen to be in line with what countries have already prioritized.
- The fact that some issues, such as flooding, offer both an opportunity and a threat. Livelihoods that depend on inundation, while still threatened by flooding, would nevertheless also be threatened by too aggressive a flood control regime.
- The concern that infrastructure-related water indicators, such as access to clean water, cannot be clearly identified as water-specific or poverty-specific. (Note that this is addressed with the Bayesian method, where indicators can have multiple links to livelihood assets.)

Additionally, comments were offered about additional indicators that would provide complimentary and important information about the poverty context, including:

- Salt water intrusion in the Mekong Delta,
- Governance indicators (e.g., from the World Bank ant-corruption web site), such as:
    - Government effectiveness
    - Regulatory quality
    - Political and social stability
    - Governance

    - Access to institutional and decision-making processes that affect the livelihood of communities

- Irrigation ratio or the percent of farmers that have access to reliable and cost-effective irrigation systems
- Irrigation efficiency
- Per capita arable land availability and per capita forest availability.

It is not clear that all of these proposed indicators can be used effectively in the poverty mapping exercise, since the goal of the poverty mapping is to look at detailed spatial patterns, and some of these are national-level indicators. However, they are potentially important in capturing livelihood dynamics.

3.4.5 Results

Figure 3.4 illustrates the poverty index map by the Bayesian approach and the water poverty district maps by the median value (those districts with at least 4 scores of poverty related indicators and 3 scores for water incidence).

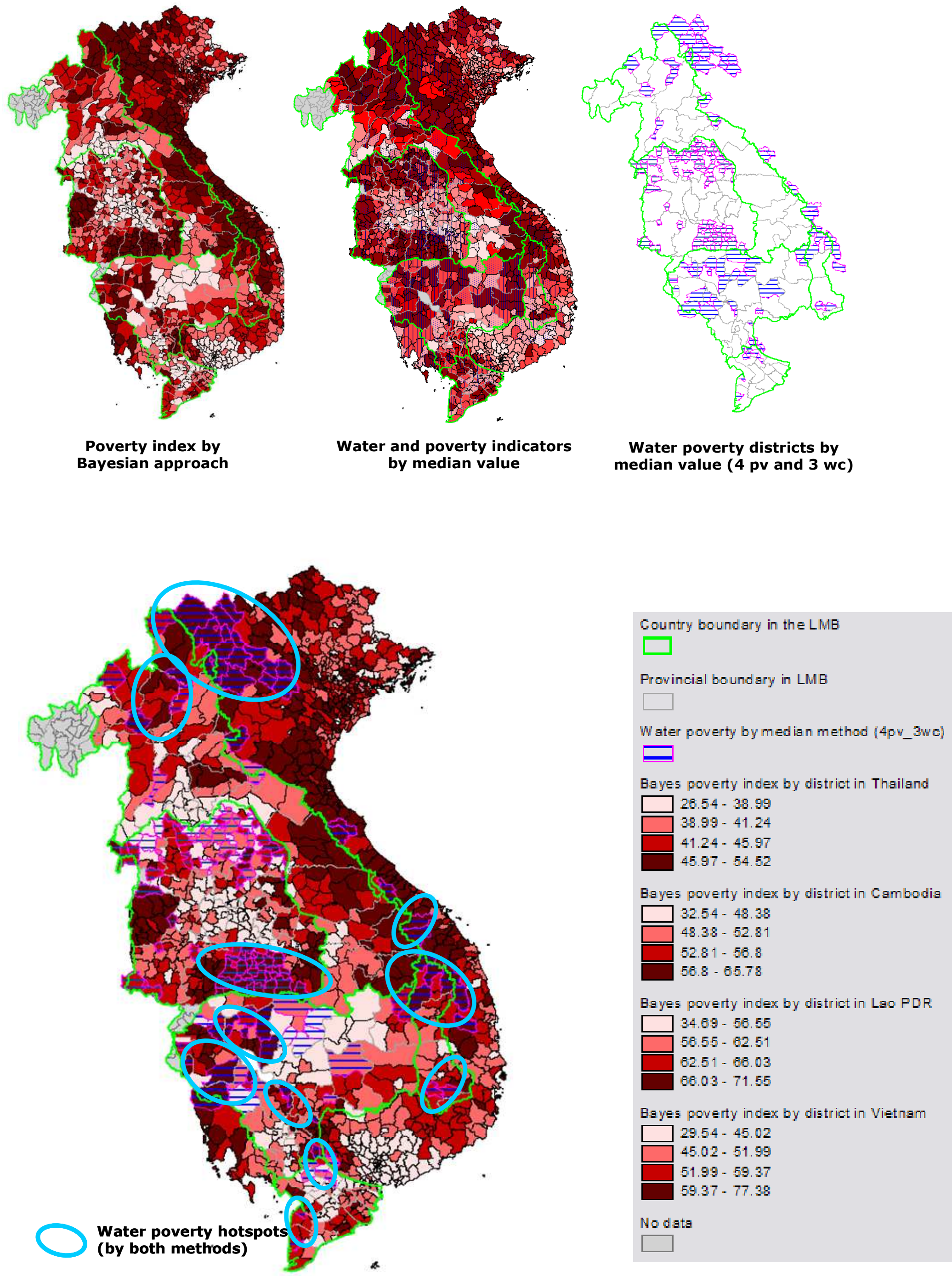


Figure 3.4 Poverty index by Bayesian approach and water poverty district by median value

3.5 Case studies for water poverty and livelihoods assessment

The household level investigations were undertaken in three water poor areas in the Mekong River Basin (SEI and FACT 2008; SEI and GMSSRC 2008; SEI and MDI 2008), which are the Tonle Sap area in Cambodia, Si Sa Ket in the Northeast Thailand and the Mekong Delta in Vietnam. Due to a constraint of the project time and available budget, a case study in Lao PDR cannot be carried out.

3.5.1 Specific objective

The specific objective of the case studies is to assess the use and demand of water at the household level; water-related problems and their impacts to livelihoods; and adaptive strategies in dealing with the water-related constraints. Subsequently, possible water-related interventions that could further improve people's livelihoods are suggested to support policy making for sustainable water resources management in the study areas in particular as well as in the Mekong River Basin in general.

3.5.2 Research partners

SEI has undertaken the household level investigation jointly with other three local research partners, who have extensive experience and knowledge of the study areas. All partners and their team leaders are in listed in Table 3.4.

Table 3.4 Local research partners

No	Case study	Research partner	Team leader of research partner
1	Tonle Sap in Cambodia	Fisheries Action Coalition Team (FACT), Phnom Penh, Cambodia	Mr. Mak Sithirith
2	Si Sa Ket in Thailand	Greater Mekong Sub-Region Social Research Center (GMSSRC), Ubon Ratchathani University, Ubon Ratchathani, Thailand	Dr. Kanokwan Manorom and Mr. David Hall
3	Mekong Delta in Vietnam	Mekong Delta Development Research Institute (MDI), Can Tho University, Can Tho City, Vietnam	Dr. Dang Kieu Nhan

3.5.3 Methodology

This research was conducted in two three phases. The first phase was carried out as a site selection, the second phase as a baseline data collection in the study sites to gain some background knowledge of the information of the village such as: wealth ranking, household list and characteristics, social map, and the third phase, the field survey through meetings and household interviews.

Site selection

From the water poverty mapping, the potential water poverty districts to be surveyed were identified and consulted with the research partners in the area. With inputs and recommendation by the local authority officials, communities and agencies, who have a thorough knowledge of the water poverty districts, the villages to be surveyed in particular areas were selected.

Baseline data collection

The study formally begun with a courtesy call to the local officials including the commune leader, village chief and other village leaders explaining the study and its objectives and expected activities to be undertaken in the sites. It was also an opportunity to arrange for appointments and meetings and obtaining the village household lists.

Wealth ranking

This exercise was carried out in the Tonle Sap and Mekong Delta case studies with village key informants. It is aimed at improving understanding of how people define poverty, their understanding of wealth or well-being and ultimately identify the relative wealth groups and their characteristics. The wealth ranking results were used as basis for sampling of households for the interviews.

Focus group discussions

Using guide questions on topics dealing with livelihoods, poverty and water-related problems and solution, face-to-face discussions were conducted with three separate groups of like key informants, men, and women. Participatory methods were used during the discussions including "what makes a good quality of life", ranking and scoring, historical analysis, and brainstorming.

Household interviews

Interviews with the households from different wealth groups were undertaken using questionnaires. Sample size was 25 percent of the village household population identified through stratified random sampling being wealth ranking as the main stratum and livelihood activities as sub-stratum for Tonle Sap and Mekong Delta case studies. Since number of households in one village in Si Sa Ket province is relatively small, for Northeast Thailand case study almost all village households took part in the interview.

Verification

This process was done through meetings with key informants of neighboring villages to confirm the accuracy of information gathered from the village being studied.

Data analysis

Field data were entered into the database and analyzed using the MS Excel and SPSS software.

3.5.4 Results

The use and demand of water for at the household level; water-related problems and their impacts to livelihoods; and adaptive strategies in dealing with the water-related constraints were assessed through household interview, focus group discussions and verifications with neighboring villages. Main results obtained from each case study are summarized and provided in Table 3.5. Subsequently, possible water-related interventions that could further improve people's livelihoods are also suggested and included in the table.

Table 3.5 Key findings from each case study

Item/Issue	Description		
	Cambodia	Thailand	Vietnam
Study area	Tonle Sap area	Si Sa Ket, northeast region	Mekong Delta
Study site	5 villages from 5 districts (Krakor, Baribour, Soutr Nikom, Siem Reap and Santok) in 4 provinces (Pursat, Kampong Chnnang, Siem Reap and Kampong Thom)	5 villages from 4 districts (Nam Kham, Non Khoon, Phak Peaw and Pi Mai Nuear) in Si Sa Ket Province	4 hamlets from 2 districts (An Bien district and Tra Cu) in 2 provinces (Kien Giang province and Tra Vinh Province)
Sample size	25% (of total 744 HHs)	262 HHs (of total 313 HHs)	203 HHs (~51 HHs/hamlet)
Water and production activities	Majority of floating communities do fishing. The better-off households do large-scale fishing while the poor and very poor do more of subsistence fishing. The closer the families have access to land, the more they do farming.	Majority of adults engage in crop farming. Rice cultivation is most important. Other crops are onions, garlic and chilli. Majority of leafy vegetables, rice and fish are consumed at home, while the largest proportion of other crops is sold.	Most of villagers do rice cultivation and shrimp farming (monoculture or rotating with rice). Rice and shrimp farming are major activities of the better-off families, while wage labor is main livelihood activity of the poor and poorest.
Common criteria for	Wealth status: house condition; land	Wealth status depends on: ownership of	Wealth status depends on: land holding;

household's well-being and elements that constitute a good livelihood defined by key informants	holding; and ownership of productive assets for their livelihood (esp. on fishing and farming) A good livelihood: having a strong and safe house; stable income; and fishing or farming equipment	agricultural land; access to water supply for agriculture; income and savings; access to credit; cattle; good knowledge in agricultural investment; good education.	productive assets; capital asset and loans; livelihood activities; education; house condition; disposable income; domestic water supply; sanitation condition; poor household's book and relief from the government. A good quality of life: good health; education; income; food security; meeting government officials; unanimity in family; good house; good production; social networks; disposable income; electricity; access to safe water; less mosquito; good roads; access to school & health care & market
Change in quality of life		Quality of life has steadily improved over last 20 years, despite the water constraints experienced. Reasons: Expanding economy, Government provision of basic services (e.g. electricity, road, school, healthcare); local development plans (e.g. widening local canals/earth storage dams); Government assistance (compensation for crops lost to flooding, free drinking water during severe drought, subsidized fertilizers); shifting to organic production; availability of low-cost consumer goods and fresh foods; mobile phones; motorbike ownership; sustained community solidarity, including support to the poor.	Improved livelihood was found mostly in better-off households but for poorest and poor households found only few, while the remaining households have no change in their well-being or have even declined (44% improved and 21% deteriorated). Reasons: Government advocacy for agricultural diversification, grass-root agricultural extension, micro-credit, infrastructure, high production price. Investments from government may not be sufficient for the poor. Rich households with sufficient resources have improved their lives considerably, while the poor become worse and weaker in their social status.
Use and demand of water	Floating communities collect water for drinking and cooking from the inner part of the lake. For other household chores, they use water around the house.	Villagers use more than one water source and switch between sources according to need and availability. Majority of households have either their own tap or have their own private	Drill-well and rainwater are used for domestic. More households with tap water in Tra Cu than in An Bien. Dug well is only used in rain-fed area of Tra Cu. Crop production relies on

	Families living in stilt houses use water from Tonle Sap river for drinking and other domestic use. In the dry season, they collect water from a village common pond (1 km from most of the houses). Communities on land use water from a hand dug well or a deep drill well with pump for domestic use. Only better-off families have either this type of well which is built near their house. The poor collect water from their neighbours' well.	drill wells powered by electric pumps. Rainwater is used in all villages. Household storage tanks are common but mostly run out during the dry season. The purchase of drinking water bottles or from tanker operators occurs either because of seasonal groundwater shortages or because of poor groundwater quality. At times of severe shortages local authorities assist households with tanker deliveries	rainfall and canal fresh water during rainy season, particularly in saline areas. In rain-fed area, less than 20% of households use groundwater to irrigate upland crops during the dry season. For livestock, they use drill-well water. Dug-well and rain water are secondary source in rain-fed area in Tra Cu. Aquaculture & shrimp farming relies on saline water from canals, while pond fish culture depends on rainfall or canals during the rainy season.
Water-related issues and impacts to livelihoods	Low and declining fish catch due to: poor access to good fishing grounds; degradation of the flooded forest – habitat for fish spawning; competition from increasing population and in-migration; use of modern fishing gears by large motor powered boat operators Low farm yield due to: flash floods (overflow from the irr. channel, sudden flow from upstream; pest infestation (e.g. rats); no or little use of fertilizer; thieves; variety of crop? Sanitation is a big problem in Tonle Sap. Majority of the households do not have toilets (they go to the forest to defecate).	Water scarcity and flooding are often faced. But more than half of households reported that these did not impact on production, indicating that they adapted to these. Poorer households tend to feel more impacts of flood and drought on resource collection compared to those who are better-off. Due to groundwater conditions, some villages experience high levels of iron, salt and/or other minerals, forcing them to use alternatives for domestic use. Problems associated with quality impact all households. A decline in fish and other aquatic resources over the last five years due to water pollution by agricultural chemicals. This perception was consistent across wealth ranks and villages. Access to different sources is evenly distributed. However, the poor do experience seasonal shortages more than the rich, possibly because the rich have invested in better technology or can afford	Water salinisation and acidification is serious problem. It affects crop production, degrades water quality for aquaculture and aquatic systems and leads to lower income and affects food security and health risks through poor quality of domestic water. Effluent discharges of shrimp farms result in polluting canal water of shrimp farming areas. Heavy uses of agro-chemicals for rice production, disposals of raw human and animal wastes and poor sanitation cause water pollution in rice fields and canals, which in turn leads to mosquito reproduction and water-related diseases. Poor sanitation conditions in Mekong Delta. Direct defecation in ponds and rivers is prevalent. Droughts and floods cause significant decline in farm yields while increases production costs. Poor access to irrigation canals and unpredictable variations of climate is claimed to

		purchased water which is not subject to seasonal change.	cause droughts.
Current adaptive strategies to deal with livelihoods and water-related constraints	Treating water for drinking and cooking (boiling, filtering, using alum) For floating villages, go further to the lake to collect cleaner water For stilt houses on land, go further to the pond or well to collect cleaner water Mostly, better-off households buy container water in the dry season Treatment by the medicines from a general merchandise store for illnesses (diarrhea, skin disorders)	Changing rice growing practices from transplanting to direct seeding which requires less water during the early growth stages. Villagers have adapted to new cash crops (such as eucalyptus) and limiting production area. Villagers switch between water sources, according to water availability. In some villages where groundwater quality is not good, the better-off households have adapted by purchasing more rainwater storage tanks and can better afford to switch to purchased water.	Deep groundwater contains high concentrations of heavy metal. Majority of households use simple treatment methods such as using alum or water ageing before drinking and cooking. They do not know more effective but simple methods to reduce metal contents in well water. To overcome losses damage by droughts in early rainy periods, use of rice varieties tolerant to drought and salinity.
Option for interventions in water to improve livelihoods	*<u>Water pollution</u>* Scientific study to validate the degrading quality of water in the Tonle Sap Awareness raising, i.e. proper disposal and management of household wastes Set up sanctions for those who do not abide by the law Provide a place for collecting wastes far away from the lake Introduction of ecological sanitation toilets, composting and organic farming Provide know-how on the appropriate and proper application of fertilizers and biological control of pests and diseases Strengthen capability of local leaders to implement and monitor the policies or projects	*<u>Structural strategies</u>* Prioritise small-scale local schemes rather than mega-projects. Increase access to electricity for small-scale irrigation from wells and other water sources. Promote improved rainwater storage at household level. Institute sustainable maintenance programmes for public water supplies. *<u>Non-structural strategies</u>* Expand training programmes aimed at strengthening villagers own plans for farm production and off-farm income generating projects. Promote fishponds as a poverty alleviation measure. Require contractors to meet minimal water	*<u>Technical strategies</u>* Development and adoption of adaptive agricultural technologies like developing crop cultivars that can tolerate drought, salinity and acidity through breeding and on-farm testing programs Improve quality of well water for domestic uses including increased rainwater collection and storage; Improving sanitation and environmental quality *<u>Structural strategies</u>* Improvement and development of water supply and drainage systems, Constructing saline-control structures; Early warning systems for extreme events. *<u>Non-structural strategies</u>* Training and outreach programs;

	Designate an extension worker for supervising and monitoring policies, projects and programmes *Flash floods* Lobby or dialogue with MOWRAM on effective and efficient use of irrigation scheme	quality standards when constructing village water supply systems.	Increase public awareness of and action on hygiene and environment and disease prevention by villagers; Diversification of livelihoods Improve assessment, planning and budgeting; Policy and institutional measures

From the livelihood case studies, we found that the overall level of poverty is decreasing (Source: SEI and FACT 2008; SEI and GMSSRC 2008; SEI and MDI 2008). The rich and medium families have improved their livelihoods and become wealthier, while the quality of life of the poor did not improve much, this is particularly true for Vietnam case. (Source: SEI and MID 2008)

Tables 3.6 to 3.9 show the evidence from our livelihood case studies in Vietnam, showing the better-off families have improved their well-being more than the poor and poorest)

In recent years, livelihoods of the majority of rich and medium households have improved. In contrast, few of the poor and poorest households have their livelihoods improved while the remaining proportions of the households have no change in their well-being or have even declined. Overall, the poverty is clearly decreasing. Rich households with sufficient resources have improved their lives considerably, while the poor with insufficient resources have become worse.

Table 3.6 Percentage of households by wealth group, livelihood activity and wealth mobility at Nam Chua hamlet, An Bien.

Groups	n[1]	% of household	Livelihood activity				Wealth mobility		
			Rice	Shrimp	Small-scale trading	Wage labour	Improved	Stable	Declined
Poorest	53	13.7	43.4	20.8	3.8	22.1	18.9	62.3	18.8
Poor	147	38.1	17.7	4.1	2.0	76.1	10.2	44.2	45.6
Medium	127	32.9	43.3	33.9	9.4	13.4	66.1	32.3	1.6
Rich	59	15.3	42.4	50.8	6.8	0.0	100.0	0.0	0.0
Total	386	100.0	33.4	23.1	5.4	37.9	44.2	35.6	20.5

[1] n = sample size

Table 3.7 Percentage of households by wealth groups, livelihood activity and wealth mobility at Tay Son 1, An Bien.

Groups	n	% of household	Livelihood activity			Wealth mobility		
			Rice	Trading	Wage labour	Improved	Stable	Declined
Poorest	35	13.6	22.9	0.0	77.1	8.6	0.0	91.4
Poor	61	23.6	65.6	1.6	32.8	8.2	13.1	78.7
Medium	107	41.5	98.1	0.0	1.9	38.3	47.7	14.0
Rich	55	21.3	100.0	0.0	0.0	94.5	1.8	3.6
Total	258	100.0	80.6	0.4	19.0	39.1	23.3	37.6

Table 3.8 Percentage of households by wealth groups, livelihood activity and wealth mobility at Lang Chua, Tra Cu.

Groups	n	% of household	Livelihood activity					Wealth mobility		
			Rice	Shrimp	Nippa	Trading	Wage labour	Improved	Stable	Declined
Poor	197	56.3	6.6	18.3	0.5	0.5	74.1	0.0	91.9	8.1
Medium	119	34.0	6.7	63.5	1.7	0.8	27.2	58.0	41.2	0.8
Rich	34	9.7	14.7	75.3	0.0	0.0	11.8	94.1	5.9	0.0
Total	350	100.0	7.4	38.9	0.9	0.6	52.3	28.9	66.3	4.8

Table 3.9 Percentage of households by wealth groups, livelihood activity and wealth mobility at Giong Chanh A hamlet, Tra Cu.

Groups	n	% of household	Livelihood activity				Wealth mobility		
			Rice	Rice-upland crops	Upland crops	Wage labor	Improved	Stable	Declined
Poor	149	75.3	0.7	20.8	49.6	28.9	0.0	99.3	0.7
Medium	37	18.7	5.4	64.9	29.7	0.0	100.0	0.0	0.0
Rich	12	6.1	25.0	50.0	25.0	0.0	91.7	8.3	0.0
Total	198	100.0	3.0	30.8	44.4	21.7	24.2	75.3	0.5

3.6 Analysis on Livelihoods, Vulnerability and Water Constraints

A major aim of the Mekong Basin Focal Project is to assess the impact of water-related interventions on livelihoods. The data to support this effort are drawn from field studies that collected both quantitative indicators and qualitative observations (SEI and FACT 2008; SEI and GMSSRC 2008; SEI and MDI 2008). The field studies are summarized in reports that describe the state of the community, its recent trajectory, and major dynamics affecting it. Because the Mekong Basin Focal Project is concerned with the basin as a whole, a further aim is to generalize the results of the field studies beyond the field study sites. For this purpose, the field studies were used to develop livelihood models that can potentially – with relatively modest demands for additional data – be transferred to other sites. Consequently, this section will focus on these models. However, there are also insights from the field studies that are potentially of wider significance. These are summarized in the key findings at the end of this chapter.

3.6.1 A Bayesian approach to modeling livelihood dynamics

The specific approach taken for the Mekong Basin Focal Project in analyzing livelihoods is to build Bayesian network models that are informed by the field data and the Sustainable Livelihoods framework. Bayesian networks are probabilistic models that systematically combine probabilistic statements of the form "the probability of *Y* occurring given that *X* has occurred is *p*" (Ben-Gal 2007; Cain 2001).

When considering the Sustainable Livelihoods framework as a guide for modeling, it should be pointed out that the Sustainable Livelihoods Guidance Sheets state that the framework "does not try to present a model of reality," but is instead intended to stimulate discussion (DFID 2001). Indeed, as a framework it does not have enough detail to be a model. However, it does pretend to capture some part of reality, and it is possible to ask of a model whether it is consistent or inconsistent with the framework. In this way it can provide a conceptual basis for model building (Newton et al. 2006; Jansen et al. 2006).

3.6.2 Features and limitation of Bayesian network models for modeling livelihoods

There are several benefits to building livelihood models as Bayesian networks. In common with the Mekong Basin Focal Project, livelihoods are usually studied using data from field studies. Typical outputs of such studies are coded responses to interview questions, qualitative observations, and a summary report that describes the current state of a community, its recent trajectory, and the factors influencing it. In this way, the summary report presents a qualitative model of the community that can be captured in a formal model. Indeed, for a closed physical system, this is precisely the sort of information that would be needed to create a model. The current state and recent changes describe the location of the community in "phase space", while the influencing factors determine the future path through the phase space. But unfortunately – for those who have to build the models – and also fortunately – for those who like the rich complexity of social systems – the communities are open, not closed, and are built of people, rather than inanimate objects. Many strands of evidence are required for the characterization of social systems, and the description of the system is always partial. The characteristics of the systems to be described by a livelihood model are therefore:

1. A mix of qualitative and quantitative information,
2. Tabulated data (as provided by field interviews),
3. Irreducible uncertainty, due both to incomplete information and complexity (Miller and Page 2007; Rihani 2002; Berkes 2007; Costanza et al. 1993).

These features suggest the use of Bayesian networks as a modeling tool. While Bayesian networks require some quantification, qualitative information and understanding is used to create the network structure and can be used, through an elicitation process, to assign values within the network. Quantitative information can come from data, model output, or expert opinion (MERIT, 2005). Tabulated data can be used directly to fill in the conditional probability tables that link variables in a Bayesian network model, while the use of probabilistic statements provides a natural way to represent uncertainty. Furthermore, Bayesian networks are relatively easy to adapt to new situations as more information becomes available (Cain, 2001).

Beyond these core features of livelihood systems that makes a Bayesian analysis relevant are some practical features of building Bayesian network models that make such models an attractive alternative. Depending on the use to which the Bayesian network is put, it may not require specialist skills (Cain 2001; MERIT 2005). Certainly the initial network design can be carried out by a non-specialist, although entering quantitative data requires some knowledge of probability. Second, Bayesian networks can be represented graphically, which makes them well suited for participatory model building (Antona et al., 2003). Third and finally, standard tools are available for building Bayesian networks.

There are two major challenges to using Bayesian networks, and they are related. As discussed in the background report (Kemp-Benedict 2008b), the number of parameters entering a Bayesian network model can grow rapidly. If the parameters are generated from a model (for example, a hydrological model) then this is not a problem. However, if they are estimated from data or by eliciting expert opinion, problems can arise. Whenever the parameters of a model are estimated by fitting to data, it is necessary to have a large amount of data compared to the number of parameters. Otherwise, roughly speaking, the value of each parameter is established using only a few data points. In this case there is less confidence that the data represent "normal" behavior for the system, as opposed to random chance. In the case of expert elicitation, asking experts for many parameter values is mind-numbing. The confidence of even the best-informed experts begins to drop off as they consider more and more combinations of variables. Fortunately, these problems can be avoided by using elicitation techniques that take a few inputs from experts and then use those inputs to generate other parameters. One such technique is described by Cain (2001) and two further techniques were developed for the Mekong Basin Focal project (Kemp-Benedict 2008c).

3.6.3 Bayesian networks

Bayesian networks are probabilistic models that systematically combine conditional probabilities (Ben-Gal 2007; Cain 2001). The reason they are called "Bayesian" models is for an insight generated by the mathematician the Reverend Thomas Bayes (1763). Bayes' theorem is easy to state mathematically but can be hard to comprehend. Rather than stating it directly, consider an example of water quality testing.

In this example, suppose that water quality testing has been carried out using a slow but very precise method at 100 sites, and 10 sites have tested positive for the pollutant, with possible public health risks. From these pilot results, it is expected that of the 1,000 sites in the country, around 10%, or 100, of them are contaminated. From a public health perspective it is necessary to establish with some degree of certainty which ones actually are polluted. In this simple example, suppose that there are no readily observable factors that make one site more likely than another to be polluted, so to address the public health concerns it is necessary to test all 1,000 sites. However, the same slow and precise method that was used to establish the frequency of polluted sites cannot be used to identify all of the sites where action needs to be taken because it would be prohibitively expensive. To address the problem, a promising new test for the pollutant is put under trial. The new test is quick and inexpensive, but not as precise as the original test. To establish the reliability of the new test, a total of 100 trials are carried out on sites known to be polluted, and a further 100 trials are applied on sites that are known to not be polluted. The results shown in the following table are compiled.

Actual State	Test Results		Total Tests
	Positive	Negative	
Polluted	95	5	100
Not Polluted	10	90	100

From these results, it is estimated that the false positive rate is 10%, and the false negative rate is 5%. Given the public health risk, it is felt that a higher false positive rate than false negative rate is a good property of the test, and it is prepared for use in the field. However, at this stage it is pointed out that the prior information that around 10% of sites are expected to be polluted can be used to refine the assessment of the test. Suppose that a positive result is obtained. What is the probability that the site is polluted? This question turns out to be somewhat complicated. To get at the answer, turn the question around, and ask, of all of the 1,000 sites, for how many can a positive test be expected? From the table above, if the site is polluted, then the probability of a positive result is 95%, while if the site is not polluted, then the probability is 10%. But it is expected that 100 sites will be polluted, while 900 will not, so the number of positive tests is expected to be

Number of positive tests = 95% × 100 + 10% × 900 = 185

This is nearly twice the number of polluted sites. The number of sites that are both polluted and that give a positive result is expected to be 95% × 100, or 95. Therefore, the probability that a positive result actually indicates a polluted site is

Probability that positive indicator means polluted = 95/185 = 51%

This is a much less encouraging result than the laboratory results for the quick and inexpensive test shown in the table seemed to suggest. Only about one-half of the time will a positive test actually correspond to the presence of the pollutant.

The procedure used to obtain this result is formalized in Bayes' theorem. Using the standard notation that $P(X|Y)$ means "the probability of X given that Y is true", the equation above can be written

$$P(\text{polluted} \mid \text{positive}) = \frac{P(\text{positive} \mid \text{polluted}) \times P(\text{polluted})}{P(\text{positive} \mid \text{polluted}) \times P(\text{polluted}) + P(\text{positive} \mid \text{not polluted}) \times P(\text{not polluted})}$$

Bayesian networks can be used to quickly answer such questions. This is shown in Figure 3.5, where the problem described above is implemented as a Bayesian network in the GeNIe software. As shown in the figure, when "evidence" is provided that the test result is positive, then the inferred probability that the site is polluted is found to be 51%, the same as found by reasoning from first principles.

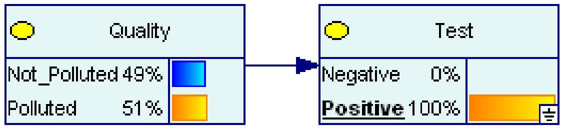


Figure 3.5 Bayes network for water quality testing example

Once the problem is implemented as a network in Bayesian network software, then alternative options can be rapidly explored. For the current example, a refinement is proposed in which the test is carried out twice at each site, and it is labeled as polluted only if two positive tests are observed. If the appearance of false positives and false negatives is random, and is not due to the properties of the site, then the two tests will be independent. As shown in Figure 3.6, the repeated test is much more effective in identifying polluted sites.

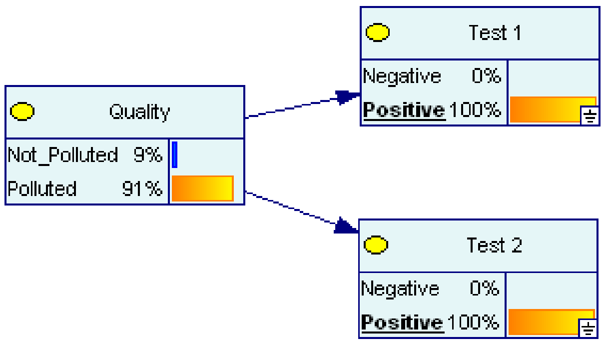


Figure 3.6 Bayes network for the use of two tests in identifying polluted sites

For modeling purposes, Bayesian networks can be used to represent hypotheses about causality (Pearl 1994; Pearl 2001). In this case, the arrows in a Bayesian network (as in Figure 3.5) are interpreted as statements that the value of one variable helps to establish the value of another variable, and not the other way around. For example, consider the model shown in Figure 3.7. It was developed based on a field study carried out in Northeast Thailand for the Mekong Basin Focal Project (SEI and GMSSRC 2008). Interpreting the arrows as causal links, it can be seen that water supply is thought to influence rice production, but not the other way around – a successful rice crop does not bring the rain. Note that in some cases the arrows do not necessarily represent causal links. For example, being in a particular wealth group does not cause someone to have a drill well. In this case the link indicates a category – many of the variables are classified by wealth group, so that by restricting the network to one wealth group it is possible to see how outcomes vary between wealth groups. Alternatively, it is possible to specify a possible outcome and, using Bayesian inference, determine the probability of different wealth groups attaining that outcome.

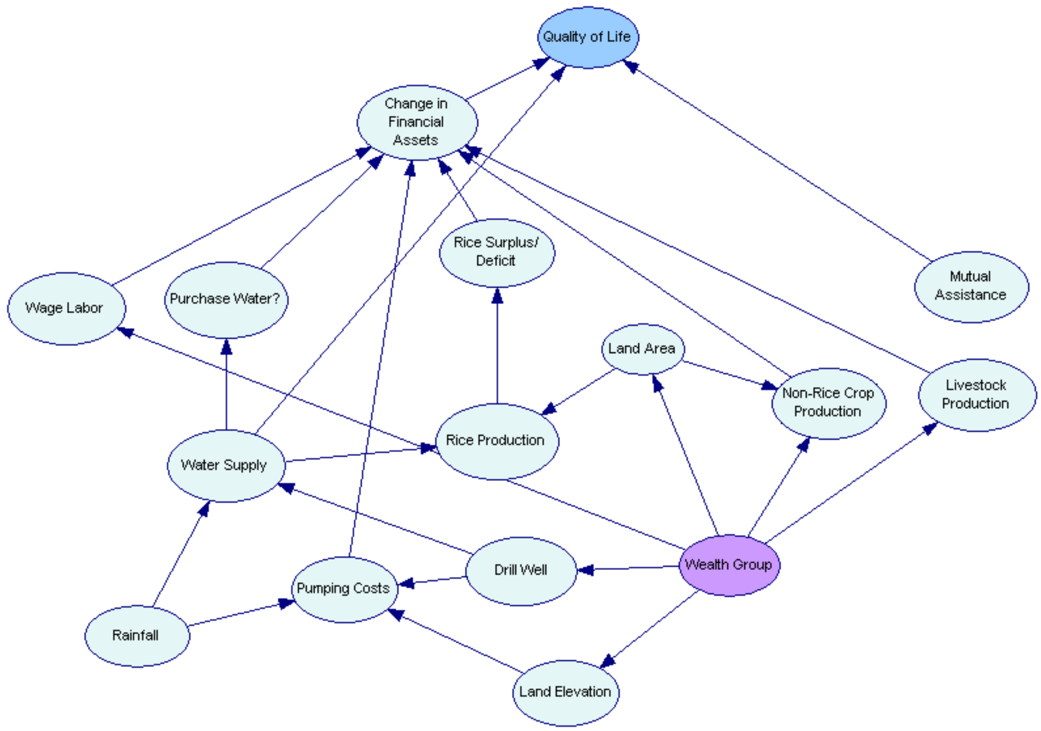


Figure 3.7 Sample Bayes network for the village of Kean in NE Thailand

3.6.4 A Model for Northeastern Thailand

Several Bayesian models were created as part of the Mekong Basin Focal Project. These are described in detail in a companion report (Kemp-Benedict 2008b). This section focuses on a model for farming villages in Northeast Thailand. The village sites are described in the companion report (SEI and GMSSRC 2008). The report includes a detailed narrative of each village, including commentary on the geographic setting of the village, the nature of its water problems and how it has responded to those problems, socioeconomic conditions and mobility between wealth groups, changing livelihoods and changes in the quality of life, and water management and other development.

The model was built as the village descriptions were read in sequence, with the goal of creating a model that would capture the major dynamics described in the report while being applicable to a greater or lesser degree to each of the villages. The model-building approach is described in detail elsewhere (Kemp-Benedict 2008b). To give an indication of how the report was used to generate the model, consider the following description for the village of Kean:

> Villagers say their area is water deficient and they experience drought almost every year. Even in normal years villagers say production of the rainfed rice is very low and that many households do not have enough to meet their requirements. This is especially true of the poor families who have little or no land.

This passage suggests the sequence shown in Figure 3.8. As shown in the figure, water supply is dependent on rainfall, and the availability of water is an important constraint on rice production.

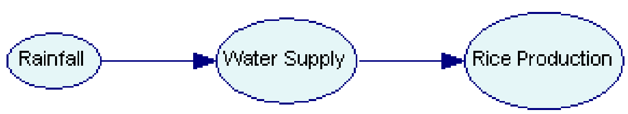


Figure 3.8 Partial Bayesian model based on field report

Proceeding in this way through the rest of the report, the model shown in Figure 3.9 was developed. It is somewhat complicated, so to make it easier to understand, parts of the model have been grouped into five sub-models: Livelihood Assets, Finances, Land, Rice Production, and Water Supply. Each of the sub-models contains further linked nodes. For example, the Water Supply sub-model is shown in Figure 3.10.

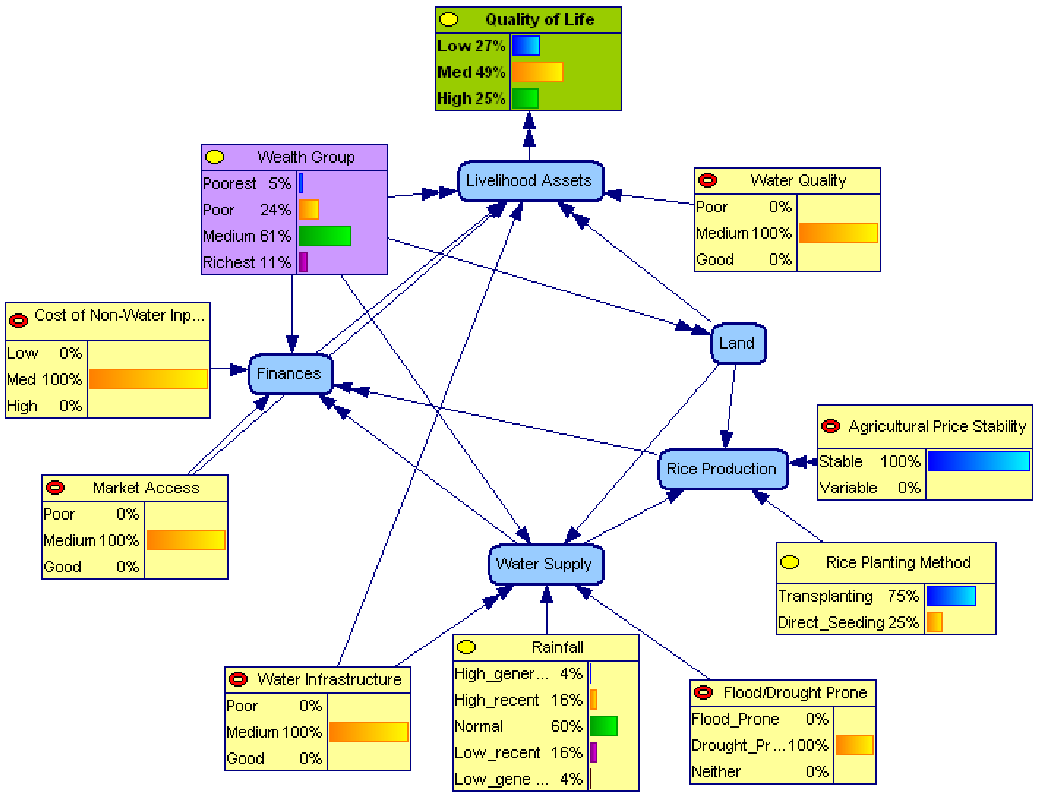


Figure 3.9 Bayesian model for Northeast Thailand

The quantitative values that enter the conditional probability tables for each of the nodes were generated from field data, from simple statistical models, or by using elicitation tools (Kemp-Benedict 2008b; Kemp-Benedict 2008c). However, the values for the elicitation tools were based on the report, rather than through a formal elicitation process.

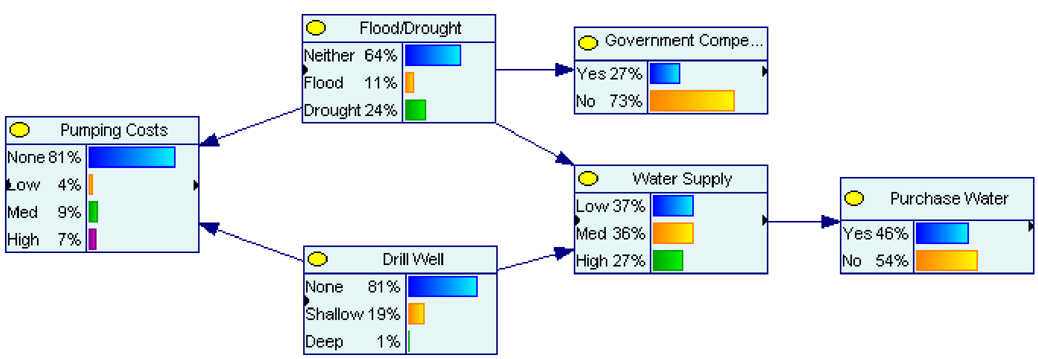


Figure 3.10 Water Supply sub-model

3.6.5 Results

The model is used by specifying the state of some of the nodes and then observing how other nodes are affected. For example, by setting *Rainfall* to "normal" and then to "low-generational" (that is, a 25-year drought), it can be seen that under conditions of a serious drought the probability of having the value "high" for *Quality of Life* drops only slightly, from 25% to 23%. At the same time, the probability that *Water Supply* is "low" increases significantly, from 28% to 91%.

The relative insensitivity of the quality of life indicator that is seen when changing from normal to drought conditions is a fairly robust feature of the model. This is a reflection of the multiplicity of ways that households and villages seek to buffer shocks. Examining other nodes in the network under 25-year drought conditions versus normal rainfall, it can be seen that financial assets are much more likely to decrease (that is, financial flows are negative, as households pay more than usual for pumping, for water, and for food), but that financial diversification and government support offsets these losses, while other elements that villagers say contribute to a good quality of life, such as strong communal ties, traditional beliefs, and the support of the government remain at their original levels.

The implication from this application of the model is that, under stress, the villages face real hardship. At the same time, they have developed complex ways to offset the impact of the stress. The result is that an intervention, even when successful, may appear to have only a small impact on overall quality of life. The resilience of livelihoods blunts the apparent effectiveness of interventions.

A further observation that is made clear by the probabilistic nature of the Bayesian models is that for any given intervention, a range of outcomes can be expected. This might be seen as different outcomes across the population in a village, or as a different set of outcomes in different villages after an intervention, or as different outcomes in different years in a village in which an intervention has been carried out. Whichever way it is manifested, the end result is uncertainty of outcome. For this reason, it is suggested that instead of seeking or expecting a consistent outcome, the goal should be to make positive outcomes more likely and negative outcomes less likely. Over time, such a change will allow households and communities to build up assets rather than drawing on them to buffer shocks.

3.7 Key findings

The research aspect to the water poverty mapping exercises is to determine whether the use of maps can improve the targeting of poverty reduction interventions. Expert reviewers of the wealth ranking activity indicated that the use of maps to rapidly asses the state of poverty in the basin was a useful approach, combining simplicity in presentation with effectiveness.

Regarding the approaches themselves, the results of the median value and Bayesian methods are very similar. The Bayesian approach specifically addresses some of the criticisms leveled against aggregate poverty indicators, and for this reason may be of interest to future efforts. However, the similarity of the outputs from the two methods suggests that for the purposes of the Mekong Basin Focal project, either approach would suffice. The relative simplicity of the median value method recommends it as a useful tool for the rapid assessment of poverty indicators. The active discussions prompted by the maps generated using the median value approach and the positive feedback from the expert reviewers provides evidence that the process in which a poverty mapping exercise is embedded makes an important contribution to its effectiveness.

In summary:

1. There are common features across wealth ranking studies. This suggests that, in the absence of a detailed wealth ranking study, a common set of dimensions for measuring poverty can be adopted that is consistent with the way that knowledgeable local people view poverty.
2. The process by which aggregate poverty indicators are developed and applied is more important than the method used to generate them.
3. Aggregate poverty indicators should be used close to their source. They quickly become less useful as their application moves farther from the group that helped to construct them.

3.7.1 Key findings from the model development

1. Paradoxically, the resilience of existing livelihood strategies blunts the apparent effectiveness of interventions.

2. A potentially fruitful goal for an intervention is to make targeted negative outcomes less likely while making targeted positive outcomes more likely. In a situation where variability and uncertainty are central, such an approach will support the build-up of livelihood assets over time, which helps make households and communities more resilient.

3.7.2 Key findings from the field studies that potentially apply beyond the specific field sites

1. Poverty is decreasing in the Mekong basin, but the poorest households are not sharing the improvements.
2. Livelihood activities are closely linked with water. Majority of villagers in water poor areas engage in crop farming, fishing or shrimp production in which water is considered as important element that constitute a good quality of life.
3. Common criteria for household's well-being defined by key informants in water poor areas agree well with seven broad categories of poverty criteria of the wealth ranking study (de la Rosa and Chadwick 2008) which are food security, land holding, shelter, livestock, productive assets, disposable income, and income and debt.
4. Problems of water are different area by area. It depends largely on hydrological conditions, environment and livelihoods of the communities. Water quantity problem such as flooding or water scarcity is obvious and occurs regularly, and therefore to some extent people have adapted themselves to it. For most of the water poor areas, quality of water seems to be a major issue causing significant impact to the livelihoods, food security, health and income of the poor (i.e. water pollution in the Tonle Sap lake, quality of groundwater in Northeast Thailand, and water salinisation and acidification in the Mekong Delta of Vietnam).
5. The rich and medium households with sufficient resources can better cope with water problems than the poor. Even some water problems are equally distributed to all families but often cause greater impact to the livelihoods of the poor than to the rich.
6. Large water infrastructure projects were considered less effective than smaller-scale interventions by farmers. For this reason, the extension of the electrical grid was seen as more useful than the creation of large irrigation schemes. However, to supply more electricity to larger area, more hydropower dams may need to be built. Hence, the farmer's preference for small interventions could cause a large intervention.
7. Cash crops irrigated with water from drill wells, canals and other water bodies provide many farmers with a reliable income, but profits are undermined by the high costs of fuel.
8. Fish ponds excavated in the rice paddies and supplied by water and fish naturally during the rainy season, provide a valuable and reliable source of nutrition and cash for farmers.
9. Rainwater harvesting provides much valued drinking water to virtually all households, but storage is not sufficient enough to see households through the dry season.
10. Several available options for interventions in water to improve livelihoods are of non-structural measure and so less expensive. A collaboration of various stakeholders is however crucial.

3.8 Tool Development

1. Water poverty maps at a district level have been created on a basis of the poverty and water-constraint indicators to help the project experts identify the potential water poverty hotspots in which the livelihoods case studies were carried out under the Mekong BFP project framework.

   Our maps and list of initial water poverty hotspot districts in Vietnam have been used by the International Federation of Agricultural Producers (IFAP) to select the villages where the workshops with local farmers were organised to gather farmers' priorities for research on water related issues in agriculture. This is for a collaboration project with the CPWF in the Mekong river basin.

2. To investigate the link of water constraints to livelihoods especially of the poor at the household level, three sets of questionnaires and checklists of Focus Group Discussions (FGDs) specifically designed for the Tonle Sap area in Cambodia, northeast region of Thailand and Mekong Delta region of Vietnam have been developed and used as the surveyed tools in the project case studies. All questionnaires and lists will be made available in separate case study reports. Other researchers can make use of these questionnaires directly or with some adjustments if applicable.

3. Bayesian method for poverty mapping has been used in the project in parallel with the median value method to help identify the areas with high incidence of poverty and high incidence of water constraint. More detailed information can be accessed from the project background report on the Bayesian Method for Poverty Mapping.

   Our Bayesian method is considered as useful approach for water poverty mapping. It is now being applied for water poverty mapping in Volta BFP project as well.

4. Bayesian network livelihood models have been built to analyse the livelihood dynamics of the livelihood case studies around the Tonle Sap Lake area in Cambodia, Northeast region in Thailand and Mekong Delta region in Vietnam, using the field data and the Sustainable Livelihoods framework. More detailed information can be accessed through the project background report on the Bayesian Network Livelihood Models.

   There is a great potential to apply out Bayesian network livelihood approach in other BFP projects as well.

3.9 Outputs

1. de la Rosa, E., Chadwick, M. T. (2008). Wealth Ranking Study. Report for the Challenge Program on Water and Food.
2. Kemp-Benedict, E. (2008a). Bayesian Method for Poverty Mapping. Report for the Challenge Program on Water and Food.
3. Kemp-Benedict, E. (2008b). Report on Bayesian Network Livelihood Models. Report for the Challenge Program on Water and Food.
4. Kemp-Benedict, E. (2008c). Technical Report on New Elicitation Techniques. Report for the Challenge Program on Water and Food.
5. Kemp-Benedict, E., Chadwick, M. T., Krittasudthacheewa, C. (being prepared). 'A Combined Data-Based and Participatory Bayesian Approach to Mapping Water-Related Poverty'. A Paper being prepared for the Ecology and Society (http://www.ecologyandsociety.org/).
6. Kemp-Benedict, E., Chadwick, M. T., Krittasudthacheewa, C. (2008). 'The Bayesian Methods for Livelihood, Water and Poverty Analysis'. 2nd CPWF International Forum on Water and Food, Addis, Ababa, Ethiopia, 9-14 November 2008.
7. Krittasudthacheewa, C., Kemp-Benedict, E. (2008). Expert Review of Poverty Maps Generated with the Median Value Method. Report for the Challenge Program on Water and Food.
8. SEI and FACT (2008). Household Level Investigation on Water Poverty and Livelihoods: 1. Tonle Sap Case Study. Report for the Challenge Program on Water and Food.
9. SEI and GMSSRC (2008). Household Level Investigation on Water Poverty and Livelihoods: 2. Northeast Thailand (Si Sa Ket) Case Study. Report for the Challenge Program on Water and Food.
10. SEI and MDI (2008c). Household Level Investigation on Water Poverty and Livelihoods: 3. Mekong Delta Case Study. Report for the Challenge Program on Water and Food.

3.10 Key recommendations

1. Carry out detailed wealth-ranking studies where possible. However, take advantage of the general outcomes of such studies. Criteria for wealth ranking can be transferred between sites with very different characteristics.
2. When carrying out a poverty mapping exercise, emphasize process and participation over data manipulation.
3. Build the application of poverty maps into the process used to generate them, so that the context and assumptions that lie behind the maps are clear to the people making use of them.
4. Continue to monitor the effectiveness of poverty mapping in targeting poverty interventions, including downstream impacts.
5. When designing water-related interventions to reduce water poverty, aim for changes that make incremental improvements more likely over time: these can have a significant cumulative effect. Project monitoring should reflect this long-term perspective.
6. Accompany water-related interventions with other interventions such as: compensation programs for distressed families during drought and flood; improved market access; and opportunities for alternative livelihoods.
7. Interventions that allow for a degree of local control and maintenance have a higher chance of success than large-scale projects that rely on the efforts and attention of people outside of the community for their success.
8. Financial and nutritional diversification is an important means of buffering shocks. The development of fish ponds is seen as particularly effective.
9. Water quality impacts in the Tonle Sap region require greater information and awareness, as well as strengthened capability and power of local leaders to manage pollution. Better waste collection and improved sanitation is also required.
10. A range of technical, structural and non-structural strategies in water management have been identified. Technical strategies include development of improved crop cultivars and improved sanitation and water supply. Structural strategies include access to electricity, storage of rainwater, and maintenance programmes for public water supply. Non-structural strategies include training programmes and improved awareness of public hygiene.
11. To better assess the water poverty and livelihoods basin-wide, a case study on this in the water poverty area of Lao PDR should be carried out.

4. WATER AVAILABILITY

In this study, we developed two complementary models of the water availability in the Mekong. The first is a water accounting model, and covers the whole of the Mekong basin. Its primary purpose is to provide basin-wide overviews of the main water uses and their likely change. It is thus mainly an aid to broad understanding of constraints and opportunities, rather a detailed quantitative assessment of management options. The second is a more detailed model developed in the WEAP package, and provides a more detailed assessment of management options.

4.1 Literature

The hydrology of the Mekong River is well documented (see MRC, 2005) and numerous hydrological models have been proposed and applied in the Mekong Basin. They include:

- SWAT / IQQM / ISIS suite (Podger et al, 2004)
- MIKE11, lower floodplains only (Fujii et al, 2003; Morishita et al, 2004)
- SLURP (Kite, 2001)
- RAM (relies on SWAT/IQQM inputs, and only perturbs them) (Johnston and Rowcroft 2003)
- Economic – hydrology model of Ringler (2001).
- EIA 3D Model for the Tonle Sap Lake (Kummu et al., 2005)

The first three are not integrated with social and economic models and, furthermore, are large and would be difficult to integrate. The MIKE11 model does not deal with the whole of the basin. RAM and economic-hydrology model of Ringler (2001) integrate water use and hydrology with economics, but do not deal with all aspects of the water use. The RAM model deals mainly with flows, with the runoff inflows supplied by the SWAT/IQQM suite. Thus, it cannot deal with the climate change scenarios, for example, unless the scenario is first run with the comprehensive suite, and the results used as an input to the RAM. The economic - hydrology model of Ringler deals only with average conditions and does not deal with runoff inflows. EIA 3D model is for Tonle Sap lake only.

For this study, we have developed a simple water use account for the Mekong Basin. Water use accounting is used at national (ABS, 2004; Lenzen, 2004) and basin (Molden, 1997; Molden et al., 2001a) scales to allow assessment of the consequences of economic growth; the contribution of economic sectors to environmental problems; the implications of environmental policy measures (such as regulation, charges and incentives); to identify the status of water resources and the consequences of management actions; and, identifying the scope for savings and improvements in productivity. However, those accounts are static, providing a snapshot for a single year or an average year. Furthermore, they do not link water movement to use. In contrast to the static national and basin water use accounts referred to above, our accounts are dynamic, with a monthly time-step, and thus account for seasonal and annual variability. They can also examine dynamic effects such as climate change, land use change, changes to dam operation, etc. The accounts are assembled in Excel, and are quick and easy to develop, modify and run. We have applied this accounting method to all Challenge Program Benchmark River Basins (Yellow, Indus, Ganges, Karkekh, Nile, Limpopo, Volta, Niger, and Sao Francisco) including the Murray-Darling Basin in Australia (Kirby et al., 2006a; Kirby et al., 2006b; Kirby et al., 2009a; Kirby et al., 2009b; Kirby et al., 2009c; Eastham et al., 2009a; Eastham et al., 2009b; Eastham et al., 2009c; Mainuddin et al., 2009a; Mainuddin et al., 2009b; Mainuddin et al., 2009c).

Molden et al. (2001b) and Sakthivadivel and Molden (2001) show that basin water use accounting is central to linking institutions to water resources development and conservation. They develop a static water account that aggregate water uses across whole basins. Such accounts do not readily indicate which parts of a basin (if any) might be most vulnerable to change or in need of institutional attention, nor do they indicate issues such as seasonal shortages, floods, or agricultural or ecosystem productivity. Biltonnen et al. (2003) show that water use accounting is central to water policy development of the Mae Klong Basin in Thailand. In contrast to Sakthivadivel and Molden (2001) and Molden et al. (2001), they develop accounts for different parts of the basin, though the accounts are nevertheless static. Our accounts are dynamic and thus suited to investigation of a wider range of issues.

4.2 Water accounting

The simple water account has two parts:

- a hydrological account of the water flowing into the basin (primarily rain), flows and storages within the basin, and water flowing out of basin (primarily as evapotranspiration and discharge to the sea);
- a further partitioning of the evapotranspiration into the proportion of evapotranspiration accounted for by each vegetation type or land use, including evapotranspiration from wetlands and evaporation from open water.

The account is based on a monthly timestep, which we consider adequate for our purpose. The account links known quantities in the water balance, such as rain and streamflow measured in gauges, with simple, physically plausible models. The irrigation crop water demand is based on the FAO crop modelling principles using crop coefficients (Allen et al., 1998).

The account is a top-down model (Sivapalan et al., 2003), based on simple lumped partitioning of rainfall into evapotranspiration and runoff. This is done at the catchment level, with no spatial separation into different vegetation types. Runoff flows into the tributaries and into the Mekong, with downstream flow calculated by simple water balance. During high flows, some of the flow is stored in the channels, and some in lakes and wetlands from which much water is lost to evaporation. The method is described in detail in Kirby et al. (2009d).

We calibrate the water use accounts using two main calibration steps.

1. The runoff into any reach must equal the sum of the outflow, losses, diversions and changes to storage minus the sum of the inflows. This is true for any period, from a single month to the full length of the record being considered. We set the sum of the runoff over the full period to be modelled to equal the sum over the full period of the outflows and changes to storage less the sum of the inflows. We did not calibrate monthly or seasonal behaviour.

2. We made the calculated annual average diversions equal to independently measured values where we had them. Again, we did not calibrate monthly or seasonal behaviour.

The spreadsheet has three checks of the overall water balance for each catchment. The first check is for the rainfall-runoff part of the water balance. The sum of the monthly rain over the full period must equal the sum of the monthly evapotranspiration plus the sum of the monthly runoff plus the difference in the surface storage between the beginning and end of the period. The second check is for the river flow part of the water balance. For each catchment the sum of the monthly river reach inflows must equal the sum of the monthly losses to discharge, evaporation from storages and diversions plus the difference in storages between the beginning and end of the period. The third check is the overall catchment water balance. The sum of all the inflows to a catchment must equal all the outflows for all land types / water uses plus the change in all storages.

4.2.1 Data

The datasets used in this water use account were taken from several sources. Some were readily available on the internet, others were obtained from the authors of reports and papers about the Mekong.

- The rainfall and other climate data were taken from the Climate Research Unit at the University of East Anglia (specifically, a dataset called CRU_TS_2.10). They cover the globe at 0.5° (about 50 km) resolution, at daily intervals for 1901 to 2002. We sampled the rainfall and other climate surfaces for each catchment within the basin, to calculate catchment area-means of rainfall and potential evapotranspiration for each month. The method is described in more detail in Mainuddin et al. (2008).

- Reach flows were taken from a dataset called dss522.1, available on the internet (http://dss.ucar.edu/catalogs/free.html) (Bodo, 2001). For downstream catchments, the flow results used in the RAM (Johnston and Rowcroft 2003) were used here.
- Land use was taken from the 1992-3 AVHRR dataset available from IWMI database http://dw.iwmi.org/idis_dp/home.aspx.

4.2.2 Results

The Basin was divided into 18 sub-catchments (Figure 4.1). We have modelled the flow for each of these hydraulically linked sub-catchments. We show here the flow modelling for an upstream location (Chiang Saen, Figure 4.2), Tonle Sap catchment at the middle (Figure 4.3) and a downstream location (Phnom Penh, Figure 4.4) on the Mekong.

The flow at Chiang Saen shows the pronounced seasonal pattern, with some baseflow. The middle reaches of the Mekong preserve this flow pattern established at Chiang Saen, with the volumes growing greater as tributaries add to the flow. When the Mekong is at the peak flow, its level is above that of the Tonle Sap River which drains the Tonle Sap (Great Lake). Hence water is pushed up the Tonle Sap River and is stored in the lake. This reverse flow reverts to normal flow when the Mekong flow recedes, and the Tonle Sap River then drains the stored water plus additional water from runoff within the Tonle Sap catchment. The storage of water within the lake is of great importance to local fisheries and livelihoods.

At Phnom Penh, the Tonle Sap River joins the main stem of the Mekong. Flow at this point combines the influences of the floods in the reach from Kratie to Phnom Penh and the reversing flow of the Tonle Sap (Figure 4.4). The draining of the Tonle Sap back to the Mekong in the dry season results in greater dry season flows. Flows from Phnom Penh to the mouths of the Mekong in the delta in Vietnam are, in aggregate, similar to those at Phnom Penh, but are divided amongst several main channels.

The distribution of the different water uses across the basin is shown in Figure 4.1. The figure shows the different behaviour of the runoff-generating upper and eastern part of the basin, and the agriculture dominated middle-western parts of the basin in Thailand. Irrigation is a major water use in most parts of the basin. The figure depicts the water uses in each catchment, and the distribution of water uses across the basin. It does not, however, represent the water balance at the basin level. The irrigation in the delta part of the basin, for example, uses the runoff water from upstream, and thus this water is double counted at the basin level – the net runoff from the whole basin is shown in Figure 4.5. The mean annual input by precipitation to the Mekong basin totals about 1,200,000 mcm. Net runoff comprises the runoff remaining after all the water uses in the basin have been satisfied, and includes all other storage changes and losses. Net runoff from the basin is about 441,000 mcm or about 37 % of the total precipitation input. Forest and woodland is the most extensive land use, covering 43 % of the basin. Its water use is correspondingly high, with a mean annual water use of about 390,000 mcm, or 33% of the total precipitation, or about 52 % of the water consumed by the various land uses (ie, the latter figure excludes net runoff).

Irrigated agriculture covers about 6% of the basin. The estimated mean annual water use by irrigated agriculture is about 46,000 mcm, or 4% of the rainfall and 6 % of the total water use (excluding net runoff). The majority of the irrigated water use is from crops irrigated from the surface water resources. Grassland covers 22% of the basin, almost all in the upper basin, and consumes about 72,000 mcm (10%) of the water used.

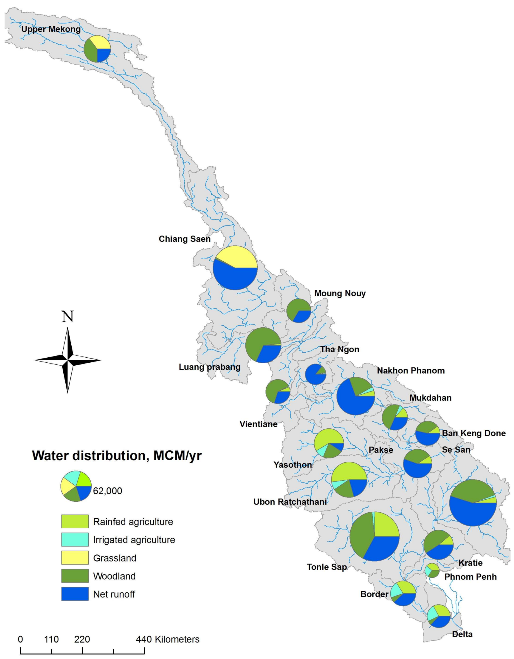


Figure 4.1 Sub-catchments of the Mekong Basin with the spatial distribution of major water uses

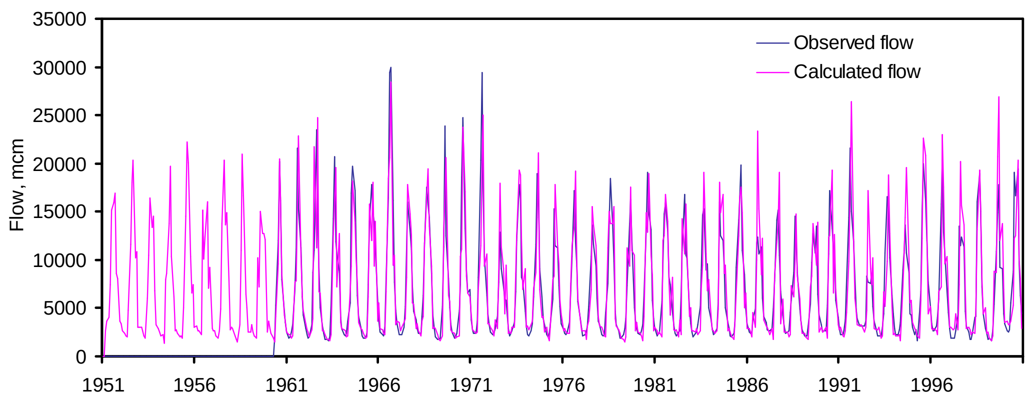


Figure 4.2 Flow from the upper Mekong at Chiang Saen for 1951 to 2000

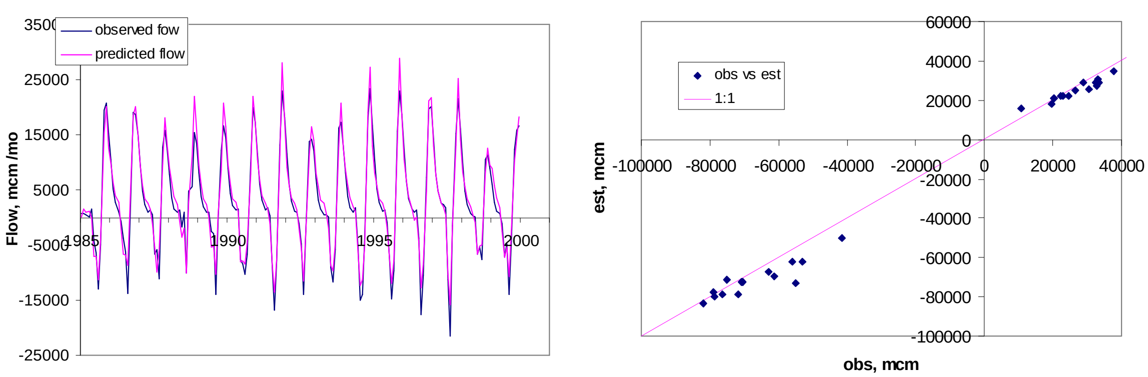


Figure 4.3 Comparison of observed and modelled flows in the Tonle Sap River, 1985 to 1999. Left: hydrograph of the Tonle Sap River flows. Right: observed and estimated total annual outflows and inflows into the Tonle Sap lake from the Tonle Sap River.

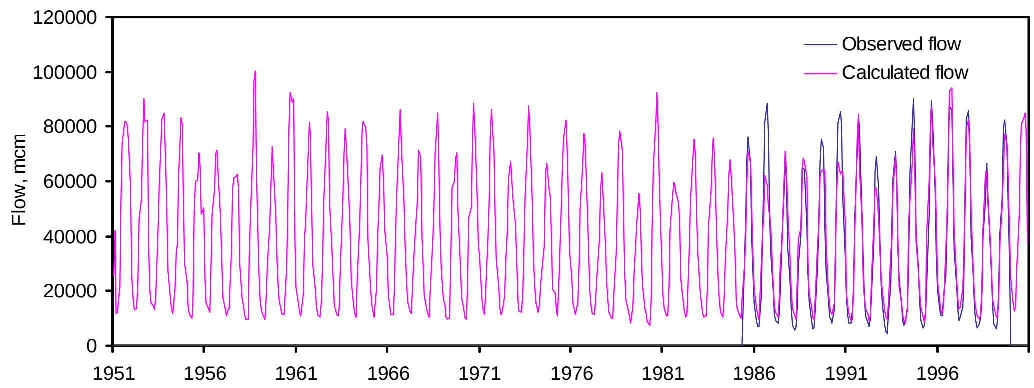


Figure 4.4 Flow in the Mekong at Phnom Penh for 1951 to 2000

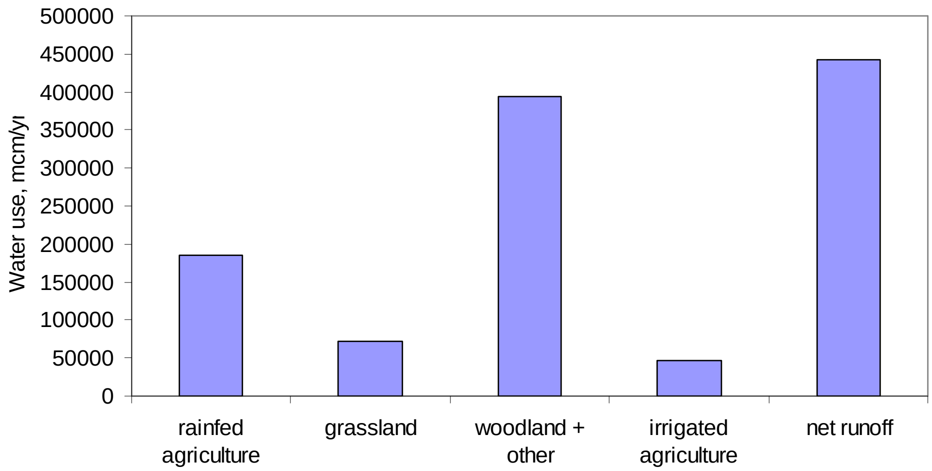


Figure 4.5 Summary of major water uses in the Mekong basin

The water use account spreadsheet is an example of top-down modelling in that it describes the overall behaviour of a basin based on observed responses, which Sivapalan et al. (2003) regard as the defining feature of a top-down approach. It is at a level of detail appropriate to an overview of the Mekong Basin. The account facilitates systematic learning about the catchment and basin behaviour, helps identify gaps and deficiencies in data, and make hypothesis testing quick and easy. However, Sivapalan et al. (2003) note problems and caveats with the top-down approach. Finer scale processes are glossed over, and the user must be confident that key features are not ignored, and that large scale models are physically reasonable interpretations of the processes. There are dangers in generalisations and extrapolations to new situations. Thus, the water use accounts should be used to investigate scenarios that are but modest perturbations of the conditions for which they are tested and calibrated.

4.2.4 Analysis

The water use account spreadsheet provides a basin overview of major natural, dryland and irrigated water uses, flows, storage, major losses and discharge. It provides a basis for examining the impact of physical changes to the system and for interactions with agricultural productivity, economics and livelihoods. We have used the water account spreadsheet to briefly examine three of the key issues in the Mekong: climate change, dam development and irrigation development. We have also used it to help in the development of a WEAP model of the Mekong.

Climate change

Several studies on climate change suggest that in several regions the dry season may lengthen and intensify, and that the rainy season may shorten and intensify. Thus both seasonal water shortages and floods may be exacerbated, as may saltwater intrusion into the delta (Hoanh et al., 2003; Snidvongs et al. 2003; Chinavanno, 2004). To demonstrate the sensitivity of flows to such changes in rainfall, the rainfall amount each month were adjusted using a shift factor which reduces the rainfall in the dry season and increase rainfall in the wet season keeping the mean annual rainfall after the transformation equal to that before it.

With the changed rainfall, more water is modelled as flowing both out of (normal flow, positive values) and into (reversing flow, negative values) the Tonle Sap (Figure 4.6). The lake is predicted to expand more in the wet season with the greater reversing flow and greater local inflows, and to shrink to a smaller volume with the longer and drier dry season. Similarly, the peak wet season flow at Phnom Penh is predicted to be greater, and the dry season flow less, under the demonstration climate change scenario (Figure 4.7).

The floods in the Mekong destroy life and property on the one hand, while on the other they are vital to many ecosystems and to fish production and hence food resources. The anticipated changes to climate and hence flow are expected to affect agriculture and food production greatly, and exacerbate the problems of supplying the increase in food demand with growing populations (Hoanh et al., 2003; Snidvongs and Teng, 2006).

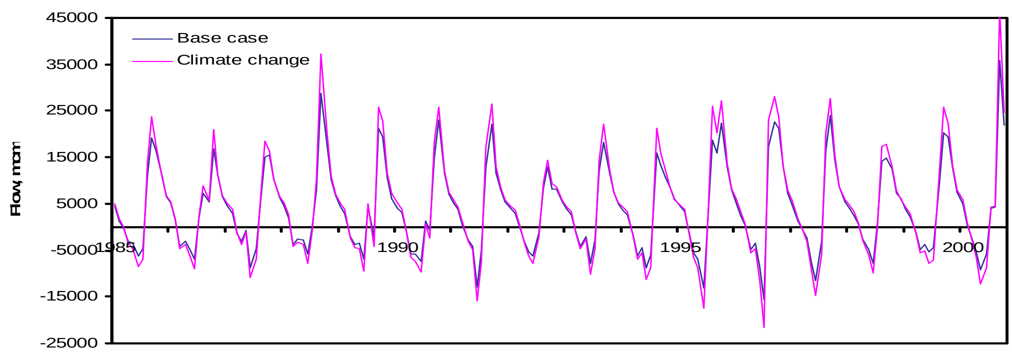


Figure 4.6 Flows in the Tonle Sap River with historical rainfall and a demonstration climate change rainfall

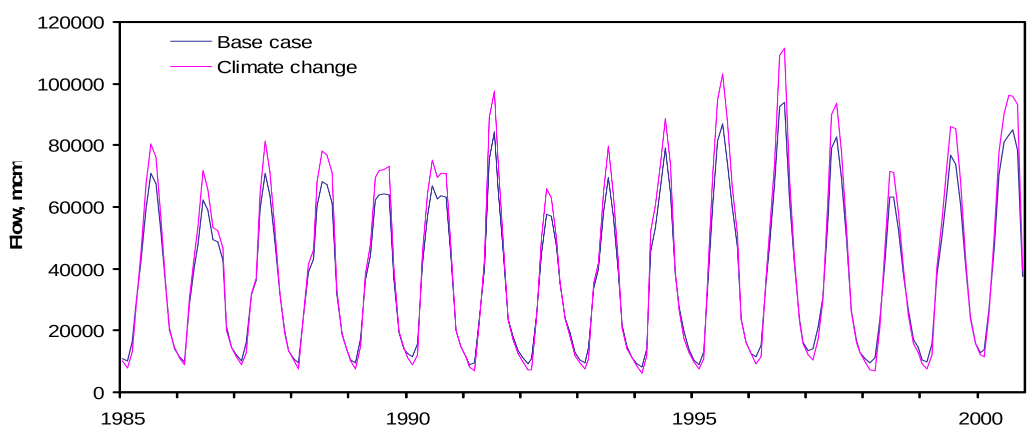


Figure 4.7 Flows in the Mekong at Phnom Penh with historical rainfall and a demonstration climate change rainfall

Presently, we are exploring in more detail the impact of climate change and irrigation development using this account in a project funded by AusAID.

Dam development

Development of dam in the upstream areas reduces the peak flows in the wet season and increases flow in the dry season. We examined this scenario in Kirby et al. (2006b). Reduction of flow peaks will reduce the risk of flood and increased flow in the dry season will enable irrigation development. Increased flow in the dry season will also reduce the salinity intrusion in the delta region. In terms of quantity of water the change is not great, but the effect of this change on the ecology and environment of the river could be very significant. Change of the natural flow regime in the river may change the reverse flow cycle on the Tonle Sap which would affect fish production. Millions of poor people of Cambodia are dependent on the fisheries of the Tonle Sap for their livelihoods. Increased dry season flow could reduce the salinity intrusion in the Delta and affect the management of shrimp farming and rice farming and other cropping.

Irrigation development

The population of the Mekong is expected to increase from the current 60 million to more than 90 million in 2050 (based on medium variant projection, UN Population Division, 2006). The increase in population with apparent (including losses from field to market) rice consumption at 150 kg per person per year (cf. Minot and Goletti, 2000) require about 6 m extra tonnes of rice. What are the water implications of the required increase? As a worst case, we will assume that the whole of the increased production will come solely from irrigation at the current level of productivity, and none is due to improvements in management or variety. The irrigation requirement of a rice crop might vary from 1.5 to 3 metres or even more for soils which drain rapidly. In the latter case much of the water would return to the system for re-use. Assuming 2 metres of water is the net requirement, and noting that at 3 tonnes/ha (the average yield currently) some 20,000 km2 is required to grow 6 m tonnes, then the net diversion requirement would amount to 40 km3, which is about 8 % of the current discharge to the sea.

This rough estimate is, on the one hand, a great overestimate of the likely water requirement (because irrigation will not be the sole factor in increased production), while on the other it is an underestimate since production increases will be demanded also of other crops and livestock. On balance, it would appear that the water demand of required increases in agricultural production is modest relative to the total volume of water in the Mekong. Locally, especially in the drier NE Thailand, the impact could be greater. Podger et al. (2004) estimated that the impact of a high agricultural development scenario on flows in the Mekong would be modest. However, the impact on the ecology and the environment is yet to be fully understood and could be significant.

Other uses

The water account has also been used in developing the WEAP model for the Mekong, in particular to develop the model for simulating flow in the Tonle Sap River.

We emphasize here that the applications of the account to see the impact of climate change, dam and irrigation development are mainly demonstrations.

4.3 WEAP applications in the Mekong River Basin

4.3.1 Introduction

The present study developed an initial application of the Mekong basin using the Water and Evaluation and Planning (WEAP) software platform (Raskin and Zhu 1992; Yates et al. 2005a,b, Vogel et al 2007) and used this application to begin to explore relationships between climate and development drivers and water availability at the basin and sub-basin scale. The WEAP modeling platform allows integration of pertinent demand and supply-based information together with hydrologic simulation capabilities to facilitate analysis of a range of user-defined issues and uncertainties, including those related to climate, watershed conditions, anticipated demand, ecosystem needs, land use change, regulatory drivers, operational objectives, and infrastructure. The user-defined demand structure and water allocation priority and supply preference designations drive the linear programming allocation algorithm for the water balance, allowing investigation of water allocation ‘trade offs’ within possible future hydrologic and ecologic regimes developed in a scenario framework. This priority-based optimization algorithm, an alternative to hierarchical rule-based logic, uses the concept of Equity Groups to allocate water in times of insufficient supply. WEAP performs these functions in a manner that emphasizes transparency of process, with interface functionalities that facilitate a collaborative model-building process for situations where diverse stakeholder groups with non-technical backgrounds may be involved.

In its present level of spatial aggregation, the Mekong basin WEAP model described here performs primarily as a scoping tool that allows one to broadly probe the impact to water availability of a number of hydrologic and demand drivers at the basin-scale and at a somewhat disaggregated scale delineated by thirty-one sub-basins. To illustrate the functionality of the developed model, we perturbed the Lower Mekong basin system over the period 2003-2026 (the model was calibrated over the period 1995-2002) with the following:

(1) two different assumptions regarding irrigation water demand derived from expected and high development projections incorporated in MRC Basin Development plan scenarios

(2) two possible future climate projections, one obtained by simply repeating historical conditions for the period 1995-2002, and the other derived from the SCENGEN climate projection database and modeling suite

(3) two different assumptions regarding the character of land cover replacing forested area across the basin, each assuming a deforestation rate of 50% by 2026. One permutation assumes grassland replaces forested areas, the other assumes a land cover with approximately 50% lower evapotranspirative demand and a 20% lower runoff resistance replaces forested areas.

This initial WEAP application for the Mekong basin is intended to complement, rather than replace, existing models and decision support tools already being utilized in the basin. While WEAP does have a climate-driven hydrologic simulation functionality, for example, its flexible structure allows it to serve also as a simple integrative framework for outputs from more sophisticated hydrologic modeling tools or to be linked dynamically to such models. This integrative feature becomes more important in areas where WEAP does lack direct functionality, such as the hydraulic simulation capability to inform channel navigation, flooding extent, and deltaic salinity encroachment issues – all very important in the Mekong basin.

A schematic of the basin was constructed in WEAP, using GIS data layers and maps to aid in positioning of major tributaries, sub-basin boundaries, stream gauges, and reservoirs (Figure 4.8). The basin was divided into 31 major sub-basins delineated by aggregating 265 smaller catchments developed for a SWAT-based model of the basin (Kite, 2002). The movement of water between destinations occurs via several types of links, such as transmission links (green arrows; Figure 4.9) routing water from a river to a demand node representing domestic water use, return flow links (red arrows; Figure 4.9) returning unconsumed portions of delivered water, and runoff/infiltration links (blue dashed arrows; Figure 4.9) moving runoff and base flow to rivers, infiltrated water to aquifers, and irrigation runoff back to the appropriate supply source.

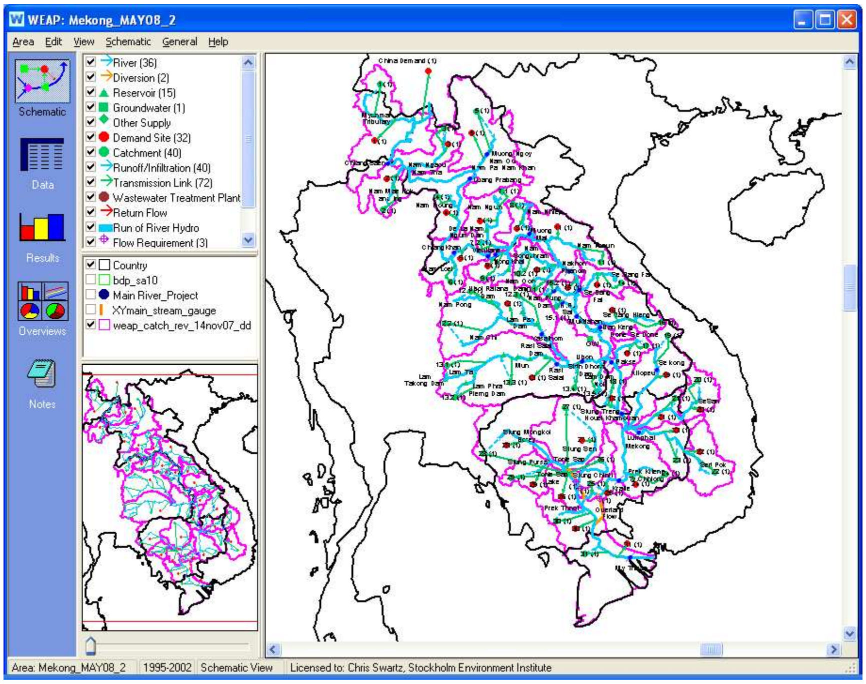


Figure 4.8 WEAP schematic developed for the Mekong basin

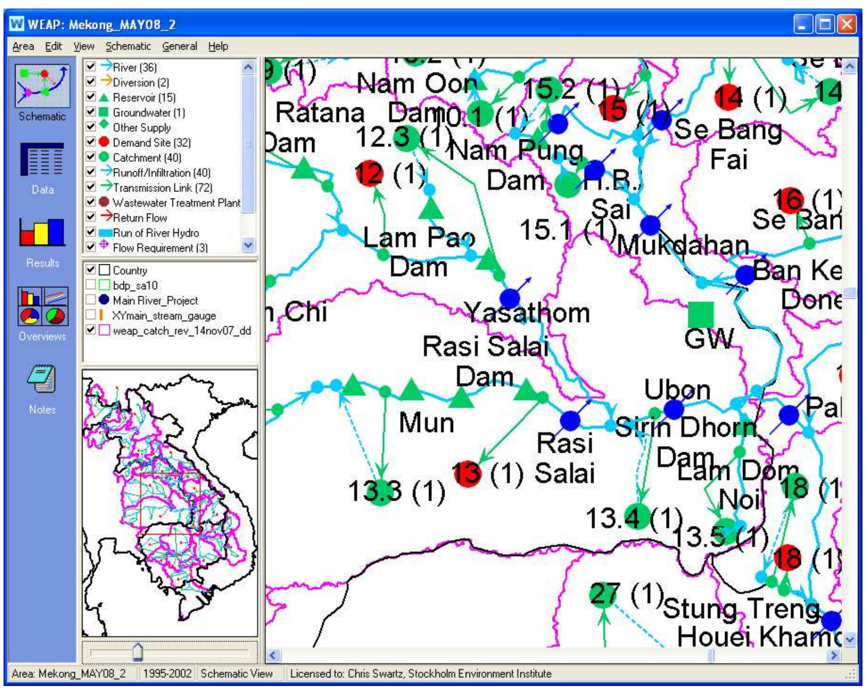


Figure 4.9 Detail of WEAP schematic along Mun river

4.3.2 Scenario Development

Growth in water demand

To investigate the impact of growth in population and irrigation water demand on the Lower Mekong and its tributaries, we implemented trends in future population and irrigation water use that have been featured in development scenarios formulated by the MRC for its Basin Development Plan (BDP) Programme. Two different growth trajectories were studied, paralleling that investigated by the BDP. To simulate growth in irrigated area, we applied annualized growth rates in irrigation agriculture calculated using the target increases identified by the BDP development scenario study for expected (their *Low Development* scenario) and intensified agricultural growth (i.e, their *Irrigation* scenario). The 'expected' growth trajectory comprises the '*Reference*' scenario in the present study. The higher growth trajectory is identified as '*Higher Irrigation Growth*' for this analysis. For each of these scenarios, we implemented a 1.3% per year rate of growth in population for each of the sub-basins, assuming uniform growth throughout the basin.

Deforestation

Substantial changes in land cover have been occurring in the Mekong basin over the last several decades as development modifies the landscape. In particular, deforestation is estimated to have occurred at a rate of 1.6% per year (FAO); areas of northern and northeastern Thailand, for example, have experienced a 50% decrease in forested area from 1980 to 2000 (Weesakul, 2005). To explore the impact of deforestation on flow patterns in the Mekong and its major tributaries, we developed a scenario, *Deforestation,* that employs a 1.6% year decrease in the deciduous, mixed forest, and evergreen land cover classes. This rate obtains an approximately 50% decrease in these land cover classes by 2026. Two different permutations of the deforestation scenario were simulated. In one iteration, the converted forested area acquires the soil moisture parameters assigned to the grassland land cover. In the second, the converted area acquires the properties of the 'other' land cover, which was given a lower evapotranspirative demand and greater runoff response more like a fallow or sparsely vegetated land cover.

Climate change

We incorporated possible future climate trajectories into the application using a data set derived from the MAGICC/SCENGEN software suite (http://www.cgd.ucar.edu/cas/wigley/magicc/index.html), which allows users to calculate and extract projections for geographically explicit temperature and precipitation based on global mean warming results published in the IPCC Third Assessment Report (1997) for various emissions scenarios. With this software suite, one or more atmospheric/ocean general circulation models can be selected to obtain regional results. For our analyses, we employed the A1BAIM scenario and models CSM_98, ECH395, ECH498, GFDL90, HAD295, and HAD300. Global mean change in temperature was 0.63 °C by 2025. The output from this selection was given for three broad areas for the basin (Figure 4.10) and temporally by the four quarters of the year (Table 4.1).

Figure 4.10 Spatial delineation for climate projections

Table 4.1 SCENGEN climate projection output

Year 2025	Precipitation (% change)			Temperature increase (deg C)		
	B	C	D	B	C	D
Q1	6.7	-0.4	-3.4	0.7	0.6	0.5
Q2	3.4	0.2	-2.3	0.7	0.8	0.7
Q3	2.4	1.9	2.3	0.5	0.6	0.6
Q4	2.4	2.4	3.6	0.6	0.6	0.6

4.3.3 Calibration

Simulated and observed flow over the period 1995-2002 compared reasonably well with available stream gauge data in the Mekong and major tributaries (Figure 4.11). WEAP also adequately captured the timing of the reversal of flow in the Tonle Sap river and cyclic fluctuations in the volume of the Tonle Sap Lake, although the magnitude of the peak forward and reverse flows and maximum and minimum lake volumes is somewhat attenuated compared to the observed values (Figure 4.12). See Swartz et al (2008) for a more detailed discussion of flow calibration results for the model. Total average annual evapotranspirative demand over the period 1995-2002 as simulated by the WEAP model was 740 bcm for the entire area modeled. This total includes natural land cover and agricultural areas. Excluding the delta region facilitated comparison with Kirby et al. (2009e) results - evapotranspiration totaled 670 bcm on average, approximately 16% higher than the average of 580 bcm simulated by Kirby et al. (2009e) over 1995-99.

Total anthropogenic demand in the modeled area ranged from 41 to 61 bcm per year, comprising mostly irrigation demand, which averaged 49 bcm per year. Net irrigation demand (total irrigation demand less average annual irrigation return flows of 5.0 bcm) was 45 bcm, similar to that simulated by the MRC DSF (personal communication). Irrigation in the delta region dominated water use in the basin at 65% of the total demand on average. Domestic and industrial water demand averaged 3.3 bcm over the basin, less than 10% of the total water demand.

Application rates of irrigation water varied by land class, with paddy areas requesting three to four times the volume of water than all other types of agriculture combined. Paddy areas requested on average 370 mm in the dry season and 120 mm in the wet season months, while application rates for all other agriculture were 110 mm and 30 mm in the dry and wet seasons, respectively.

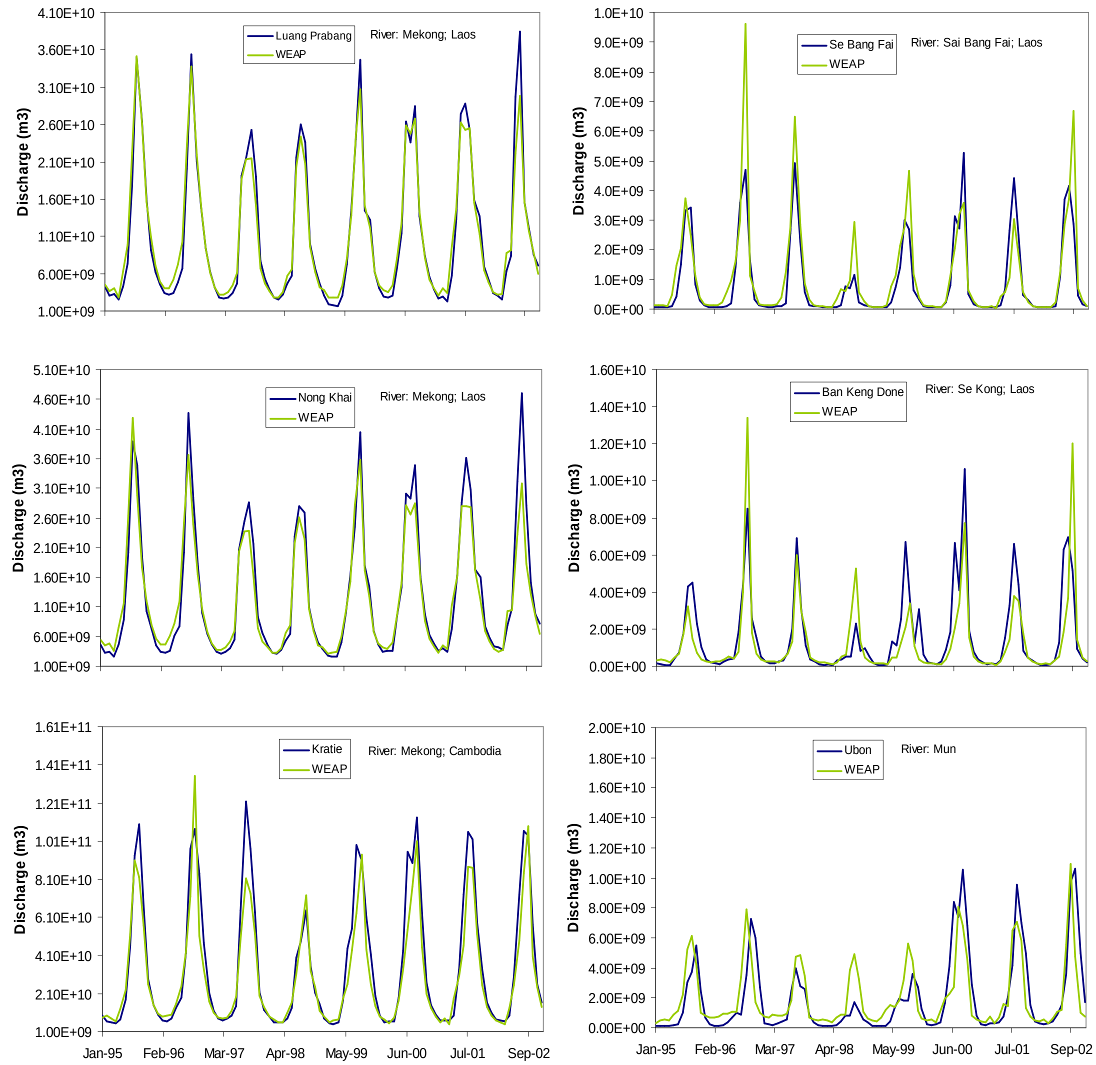


Figure 4.11 Streamflow calibrations for the Mekong and several major tributaries in Laos, Cambodia, and Thailand

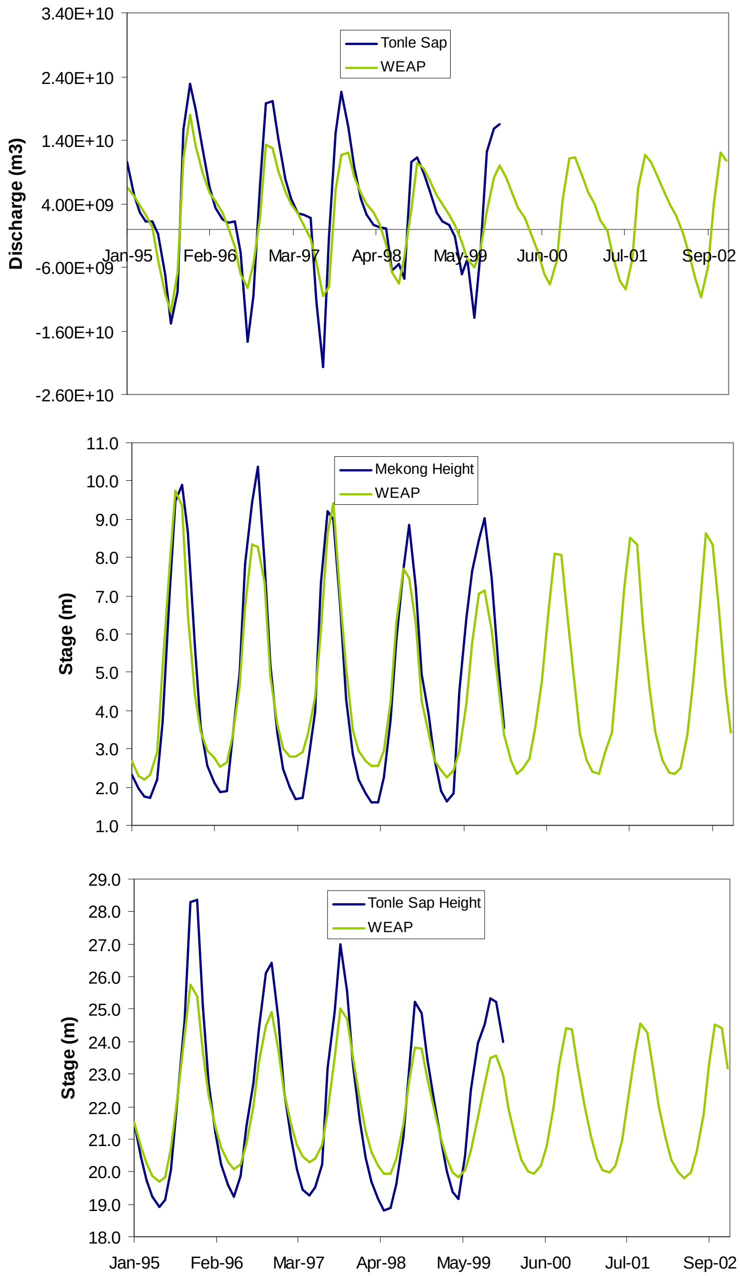


Figure 4.12 Tonle Sap River streamflow and Tonle Sap Lake volume calibrations

4.3.4 Scenario simulations

Expansion of irrigation

Basin-wide irrigation demand as a percent of total ET increased only slightly, from 6.8% to 7.4 and 8.6%, respectively, in the *Reference* and *High Development* scenarios over the period 2003-2026. However, the results indicate that periodic unmet demand develops in individual sub-basins under the assumed growth trajectories and climate conditions characterized by a repetition of the 1995-2002 observed climate sequence. For sub-basins 16 (Se Bang Hieng tributary; Lao), 17 (Se Done tributary; Lao), 20 (Se San tributary headwaters; Vietnam) and 22 (Sre Pok river headwaters; Vietnam), coverage of irrigation demand declines from 100% (i.e., streamflow is available in that time step to fully cover water requests) typically in late dry season month of April, but expands to include earlier dry season months for the example of sub-basin 22 (Figure 4.13). For sub-basin 22, irrigation demand is frequently not met and coverage drops to approximately 20% in some months of later years. Note that unmet demand is realized even during the calibration period (1995-1999) for this sub-basin (Figure 4.13).

These results assume that there is a complete reliance on surface water (i.e., streamflow in the respective tributary) - the use of groundwater as a supplement to surface water is not simulated here although it is likely occurring. With this caveat in mind, it may be more appropriate to view these results as suggesting a trend toward greater reliance on groundwater, if available, under these simulated conditions. In addition, no surface storage that would capture wet season flows for use in the dry season is presently being represented and simulated in these sub-basins. In reality, irrigation may rely on these impoundments in the dry season in these sub-basins.

For each of these sub-basins where increasing water scarcity is suggested, the slope of a linear regression through the water demand and unmet demand trajectories, plotted on an annual basis, provides an approximation of the per year increase in each of these two variables. The rate of increase in irrigation demand in these basins ranges from 0.1 to 10 mcm/yr in the *Reference* scenario and 9 to 30 mcm/yr under the *High Development* conditions. Increases in unmet demand range from 0.4 to 5 mcm/yr and 1 to 10 mcm/yr for these scenarios. Note that sub-basin 20 appears the most resilient, in that a ten-fold increase in demand is coupled with only a two-fold increase in unmet demand.

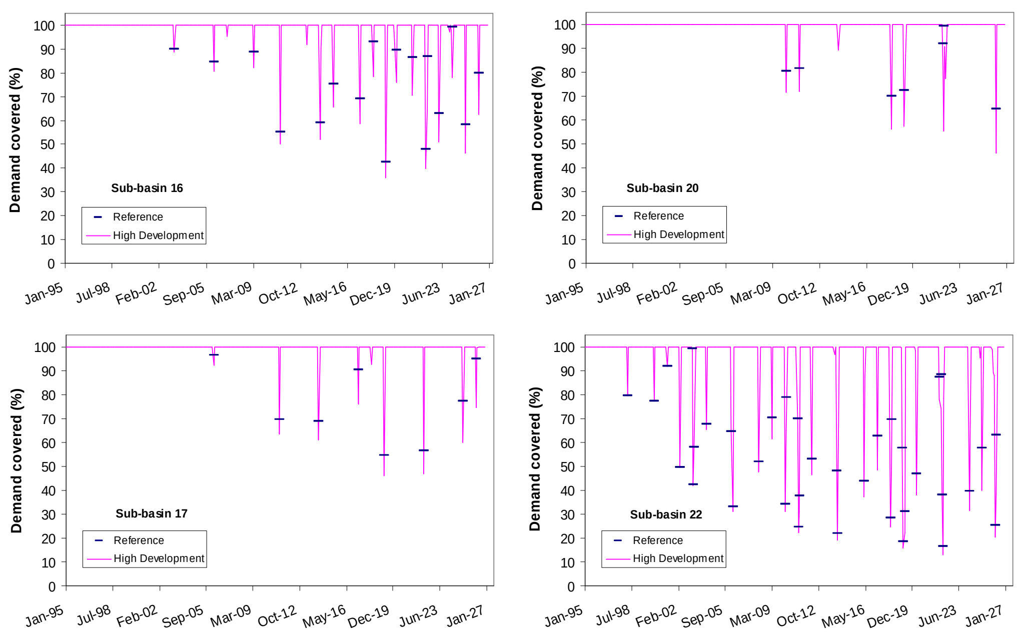


Figure 4.13 Irrigation demand coverage in sub-basins with water scarcity

Deforestation

As forested land cover is replaced by land cover with characteristics of either grassland or the 'other' land cover category (i.e., fallow or barren) over the 24 year period of the scenario, relative changes in evapotranspiration (Figure 4.14a) and runoff (Figure 4.14b) are manifest basin-wide and within individual sub-basins, particularly where forested land cover is originally a dominate feature, such as the Se Kong sub-basin (sub-basin 19). At the basin-scale, the simulations suggest that total annualized ET flux could decrease by as much as 6% percent compared to the *Reference* scenario conditions depending on the character of the land cover replacing the forest. Larger decreases in ET are simulated in sub-basins such as the Se Kong where forest land cover initially dominates (Figure 4.14a). Changes in annual runoff may be even larger – as much as 5 to 30% of more for these forest-dominated sub-basins (Figure 4.14b), again depending on the character of the replacing land cover.

The integrated effect of this land use change can be observed in the Mekong River at the Kratie stream gauge (Figure 4.15a). Here, simulations suggests that streamflow in the wet season could increase by as much as 8% to 30% by 2026 depending on the character of the land cover replacing the forest. Note that when grassland cover replaces forest, the percent change in streamflow, relative to the *Reference*, is similar, but opposite in sign, in the wet and dry seasons, resulting in a near-zero annualized percent change in flow. When forest is replaced with the 'other' land cover, a much higher percentage increase in streamflow occurs during the wet months, and a small increase in streamflow in the dry season results in some years as well.

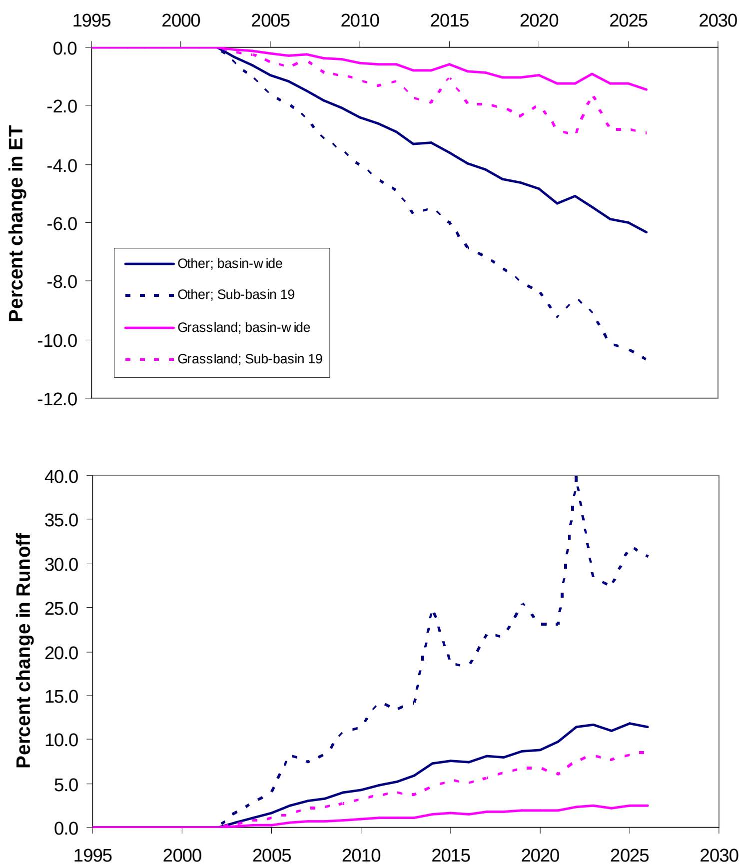
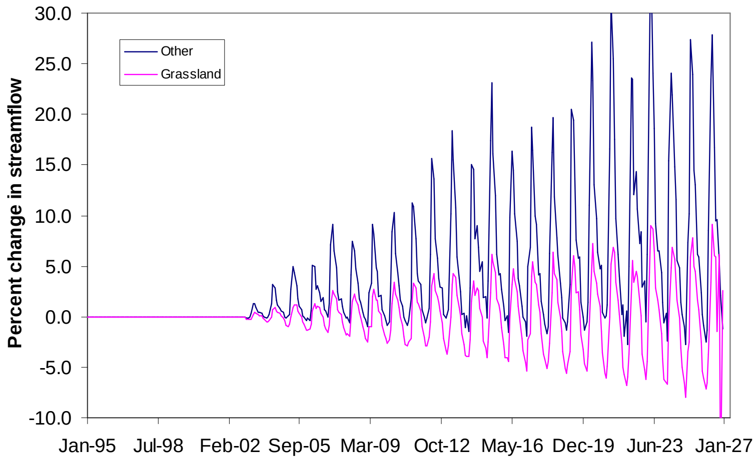


Figure 4.14 Annualized percent change in ET and runoff due to deforestation

Similar patterns of relative change are simulated for the volume of the Tonle Sap lake (Figure 4.15b), although the magnitude of the change is much lower than that simulated for streamflow at Kratie, and the change in volume is always positive (wet and dry seasons) when replacement by the 'other' land cover occurs. These results suggest that not only would the average wet season volume of the lake continue to grow concomitant with the replacement of forest with this type of land cover, but that the average dry season volume would grow as well. In contrast, the results suggest that while a similar, but smaller, increase in wet season volume would occur with replacement of forest with grassland cover, the volume of the Tonle Sap lake may progressively grow smaller in the dry season relative to the *Reference* condition.

It must be noted though that these deforestation simulations do not consider the effect of spatial juxtaposition in the dynamics of land cover change. The location of land cover change in a particular sub-basin relative to surface channel structures would influence the magnitude of the impact that land cover change has on the volume of runoff reaching the surface channel. Intact riparian vegetative buffers between the area undergoing change and the surface channel may partially attenuate any fluctuations in runoff that would otherwise be manifest as changes in streamflow in the sub-basin's channel structure. However, the flexibility of the WEAP model framework would allow future incorporation of any empirically or analytically derived quantitative relationships between deforestation magnitude and position in a sub-basin and the resulting changes in streamflow in its channel structure. Such expressions could refine the simulation of runoff and infiltration responses to these types of land cover change in the basin.

Returning to the example of sub-basin 22, the impact of the shifting land use patterns described above typically results in a small or no decrease in coverage of irrigation demand compared to the *Reference* (Figure 4.16). The coverage typically drops by 1 to 14% during the time period simulated, although in several instances, coverage actually increases.



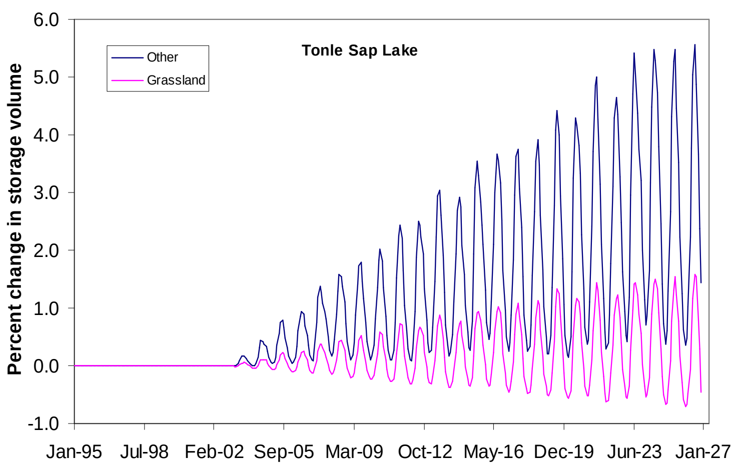


Figure 4.15 Monthly percent change in Mekong streamflow at Kratie and Tonle Sap lake volume due to forest replacement with either grassland or 'other' land cover

Climate change

The modest changes in precipitation and temperature incorporated in the model, as obtained from the SCENGEN climate projection tool, resulted in correspondingly small changes in hydrologic and demand trajectories at the basin scale. When the projected change in precipitation was superimposed on the repeated historical precipitation pattern (the reference climate), the modified climate pattern resulted in an overall increase in basin-wide annual precipitation by approximately 2.2% by 2026. Runoff increased basin-wide by approximately 4% by the end of the period.

Concomitant with the increase in precipitation and slight rise in temperature, total evapotranspirative flux also increased somewhat at the basin-scale – by approximately 1% in the later portion of the time period. However, differences between basin-wide irrigated area ET or irrigation water demand were practically indifferentiable with or without climate change superimposed for either the *Reference* or *High Development* growth trajectories. This is consistent with the small fraction of total ET represented by irrigated area in the basin.

At the individual sub-basin scale, small effects from this particular climate trajectory on irrigated agriculture can be differentiated. Using sub-basin 22 again as an example, the superposition of the assumed climate change trajectory onto the *Reference* and *High Development* growth projections results in some change in the pattern of unmet demand with time (Figure 4.17). In late dry season months, when the climate change trajectory produces less precipitation than the *Reference* climate (i.e., change in precipitation is negative relative to the *Reference* climate condition), unmet demand is greater (i.e., the change in unmet demand is positive) for both the *Reference* and *High Development* growth projections (Figure 4.17). Conversely, in the wet season, when the climate change trajectory produces greater rainfall, unmet demand decreases relative to the *Reference* climate condition. Note that the instances where unmet demand increases relative to the *Reference* climate are more numerous than the few instances when unmet demand decreases, although the decreases in unmet demand are of a higher volume.

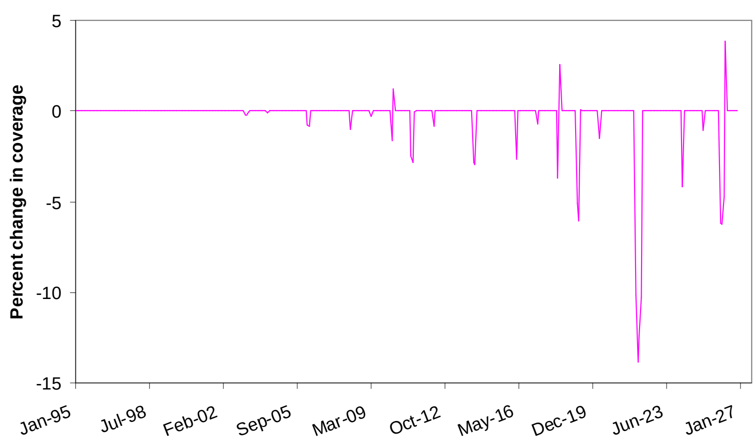
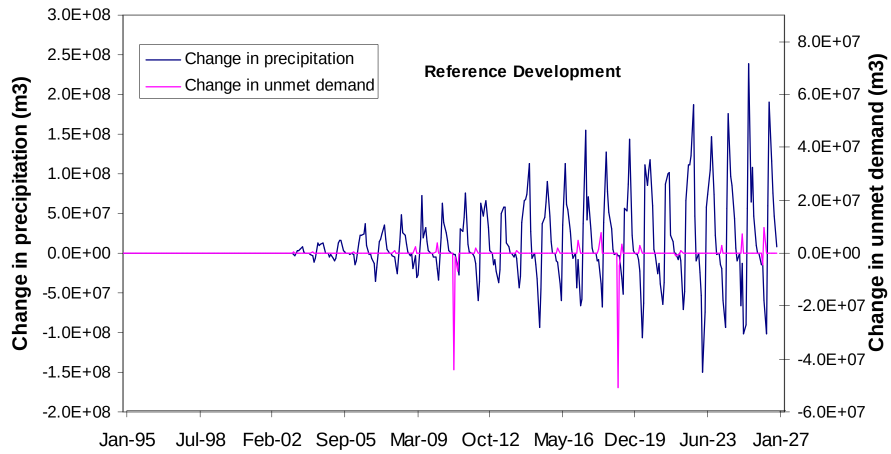


Figure 4.16 Monthly percent change in coverage of *Reference* irrigation demand in sub-basin 22 due to forest replacement by grassland



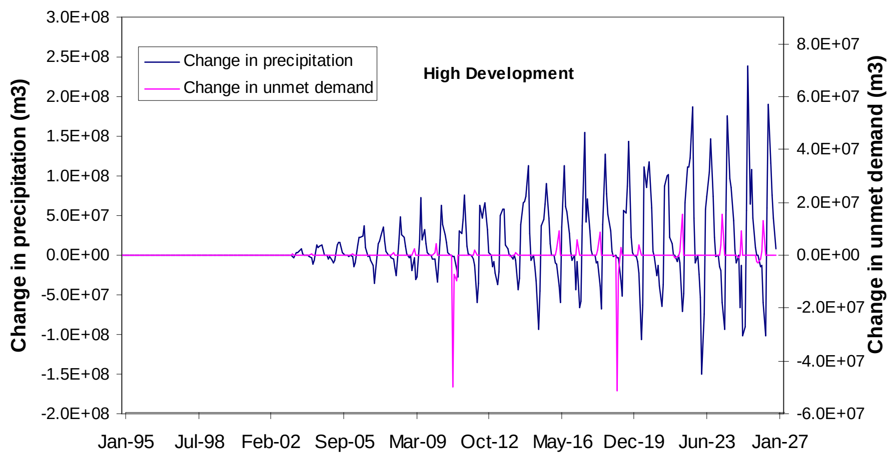


Figure 4.17 Changes in precipitation and unmet demand in sub-basin 22 under one climate change simulation with *Reference* and *High Development* conditions

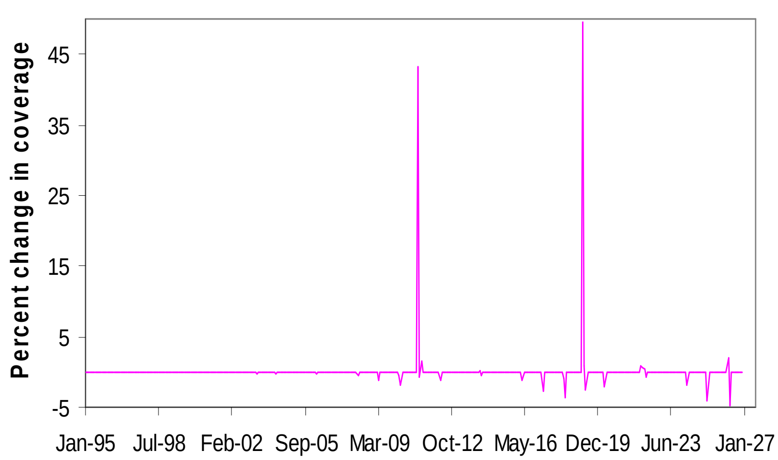


Figure 4.18 Change in *Reference* irrigation demand coverage in sub-basin 22 due to climate change

Expressed in terms of change in demand coverage, with *Reference* growth as an example, the simulated climate change trajectory causes small decreases in coverage of irrigation demand in sub-basin 22 during the period and a few instances of increased coverage (Figure 4.18). For the instances where coverage decreases, the magnitude of the decrease is overall similar to that manifest by the deforestation scenario for the *Reference* growth condition (Figure 4.16).

We found that deforestation and climate change, as formulated in these scenarios, altered runoff basin-wide at similar magnitudes, and also produced similar relative increases in unmet demand (i.e., reduced coverage of demand) for irrigated agriculture in several sub-basins where unmet demand is suggested to exist presently (as defined by the calibration period 1995-2002). These four sub-basins include the Se Bang Hieng (16) and Se Done (17) tributary sub-basins in Lao, and the headwater sub-basins of the Se San (20) and Sre Pok (22) tributaries in Vietnam. Here, when the *Reference* development growth trajectory for each of the sub-basins is superimposed on either a climate change scenario or a deforestation scenario where grassland replaces forested areas, coverage of irrigation demand typically decreases by 5% or less during the dry season months up to 2026.

It must be noted that these simulations assume a complete reliance on unmanaged surface water resources along these tributaries; no managed surface storage structures that capture wet season excess flows for use in the dry season or supplemental use of groundwater was included in this initial model construct These additional sources would mitigate any simulated dry season water scarcity in these areas.

Deforestation altered to only a minor extent the cyclical fluctuations in the Tonle Sap Lake volume, an ecosystem dynamic on which many fishing-dependent livelihoods in the basin are based. For the grassland permutation of the deforestation scenarios, wet season peak volume increased by only about 1.5% by 2026, and dry season volume decreased by approximately 0.5%. Replacement of forest with the 'other' land cover induced larger changes in volume – increasing both wet season and dry season volumes by up to 5.5% and 0.5%, respectively, by 2026.

4.4 Key Findings

1. A very simple spreadsheet model with few adjustable parameters has captured most of the runoff and river flow behaviour in the lower Mekong Basin. Obvious features such as the flow reversal of the Tonle Sap are modelled reasonably well. Less obvious features such as flow lags and local storages are also simulated reasonably well.
2. The main issue in the Mekong Basin is not water availability (except for seasonally in certain areas such as northeast Thailand) but the impact of changed flows on ecology, fish production, access to water and food security. Changes in the natural flow regime may alter the environment of fisheries in the Tonle Sap and elsewhere. Altered low flows may impact salinity intrusion in the delta, thus altering the balance of rice and shrimp production, which in turn may affect food security and incomes.
3. The impact of climate change, dam and irrigation development on water availability or flow is not great. The real issue, however, is the extent to which changes in flow will affect food production, the environment, floods and salinity intrusion in the delta.
4. The amount of water required for full irrigation development is small compared to the amount of water flowing to the sea. However, the impact of such development on the overall environment could be significant.
5. Deforestation and climate change, as formulated in these scenarios, altered runoff basin-wide at similar magnitudes, and also produced similar relative increases in unmet demand (i.e., reduced coverage of demand) for irrigated agriculture in several sub-basins where unmet demand is suggested to exist presently.
6. Deforestation altered to only a minor extent the cyclical fluctuations in the Tonle Sap Lake volume, whereas other land cover changes could cause larger changes in volume.

4.5 Tool Development

1. We have developed a spreadsheet based dynamic water use account, which is a tool to study the overall water use and flow behaviour of a river basin. The account can be used for testing the impact of climate change, landuse change, increase in irrigation area, dam development, etc.

2. We have used this account in 9 other Challenge Program Benchmark Basins (Yellow, Indus, Ganges, Karkekh, Nile, Limpopo, Volta, Niger and Sao Francisco) around the world. We have also used this account to the Murray-Darling River Basin. The Mekong account will be generally available through CPWF when fully revised.
3. A WEAP application covering the Mekong basin has also been developed to help determine the likely water-related changes and impacts of the envisaged development path in various basin-wide scenarios: (1) expansion of irrigation; (2) deforestation; and (3) climate change. The Mekong WEAP will be generally available through the CPWF when fully refined.
4. To fully activate a copy of WEAP, a valid License is required. Non-profit, governmental or academic organizations based in a developing country are eligible to request a renewable 2-year waived license. More detailed information can be found at www.weap21.org.
5. As a continued effort beyond the Mekong BFP project, SEI will expand and refine the Mekong WEAP application further, focusing on modelling water flows (quantity and quality) in the Phnom Penh area as part of a project (Water, Socioeconomic and Ecological Relations in Phnom Penh) funded internally through SEI.

4.6 Outputs

1. Kirby, M., Mainuddin, M. Eastham, J. (2009). Water-use Accounts in CPWF Basins: 1. Model Concepts and Description. CPWF Working Paper, Colombo, Sri Lanka.
2. Kirby, M., Mainuddin, M., Thomas, M. and Eastham, J. (2009). Water-use Accounts in CPWF Basins: 6. Simple Water-use Accounting of the Mekong Basin. CPWF Working Paper, Colombo, Sri Lanka.
3. Kirby, M., Eastham, J., Mainuddin, M. (2009). Water-use Accounts in CPWF Basins: 12. Spreadsheet Description and Use. CPWF Working Paper, Colombo, Sri Lanka.
4. Kirby, M. and Mainuddin, M., (2008). Water management and food issues in SE Asia. Invited talk at the International Symposium on Agrometeorology and Food Security, Feb 18-21, 2008, Hyderabad, India
5. Kirby, M., Mainuddin, M., Mobin-ud-Din, A., Marchand, P., and Zhang, L. (2006a). 'Water use account spreadsheets with examples of some major river basins', in 9th International River Symposium, 4 September, 2006-7 September, 2006, Brisbane.
6. Kirby, M., Mainuddin, M., Podger, G., and Zhang, L. (2006b). 'Basin water use accounting method with application to the Mekong Basin', in Proceedings on the International Symposium on Managing Water Supply for Growing Demand, Bangkok, Thailand, 16-20 October 2006, Sethaputra, S. and Promma, K. eds, UNESCO, Jakarta.
7. Krittasudthacheewa, C. (2008). Changes of Mekong's Hydrology and Their Relationship to the Fisheries Sector, invited keynote speech in the International Symposium on Sustaining Fish Biodiversity, Fisheries and Aquacultures in the Mekong, 3-5 September 2008, Ubon Ratchathani, Thailand.
8. Krittasudthacheewa, C., Swartz, C., Chadwick, M. T. (submitted). 'Impact of Climate Change and Hydropower Dam in the Mekong River Basin'. Abstract submitted to the International Conference on An International Perspective on Environmental and Water Resources, January 5-7 2009, Bangkok, Thailand. Organized by the Environmental & Water Resources Institute of ASCE (EWRI of ASCE) in cooperation with Asian Institute of Technology (AIT).
9. Swartz, C., Krittasudthacheewa, C., Kemp-Benedict, E. (2008). Application of the Water Evaluation And Planning System in the Mekong River Basin. Report for the Challenge Program on Water and Food.

4.7 Key Recommendations

1. To develop policies and management practices for water, food and poverty, water availability (water resources, hydrology) should not be considered in isolation. Water availability is not the main issue in most places, but rather the impacts of

changed availability and future demand on the environment, food production and poverty. Integrated analyses and integrated policy development should be undertaken. We will return to this in the sections on poverty and water productivity.

2. Again, while water availability is not a major issue in most places, management and governance of water is a major issue with the potential to affect food security, poverty and the environment, and should be considered in policy development. We will discuss this in the institutional analysis section.
3. There are water shortages in some part of the basin such as northeast Thailand. More integrated analysis is needed to formulate policy and management alternatives to minimize their adverse impacts on the environment and downstream.
4. The impact of climate change on flows, agricultural productivity, fisheries ecology, environment and sea level rise needs further works based on the 4^{th} assessment report of the IPCC. The uncertainty related to climate change also warrants more analysis.

5. WATER PRODUCTIVITY

Water and agricultural productivity is a critical influence on both rural welfare and economic growth in the lower Mekong River basin which ultimately helps alleviate poverty. Agricultural productivity also strongly influences food security. Growth in productivity can increase and stabilize food supplies, as well as increase the ability to purchase food. It is important to assess the current level of and trend in productivity and the link with poverty and other socio-economic conditions. This will help us identify the constraints for low productivity and suggest measures to improve them, which will eventually help alleviate poverty in the region.

5.1 Literature survey

Lower Mekong River Basin has been the subject of numerous studies on hydrology and water availability (Takeuchi et al., 2000; Hearth and Yang, 2000; and Kite, 2001; Fujii et al., 2003) and agricultural productivity. Chea *et al.* (2001) focused on the rainfed lowland agro-ecosystem and different cropping models to demonstrate an approach intended as a precursor to increasing the productivity of rainfed ecosystems in Cambodia. Kono *et al.* (2001) used a GIS-based crop modelling approach to evaluate the productivity of rainfed lowland paddy rice in Northeast Thailand. Yamamoto *et al.* (2004) and Nawata *et al.* (2004) used a simple cassava model to estimate attainable yields for productivity analysis within Northeast Thailand. Shimizu *et al.* (2006) examined the relation between yields of rainfed paddy rice and factors that affect the yields in Cambodia. Schiller *et al.* (2001) summarized the known main abiotic and biotic production constraints in each of rice-producing environments of Laos but did not examine the socioeconomic constraints, which can also have significant impact on farmer attitudes and production. Buu and Lang (2004) discuss the constraints affecting rice production and ways of improving productivity in the Mekong Delta of Vietnam.

Most of the previous studies of agricultural productivity in the lower Mekong Basin were based on part of the basin such as areas within one riparian country, on a single crop such as rice, and for a short period or for just one growing season. None of the previous studies considered the whole of the lower Mekong Basin, nor did they consider the economics of production. Moreover, they concentrated only on rice, and did not take into account the other sectors such as livestock. Furthermore, these previous studies did not consider the temporal trends.

Fisheries of the Mekong has also been the subject of numerous studies (Sverdrup-Jensen, 2002; Van Zalinge et al., 2003; Hortle and Bush, 2003; Baran et al., 2007) in the past. However, precise estimates of the total fisheries production are lacking (Rab et al. 2005). There are no studies on fisheries productivity for the whole lower Mekong basin below the country level, none that compare the contribution of this sector to overall agricultural production, and few that give trends (none for the whole of the lower basin). Most of the studies provide aggregated country level information for a season or a year.

Here we analyse agricultural and fisheries productivity of the basin both spatially and temporally. We consider all the crops grown in the basin for which data are available, and include all types of livestock and fisheries in productivity analyses. We consider provincial administrative boundaries as the spatial unit and analysed the trends in the data from 1993 to 2004. We estimated productivity both in terms of production (e.g. kg per ha, per m^3 of water and per capita) and production value ($ per ha, per m^3 of water and per capita).

5.2 Method

Productivity, in general terms, is a ratio between a unit of output and a unit of input. The most encompassing measure of productivity used by economists is total factor productivity (TFP), which is defined as the value of all outputs divided by the value of all inputs. However, partial factor productivity (PFP) is more widely used by economists and non-economists alike. Partial factor productivity is relatively easy to measure and is commonly used to measure the return to scarce or limited resources, such as land or labor (Barker *et al.* 2003). In this study we have estimated 4 types of productivity:

i) Land productivity, which is also called agricultural or crop productivity, dividing the crop production, gross value of production (GVP), or standardized gross value of production (SGVP) by the harvested area, total agricultural area and population. GVP and SGVP has been estimated at constant 1994 prices after converting nominal prices to real values using inflation data available in the statistical websites of the riparian countries.

ii) Livestock productivity, in terms of density of livestock units and GVP of livestock production per unit area and per head of population.

iii) Water productivity, as the mass of product per unit of water consumed termed as physical water productivity and GVP and SGVP per unit of water consumed which is called as economic water productivity (Cook et al. 2006; Immerzeel 2008, Abdullaev and Molden, 2004).

iv) Fisheries productivity, as the production and GVP of fisheries per capita.

The detail about the methods, definitions of the indicators can be found elsewhere (Mainuddin et al. 2008; Mainuddin et al. 2009d).

5.3 Data Sources

Provincial time-series data of planted and harvested area, yield and production of different crops, population and the number of livestock, production of capture fisheries and aquaculture, currency exchange rate, farm gate price of different crops and livestock were obtained from the website of the Statistical Office of the respective riparian countries, Regional Data Exchange System on food and agricultural statistics in Asia and Pacific countries (http://www.faorap-apcas.org) and from the FAOSTAT database (http://faostat.fao.org). The conversion factors to estimate the livestock unit density, carcass weight and percentage slaughtered by species for the countries were taken from the Livestock Sector Brief published in 2005 by FAO (FAO 2005a; FAO 2005b; FAO 2005c; FAO 2005d). The international price of rice to estimate standardized gross value of production was obtained from the IRRI database (http://www.irri.org/science/ricestat/).

The statistical production data of fisheries are regarded as low and unreliable. Therefore, in addition to this, we used literature source of the production data which are mainly the papers and reports available in the MRC website (www.mrcmekong.org) and the CD 'Fisheries Information in the Lower Mekong Basin Version 1' published by the MRC.

Climate data for observed rainfall, and maximum and minimum temperature were obtained from the global surface at 30 arcminutes resolution of precipitation and temperature from the Climate Research Unit (CRU) of the University of East Anglia (http://www.cru.uea.ac.uk/cru/data/), and from the global surface summary of daily data produced by the National Climatic Data Centre (NCDC) of National Oceanic and Atmospheric Administration (NOAA) (http://www.ncdc.noaa.gov). Daily rainfall data of the meteorological stations within the Basin from IWMI database (www.iwmi.org) have also been used. We have estimated reference evapotranspiration (ET_o) by Hargreaves' method (Allen *et al.* 1998) and generated monthly rainfall and ET_o surfaces using the CRU data for 1981-1996 and the NCDC-NOAA and IWMI data for 1997-2005. We then overlayed these surfaces with the provincial administrative boundaries of the lower Mekong Basin to obtain time series of the monthly average rainfall and ET_o by province for the period of 1981-2005.

We estimated actual crop evapotranspiration (ET_a) using a soil water balance simulation model with 10-day time step. The model is based on the FAO Irrigation and Drainage Paper 56 (Allen *et al.* 1998), and similar to that of the CROPWAT model developed by FAO. The inputs of the model are monthly rainfall and reference crop evapotranspiration (ET_o), crop coefficients, rooting depth, crop planting time and growing period, length of growth stages, soil properties such as field capacity, wilting point, saturated moisture content, depletion factor, ponding water depth and percolation rate for rice. All these parameters are taken from published literatures (Allen et al. 1998, Nesbitt 2005, Chea et al. 2001, Sihathep et al. 2001, Makara et al. 2001). The model can simulate both irrigated and rainfed crops. The outputs of the model are ET_a, potential crop evapotranpiration, irrigation requirement (for irrigated crops), and effective rainfall during the cropping period. The model has been used to estimate ET_a and irrigation water requirements for a range of crops grown in the Murray-Darling Basin (Mainuddin *et al.*, 2007 and Qureshi *et al.*, 2007).

We considered 18 crops for Laos, 18 for Thailand, 14 for Cambodia and 9 for Vietnam, which are all the crops for which data were available. Livestock comprises of cattle, buffalo, pig, and poultry. For fisheries productivity, we considered inland capture fisheries, aquaculture and capture marine fisheries.

5.4 Results

We considered provincial administrative boundary as the spatial unit to estimate the productivity indicators. There are 18 provinces in Laos, 22 provinces in Thailand, 20 provinces in Cambodia, 4 provinces in the Central Highland of Vietnam and 12 provinces in the Mekong River Delta of Vietnam within the basin area. Data for agriculture and livestock were available for the period of 1993-2004 for Laos, 1995-2003 for Thailand, 1993-2003 for Cambodia and 1995-2004 for Vietnam at the time of collection. Data for fisheries were available up to 1995. Estimated provincial productivity indicators were presented in a series of maps using GIS. For comparison between countries, we estimated the average value of the indicators for the whole area of the lower Mekong Basin within the political boundaries of the individual riparian countries. Vietnam has two distinctly different regions in the Mekong Basin, the Mekong Delta and the Central Highlands. The productivity of these two regions is quite different so we have considered these two regions separately as well as combined for the whole country. The maps of all the indicators and the detailed results can be found in two reports published separately based on the analysis by Mainuddin et al. (2008 and 2009e). In this report, the name of the country indicates the area of that country within the Mekong Basin, not the whole country unless otherwise mentioned.

5.4.1 Agriculture or crop productivity

Figures 5.1 and 5.2 show the provincial and regional differences in average yield of rice and its trend during 1993-2004. Yield of rice varies from 1.0 to over 5.0 t/ha, with the highest yield in the Delta region of Vietnam, moderate yields in some part of Laos and the Vietnam Highlands and the lowest yields in Cambodia and Northeast Thailand. The regions of highest productivity are those of highest rainfall or irrigation water use. The lower productivity of Northeast Thailand presumably results from the lower rainfall and longer annual dry period, though it could also result from other factors such as poorer soil nutrition. In all regions, productivity increased from 1993 to 2004, with the increase being more prominent in Laos and Mekong Delta and Central Highland of Vietnam. However, the population also increased, and thus the increase in production per capita was much less than that of yield alone (Figure 5.3).

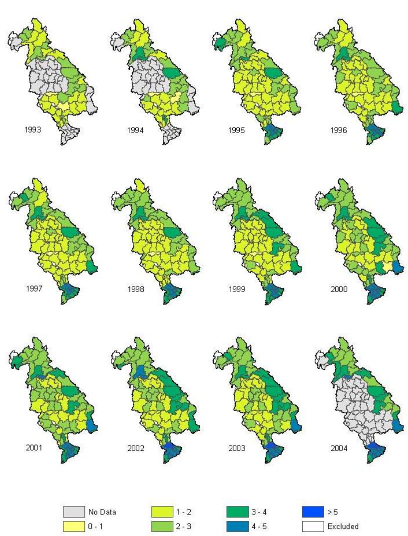


Figure 5.1 Spatial and temporal variability of average yield of rice (tonne/ha)

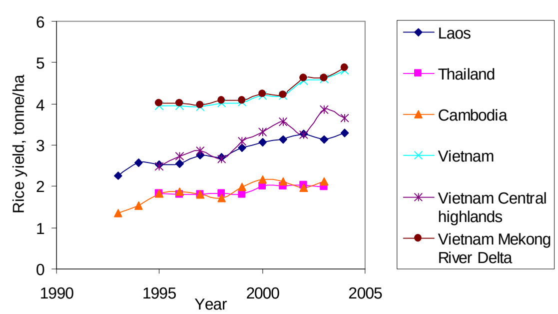


Figure 5.2 Regional average yield of rice

Rice productivity per capita (Figure 5.3) is highest in the Mekong delta in Vietnam followed by Cambodia and Laos, and lowest in the Central Highlands. Though rice yield is among the lowest in the northeast Thailand, per capita production is comparatively higher, next to the Mekong Delta of Vietnam. This is due to higher per capita rice cultivated area than that of Laos and Cambodia. Productivity per capita is increasing rapidly in the Mekong delta, as is overall production. Production of rice per capita is the lowest in the Central Highlands of Vietnam though the yield is much higher. This is because of less per capita land available for rice cultivation. Agriculture in Central Highlands is dominated by the upland crops.

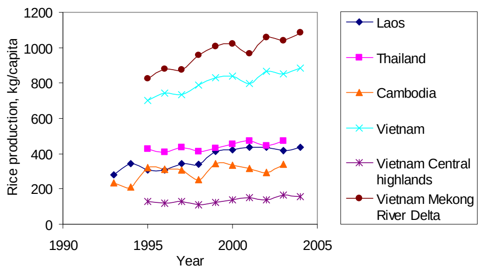


Figure 5.3 Production of rice per capita

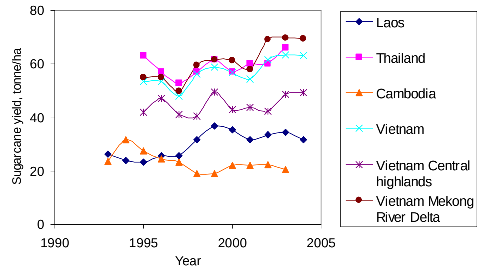


Figure 5.4 Regional average yield of sugarcane

The spatial variation of yield among the provinces within a country was not very high. Table 5.1 shows the coefficient of variation (CV) of yield of rice. The variation was the highest in Cambodia and Thailand and the lowest in the Mekong Delta. There is a slightly decreasing trend of CV over the years.

In contrast to rice, the productivity of sugarcane is high in Thailand, presumably reflecting the use of greater inputs for a crop grown commercially (as opposed to for subsistence) (Figure 5.4). This suggests that, in Thailand at least, better crop management with greater inputs can lead to higher yields. The highest productivity of sugarcane is in the Delta region of Vietnam. Much less was grown elsewhere, and we presume that the larger, more commercially grown crops of those two regions led to better management and higher yields. Yield of cassava and maize are also higher in Thailand and Vietnam and lower in Laos and Cambodia. There is a trend for the yield for cassava and maize to increase. For other crops, yield fluctuates from year to year but with no clear trend of increasing yields (Mainuddin et al., 2008).

Table 5.1 Spatial (among the provinces) coefficient of variation (CV) of average rice yield

Region	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Laos	0.18	0.21	0.20	0.19	0.17	0.19	0.17	0.18	0.19	0.18	0.15	0.14
Thailand			0.24	0.20	0.19	0.19	0.21	0.18	0.20	0.18	0.16	
Cambodia	0.41	0.48	0.39	0.42	0.41	0.40	0.42	0.29	0.27	0.29	0.24	
Vietnam			0.24	0.21	0.23	0.22	0.18	0.17	0.15	0.19	0.15	0.18
Vietnam Central highlands			0.15	0.21	0.21	0.16	0.21	0.21	0.18	0.10	0.17	0.14
Vietnam Mekong River Delta			0.15	0.14	0.19	0.14	0.12	0.11	0.12	0.13	0.12	0.14

Figure 5.5 shows the GVP of rice per unit of harvested area. Like yield, GVP is also lower in Cambodia and Thailand. The sharp increase of GVP of Laos in 1997 is due to the sudden increase in the price of rice in local currency. Upland crops are often grown for cash rather than subsistence, and the gross value of production of upland crops gives an idea of income generation. Unlike yield, GVP of the upland crops per unit of harvested area is highest in Laos and lowest in Thailand (Figure 5.6) because their prices are increasing in Laos while they are either falling or remaining static in Thailand. Income or GVP from upland crops is higher (almost double) than it is from rice in all the riparian countries. The inter-provincial variation of GVP of upland crops is much higher than that of GVP of rice.

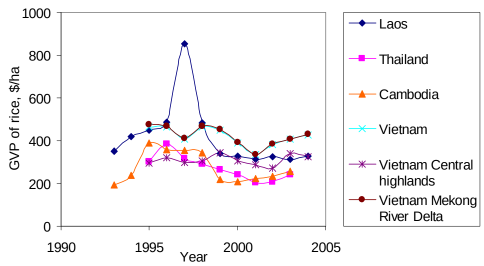


Figure 5.5 GVP of rice per unit of harvested area

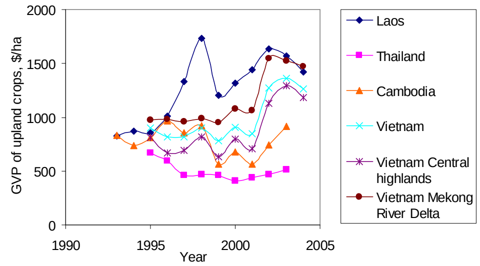


Figure 5.6 GVP of upland crops per unit of harvested area

The total GVP from crop production is dominated by the GVP from rice in all countries (Figure 5.7). Rice is the dominant crop contributing to the overall gross value of crop production in the Delta region (around 90%), Cambodia and Thailand, whereas other crops are more important contributors in Laos (60%), the Vietnam Central Highlands (90%). The contribution of GVP of other crops to total GVP has gradually increased significantly in Laos and Central Highlands of Vietnam over the years resulting in less proportional contribution from rice. One main reason of this is the sharp increase in cropping intensity of the upland crops in these two areas since 2000 (Figure 5.8). The cropping intensity of rice remains more or less static with slight increase in Laos and Cambodia (Figure 5.9). This indicates that almost all the land suitable for rice cultivation are already in use. Increase in rice cropping intensity may be possible by double cropping in Thailand, Laos and Cambodia subject to the availability of the resources such as water.

Figure 5.10 shows the standardized gross value of crop production (rice and upland crops) per capita. SGVP of crops per capita was highest in the Mekong Delta and was lowest in Laos in 1995. Over the years the gap has been narrowed and becomes almost equal in 2004. This is because of sharp increase in price and production of upland crops in Laos.

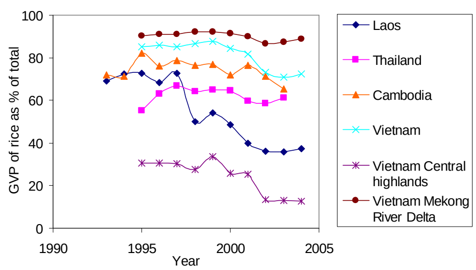


Figure 5.7 GVP of rice as percentage of total crop production

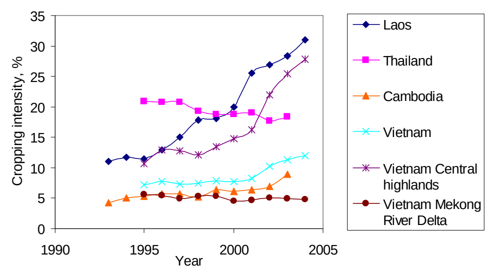


Figure 5.8 Cropping intensity of upland crops

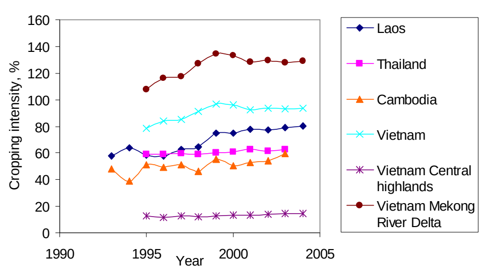


Figure 5.9 Cropping intensity of rice

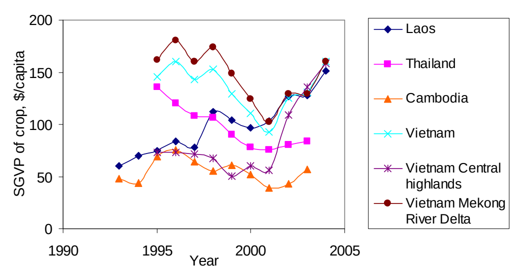


Figure 5.10 SGVP of all crops per capita

5.4.2 Water productivity (WP_{ET})

Figure 5.11 shows the spatial and temporal variation of water productivity of rice based on the total production in a year which follows the pattern similar to that of yield. The productivity has increased greatly in Laos (59%) which is much higher than the increase in the Mekong River Delta (26%) over the same period, 1995 to 2004. The total production of rice is dominated by the production of rainfed rice in Laos, Thailand and Cambodia. In the Mekong Delta, however, the production of irrigated rice (winter rice) is almost equally important to that of the rice grown in rainfed condition (autumn rice). However, the productivity of rainfed rice is similar to that of the total rice production with similar trend for all countries. The spatial variation of WP_{ET} among the provinces is similar to that of yield. Like yield, WP_{ET} of sugarcane is also highest in Thailand and the lowest in Cambodia with high year to year variation (Figure 5.12). There is a trend of increasing productivity in Laos and Vietnam while decreasing in Cambodia.

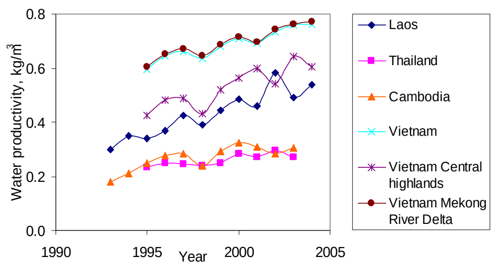


Figure 5.11 WP_{ET} of total rice production

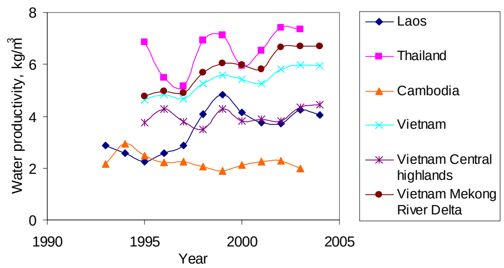


Figure 5.12 WP_{ET} of sugarcane

Economic water productivity, SGVP per unit of ET, for rice is shown in Figure 5.13. The productivity was higher in the Mekong Delta, moderate in Laos and Central Highlands of Vietnam and the lower in Thailand and Cambodia. Productivity peaked in 1996, then declined gradually until 2001, and started to rise again. This is likely to be because of the devaluation of the local currencies after the economic problems that beset the Southeast Asia region in 1997. The spatial variation of economic productivity among the provinces within the country was higher than that of physical water productivity.

Figure 5.14 shows the economic water productivity of upland crops in terms of ET. Productivity in Laos was more than twice that in Cambodia and more than 5 times that in northeast Thailand. Economic water productivity of upland crops was always higher than the economic water productivity of rice in all countries, and the difference is growing. There was sharp increase in economic water productivity of upland crops since 2001 in all countries except Thailand where it has almost remained static. Though the economic water productivity of upland crops was much higher than that of rice, the spatial variation among the provinces within a country was also very high, unlike rice.

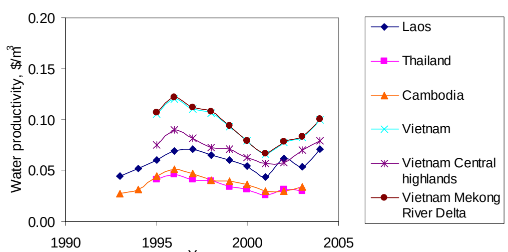


Figure 5.13 Economic water productivity of total rice production in terms of ET

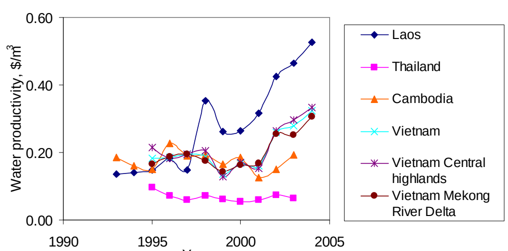


Figure 5.14 Economic water productivity of upland crops in terms of ET

Economic water productivity values of crop production (both rice and upland crops) are closer to that of rice and also follow the pattern to that of rice except for the Central

Highlands of Vietnam. This indicates the dominance of rice in overall crop production and hence on physical and economic water productivity.

5.4.3 Livestock Productivity

Like crop production, livestock production also varies regionally, with Vietnam having the lowest per capita densities of livestock (Figure 5.15). Densities per capita are the highest in Laos. Whereas per capita livestock density has increased in Vietnam, it has declined elsewhere. The increase in Vietnam is due to the increasing intensive poultry and pig farming in the area. Though the availability of livestock unit per capita is the highest in Laos, the GVP is the lowest, around 10$ per capita per year in recent years (Figure 5.16). While Thailand and Vietnam export meats, Laos supplies only into the domestic market. The price of meat is therefore very low compared to the price in Thailand and Vietnam. GVP of livestock per capita for Cambodia is also lower (slightly higher than that in Laos). GVP is increasing gradually in Thailand and Central Highlands of Vietnam since 2000 where as in other regions this remains static.

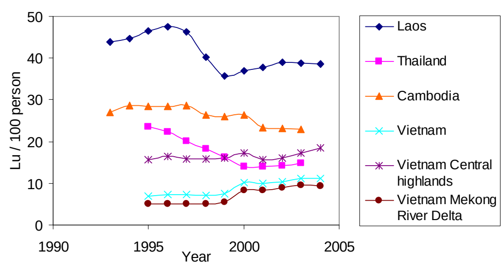


Figure 5.15 Livestock unit per 100 persons

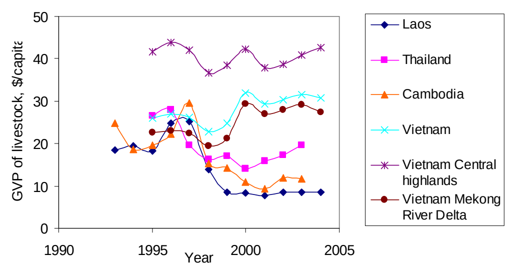


Figure 5.16 GVP of livestock per capita

5.4.4 Fisheries Productivity

Here we issue a strong caveat: national statistical data are available for fisheries production and economics in all the lower basin countries, but the data are known to be unreliable. The data for Cambodia show a sudden jump in production around 2000. This was due to a change in measurement method and is part of the evidence that many of the figures are unreliable (Coates, 2002; Hortle, 2007). Other evidence comes from fisheries experts, and has been commented on many times in the literature (see Mainuddin et al. 2009)

However, the national statistical data do show that fisheries production has grown strongly in recent years in Vietnam, based almost entirely on the Delta (fish production is limited in the Central Highlands). The growth is in aquaculture, which is both of shrimp and fish production.

Consumption based estimates yield much larger values than those of the catch based national statistics estimates, and are generally regarded as much more reliable. However, they are generally available only for 2000, and give us little idea of trends. For Laos the estimate is around 42 kg/person/year, which in turn gives an estimate of the total fish production of around 183,000 tonnes/year in (Hortle and Bush 2003, Van Zalinge et al. 2003). The gross value of production implied by the estimate is perhaps of the order $200 million per year. Van Zalinge et al. (2003) reported that among the four riparian countries, Thailand had the highest capture fisheries production, estimated at 932,300 tonnes, based on per capita consumption as 52.7 kg. Mahasarakarm (2007) reported that annual consumption of fish and fish products in the Mekong Basin of Thailand amounts to 30-35 kg/capita, equating to an estimated total consumption of inland fish of 795,000 tonnes. At a conservative first sale price, of about $1/kg, the freshwater fisheries (both capture fisheries and aquaculture) of the Mekong in Thailand are worth about $700 million per year (Mahasarakarm 2007).

Production and GVP per capita for Cambodia was estimated by Van Zalinge et al. (2003) based on consumption survey in 2000, as 719000 tons (65 kg/capita) with total GVP of 680 million dollars (61 $/capita). Production is dominated by capture fisheries.

Among the four riparian countries, Vietnam has the highest per capita production and GVP. Aquaculture is highly well developed and unlike Cambodia the production is significantly higher than capture inland fisheries production. Aquaculture production was 71% of the total in 1995; in 2004 this was 91%. Inland fisheries production appears to have remained static over the years, though this observation is based on the national statistics and may be unreliable. The Central Highlands produce only around 1% of the total fisheries production.

Being located along the coastline, the Mekong Delta of Vietnam has an additional source of fisheries; that is marine fisheries. The Mekong Delta is one of the major sources of marine fisheries in Vietnam. In 1995, it was the most important part of the fishery, but by 2005 marine production had been superseded by that of the rapidly growing aquaculture sector.

Finally, while there is known uncertainty in the national statistics, the alternative and better estimates are generally available only for one year (2000), and many of the underlying methods and data are hidden in the grey literature. There is a crucial need for more and better documented studies of fisheries production and consumption.

5.4.5 Relative contribution of different sectors

Figure 5.17 shows the comparison of GVP for crop, livestock and fisheries sector. The overall production is dominated by the crop production in Laos, Thailand and Cambodia. In Vietnam, due to rapid increase in aquaculture production, the contribution of crop sector to overall production is decreasing though the total production remains almost static. The value of fisheries in the Lower Mekong is, even if the unreliable lower catch-based estimates are used, at least as important as that of livestock. The consumption-based estimates lead to estimates of the value of fisheries as considerably greater than that of livestock.

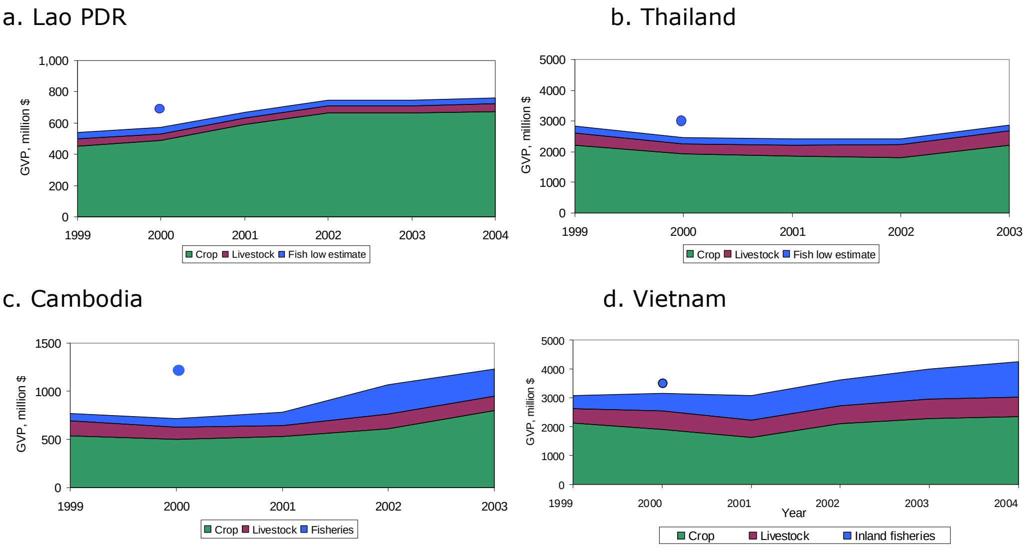


Figure 5.17 Agriculture and fisheries gross value of production in the Lower Mekong Basin. The blue point shows the high estimate of van Zalinge et al. (2003).

5.5 Analysis

5.5.1 Agricultural and water productivity

Agriculture in Laos, Cambodia, the Thai part of the lower Mekong Basin and in the provinces of Central Highlands of Vietnam are dominated by rainfed agriculture (Makara *et al.* 2001, Kono *et al.* 2001, Nesbitt *et al*. 2004, Chea *et al.* 2004). Rainfed rice is the dominant crop in Laos and Cambodia, the Central Highlands of Vietnam and the Northeast and part of North Thailand, while Irrigated rice dominates the Mekong Delta in Vietnam, with three crops a year (Nesbitt *et al.* 2004, Buu and Lang 2004). A characteristic of the rainfed lowland rice production is the large yearly fluctuations in grain production, as observed in Laos and Cambodia. Drought and flood are the major problems for rainfed lowland rice in each of the three countries, and contribute to the yearly fluctuations (Fukai, 2001). Low soil fertility is another major constraint to rice production. Because of the high variability in rainfall and therefore the high risk to production, farmers usually avoid purchasing inputs such as fertilizer. Under these low input systems, farmers grow traditional cultivars and yields are low. However, yields have increased in recent years.

The data suggest that agricultural production can be further increased in the lower Mekong, particularly in Thailand and Cambodia where the low productivity of rice may be increased with better management, and more inputs of water (in Thailand) and fertilisers (especially in Cambodia). However, where productivity is limited by environmental factors, as may be the case in the poorer soils of Thailand and Cambodia, there is a case for better land suitability assessment to replace unsuitable crops with more suitable ones. Greater crop production would also support greater animal production, to cope with the expected shift in diet towards higher animal protein consumption.

The increase in population of about 40 m to 2050 would, with apparent (including losses from field to market) rice consumption at 150 kg per person per year (cf. Minot and Goletti, 2000) require about 6 m extra tonnes of rice. For comparison, total rice production in the lower Mekong increased from about 39 to 46 m tonnes from 1995 to 2003 – a greater increase in eight years than is required in the next 40. An alternative perspective is that a yield increase across the Lower Mekong of just over 0.4 tonnes / ha (or approximately 15 % increase on the current average yield) would be required to lift production by the 6 m tonnes. For comparison, the average yield increase from 1995 to 2003 was about 0.5 tonnes / ha – again a greater increase in the last eight years than is required in the next 40. The figures, however, are those only for maintaining average food security and do not deal with export of rice (which accounts for much of the recent increases) nor distribution amongst the population.

Though the basin agriculture is dominated by rice cultivation, in recent years, cultivation of upland crops is growing in Laos and Central Highlands of Vietnam. The return from upland crops is much higher than that from rice. The results suggest that cultivation of more upland crops can significantly increase the income of the farmers which will have positive impact on reducing poverty. Therefore, in the long term a shift toward integrated, diversified agriculture with a more balanced cropping pattern throughout the year is most likely to be more profitable than the present strong dependency on wet-season rice production. Plans for related infrastructure and investments in agricultural marketing development, institutional development, and support services should therefore be a prime consideration in a planning process for the whole region (Kristensen, 2001).

A large potential for increasing production exists in irrigated agriculture, mainly through an expansion of the irrigated area (in Cambodia and Lao PDR), and through increasing the water consumption for irrigation (in Cambodia, Lao PDR, and Thailand). This, however, may affect downstream areas: the Mekong Delta is vulnerable to reduced dry season mainstream flow, accompanied by enhanced salinity intrusion from the sea (Kristensen, 2001). In the previous chapter (water availability), we have discussed in detail the likely consequences of irrigation development to produce more food for the growing population.

5.5.2 Livestock productivity

From the early 1980’s to the late 1990s, meat consumption is Southeast Asia has grown between 4 and 8 percent per year (Delgado et al. 1999). This increase was fuelled by rapid annual income growth, population growth and progressive urbanization (FAO, 2005d). It is expected that the growth would continue into the future. Therefore, it is important to increase and maintain the productivity of livestock in the region. Among the four riparian countries of the Basin, Thailand and Vietnam are net exporter of beef, pig meat and poultry. The poultry sector is growing rapidly in these two countries and important for export earnings. The growth in Thailand is in close proximity to Bangkok, not in northeast Thailand within the Basin. The productivity growth in Vietnam is remarkable in the Delta. Though livestock industry generates a lot of export earning, there is concern about environmental damage due to heavy concentration of animals in the peri-urban areas.

Livestock density per capita is highest in Laos. However, meat and milk consumption are below developing countries’ average (FAO, 2005a). Laos also does not export meat or livestock product. Live cattle and buffalo are exported to Thailand through unrecorded or unregulated border trade. A serious constraint to livestock production is the animal mortality rate due to widespread incidence of animal diseases. National Growth and Poverty Eradication Program (NGPEP) recognizes low productivity and livestock diseases as priority issues for the poor, loss of livestock as one of the main causes of poverty. The socio-economic development plan for 2001-2005 emphasizes increased livestock production and productivity as strategic poverty reduction measures (FAO, 2005a).

The livestock sector in Cambodia is dominated by small landholders. Only recently, large scale commercial businesses are entering the livestock industry (FAO, 2005c). There is a lot of scope to increase livestock productivity by reducing and eliminating selected animal diseases, promotion of better management, encouraging businesses and investment and developing community based livestock services.

5.5.3 Fisheries productivity

The population of the Lower Mekong Basin is likely to rise from the present 60 million or so to perhaps 80 million or more by 2020 and greater than 100 million by 2050. Delgado et al. (2007) suggest that fish consumption in SE Asia to 2020 will grow at between 1.4 and 1.7 % per annum, partly because of rising population and partly because of improving diets with increasing development. Sokhem and Sunada (2006) suggest that an increase of between 0.4 and 1.6 million tonnes will be required by 2050, based on a production of 3.1 m tonnes in 2003. These increases are roughly proportional to the expected increase in population, and therefore appear not to anticipate increase in fish in the diet. A growth rate of 1.4 % per annum, as suggested by Delgado et al. (2007), from the 3.1 m tonne base figure would lead to an increase of 0.8 and 2.9 million tonnes to 2020 and 2050, respectively, and a growth rate of 1.7 % per annum would lead to increases of 1.0 and 3.7 million tonnes.

There is some evidence of overfishing in the Mekong: combined with the apparent low growth of capture fisheries (albeit based on unreliable statistics), it appears reasonable to suppose that capture fisheries are unlikely to meet this demand. At the same time, there are concerns about several threats to the capture fisheries of the Lower Mekong Basin as a result of dam construction, increased diversions, and increased sediment load due to deforestation correlated with upland crops (Sverdrup-Jensen 2002). Although growth appears unlikely, capture fisheries are the greatest source of fish in the Mekong, and efforts to maintain the production, and minimise impacts from these threats, is clearly crucial.

A key issue in understanding the impacts of dams and irrigation development on fisheries production is the relationship between flow (both volume and timing – the latter is linked to spawning and migration timing) and the production of fish. While there are general understandings of the underlying biological principles, there are few quantitative studies that give relationships for the Mekong. The main study is that of the Dai fishery in the Tonle Sap river. A better understanding is required, and for more parts of the river system, so that the impact and trade-offs of development can be quantified.

There has been considerable growth in aquaculture in the Lower Mekong Basin, particularly in the delta in Vietnam. It is reasonable to suppose that further growth is likely. Rice fish farming systems also offer prospects for improved production and livelihoods, but they must be managed with considerable care as integrated systems so that rice farming and pesticide use does not affect the fish production (Frei and Becker 2005). External impacts such as river pollution from aquaculture must also be managed. Whether these systems can meet future demand is unclear.

The future development of fisheries will be constrained by the limits to capture fisheries – if overfishing is seen now, increases in the catch could endanger the stocks. However, the main factors in the future development will be primarily governed by political choices – whether capture fisheries are managed sustainably; whether dams, diversions for irrigation or other developments are allowed in a way that impacts downstream fisheries; whether aquaculture grows unchecked and is allowed to pollute or endanger other fish stocks (through provision of feed).

5.6 Key Findings

1. Yield of rice, the dominant crop, varies from 1.0 to 5.0 ton/ha with the highest yield in the Delta region of Vietnam. The yield is lowest in north-east Thailand. However, in general, yield has increased over the years, and there appears to be scope for continuing increases.

1. The current rate of increase of both production and productivity of rice is considerably greater than is required to feed the expected extra population to 2050, suggesting that producing the food may not be the main challenge. Policies and institutions for distribution, and ensuring that the development is sustainable and has low environmental impact, will presumably be the main challenges.
2. As discussed in the water availability chapter, it would appear that the water demand of required increases in agricultural production is modest relative to the total volume of water in the Mekong. In addition, the water demand of the required increases may be mitigated by the strong increases in water productivity – more crop is being grown per drop now than a decade ago. Locally, especially in the drier NE Thailand, the impact of increases in demand, and the consequent demand for irrigation water, could be greater. While the hydrological impact overall is modest, the impact on the ecology and the environment is yet to be fully understood and could be significant.
3. The productivity of sugarcane is high in Thailand, presumably reflecting the use of greater inputs for a crop grown commercially (as opposed to for subsistence). This suggests that, in Thailand at least, better crop management with greater inputs can lead to higher yields. Again, policies and institutions for production and income distribution may be the main challenges.
4. There appears to be no growth (from 1993-2003) in livestock production in Laos, Thailand and Cambodia. In fact, the livestock density in terms of population declined. Production has increased in Vietnam since 2000 due to an increase in commercial poultry and pig farming.
5. There are major uncertainties in estimates of fisheries production and value in the Lower Mekong Basin. The uncertainties over production estimates make other conclusions tentative, but it appears that production from capture fisheries increased relatively little from about 1995 to 2005 in all four Lower Mekong countries.
6. Fisheries production is dominated by capture fisheries in Cambodia (where it is concentrated around the Tonle Sap and the Mekong), Laos and Thailand. In Vietnam, aquaculture dominates production, and is concentrated around the main rivers in the delta and along the coastal strip. Aquaculture in the delta is growing strongly, whereas capture fisheries appear not to be growing.
7. The value of fisheries in the Lower Mekong is, even if the unreliable lower catch-based estimates are used, at least as important as that of livestock. The consumption-based estimates lead to estimates of the value of fisheries as considerably greater than that of livestock.
8. It appears reasonable to suppose that in coming decades capture fisheries are unlikely to meet the projected growth in demand due to rising population.
9. The Lower Mekong fisheries face threats to production from changed water availability, quality, barriers to fish migration and overfishing. If the projected increase in demand is to be met, these threats must be managed such that developments do not reduce the production of fish, especially capture fish.
10. The future development of fisheries will be primarily determined by political choices - whether capture fisheries are managed sustainably; whether dams, diversions for irrigation or other developments are allowed in a way that impacts downstream fisheries; whether aquaculture grows unchecked and is allowed to pollute or endanger other fish stocks (through provision of feed).

5.7 Tool Development

1. We have extensively used FORTRAN programs, ArcGIS and EXCEL spreadsheets to process the data collected from various sources as described before. The soil water balance simulation model is also developed in FORTRAN language. The programs and spreadsheets can be made available for use by others.

5.8 Outputs

1. Kirby, M., Mainuddin, M., (under review). Fisheries production and value in the lower Mekong River Basin: trends, threats and opportunities. Fisheries Research.
2. Mainuddin, M., Kirby, M. (2009). Spatial and temporal trend of water productivity in the lower Mekong River Basin. Agricultural Water Management, doi:10.1016/j.agwat.2009.06.013
3. Mainuddin, M., Kirby, M., (2009). Agricultural productivity in the lower Mekong Basin: trends and future prospects for food security. Food Security 1, 71-82.
4. Kirby, J. M., Mainuddin, M. (2009). Water and agricultural productivity in the lower Mekong Basin: Trends and future prospects. Water International 34 (1), 134 – 143.
5. Mainuddin, M., Kirby, M. and Chen, Y. (2009). Fisheries Productivity and its Contribution to Overall Agricultural Production in the Lower Mekong River Basin. CPWF Working Paper, Colombo, Sri Lanka.
6. Kirby, J. M. and Mainuddin, M., (2008). Water and agricultural productivity in the lower Mekong Basin: trends and future prospects. Proceedings the 13th IWRA World Water Congress on Global Changes and Water Resources, 1-4 September, Montpellier, France.
7. Kirby, J.M. and Mainuddin, M., (2008). Water management and food issues in SE Asia. Invited talk at the International Symposium on Agrometeorology and Food Security, Feb 18-21, 2008, Hyderabad, India.
8. Mainuddin, M. and Kirby, M (2008). Fisheries productivity and its Contribution to overall agricultural production in the lower Mekong River Basin. Proceedings of the International Forum on Water and Food (IFWF2) held in Addis Ababa, Ethiopia in 9-14 November 2008.
9. Mainuddin, M., Kirby, M. and Chen, Y. (2008). Spatial and Temporal Pattern of Land and Water Productivity in the Lower Mekong River Basin. Basin Approach. Basin Focal project Working Paper No. 5, CGIAR Challenge Program on Water and Food. http://www.waterandfood.org/fileadmin/CPWF_Documents/Documents/Basin_Focal_Projects/BFP_Publications/Spatial_Temporal_Pattern_Land_Water_Productivity_Mekong_BFPWP5_pgs1-21.pdf
10. Kirby, M., Mainuddin, M. 2006. Water Productivity Assessment: Mekong River Basin Approach. Basin Focal project Working Paper No. 4, CGIAR Challenge Program on Water and Food. http://www.waterandfood.org/fileadmin/CPWF_Documents/Documents/Basin_Focal_Projects/BFP_Working_Papers/MekongBasinWaterProductivityBFPwp04Draft02.pdf
11. Kirby, M., Geheb, K., Mathur, V., Chadwick, M., Mainuddin, M., Delrosa, E. and Yamamoto, Y. 2006. Mekong Basin Focal Project: Draft Phase 1 Report on Scoping of Water Productivity and Poverty Issues within the Lower Mekong Basin. Submitted to the Challenge Program on Water and Food.

5.9 Key Recommendations

1. While there are many issues of detail in maintaining the increase in agricultural production (such as research and extension into fertiliser practices), in the main it appears that the sector will meet future demand. What is required is work on policies and institutions for distribution, and ensuring that the development is sustainable and has low environmental impact.
2. A particular case of the above is the potential to increase production by irrigation development. The environmental impact of such development must be better defined, as must the trade-offs of the benefit of irrigation development with the environmental and ecological costs. Work on policy and governance is urgently required on these questions.

3. There is a crucial need for more and better documented studies of fisheries production and consumption, especially on the impacts of changed flow regimes.
4. Work on policy and governance is urgently required to manage the threats to the production of capture fisheries.
5. Work on policy and governance is urgently required to manage the current and potential increases in production of aquaculture fisheries, and to ensure that its development is sustainable.
6. The manner in which the projected increase in demand (a near doubling) to 2050 can be met should be a key focus – capture fisheries won't do it, so what policies and practices will be put in place? Is current research really considering this question, or will it simply be left to the market to solve (with likely lack of attention to pollution and other aspects of sustainability)? Work on policy and governance is urgently required on these questions.
7. A particular issue in understanding the impacts of dams and irrigation development on fisheries production is the relationship between flow (both volume and timing – the latter is linked to spawning and migration timing) and the production of fish. A better understanding is required, and for more parts of the river system, so that the impact and trade-offs of development can be quantified.
8. The impact of climate change on agricultural, livestock and fisheries productivity should be further studied.

6. INSTITUTIONAL ANALYSIS

The institutions and governance of the Mekong have been well studied. The Mekong Basin Focal Project therefore made no first-hand study on any organisation individually. Rather, we examined the literature, particularly in relation to the key concerns that we identified in Chapter 2, "Brief Description of the Mekong and Key Issues", and through the livelihood case studies identified the institutions that are perceived by the villagers as the key actors in solving the water problems in the water poor areas.

6.1 Literature

Studies of cooperation and conflict in global basins point to the Mekong as a basin with potential for conflict (Wolf et al., 2003; Yoffe et al., 2003). Stahl (2005), on the other hand, analysed conflicts and agreements in major river basins around the world, and concluded that the Mekong has a pattern of moderately positive cooperation, yet without much concrete action – though this is an analysis of past tensions, and thus is not inconsistent with predictions of Wolf et al. (2003) and Yoffe et al. (2003). Basins where rapid change (either biophysical, such as dam development, or institutional) outpaces the institutional capacity to absorb the changes are at risk of conflict (Wolf et al., 2003); the Mekong is one where the pace of change and unilateral developments suggest that there may be political tensions within the next five to ten years. (Wolf et al. note that armed conflict over water is actually quite rare.) Institutional factors are probably more important than biophysical factors. Amongst biophysical factors, water scarcity is the greatest indicator of potential conflict (Hensel et al., 2006), though Gleditsch et al. (2006) conclude that water scarcity and drought are almost unrelated to conflict.

Many studies in the Mekong conclude that water governance is narrowly concentrated, primarily in the national governments and their agencies, and that it is necessary to broaden the sharing of information, decisions and benefits. In Lebel et al. (2007), the narrow politics of water governance and the lack of democratic participation are documented for key issues in the Mekong, including irrigation development (see also Molle, 2005), floods, and hydropower expansion. Even the development and use of hydrological models and scientific knowledge more generally are explored as issues in which limited participation may lead to unequal exercise of power and outcomes that do not benefit the poor. Neither regards this as inevitable; science and models can also provide the information for alternatives and rational decisions. Dore et al. (2007) provides the most explicit call for greater engagement, through multi-stakeholder platforms.

Woods (2003) echoes these calls for greater participation, writing that "legislation must be formulated for multilateral donor institutions and regional inter-governmental institutions, and most importantly national governments, to allow civil society to penetrate into the transnational environmental decision-making process." Hirsch et al (2006) also recommend a strengthening of local stakeholder engagement and a move to more stringent laws and rules governing the management of the Mekong. However, unlike Woods, their call for new laws is not simply to permit civil society engagement, but to produce a system of enforceable rights and responsibilities.

Associated with the calls for greater participation, are calls for greater transparency and accountability. Badenoch (2002) calls for enhanced institutional structures for cooperation, with the environment defined more broadly than simply on water issues, since this would increase the areas of common interests. He also calls for enhanced governance practices, with increased transparency and accountability, and greater public involvement through multi-stakeholder dialogues. Lebel et al. (2004) propose "Nobody Knows Best" as a heuristic for forest management in southeast Asia. In Nobody Knows Best, all sources of knowledge and perspectives are welcomed giving, for example, poor forest dwellers with their different values and uses a voice in forest management. The principles would also apply to water management (cf Foran and Lebel, 2006, who characterise current water governance as a more limited State Knows Best perspective). The M_POWER dialogue 'Informed and Fair' recommended that information on developments should be freely available, that there should be more dialogue based and cross sectoral planning, that benefits should be shared and the disadvantaged should be compensated (Foran and Lebel, 2006).

However, Middleton and Tola (2008), citing Agrawal and Gibson (1999), point out that community participation is somewhat idealised in the development literature.

Communities, such as the Tonle Sap village studied by Middleton and Tola, comprise many actors with many agendas, internal difference and local politics. Clearance of flooded forests has arisen from the community based organisation, but the benefits have gone to the few. Furthermore, local communities cannot engage in basin-wide management, which must be taken on by larger institutions. Middleton and Tola (2008) argue for both local institutions and basin-wide management organisations.

Increased participation requires the commitment of local officials. Heyd and Neef (2006) describe how the espousal of greater openness and stakeholder inclusion in Thai water planning since the 1990s has led to little difference on the ground, partly because government officers are not disposed to devolve power.

Many papers study the roles of institutions, especially the Mekong River Agreement and the Mekong River Commission, these being the main transboundary institutions in the Mekong. The general conclusion is that they are too weak to ensure sharing of information, decisions and benefits. Hirsch et al. (2006) describe a major study into the tensions between national interest and transboundary water governance. In particular, they focus on the role of the Mekong River Commission. They describe the current legal and institutional framework as too weak both for transboundary and national governance. The Mekong River Commission is likewise too weak and uncertain in its directions and which interests its serves; in particular, it does not embrace a large diversity of stakeholders and, being captive of a smaller range of issues and influenced by the National Mekong Committees, it fails to tackle many major issues head-on. Myint (2002) noted that the Mekong is at a preventive stage of environmental issues such as water pollution. Whether the Mekong River Commission will be able to achieve stated goals is yet to be seen and will depend on how regime incorporates issues, interests and actors at transnational, national and local scales into governance process.

Rena (2005) and the International Rivers Network (2005) likewise argue that the Asia Development Bank has a narrow focus on development – essentially hydropower dam and other development in the basin. They are concerned that many environmental and community concerns are overlooked. Jusi (2006) also argues that the lack of effective governance and consultation by the Bank leads to inadequacies in decision making and project implementation. In addition, the general benefit to the Lao economy of large dams often does not trickle down to the poor immediately affected by the development.

Lebel et al., (2006) conclude that in many flood prone areas in developing nations, institutions remain weak, and institutional reform to cope with floods has largely failed. They argue for a systematic approach to diagnosing institutional capacities and identify critical gaps beforehand.

Hirsch et al. (2006) more broadly argue that many of the choices in the Mekong will ultimately be national political choices, rather than choices based on law, sustainable development principles and agreements amongst the countries of the Mekong.

Most literature focuses on water quantity, whereas water quality is also important for both human use and the environment. Few basins have the institutional capacity to deal with quality (Giordano, 2003). Most effort has concentrated on generalised international principles of water quality management, but what is required is local, basin-specific institutions and solutions.

China, regionalisation and the role of states dominate many of the discussions. China is in a position of great power, both because of its upstream location and because of its economic might, and it's planned dam developments are unchecked and largely uncriticised by the lower basin countries (Osborne, 2004). The Mekong River Commission is in a weak position to deal with this, partly because it is sponsored by the four lower riparian countries. Criticisms should be directed at the states, rather than the MRC. China shows increasing engagement but only at the level of technical cooperation and a cooperative regionalism focussed on economic growth, the benefits of which are not necessarily shared equitably (Sokhem and Sunada, 2008). The increasing regionalism of the Mekong area is primarily state led and focussed on economic development, and will not automatically lead to common prosperity.

The main downstream opposition to upstream development comes not from the national governments, which are beneficiaries of Chinese aid or access to hydropower and other forms of trade, and also may be engaged in similar forms of development often with Chinese help (Mehtonen, 2008). The main opposition comes from civil society and NGOs.

Therefore, criticism should be directed not just towards China, but to all the parties involved in the projects.

Ojendal et al. (2002) show that while in principle poor people may desire dam development and the benefits it brings, in practice the benefits go elsewhere. The only way of dealing with cross-boundary environmental impacts and damages without causing unnecessary friction, or even regional conflicts is to move towards a mutually recognised regional regime. The Mekong River Commission should facilitate information flow, encourage an increased degree of transparency with the member countries, and work to improve member countries' accountability.

Sneddon and Fox (2006) argue that the Mekong River Agreement, being an agreement amongst states, limits the debates to transboundary environmental issues, and renders less visible issues within states (they use the Pak-Mun dam as an example). The agreement also limits debates to certain actors, excluding non-state actors. Sneddon and Fox also see future conflict as likely. In Sneddon and Fox's view, movements opposed to developments (such as the anti Pak-Mun movement) and the nature of the Mekong itself offer powerful counter-narratives to the perspective implicit in the Mekong River Agreement of the Mekong as a resource amenable to development.

IWMI (2006) describe as a major weakness the mindset that accepts the dominant position of the state in policy processes. They, too, call for more dialogue which includes broad representation from civil society.

6.2 Analysis

Several key messages emerge from the literature:

- increasing tensions over water and environmental issues are likely in the Mekong;
- information, decision making and benefits are all shared unequally in the Mekong, and the poor are particularly disadvantaged in all three;
- public participation in sharing information, decision making and benefits is necessary for fairer outcomes;
- current institutions, particularly the Mekong River Agreement and the Mekong River Commission are too weak for debating and enforcing hard decisions; and,
- both greater regionalism and greater local decision making are required, both pointing to a lessening of the power of states in water governance.

In Chapter 2 (Brief Description of the Mekong and Key Issues) we noted the rising pressure on the natural resource base leading to trade offs over resources between upstream and downstream interests, urban and rural areas, upland and low-land communities, sectors (notably between fisheries and hydropower), subsistence-based livelihoods and activities oriented towards industrialisation, and civil society interests and formal resource agencies. These tensions are likely to increase with growing population, increasing development and resource use (especially hydropower and the growing demand for food). These tensions will reinforce the perceptions of institutional failures and the demands for improved governance.

As we noted in Chapter 5 (Water Productivity), capture fisheries will not meet the likely future level of demand for fish in coming decades. The future of fish productivity in the Mekong will be determined primarily by political choices (barring a dramatic ecological change, such as might be caused by severe climate change). World Bank (2006) likewise notes that the future of capture fisheries in Bangladesh will depend on effective governance, including community participation. In both the Mekong and Bangladesh, the choices include: basin-wide choices, in particular of dams (or the Farakka Barrage in the case of Bangladesh) upstream and their effect on dry season flows and the timing and extent of floods; local choices on determining the conservation of wetlands and the access to the resource.

Climate change, with the greater floods and greater saline intrusion in the delta it will likely bring, will also further strain the capacity of institutions to cope, again reinforcing perceptions of institutional failures and demands for improved governance.

Thus, we see that the short to medium term future will vary likely bring greater tensions and political conflict, greater benefits to some with loss of benefits by others. This will strengthen calls for greater public participation, with presumably more noticeable protests over key issues.

The literature points to the key developments required to create an alternative future, with lower conflict and more participation and more sharing of the benefits. We are not experts in this area, but it would seem to us that enough is known: it is time to act. Some actions are, of course, being taken, but not enough and not quickly enough.

Apart from the literature review mentioned above, an institutional analysis on the organisations that are perceived by the local communities as key actors in solving water related problems and poverty was undertaken through three livelihood case studies: Tonle Sap area in Cambodia; Si Sa Ket province in Northeast Thailand and Mekong Delta in Vietnam (SEI and FACT 2008; SEI and GMSSRC 2008; SEI and MDI 2008).

For Si Sa Ket case study in Thailand, 'card sorting' exercise was adopted. The villagers were asked to sort the card (water problem written on it) into three piles, showing which ones could be solved by national government, local authorities and the village. Table 6.1 below shows the overall results of the exercise, regardless of rank, but in relation to the level of authority respondents felt could help solve the problem.

Table 6.1 Perceptions of Level of Responsibility Solving Water Problems

Problem	Percent Reporting Problem	Percent Seeing National Govt. as responsible	Percent Seeing Local Govt. as responsible	Percent Seeing Village as responsible
Insufficient water in dry season	67	47	46	7
Have to buy drinking water	41	4	26	44
Area very dry	41	40	15	2
Sedimentation in water	38	6	21	40
Annual flood	34	34	6	4
Drinking water expensive	30	5	27	21
Unclean drinking water	25	3	12	34
Iron in water	23	10	15	10
No public water sources	23	17	17	2
No irrigation canal	22	18	14	2
Insufficient water for livestock	16	4	4	17

Villagers do not feel that they themselves could do much about the problem of annual flooding, however they believed the inverse with regard to insufficient water in the dry season, where they placed little hope in national Government and instead emphasised their own capacity to take measures as well as that of local authorities. Given the frequency at which insufficient water in the dry season was mentioned, it is interesting to note that 'lack of an irrigation canal' is virtually at the bottom on the pile, second only to insufficient water for livestock. This is a critical finding given national Government's long history of attempts to 'green Isan' through large-scale irrigation projects. Clearly these projects have failed the five villages in the current case study and villagers do not expect national Governments' track record to improve: essentially they have given up hoping that any mega-project will resolve their annual water shortages and are looking, instead, for solutions they can devise and implement themselves (SEI and GMSSRC 2008).

For the Mekong Delta case study in Vietnam (An Bien and Tra Cu districts), the agencies or actors at different administrative levels can solve the identified problems were assessed according to the importance (1= most important). Tables 6.2 and 6.3 below show the key institutions perceived to be important and influential by the worse-off group (poor and poorest) and by the better-off group (medium and rich), respectively, at Nam Chua hamlet.

As presented in the table, the three most important as well as most influential institutions in the hamlet and for the hamlet development are: district Department of Education and Training, commune Health Care Station and hamlet Government. According to the worse-off group participants, these institutions supported them a lot in matters like children's education, health problems, paper works and daily livelihood issues. State and provincial government were perceived more influential but less important to local villagers, because they are not easily reachable in times of immediate assistance. Results of the better-off group were almost similar to those of the worse-off. Community-Based Organizations at hamlet and commune level, commune People's Committee and Health Care Station were considered more important and influential. However, State and provincial Government were perceived more influential but less important. The District Department of Preventive Medicine, Department of Transportation and Department of Nature Resources and Environment, which were not mentioned by the worse-off group, were perceived as important as well as influential.

Table 6.2 Key actors in solving local problems as perceived by the worse-off group at Nam Chua hamlet, An Bien.

Actors	Importance	Influence
District Department of Education and Training	1	1
Commune Health Care Station	1	1
Hamlet Government	1	1
District Station of Agricultural Extension	2	1
Commune People's Committee	2	1
District People's Committee	2	2
State government	3	1
International NGOs	3	2
Provincial People's Committee	3	2

Table 6.3 Key actors in solving local problems as perceived by the better-off group at Nam Chua hamlet, An Bien.

Actors	Importance	Influence
Hamlet Community-Based Organizations	1	2
Commune Community-Based Organizations	1	2
Commune Health Care Station	1	2
Commune People's Committee	1	2
District Department of Agriculture and Rural Development	2	1
District Department of preventive medicine	2	1
District Department of transportation	2	1
District Station of Agricultural Extension	2	2
District Department of Nature Resources and Environment	2	2
State government	3	1
Provincial People's Committee	3	1
International Non-Governmental Organisations	3	2

Figure 6.1 illustrates the relationships among the actors in solving local problems.

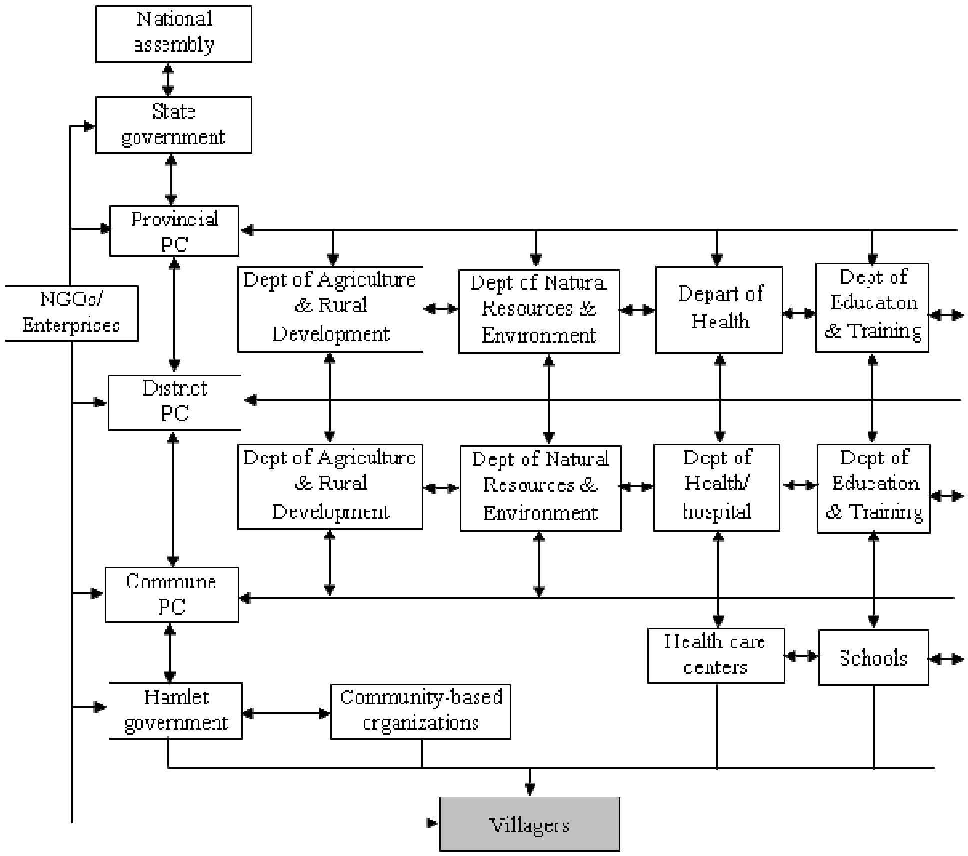


Figure 6.1 Key actors and their linkages in solving local problems in An Bien and Tra Cu districts

6.3 Key Findings

1. There is a well developed literature on institutions and governance in water issues in the Mekong.
2. Political choices will govern the future development of the Mekong – it is not primarily limited by physical constraints such as cropland productivity and water availability.
3. Virtually all studies agree that greater public participation in decision making is required, though many add that other factors are necessary for full sharing of benefits. The other factors include strengthened laws and the espousal of public participation by local officials.
4. The Mekong River Agreement and the Mekong River Commission are too weak for debating and enforcing hard decisions, and must be strengthened if they are to have a leading role in basin-wide management.
5. Key actors who can solve the local water problems as perceived by the villagers are different, depending on the nature of the problems and resources and authorities required to take the actions.
6. Communities do not consider research organisations play any role in solving their problems but rather rely on the national government, local government, NGOs or themselves.
7. The government should support: diverse, small-scale, locally-driven projects that are designed and managed by the villagers.

8. State and provincial government were perceived more influential but less important to local villagers, because they are not easily reachable in times of immediate assistance

6.4 Outputs

Apart from the brief literature review in this chapter, the Mekong Basin Focal Project has produced three case study reports where a session on analysis of key actors in solving water and livelihood problems is included.

1. SEI and FACT (2008). Household Level Investigation on Water Poverty and Livelihoods: 1. Tonle Sap Case Study. Report for the Challenge Program on Water and Food.
2. SEI and GMSSRC (2008). Household Level Investigation on Water Poverty and Livelihoods: 2. Northeast Thailand (Si Sa Ket) Case Study. Report for the Challenge Program on Water and Food.
3. SEI and MDI (2008). Household Level Investigation on Water Poverty and Livelihoods: 3. Mekong Delta Case Study. Report for the Challenge Program on Water and Food.

6.5 Key Recommendations

1. We echo the many calls in the literature for greater sharing of information, decisions and benefits. We also echo the calls for strengthening of the Mekong River Agreement and the Mekong River Commission, to a level where they provide true basin-wide rules and management.
2. There should be a clear and practical mechanism to allow the public be informed of and participate in planning and management of water and its related resources. Having the River Basin Organizations (RBOs) under the Integrated Water Resources Management (IWRM) concept undertaken by the four LMB countries' governments will be one promising option if their mandate and authority are clearly defined and the members of the RBOs well represent the groups and societies they belong, not influenced by other stronger groups. Since having the RBOs in the LMB countries is in an early stage, more studies on the current status and how to strengthen the institutional capacity of RBOs specifically for the Mekong countries should be carried out.
3. We think, however, that there should be studies on how the democratisation agenda might be accelerated. Action oriented research of the kind undertaken by Australian Research Centre for Water in Society (ARCWIS) should be undertaken more in the Mekong.
4. We also think that other information, such as that on fish and dams, should pose more starkly the difficult choices ahead. We are unaware, for example, of studies in the mainstream Mekong fish literature that point out the obvious fact that preservation of the capture fisheries (undoubtedly important as it is) appears most unlikely to sustainably feed the future populations.
5. To solve water problems and reduce the poverty, the integrated solutions and interdisciplinary participation involving the national government, local government and community-based organisations as well as villagers from planning to implementation should to be enhanced.
6. Since the state and provincial government are more influential but are not easily reachable in times of immediate assistance, the participation of local governmental sections particularly at village, commune and district levels need to be enhanced and their capacities need to be strengthened

7. ANALYSIS OF INTERVENTIONS

In the foregoing chapters we have described interventions to address issues in poverty, water availability, agricultural and fisheries productivity, and institutions. Here we describe an integrated approach to analysis of interventions, and apply it to two case studies.

7.1 Scenarios

The interventions described in this report were analyzed using a scenario-based methodology. Scenario analysis is a planning tool that is used to study the impacts of possible future trends or current policy. Scenarios take into account uncertainty about the future by presenting multiple ways in which trends or policies can unfold. The scenarios for the Mekong BFP were carried out using two quantitative frameworks, the WEAP scenario planning system and a set of water accounts. These frameworks are discussed in other chapters. A summary of the scenarios explored in each of the frameworks is summarized in Table 7.1.

Table 7.1 Scenarios explored for the Mekong Basin Focal Project

Scenario	WEAP	Water Accounts
Irrigation	✓	✓
Climate change	✓	✓
Dam Development		✓
Deforestation	✓	

The WEAP framework is designed for scenario analysis and is used to explicitly study the period 2002-2026 in four scenarios: *Reference*, *High Development*, *Climate Change*, and *Deforestation*. The first two scenarios are based on the development scenarios formulated by the MRC for its Basin Development Plan (BDP) Programme. All four scenarios are described in (Swartz et al. 2008). The water accounts framework is used in a sensitivity-analysis mode, in which current parameters are changed in ways that reflect possible future developments, as discussed in (Kirby et al, 2008e). The results from each framework are combined in a discussion of findings.

7.1.1 Population

The main driver of change in water use in the basin is population growth. Population in the Mekong countries as a whole is expected to increase by over 50% from the present to 2050, while within the basin population growth is estimated to reach a rate of close to 1.3% per year, leading to an increase of over 35% between 2002 and 2026. One direct result will be a concomitant increase in water use for domestic needs, but this increase will be much smaller than the accompanying increase in water use needed for food production. Both rainfed and irrigated crops will require water to meet evapotranspirative demand, and as demand rises across the basin local shortfalls can be expected in dry months.

7.1.2 Irrigation

In the WEAP framework, the impact of rising population on demand for food combined with growth in irrigated area in the basin changes evapotranspirative demand for water in the basin by close to 9% in the *High Development* scenario, and less in the *Reference* scenario. However, this modest change is associated with a significant increase in the degree to which water demands fall below what can be supplied. In WEAP, irrigation demand increases at an average rate of between 0.1 to 10 million cubic meters per year (mcm/year) in different sub-basins in the *Reference* scenario, and at a rate of 9 to 30 mcm/year in the *High Development* scenario. The corresponding rate of increase in unmet demand is from between 0.4 to 5 mcm/year under the *Reference* scenario and from between 1 to 10 mcm/year in the *High Development* scenario. These findings are consistent with those derived from the water accounts framework, in which the total increase in water demand from increased food demand and expanded irrigation is somewhat modest, at around 8% of the current discharge to the sea. However, local impacts on livelihoods and ecosystems could be significant, a topic that is discussed further later in this chapter.

7.1.3 Climate Change

By 2026, changes in precipitation and temperature in the basin are not expected to be substantial. Within the WEAP framework, a slight rise in precipitation as well as a slight rise in temperature leads to a very slight increase in evapotranspirative demands, with higher demand in the dry season and lower demand in the wet season. As with irrigation, this small basin-wide change masks more substantial changes at the sub-basin scale, leading to noticeable increases in unmet dry-season irrigation water demand in some basins.

The expected lengthening of the dry season and shortening of the rainy season, with increased intensity of both, was represented by adjusting monthly rainfall amounts while keeping annual rainfall fixed. Under this change, Tonle Sap lake expands more in the wet season and shrinks to a smaller volume in the dry season.

7.1.4 Dam Development

Dams upstream of the Lower Mekong Basin and in the upper reaches of the LMB attenuate seasonal variations in flows over the course of a year, leading to lower peak flows in the wet season and increased flow in the dry season. While providing opportunities for irrigation and helping to control flooding, these manipulations of flow could lead to negative impacts on the ecology, environment, and livelihoods downstream.

7.1.5 Deforestation

Substantial changes in land cover have been occurring in the Mekong basin over the last several decades as development modifies the landscape. In particular, deforestation is estimated to have occurred at a rate of 1.6% per year (FAO); areas of northern and northeastern Thailand, for example, have experienced a 50% decrease in forested area from 1980 to 2000 (Weesakul, 2005).

The *Deforestation* scenario explores the impact of deforestation on flows. The scenario employs a 1.6% year decrease in all types of forest. In this scenario, all forest is assumed to be converted to grassland. As forested land cover is replaced by grassland over the 24-year period of the scenario, relative changes in evapotranspiration and runoff are manifest basin-wide and within individual sub-basins, particularly where forested land cover is originally a dominate feature such as the Se Kong sub-basin. At the basin scale, the simulations suggest that total annualized ET flux could decrease by several percent, with larger decreases in initially forest-dominated sub-basins such as Se Kong. Relative changes in annual runoff may be even larger – on the order of 30% or more for these forest-dominated sub-basins, depending on the character of the land cover replacing forest.

The integrated effect of this land use shift can be observed in the Mekong mainstem at the Kratie stream gauge. Here, the simulation suggests that streamflow in the wet season could increase by as much as 30% by 2026 given such land cover changes. However, changes in the cyclical pattern of the Tonle Sap lake volume fluctuations are appear to be more limited, with an increase in peak volume of approximately 5% and an increase in dry season volume of less than 1%.

7.2 Analysis

In this section, some local impacts of the *Reference* and *High Development* scenarios are explored by combining WEAP outputs with Bayesian livelihood models. Two locales are studied: Northeast Thailand and Tonle Sap Lake.

7.2.1 Northeast Thailand

Field studies were carried out in five villages in Northeast Thailand as part of the Mekong Basin Focal Project. The five villages, from Si Sa Ket Province, are located within the Chi-Mun River Basin (Figure 7.1). The corresponding catchment in the WEAP scenario model is the Nam Chi 13.4 catchment.

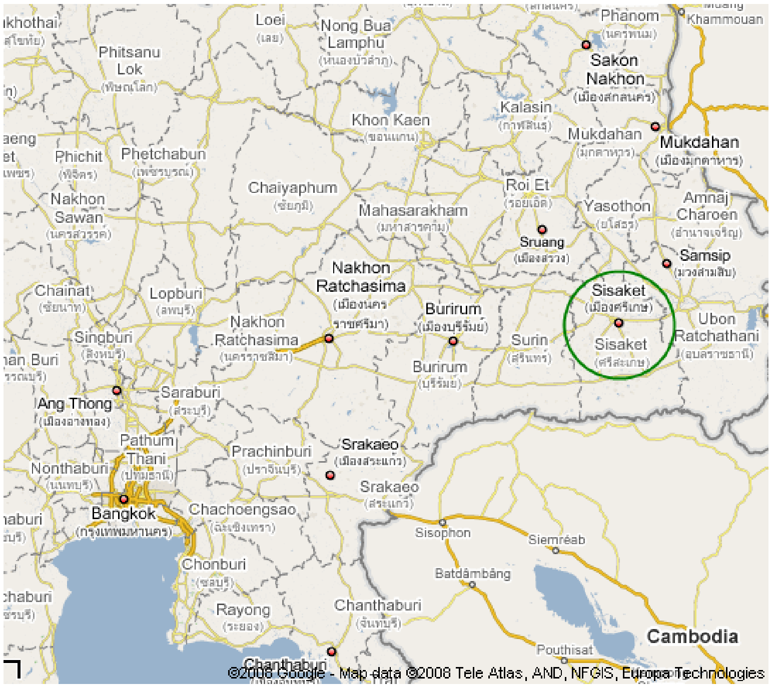


Figure 7.1 Si Sa Ket Province, Thailand

While the WEAP catchment that contains Si Sa Ket province is considerably larger than the province itself, the areas within the catchment are climatically similar to the village sites. This is indicated in Figure 7.2, which shows a map of sites generated by the Homologue program. Homologue takes evidence, in the form of climate – and, optionally, soil – variables, and assesses the degree of similarity between an initial site and other sites around the world. As can be seen from the map, a large area surrounding the case study site shares many of its characteristics.

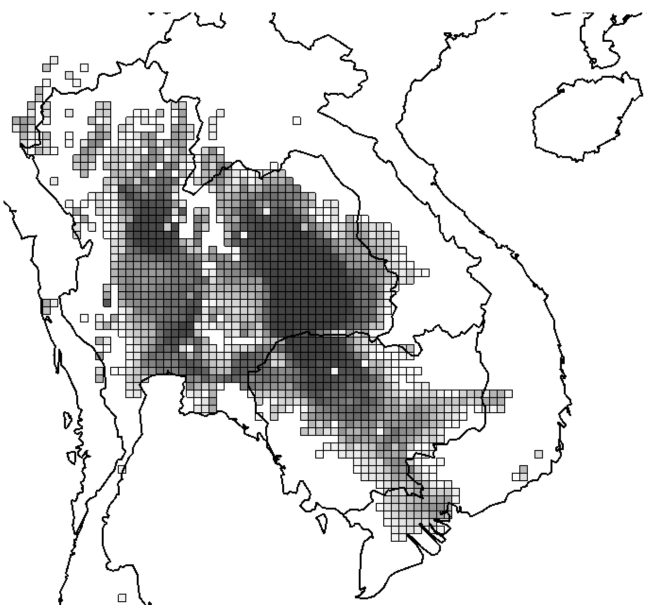


Figure 7.2 Climatic "homologues" to the village of Kean, Si Sa Ket Province, Thailand

Climatically, Northeast Thailand is relatively dry. Within the case study area, average precipitation is between 1,000 and 1,300 mm per year (SEI and GMSSRC 2008). There is a pronounced bimodal seasonal variation, and in the dry season, which occurs December through February, mean rainfall in the Nam Chi 13.4 WEAP catchment drops to less than 15 mm per month on average. This makes agriculture, which relies heavily on rainfed paddy rice production, particularly vulnerable to variations in rainfall. Between the calibration years of 1995 and 2002, actual evapotranspiration divided by potential evapotranspiration for rainfed paddy in the Nam Chi 13.4 catchment ranged from 3% to 32%, with a mean of 12%, indicating severe water stress. The distribution of paddy area under rainfed and irrigated production is shown in Figures 7.3 and 7.4. The two figures show how the distribution changes over the *Reference* and the *High Development* scenarios. The key feature of the *High Development* scenario, a strong expansion of irrigated production, is evident, but the catchment remains heavily dependent upon rainfed paddy rice production throughout both scenarios, and water stress remains a concern.

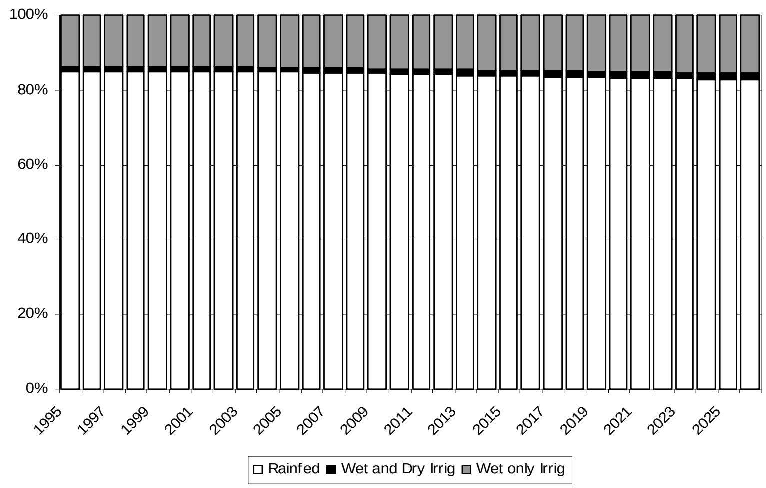


Figure 7.3 Paddy area in the Nam Chi 13.4 catchment in the *Reference* scenario

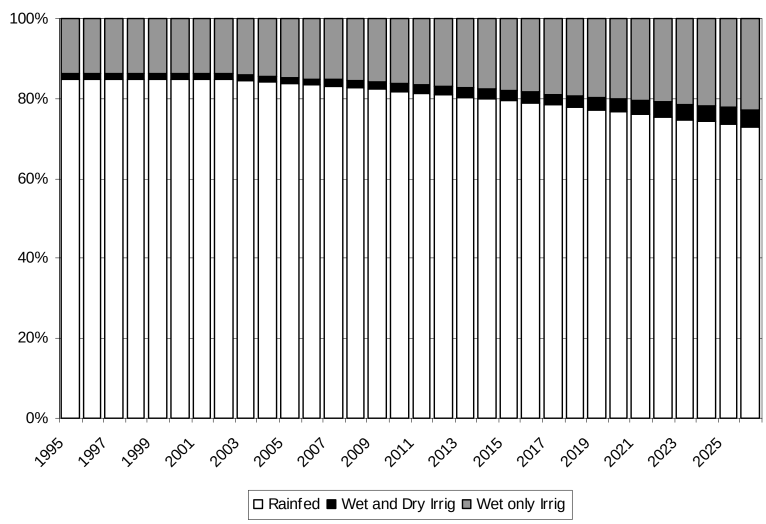


Figure 7.4 Paddy area in the Nam Chi 13.4 catchment in the *High Development* scenario

Interestingly, results from the field study indicate that the inhabitants of the five villages do not think that large-scale irrigation will be helpful for them (SEI and GMSSRC 2008). They have been ill-served by previous large-scale schemes, and think that smaller-scale interventions will be more successful at improving their livelihoods. Using techniques described in the Water Poverty Chapter, a Bayesian network model was developed based on the field study. The network model is depicted in Figure 7.5. As shown, part of the model is shown as five sub-models: Livelihood Assets, Land, Rice Production, Water Supply, and Finances. The Water Supply sub-model is shown in Figure 7.6.

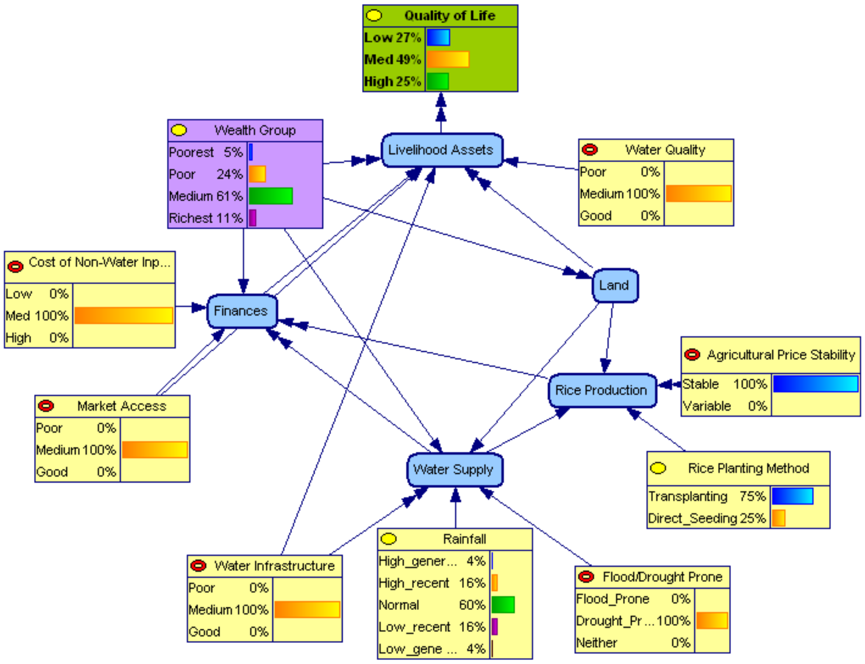


Figure 7.5 Livelihood model for the Si Sa Ket study area

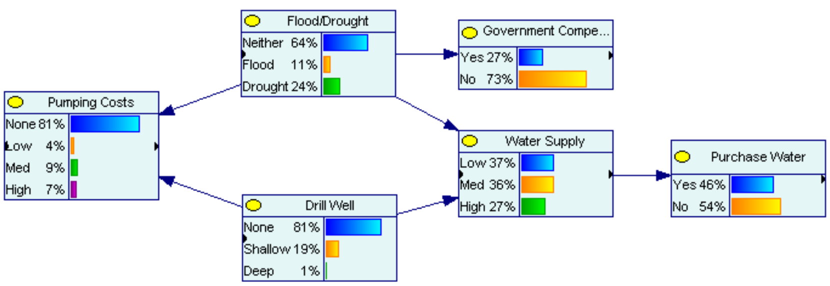


Figure 7.6 The Water Supply sub-model in the Si Sa Ket model

The model shown in Figure 7.5 was used to explore different management options at the local scale, to complement the analysis carried out at the catchment scale. Sample outputs are shown in Figure 7.7, which indicates that in this drought-prone region, under normal rainfall conditions, there is a significant chance of low rainfall at some times or for some fields. Accordingly, even in normal years there is a chance of a deficit in rice production. Not shown in Figure 7.7 is the dependence on wealth group: the chance of low rice production is nearly twice as high for the poorest households compared to the richest households, due to different opportunities for supplementing the water supply. In extremely dry years, defined as a 25-year drought (labeled "low-generational"), water supply is extremely low, and there is an 80% chance of having a low level of rice production, over twice the rate for a normal year. There is still some chance of having a high level of production due to unequal access to water supplies and, perhaps, some rainfall on a few fields, where some crops may be relatively productive. These results indicate the benefits gained from an extremely wet year are relatively small compared to the large shortages produced by dry years. This is partly due to the fact that this region is drought-prone, and therefore even a "wet" year is relatively dry - there is a small marginal benefit of increased rainfall.

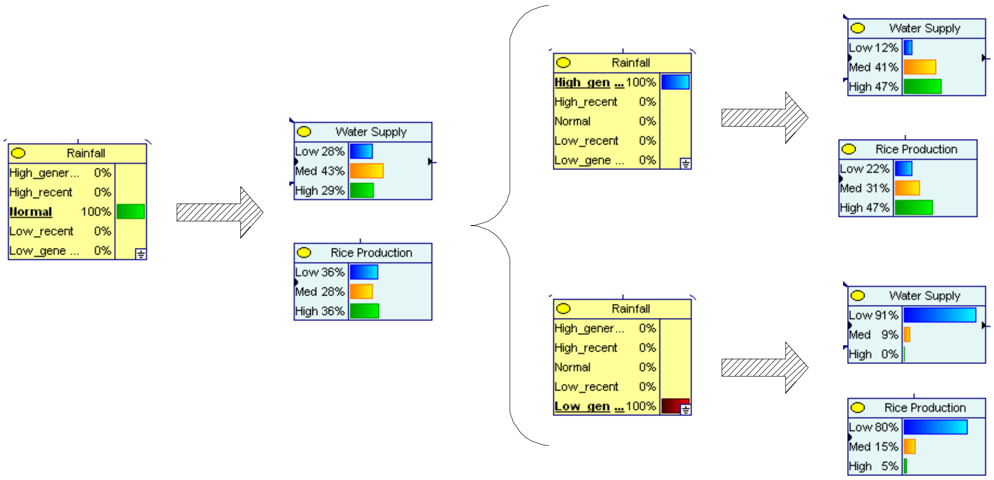


Figure 7.7 Sample outputs from running the Si Sa Ket model

Under the *Climate Change* scenario, temperature goes up slightly, increasing evapotranspiration, but precipitation also increases. The net effect in the Mun Chi 13.4 catchment is that soil moisture increases slightly. This suggests that climate change, potentially the most important factor impacting the catchment, is unlikely to negatively impact livelihoods.

7.2.2 Tonle Sap Lake, Cambodia

Tonle Sap Lake is one of the most well-studied freshwater lakes in the world. It features a flow reversal, in which different relative heights between the lake level and the Mekong river in wet and dry seasons leads to seasonal shifts in flow into and out of the lake. This is a feature seen at a smaller scale in several lakes and wetland areas throughout the Mekong basin. The area is ecologically sensitive and also supports a complex web of livelihoods which depend on the seasonal flooding of the lake. Because the lake is extremely shallow, the flooding leads to dramatic changes in the lake's surface area. A relationship between the volume and the surface area of the lake was reported in (Kite 2000). Based on that study, the following curve was input into WEAP.

Area [km^2] = 1711+202.3 $\times$ Volume [$10^9 m^3$] - 0.359 $\times$ Volume^2 [$10^9 m^3$]

This formula was then used as an input to a Bayesian livelihood model. Unlike the model for Si Sa Ket province, which was based on detailed field studies, the model for Tonle Sap Lake is a theoretical conceptual model that is based on livelihood asset accumulation and depletion. The model is shown in Figure 7.8.

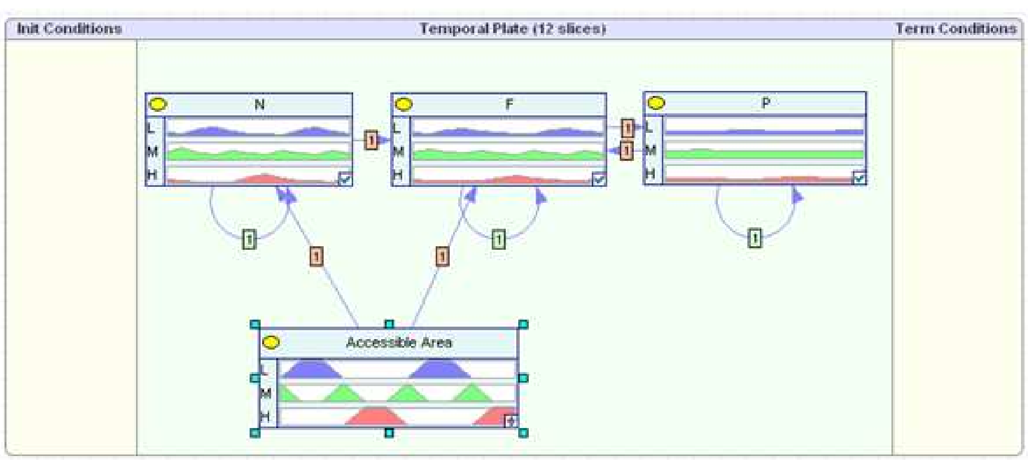


Figure 7.8 The livelihood asset accumulation model for Tonle Sap Lake

As shown in the model in Figure 7.8, the accessible area of the lake rises and falls as a result of the changing lake area. The "accessible area" is limited for small fishermen who do not have rights to fish in the center of the lake, which is wet for much of the year. Wealthier fishermen have greater access and a greater supply of physical and financial assets. The small fishermen live at the margins of the lake and do best when the lake is significantly flooded. Otherwise, their available fishing area is small and they need to use more fuel to travel to promising fishing areas. The model shown in Figure 7.8 captures some of these dynamics in a simple way. First, it is assumed that the state of the natural (N), financial (S), and physical (P) assets are in part determined by their levels in the previous time step. Second, it is assumed that the state of natural capital is influenced by the accessible area – the larger the accessible area, the more water for nature, as well as for fishing. Furthermore, physical capital, natural capital, and accessible area all affect financial capital – the quality of nets and boats, the quality of the fishing areas, and the size and accessibility of the fishing area all affect income for fishermen. Finally, physical capital is determined in part by financial capital, as financial capital is invested in physical capital.

The Bayesian network in Figure 7.8 was linked into WEAP using one of WEAP's extension features. Running the model with the Bayesian network included, for a representative year it was found (Figure 7.9) that the lake area is not very different in the *Reference* and *High Development* scenarios, although the peaks and lows seem to be shifted somewhat toward later months under *High Development*. The implication is that although increased irrigation has significant impacts in some sub-catchments with respect to evapotranspiration and water withdrawals, the net effect on Tonle Sap Lake itself is not large. Correspondingly, the impact on livelihoods is similarly modest. However, it should be noted that the life cycle of the fish in the lake depends on the seasonal flows of the river that feeds the lake. Modest changes in these flows may have significant impacts on fish. This is not taken into account in the model.

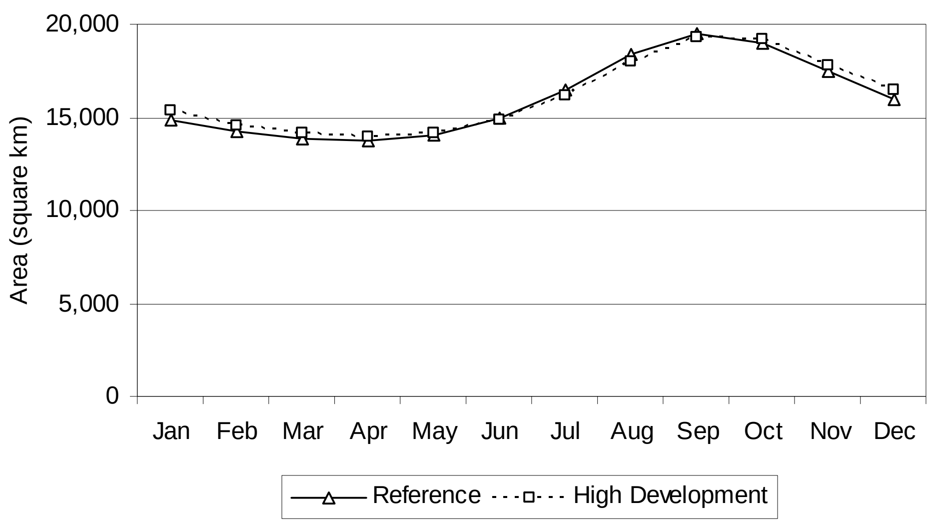


Figure 7.9 Tonle Sap Lake area in the *Reference* and *High Development* scenarios

The results in the Bayesian livelihood model are identical for the two scenarios (Figure 7.10). Within the Bayesian network model, variables take on discrete values. The two different lake levels in the two scenarios, when they are discretized, have the same value. For this reason the livelihood outcomes are the same in the two scenarios when this Bayesian livelihood model is used. The results are expressed as probability that a given fishing household will have "low", "medium", or "high" levels of financial assets. According to the model shown in Figure 7.8, those with high levels of financial assets are essentially unaffected by fluctuations in the lake level (Figure 7.10). Otherwise, financial assets decline and rise over the year as the lake level changes. In the dry period that ends in July, assets are gradually drained, but are then restored rapidly as the lake begins to flood.

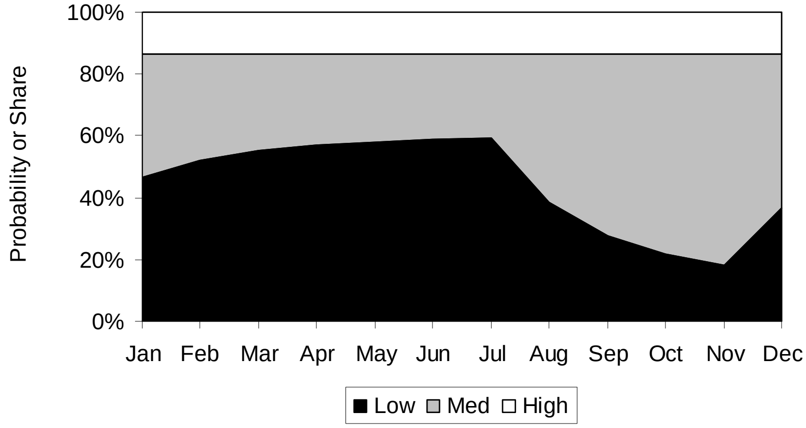


Figure 7.10 Probability that financial assets are "low", "medium", or "high" over time

7.3 Tool development

1. As mentioned in the text, a link has been created between Bayesian network models created in GeNIe and WEAP. While requiring some technical expertise, it is relatively simple to create a Bayesian model from WEAP using this tool.

7.4 Key findings

The main findings from this work are the following:

1. Individual sub-catchments can be significantly affected by changes in irrigation, deforestation, climate change, and dam development. Of these possible drivers of hydrological change, none is clearly more significant than the others. However, some are more amenable to change, and the policy decisions that affect them operate at different scales.
2. Tonle Sap Lake and similar ecosystems are more likely to be affected by subtle changes in the inflow and outflow rates into the lake, and the consequent impact on fisheries, rather than by gross changes in volume or surface area due to climate change, increased irrigation, dam development, or deforestation.

7.5 Outputs

1. Kemp-Benedict, E., Swartz, C., Krittasudthacheewa, C., de la Rosa, E. (to be prepared after a refinement of the models). 'Application of the Bayesian Belief Networks and Water Evaluation and Planning System to Explore the Livelihood Impacts of Changes in Water-Related Constraints on Livelihoods: 1. Tonle Sap case study '. A paper to be prepared for submission to academic journal.
2. Kemp-Benedict, E., Swartz, C., Krittasudthacheewa, C., de la Rosa, E. (to be prepared after a refinement of the models). 'Application of the Bayesian Belief Networks and Water Evaluation and Planning System to Explore the Livelihood Impacts of Changes in Water-Related Constraints on Livelihoods: 2. Northeast Thailand (Si Sa Ket) case study'. A paper to be prepared for submission to academic journal.

7.6 Key recommendations

The recommendations following from the main findings are the following:

1. The following activities should be pursued jointly:
    a. Preparing mitigation strategies for the common problems that can arise in hot spot areas due to changes in hydrology. These strategies should be similar for a range of drivers.

   b. Engaging in policy at the global level (for climate), the regional level (for dam development), the national level (for irrigation), and the national and local level (for deforestation). All of these issues should be the subject of regional negotiations over the shared water resource.

2. The role of the inflows and outflows in affecting fisheries in Tonle Sap and similar lakes and wetlands should be a priority area of study.

Recommendations for future research beyond the scope and timeline of the current project include:

1. Refine further the Bayesian livelihood model for the Tonle Sap lake area, where fisheries-based livelihoods predominate, to include the life cycle of fish in the lake, relationships of the lake surface area and accessible area to fishing, and incorporation of closed and open seasons for fishing.
2. Pursue research on the impact to livelihoods in hotspot areas due to dam development using scenario outputs and household level data obtained through the field case studies. For the Tonle Sap case study, the possible blocking of fish migration routes by dams should be considered in these analyses as well.
3. Since water quality is found to be a key water issue and has great impact to the livelihoods in many parts of the basin, it would be useful to further develop the WEAP model to capture the behavior (and changes) of water quality resulting from different development paths. The Bayesian livelihood models could also be modified to incorporate dependencies of both natural and financial assets on the quality of water (e.g. salinity levels of water for the Mekong Delta case study).

8. KNOWLEDGE MANAGEMENT

Here we summarise the outputs and tool development developed during the study. We also document dealings with the CWPF knowledge team and give key recommendations. We document datasets developed or gathered during the study (Table 8.1).

8.1 Outputs

1. de la Rosa, E., Chadwick, M. T. (2008). Wealth Ranking Study. Report for the Challenge Program on Water and Food.
2. Kemp-Benedict, E. (2008a). Bayesian Method for Poverty Mapping. Report for the Challenge Program on Water and Food.
3. Kemp-Benedict, E. (2008b). Report on Bayesian Network Livelihood Models. Report for the Challenge Program on Water and Food.
4. Kemp-Benedict, E. (2008c). Technical Report on New Elicitation Techniques. Report for the Challenge Program on Water and Food.
5. Kemp-Benedict, E., Chadwick, M. T., Krittasudthacheewa, C. (being prepared). 'A Combined Data-Based and Participatory Bayesian Approach to Mapping Water-Related Poverty'. A Paper being prepared for the Ecology and Society (http://www.ecologyandsociety.org/).
6. Kemp-Benedict, E., Chadwick, M. T., Krittasudthacheewa, C. (2008). 'The Bayesian Methods for Livelihood, Water and Poverty Analysis'. 2nd CPWF International Forum on Water and Food, Addis, Ababa, Ethiopia, 9-14 November 2008.
7. Krittasudthacheewa, C. (2008). Changes of Mekong's Hydrology and Their Relationship to the Fisheries Sector, invited keynote speech in the International Symposium on Sustaining Fish Biodiversity, Fisheries and Aquacultures in the Mekong, 3-5 September 2008, Ubon Ratchathani, Thailand.
8. Krittasudthacheewa, C., Kemp-Benedict, E. (2008). Expert Review of Poverty Maps Generated with the Median Value Method. Report for the Challenge Program on Water and Food.
9. Krittasudthacheewa, C., Swartz, C., Chadwick, M. T. (submitted). 'Impact of Climate Change and Hydropower Dam in the Mekong River Basin'. Abstract submitted to the International Conference on An International Perspective on Environmental and Water Resources, January 5-7 2009, Bangkok, Thailand. Organized by the Environmental & Water Resources Institute of ASCE (EWRI of ASCE) in cooperation with Asian Institute of Technology (AIT).
10. Kemp-Benedict, E., Swartz, C., Krittasudthacheewa, C., de la Rosa, E. (to be prepared after a refinement of the models). 'Application of the Bayesian Belief Networks and Water Evaluation and Planning System to Explore the Livelihood Impacts of Changes in Water-Related Constraints on Livelihoods: 1. Tonle Sap case study '. A paper to be prepared for submission to academic journal.
11. Kemp-Benedict, E., Swartz, C., Krittasudthacheewa, C., de la Rosa, E. (to be prepared after a refinement of the models). 'Application of the Bayesian Belief Networks and Water Evaluation and Planning System to Explore the Livelihood Impacts of Changes in Water-Related Constraints on Livelihoods: 2. Northeast Thailand (Si Sa Ket) case study'. A paper to be prepared for submission to academic journal.
12. Krittasudthacheewa, C. (2008). Changes of Mekong's Hydrology and Their Relationship to the Fisheries Sector, invited keynote speech in the International Symposium on Sustaining Fish Biodiversity, Fisheries and Aquacultures in the Mekong, 3-5 September 2008, Ubon Ratchathani, Thailand.
13. SEI and FACT (2008). Household Level Investigation on Water Poverty and Livelihoods: 1. Tonle Sap Case Study. Report for the Challenge Program on Water and Food.
14. SEI and GMSSRC (2008). Household Level Investigation on Water Poverty and Livelihoods: 2. Northeast Thailand (Si Sa Ket) Case Study. Report for the Challenge Program on Water and Food.

15. SEI and MDI (2008). Household Level Investigation on Water Poverty and Livelihoods: 3. Mekong Delta Case Study. Report for the Challenge Program on Water and Food.
16. Swartz, C., Krittasudthacheewa, C., Kemp-Benedict, E. (2008). Application of the Water Evaluation And Planning System in the Mekong River Basin. Report for the Challenge Program on Water and Food.
17. Kemp-Benedict, E., Swartz, C., Krittasudthacheewa, C., de la Rosa, E. (to be prepared after a refinement of the models). 'Application of the Bayesian Belief Networks and Water Evaluation and Planning System to Explore the Livelihood Impacts of Changes in Water-Related Constraints on Livelihoods: 1. Tonle Sap case study '. A paper to be prepared for submission to academic journal.
18. Kemp-Benedict, E., Swartz, C., Krittasudthacheewa, C., de la Rosa, E. (to be prepared after a refinement of the models). 'Application of the Bayesian Belief Networks and Water Evaluation and Planning System to Explore the Livelihood Impacts of Changes in Water-Related Constraints on Livelihoods: 2. Northeast Thailand (Si Sa Ket) case study'. A paper to be prepared for submission to academic journal.
19. Kirby, M., Mainuddin, M. Eastham, J. (2009). Water-use Accounts in CPWF Basins: 1. Model Concepts and Description. CPWF Working Paper, Colombo, Sri Lanka.
20. Kirby, M., Mainuddin, M., Thomas, M. and Eastham, J. (2009). Water-use Accounts in CPWF Basins: 6. Simple Water-use Accounting of the Mekong Basin. CPWF Working Paper, Colombo, Sri Lanka.
21. Kirby, M., Eastham, J., Mainuddin, M. (2009). Water-use Accounts in CPWF Basins: 12. Spreadsheet Description and Use. CPWF Working Paper, Colombo, Sri Lanka.
22. Kirby, M. and Mainuddin, M., (2008). Water management and food issues in SE Asia. Invited talk at the International Symposium on Agrometeorology and Food Security, Feb 18-21, 2008, Hyderabad, India
23. Kirby, M., Mainuddin, M., Mobin-ud-Din, A., Marchand, P., and Zhang, L. (2006a). 'Water use account spreadsheets with examples of some major river basins', in 9th International River Symposium, 4 September, 2006-7 September, 2006, Brisbane.
24. Kirby, M., Mainuddin, M., Podger, G., and Zhang, L. (2006b). 'Basin water use accounting method with application to the Mekong Basin', in Proceedings on the International Symposium on Managing Water Supply for Growing Demand, Bangkok, Thailand, 16-20 October 2006, Sethaputra, S. and Promma, K. eds, UNESCO, Jakarta.
25. Kirby, M., Mainuddin, M., (under review). Fisheries production and value in the lower Mekong River Basin: trends, threats and opportunities. Fisheries Research.
26. Mainuddin, M., Kirby, M. (2009). Spatial and temporal trend of water productivity in the lower Mekong River Basin. Agricultural Water Management, doi:10.1016/j.agwat.2009.06.013
27. Mainuddin, M., Kirby, M., (2009). Agricultural productivity in the lower Mekong Basin: trends and future prospects for food security. Food Security 1, 71-82.
28. Kirby, J. M., Mainuddin, M. (2009). Water and agricultural productivity in the lower Mekong Basin: Trends and future prospects. Water International 34 (1), 134 – 143.
29. Mainuddin, M., Kirby, M. and Chen, Y. (2009). Fisheries Productivity and its Contribution to Overall Agricultural Production in the Lower Mekong River Basin. CPWF Working Paper, Colombo, Sri Lanka.
30. Mainuddin, M. and Kirby, M (2008). Fisheries Productivity and its Contribution to Overall Agricultural Production in the Lower Mekong River Basin. Paper is prepared, currently under internal review, for submission by 30 June 2008 to the International Forum on Water and Food (IFWF2) to be held in Addis Ababa, Ethiopia in November 2008.

31. Kirby, J. M. and Mainuddin, M., (2008). Water and Agricultural Productivity in the Lower Mekong Basin: Trends and Future Prospects. Paper to be presented in the 13th IWRA World Water Congress on Global Changes and Water Resources, 1-4 September, Montpellier, France.

32. Kirby, J.M. and Mainuddin, M., (2008). Water management and food issues in SE Asia. Invited talk at the International Symposium on Agrometeorology and Food Security, Feb 18-21, 2008, Hyderabad, India.

33. Mainuddin, M., Kirby, M. and Chen, Y. (2008). Spatial and Temporal Pattern of Land and Water Productivity in the Lower Mekong River Basin. Basin Approach. Basin Focal project Working Paper No. 5, CGIAR Challenge Program on Water and Food. http://www.waterandfood.org/fileadmin/CPWF_Documents/Documents/Basin_Focal_Projects/BFP_Publications/Spatial_Temporal_Pattern_Land_Water_Productivity_Mekong_BFPWP5_pgs1-21.pdf

34. Kirby, M., Mainuddin, M. 2006. Water Productivity Assessment: Mekong River Basin Approach. Basin Focal project Working Paper No. 4, CGIAR Challenge Program on Water and Food.

35. http://www.waterandfood.org/fileadmin/CPWF_Documents/Documents/Basin_Focal_Projects/BFP_Working_Papers/MekongBasinWaterProductivityBFPwp04Draft02.pdf

36. Kirby, M., Geheb, K., Mathur, V., Chadwick, M., Mainuddin, M., Delrosa, E. and Yamamoto, Y. 2006. Mekong Basin Focal Project: Draft Phase 1 Report on Scoping of Water Productivity and Poverty Issues within the Lower Mekong Basin. Submitted to the Challenge Program on Water and Food.

8.2 Tool Development

1. Water poverty maps at a district level have been created on a basis of the poverty and water-constraint indicators to help the project experts identify the potential water poverty hotspots in which the livelihoods case studies were carried out under the Mekong BFP project framework.

   Our maps and list of initial water poverty hotspot districts in Vietnam have been used by the International Federation of Agricultural Producers (IFAP) to select the villages where the workshops with local farmers were organised to gather farmers' priorities for research on water related issues in agriculture. This is for a collaboration project with the CPWF in the Mekong river basin.

2. To investigate the link of water constraints to livelihoods especially of the poor at the household level, three sets of questionnaires and checklists of Focus Group Discussions (FGDs) specifically designed for the Tonle Sap area in Cambodia, northeast region of Thailand and Mekong Delta region of Vietnam have been developed and used as the surveyed tools in the project case studies. All questionnaires and lists will be made available in separate case study reports. Other researchers can make use of these questionnaires directly or with some adjustments if applicable.

3. Bayesian method for poverty mapping has been used in the project in parallel with the median value method to help identify the areas with high incidence of poverty and high incidence of water constraint. More detailed information can be accessed from the project background report on the Bayesian Method for Poverty Mapping.

   Our Bayesian method is considered as useful approach for water poverty mapping. It is now being applied for water poverty mapping in Volta BFP project as well.

4. Bayesian network livelihood models have been built to analyse the livelihood dynamics of the livelihood case studies around the Tonle Sap Lake area in Cambodia, Northeast region in Thailand and Mekong Delta region in Vietnam, using the field data and the Sustainable Livelihoods framework. More detailed information can be accessed through the project background report on the Bayesian Network Livelihood Models.

   There is a great potential to apply our Bayesian network livelihood approach in other BFP projects as well.

6. We have developed a spreadsheet based dynamic water use account, which is a tool to study the overall water use and flow behaviour of a river basin. The account can be used for testing the impact of climate change, landuse change, increase in irrigation area, dam development, etc.
7. We have used this account in 9 other Challenge Program Benchmark Basins (Yellow, Indus, Ganges, Karkekh, Nile, Limpopo, Volta, Niger and Sao Francisco) around the world. We have also used this account to the Murray-Darling River Basin. The Mekong account will be generally available through CPWF when fully revised.
8. A WEAP application covering the Mekong basin has also been developed to help determine the likely water-related changes and impacts of the envisaged development path in various basin-wide scenarios: (1) expansion of irrigation; (2) deforestation; and (3) climate change. The Mekong WEAP will be generally available through the CPWF when fully refined.
9. To fully activate a copy of WEAP, a valid License is required. Non-profit, governmental or academic organizations based in a developing country are eligible to request a renewable 2-year waived license. More detailed information can be found at www.weap21.org.
10. As a continued effort beyond the Mekong BFP project, SEI will expand and refine the Mekong WEAP application further, focusing on modelling water flows (quantity and quality) in the Phnom Penh area as part of a project (Water, Socioeconomic and Ecological Relations in Phnom Penh) funded internally through SEI.
11. We have extensively used FORTRAN programs, ArcGIS and EXCEL spreadsheets to process the data collected from various sources in analysing agricultural and livestock productivity and fish production. The soil water balance simulation model is also developed in FORTRAN. The programs and spreadsheets can be made available for use by others.
12. A link has been created between Bayesian network models created in GeNIe and WEAP. While requiring some technical expertise, it is relatively simple to call a Bayesian model from WEAP using this tool.

8.3 Summary of dealings with BFP central knowledge team

In 2007, the BFP team received the Mekong Basin Kit from the BFP central knowledge team.

In 2007, the BFP team discussed climate and other biophysical data requirements with the BFP central knowledge team. This led to suggestions of what data are key for biophysical modeling of the sort undertaken in BFPs, and to some testing of the climate data extraction for use in IDIS (The Integrated Database Information System, IDIS, is an on-line data sharing platform maintained by the Challenge Program on Water and Food and International Water Management Institute)

In August 2007, the BFP team sent data and metadata to the IDIS team.

In our view, however, the interactions have not been as extensive as they should have been. Most of the data we received from the central knowledge team we had already acquired directly (the CRU climate data set is one example).

8.4 Key Recommendations

1. As stated in the rationale for having the IDIS, it is true that researchers need to spend significant time and efforts in gathering, managing and analyzing data are significant. Such data is usually located in different places, stored under different file formats, organized according to varying data structures and very often not documented. To help the researcher spend less time on data management and focus more on research and data analysis, it is important for the IDIS team to enhance its data bank in collaboration with the data contributors and communicate more with the wider research communities on an existence of the IDIS.
2. For the Mekong context, there is a great opportunity for the IDIS to enhance their databank through its collaboration with other Mekong data holding organizations (e.g. MRC and ADB). MRC is one of the Mekong BFP project partners and has its

own data and information exchange and sharing policy (PDIES) being implemented under the Information and Knowledge Management Programme (IKMP). This might be a good channel for the IDIS team to start its consultation with the MRC.

3. Apart from data management, the tools developed and research products produced by all BFP projects should be managed by the BFP central knowledge team as well. It might be a case where the tools and materials developed by one project are suitable and can be applied to other BFP projects.
4. For the Mekong context, a lack of data from the upstream countries is often a limitation to a study on water related changes and impact of the basin-wide scenarios. There should be a mechanism to encourage an engagement of the researchers from the upstream countries for data and information exchange and sharing, probably through joint research projects or academic and policy fora.
5. To have a greater impact of the BFP project products on the policies for water, food and poverty, the project products and findings should be presented to the stakeholders (including the policy makers) in easy way to understand.

Table 8.1 List of data collected under the Mekong BFP project

Item	Census/Survey/ Project/Study Name	Country coverage	Description of data	Year	Scale/resolution/sample size	Source	Data sharing type
1	Seila Program 2003 Commune Database (CDB)	Cambodia	Population and housing characteristics, dependency, possession of livestocks&durable assets&crops&irrigation area, social problems&criminal, education &school facility	2003	village level, commune level, 13,877 villages, 1,621 communes	Seila Phnom Penh (data obtained through FACT)	For CPWF and IWMI researchers only
2	The General Population Census of Cambodia 1998 (This was the first census in 36 years. The last census was held in 1962)	Cambodia	(1) village names, urban/rural classification, and number of households, number of regular households, number of males, number of females and total number of persons in the village; (2) relationship to Head of Household and Marital Status for all Males and Females in the village; (3) Age in five-year age groups for all Males and Females in the village; (4) Literacy, School Attendance and Educational Attainment; (5) Household Amenities (characteristics) for all Regular (or normal) households in the village; (6) Age in single years for Males and Females Aged 5 to	1998	village level (In 1998, there are 24 provinces, 183 districts, 1,609 communes, and 13,406 villages in Cambodia). Census enumeration covered the entire inhabited geographical areas with the exception of a few areas which were inaccessible during the census due to military operations. These areas were: (i) Whole districts of Anlong Veaeng in Otdar Mean Chey province, Samlot in Bat Dambang province and Veal Veaeng in Pousat province (ii) Ou Bei Choan village of Ou Chrov district in Banteay Mean Chey province. The population in these excluded areas is estimated to be about 45,000. The refugee population, temporarily displaced to Thailand, was not included in the census as it was conducted on a de facto basis. The village databases on the CD ROM constitute 180	National Institute of Statistics of the Ministry of Planning (data obtained through FACT)	For CPWF and IWMI researchers only

			24; (7) An auxiliary database containing the names for the provinces, districts and communes in Cambodia.		districts, 1,594 communes and 13,339 villages.		
3	WFP Food Security Web Atlas	Cambodia	This Atlas contains up to date information, including the recently released Cambodia Demographic and Health Survey 2005 (preliminary results), the Cambodia Socio-economic Survey 2004 and other recent data sets. Maps are generated from these data sources at the national and provincial levels.	2003	provincial level, commune level (This Atlas concentrates on providing insights in to the food security situation of all 24 individual provinces and municipalities of Cambodia)	WFP Food Security Web Atlas (http://www.methodfinder.com/wfpatlas/index.php?page=01&lang=e)	For global public goods
4	Ministry of Agriculture Forests and Fisheries (MAFF) 2004 Crop Cut and Agricultural Statistics	Cambodia	Data related to crop, irrigation, production, agricultural land ownership,	2004	commune level, 1573 communes	MAFF Phnom Penh (through WFP Food Security Web Atlas, http://www.methodfinder.com/wfpatlas/index.php?page=09&lang=e)	For global public goods

5	Commune Level Poverty Estimates and Ground Truthing by World Food Programme & Tomoko Fuji 2003	Cambodia	poverty rate, poor people, number of female living below the poverty line, Poverty Rate (Head Count Index) of Poverty Measure for Children under 5, communes in drought prone areas, communes in flood prone areas	2003	commune level, 1594 communes	WFP Phnom Penh (through WFP Food Security Web Atlas, http://www.methodfinder.com/wfpatlas/index.php?page=09&lang=e)	For global public goods
6	Agriculture, Forestry and Fisheries Statistics in Cambodia 2005-2006	Cambodia	Rice, crop, livestock, rubber, forestry, fishery, hydrology, tractor and material	2005-2006	provincial level	Statistics Office of the Department of Planning, Statistics and International Cooperation (DPSIC) of the Ministry of Agriculture, Forestry and Fisheries (MAFF) (Data obtained through http://www.faorap-apcas.org/cambodia/index.htm)	For global public goods
7	Population and Housing Census 2005	Lao PDR	(1) Population size and composition; (2) Population distribution and migration; (3) household characteristics; (4) education and literacy; (5) Economic activity and labor force; (6) Fertility; (7) Mortality; (8) housing characteristics; (9) Population projection	2005	provincial level, village level	Committee for Planning and Cooperation, National Statistics Centre, Lao PDR, http://www.nsc.gov.la	For CPWF and IWMI researchers only

8	Lao Expenditure and Consumption Survey 2002/03 (LECS III) (The survey is the third of this type; the first was conducted in 1992/93 and the second one in 1997/98). It enumerated over 12 months starting 1st of March 2002 and ending 28th of February 2003.	Lao PDR	a wide range of subject matter areas related to the household living situation, social and economic indicators, health, education	2002/2003 (NSC plans to conduct every 5 years)	village level, household level, The LECS 3 sample was made up of 8,100 households from 540 villages, 15 households from each The sample was selected using the NSC village list as a sampling frame.	Committee for Planning and Cooperation, National Statistics Centre, Lao PDR, http://www.nsc.gov.la	For CPWF and IWMI researchers only
9	Agricultural statistical data- 30 years	Lao PDR	(1) Crop; (2) Forestry; (3) Irrigation; (4) Livestock; (5) Meteorology and meteorology	1976-2005	provincial level	Ministry of Agriculture and Forestry of Lao PDR (Data obtained through http://www.faorap-apcas.org/lao/Lao%20PDR(1976-2005%20year%20Book)	For global public goods
10	WFP District Vulnerability Analysis- 2005	Lao PDR	Malaria incidence	2002	district level	Center for Malariology, Parasitology and Entomology, Lao PDR (Data obtained through World Food Programme District Vulnerability Analysis- 2005 Update, Lao PDR, Final Draft 26 June, 2005)	For CPWF and IWMI researchers only

11	Population and Housing Census 2000 (The National Statistical Office carries out a Population and Housing Census every ten years according to international standards. Preliminary results of the 2000 Population and Housing Census were released in August 2000)	Thailand	Demographic, socioeconomic characteristics of population, as well as housing chracteristics	2000	provincial level (A stratified two-stage sampling was adopted. Bangkok Metropolis and region were constituted strata. The primary and secondary sampling units were enumeration districts and households respectively. Group of provinces in each region and Bangkok Metropolis were constituted strata. There were altogether 5 strata, i.e., Bangkok Metropolis, Central (excluding Bangkok Metropolis), North, Northeast and South. Each stratum was divided into two parts according to the type of local administration, namely municipal areas and non-municipal areas. A number of sample enumeration districts were selected systematically in each sub-stratum with a sampling fraction of 1 in 20. The total sample enumeration districts was 1,963 from 39,280 enumeration districts)	National Statistical Office of Thailand (http://web.nso.go.th/eng/index.htm)	For CPWF and IWMI researchers only

12	Agricultural Census in 2003. (The National Statistical Office conducted the Fifth Agricultural Census in 2003)	Thailand (all holdings which agricultural activity were cultivating crops, rearing livestock and culturing fresh water)	The data collected in the 2003 Agricultural Census are as follows : 1) Activity and legal status, 2) Holding area by land use, land tenure and documentary of right, 3) Livestock, 4) Rice, 5) Para rubber, 6) Permanent crop and forest (planted), 7) Field crop, 8) Vegetable crop, herb, flower and ornamental plant, 9) Fresh water culture, 10) Fertilizer and pesticide, 11) Employment on holding,12) Machinery and equipment,13) Holder household's members and activity status,14) Education and membership of agricultural activity groups,15) Income and debt for agriculture of holder's household. **Note** Item 1) - 9) are basic agricultural structure data Item 10) - 15) are other agricultural structure data	2003	Provincial level (A combination of complete and sample enumeration was applied for the 2003 Agricultural Census. In this method, the questionnaire was divided into two parts. The first part was used for collecting data on basic agricultural structure from all holdings whereas the second part was used for collecting other agricultural structure data from a 25% sample of holdings)	National Statistical Office of Thailand	For CPWF and IWMI researchers only
13	Rural Commune Development 2004	Thailand	Population, sex, age,death, living standard, employment, education, religious, health, income, expenditure, agricultural land ownership, livestock, agricultural activities, irrigation, transportation, pollution,	2004	commune level, district level (only rural areas outside the municipality)	National Statistical Office of Thailand	For CPWF and IWMI researchers only

			number of poor villages				
14	Population and Housing Census 1999	Vietnam	Population and housing characteristics (1. Type of housing, 2. Living area (square meters), 3. Type of ownership, 4. Year of using, 5. Electric lighting, 6. Main drinking water source, 7. Toilet facilities, 8. Having television, 9. Having radio)	1999	district level (a 3%-sample was used to obtain information on births and deaths. The housing information has been collected with 100-percent enumeration that is for each household of all enumeration areas throughout country. So, information of housing variable has been gathered in all the sample areas (about 5.300 enumeration areas)). 2,368,167 Individuals, 534,139 sample households	General Statistics Office of Vietnam http://www.gso.gov.vn (data obtained through NISTPASS)	For CPWF and IWMI researchers only
15	Household living standard survey (VHLSS 2004)	Vietnam	Population, living standard data, income, expenditure, possession of the durable assets	2004	commune level, household level (45,000 sample households, 9,000 households with all topics: Core and Rotated modules, and 36,000 households without Expenditure Topic (Income Sample/Households).	General Statistics Office of Vietnam http://www.gso.gov.vn (data obtained through NISTPASS)	For CPWF and IWMI researchers only
16	Agricultural Census 2001	Vietnam	Durable assets of households	2001	country level	General Statistics Office of Vietnam http://www.gso.gov.vn (data obtained through NISTPASS)	For global public goods
17	Vietnam - Poverty Distribution	Vietnam	Percent of population below poverty line, The Poverty Gap Index	2005	district level	International Food Policy Research Institute, 20051201, Vietnam - Poverty Distribution. http://gisweb.ciat.cgiar.	For global public goods

						org/povertymapping/>	
18	Social Atlas of the Lower Mekong Basin 2003	Cambodia, Lao PDR, Thailand, Vietnam	Population, labor force, living standards, health, education, environment	various data from different years	provincial level	Mekong River Commission (www.mrcmekong.org)	For CPWF and IWMI researchers only
19	Agricultural productivity	Laos, Thailand, Cambodia, Vietnam	Land use, crop area, yield, production and number of livestock	1993-2004	Provincial level	FAO Regional Office for the Asia Pacific Region http://www.faorap-apcas.org/lao/busdirectory/search_results.asp Ministry of Agriculture and Forestry of Laos http://www.maf.gov.la/Census/Land_Use/land_use.html Laotian National Statistics Centre http://www.nsc.gov.la/ Ministry of Agriculture, Forestry and Fisheries of Cambodia http://www.maff.gov.kh/statistics/index.html Ministry of Agriculture and Cooperative of the Royal Thai Government http://www.oae.go.th/English/index.htm General Statistical	For CPWF and IWMI researchers only

						Office of Vietnam http://www.gso.gov.vn/	
20	Agricultural productivity	Laos, Thailand, Cambodia, Vietnam	Price of crop and livestock, milling ratio of rice	1993-2004	country level	FAOSTAT database (http://faostat.fao.org/faostat/collections?version=ext&hasbulk=0 Thai Office of Agricultural Economics http://www.oae.go.th/English/index.htm International Rice Research Institute (IRRI) database http://www.irri.org/science/ricestat/ http://vietnamgateway.org/vanhoaxa/english/know_pub_detail.htm	For CPWF and IWMI researchers only
21	Agricultural productivity	Laos, Thailand, Cambodia, Vietnam	Currency exchange rate	1993-2004	country level	General Statistical Office of Vietnam http://www.gso.gov.vn/default_en.aspx?tabid=491 Economic and Social Commission for Asia and the Pacific of the United Nations (UNESCAP) http://www.unescap.org/stat/data/statind/datatable.aspx	For CPWF and IWMI researchers only

						http://en.wikipedia.org/wiki/List_of_historical_exchange_rates#Table http://www.jeico.com/cnc57vtn.html http://fx.sauder.ubc.ca/etc/USDpages.pdf	
22	Agricultural productivity	Laos, Thailand, Cambodia, Vietnam	Population	1993-2004	province level	Cambodian Government website http://www.cambodia.gov.kh/unisql1/egov/english/organ.admin.html FADINAP) website http://www.fadinap.org/cambodia/Agstat20002001/population.htm Ministry of Agriculture, Forestry and Fisheries of Cambodia http://www.maff.gov.kh/statistics/index.html National Statistical Office of Thailand http://web.nso.go.th/pop2000/table/tab2.pdf General Statistical Office of Vietnam http://www.gso.gov.vn/	For CPWF and IWMI researchers only
23	Agricultural productivity	Laos, Thailand, Cambodia,	Livestock information	1993-2004	country level	Livestock Sector Brief published in 2005 by the Livestock Information, Sector Analysis and Policy	For CPWF and IWMI researchers only

		Vietnam				Branch of FAO http://www.fao.org/ag/againfo/resources/en/publications/sector_briefs/	
24	Water availability and agricultural productivity	Laos, Thailand, Cambodia, Vietnam	Rainfall and maximum and minimum temperature	1951-2000	0.5 degree grid, daily point data of the stations	Climate Research Unit (CRU) of the University of East Anglia http://www.cru.uea.ac.uk/cru/data/ Data Centre (NCDC) of National Oceanic and Atmospheric Administration (NOAA) http://www.ncdc.noaa.gov IWMI www.iwmi.org	For CPWF and IWMI researchers only
25	Fisheries productivity	Laos, Thailand, Cambodia, Vietnam	Production of fish, consumption	2000	Country level	Mekong River Commission http://www.mrcmekong.org/programmes/fisheries.htm	For CPWF and IWMI researchers only
26	Fisheries productivity	Laos, Thailand	Production of fish, consumption	1999-2005	Country level	FAOSTAT database http://www.fao.org/figis/servlet/TabLandArea?tb_ds=Production&tb_mode=TABLE&tb_act=SELECT&tb_grp=COUNTRY	For CPWF and IWMI researchers only
27	Fisheries productivity	Cambodia	Production of fish	1999-2005	Provincial level	Statistical Yearbooks	For CPWF and IWMI researchers only

28	Fisheries productivity	Vietnam	Production of fish, fish price	1999-2005	Provincial level	General Statistical Office of Vietnam http://www.gso.gov.vn/default_en.aspx?tabid=469&idmid=3	For CPWF and IWMI researchers only
29	Fisheries productivity	Thailand	Fish price	1999-2005	Country level	Office of the Agricultural Economics of the Ministry of Agriculture and Cooperative of the Royal Thai Government http://www.oae.go.th/English/statE.htm	For CPWF and IWMI researchers only
30	Water availability	Laos, Thailand, Cambodia	Reach flow	1950-2000	Gauging station	Dataset called dss522.1, available on the internet http://dss.ucar.edu/catalogs/free.html	For CPWF and IWMI researchers only
30	Water availability	Laos, Thailand, Cambodia, vietnam	Land use	1992-93	Remote sensing grid	AVHRR dataset available from IWMI database http://dw.iwmi.org/idis_dp/home.aspx	For CPWF and IWMI researchers only

9. CONCLUSIONS

We have identified key findings for each main area of work and, in one sense, these are our conclusions. But they do not add up to an overall sense of the Mekong, its issues and what is gained from the overall research effort, other research as well as ours. Here we aim to distil the essence of our own work, and put it in the context of some main features of the overall research scene – and hence look at some gaps.

9.1 Main conclusions

Much is known about the Mekong and the main issues: the rising pressure on the natural resource base leading to trade offs over resources between upstream and downstream interests, urban and rural areas, upland and low-land communities, sectors (notably between fisheries and hydropower), subsistence-based livelihoods and activities oriented towards industrialisation, and civil society interests and formal resource agencies. These tensions are likely to increase with growing population, increasing development and resource use (especially hydropower and the growing demand for food). These tensions will reinforce the perceptions of institutional failures and the demands for improved governance.

Although there are biophysical constraints to water use and food production – especially the probable limit of capture fish production being somewhere around current production – the key factors in future development and poverty alleviation appear to have more to do with institutions. Political choices will govern the future development of the Mekong.

Poverty is reducing in the Mekong, though the benefits are not shared equally, and many rural people remain very poor. Many view development – of infrastructure, production, energy and especially hydropower – as the way to reduce poverty further. Others vehemently criticise this view for failing to share information, decisions and especially the benefits, and point to the poor that are disadvantaged and not compensated by development – especially to those disadvantaged by hydropower development.

Virtually all studies agree that greater public participation in decision making is required, though many add that other factors are necessary for full sharing of benefits. The other factors include strengthened laws and the espousal of public participation by local officials.

Within this broad picture, research has a place. It can, as we have tried to, document the issues, point out the choices and trade-offs, point out the constraints and opportunities, anticipate problems and suggest solutions. It can also be pursued in a more participatory, action oriented, problem solving approach, such as that undertaken by the Australian Research Centre for Water in Society. This approach is well suited to the calls for democratization of water governance in the Mekong.

The research landscape, however, appears to us highly fragmented. There are many research projects are there, involving how many institutions, but there is no overall sense of direction. Perhaps this doesn't matter, perhaps the research marketplace, like markets are supposed to everywhere, produces the optimum result. Perhaps, on the other hand, there are too many overlaps, such as the many hydrology models that have been developed, many of which appear not to be used, and such as what appears to be the parallel and largely disconnected efforts of Japanese sponsored research and western sponsored research. A key consideration for research in the region is whether greater gains could be made with better coordination. In this regard we are, through a project on climate change that builds on the project described here, attempting to build with other climate change researchers in the region a network of all climate change researchers with an interest in the region.

9.2 Gaps in research

Key gaps that emerge directly from our findings are:

- Developing institutions of water governance that effectively share knowledge, decisions and benefits. This is both a matter of research and of action, and the research should take place with the action, not as an independent observer of the action.
- We identified that agricultural productivity is low especially in NE Thailand and Cambodia. Sustainable management, including crop varieties, fertilisation and water management, is an area for research. Extension, marketing and other institutional factors, such as micro-finance for fertilisers, machinery etc., also require better information.

- In fisheries, the key questions are maintaining the current capture fishery yield and developing an alternative supply of approximately the same overall production by 2050 just to maintain the current level of fish in the diet – and more production if fish are to be exported. How this is to be done (other than preventing developments such as hydropower that may damage current capture fishery production) in a sustainable way (avoiding pollution from aquaculture, for example) requires much new information.
- Climate change may add further tensions – larger floods and greater seasonal water shortages are both predicted. However, the uncertainties in climate change predictions are great. More information on the likely impacts and the adaptation strategies is required.
- Poverty is reducing in the Mekong but the benefits are not shared equally. A top priority research gap in poverty, it is not to find the most cost-effective actions to reduce the poverty rate but rather to narrow down the poverty gaps of the rich of the poor. Policy-making and solutions to water-related problems need to be considered for the poor who have less resources and power of negotiations, because of large proportion of poor households whose livelihoods have not been improved or even deteriorated.
- Local authorities and community-based organisations are playing an important role in solving local water-related problems. However, the local authorities appear to face problems in integrating water poverty concerns into local specific context policies, due to limited resources and institutional capacity. For sustainable development, building capacity and resilience at community level is important and necessary. More research on adaptive strategies to water problems that can be implemented by the communities is required.
- Poor sanitation conditions especially in the Tonle Sap and the Mekong Delta. Most households do not have a toilet in house. They go to the forest or river to defecate. More research and introduction of ecological sanitation toilets, composting and organic farming is required.
- Water quality is a key water problem to the poor especially in the Tonle Sap and the Mekong Delta. To assess its current status and monitor the changes in water quality, water quality data from more monitoring stations and measurements are required.
- A less developed threat, but one that could emerge as a major issue is arsenic contaminated groundwater in parts of Cambodia and the Delta. With growing demand for fresh drinking water and also the prospect of climate change further increasing the demand through longer dry seasons, this resource is likely to be exploited much more than it currently is. The extent of the threat should be documented as a matter of urgency, and disaster averted before it happens.
- There are few estimates of use of groundwater use in the Mekong basin at a least a provincial level. In order to get an accurate estimate of overall unmet demand in any given area, both surface water availability and groundwater availability (and preference for particular uses) would be needed.
- There are few estimates at local and sub-basin level of the use of surface storages. Although these would not be input into WEAP on an individual basis, expression could be entered that describe the surface storage behaviour in aggregate (such as has been derived for the CPWF Small Reservoirs project and is done in the water use account).

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