WATER PRODUCTIVITY ASSESSMENT:
Mekong River Basin Approach

Basin Focal Project
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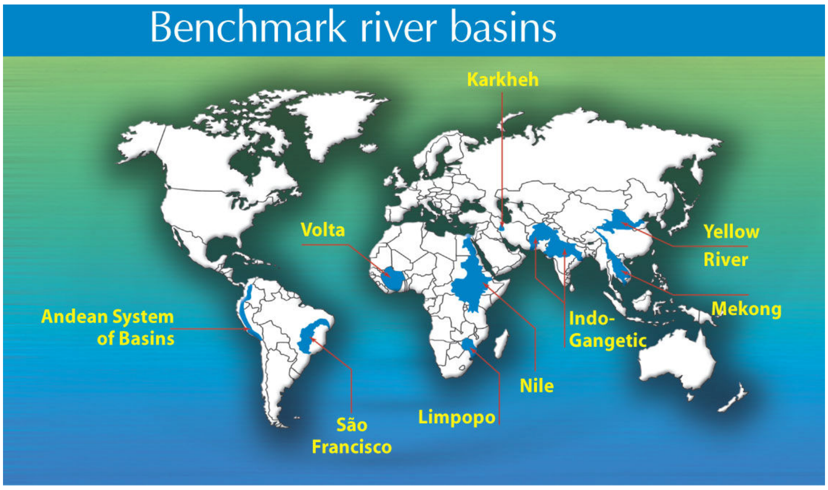
CGIAR Challenge Program on WATER & FOOD

WORKING WITH PARTNERS TO ENHANCE AGRICULTURAL WATER PRODUCTIVITY SUSTAINABLY IN BENCHMARK RIVER BASIN



DISCLAIMER

This is an advance edition of the *Water Productivity Assessment: Mekong River Basin Approach*, and is a **draft version** of a working paper to be published formally by the Challenge Program on Water and Food. This report contains less than fully polished material. Some of the works may not be properly referenced. The purpose is to disseminate the findings quickly so as to invigorate debate.

The findings, interpretations, and conclusions expressed here are those of the author(s) and do not necessarily reflect the views of the Challenge Program.

Comments and additional inputs that could contribute to improving the quality of this work are highly welcomed.

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1 INTRODUCTION

The Mekong River basin is one of the most dynamic, productive and diverse river basins in the world. It is home to approximately 65 million inhabitants, most of who 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 living in the basin many at the 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 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).

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, the assessment of the trade-offs and burden transfers these changes may lead to through analysis across multiple, spatial and temporal scales, and the integration of this understanding within adaptive governance structures is a key challenge.

This paper reviews available literature on water productivity, hydrology and scenario modeling and presents the methodology to be used in assessing water productivity in the Mekong river basin. Finally the paper concludes that by taking the Mekong river basin assessment as an example it will try to address issues and trade-offs arising naturally from the water productivity assessment.

2 LITERATURE REVIEW

2.1 WATER PRODUCTIVITY

Productivity, in general terms, is a ratio between a unit of output and a unit of input. Water productivity broadly denotes the outputs (goods and services) derived from a unit volume of water. According to Molden (1997) water productivity is the physical mass of production or the economic value of production measured against gross inflows, net inflows, depleted water, process depleted water or available water. At basin level, water productivity spans multiple uses and sectors: crop production, livestock production, tree production, fisheries production, ecosystem services, domestic, industrial, power generation, tourism and recreational. However, there is no definition that suits all situations (Barker et al. 2003). Barker et al. (2003) laid down some of the concepts and complexities in economic analysis related to increasing water productivity and show that increases in water productivity in one sector might reduce the water productivity elsewhere – that is, in economic jargon, there are significant externalities.

‘Water Productivity in Agriculture: Limits and Opportunities for Improvement’ edited by Kijne et al. (2003) gives a state of the art review of the limits and opportunities for improving water productivity in crop production focusing on both irrigated and rain-fed agriculture. It demonstrates how efficiency of water use can be enhanced to maximize yields. Molden et al. (2001) provide a comprehensive list of alternatives for increasing water productivity. These are changing crop varieties, crop substitution, deficit, supplemental and precision irrigation, improved water management, and improving non-water inputs. Molden et al. (2003) further illustrate how these can be applied at the crop, farm, system and basin levels.

Nesbitt (2005) provides a review on water used for agriculture in the Lower Mekong Basin as part of the process of establishing a framework conducive to investment and sustainable development. Agriculture is by far the most important activity in the Lower Mekong Basin, which is dominated by rice cultivation. Rainfed rice dominates farming in Laos, central highlands of Vietnam, north-east and part of north Thailand and Cambodia, while fully or partially irrigated rice is grown year round in parts of the Mekong Delta of Vietnam (Nesbitt et al. 2004). Yield of rice varies greatly with rice yields ranging from 1.55 tonnes/ha in upland Lao PDR to 5 tonnes/ha in the Vietnam Delta. The constraints to rice production in Lao PDR, Cambodia and north-east Thailand are poor soil fertility and physical conditions, highly seasonal pattern of rainfall, lack of access to inputs and credit, and lack of improved varieties and supplementary irrigation facilities, etc. (Chea et al. 2004, Nesbitt et al. 2004).

Production functions, which link yield of crop with the factors of production, are important in analysing the potential yield of the crop under a given climatic condition. The production function of rice and other crops can be developed with the available information albeit with the varying degrees of uncertainty.

Fishing is important for the basin economics and productivity analysis, particularly for Cambodia and Vietnam. In Lao PDR, fish is second only to rice for food security and income (Nguyen-Khoa et al., 2005). Standard functional forms are not available in the literature for the evaluation of the relationship water flows and the value of fish production. Ringler (2001) treated fish production as an increasing function of water availability up to a doubling of pre-defined normal flow. Profit from fish production is calculated as a function of fish price and production cost, and water availability in the Tonle Sap Lake and on the mainstream at fisheries demand sites.

Turral et al. (2005) reviewed water productivity for the basin focal projects, describing why it should be used, and means of estimating it. They focused primarily on agricultural water productivity, and mentioned fisheries and forestry in passing.

2.2 HYDROLOGY

The hydrology of the Mekong River is well documented. The Overview of the Hydrology of the Mekong Basin (MRC, 2005) report uncovers and describes the key patterns and features of the Mekong Basin Hydrology and synthesises the results in a way that provides some basic insights into the regime of this fascinating river.

Numerous mathematical models have been proposed and applied in the Mekong Basin. Takeuchi et al. (2000) used a distributed rainfall runoff simulation model BTOPMC (Block-wise use of modified TOPMODEL with Muskingum-Cunge method) for simulating the Mekong River using a digital elevation model and satellite observations. The model was applied to the part of the basin and the preliminary results indicated the use of the model as an aid for analysing and planning basin-wide comprehensive water resources management. Herath and Young (2000) also used a distributed hydrological model to the upper central part of the Basin as an initial study on distributed hydrological simulation in Mekong river basin.

Kite (2001) used the semi-distributed land-use runoff process (SLURP) hydrological model to simulate the complete hydrological cycle of the Mekong and its tributaries. The model was verified by comparing simulated flow with the recorded daily flows for the Mekong River and by comparing simulated levels of the Tonle Sap Lake with recorded daily levels. The daily computed levels of the Tonle Sap Lake were then converted into flooded areas for each land cover around the lake which were then used in a fish production model to evaluate the possible impacts of basin development on fisheries.

Fujii et al. (2003) assessed the hydrological role of the Cambodian Floodplain of the Mekong River using MIKE 11, a generalized one-dimensional model system for river and estuaries. The model was able to reproduce the main mechanisms of the river flows, as well as the floodplain inundation and drainage in the Lower Mekong Basin and floodplain system of southern Cambodia.

Ringler (2001) developed an aggregate economic-hydrologic model for the Mekong River Basin that allows for the analysis of water allocation and use under alternative policy scenarios. Multi-country and inter-sectoral analyses of water allocation and use are carried out for the Basin to determine tradeoffs and complementarities in water usage, and strategies for the efficient allocation of water resources. An analysis of alternative water allocation mechanisms by the model shows that to achieve both equitable and large benefit from water uses across countries and sector, the ideal strategy would be to strive for optimal basin water use benefits and then to redistribute these benefits instead of water resources.

Johnston et al. (2003) developed the Resource Allocation Model (RAM) for the valuation of water resources demands in the Lower Mekong Basin. The model describes the value added by water in the Lower Mekong Basin by country, by activity and by various design and resource allocation assumptions using the planning scenarios that are currently being discussed within the MRC. The model uses the output from the simulation models in the MRC's Decision Support Framework (described further below) as hydrological input data.

Kummu et al. (2005) developed the EIA 3D Model for the Tonle Sap Lake to increase the understanding of ecosystem processes and possible basin-wide and local impacts. The integrated modelling is based on hydrodynamic model that is connected to socio-economic data through ecological links. The model has been used to analyse the impacts of upstream development on Tonle Sap Lake based on high development scenario which is one of the six basin-wide development scenarios of the Mekong River Commission. The modelling results show that the upstream developments can have significant impacts on the Tonle Sap Lake and flood plain. However, the development scenario used in the study was extreme.

All these models use data at different spatial and temporal resolution and collected from different sources. Therefore it is difficult to compare findings and approaches that could form the basis of future policies on water sharing and management. To foster research towards problem solving through shared data and methods, the MRC has developed the Decision Support Framework to assist planners to assess both the magnitude of changes brought about through natural and man-made interventions in the water resources system, as well as the impacts that these will have on the natural environment and people's livelihood (MRC, 2005).

The Decision Support Framework consists of three main parts including Knowledge Base, a package of three simulation models and a set of Impact Analysis Tools and the information can be internally transferred between each other. The Knowledge Base stores historical data, spatial data, simulation results and generated flood and salinity maps. For Simulation Models, the Soil Water Assessment Tool or SWAT has been selected as the hydrological model to generate the runoff fed into the Basin Simulation Model and Hydrodynamic Model. IQQM receives the runoff and estimates and the basin-wide water demand and hydrological regime upstream of Kratie, Cambodia. ISIS Hydrodynamic Model has been applied for the area downstream of Kratie including the Tonle Sap Lake and Delta to calculate flow and salinity concentration. A set of Time Series Impact Analysis Tools inside the package allows the users to investigate the full range of flow regime. The Decision Support Framework has been successfully used as the planning and trans-boundary analytical tool to assess various scenarios by the MRC (Jirayoot and Trung, 2005). It is also the only modelling package that has been accepted by all MRC member states (MRC, 2005).

The hydrological models described above (Takeuchi et al., 2000; Herath and Young, 2000; Kite, 2001; Fujii et al., 2003) 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. The economic-hydrologic model developed by Ringler (2001) integrates hydrology with economics, but do not deal with all aspects of the hydrology. The model deals only with average conditions and does not deal with runoff inflows. The Resource Allocation Model deals mainly with flows, with the runoff inflows were supplied by the Decision Support Framework simulation models. Thus, it cannot deal with the climate change scenarios, for example, unless the scenario is first round with the Decision Support Framework suite, and the results used as an input to the Resource Allocation Model. Though the EIA 3D model connected to socio-economic data through ecological links but it is mainly developed for the Tonle Sap Lake not for the whole Basin. The Decision Support Framework is also a suite of hydrological models which is not integrated with social and economic models. However, the output of DSF can be used by the social, economic and environmental model as has been done by Resource Allocation Model and EIA 3D models.

2.3 SCENARIOS

The hydrologic, economic and environmental models considered different scenarios based on climate, population and development options. MRC-DSF considers six scenarios in addition to a nominal baseline scenario (2000 development conditions) (MRC, 2005). These are: i) impact of climate change, ii) impact of catchment cover changes, iii) impact of high irrigation demand, iv) impact of Chinese dams, v) impact of Lower Mekong Basin dams, and vi) impact of flood embankments.

The Asian Institute of Technology (1999) considered two scenarios of population growth for studying the sustainable water management of the Mekong River Basin. For the first scenario, it was assumed that the current (1995) population growth rate continues till 2040. For the second scenario, it was assumed that the current population growth rate continues till 2000. Later successive reduction of the overall population growth rate by a factor of 25% has been taken for the periods of 2000-2020 and 2020-2040. For both of the population projection scenarios, the per capita water availability has been evaluated on the basis of the runoff contribution from the corresponding country.

Ringler (2001) tested the hydrologic-economic model by changing the different input parameters such as runoff, irrigation efficiency and irrigated area. Runoff was varied from 50-120%, irrigation efficiency from 50 to 90% and irrigated area from 75 to 175%. Two alternative water allocation scenarios were also examined. In the first scenario, the five basin water users share equally in the total basin water depletion. In the second scenario the countries share off-stream uses in proportion to their respective basin populations. Two alternative inter-basin transfer scenarios related to the Kok-Ing-Nan Water Diversion project in Thailand and water withdrawal in Northern Thailand and one development scenario (upstream hydropower development) were also considered.

Johnston and Rowcroft (personal communication) and Kummu et al. (2005) considered the basin development scenarios of the MRC.

3 WATER PRODUCTIVITY ASSESSMENT

3.1 *PREAMBLE*

Turral, Cook and Gichuki (2005) have circulated a draft report justifying why we should estimate water productivity and noting some ways of measuring it. They review some of the literature. Here, we note some differences with that report and describe our proposed methods. We do not repeat the justification or literature review.

Turral, Cook and Gichuki focus primarily on agricultural water productivity, and mention fisheries and forests in passing. We think it is necessary to extend the concept to other issues. Our list of water productivity includes: food production (rainfed and irrigated agriculture, livestock production, fisheries, etc.); health (waterborne diseases are a major factor in the Mekong, (Geheb and Gichuki, 2003); ecosystem production (the basis for the large capture fisheries in the Mekong, for example); other (ie non-food production) income generated directly from water (tourism, for example); and other income generated indirectly from water (from power generation or other urban and industrial development).

The method we propose for estimating water productivity involves: developing a water account; establishing production functions linking items in the water account to consequences or production; estimating values of consequences or production; and, identifying constraints opportunities and trade-offs in water productivity.

Data from the MRC, IWMI or freely available on the internet are generally adequate for basin scale water productivity studies in the Mekong. Kite (2001) has shown that the hydrology of the Mekong can be modelled sufficiently well for many purposes using data freely available on the Internet.

3.2 *DEVELOPING A WATER ACCOUNT*

This involves estimating how much water there is, where it goes, how much is used and by what, and its quality - in short, a water account.

A water account is based on a water balance. A water balance can be applied to any region or volume - A water balance applies to any component of the hydrological cycle from the whole of the Mekong basin, the Mekong River, the Great Lake, an aquifer, and irrigated field, a town. The volume of all the water entering a river basin (from precipitation and surface or groundwater imports), minus the volume of all the water leaving the basin (as evapotranspiration, discharge to the sea, and surface or groundwater exports) must equal the change in volume of all water stored in the basin (as surface water, water in the soil, and water in the underlying rock formations).

Rarely if ever are all components of a water balance measured, and those components that are measured are rarely known with great certainty. It is usual to combine such measurements as are available with modeling, and with the fundamental requirement that the items in the account must balance. This fundamental requirement is a strong one: for example, in every region within the basin the water entering the rivers must equal the rainfall minus (the evapotranspiration plus any changes in storage), and the flow in the rivers at any point must equal the water entering all the tributaries upstream of that point minus (evaporation plus other losses plus changes in storage). Thus a single reliable measurement of flow volumes sets a bound to all the tributary flows, runoff, and evapotranspiration in all the rivers catchment above that point.

As indicated in sections 1 (literature review) and 2 (data availability review), there are previous studies and much information in the Mekong. All the data are patchy and contain uncertainties, but combined with modelling and the requirement to balance, permit the construction of an account sufficient for the project. Rainfall data are available, providing direct spatial estimates of the major source of water entering the basin. The evapotranspiration can be estimated in (at least) three different ways: SEBAL techniques from remote sensing of vegetation productivity; modelling of vegetation water use from land use data plus crop / vegetation growth modeling; large scale rainfall / ET / runoff partitioning using methods that stem from Budyko. All three methods can be applied and used to cross check each other.

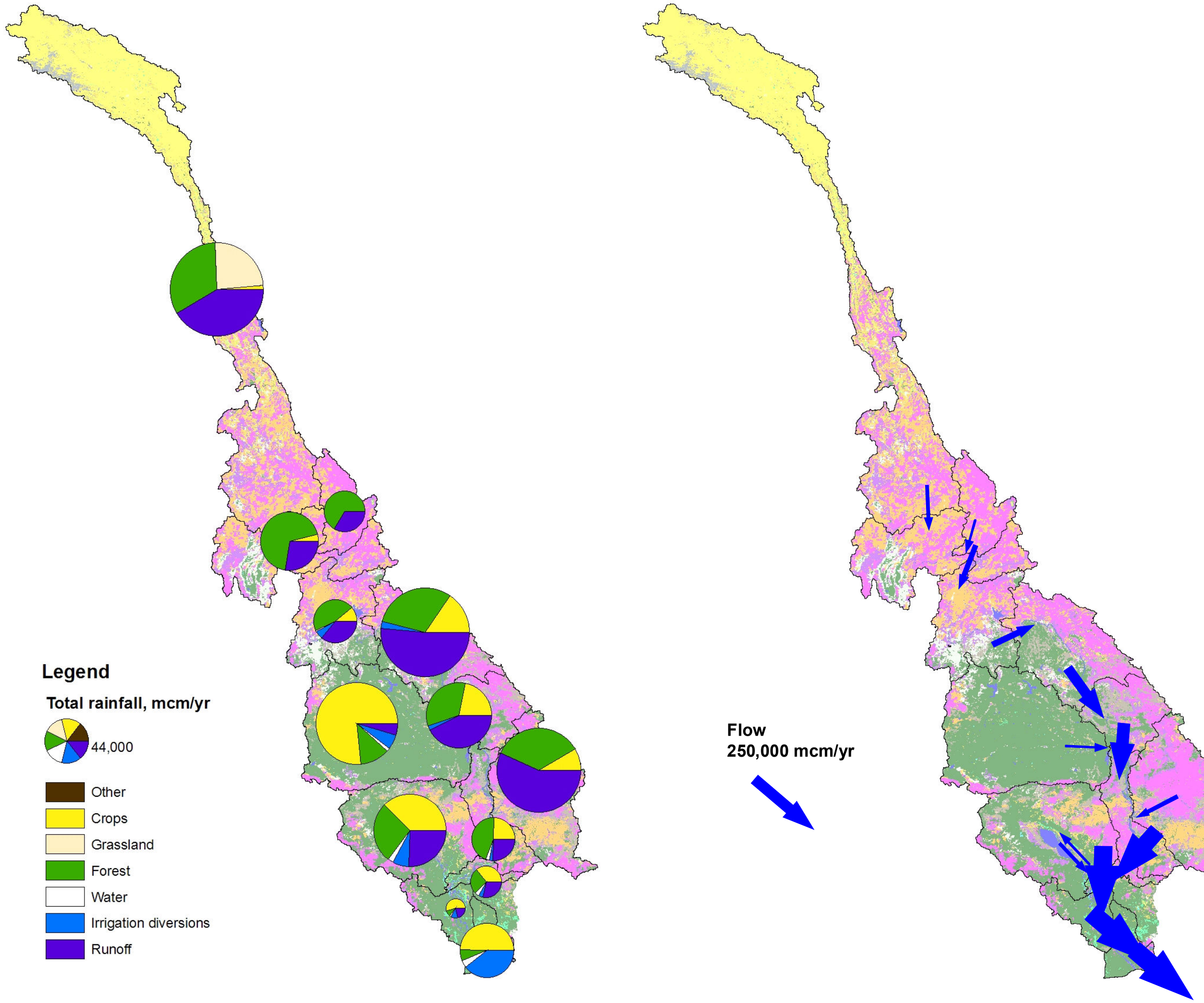

Figure 1: Schematic representation of a rough, sub-basin water account for the Mekong, based on crop / vegetation modeling (using 1 km land use data available on the Internet), rainfall / ET / runoff partitioning, and surface flow accounting. Left, annual average water use by major land uses (aggregated from 25 land use categories). Right, annual average river flows between sub-basins. The annual averages were calculated from monthly data for 1984 to 1999.

Further work is required to improve the detail and accuracy of this rough account, and to add water quality information to it. Note that, while we show the annual average water account in the figure, it is based on taking the annual average of monthly data for 1984 to 1999.

We have also started to establish the modeling / process framework for building a WEAP model of the Mekong basin. A simple, monthly time step model has been developed in Excel, and used to test model components for building into a WEAP model. The model starts with rainfall / ET / runoff partitioning in the major catchments, and builds the runoff into the flow and storage model of the Mekong, its major tributaries, and the Tonle Sap. It has been used to test how we might handle the Tonle Sap, for example. Example results are given in the figures below.

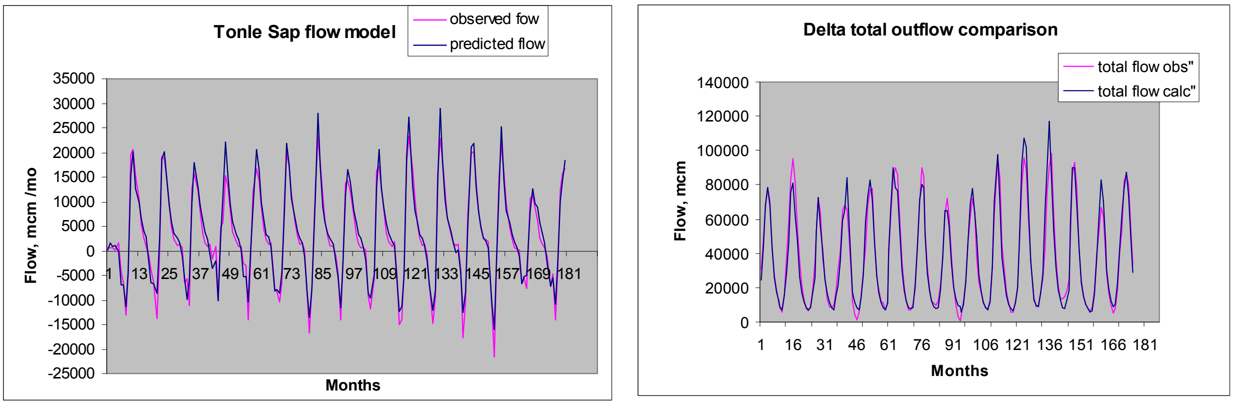

Figure 2: Example flow simulations and comparison to “observed” (SWAT / IQQM suite results)

WEAP modelling has also commenced. The year 2002 was chosen as the base year or 'Current Accounts' (CA) for the WEAP model of the Mekong in consultation with research team members, including CSIRO and MRC. In WEAP, the CA act as the baseline description for hydrologic conditions, land use, and water demand/supply relationships existing in a river basin; it is from this baseline that scenarios of possible water futures are developed and to which outcomes are compared. The year 2002 was chosen because it is a recent year in which hydrologic data are broadly available throughout the basin and for which there has been comprehensive study of the flood season hydrology in the Cambodian floodplain (Morishito et al, 2004; Fujii et al, 2003).

Representation of the floodplain hydrology will be a critical component in the use of WEAP to explore water productivity-poverty linkages. Discussions with CSIRO regarding the representation in WEAP of floodplain hydrology for the Tonle Sap in particular are ongoing. Empirical relationships developed by CSIRO (Figure 2) that describe the flow reversal of the Tonle Sap River, and the subsequent expansion of the Tonle Sap lake area, already show promise for incorporation in the WEAP application. Empirical relationships have also been developed for the rest of the basin.

3.3 PRODUCTION FUNCTIONS

A production function in economics is a function linking the production of something to its inputs (factors of production). An example of agricultural production might be

Yield = f1 (water, nitrogen, labour, capital,......)

Where f1 is a function, which might be based on the analysis of data, or on theoretical principles. Water productivity is sometimes defined as Yield / (volume of water). It should be noted that by this definition water productivity could be increased without any change to water inputs - yield could be increased by changing nitrogen application, for example. In agriculture, the yield might be tones of grain, whereas for forests and other natural areas such as wetlands the yield might be total biomass productivity – ie the net primary productivity given in **Figure 3**.

Although the terminology suggests the production of tangible items, it can also be applied to other things such as health. An example might be:

Disease X = f2 (water, nutrition, medical support, education,.......)

Information in the Mekong is sufficient to develop and use production functions (albeit with varying degrees of uncertainty) for agricultural and other food or biophysical production (such as the net primary productivity example in Section 3.1). However, it will be difficult to establish with any degree of certainty production functions describing health or poverty. Nor does this form part of the poverty and vulnerability methods. Therefore, we will restrict ourselves to production functions for food and other biophysical production.

The net primary productivity in Figure 3 and the monthly water use accounts used to generate Figure 1 can be combined to give a rough, sub-basin scale estimate of ecosystem water productivity. With further work, this could be done at the 1 km resolution of the underlying satellite and land use data.

3.4 ESTIMATING THE VALUE OF CONSEQUENCES OR PRODUCTION

The previous step results in estimates of production of many things. However, many of those things will be reckoned in unlike units. Food might be reckoned and tons of grain, for example, whereas electrical power might be reckoned in units of megawatts. In order to determine which is of greater benefit in alleviating poverty, we must have some way of comparing them.

The common method for comparing unlike factors is to value them all in a common unit of measure - a monetary unit, dollars, being the unit of choice. This is commonly done in economies such as Australia, Europe and the USA, but not without difficulty. The value of the environment (clean air, clean water, wilderness, etc) has proven particularly difficult, and is the subject of a great deal of research. The difficulties are greater in economies, such as those in the Mekong, where livelihoods are based on much that is never traded and is therefore hard to value - food, for example, is often the result of subsistence agriculture and fishing. Notwithstanding the difficulties, it is possible to develop common valuations in the Mekong: Ringler (2001) studied the net (dollar) benefits of optimal water allocation in the lower Mekong basin.

Alternatively, we might sidestep the issue. For example, it might be deemed by international agreement that the annual flow past some point in the Mekong will not be allowed to fall below a given amount. We are then relieved of the obligation of comparing values above and below that point.

In practice, the Mekong BFP will use both methods. Which we use will depend on the problem. For basin wide problems, involving optimal solutions, we will endeavour to develop common measures. For many problems, however, we will restrict our attention to a small part of the basin, and it will not be necessary to strive for common units and comparable values with other parts of the basin

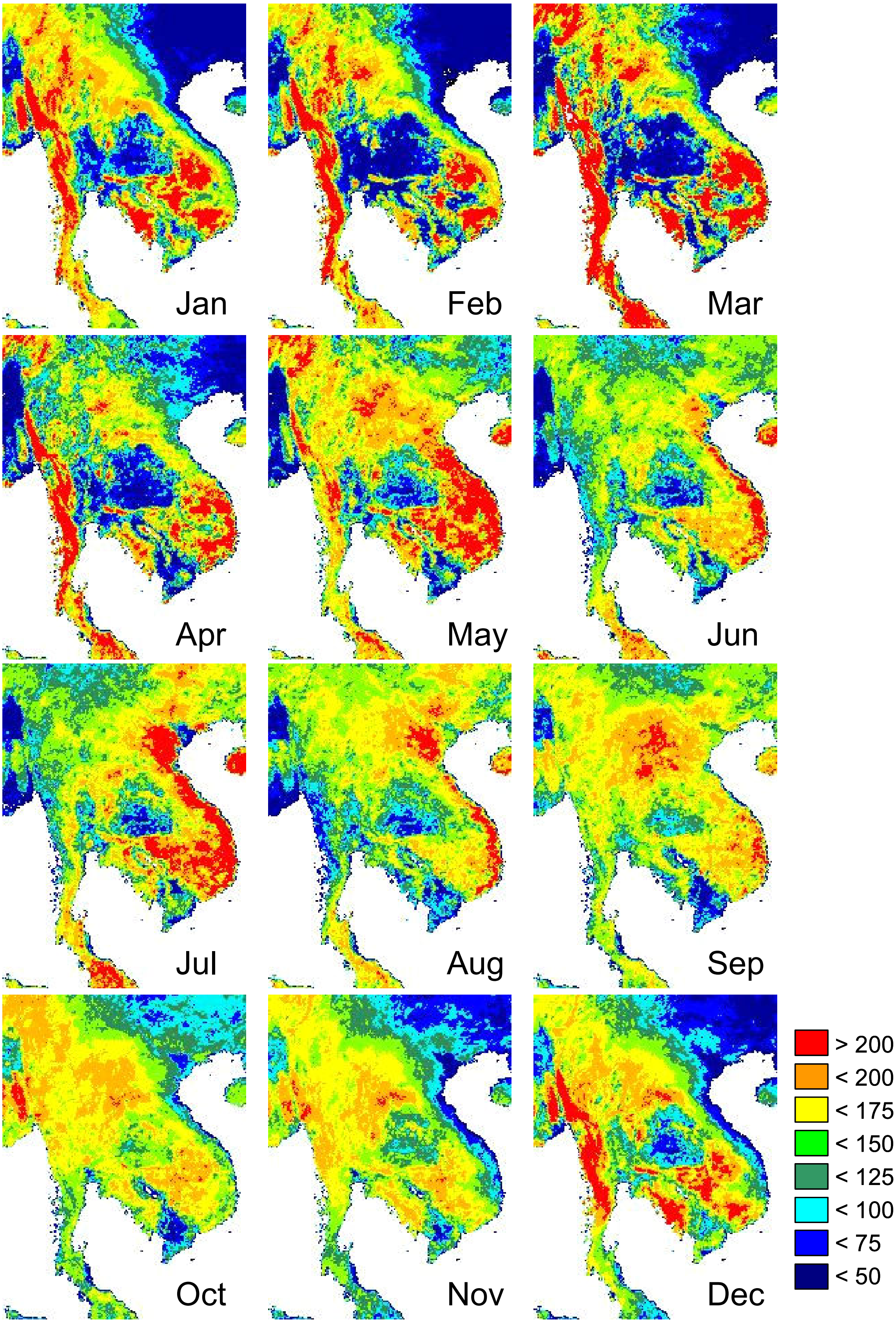

Figure 3: Average monthly Net Primary Productivity for 1982-1993, developed using NOAA/AVHRR monthly composite imagery.

4 IDENTIFYING CONSTRAINTS, OPPORTUNITIES AND TRADE-OFFS IN WATER PRODUCTIVITY

Constraints, opportunities and trade-offs are part of scenario generation that also occurs in other parts of the project, such as poverty assessments. Some constraints, opportunities and trade-offs arise naturally from the water productivity component. Thus, climate change scenarios and their impacts can be assessed and modelled directly in this component. Similarly, opportunities can be identified in this component for increasing agricultural productivity with this falls well below potential (as, seemingly, it does in much of Cambodia). Again, trade-offs can be assessed in this component, such as the upstream-downstream trade-offs in the development of hydropower dams.

The Mekong BFP will identify constraints and opportunities, and examine trade-offs as part of the water productivity estimation. Many of the scenarios will be taken from those identified in the Basin Development Plan within the MRC.

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