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Optimal Water Allocation in the Mekong River Basin

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Abstract

The Mekong River is the dominant geo-hydrological structure in mainland Southeast Asia, originating in China and flowing through or bordering Myanmar, Laos, Thailand, Cambodia, and Vietnam. Whereas water resources in the wet season are more than adequate to fulfill basin needs, there are regional water shortages during the dry season, when only 1-2% of the annual flow reaches the Delta. Recent rapid agricultural and economic development in the basin has led to increasing competition among the riparian countries for Mekong waters. This development calls for a structured approach to the management of the basin, including efficient, equitable, and environmentally sustainable water allocation mechanisms that support the socioeconomic development in the region. Institutional mechanisms for Mekong cooperation among the riparians in the lower basin have been in place since 1957, and were revived in 1995. However, comprehensive water allocation mechanisms for the (lower) basin have not been developed to date.

In this study, multi-country and intersectoral analyses of water allocation and use are carried out for the Mekong River Basin with the objective to determine tradeoffs and complementarities in water usage and strategies for the efficient allocation of water resources. An aggregate economic-hydrologic model for the basin is developed that allows for the analysis of water allocation and use under alternative policy scenarios.

Results from the analytical framework indicate that although competition for Mekong water still appears to be very low, there are substantial tradeoffs between instream and off-stream water uses. An analysis of alternative water allocation mechanisms shows that to achieve both equitable and large benefits from water uses across countries and sectors, the ideal strategy would be to strive for optimal basin water use benefits and then to redistribute these benefits instead of the water resource.

The development of such an integrated framework of analysis can be a critical first step to overcome some of the obstacles to effective management and joint cooperation in the Mekong River Basin. It could also facilitate the upcoming negotiations of water allocation rules in the lower basin and thus contribute to the reasonable and equitable utilization of Mekong River waters, as envisioned in the 1995 Mekong Agreement.

Kurzfassung

Der Mekong, der von China aus an Myanmar, Laos, Thailand, Kambodscha und Vietnam vorbei ins Südchinesische Meer fließt, ist die bestimmende hydro-geologische Struktur auf dem südostasiatischen Festland. Während das Wasserangebot in der Regenzeit mehr als ausreichend ist, kommt es in der Trockenzeit, wenn nur 1-2% der jährlich abfließenden Wassermenge das Mekongdelta erreichen, regional zu Wassermangel. Das rapide Wirtschaftswachstum, das die Region in den letzten Jahren charakterisierte, hat zwischen den Flussanrainerstaaten zu einem sich verschärfenden Wettbewerb um Mekongwasser geführt. Diese Entwicklung erfordert die Schaffung von am Flusseinzugsgebiet orientierten Strukturen des Wassermanagements auf der Basis von effizienten, gerechten, und nachhaltig die Umwelt schützenden Wasserallokationsregeln, die die sozioökonomische Entwicklung der Region unterstützen. Institutionen, die der Kooperation zwischen den Anrainerstaaten am Unterlauf des Mekong dienen, bestehen seit 1957 und wurden 1995 wiederbelebt. Jedoch wurden bislang noch keine umfassenden Wasserallokationsmechanismen für das Flussbecken oder seinen Unterlauf entwickelt.

Diese Studie befasst sich mit länderübergreifenden und intersektoralen Wasserallokations- und Nutzungsanalysen für den Mekong und hat das Ziel, Wechselwirkungen und wechselseitige Ergänzungen in der Wassernutzung sowie Strategien für die effiziente Allokation der Wasserressourcen herauszuarbeiten. Für das Flusseinzugsgebiet wird ein aggregiertes ökonomisch-hydrologisches Modell entwickelt, das eine Analyse der Wasserallokation und -nutzung unter verschiedenen wasserpolitischen Szenarien ermöglicht.

Modellergebnisse zeigen, dass bedeutende Wechselwirkungen zwischen Wasserentnahmen und Nutzungen im Fluss bestehen, auch wenn der Wettbewerb um Mekongwasser noch relativ gering erscheint. Die Analyse alternativer Allokationsmechanismen für Wasser demonstriert, dass das Ziel einer sowohl optimalen als auch gerechten Wassernutzung sein sollte, höchstmögliche Wassererträge zu erzielen und diese dann—und nicht das Wasser selbst—zu verteilen.

Die Entwicklung eines solchen integrierten Analyseansatzes kann dazu beisteuern, sowohl die Kooperation als auch das Management im Mekongbecken zu verbessern. Zudem könnte die Modellstruktur die anstehenden Verhandlungen um Wasserallokationsregeln im unteren Mekongbecken erleichtern und damit zu einer verantwortungsvollen und gerechten Nutzung des Mekongwassers beitragen, wie sie im Mekongvertrag von 1995 postuliert wird.

1 Introduction

“Freshwater is a finite and vulnerable resource, essential to sustain life, development and the environment. Since water sustains life, effective management of water resources demands a holistic approach, linking social and economic development with protection of natural ecosystems. Effective management links land and water uses across the whole of a catchment area or groundwater aquifer.”[1] Population and economic growth in developing countries will put significant pressure on the world’s water resources to meet both future food requirements and water demands in the domestic, industrial and, increasingly, environmental sectors. The challenge is particularly great as water resources are seldom managed in an integrated manner, that is, trans-boundary or across water-using sectors.

In this study, multi-country and intersectoral analyses of water allocation and use are carried out for the Mekong River Basin (MRB) to determine water availability and use patterns, to identify tradeoffs and complementarities in water use, to examine the role of institutions in the basin, and to suggest strategies for the efficient allocation of water resources. Analyses are carried out based on an aggregate economic-hydrologic river basin model that has been developed for this study. The model describes the water supply situation along the river system and the water demands by the various water-using sectors. Water benefit functions are developed for the major water uses subject to a series of physical, system control, and institutional constraints. Water supply and demand are then balanced based on the economic objective of maximizing net benefits to water use. Based on this modeling framework, the optimal allocation of water is determined for water-using sectors and countries. The role of the Mekong River Commission in transboundary water management is also briefly examined.

The first part of the paper gives a broad introduction of the Mekong River Basin, including its geographic location, economic situation, water availability and uses, and institutional regime. The focus is on the lower basin area, including Cambodia, Laos, Thailand, and Vietnam. The second part describes the methodology, modeling framework, and structure of an aggregate economic-hydrologic model for the basin. Model results from the baseline and a series of alternative scenarios are presented in the third part. The paper concludes with some final remarks.

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[1] Principle No. 1, Dublin Conference (1992).

2 The Mekong River Basin

2.1 Geographic Location

The source of the Mekong River is located on the Tibetan Plateau, Qinghai Province, China, at an elevation of over 5,000 m. The Mekong River flows through or forms the border of six countries: southern China, in particular Yunnan Province, Myanmar, Laos, Thailand, Cambodia, and Vietnam (see Figure 1). Globally, the Mekong ranks 8th in terms of discharge (15,000 m^3/sec), 12th in terms of length (4,800 km), and 21st in terms of catchment area (795,000 km^2) (Table 1). The lower Mekong basin is typically defined to begin at the common border of Laos, Myanmar, and Thailand (the 'Golden Triangle'). About 609,000 km^2 or 77% of the total catchment area is located in the lower MRB, which includes Cambodia, Laos, Thailand, and Vietnam.

In the upper basin, China contributes 16% to Mekong flows and 21% to the catchment area. Myanmar has the lowest contribution to both flows (2%) and area (3%). The Mekong drains almost all of Laos (97%), accounting for a quarter of the total catchment area of the basin and 35% of total flows. Thailand's area contribution—36% of the country and 23% of the basin—exceeds its contribution to Mekong flows (17%). The Thai basin area includes the entire Northeast of the country, about 10% of the northern region and two small parts of the eastern region (draining into Lake Tonle Sap). Eighty-six percent of Cambodia's land area is contained in the Mekong basin and the country contributes 19% of total flows. In Vietnam, the bustling Mekong Delta, a part of the sparsely populated Central Highlands, two small areas in the central coast, and the small area of Dien Bien Phu in the northeast of the country together contribute 8% of the basin area and 11% of basin flows (Table 1).

Table 1: Water Resources in the Mekong River Basin

Country/Region	Catchment			Average flow	Flow contribution
	Area	Share/ country	Share/ basin		
	(km^2)	*(%)*	*(%)*	*(m^3/sec)*	*(%)*
Yunnan, China	165,000	38	21	2,410	16
Myanmar	24,000	4	3	300	2
Laos	202,000	97	25	5,270	35
Thailand	184,000	36	23	2,560	17
Cambodia	155,000	86	20	2,860	19
Vietnam	65,000	20	8	1,660	11
TOTAL	795,000		100	15,060	100

Source: MRC (1998c)

Figure 1: Location of the Mekong River Basin

Source: MRC (1997)

2.2 Economy

The latest thrust in economic growth in the basin occurred at the beginning of the 1990s, following the end of civil strife and the dismantling of ideological barriers among the basin states.[2] During 1987-97, economic growth averaged 5-8%/yr in all lower basin states. Thailand experienced spectacular growth for a much longer period, with growth averaging 7.5%/yr during 1960-97. This helped transform the country from an agriculture-based economy into a major regional production base of manufactured products and the largest economic player in the lower basin. In 1979, Vietnam began a reform process that has gradually transformed the economy from a centrally-planned to a more market-based economy. The reform process accelerated after 1986 when the government adopted the *doi moi* or renovation policy, leading to sustained levels of economic growth of 7.4%/yr during 1987-97. However, growth in both Thailand and Vietnam was centered outside of the basin area. Laos experienced a rapid expansion in industrial sector output and annual economic growth of 7.4% between 1988 and 1997, following the adoption of the 'New Economic Mechanism', a transition path to a market-based economy. Moreover, after more than two decades of war and civil strife, the Cambodian economy has also begun to shift from a centrally-planned economy to increased market orientation. Since 1989, private property rights have been restored and most prices have been freed. As a result, the country achieved average annual growth of 5.4%/yr in 1987-97. Growth in both Cambodia and Laos accelerated from low levels of GDP and has remained fragile. In 1996, GNP per capita ranged from a low US$289 in Vietnam, US$306 in Cambodia, and US$347 in Laos to US$2,945 in Thailand. Growth has slowed down in the basin economies following the onset of the Asian economic and financial crisis, particularly in Thailand and Vietnam. However, growth has begun to resume (World Bank, 2000a).

Agriculture has remained the backbone of the lower Mekong basin countries. In 1996, agriculture contributed between 11% (Thailand) and 52% (Laos) to national incomes. During 1987-97, growth in agricultural GDP was most rapid in Vietnam (5.4%/yr) and slowest in Cambodia (3.6%/yr). Moreover, in 1996, at least one third of the economically active population was employed in agriculture in all basin countries. Cambodia retains the largest share of labor employed in agriculture at 41% of total labor. Rice continues as the major crop in all (lower) Mekong riparians, accounting for 84% of national harvested area in Cambodia, 75% of total area in Laos, 54% in Thailand, and 48% in Vietnam (FAOSTAT, 1999).

About 65 million people live in the MRB, with the highest population densities in the Mekong Delta, followed by Northeast Thailand.[3] Over the last decade, the basin population has experienced rapid growth, ranging from 1.4%/yr in Myanmar's Shan State to 2.8%/yr in Cambodia, with growth averaging about 2%/yr. By 2010, the population in the Mekong basin is

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[2] The Paris Peace Accord of 1991, facilitated by the end of the Cold War, officially ended the ideologically motivated civil war in Cambodia, for example.

[3] The total population in the basin countries, including only Yunnan Province in the Chinese portion, is estimated at 250 million.

expected to increase to 75-90 million people (MRC, 1997; UN, 1998). The quality of life of the poorest people in the basin area has improved only slowly, if at all, as a result of recent economic growth, and a significant share of the rural population—more than 80% of the total basin population—continues to live in poverty. Socioeconomic indicators in the riparian countries, and particularly in Cambodia and Laos, remain among the lowest in the world. Although life expectancy has improved considerably over the last few decades, in 1997, it was still only 53 years in Laos and 54 years in Cambodia. Furthermore, adult female illiteracy is particularly high in Cambodia and Laos, at 42% and 56%, respectively.

2.3 Water Availability and Uses

2.3.1 Water Availability

Although the Mekong riparians enjoy abundant water resources, availability varies widely by country, by region within countries, and by season. Water availability in Laos and Cambodia depends virtually entirely on the Mekong. In Thailand and Vietnam, large regions are fully dependent on MRB resources. The Mekong is a major water source in Yunnan Province, China. Only Myanmar is relatively independent of Mekong waters. On a per capita basis, Laos has the largest internally renewable water resources in the region at 55,305 m^3/yr, whereas Thailand has the lowest resources among the riparian countries in the lower basin, at 3,559 m^3/yr (Table 2).

Table 2: Water Resources Availability and Withdrawals in Mekong Basin States, 1995

	Availability		**Withdrawals**		**Withdrawal share of availability**
	(km^3/yr)	*(m^3/cap/yr)*	*(km^3/yr)*	*(m^3/cap/yr)*	*(%)*
Cambodia	88	8,585	1	98	1
China	2,812	2,292	500	407	18
Laos	270	55,305	1	205	<1
Myanmar	606	13,024	4	86	<1
Thailand	210	3,559	33	559	16
Vietnam	318	4,479	65	915	20

Note: Availability refers to annual internally renewable water resources.
Source: Adapted from ESCAP (1998a).

A monsoon rainfall pattern—made up of the southwest monsoon from mid-May to early October and the northeast monsoon from early November to mid-March—predominates throughout the lower Mekong basin, causing the river to undergo cyclical changes in flow. The large seasonal variation in water availability can be seen from discharge measurements at Pakse station (Laos, close to the Cambodian border). At this point, the maximum discharge of 57,800 m^3/sec measured during the wet season is more than 30 times the minimum discharge of 1,600 m^3/sec during the dry season.

The lower reaches of the Mekong (below Phnom Penh, Cambodia) can be characterized as an estuary, with tidal influences particularly prevalent during the dry season. At Phnom Penh, the Mekong divides into the Bassac, the Lower Mekong, and the Tonle Sap rivers. The Tonle Sap River is the connection between Lake Tonle Sap (or Great Lake)—the largest permanent freshwater body in Southeast Asia—and the Mekong River. Every year, the river reverses its flow direction from the Mekong to the lake in about mid-June, after the flow level in the Mekong surpasses a certain level at the onset of the rainy season; the area of the lake increases from about 2,600 km^2 to about 10,500 km^2, and its depth from about 2 m to 4 m. About 70 km^3 are thus stored in the lake. Other flood flows spill into the lowlands around the Bassac and Mekong. Annually, the Mekong inundates about 30,000 km^2 in the lower reaches (MRC, 1997). Around October, or beginning of November, when Mekong flows decrease, the Tonle Sap releases the water stored as well as flows from its catchment area into the Mekong Delta. Thus, the lake acts as a natural reservoir that alleviates floods during the wet season and augments dry-season flows in the Delta (ESCAP, 1998a).

2.3.2 Water Uses

The MRB is far from having reached closure or full exploitation of its renewable water resources. In 1995, water withdrawals were estimated at 98 m^3/capita in Cambodia, 205 m^3/capita in Laos, 559 m^3/capita in Thailand, and 915 m^3/capita in Vietnam (Table 2). The largest water user by far in the basin is irrigated agriculture. It is estimated that water withdrawals for irrigated agriculture account for 94% of total withdrawals in Cambodia, 82% of withdrawals in Laos, 91% of withdrawals in Thailand, and 86% of withdrawals in Vietnam. Thailand and Vietnam are the major industrial centers in the basin, with water withdrawals for industrial uses accounting for 4% and 10% of total withdrawals, respectively. The share of domestic withdrawals is estimated at 4-8% of total water withdrawals, depending on the basin country (FAO, 1999). Water withdrawals in China, Thailand, and Vietnam are close to 20% of total annual internally renewable resources. According to the United Nations (UN, 1997; ESCAP, 1998a), when withdrawals exceed this threshold level, water tends to become a limiting factor in national socioeconomic development. Moreover, a seasonal calculation of the ratio between water withdrawals and availability would likely show that both Thailand and Vietnam already surpass the threshold level during the dry season, when water availability is much reduced.

Irrigation

Irrigated agriculture plays an important role in Mekong basin countries; but estimations indicate that overall only 7-10% of the cultivated area in the lower Mekong basin is irrigated. In 1996, equipped irrigated area as a share of agricultural area was lowest in Cambodia (7%) and highest in Vietnam (31%) among the lower basin countries (FAOSTAT, 1999). In 1995, the total water-managed area in Laos was estimated 386,894 ha, about 40% of which were equipped with irrigation infrastructure; the remainder was used for deep-water/flood recession cropping. Most of the irrigated area was for wet-season irrigation (80%) (FAO, 1999). In Thailand, only about 10% of the Korat Plateau in the Northeast is irrigated, mainly in the form of supplementary wet-season irrigation. Total irrigated area is estimated at 450,000-900,000 ha. In the dry season, less than 100,000 ha are irrigated, with most irrigation water derived from a series of reservoirs constructed for irrigation purposes (Kingdom of Thailand, 1997).

In Cambodia, water managed areas were estimated at about 390,500 ha in 1993; 70% of which were equipped with full or partial control irrigation. The remainder was largely used for floating rice production (FAO, 1999). A large number of existing schemes are not in operation. It is estimated that if existing and past irrigation schemes were rehabilitated and improved, the total irrigated area could be increased to 419,300 ha in the wet season and 187,000 ha in the dry season (Mekong Secretariat, 1994b).

Irrigation has been of particular importance in the rapid agricultural development of the Mekong Delta. In 1990, 2.4 million ha were cultivated, and 1 million ha were irrigated in some form, mostly for rice production. Irrigation development helped increase cropping intensities from one floating paddy crop with low yield to two short-term high-yield paddy crops, which almost tripled food production from 4.5 million metric tons (mt) to 13.0 million mt during 1975-95 (Phan, 1996). In 1990, irrigated area in the Chinese portion of the MRB was estimated at 291,000 ha; 94% or 274,000 ha of which were located in Yunnan Province (estimated based on CIESIN, 2000).

Hydropower Generation

The hydropower potential in the MRB is estimated at about 246,700 GWh/yr, 70% of which is located in the lower basin (Table 3). Demand for hydropower has surged with the rapid economic development experienced in some of the riparian countries and elsewhere in Southeast Asia. Demand has increased most rapidly in Thailand and is expected to reach 62 GW by 2020, a more than 6-fold increase from 1993 levels. Demand is also set to rapidly increase in Vietnam, but will likely remain below 1 GW in Cambodia and Laos (Table 3). With the exception of Thailand, per capita electricity consumption in the lower Mekong basin is very low. In Cambodia, for example, consumption in 1993 was estimated at 19 kWh per capita, compared with 1,142 kWh in Thailand (Phanrajsavong, 1996). This is partly due to the low share of households with electricity supply in the country and basin (Table 3).

Table 3: Energy Situation in Mekong Basin States, 1993 and Projected 2020

Country/ Region	Hydropower Potential	Power Demand 1993	Est. Power Demand 2020	Est. Power Demand 2020[/a]	Households with Electricity
	(GWh/year)	*(GW)*	*(GW)*	*(GW)*	*(%)*
Cambodia	36,300	0.09	0.8	0.8	4
Laos	102,300	0.05	0.3	0.7	13
Myanmar	500	0.5	2.5		7
Thailand	26,100	9.8	61.8	37.9	72
Vietnam	10,000	2.0	15.8	17.4	10
Yunnan, China	71,500	2.0	11.2		8
Total	246,700	14.4	92.4	56.8	19

Sources: MRC (1997); [/a] cited in Rothert (1995).

Due to the unequal distribution of supply and demand—the low-cost hydropower potential is located in Laos, Myanmar, and Yunnan Province, China, whereas the main markets are Thailand, increasingly Vietnam, and the more distant markets of Malaysia and Singapore—the Greater Mekong Sub-region (including all six riparian countries) has substantial potential for power trade (Crousillat, 1998).

Most of the planned dam projects are located on Mekong tributaries in Laos. The country has signed concession agreements for the development of 23 power projects with a combined installed capacity of some 6,800 MW, annual generation of 38,000 GWh, and total estimated construction costs of US$9.5 billion (Lao PDR, 1997). Altogether, Laos has plans for up to 60 hydropower projects (see Rothert, 1995 for a complete listing). No new tributary projects are planned in Thailand, as the most suitable sites in the country have already been developed, and the active environmental movement in the country has made it increasingly difficult to develop large-scale infrastructure projects. Cambodia has considerable potential for dam construction, but by 2000, there was only one dam with a height in excess of 15 m, and no power generation was carried out. Several smaller projects are planned, including the completion of Prek Thnot dam, whose construction had begun before the civil war. Vietnam has plans for several hydropower projects on Mekong tributaries in the Central Highlands. The largest project, Yali dam with a capacity of 720 MW, has been completed recently.

By far the most ambitious hydropower projects are located on the Mekong mainstream. In the upper basin, a total of 7 hydropower projects are slated for construction in Yunnan Province, China. Manwan dam with a capacity of 1,500 MW and Dachaoshan dam with a capacity of 1,350 MW have been completed; work on Xiaowan has started; and funds for Jinghong have been sought from the Asian Development Bank. In the lower basin, the Mekong River Commission (MRC) has plans to develop up to 13 run-of-the-river hydropower projects; 9 sites with a total capacity of 14,000 MW are considered priority projects (Mekong Secretariat, 1994a; MRCS, 1995). Mainstream projects in the lower basin have so far not attracted investment interests, because the political situation in the region has not been favorable to the development of multi-national projects, the magnitude and cost of the projects are large in relation to the economies and power demands of the riparian countries, and the associated environmental problems, particularly resettlement, are perceived as too large (MRCS, 1995).

The possibility of increased dry-season flows from upstream dam construction has improved the willingness to cooperate among the downstream riparians and has contributed to the successful negotiation of the 1995 Agreement (see also Section 2.4). However, the net benefits and costs of upstream hydropower development and their distribution across countries and sectors are not known. In fact, all riparian countries in the lower Mekong basin could use the estimated additional 1,000 m^3/sec after completion of the 7 hydropower projects in Yunnan Province, China.[4] Vietnam could use an additional 2,000 m^3/sec in the delta area to meet full irrigation requirements that have increased rapidly due to increased double- and triple-cropping of modern rice varieties.[5] Northeast Thailand suffers from dry-season irrigation water deficits of up to 1,000 m^3/sec. In Cambodia, water demands for irrigation will likely increase rapidly following the rehabilitation of its irrigation infrastructure. Laos also has ambitious plans regarding irrigation development; according to government plans the dry-season irrigated area will increase by a factor of 15 by 2020 to reach 200,000 ha (Department of Livestock and Fisheries, 1999). However, it is unclear if these increases will materialize. Moreover, although Myanmar currently makes the least use of basin water resources, there is a possibility of increased future dry-season water use in the country.

In addition to potential off-stream uses, the increase in dry-season flows could increase the economic viability of the planned run-of-the-river hydropower projects on the lower mainstream, which depend for their power production on flows rather than storage. However, achieving these benefits would require careful coordination of reservoir operations between upstream and downstream riparians. At the same time, reduced wet-season flows could threaten the inflows to Tonle Sap, and reduce the benefits from fisheries and other environmental water uses.

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[4] Little increase in irrigation development is expected in Yunnan, China, following completion of its hydropower projects.

[5] Average dry-season flows into the Mekong Delta prior to upstream development have been estimated at 2,000 m^3/sec. According to NEDECO (1993a, cited in Browder, 1998), a quarter of this flow is currently used for irrigated agriculture, and the remainder, 1,500 m^3/sec, is needed to combat saltwater intrusion.

Urban-Industrial Water Uses

In the two largest urban centers in the MRB, Phnom Penh, Cambodia, and Vientiane, Laos, 60% and 33% of the population are connected to public water supply systems, respectively. In Vientiane, water supply is about 55,000 m^3/day. In Phnom Penh, water supply was less than 100,000 m^3/day in 1993. By 2010, water supply is expected to increase to 272,000 m^3/day (Chea, 1998). Whereas water vendors charge up to US$1/m^3 for water, charges by the Water Supply Authority range from US$0.08-0.50/m^3; a block tariff rate is applied (Chea, 1999). Whereas in Cambodia and Laos, industries are concentrated in the respective capitals, industrial development can be found in several areas of the Thai and Vietnamese Mekong basin; in the latter in particular in the delta. Normally, water-consuming industries are located near water bodies in order to have access to an inexpensive (often free) and reliable source of water. Small- and medium-sized enterprises are often located in metropolitan areas and use high-quality drinking water, which might not be needed for their production purposes. The share of potable water used for industrial purposes can reach up to 40% of total urban water use (ESCAP, 1998b). Table 4 presents estimates for total water demand per capita in 1990 and domestic and industrial demand in 1990 and 2020 in the MRB.

Table 4: Total and Domestic-Industrial Water Withdrawals, 1990 and 2020, Mekong River Basin

Country/Region	Total Demand Per Capita	Domestic-Industrial Demand	
	1990	1990	2020
	(m^3/capita)	*(million m^3)*	
Yunnan, China	250	121	328
Thailand	350	725	1,467
Laos	280	70	168
Cambodia	150	78	187
Vietnam	550	899	1,994
Total		1,893	4,144

Note: M&I (municipal and industrial) and domestic-industrial are used interchangeably in this study.
Source: Author's calculations, based on FAO (1999) and MRC (1997).

Fisheries

The MRB supports an estimated 1,200-2,000 fish species, including numerous migratory and endemic species. Capture fisheries production in the lower Mekong basin has been estimated at between 775,000 and 900,000 tons per year (van Zalinge et al., 1998; Schouten, 1998).

Capture fisheries is particularly important in Cambodia, where inland fisheries alone are estimated to yield about 400,000 tons, valued at US$220-250 million at farmgate prices during the late 1990s (Table 5).

Wetlands

Wetlands are an important source of nutrition, income, firewood, construction material, and water supply in the MRB and many of the wetlands are under intense and extensive use. Size and definitions of wetland areas in the basin vary widely by source (see, for example, MRCS, 1998; Scott and Poole, 1989; Mundkur et al., No year). Wetland areas cover an estimated 36,500 km^2 in Cambodia and 590-21,800 km^2 in Laos. According to MRC (1997) there are 11 wetland areas in Northeast Thailand and two small areas in Vietnam's Central Highlands. Moreover, the entire Mekong Delta can be considered a wetland, particularly the floodplain between the Mekong and the Bassac, the Plain of Reeds, the Melaleuca forests, and the tidal floodplain. Table 5 presents estimates of wetland areas used in the study.

Table 5: Fish Production and Wetland Areas in the Mekong Basin

	Fish Production	Wetlands
	(tons)	*(ha)*
Yunnan, China	100	
Laos	40,250	220,000
Thailand	322,000	200,000
Cambodia	400,000	3,650,000
Mekong Delta, Vietnam	400,000	2,000,000
Total	1,162,350	6,070,000

Sources: Estimates, for fish production, based on MRC (1997); FAOSTAT (1999); van Zalinge et al. (1998); for wetland areas: Scott and Poole (1989).

Navigation

Since the 19th century, there has been considerable interest in using the Mekong as a potential navigation route to increase trading between French-controlled Indochina and southern China (Osborne, 1975). However, the large Khone Falls at the border of Laos and Cambodia and the rapids at Stung Treng in Cambodia impede full-scale navigational development on the river. Moreover, during the dry season, low water levels prevent large-scale navigation. However, water transport plays an important role in navigable reaches. In the Vietnamese Mekong Delta, the transport volume is estimated at 6 million tons per year; between the sea and Phnom Penh, at 150,000 tons per year; between Laos and Thailand, at 40,000 tons per year; and between Vientiane and Myanmar, at 20,000 tons per year (Bogardi, 1997). Moreover, navigation is of economic importance between Yunnan Province, northern Thailand, Myanmar, and northern Laos.

2.4 The Mekong Regime

The lower MRB, including Cambodia, Laos, Thailand, and Vietnam, has a history in transboundary water management of more than 40 years, based on the Mekong Statutes of 1957, 1978, and 1995. The Mekong Regime can be divided into four phases. The first phase lasted from 1957—the establishment of the Mekong Committee—to 1978, when the Committee was replaced by an Interim Committee, in which Cambodia did not participate.[6] The second–Interim Mekong Committee–phase, continued until 1991, when Cambodia asked for readmission into the Committee. The third phase characterizes the negotiation of the 1995 Mekong Agreement, and the most recent phase refers to the evolution of the Mekong Regime following the signing of the 1995 Agreement.

The negotiations of the 1995 "Agreement on the Cooperation for the Sustainable Development of the Mekong River Basin" lasted several years, as the potential for conflict and real tradeoffs emerged among the interests of the riparian countries regarding Mekong development, particularly between Thailand and Vietnam. The 1995 Agreement has the following major features:[7] (1) Only inter-basin projects by member countries that involve water diversion from the mainstream during the dry season are subject to approval by all MRC members; (2) the maintenance of minimum natural flows during the dry season is the major criterion to judge the appropriateness of water-related projects; (3) the Agreement not only created the MRC but also requires the MRC to negotiate additional agreements related to three specific water allocation issues: (a) determination of minimum monthly flow at various points along the Mekong River; (b) formalization of procedures for the review of proposed water uses; and (c) drafting of the Basin Development Plan (BDP) that would guide water resources development in the lower Mekong basin (Browder, 1998).

According to Browder (1998) the Agreement was negotiated because the Mekong states, particularly the two regional powers of Thailand and Vietnam, wanted to maintain amicable relations in the post-Cold War era. Moreover, planned Chinese reservoirs were expected to augment the critical dry-season flows in the Mekong River. International development agencies were willing to assist the Mekong cooperation technically and financially. Furthermore, the United Nations Development Programme provided important negotiation assistance for the drafting of the Agreement. Finally, the Mekong Agreement is a framework document that contains general principles and procedures for the cooperation in water allocation, but does not actually allocate water among the four member countries (see, for example, Article 26, 1995

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[6] In mid-1975, the political situation in the lower basin countries changed dramatically when communist regimes took over in Cambodia (Khmer Rouge) and Laos, and Vietnam became united under a Communist regime. During 1975-77, Cambodia, Laos, and Vietnam did not send representatives to the Mekong Committee meetings, but the Mekong Secretariat continued to function in Bangkok.

Mekong Agreement).[8] None of the subsidiary agreements had been negotiated by 2000, which underlines the argument that real tradeoffs among water-using sectors and countries are involved in the formulation of water allocation mechanisms for the lower MRB. The recently approved World Bank/GEF (Global Environment Facility) Water Utilization Program project that aims at supporting "the MRC in developing an integrated and comprehensive Basin hydrologic modeling package and a functional and integrated knowledge base on water and related resources and [in using] these tools … [to]… establish guidelines for water utilization and ecological protection, primarily the sensitive ecological systems including wetlands and flooded forests" (World Bank 2000b) could help change this situation.

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[7] More details can be found in Browder (1998) and Ringler (2001).

[8] "The Joint Committee shall prepare and propose for approval of the Council, inter alia, Rules for Water Utilization and Inter-Basin Diversions pursuant to Articles 5 and 6, including but not limited to: 1) establishing the time frame for the wet and dry seasons; 2) establishing the location of hydrological stations, and determining and maintaining the flow level requirements at each station; 3) setting out criteria for determining surplus quantities of water during the dry season on the mainstream; 4) improving upon the mechanism to monitor intra-basin diversions from the mainstream." (Art. 26, 1995 Agreement)

3 Methodology for Integrated Economic-Hydrologic River Basin Model

3.1 Methodology

3.1.1 Background

According to Young (1995), combined hydrologic and economic studies at the river basin level are best equipped to assess water management and policy issues. Ideally, an integrated hydrologic-economic model at the basin scale includes the following characteristics: (1) depiction of the entire river basin; (2) integration of hydrologic and economic relationships in an endogenous system; (3) representation of the spatial and temporal distribution of water flow and pollutant transport and mass balance through the river basin; (4) incorporation of water demands from all water-using sectors, including instream or environmental uses; (5) possibility to evaluate economic benefits and costs of each of these demands; and (6) incorporation of economic incentives and institutional rules for policy analysis based on the model (McKinney et al., 1999).

However, many challenges to the integrated modeling of economic and hydrologic components remain. Despite the critical importance of economic variables in water resource allocation and management water resources studies have generally been dominated by hydrologic analyses for flood control management and water resources planning from an engineering point of view. At the same time, economic or policy analysis studies have usually focused solely on profit maximization of water uses for irrigation, industrial, and domestic purposes, conditioned on the amount of water supplied at the off-take or delivery point. Information exchange between hydrologic and economic model components can be difficult due to differences in the modeling techniques—simulation and optimization—used. Moreover, the spatial units of these two modeling components can differ with the economic approach typically related to political and administrative boundaries, and the hydrologic approach referring to the river system. In addition, the area over which the model results apply and over which results need to be validated can differ. Time intervals and temporal horizons can also vary. Whereas optimization models use larger time intervals (seasonal or year) and short-term optimization or long-term forecasting time horizons, hydrologic components need to include time intervals that reflect the hydrologic system operation, and the horizon can be very long (for example, for climate change simulations), but is restricted by computational capacity and data availability. Insufficient and inadequate data can be a further constraint on integrating economic and hydrologic model components (McKinney et al., 1999, based on Braat and Lierop, 1987).

3.1.2 Study Methodology

A wide variety of issues need to be addressed to effectively manage MRB water resources. These include the need to identify the relative costs and benefits and the tradeoffs and complementarities in water allocation among different water-using sectors and countries; and among the goals of efficiency, equity, and sustainable resource use; and to determine the role of institutions and organizations in water allocation processes. To approach these issues, a holistic, integrated economic-hydrologic model for the basin is developed for this study that optimizes water allocation based on an objective function and accompanying constraints. The model draws from previous economic-hydrologic modeling carried out at the International Food Policy Research Institute, in particular, for the Maipo River Basin in Chile (Rosegrant et al., 1999, 2000). It includes hydrologic, agronomic, economic, and institutional components, with a focus on the economic component. The model is highly aggregated with country/regional-level water supply and demand, and economic benefit functions and solves for optimal water allocation at the basin level subject to a series of physical, system control, and policy constraints. The optimal allocation of water across water-using sectors is determined on the basis of the economic value of water in alternative uses.

Other models, which have been developed for the MRB or parts of it, are discussed in Ringler (2001). Currently, the MRC is not actively using river basin models for basin-wide water planning and management; however, modeling tools are planned under the recently approved World Bank/GEF project. Moreover, no comprehensive economic-hydrologic model has been developed for or applied in the basin.

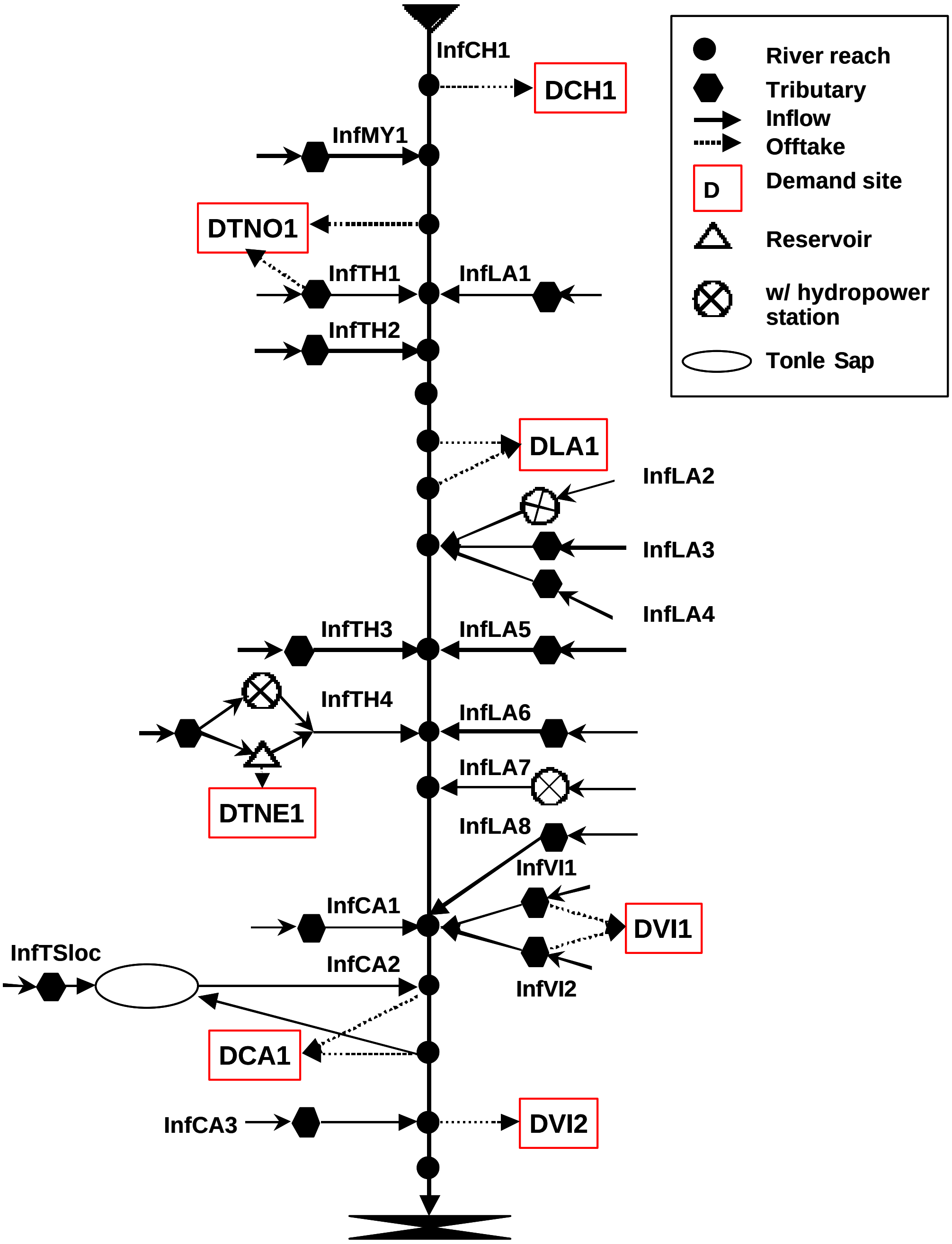
3.2 Model Structure and Formulation

The model framework takes into account the sectoral structure of water users (agriculture, industry, hydropower, households, and the environment), the location of water-using countries and regions, and the institutions for water allocation in the basin. This allows the assessment of interactions and tradeoffs and intersectoral competition for water resources among the various water-using sectors and countries. Moreover, the model framework can be used to analyze alternative policy options and strategies for water allocation and use and their implications on the basin economy. The model can also be useful for identifying crucial data gaps that need to be filled to better understand the economics of water allocation in the basin.

The model focus is on the water economy of the lower MRB—the major beneficiary of Mekong waters. However, the entire basin was modeled and upstream riparians are included to the extent necessary for the analysis. Water uses in Myanmar, for example, are not incorporated, as they are estimated to be negligible in the areas bordering the Mekong (Hirsch and Cheong, 1996), whereas discharge from Myanmar into the Mekong was included.

The river basin model is developed as a node-link network, which is an abstracted representation of the spatial relationships between the physical entities in the river basin. Nodes represent river reaches, reservoirs, and demand sites, and links represent the linkage between these entities (Figure 2). Inflows to these nodes include water flows from the headwaters of the river basin, as well as local rainfall drainage. Flow balances are calculated for each node at each time period, and flow transport in the basin is calculated based on the spatial linkages in the river basin network. For modeling purposes, the Mekong basin is subdivided into seven aggregate spatial units based on geographic/administrative boundaries, one for Yunnan Province, China; one for Laos; two for Thailand (Northern Thailand and Northeast Thailand); one for Cambodia; and two for Vietnam (Central Highlands and Mekong Delta). The model incorporates both off-stream and instream water uses. Off-stream uses include water diversion for irrigated agriculture, and domestic and industrial water uses. Instream uses include flows for hydropower generation, fish production, wetlands, navigation; and minimum flows for the maintenance of the river ecology and to control saltwater intrusion into the Mekong Delta.

Figure 2: Mekong River Basin Network

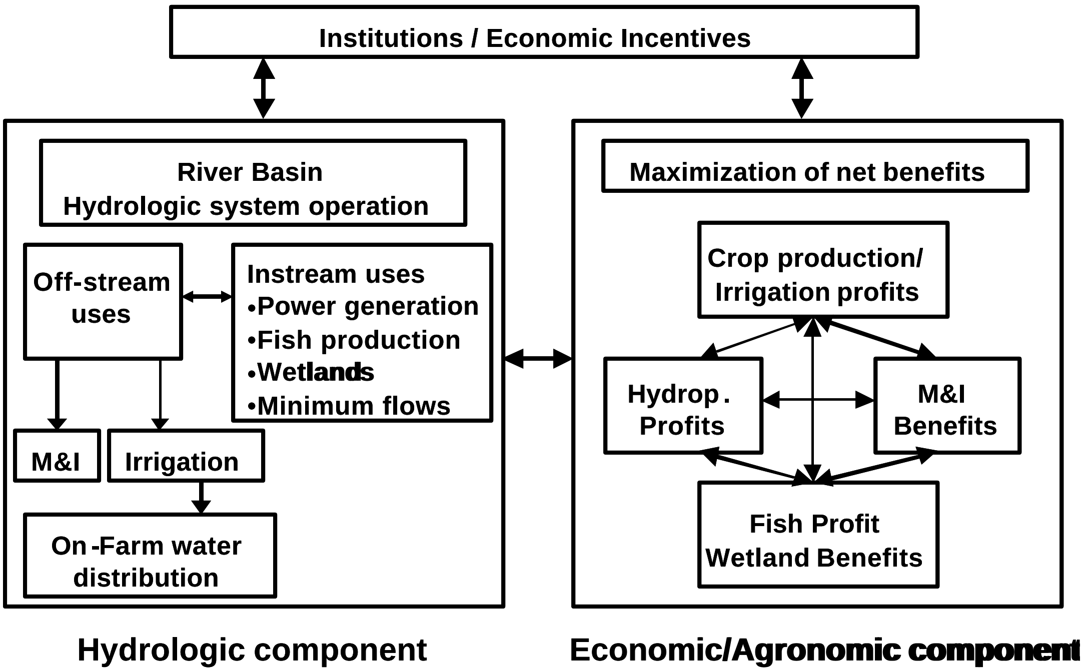


A number of aggregate demand sites for these water uses are connected to the seven spatial units in the river basin network. Agricultural demand sites are delineated according to the size of irrigated areas and administrative boundaries. Nodes for urban-industrial demand sites are connected to the basin network at the major urban centers. Reservoirs are aggregated for either power production or irrigation/urban-industrial water supplies. Water demand sites for fish production are connected to all spatial units with the exception of the Central Highlands area, Vietnam, where freshwater capture fisheries plays a minor role. Wetland demand sites are established for Cambodia, Laos, Northeast Thailand, and the Vietnamese Mekong Delta.

Minimum instream flows for the environment and navigation, and minimum outflows to combat saltwater intrusion in the Mekong Delta are incorporated as constraints.

Thematically, the modeling framework includes three components: (1) hydrologic components, including the water balance in reservoirs, river reaches, and crop fields; (2) economic components, including the calculation of benefits from water use by sector, demand site, and country; and (3) institutional rules and economic incentives that impact upon the hydrologic and economic components. Figure 3 presents an overview of the model structure. Water supply is determined through the hydrologic water balance in the river system; while water demand is determined endogenously within the model based on functional relationships between water and productive uses in irrigated agriculture, domestic-industrial areas, wetlands, fisheries, and hydropower. Water supply and demand are balanced based on the objective of maximizing economic benefits to water use.

Figure 3: Model Structure - Hydrologic, Economic/Agronomic and Institutional Components



Thus, the river basin model provides a description of the underlying physical processes and the institutions and rules that govern the balance of flows, the flow regulation through surface water, and the water allocation to both off- and instream demand sites. The time horizon of the model is one year with 12 periods (months). In the following, the hydrologic, agronomic, and economic components are described in more detail.

3.2.1 Hydrologic Component

The MRC publishes hydrologic data for up to 68 discharge stations and 59 gauge height stations on the Mekong mainstream and major tributaries. For this model, water flow data is taken from 36 fluviometric measuring stations in the lower MRB, as well as from a series of other sources (Mekong Secretariat, 1994b; MRC, 1998c; ORSTOM/BCEOM, 1993). Flow data of smaller tributaries are aggregated. The year 1990 was chosen as representative or baseline year. Published flow data for an adequate number of flow measuring stations were available to the author from the Mekong River Commission Secretariat (MRCS) for the years 1990 and 1993. The Global Runoff Data Center (GRDC) in Koblenz, Germany, provides long-term flow observations, but only for selected measuring stations. Here, the most recent year available was 1991. Using 1990 as base year allows a comparison between one-year MRCS flows and historical GRDC records. Based on this comparison, 1990 can be considered a year with average runoff (GRDC, 1998; Interim Committee for the Co-ordination of Investigations of the Lower Mekong Basin, No year). Using only one-year flow data does not allow for stochastic analyses of flow data. However, the effects of alternative flow regimes can be analyzed based on sensitivity analyses (see Section 4.2). As the observed flow data are in fact post-depletion flows, they were augmented by consumptive uses for model purposes, that is, withdrawals were added and return flows discounted. Total estimated basin flows for 1990 add up to 475,686 million m^3. After augmentation with estimated basin depletion, basin flows amount to 500,785 million m^3.

Major hydrologic relations and processes, which are based on the flow network, include: (1) flow transport and balance from river outlets/reservoirs to crop fields or urban-industrial demand sites; (2) return flows from irrigated areas and urban-industrial areas; (3) evapotranspiration from crop fields; (4) reservoir releases; and (5) instream water uses. The rainfall-runoff process is not included in the model. It is assumed that runoff starts from rivers and reservoirs. Effective rainfall for crop production is calculated outside of the model, and included into the model as a constant parameter.

The basic flow balance at a node in the basin network is calculated as:

$$\begin{aligned} flow\_downstream &= flow\_upstream + local\_drainage + \\ &\quad return\_flows - withdrawals - (evaporation)\ losses \end{aligned} \qquad (1)$$

3.2.2 Agronomic Component

In order to establish a relationship between crop yield and water, the crop yield-water stress relationship, which has been developed by the FAO following extensive field experiments over a wide range of crops, was incorporated into the modeling framework (for details, see Doorenbos and Kassam, 1979 and Doorenbos and Pruitt, 1977). Values for yield response coefficients (ky) for most crops are derived based on the assumption that the relationship between relative yield (actual yield over maximum yield) and relative evapotranspiration (ET_a $/Et_m$) is linear, for water deficits of up to about 50% or ($1 - Et_a /Et_m = 0.5$). The function is specified for each crop and demand site as:

$$ylda = yldm * [1 - (ky * (1 - ET_a / ET_m))] \qquad (2)$$

where:

$ylda$	actual yield (mt/ha)
$yldm$	maximum yield (mt/ha)
ET_a	seasonal actual evapotranspiration (mm)
ET_m	seasonal potential evapotranspiration (mm)
ky	seasonal crop yield response coefficient

3.2.3 Economic Component

The objective of the model is to maximize the annual net profits from water uses for irrigation, households and industries, hydropower generation, wetlands, and fisheries in the MRB. The objective function is formulated as:

$$\begin{aligned} Max \quad Obj = & \sum_{agdm} VA(agdm) + \sum_{mundm} VM(mundm) + \sum_{pwst} VP(pwst) \\ & + \sum_{wetdm} VW(wetdm) + \sum_{fdm} VF(fdm) \\ & - wgt1 * agpenalty - wgt2 * powpenalty \end{aligned} \qquad (3)$$

where:

VA	net profit from irrigation, across demand sites ($agdm$)
VM	net benefit from M&I water uses, across demand sites ($mundm$)
VP	net profit from power production, across power stations ($pwst$)
VW	net benefit from wetlands, across demand sites ($wetdm$)
VF	net profit from fish production, across demand sites (fdm)
$agpenalty$	penalty for uneven water allocation to crop growth stages
$powpenalty$	penalty for uneven power production
$wgt1$, $wgt2$	weights for the penalty items

The seasonal crop yield function (Eq. 2) drives the seasonal water allocation among crops, but cannot distribute the water within the crop growth season according to the water requirements of crop-specific growth stages. In order to achieve consistency between the seasonal yield function and the monthly water balance in the hydrologic system—to fill the gap between the agronomy and hydrology in the optimization model—a penalty term is introduced into the objective function that minimizes the difference between the maximum and average crop stage deficit due to water stress for a given crop and demand site. A crop growth stage is defined as one month (see also Rosegrant et al., 1999, 2000)

$$agpenalty = \sum_{agdm}\sum_{crop} yldm(agdm,cp)*\ price(cp)*\ area(agdm,cp)* \\ (mdft(agdm,cp) - adft(agdm,cp)) \qquad (4)$$

where:

price	crop price (US$/mt) by crop (*cp*)
area	irrigated harvested area (ha) by crop (*cp*) & demand site (*agdm*)
mdft	maximum stage yield deficit due to water stress by crop & demand site
adft	average stage yield deficit

with:

$$dft(agdm,cp) = kym(cp) * (1 - ET_a/ET_m) \qquad (5)$$

where:

dft	monthly stage deficit by crop and demand site
kym	monthly crop yield response coefficient, following Doorenbos and Kassam (1979).

As no information could be obtained on the operating rules of any of the reservoirs in the MRB, a relatively constant power production across the year is assumed and implemented through the introduction of a power production penalty. The penalty term is formulated as:

$$powpenalty = \sum_{pwst}\sum_{pd} power(pwst,pd)*\ pprice(pwst)* \\ (mpdft(pwst) - apdft(pwst)) \qquad (6)$$

where:

power	monthly power production (million kWh), by power station
pprice	power selling price (US$/kWh)
mpdft	maximum power production deficit
apdft	average power production deficit

with:

$$pdft(pwst,pd) = pwst\_cp(pwst)/12*a - power(pwst,pd) \qquad (7)$$

where:

pdft	monthly power production deficit, by power station
pwst_cp	annual power production capacity (GWh)
a	factor (here: 1.15)

The function for profits from irrigation (*VA*) is specified as follows:

$$
\begin{aligned}
VA(agdm) = {} & \sum_{cp} area(agdm,cp) * ylda(agdm,cp) * \ price(cp) \\
& - \sum_{cp} area(agdm,cp)\,(\ ferc(agdm,cp) + machc(agdm,cp) + \\
& \ laborc(agdm,cp) + irrigc(agdm,cp) + ocost(agdm,cp)) \\
& - w\_ca(agdm) \sum_{pd} \left(to\_infa(agdm,pd) \right)
\end{aligned}
\qquad (8)
$$

where:

$ferc$	fertilizer input cost (US$/ha), by demand site and crop
$machc$	machinery cost (US$/ha)
$laborc$	labor cost (US$/ha)
$irrigc$	irrigation cost (US$/ha)
$ocost$	other production costs (US$/ha)
w_ca	water supply cost (US$/m^3)
to_infa	monthly withdrawals for irrigation (million m^3) at off-take level

Crop yield data were obtained from FAOSTAT (1999) and local sources. Yields were adjusted by a factor of 1.1 to transfer actual (*Ya*) to potential yield (*Ym*). Seven major irrigated annual and perennial crops in the Mekong Basin are included (coffee, fruit tree, maize, rice, soybean, sugarcane, vegetables); if the various types of and cropping patterns for rice are considered separately, a total of 13 crops are incorporated. Rice yields for different types of rice (flood recession, floating, double and triple-cropped, wet season and dry season) were adjusted based on various reports from the region. As only sparse, incomplete, and often inconsistent data for crop input costs could be obtained, all costs (for fertilizer, labor, irrigation, and other costs, principally seed), as well as farmgate prices were estimated based on output data from crop models for Cambodia (FAO/UNDP, 1994) and adjusted upward for Thailand and Vietnam.

The net benefit function for M&I water uses (*VM*) is derived from an inverse demand function for water. Net benefit is calculated as water use benefit minus water supply cost. Values are synthesized from secondary sources. The function is specified as:

$$
VM(mundm) = \sum_{pd} \left[\begin{array}{l} w_0(mundm,pd) * p_0 * \left[\begin{array}{l} \left(1/(1+a)*(w(mundm,pd)/w_0(mundm,pd))^a \right) \\ +(0.743 - 1/(1+a)) \end{array} \right] \\ - w(mundm,pd) * w\_cm(mundm) \end{array} \right]
\qquad (9)
$$

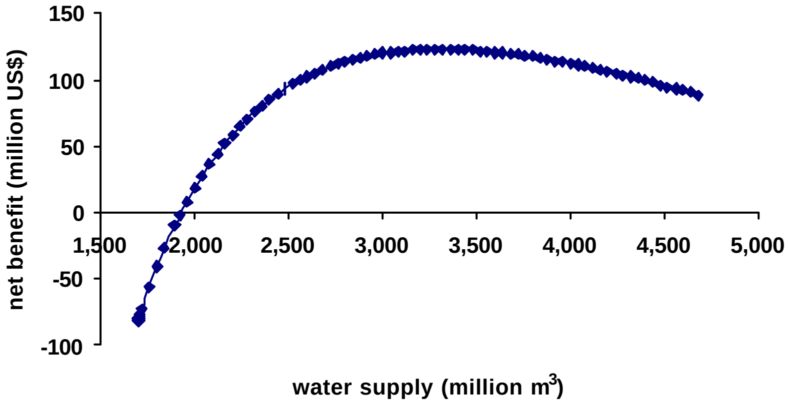
where:

w_0	maximum normal monthly withdrawals, by demand site (million m^3)
p_o	value of water at full use (US$/m^3)
w	actual water withdrawals (million m^3)
e	price elasticity of demand

a	*1/e*
w_cm	water supply cost (US$/m^3)

As can be seen in Figure 4 the functional form displays increasing followed by declining marginal returns to increasing water supply.

Figure 4: Municipal and Industrial Net Benefit Function



Instream water uses are of particular importance in the MRB. Profit from power production (*VP*) is calculated as power production (*power*) multiplied by the difference between power selling price (*pprice*) and power production cost (*pcost*) for each hydropower station. In the base year, all power production is carried out on Mekong tributaries.

$$VP(pwst) = \sum_{pd} power(pwst, pd) \cdot [pprice(pwst) - pcost(pwst)] \tag{10}$$

Fishing is important for all basin economies, but particularly for the downstream countries of Cambodia and Vietnam. According to Dr. Jensen,[9] head of the Fisheries Programme at MRCS, three factors (at least) are important for fish production in the Mekong: (1) Fish production takes place primarily in the flooded areas during the wet season, and not in the mainstream and during the dry season; (2) total annual fish yield appears to be almost proportional to the size and duration of the flood; and (3) the most important economic fish species migrate every year, often 900 km or more. Thus, local areas of the basin, like Lake Tonle Sap, cannot be preserved without preserving a considerable part of the Basin's water bodies as well as the migrations (access) between these.

Standard functional forms are not available in the literature for the evaluation of the relationship between water flows and the value of fish production. In the model fish production is treated as an increasing function of water availability up to a doubling of pre-defined 'normal'

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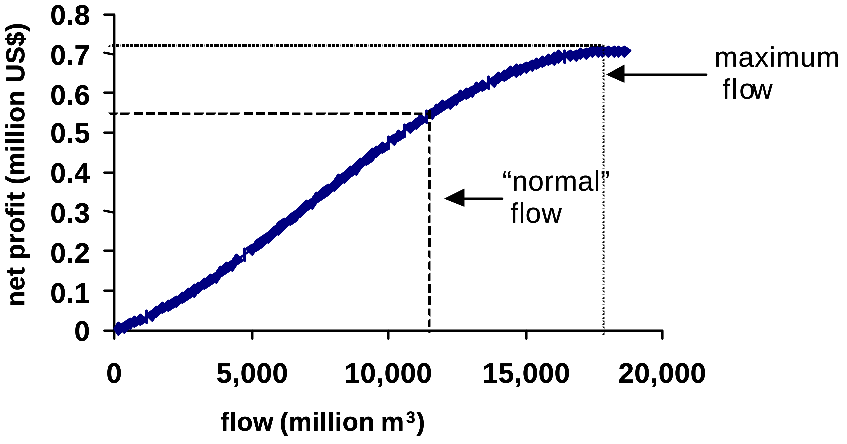
[9] J. Jensen. Personal communication (via email), April 2000.

flows.[10] Profit from fish production (*VF*) is calculated as a function of fish price and production cost, and water availability in the Great Lake and on the mainstream at fisheries demand sites. In order to account for the varying contribution of flows to fish yield, an arctans function is used that relates actual profit from fish production to maximum profit, based on monthly actual, minimum, and maximum water levels. The lowest monthly factors relating actual and maximum instream flows (*mfdft*) and actual and maximum lake storage (*mldft*), calculated from the arctans function, are included in the fish production function. Figure 5 presents an example of the functional form for Yunnan Province. Connecting fishery demand sites in Cambodia, Laos, Thailand, and Vietnam with the storage of Tonle Sap[11] allows for some representation of the importance of migration from the lake to these sites.

Figure 5: Relationship between Profits from Fish Production and Water Availability, Example, Yunnan Province



The function is specified as:

$$\begin{aligned} VF(fdm) = {} & \left[prod(fdm) * a * (fprice(fdm) - f\cos t(fdm))\right] * \\ & mfdft(fdm) * mldft(fdm) \end{aligned} \qquad (11)$$

where:

prod	fish production (mt), by demand site (*fdm*)
fprice(fdm)	fish price (US$/mt)
fcost(fdm)	fish production cost, estimated (US$/mt)
a	parameter relating normal to an estimated maximum fish production
mfdft(fdm)	calculated lowest monthly factor for instream flows from arctans function
mldft(fdm)	calculated lowest monthly factor for Lake Tonle Sap storage from arctans function

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[10] Normal or average flows are defined as baseline flows that account for off-stream water withdrawals and return flows.

[11] The fisheries demand site in Yunnan Province, China, was not connected to Lake Tonle Sap as the influence of the lake on fish production in China is considered negligible.

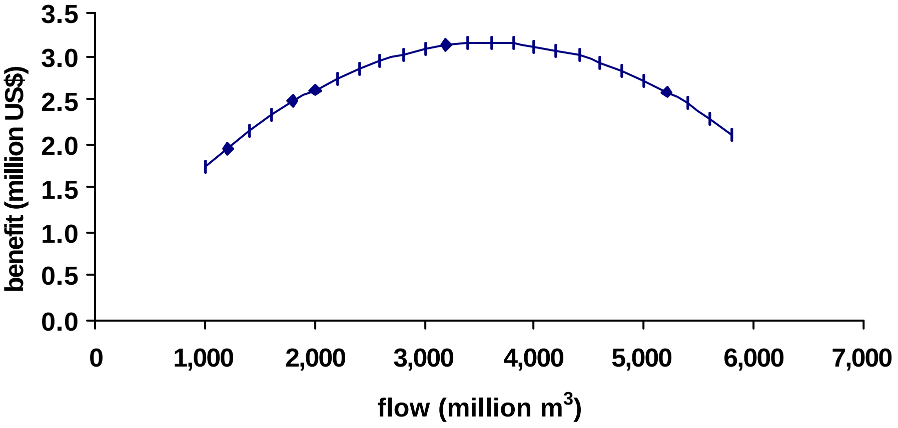
Net benefits from wetlands (*VW*) are specified as a function of wetland area and yield with potential wetland damage related to the deviation of actual flows from representative monthly flows towards both flooding and drought. Thus wetland benefits are a declining function of increasing flow deviations from 'normal' flows (see Figure 6). The flow deviation, *flowdew*, is calculated as the difference between 'normal' flows and flows calculated in the model. The damage coefficients are estimated for each month so that at a flow deviation equal to a doubling of normal flows the damage to wetland benefits equals one twelfth of the maximum wetland benefit. Monthly wetland damages accumulate over the year. The same procedure was used for water storage in the Great Lake, which is assumed to account for half of total wetland benefits in Cambodia.

$$\begin{aligned} VW(wetdm) = & \sum_{pd} warea(wetdm) * wyld(wetdm) * f \\ & - \sum_{pd} (flowdew(wetdm, pd)^2 * damfw(wetdm, pd)) \\ & - \sum_{pd} (lakew(wetdm, pd)^2 * damlw(wetdm, pd)) \end{aligned} \tag{12}$$

where:

warea	area of wetland (ha)
wyld	wetland yield, estimated (US$/ha)
flowdew	deviation of flows from 'normal' flows
lakew	deviation of lake storage from 'normal' storage (only for Cambodia)
damfw	damage coefficient for flows at wetland sites
damlw	damage coefficient for lake storage at wetland site (only for Cambodia)
f	parameter (here: 1.1)

Figure 6: Wetland Net Benefit Function, Example Laos



The model has been coded in the GAMS modeling language, a high-level modeling system for mathematical programming problems (Brooke et al., 1988). The CONOPT2 solver has been used. The model is calibrated to 1990 data. Model calibration is described in Ringler (2001).

4 Model Results

As most of the data in the model have been synthesized from secondary sources and some data has been estimated by the author, model results do not necessarily fully reflect the real situation as far as water uses, users, and the value of water in the basin are concerned. Furthermore, the basin economy is not fully represented as some users, for example, tourism and forestry, and some water sources, for example, groundwater, are not incorporated into the model framework. The focus of analysis of this study is thus less on specific numbers and more on the types of analyses that can be carried out based on such a framework. In the following, the results of the baseline scenario are described and discussed and alternative policy scenarios related to intersectoral and multi-country water allocation are presented.

4.1 Basin-Optimizing Solution (Baseline)

In the baseline, off-stream withdrawals and instream flow demands are driven by the objective of maximizing basin benefits from water use subject to a series of physical and system control constraints as well as minimum instream and downstream flow requirements. According to baseline results, discharge into the South China Sea amounts to 467,584 million m^3. These flows are below estimated 1990 basin flows, which can be explained, in part, from the optimization approach of the model. Outflows to the sea during the dry season (Jan-May) average 4,258 m^3/sec; the lowest flow level occurs in April with 2,036 m^3/sec.

Total effective rainfall for irrigation demand sites amounts to 39,868 million m^3. Actual crop evapotranspiration is estimated at 53,095 million m^3, 95.8% of the total potential crop evapotranspiration of 55,449 million m^3. Total water withdrawals are estimated at 39,279 million m^3, 7.8% of total runoff. A total of 34,356 million m^3 are withdrawn for irrigation and 4,923 million m^3 for domestic-industrial uses. Model results indicate return flows of just over 2% of annual runoff. Return flows as a share of water withdrawals are estimated at 27% for agricultural and at 35% for urban-industrial uses. Effective irrigation efficiency for the Mekong basin, defined as the ratio of crop water evapotranspiration to total water depletion for irrigation in the basin, following Keller and Keller (1995), is estimated at 0.53[12], that is, 53% of the net water delivered to irrigation demand sites is beneficially used. As irrigation efficiency is included as a constant parameter (distribution and conveyance efficiency and field application efficiency are fixed at 0.55 and 0.70, respectively, or at an overall efficiency of 0.39, a value considered typical

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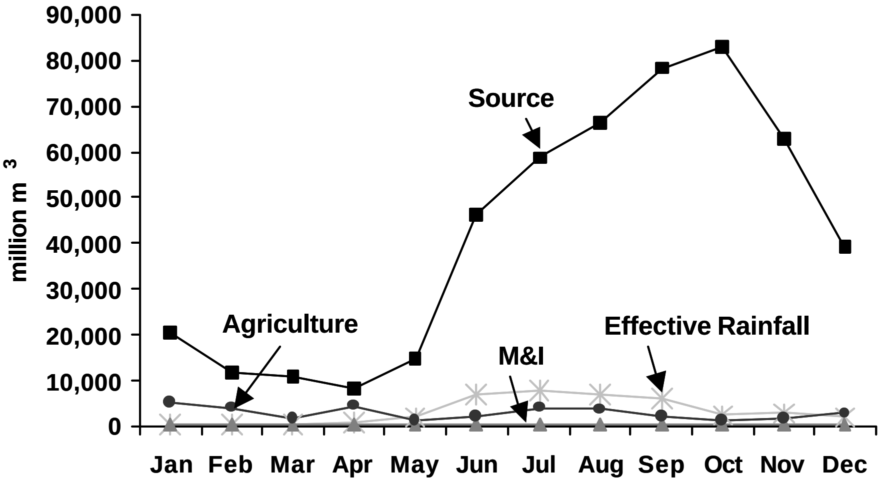
[12] Effective efficiency (IE_e) takes into account the total volume of water delivered from and returned to a basin's water supply (see also Cai et al., 2000 and Keller and Keller, 1995) and is defined here as:

$$IE_e = \frac{\textit{Crop evapotranspiration - Effective rainfall}}{\textit{Volume of water delivered - Volume of water returned}}$$

for the region), effective efficiency does not vary across the year. Total power production amounts to 1,441 GWh.

Figure 7 shows the distribution of water withdrawals, total source flows, and effective rainfall across the year for the baseline solution. A bottleneck in the water supply/demand situation can be seen for the dry-season month of April when gross water demands of 9,661 million m^3—consisting of 4,933 million m^3 of off-stream demands and 4,728 million m^3 of minimum instream flows[13]—need to be met from total inflows of 8,398 million m^3; but also throughout the dry season. Irrigation water demand drops in May, increases again until July, and is again low during September-November when precipitation can meet most crop water demands. Based on this graph, the MRB can be characterized as a basin that has reached a semi-closed state, as off-stream water requirements compete with instream demands during the dry season. In 'open' river basins, excess water is available, over and above all committed legal, ecological and environmental requirements, even during the dry season. In 'closed' basins, on the other hand, there is no excess water flowing out of the basin; all water resources are committed to use. In semi-closed basins, there is excess outflow during the wet season, but not during the dry season (Keller et al., 2000). Many river basins in the world have become closed due to rapid increases in water diversion and depletion and/or increased environmental commitments. The MRB will likely move towards this direction in the future.

Figure 7: Distribution of Inflows and Withdrawals, Mekong River Basin, Baseline Scenario



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[13] Instream flow requirements are not shown in Figure 7.

Total profits from optimal water allocation and use at the basin level are estimated at US$1.8 billion for the baseline year of 1990 (Table 6); US$917 million from irrigated agriculture; US$170 million from M&I water uses; US$43 million from hydropower production; US$546 million from fish catch; and US$134 million from wetlands uses. Vietnam obtains the largest benefits from basin water uses, contributed chiefly by irrigated agriculture and fish production. Thailand ranks second in overall basin profits. Profits from hydropower are largest in Laos, and fish catch and wetlands are the major water-related income sources in Cambodia. To achieve these profits, off-stream water withdrawals are 17,434 million m^3 in Vietnam, 13,004 million m^3 in Thailand, 4,145 million m^3 in Cambodia, 3,318 million m^3 in Laos, and 1,379 million m^3 in Yunnan Province, China. Rice accounts for 88% of total irrigation water withdrawals, and irrigation withdrawals account for 87% of total off-stream withdrawals.

Shadow prices reported in the baseline solution are generally highest during the dry season, reflecting the scarcity value of water during this period. The monthly variation in shadow prices for irrigation demand sites is largest for Northeast Thailand and least for the Vietnamese Mekong Delta. The highest marginal value is reached in Northern Thailand in December at US$0.036/$m^3$. Cambodia and Laos exhibit the lowest monthly shadow prices among all irrigation demand sites. As the urban-industrial water demand sites are at or close to their maximum benefit level the marginal value of additional water use is rather low, on average. Shadow prices for hydropower production are limited to the dry season months of January to May.

Table 6: Baseline Scenario, Profits from Water Use

Country/Region	Irrigation	M&I	Hydro-power	Fisheries	Wet-lands	Total
			(million US$)			
Yunnan, China	20	11		0.05		31
Laos	38	6	33	19	5	101
Vietnam	513	81		188	44	825
VN, Central Highl.	29	6				35
VN, Mekong Delta	484	75		188	44	790
Thailand	320	65	10	151	4	551
N. Thailand	52	5		10		68
NE Thailand	268	60	10	141	4	483
Cambodia	26	7		188	80	301
Total Basin	917	170	43	546	134	1,809

Water stress causes crop yield declines in Vietnam for double- and triple-cropped and floating rice, in Laos for floating rice, in Yunnan Province for wet-season rice, and in Northeast Thailand for dry-season rice with yields declining to 70-90% of maximum (unstressed) levels. As a result, irrigated crop production is 662,000 mt or 3% below maximum potential production. In addition, profits from fisheries and hydropower production reach only 92% and 94% of maximum possible levels, respectively.

The irrigation withdrawal capacity is fully utilized in the baseline solution. Location-specific crop water requirements, irrigation water availability, effective rainfall, crop planting date, length of the growing period, and crop profitability jointly determine water withdrawals. Irrigation water application, measured at the off-take level, is largest for fruit trees, at 20,928-26,768 m^3/ha. Whereas 2,269-3,548 m^3 of irrigation water per hectare are withdrawn for wet-season rice, 11,158-14,157 m^3/ha are allocated to dry-season rice, depending on the demand site. According to Chun (based on Dung),[14] field irrigation requirements of coffee plants in Vietnam are about 6,200 m^3/ha in Lam Dong and Binh Phuoc provinces, which are adjacent to the Central Highland provinces within the basin. This compares well with withdrawals of 10,946 m^3/ha at the off-take level from model results, at a distribution/conveyance efficiency of 0.55.

Net profits per ha harvested area are largest for fruit trees, followed by coffee and sugarcane. Net irrigation profits per ha are largest in the Central Highlands of Vietnam, due to its coffee production. Net profits are lowest for rice production, in particular for dry-season and floating rice production. The productivity of irrigation water, defined as US\$/m^3, depends on both the profitability of the crop and its need for irrigation. Baseline results indicate that water productivity is highest for sugarcane, followed by coffee and maize. Net profits per unit of irrigation water are lowest for dry-season, flood recession, and floating rice production.

Figure 8 presents average water consumption (actual evapotranspiration) from irrigation and effective rainfall per ha harvested area in the basin. Fruit trees consume the largest amount of water on a per-hectare basis, followed by sugarcane, coffee, and triple-cropped rice. Soybean, on the other hand, consumes least. Although, in general, effective rainfall meets the largest share of crop water demands, the average contribution of irrigation water to total crop evapotranspiration is more than half for dry-season rice (77%), vegetables (76%), flood recession rice (54%), and fruit trees and soybean (both 52%).

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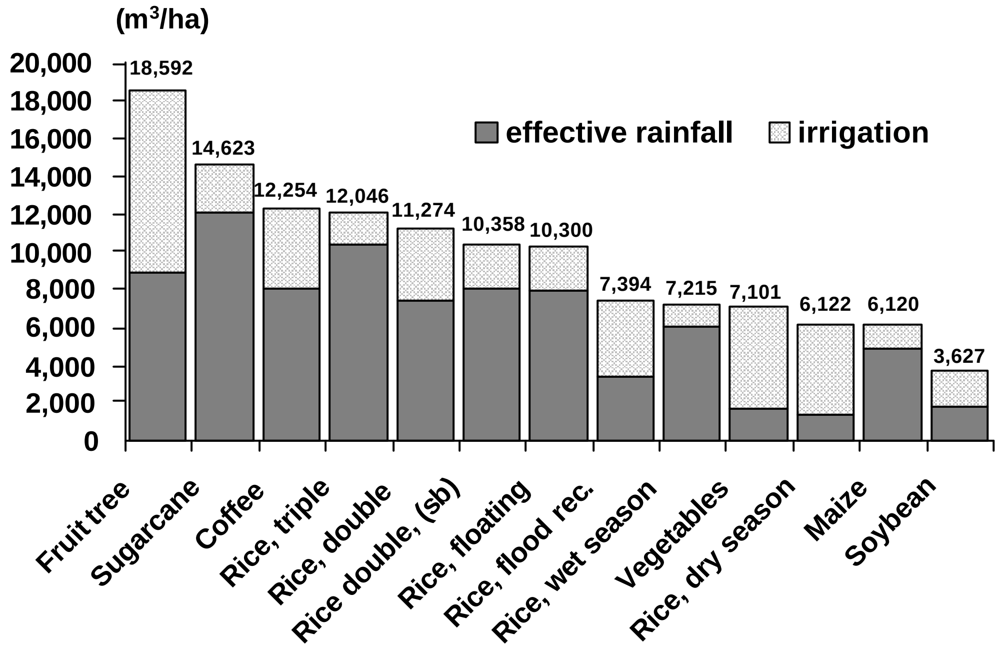
[14] Chun, S. and D.D. Dung. 2000. Personal communication (via email). April.

Figure 8: Average Water Consumption Per Hectare and Crop from Irrigation and Effective Rainfall, Baseline Scenario



Note: Hectare refers to irrigated harvested area.

4.2 Sensitivity Analyses

Table 7 presents a series of sensitivity analyses for the baseline scenario. A reduction in basin runoff by half[15] causes a decline in profits from water uses by 42%. Irrigation profits decline by 36%, M&I benefits by 5%, hydropower profits by 44%, fishery profits by 68%, and wetland benefits by 8%. Agricultural water withdrawals decline by 6%. Moreover, total crop area harvested declines by 2 million ha or 32%. The harvested area of all crops—save coffee and sugarcane—declines. As effective rainfall is reduced concomitantly with a reduction in hydrologic flow levels—here to 75% of normal levels—total agricultural water withdrawals decline less than expected to compensate, at least in part, for the decline in effective rainfall. In the real world, the cost of water abstractions at low flow levels is typically high, causing further declines in farm incomes. Urban-industrial water withdrawals, on the other hand, are typically maintained. At inflow levels of 120%, total basin profits from water use increase to 111%. Profits from irrigation increase to 103%, and irrigation withdrawals decline as effective rainfall availability for crops is increased (here to 110% of average effective precipitation). In addition, profits from fish catch rise sharply whereas benefits from wetlands decline by 4% due to flooding from unusually large flows.

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[15] In scenarios with changes in flow levels, fixed inflows to and outflows from Lake Tonle Sap are replaced with a range of 0.8-1.2 of average flows, and effective rainfall is adjusted.

In the baseline scenario, field application efficiency is estimated at 0.7, that is, 70% of the water applied at the field level is used beneficially by the plant. Overall irrigation efficiency (including distribution and conveyance efficiency) is estimated at 39%. When field application efficiency is reduced to 0.5 (equal to an overall irrigation efficiency of 28%), total basin profits decline by 16%. Under this scenario, irrigation water withdrawals would need to increase by 39% to reach the baseline irrigation level.

However, due to irrigation withdrawal capacity constraints incorporated in the model, the volume of water withdrawals cannot be further increased anywhere but for multipurpose reservoirs in Northeast Thailand, where withdrawals would directly take water away from M&I and instream uses. In fact, there is a slight decline in irrigation water withdrawals in Northeast Thailand in this scenario, due to an existing tradeoff between fish production and irrigation water withdrawals. As incentives for irrigation in the region decline, keeping a small additional amount of water instream for additional income from fish production becomes the preferred strategy. On the other hand, when field application efficiency increases to 0.9 (equal to an overall irrigation efficiency of 50%), total basin profits increase to 104%, due to increased profits in irrigation and, to a lesser extent, increased hydropower and fish production, as less irrigation withdrawals are required to achieve higher profits in the irrigation sector.

A decline in irrigated area by 25% results in a drop in basin profits by 12%.[16] Irrigation profits decline by 24% and irrigation withdrawals by 21%, whereas profits from fish production increase slightly. On the other hand, if irrigated crop harvested area were increased to 175% of baseline levels, total basin profits would increase by 11%, and profits from irrigation alone by 22%. At the same time, profits in the urban-industrial sector and hydropower would decline by 3% and 9%, respectively. Although profits from fish production should drop sharply in this scenario, there is actually a tiny increase in overall profits. This outcome is the result of a substantial increase in fish production profits in Northeast Thailand of US$6.3 million (offsetting sharp declines in other fish production sites). The increase in profits from fish production is achieved at a cost of US$5.2 million of M&I net benefits and US$1 million of hydropower profits, and a relatively low increase in profits from irrigation at just under 8%, corresponding to US$20 million, due to a drop in dry-season rice yield to 50% of maximum potential yield and of fruit tree yield to 97% of maximum potential yield.

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[16] In the sensitivity analysis for irrigated area, agricultural withdrawal capacity levels are adjusted proportionally, as an increase in irrigated area is typically accompanied by an increase in capacity, whereas the deterioration or elimination of irrigated areas is accompanied by a decline in capacity.

Table 7: Sensitivity Analyses, Various Parameters

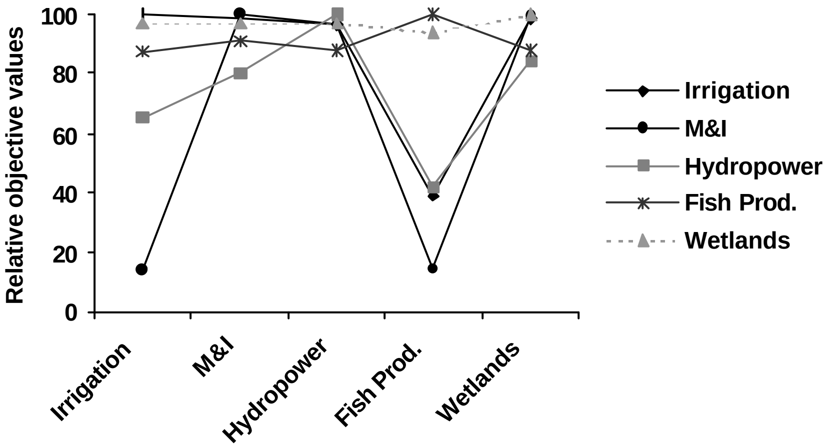
Parameter	Levels/ Values	Irrigation Profit	M&I Benefit	HP Profit	Fish Profit	Wetland Benefit	Total Profit	Irrig. With-drawal
Inflow	50%	64	95	56	32.0	82.0	58	94
	60%	69	99	65	45.0	87.0	66	96
	80%	95	99	76	82.0	95.0	91	87
	120%	103	100	102	133.0	96.0	111	82
Irrigation Efficiency	0.5[/a]	70	98	95	100.3	100.0	84	99
	0.9[/a]	108	100	101	100.7	100.0	104	92
Irrigated Area	75%	76	100	100	101.1	99.9	88	79
	150%	106	98	84	100.0	99.9	103	108
	175%	122	97	91	100.6	99.8	111	123

Note: [/a] Field application efficiency, baseline: 0.7.

4.3 Tradeoff Analyses

In order to show tradeoffs among the competing objectives of irrigated agriculture, urban-industrial water uses, hydropower, fish production, and wetlands, a tradeoff analysis is carried out based on the weighting method. This method is implemented by running a separate scenario for each primary objective. The primary objective in case is multiplied by a factor of 100 while the other objective functions remain unchanged. Scenarios are run for the case of 80% of normal inflows to better demonstrate potential tradeoffs. Overall profits from water uses decline under each of the alternative runs. Figure 9 shows the results from this analysis. The result from the primary objective function in each scenario was scaled to 100. The curves for the individual objective functions show how they fare under the various primary objectives listed on the x-axis.

Figure 9: Tradeoff Analysis among Competing Objectives



Note: Inflow levels are 80% of base levels.

The largest tradeoff for irrigation is with fish production. When fish production is the primary objective, profits from irrigation decline to 39% of the maximum potential level, as fisheries strive for large instream flows, whereas irrigation water withdrawals reduce instream flows with direct negative impacts on fish yield. Tradeoffs with other water users do exist, but at much lower levels: irrigation profits decline to 97% of maximum levels when hydropower is the primary objective, and to 99% of maximum levels when domestic-industrial uses or wetlands are the primary objectives. Strong tradeoffs exist between M&I water uses and both fish production and irrigated agriculture. When either profits from fish production or irrigation are the primary objectives, M&I net benefits drop sharply to 14% of maximum levels. M&I benefits still decline to 80% and 97% of maximum levels when either hydropower or wetlands are the primary objective.

Hydropower competes for instream flows particularly with fish production and irrigated agriculture. When fish production is the favored objective, profits from hydropower generation decline to 42% of maximum levels and when irrigation is favored, hydropower profits decline to 80% of maximum levels. The strong tradeoff with fish production is due to the strategy of fisheries to reduce off-stream withdrawals, to increase the storage level in Tonle Sap, and to ensure large instream flows at fisheries demand sites, particularly during the wet season. This strategy, in turn, changes the timing of hydropower releases and uneven releases from dams reduce hydropower production and profits.

Fish production has similar tradeoffs with irrigation, wetlands, and hydropower. When the latter uses are the primary objectives, profits from fish production decline to 87-88% of maximum levels. The tradeoff between fish production and wetlands is due to their different specifications. The incorporation of a minimum factor relating actual to maximum monthly flows into the fish production function results in increasing wet-season flows for this low-flow scenario, when fish production is the primary objective. When wetlands are favored, on the other hand, dry-season flows increase under low-flow conditions. Changes in flows are produced through changes in reservoir releases and off-stream withdrawals. The tradeoff with M&I water uses is smaller—fish production profits decline to 91% of maximum levels.

The largest tradeoff for wetlands is with fish production; net wetland benefits decline to 94% of maximum levels when fish production is the primary objective, due to differences in their specification as explained above. There is no large tradeoff with other uses (net benefits decline to 97% of maximum levels when the other objectives are favored).

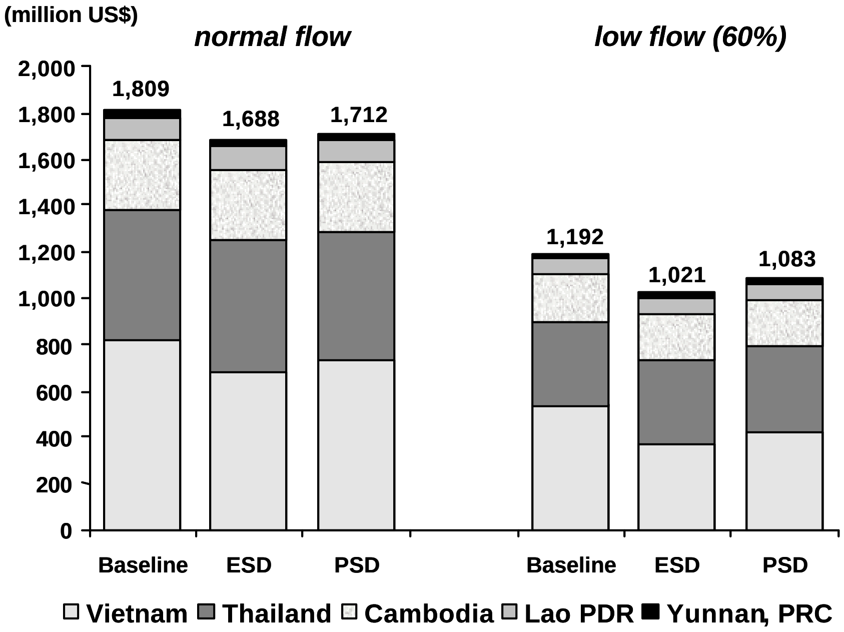
4.4 Alternative Policy Scenario: Parity in Water Allocation

The baseline scenario is a basin-optimizing solution, that is, an omniscient decision-maker maximizing benefits across water uses and regions/countries for the entire basin is assumed. In the real world, the transaction costs for such a decision-maker with 'perfect' knowledge about the basin water economy and the tradeoffs in intersectoral water allocation and use would be prohibitive. In addition, adequate mechanisms to compensate those countries and sectors that give up lower-valued water uses for the benefit of higher-valued uses in other countries and sectors are difficult to implement and seldom exist. Moreover, there are a series of goals and objectives that influence policymakers in their water allocation decisions that are not necessarily congruent with the objective of economic efficiency; for example, water allocation decisions reflecting the relative power structure in the basin or those based on customs and traditions.

Two alternative policy scenarios that incorporate simplified water allocation mechanisms related to parity in water allocation are examined. In the first scenario, named 'Equal Share in Depletion' or ESD, the five basin water users share equally in the total basin water depletion of 28.1 km^3 estimated in the baseline scenario. In the second scenario, 'Proportional Share in Depletion' or PSD, the countries share off-stream uses in proportion to their respective basin populations. Figure 10 presents the results of these two scenarios for total profits from water use in the basin for normal and low levels of runoff (60% of average flows). Total profits from water use decline under both alternative scenarios and for both levels of inflow compared with the baseline scenario. For average flow conditions, total profits in the ESD and PSD scenarios decline to 93% and 95% of baseline profits, respectively. For low flow conditions, profits decline to 86% and 91%, respectively. As the parity condition is only instituted for off-stream water uses, these are affected more than proportionately in the decline in income: Under average flow conditions, profits from irrigation decline to 84% of baseline levels under the ESD scenario and to 89% of baseline levels under the PSD scenario. Under low flow conditions, irrigation profits decline to 70% and 83%, respectively. There is no change in M&I net benefits.

In the ESD scenario, at normal flow levels, Vietnam experiences a large decline in profits from irrigated agriculture, 28%, and a significant drop in overall profits of 17% compared to baseline scenario results. Thailand's irrigation profits decline by 0.5% but the country's total profits from water uses actually increase by 4% due to an increase in fisheries yield. Profits in other countries remain basically the same. In the PSD scenario, irrigation profits decline by 18% in Vietnam and by 9% in Laos, and total profits decline by 11% and 3%, respectively. Thus, in the baseline scenario, both Laos and Vietnam deplete more water on a per capita basis, than Cambodia, Thailand, and Yunnan Province, China. The PSD scenario results in higher overall net profits and a lower decline in irrigation profits for Vietnam, as the Vietnamese basin population allows the country a higher share in depletion than could be achieved in the ESD scenario.

Figure 10: Alternative Scenarios for Parity in Water Allocation



The outcome of these alternative scenarios shows the potentially large impact that water allocation mechanisms and changes in these mechanisms can have on the relative cost/benefit situation in the basin countries and regions. Moreover, to achieve both equitable and optimal benefits from water use across countries and sectors, the optimal strategy would be to strive for the largest basin water use benefits and then to redistribute these benefits instead of the water resource. However, there are few examples of effective compensation mechanisms in a river basin context.

4.5 Alternative Policy Scenario: Inter-Basin Transfer

The guidelines for water allocation mechanisms stipulated in the 1995 Mekong Agreement (Article 26, see Section 2.4) were influenced by the prospect of several large-scale infrastructure development projects in the basin that had been under discussion for some time. Although some very rough estimates on potential flow impacts of some of these development options exist, there has been little examination of their consequences for water allocation and use at the basin level. One of the development options that have been contemplated for a number of years is the Kok-Ing-Nan Water Diversion Project in Thailand that, according to one version, would transfer a total of 2.0 km^3 of water during the wet season and an additional 0.2 km^3 during the dry season from the Northern Thailand tributaries of the Mekong into the Chao Phraya River Basin in central Thailand.

This scenario was implemented into the basin model by decreasing monthly dry- (Dec-May) and wet-season (June-Nov) flows in the Northern Thai tributary to the Mekong proportionally by the specified amounts. If implemented in this way, total basin runoff declines by between 0.13% (December) and 0.80% (August). It is assumed that none of the benefits (and costs) from additional water availability in the Chao Phraya Basin will be transferred back to the Mekong basin.

Two alternative inter-basin transfer scenarios are compared with baseline scenario results. Under the DIV scenario, the diversion is implemented but Northern Thailand can still withdraw water from the Mekong mainstream to compensate for the decline in local sources. Under the DIV/LS scenario, Northern Thailand has to rely on its local surface water sources to fulfill competing agricultural, domestic, and instream water demands in addition to the water transfer out of the basin. To show the cumulative effects of this scenario, the baseline scenario is re-run restricting Northern Thailand water withdrawals to local surface flows without the inter-basin diversion (BASE/LS). Selected scenario results are shown in Table 8 for hydrologic flow levels of 80% of average flows.

Table 8: Alternative Scenarios: Thailand Inter-Basin Diversion

	BASE	**BASE/LS**	**DIV**	**DIV/LS**
		(million US$)		
Irrigation				
Northern Thailand	50.7	44.9	50.7	38.1
Rest, Basin Area	820.3	820.3	820.3	820.3
Fish Production				
Northern Thailand	8.8	0.5	3.7	0.2
Rest, Basin Area	436.5	441.3	434.1	439.7
Basin Profit	1,644.6	1,631.0	1,636.9	1,621.5

Note: Inflow level of 80%.

Total basin profits decline under all alternative scenarios, albeit by small amounts. The basin diversion alone, DIV scenario, has no effects on profits from irrigated agriculture in the region. However, profits from fish production drop by more than half under this scenario; and fish production and, to a lesser extent, hydropower generation in other basin areas are also negatively affected. To ensure that no Mekong basin water users are made worse off under the DIV low-flow scenario, the Chao Phraya basin would need to compensate Northern Thailand for US$5.1 million of lost water use benefits annually, Northeast Thailand for US$25,000, and Cambodia, Laos, and Vietnam jointly for US$2.6 million. This relatively small impact from the planned diversion can be explained by the low planned abstraction compared to total runoff, as well as the possibility of Northern Thailand to withdraw water from the Mekong mainstream to compensate for losses of local sources.

If water abstractions for both irrigation and domestic-industrial water uses in Northern Thailand would have to rely solely on local surface supplies, as specified in scenario DIV/LS, profits in irrigated agriculture would plunge by 25%; and profits from fish production would basically be wiped out. Approximately 60% of the drop in total basin profits under this scenario can be attributed to the reliance on local surface sources as specified in BASE/LS, one third to the diversion itself, and the remainder to the joint effects of reliance on local sources and the inter-basin transfer. About 7% of the net decline in total benefits from water use under the DIV/LS scenario result from negative impacts on basin water uses outside of Northern Thailand—in the fishery and hydropower sectors.

Model results show that if water abstractions are implemented proportionally to existing inflows, and at the relatively low levels postulated, there will likely be little overall impact on the basin economy. Moreover, the impact of the inter-basin transfer on Northern Thailand depends, to a large extent, on its withdrawal infrastructure and capacity and its flexibility to increase withdrawals from the Mekong. If the region has sufficient infrastructure facilities to fully compensate for drops in local surface sources with additional Mekong mainstream withdrawals at no additional cost, the impact on off-stream water uses will be minimal. However, adverse effects on the region's instream uses cannot be avoided. In addition, model results show that an inter-basin water transfer is likely to affect not only the water-exporting region but also water uses in other regions and countries.

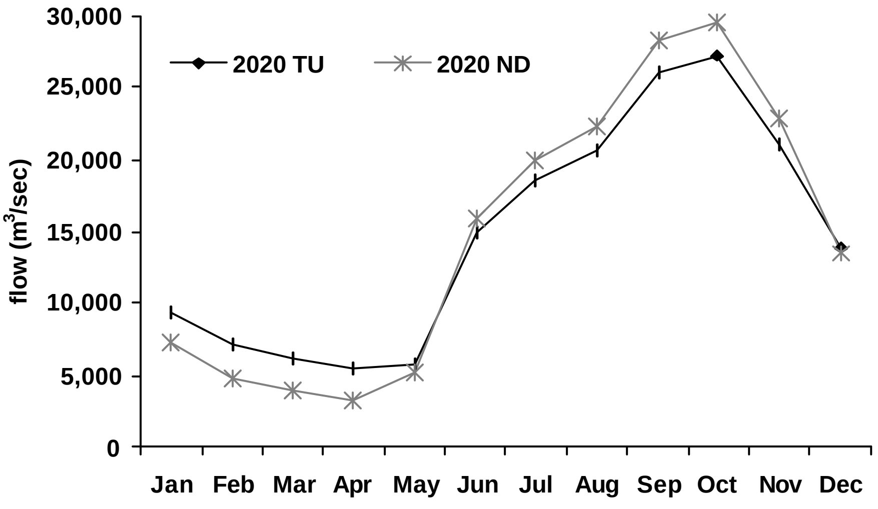
4.6 Alternative Policy Scenario: Upstream Hydropower Development

Increased dry-season flows have been hailed as one of the largest benefits of upstream hydropower development. In order to analyze the effects of additional hydropower projects on the basin water economy, three alternative scenarios were developed for the year 2020, when most of the proposed hydropower projects are supposed to be completed. These scenarios include conservative projections for 2020 off-stream water uses and incorporate additional tributary/upstream and lower mainstream dams into the modeling framework. Projections include an increase in irrigated area of 45%, a more than doubling of M&I withdrawals (Table

4), an increase in fish production by 40%, to reach 1,625,000 mt, and the adjustment of various parameters as described in Ringler (2001). For the 2020 ND scenario, additional water uses are projected without additional hydropower development. For the 2020 with tributary/upstream dams scenario (2020 TU), projected water uses to 2020 were combined with a total of 39 additional hydropower projects in Cambodia (1), Laos (21), Thailand (1), Vietnam (12), and Yunnan Province, China (4). For the 2020 with tributary/upstream/lower mainstream dams scenario (2020 TUM), an additional nine dams were added on the lower Mekong mainstream. These dams were implemented as run-of-the-river hydropower projects, that is, power generation is not dependent on reservoir release but on instream flows. As some of these dams are international, their profits are not allocated to a specific country.

In the 2020 ND scenario, the minimum downstream flow requirement to control saltwater intrusion of 1,500 m^3/sec is reached in April under normal flows. Under low-flow conditions (80% of average flows), it is reached in both February and April. In the 2020 TU scenario, flows into the Mekong Delta increase in April by 64% and, on average, by 26% during the dry-season months of Dec-May (see also Figure 11) compared to the 2020 ND scenario. On the other hand, flows during the rainy season decline, on average, by 8%, with the largest drop in September. The total volume of inflows into the Mekong Delta declines by 2,378 million m^3 or 0.5% due to slightly increased abstractions and thus lower inflows from Thai tributaries into the Mekong as well as increased abstractions by Cambodia, both for irrigated agriculture. The influence on downstream flows is more pronounced under low-flow conditions. At 80% of average flows, dry-season flows into the Delta are 76% higher in March, and 29% higher, on average, in the 2020 TU scenario compared to the 2020 ND scenario. Moreover, runoff decreases by 1.1% or 5,713 million m^3 in the 2020 TU scenario compared to the 2020 ND scenario. The hydrologic regime in the 2020 TUM scenario is very similar to the regime in the 2020 TU scenario as the additional projects are run-of-the-river power stations.

Figure 11: Flows into the Mekong Delta, 2020 ND and 2020 TU Scenarios



Total net profits from water usage, without considering the capital cost of hydropower construction, are largest under the full development or 2020 TUM scenario at almost US$8.3 billion under average flow conditions, compared to US$6.8 billion and US$4.8 billion under the 2020 TU and 2020 ND scenarios, respectively. The increase in profits between the 2020 ND and 2020 TU scenarios is largest for Yunnan, China, at 639%, followed by Laos with 378%. Profits for Vietnam increase by 6%, and for Thailand by 0.3%, but overall profits from water uses decline in Cambodia by 4.4%.

In the 2020 TU scenario, Cambodia benefits from increased water availability during the dry season afforded by flow regulation through additional dams and profits from irrigation increase by US$0.9 million. This increase in profit is minor as values close to maximum potential areas and yields are already achieved for the irrigated areas specified in the 2020 ND scenario. At the same time, profits from fish production and wetlands drop sharply, leaving the country worse off by US$22 million under the 2020 TU scenario compared to the 2020 ND scenario. The drop in fish production is due to the substantial decrease in wet-season flows from hydropower development.[17] Laos, on the other hand, reaps substantial profits from additional hydropower generation in the 2020 TU scenario, most of which would likely be sold to Thailand. These profits are much larger than losses from declines in fish production and wetland uses, affording the country an added annual net wealth of US$810 million, without taking into account construction costs for the additional 21 dams.

Under normal flow levels, Thailand increases its net profit situation by US$3 million in the 2020 TU scenario compared to the 2020 ND scenario, due to increased profits in irrigated agriculture and hydropower production (assuming no decline in fish catch in Northeast Thailand following construction of Pak Mun dam). The net result for Vietnam from increased hydropower production, a small increase in wetland benefits, no change in irrigated agriculture, and a decline in profits from fish production is an increase in total profits of US$188 million. The addition of nine lower mainstream hydropower projects (2020 TUM scenario) results in small increases in basin profits from irrigated agriculture compared to the 2020 TU scenario, an increase in hydropower profits of 69%, a small additional negative impact on fish production, and no additional impact on wetlands. Detailed impacts on the river ecology from lower mainstream dam construction cannot be evaluated based on the current modeling framework.

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[17] Other consequences for the flow regime and migration patterns from additional hydropower development cannot be accounted for in the model.

5 Conclusions

Rapid agricultural and economic development in mainland Southeast Asia during the 1990s has fueled the demand for water resources in the MRB. At the same time, competition over water resources between the various water uses and users has increased rapidly, especially during the dry season. Off-stream uses are directly competing with instream flows for hydropower production, fisheries, wetlands, navigation, a balanced river ecology, and to combat saltwater intrusion in the Mekong Delta. Recent economic growth has also renewed interest in large-scale development of Mekong waters, particularly for hydropower. The Asian financial and economic crisis of the late 1990s has only postponed some of the more ambitious national and international development programs.

Balancing the economic, political, and environmental interests in the basin is a highly complex task. Equitable sharing of transboundary water resources by riparian countries with highly diverse economic development and water resource needs, efficient and beneficial use of scarce water resources, and sustainable development of the natural resources in the basin requires effective international cooperation for the allocation and management of water resources. Tradeoffs among the diverse national and regional development goals must be carefully accounted for and examined in an integrated framework of analysis, in order to facilitate a structured approach to the development of Mekong water resources.

This study introduces an innovative integrated economic-hydrologic model for the entire MRB that allows an analysis of water allocation and use under alternative policy scenarios. The model describes the water supply situation along the river system and the water demands by the various water-using sectors. Water benefit functions are developed for irrigation and domestic-industrial water uses, for hydropower, wetlands, and for fish production. Minimum flows for navigation, ecological water use, as well as minimum outflows to the sea to counter salinity intrusion are included as constraints. Water supply and demand are then balanced based on the economic objective of maximizing net benefits to water use. This structure allows for multi-country and intersectoral analyses of water allocation and use with the objective to determine tradeoffs and complementarities in water usage and strategies for the efficient allocation of water resources. Moreover, the modeling framework can be used for the analysis of the impacts of alternative institutions and water allocation mechanisms on the basin water economy.

Based on the analysis, the MRB can be characterized as a basin that has reached a semi-closed state, as off-stream water requirements compete with instream demands during the dry season. Tradeoffs in water allocation and use are particularly evident between capture fisheries and off-stream water uses. Irrigated agriculture, which includes a wide range of irrigation technologies in the monsoon climate of Southeast Asia—from floating rice production, over wet season supplementary irrigation, to dry-season irrigation—is by far the largest water user in the basin. Moreover, the Mekong Delta in Vietnam is by far the largest water user and the region benefiting most from water uses in the basin. The dependency on large dry-season water withdrawals and its location at the downstream end of the basin makes the Vietnamese delta particularly vulnerable to changes in upstream water management and uses.

Model results show that a change in the cropping pattern and the choice of crop alone could save large amounts of water resources in the dry season, as both, the water consumption per hectare from irrigation and the water productivity vary substantially by crop. Moreover, increases in the field application and overall water use efficiency, which allows for the irrigation of more area with the same amount of water not only improves the water productivity in agriculture, but also benefits fisheries and hydropower production.

An analysis of alternative water allocation mechanisms that explores the impact of parity in allocation on basin profits shows that to achieve both equitable and optimal benefits from water use across countries and sectors, the strategy should be to strive for the largest basin water use benefits and then to redistribute these benefits instead of the water resource. However, there are only few functioning examples of transboundary compensation mechanisms in international river basins. Results from an alternative scenario of a relatively low unilateral inter-basin water transfer by Thailand show that if water abstractions are implemented proportionally to existing inflows, and at the relatively low levels postulated, and if the exporting basin has sufficient means to compensate for declines in local sources, there will likely be little overall impact on the basin economy. However, profits from (instream) water uses decline in the exporting basin and the transfer can negatively affect water uses in other basin regions and countries.

The analysis of alternative hydropower development scenarios for the year 2020 shows that changes in technical parameters related to future water allocation and use in the basin lead to a series of new intersectoral and inter-country tradeoffs. The incorporation of additional hydropower projects can help alleviate dry-season water shortages in the Mekong Delta and elsewhere—although the effects on basin income from off-stream water uses are minor, according to model results, due, in part, to conservative projections of future water uses. The added benefits from future hydropower development for other sectors—here US$4.4 million for irrigated agriculture—are overshadowed by losses in the fishery and wetland sectors of US$62 million. Cambodia is particularly vulnerable to large-scale hydropower development.

The countries in the Mekong River Basin need to cooperate very closely to achieve the benefits indicated from model results. The optimal utilization of the basin water resources through allocation of water to the highest valued uses requires extensive information about the quantity and value of Mekong waters over space and time. Although the Mekong River Commission cannot play the role of ‘close-to-omniscient’ decision-maker in the basin with ‘perfect’ knowledge about the basin water resources—the information and transaction costs would be prohibitive—the riparian countries should still strive to collaborate more closely so as to increase both national and overall basin benefits.

The development of integrated economic-hydrologic modeling tools together with complementary analyses can be a critical first step to overcome some of the obstacles to effective management and joint cooperation in the Mekong River Basin. It could also facilitate the upcoming negotiations of water allocation rules in the lower basin and thus contribute to the reasonable and equitable utilization of Mekong River waters, as envisioned in the 1995 Mekong Agreement.

References

Bogardi, J.J. (1997): Report on the Review Mission of the Mekong Hydrology Programme. Prepared for the Mekong River Commission Secretariat. Bangkok: Thailand.

Braat, L.C. and W.F.J. Lierop (1987): Integrated economic-ecological modeling. In Integrated Economic-Ecological Modeling, eds. Braat, L.C. and W.F.J. Lierop. Amsterdam: North-Holland.

Brooke, A. Kendrick, D., and A. Meeraus (1988): GAMS: A User's Guide. San Francisco, California: Scientific Press.

Browder, G. (1998): Negotiating an International Regime for Water Allocation in the Mekong River Basin. PhD Dissertation. Stanford University.

Cai, X., Ringler, C., and M.W. Rosegrant (2000): Examining physical and economic efficiencies of water use at the river basin scale through integrated economic-hydrologic water modeling. Paper prepared for the International Symposium on 'Integrated Water Resources Management', April 9-12. Davis, California.

Chea, V. (1999): Interview at the Phnom Penh Public Water Supply Authority. Interview notes, BDP detailed planning phase, March. Phnom Penh, Cambodia. (Mimeo).

Chea, V. (1998): Water supply in Phnom Penh. In: Towards Efficient Water Use in Urban Areas in Asia and the Pacific. ESCAP. ST/ESCAP/1874. New York: UN.

CIESIN (Center for International Earth Science Information Network) (2000): Accessed at <http://sedac. ciesin.org/china/popuhealth/popagri/census90. html>.

Crousillat, E. (1998): Developing international power markets in East Asia. Public Policy for the Private Sector Note No. 143. Accessed at <http://www. worldbank.org /html/fpd/notes/143/143summary.html>.

Department of Livestock and Fisheries (1999): Irrigated area projections for Lao PDR. Information received by Mr. Singkham Phonvisay, Dir. General, Department of Livestock and Fisheries, Ministry of Agriculture and Forestry. Interview notes, BDP detailed planning phase, March, Vientiane, Lao PDR. (Mimeo).

Doorenbos, J. and A.H. Kassam (1979): Yield Response to Water. FAO Irrigation and Drainage Paper No. 33. Rome: FAO.

Doorenbos, J. and W.O. Pruitt (1977): Guidelines for Predicting Crop Water Requirements. FAO Irrigation and Drainage Paper No. 24 (rev.). Rome: FAO.

Dublin Conference (1992): Dublin Statement on Water and Sustainable Development. International Conference on Water and the Environment, Dublin.

ESCAP (Economic and Social Commission for Asia and the Pacific) (1998a): Sources and Nature of Water Quality Problems in Asia and the Pacific. ST/ESCAP/1874. New York: UN.

ESCAP (1998b): Towards Efficient Water Use in Urban Areas in Asia and the Pacific. ST/ESCAP/1874. New York: UN.

FAO (Food and Agriculture Organization of the United Nations) (1999): Irrigation in Asia in Figures. Water Report No. 18. Rome: FAO.

FAOSTAT (Food and Agriculture Organization of the United Nations Statistical Database) (1999): Accessed at <http://faostat.fao.org> Accessed July/August 1999.

FAO/UNDP (1994): Cambodia: Agricultural Development Options Review (Phase I). Sector review. Report No: 42/94 UNDP - CMB 1 SR. Rome: FAO.

GRDC (Global Runoff Data Center) (1998): Purchased flow data for various flow measuring stations of the Mekong and tributaries. Koblenz: GRDC.

Hirsch, P. and G. Cheong (1996): Natural Resource Management in the Mekong River Basin: Perspectives for Australian Development Cooperation. Accessed at <http://www. usyd.edu.au/su/geography/Hirsch>.

Interim Committee for Co-ordination of Investigations of the Lower Mekong Basin (No year): Lower Mekong Hydrologic Yearbook 1990. Bangkok, Thailand: Interim Committee for Co-ordination of Investigations of the Lower Mekong Basin.

Keller, A.A., R. Sakthivadivel, and D. Seckler (2000): Water Scarcity and the Role of Water Storage in Development. Research Report 39. Colombo, Sri Lanka: International Water Management Institute.

Keller, A.A. and J. Keller (1995): Effective Efficiency: A Water Use Efficiency Concept for Allocating Freshwater Resources. Discussion Paper No. 22. Center for Economic Policy Studies, Winrock International.

Kingdom of Thailand (1997): Mekong Basin Development Plan Phase I. A Country Report: Thailand. Submitted to Mekong River Commission Secretariat. Final Report. Bangkok, Thailand.

Lao PDR (1997): Mekong Basin Development Plan: Lao Economic Development, Policies, Strategies in National and Mekong Cooperation Context. Final Report. Bangkok, Thailand: MRCS.

McKinney, D.C., X. Cai, M.W. Rosegrant, C. Ringler, and C.A. Scott (1999): Integrated Basin-Scale Water Resources Management Modeling: Review and Future Directions, IWMI SWIM Paper No. 6. Colombo, Sri Lanka: International Water Management Institute.

Mekong Secretariat (1994a): Executive Summary. Mekong Mainstream Run-Of-River Hydropower. Bangkok, Thailand: Mekong Secretariat.

Mekong Secretariat (1994b): Irrigation Rehabilitation Study in Cambodia. Final report. Report prepared by Sir William Halcrow and Partners in association with Mandala Agricultural Development Corporation, Annex A, B and D. Bangkok, Thailand: Mekong Secretariat.

MRCS (Mekong River Commission Secretariat) (1998): Inventory and Management of Wetlands in the Lower Mekong Basin. Review and Assessment Report for Phase I (1990-1996). Environment Unit. Bangkok, Thailand: MRCS.

MRC (1998c): Water Utilization Program Preparation Project. Final report. MKG/R.98/013. Prepared by SMEC International Pty Ltd. Phnom Penh, Cambodia: MRC.

MRC (1997): Mekong River Basin Diagnostic Study. Final Report. MKG/R. 97010. Bangkok: Thailand.

MRCS (1995): Hydropower Programme for the Lower Mekong Basin. Programme Proposal. MKG/R.95059, September. Bangkok, Thailand: MRCS.

Mundkur, T., B. O'Callaghan, and M. Silvius (No year): Wetland resources of the Mekong River Basin. A preliminary assessment of its wildlife, particularly waterbirds. Draft. (Mimeo).

NEDECO (Netherlands Engineering Consultants) (1993a): Mekong Delta Master Plan: Thematic Study on Management of Water Resources. Vol. 1: Optimal use of water resources. Bangkok: Mekong Secretariat.

Osborne, M.E. (1975): River Road to China: The Mekong River Expedition, 1866-1873. New York: Liveright.

ORSTOM/BCEOM (1993): Development Plan for Tonle Sap and Chakdomuk. Phase I. Final Report. Prepared for the Mekong Secretariat. Bangkok, Thailand.

Phanrajsavong, C. (1996): Hydropower development in the lower Mekong basin. In Development Dilemmas in the Mekong Subregion. Workshop Proceedings, 1-2 October, Melbourne, Australia, ed. B. Stensholt. Clayton, Australia: Monash Asia Institute.

Phan, S.K. (1996): Water resources development in Vietnam. Paper presented at the International Seminar of 1996 World Day for Water, 20-25 March, Korea. (Mimeo).

Ringler, C. (2001): Optimal Allocation and Use of Water Resources in the Mekong River Basin: Multi-Country and Intersectoral Analyses. PhD dissertation. Bonn University. Frankfurt: Peter Lang Verlag. Forthcoming.

Rosegrant, M.W., C. Ringler, D.C. McKinney, X. Cai, A. Keller, and G. Donoso (2000): Integrated economic-hydrologic water modeling at the basin scale: The Maipo River basin. Agricultural Economics 24(1): 33-46.

Rosegrant, M.W., X. Cai , C. Ringler, A. Keller, G. Donoso, and D.C. McKinney (1999): Report for the Inter-American Development Bank on integrated economic-hydrologic water modeling at the basin scale: The Maipo River Basin in Chile. Washington, D.C.: IFPRI.

Rothert, S. (1995): Lessons Unlearned: Damming the Mekong River. Working Paper No. 6, Berkeley, Ca.: International Rivers Network.

Schouten, R. (1998): Effects of dams on downstream reservoir fisheries, case of Nam Ngum. Catch and Culture 4(2): 1-5.

Scott, D.A. and C.M. Poole (1989): A Status Overview of Asian Wetlands. Kuala Lumpur: Asian Wetlands Bureau.

UN (United Nations) (1998): World Population Prospects: The 1998 Revision. Population Division, Department for Economic and Social Information and Policy Analysis. New York: UN.

UN (1997): Commission on Sustainable Development. Comprehensive Assessment of the Freshwater Resources of the World. Fifth session, April 5-25. Accessed at <http://www.un.org/>.

Van Zalinge, N., N. Thuok, and T.S. Tana (1998): Where there is water, there is fish? Cambodian fisheries issues in a Mekong regional perspective. Paper contributed to the Mekong Panel at the Seventh Common Property Conference of the International Association for the Study of Common Property, Vancouver, Canada, 10-14 June.

World Bank (2000a): East Asia: From recovery to sustained growth. An update. Presentation of the East Asia and Pacific Quarterly Brief. by Jemal ud-din Kassum, Vice President, East Asia and Pacific region. March 22. Accessed at: <http://wbln0018. worldbank.org/eap/eap.nsf>.

Young, R.A. (1995): Coping with a severe sustained drought on the Colorado river: Introduction and overview. Water Resources Bulletin 31(5): 779-788.