Chapter 2
Water Sector Analysis

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1 Introduction

This Chapter focuses on the water resources and associated environs of the Mekong River Basin. First, the Chapter reviews and analyses the suite of potential implications for water arising from the implementation of the six contemplated decisions described in Chap. 1. Second, a derived cumulative analysis is described.

The Asian Development Bank (ADB 2009) divides the water sector into:

(1) Rural water – referring to aspects of rural water supply and sanitation, irrigation and drainage;
(2) Urban water – referring to urban water demands and water supply, sanitation and wastewater services, and urban environmental improvement; and
(3) Basin water – referring to the state of river health, planning, infrastructure including hydropower impoundments, natural hazard management, climate change, water catchment and wetland conservation.

The Mekong River Commission (MRC) classifies water as:

(1) Active sectors – referring to water supplies (domestic and industrial), irrigated agriculture, hydropower, and flood management and mitigation; and
(2) Passive sectors – referring fisheries, navigation and river works, tourism and water related recreation, and riverine environments (MRC 2010b).

Both the ADB and MRC water sector typologies have advocates and critiques, with for example the water sector differentiated into active and passive sectors strongly criticized by staff members of the MRC Secretariat (Regional POE 2010). The Chapter review adapted the water sector definition by the MRC, by considering an expanded

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set of relevant water use activities (including in-stream uses and other values) as equally important and active.

Where data of sufficient reliability is available, the Chapter discusses investment decision implications for the wider Mekong Region. However, the majority of available data and analyses for the water sector within the Mekong Region are concentrated on the Mekong basin.

The present Chapter contains three main sections:

Section 1. The Status Quo describes the current status of the 'water resources' sector in the wider Mekong Region and is intended to convey to the non-expert reader sufficient insight to appreciate the current sectoral perspective.

Section 2. An assessment of the six development decisions assuming they were to be implemented independently, highlighting the implications of each of these changes/decisions for Mekong basin water resources.

Section 3. A cumulative assessment of water resource outcomes, assuming the joint and concurrent implementation of the six investment decisions.

2 Status Quo of Water Resources in the Mekong Region

The Mekong Region's rich but fragile natural resources include a substantial and diverse agricultural base, timber and fisheries resources, considerable mineral potential, and extensive energy resources in the form of hydropower and large coal and petroleum reserves (ICEM 2010; ADB and SEI 2002). A number of development initiatives that effect water to varying degrees are at various stages of planning and development in the Mekong Region including; transportation (road transport, rail transport, water transport and air transport), energy generation (hydropower, natural gas), tourism, and international trade (ADB and SEI 2002; Pech and Sunada 2006; Molle et al. 2009).

The substantial and (until recently) relatively unmodified water resources of the Mekong basin have the capacity to support ongoing economic development in terms of irrigation and agricultural production, fishery and aquaculture, energy and forest products, navigation and other modes of transport, domestic and industrial water supply, and tourism (MRC 2010a).

2.1 Water Resources in the Mekong Region

Compared to many other global regions, the Mekong Region has high annual rainfall, especially in the mountainous catchments (see Table 2.2). Low annual precipitation amounts of less than 1,000 mm per year are found only in parts of Thailand, and at high elevation in the river headwater areas in Tibet, People's Republic of China (ADB and SEI 2002; MRC 2010a).

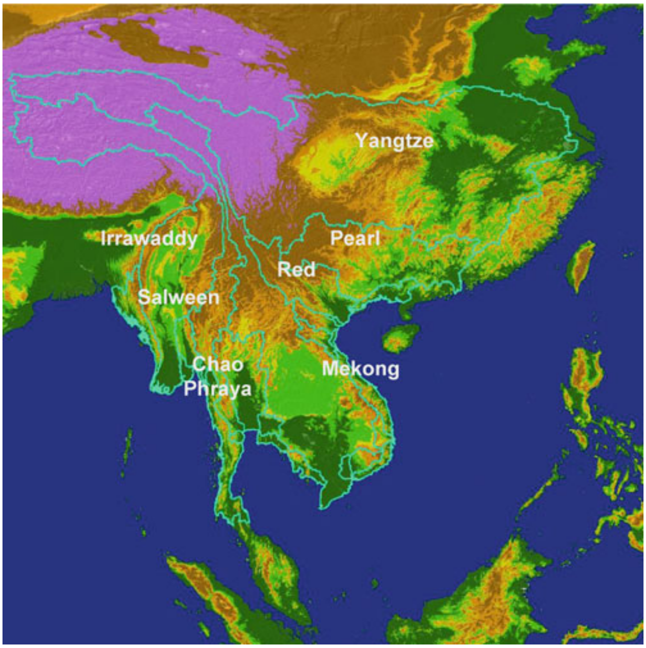

Fig. 2.1 Map of Mekong Region and major river systems (Source: Map courtesy of ICRAF)

The five major rivers in the Mekong Region depicted in Fig. 2.1 include: The Mekong (referred to as the Lancang Jiang in China), Red or Hong (Yuan Jiang), Chao Phraya, Irrawaddy and the Salween (Nu). Except for the Chao Phraya, the rivers are shared by more than two countries (ADB and SEI 2002). The mean volume of annual Mekong River runoff (475,000 million meter cubes (mm^3) in an average year) makes it the largest of the five Mekong Region rivers (Table 2.1) and the eighth largest river in the world (MRC 2010a). To date the Mekong River has also dominated development considerations and the subject of a diverse and competing set of claims. Snow melt in the upper Mekong catchment are the primary source of inflows from May to July, and summer monsoon rain from July to October are the main source of inflows (and floods) in both the main stem and tributaries, especially within Lao PDR and the Central Highlands of Viet Nam.

It is important to highlight that the upstream flows from the Upper Mekong in China contribute over 16 % of the total flow in an average year, while 55 % comes from the left bank tributaries in Lao PDR along with the Se Kong, Se San and Sre Pok (3S) River system (Vietnam Central Highlands, Lao PDR and Cambodia). However, during the dry season, snowmelt from China contributes 24.1 % of the total flows (see Table 2.2) (MRC 2010a).

Table 2.1 Summary of major river systems and reservoirs in the Mekong Region

Characteristic	Mekong	Red or Hong (Yuan Jiang)	Chao Phraya	Irrawaddy	Salween (Nu)
Countries in basin	All	PRC, Vietnam Lao PDR	Thailand	Myanmar, PRC, India	PRC, Thailand, Myanmar
Basin (catchment) area (km^2)	777,000 + 73,000 in Tibet & Qinghai	226,000 (40 % in Vietnam)	160,000	411,000	325,000
Area above 3,000 m altitude, km^2	62,000 (7 %)	Negligible	Zero	8,000 (<2 %)	90,000 (28 %)
Mean annual Runoff, mm	560	782	188	1,000	466
Water yield per annum, mm^3	475,000	177,000	29,800	410,000	151,000
Major dependent cities	Phnom Penh, Vientiane, Ho Chi Minh City, Can Tho, Khon Kaen	Hanoi, Hai Phong	Bangkok	Rangoon	Moulmein
Extent of lands under irrigation	Large	Large	Large	Large	Small
Number of existing storage reservoirs with surface area >20 km^2	xx	4	2	Data not avail	0
Level of water quality pollutants from human activities	Low (high at certain loclities during dry season low flow)	Medium	High	Low	Very low

Source: ADB and SEI (2002)

Compared to other global regions in the world in term of actual renewable water resources per capita,[1] the Mekong basin is not water stressed. The annual renewable water resources (ARWR) per capita give the maximum theoretical amount of water available per person, though in reality a large portion of this water may not be

[1]According to World Resources Institute, *Per Capita Actual Renewable Water Resources* is the maximum theoretical amount of water actually available on a per person basis for each country. It is a sum of internal renewable resources (IRWR) and external renewable resources (ERWR), including the flow for upstream and downstream countries and the potential reduction of external flow due to upstream water abstraction. Internal renewable water resources (IRWR) are comprised of the average annual flow of rivers and recharge of groundwater (aquifers) generated from endogenous (internal) precipitation. Even though IRWR measures a combination of surface and groundwater resources, it is typically less than the sum of the two because of overlap – water resources that are common to both surface and groundwater.

Table 2.2 Key hydrological characteristics of Mekong River Basin

	Yunnan	Myanmar	Lao PDR	Thailand	Cambodia	Vietnam	Total
Catchments (km2)	165,000	24,000	202,000	184,000	155,000	65,000	795,000
% of MRB total	22	3	25	23	19	8	100
% of total country's area	38	4	97	36	86	20	
Average rainfall (mm/year)	1,561		2,400	1,400	1,600	1,500	1,750
Average runoff (m^3/s)	2,414	300	5,270	2,560	2,860	1,660	15,060
Average runoff (MCM/year)	76,128	9,461	166,195	80,732	90,193	52,350	474,932
In dry season	19,032	1,419	24,929	12,110	13,529	7,852	78,871
Average runoff as % of total	16	2	35	17	19	11	100
In dry season	24.1	1.8	31.6	15.4	17.2	9.9	
Population (million)	10	0.5	4.9	24.6	10.8	21	71.8

Source: MRC (2005b), UNEP/GIWA (2006)

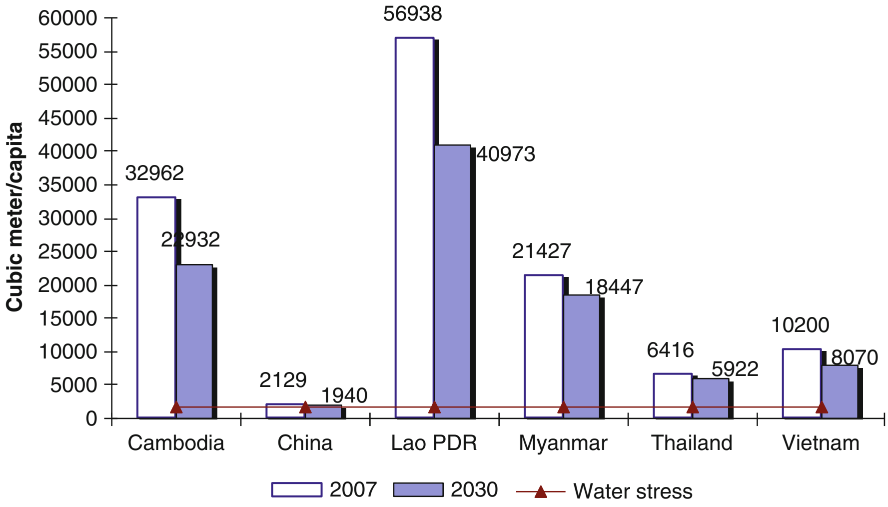

Fig. 2.2 Maximum theoretical amount of water actually available, on a per person basis, for each country in Mekong Region (provincial data for Yunnan not available) (Data source: WRI 2011)

accessible for human use (Ravenge and Mock 2000). National water stress is defined as annual per capita water availability below 1,700 m^3/year. In absolute terms, per capita water availability in Yunnan, Thailand and perhaps the Vietnam Delta are comparatively the lowest, whilst Lao PDR, Myanmar and Cambodia are well above the water stress limits (Fig. 2.2). Assuming that current water consumption patterns continue unabated, 20 year projections indicate that the most populous countries of

China, Vietnam and Thailand will tend towards increased water stress as water consumption rises (WRI 2011; see Fig. 2.1). Countries where the mean annual per capita water availability appears sufficient may actually face water shortages in the dry season and drought years. The highest marginal reduction in water availability per capita is estimated to occur in Cambodia and Lao (about 30 % of reduction), due to relatively high rates of population growth in the Mekong Region. It is important to note that the 2030 projections are slightly conservative because they are based on the UN's medium fertility assumption of population growth (UN 2007).

Competing water claims in the Mekong basin are closely related to the unequal spatial and temporal distribution of river flows, and the lack of a robust institution capable of negotiating and enforcing trans-national coordination and well-informed decision making for water resources development. Much of the runoff occurs during floods or is considered inaccessible because of remote locations. A proportional share of runoff is required to maintain other in-stream uses and non-consumptive social and ecological services (Halcrow Group 2003). For instance, the mean annual discharge of the Mekong River is 13,700 m^3/s with a peak wet season average discharge of 52,400 m^3/s resulting in widespread flooding. Minimum discharge during the dry season is approximately 30 times less at 1,600 m^3/s corresponding with the period of maximum water demand for food production (ADB and SEI 2002; MRC 2003).

Despite the relatively high renewable water resources per capita typifying Mekong basin countries, a number of locations currently face a series of critical water issues, such as:

- Water shortages in Thailand coupled with increasing irrigation water demands;
- Increasing salinity intrusion in the Vietnam Mekong delta;
- Threats and declines in basin fisheries and the degradation of natural habitats in many parts of the Basin;
- Recurring un-seasonal floods and drought;
- Reduced water quality, land-subsidence and morphological changes in delta areas; and
- Intensification of sectoral competition within and among the Mekong countries (MRC 2010a).

Based on the current hydrological reality of the Mekong River Basin, Fig. 2.3 describes a monthly assessment of water demands at key locations of River reaches.

2.2 *Water and Ecosystem Productivity and Integrity in the Mekong Basin*

The structure and functions of Mekong basin wetlands are closely linked to the seasonal flow pattern of the river, typified by a wet season flow of up to 10 m higher than the dry season. Fluctuations in river flow and consequent flooding change the

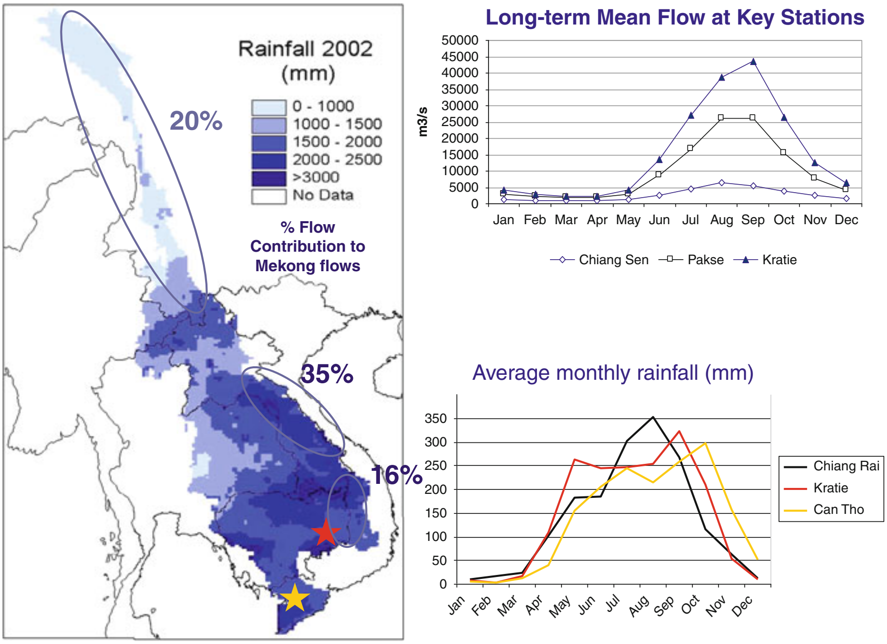

Fig. 2.3 Precipitation and flow contribution from MRB sub-basins (Source: MRC 2003)

structure and functionality of wetlands and subsequent productivity (Nikula 2008).[2] The river channel and wetland habitats are crucial for the ecological functioning of the river system.

The Mekong is a fluvial river system which changes substantially from upstream gradients to downstream deltas. Differences are evident as changes in water discharge and sediment transport (sediment flows, that are moved either on the bottom (bed load), in suspension, or in solution, or nutrients attached to the suspended matters, and/or in solution of the flows), and changes in the nature of the river geomorphology bed (bedrock, substratum, or geological base) (see e.g. Miyazawa et al. 2008). The fluvial continuum and hydro-system incorporates longitudinal exchanges of water, sediment, nutrients and species from upstream sources to the delta; lateral exchanges between the channel and its floodplain; and, vertical exchanges of water, nutrients and fauna between the river itself and the groundwater. These systems are of prime importance along the large rivers in the Mekong Region (Bravard and Goichot 2010).

The life-cycles of many Mekong fish species and adjacent coastal zones correspond to the cyclical annual fluctuations of the river's hydrological and sediment/

[2] An important feature is the Mekong Basin is its rich riverine ecology, fueled by the annual "flood pulse" especially in the Tonle Sap Great Lake where the seasonal cycle of changing water levels at Phnom Penh results in a very large flow reversal of water into and out of the lake via the Tonle Sap River.

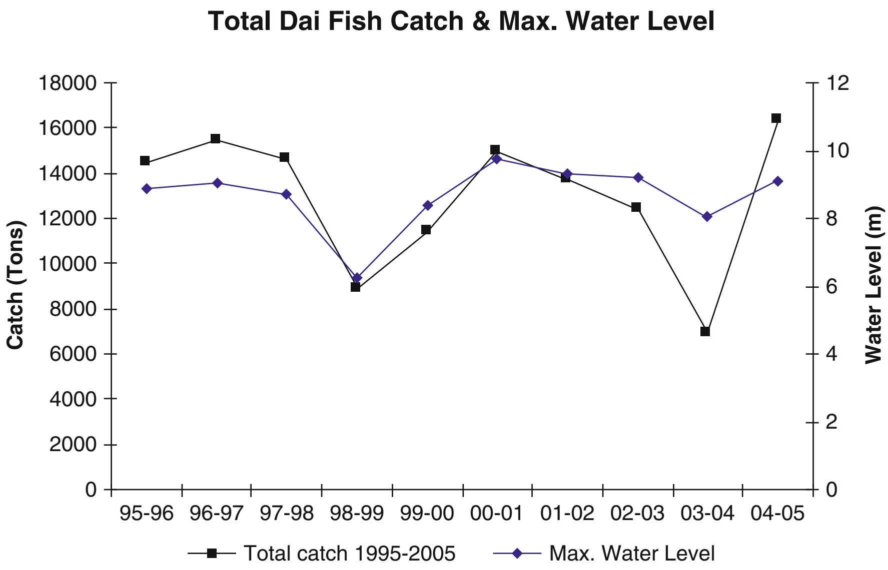

Fig. 2.4 Relationship between total Dai fish catch and maximum water level along the Tonle Sap River (Cambodia)

nutrient regime. Fish migrate to deep pools in the mainstream to take refuge during the dry season, and migrate back to spawning and feeding grounds on floodplains during the flood season. The importance of the flood pulse and morphological dynamism to the river system productivity and sustainability is considered in this study in addition to other key variables for assessing the Mekong River water sector.

Ten year time series data (1995–2005) from the Tonle Sap Lake Dai fishery (dragnet fishery targeting migratory fish species down from Tonle Sap Lake) show a strong correlation between the fish catch, the water level and inundated area (Baran 2005; Catch and Culture 2005). Based on a comparative analysis of the 1995–2005 Dai fish catch coupled with the Mekong River flood levels, Zalinge et al. (2003) maintain that higher floods and associated increase in Tonle Sap flood plain sediment and inundation areas, led to an improvement in survival and growth of fish and fishing yields.[3] The 2003–2004 fish catch of 6,000 metric tons is the lowest since systematic monitoring began in 1994–1995 (Catch and Culture 2005). 2003–2004 was also a period of reduced flow, inundated area and a shorter duration of inundation and increased fishing pressure. The increased Dai fishing catches of 2004–2005 (16,000 metric tons – the highest over the past 10 years) were associated with above average flood levels, longer flood peak duration and reduced illegal fishing (Catch and Culture 2005). The 2003–2005 fish catch and water level data illustrated in Fig. 2.4 point to a sensitivity of fish productivity to Tonle Sap flood levels

[3] ICEM report (2010) estimated that the Mekong marine fish catch is about 0.5 million tonnes/year and reliant on the Mekong marine plume.

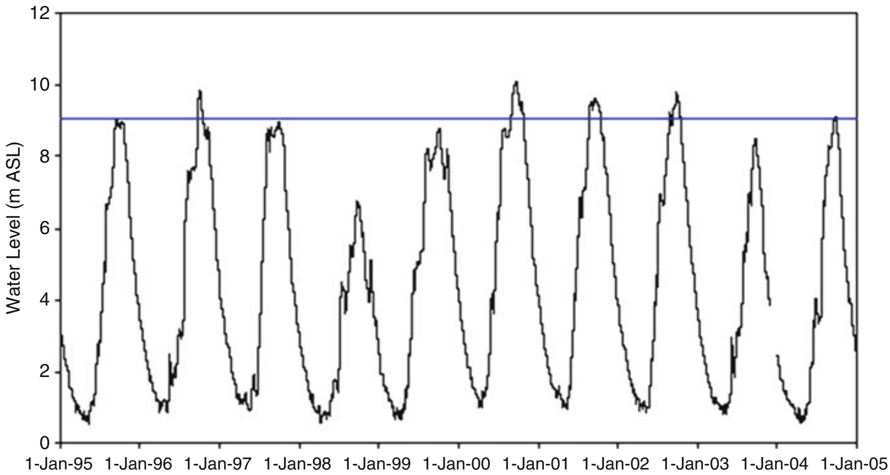

Fig. 2.5 Daily water levels at Phnom Penh port (Tonle Sap River) 1995–2005 (Source: Catch and Culture 2005)

and the spatial extent and duration of flood plain inundation (Catch and Culture 2005). Figure 2.5 illustrates the associated January water levels at the confluence of the Tonle Sap and Mekong rivers for the same period.

Elevation and duration of flood play a key role in the general ecology driving the fish production, as most of the impacts are related to time, height and duration of flood.

2.3 Observed Long Term Flow Variability

A time series hydrological analysis at selected assessment points along the Lower Mekong River (annual maximum and mean annual flows from 1924 to 2002) indicates a long term decrease in annual flow at all stations, except for Luang Prabang (Fig. 2.6). The flow decreases point either to a change in the hydrologic response of the major tributary dams downstream of Vientiane or to a decrease in the regional rainfall since the late 1960s (see also Halcrow Group 2003).

The available rainfall data from key stations shows different rainfall trends in different parts of the Mekong basin, with a general decrease in the upper parts of the Basin, and a general modest rainfall increase in the Central Highlands and Mekong delta in Vietnam.

Countries in the lower Mekong Basin are among the most vulnerable to climate change in the world. It is yet to be ascertained how rising temperatures, greater variability of rainfall, rising sea levels, and coastal inundation will affect the basin. According to the Intergovernmental Panel on Climate Change (IPCC),

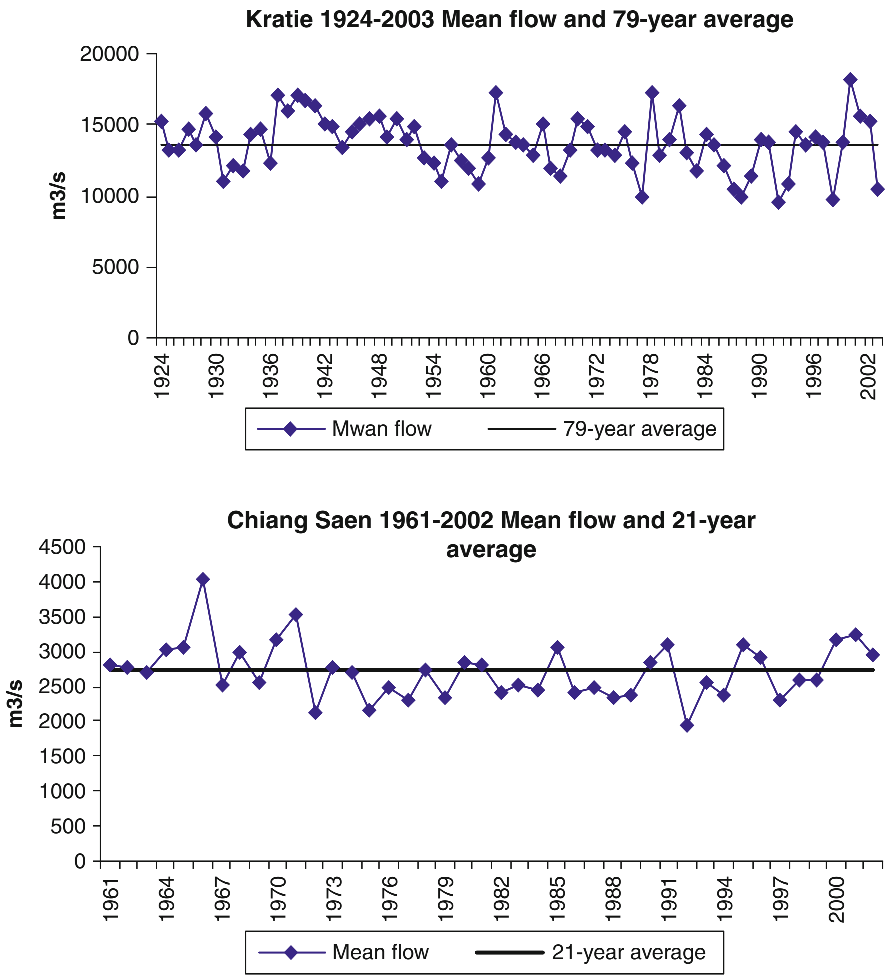

Fig. 2.6 Temporal characteristics of the annual flows at key hydrological stations on Mekong mainstream

the region is likely to experience the upper extremes of the climate scenarios forecast. The preliminary climate change downscaling method conducted by the Environment Division of the MRC predicted that that the mean annual average temperature will increase 0.9°C, 0.7°C, and 0.7°C for the upper Mekong Basin (China) (UMB), lower Mekong Basin (LMB) and the entire Mekong basin respectively. The highest temperature increase is expected in the uppermost part of the Mekong basin. The increase will be less in the LMB but slightly higher in the lower part of the LMB and the delta (MRC 2010d).

2.4 Water Dependency and Uses in Mekong Region

The majority of the approximately 278 million people in the wider Mekong Region live in rural areas where they lead subsistence or semi-subsistence agricultural lifestyles (ADB 2009; MRC 2010a). Several millions of people live within a 15 km corridor on the two sides of the mainstream Mekong River and the Tonle Sap River and Lake (MRC 2010b; ICEM 2010).

China's interests in the Mekong Region are focused on developing China's western landlocked provinces to satisfy the energy, water and resource demands of neighbouring provinces (Dore and Yu 2004); and to reduce the rate of emigration to coastal cities (Dosch and Hensengerth 2005). In parallel to hydropower development (a series of 15 dams along the stretch of upper Mekong Region have been constructed or planned Xu and Moller 2003)[4] China is developing water-borne transport infrastructure enabling manufactured exports and raw material imports to and from lower Mekong countries (Wu, Jiabao 2005).

Viet Nam and Thailand are the most intensive water users in the Mekong Region. Thailand has the largest density of roads and hydropower/irrigation projects. Thailand's annual freshwater withdrawals represent almost 30 % of the available water resource stock (ADB and SEI 2002). Ninety percent of Lao PDR and 86 % of Cambodia are located within the Mekong basin respectively, with commensurate proportions of their population dependent on access to the Mekong River Basin resources. Several plans are in place to turn Lao PDR into the "Kuwait" of South East Asia for energy/electricity export (MRC 2005b).

Irrigated agriculture in the Mekong basin is the largest consumptive water user, responsible for 78–94 % of fresh water withdrawals (ADB 2009; MRC 2010a). In 2000, irrigated agriculture use accounted for approximately 15 % (72,837.66 MCM) of the annual average discharge (475,014 MCM), or 80–90 % of the total water abstraction from the MRB. Mekong basin water abstraction is comprised of harvested receding flood water storage, diversion of water from stream and from ground water sources, and water from precipitation (soil moisture) (MRC 2003; MRC 2010b). More than 50 % of irrigated water use occurs in the Mekong delta (MRC 2010c). Estimates of sectoral water withdrawals (including the industry sector) in the Mekong Region are presented in Table 2.3 below.

Water extraction for irrigated agriculture is estimated to continue to grow as most of the MRB remains an agriculturally dominated economy (MRC BDP (Basin Development Plan) 2003), although the use of water for domestic purpose and industrial use is expected to increase to 4.3–5.3 % of available water sources respectively (Papademetriou 2000).

[4]China Hydropower Engineering Association: by 2020 the Lancang River reach will produce a total of 22–25.6 million KW installed capacity from a series of 15 hydropower dams. A cascade of eight hydroelectric power dams with 9.4 million KW installed capacity is being set up in the upper reaches. Another seven dams with 16 million KW installed capacity are built or planned for in the middle and lower reaches of Lancang.

Table 2.3 Water withdrawals in the Lower Mekong Basin, 2000

Country	Total (million m^3)	Withdrawals (m^3 per person)	Sectoral withdrawals (% of total)		
			Agriculture	Industry	Domestic
Cambodia	4,091	311	98	1	2
China	630,289	494	68	26	7
Lao PDR	2,993	567	90	6	4
Myanmar	33,224	699	98	1	1
Thailand	87,065	1,429	95	2	2
Vietnam	71,392	914	68	24	8

(FAO 2005) Note: Data presented above are for the whole countries

It is projected that by 2025, irrigated agriculture water use will account for about 22 % (104, 503 MCM) of the average annual discharge of the Mekong River and 25–30 % by 2050 depending on the irrigation scale and intensity (Pech and Sunada 2008, MRC BDP 2003). The total irrigation demand in the MRB will be lower than estimated average annual river flow, but this neglects uneven distribution of flow in time and space – severe flow fluctuations between the wet and dry seasons, from wet years compared to dry years, and geographic differences (Pech and Sunada 2008; MRC BDP 2003). In addition, a specified proportion of seasonal runoff is required to maintain environmental flows, aesthetic/recreational services and dependent ecosystems (Ravenga and Mock 2000).

Raskin and Kemp-Benedict (2002) estimate that by the year 2032 the share of domestic and industrial uses will constitute about 20–22 % and 28–29 % respectively of the total water withdrawal in Southeast Asia. Similar projections have been made for the MRB – the domestic and industrial water consumption for 2000 in the Mekong basin was estimated at 2,773.58 MCM or less than 1 % of the average annual Mekong flow. The 2050 domestic and industrial water demand is projected to increase to about 11.5–15.5 % of the total average annual Mekong flow (Pech and Sunada 2003; MRC 2003). Even though the current demand by domestic and industrial water uses remains modest, aggregate water demands for agriculture, domestic and industrial use in 2050 are estimated at between 32 % and 50 % of the total annual flow. This will further increase competition for water resources during the low flow conditions of the dry season and driest years. The increase in domestic and industrial water use leads to a proportional increase in the demand for waste water systems/facilities and improved sanitation that poorly developed, requiring substantial investment and management in many Mekong countries, except for Thailand (MRC 2003).

3 Analytical Approach and Indicators

Traditional analytical approaches have relied on a strong hydrological focus, emphasising practices to control quantity, quality, and timing of water flows. In contrast, the assessment detailed in the following Section focuses on both the availability of water for human use through time and space and the quality and quantity of water required by an aquatic for the to protect and maintain aquatic ecosystem structure, function and dependent species (Smakhtin et al. 2003). Since water is a key strategic resource, vital for sustaining life, promoting development and maintaining the environment, the water sector assessment approach is concerned with both water issues and other closely associated water resources/elements and dependent communities.

A fundamental point of departure deploys a broader perspective that highlights likely changes/impacts resulting from implementation of the six development investments and how those changes are likely to affect interrelated natural resource elements and people's livelihood. Likely changes are particularly important and critical among the rural poor who depend on subsistence livelihoods. A broader set of key indicators and variables to assess the potential water sector changes reflects this broader perspective. The main indicator classes listed in Table 2.4 are: hydrological changes and changes in other water elements; geo-morphological changes that have implication on ecosystem sustainability; and alterations to sustainable livelihoods.

The following sections discuss first the trajectory change induced by implementation of the investment decisions considered in isolation and second the cumulative impacts from a transboundary perspective.

4 Single Factor Impact Assessment

4.1 Hydropower Dams

The magnitude of Mekong River Basin change is function of the number, size and locations of constructed hydropower dams. Dams design, construction and operation also influence the magnitude and valence of change.

4.1.1 Potential Impacts of Hydropower Development

By 2030, the dams in the Mekong tributaries are estimated to substantially alter mainstream river flows (MRC 2010b). For the very first time since river monitoring commenced in 1915, the development sector will alter the hydrological regime of the entire MRB. The active storage will potentially increase by 700 % from 9.9 to 69 km^3. Approximately 23.7 km^3 or 36 % will be located within Yunnan Province, mainly from the two largest hydropower dams with an active storage of 22.2 km^3 (Xiawan and Nuozhadu) (MRC 2010e). The proposed 11 LMB mainstream projects will convert 55 % of the total length of the mainstream stretch between Chiang Saen (Thailand) and Kratie (Cambodia) to reservoir storage. The Lower Mekong River will be fundamentally transformed from a free-flowing river to a series of variable

Table 2.4 Indicators used to assess water sector impacts

Aspects	Indicators/Variables	Triggers
Hydrological changes	Water level	• Substantial impact of climate change is expected only from 2030 and beyond
	Flow level in dry season at specific locations	• Impact of large regional scale forest cover and habitat changes on transboundary water is not critical for an obvious reason
	Flood timing	• Railway link's transboundary impact on water is less obvious
	Flood duration	**Key triggers considered here are**:
	Flood area	• Multi-sector demand and associated intervention(dam, diversion etc.)
	Reverse flow/water level in Tonle Sap;	
	Inundated area, duration and timing	• Impact of large scale mining and processing;
	Storage	• Increase in water demand versus water availability
	Change in water quality (turbidity and relevant quality parameters)	
	Change in salinity intrusion – extent, duration, and concentration	
Other water elements – geo-morphological changes	Barrier effects and dis-connectivity	
	Sediment and nutrient loads from UMB	
	Reservoir conditions	
	Downstream and critical deep pool habitat	
	The state of the Mekong delta	
	Coastal zones	

energy, managed impoundments, characterised by alternate periods of slow water movement and rapidly changing flow in response to dam operations (ICEM 2010).[5] The reduced flood season flows are estimated to reduce the extent and duration of floodplains inundation and contribute to bank erosion on the critical stretches and infilling of deep pools (MRC 2009).

The operation of the mainstream dams can cause significant downstream fluctuations during any 1 day if they are operated as peaking projects. In this case,

[5] Sarkkula et al. 2010. Power Point Presentation at Regional Consultation Workshop of June 2010: About 66 % of the total 1,760 km river distance, Sambor dam (Kratie) site to the upper end of Pak Beng reservoir, will be affected.

water level fluctuations locally may amount to typically 2–4 m or more in extreme cases (MRC 2010c).[6] This may have severe implication for local navigation and the productivity of river bank gardening.

The increase in dry season flow is estimated to be able to meet a planned increase in irrigation abstractions over current levels depending on location along the mainstream. Dams located in the Yunnan reaches of the Mekong River cause a dramatic increase in mean minimum annual dry season flows at all stations, except Kratie. Estimated dry season flows increase by 70 % at upstream stations, reducing to 10 % at the Mekong delta, where notably dry season irrigation demand is highest. About 54 % of the riverbank gardens along the mainstream stretches from Chiang Sean to Kratie will be flooded due to higher dry season flows and reservoir inundation (Sarkkula et al. 2010).

The increases in dry season flow are predicted to increase consumptive water supply and lead to an expansion of commercial irrigated agriculture and land consolidation. Benefits are likely to be accrued by private interests, however these are potentially offset by the incurred public costs associated with the increased use of chemical fertilizer required to offset losses in sediments and nutrients. The variable production costs (water fee, inputs and labour) of agricultural expansion are also predicted to increase.

The change in water surface areas will cause a very significant seasonal redistribution of flow from the wet season to the dry season and reduce sediment transport in the Mekong mainstream, especially to the area above Vientiane (MRC 2010c). The reduction in the maximum water level and increase low flows will be observed over the next decades, associated with increased water storage in large capacity reservoirs. As a result the overall hydrograph will be smoother (Fig. 2.7), especially in the transition from the dry to the wet season (ICEM 2010).

The onset of the transition from dry to wet season will be significantly reduced: 7–8 weeks earlier in Chiang Saen,[7] 2–4 weeks earlier upstream of Pakse and 1 week at Kratie. This change will see a reduction in the important freshwater '*spates*' which drive many ecosystem functions such as fish spawning, lave dripping and fish migration.

There has been an ongoing and active debate about the role of dam reservoirs in regulating flood peak flow ("downstream flood benefit"). Literature insights indicate that mainstream dams in the LMB would only provide limited flood protection to reaches immediately downstream of the reservoir impondment (MRC 2010b, c, d). The peak daily flows will be reduced by 18 % (−1,100 m^3/s) at Chiang Sean, 15 %

[6] Sarkkula et al. 2010. Personal communication: The time elapse for a rapid fluctuation from opening the turbines – planned and unplanned circumstances, and breakdowns of plant and electrical transmission systems at the proposed Xayaboury dam site, will be about 1–1 ½h to the city of Luang Prabang, very little warning time for bank-side residents to prepare for inundation.

[7] MRC 2010b: At Chiang Sean, peak daily flows will be reduced by 18 % (1,100 m^3/s), and dry season flow volume will be increased by about 61 % (12,093 MCM), and peak daily flows at Kratie will be reduced by 7 %, and dry season volume will be increased by 23 %.

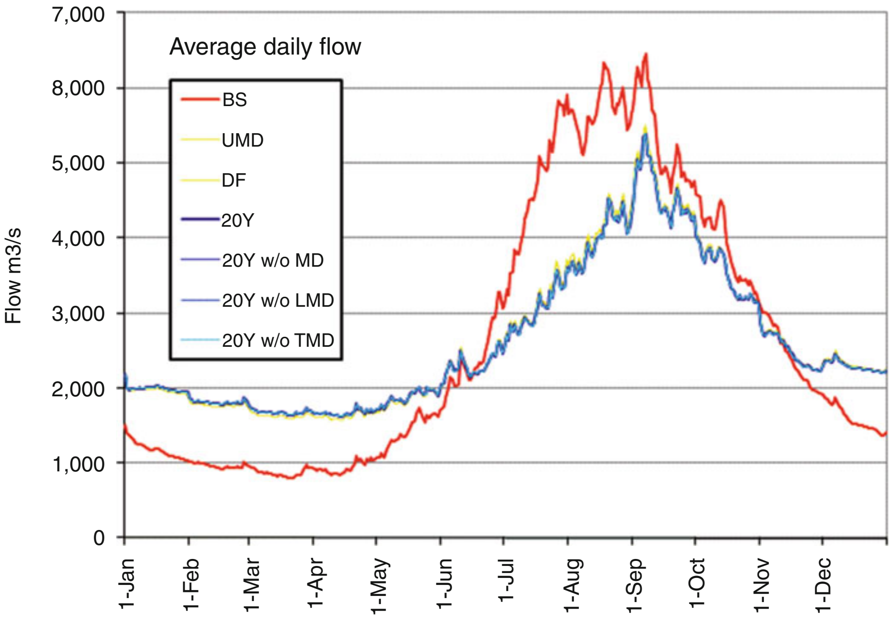

Fig. 2.7 Changes in hydrology at Chiang Sean; BS – Baseline Scenario…; UMD – Upper Mainstream Dam Scenario.; DF – Definite Future Scenario:…; MD – Mainstream Dam:…; LMD – Lower Mekong Mainstream Dam:…; TMD – Thai Mainstream Dam:…

(−2,381 m^3/s) at Vientiane, 7 % (−3,456 m^3/s) at Kratie and only 4 % (−855 m^3/s) in the Viet Nam Mekong Delta (Tan Chau). Over estimates of the flood reduction functions of dams may lead to a false sense of security in the face of historical floods (100–500 year recurrence flood), as will dam failure due to earthquakes and uncoordinated, abrupt reservoir releases of flooding waters. Records from around the world indicate that flood protection (which does not bring in revenue) tends to be neglected in multipurpose projects (Regional POE 2010).[8]

[8]Most of the dams have not been designed to take into consideration major natural disasters such as earthquakes or floods. Lessons from the typhoon Ketsana (end of September 2009) show that mis-management can inflict significant losses on vulnerable communities. Even where they have been considered, the imperatives of maximizing revenue obliges dam operators to maintain maximum reservoir levels (and thus maximize hydropower generation as well as irrigation water availability). In recent years a number of earthquakes occurred across Asia resulting in impacts to numerous dams (Mongabay.com 2008; Brewer 2008; Vijay and Ramesh 2005; Hough and Martin 2001). For example, the 12 May 2008 earthquake in Sichuan province of China (7.9 magnitude) seriously damaged hydroelectric dams and caused serious social and economic losses. Sixty-nine dams were in danger of collapse, 310 were at “high risk,” and 1,424 posed a “moderate risk” (Brewer 2008). China said it would spend more than $1.3 billion per year fixing vulnerable dams, many of which were poorly constructed (Mongabay.com 2008; Brewer 2008). USGS Earth Quake Hazards Project reported two major quake measuring 4.7 on the Richter scale in late February 2011 and 6.1-magnitude quake in 2007at the proposed mainstream dams near Xayaboury, Lao PDR.

There will be an overall 7 % reduction in flooded area (309,000 ha) in an average year. The reduction areas are expected to be smaller in wet years and larger in dry years. The greatest area of reduction occurs in Cambodia (142,000 ha), Lao and Thailand (17 % and 19 % reduction respectively) (MRC 2010d; MRC 2009)

Estimates for 2030 indicate the dam development scenarios will result in significant changes in the ecology of the Tonle Sap Lake. The inundation of the Tonle Sap Lake will be reduced by 5–10 % (500–600 km^2), the reverse flow in Tonle Sap will start at least a week sooner, and the average days of reverse flow will be shorter (about 8 days). Dry season inundated area is anticipated to increase by 5–8 % converting a seasonal terrestrial ecosystem into permanent aquatic. These changes will affect ecosystem and farming productivity, fish migration and sediment flushing capacity. The decrease in reverse flow volume to the Tonle Sap Lake will result in a reduction of flooded area, flood depth and duration; and a reduction in sediment inflow into the lake and blockage of fish migration paths by mainstream dams (ICEM 2010).

With mainstream hydropower projects operating, there will be much less velocity to suspend particles and keep them moving, and the result of this will be enhanced sedimentation, with the formation of deltaic type deposits at the head of each of the reservoirs, and middle and lower parts of each reservoir associated with reduced velocities/gradients (MRC 2010d; ICEM 2010). Only the loads of suspended (fine sized) particles has been measured at several stations on the Mekong mainstream since the 1960s. The development will also potentially reduce fined sized sediment transport from 70 % to 80 % (75–81 % reduction in sediment load) from the UMB (from 90 to 20 Mt/year at Chiang Sean, and from 165 to 88 Mt/year at Kratie) (Sarkkula et al. 2010). The reduction will result in significant nutrient losses in floodplains and coastal regions. Sediment reductions will reduce the productivity of farming and fisheries within and beyond the Mekong. Long-term changes to river bed and bank erosion rates are likely, including increased threats to the stability of the delta shaping processes, potentially exacerbated by sea level rise.[9]

The reservoirs fisheries are expected to increase fish captures by 10,000–30,000 t or US$ 40 million (MRC 2010b), but the Mekong capture fishery of 2.1 million tons or 22 % of world fresh water fisheries, will be at risk. The 2030 scenario without Mekong mainstream dams will reduce the Mekong fishery by 210,000–560,000 t/year (10–27 % reduction) and 12 mainstream dams will cause direct loss of another 340,000 t/year (US$476 million) or another 17 % of total catch. Aggregate reservoir fisheries could compensate up to 10 % of the lost capture fish production predicted to occur in the absence of mainstream dams. It is not clear about the magnitude and time scales that change will have impact on the Mekong marine fishery (currently estimated at 500,000 t/year or a replacement value of about US$ 40 million). Reductions in boat and fishing tackle manufacture, salt and

[9]Loss of sand-sized sediments to Mekong Delta and marine environment result in loss of nutrients (phosphates) to agriculture = 3,400 tonnes/year = US$ 24 million in replacement value/year, and reduction in nutrient loads to over 18,000 km^2 of Cambodia flood plain and 5,000–10,000 km^2 of Mekong Delta floodplain and Mekong marine sediment plume

ice production, and fish processing estimated at US$ 2–4 billion (MRC 2010c) are predicted as consequences of fishery losses.

Navigability will be substantially improved with lower requirements for channel improvement to provide cheaper and more affordable means of transport. However, with improvement in road and rail link, river navigation is not seen as a high priority. The 2030 development scenario will also introduce additional barriers and increase river disconnection as 37–81.3 % of the watershed will be obstructed. Table 2.5 summarises the estimated effects of hydropower development on the Mekong water sector.

4.2 Water Diversion

Possible water diversions/extractions from the main stream of the river system are generally expressed as the amount of water extraction at various places required for agriculture and other consumptive uses. Several combinations of inter-basin diversions from the Mekong River and tributaries out of the basin, and intra basin diversions – from the Mekong River and its tributaries into another part of the Mekong basin have been either proposed or subject to member country consideration (MRC 2005). It is assumed that the principle idea of diverting water from a Mekong tributary located on Lao PDR, i.e. diversions from the Nam Ngum into Isaan, Thailand is likely to occur within the duration of this assessment (2010–2030). The study assesses the implications for water availability during the dry season in the relevant catchments and downstream locations from the outtake. Lao PDR, Cambodia and Vietnam are the downstream countries considered.

Intra-basin diversions for irrigation in north-east Thailand, includes diversion of water from the Lao PDR tributary (Fig. 2.8). Based on the consultancy report by Sanyu Consultants Inc (2004), the Nam Ngum Water Management Project envisages both an irrigated agriculture development in the Vientiane Plain, and “surplus” water diverted into northeastern Thailand. Water will be diverted to Issan via a Nam Ngum barrage/diversion dyke located about 6 km from the Mekong confluence, creating a hydraulic head sufficient for gravity diversion into a siphon tunnel under the Mekong (Sanyu 2004; Molle and Floch 2008). A constant diversion rate of 300 m^3/s for the whole year has been proposed, apportioned equally to the Thailand headwaters of the Mun River and Chi River (or a total of 6,878 MCM/year)

4.2.1 Potential Impacts from the Proposed Nam Ngum to Northeast Thailand Diversion

Initial qualitative assessments indicate the proposed diversion cumulatively contributes to reductions in dry season flows, detected primarily from December to March

Table 2.5 Summary of impacts on water sector from hydropower development

Aspects	Indicators/Variables	Changes
Hydrological changes	Water level	The development sector is of sufficient magnitude to alter the hydrological regime of the entire MRB (Active storage increases from 9.9 to 69.8 km^2)
	Flow level	Dry season flow increases by 70 % at upstream stations, and 10 % at Mekong delta
	Flood timing	Reduction in the onset of transition from dry to flood season – 7–8 weeks earlier in Ch. Saen, 2–4 weeks upstream of Pakse, 1 week at Kratie
	Flood duration	To significantly affect uppermost of LMB (above Pakse and Vientiane)
	Flood level and area	Flow decrease by 18 % at upstream stations, but only 2 % at delta. Typical reduction in flooded area
	Reverse flow/water in Tonle Sap	Reduction in duration and volume of reverse flow
	Inundated area, duration, timing	Dry season inundated area increase significantly
	Storage	700 % times increase in active storage area
	Change in water quality (turbidity and relevant quality parameters)	Reduce sedimentation transport from 70 % to 80 %. Loss of nutrients in floodplains and coastal offshore
	Change in salinity intrusion – extent, duration, concentration	Increase in 5–10 % increase in flow, but combined with increased water diversion and climate change, salinity extent further increases
Other water elements – geo-morphological changes	Barrier and dis-connectivity	From 37 % to 81.3 % of the watershed will be obstructed
	Sediment and nutrient	Reduction in-stream power – lost energy in moving over the riverbed and turbulent flow dissipation. 75–81 % reduction in sediment load
	Changes in reservoirs	Siltation and formation of deltalic areas,
	Downstream and critical deep pool and habitat;	Downstream erosion and long-term impact on 48–70 % of deep pools habitat. Loss of natural fertilizer and food-chains
	Mekong delta	Erosion, instability of shore-lines – land mass advances by 60–80 annually comes to an end, at location annual erosion up to 45 m/year
	Coastal zones	Loss of nutrient and impacts on marine fisheries, but magnitude and time-scales unclear

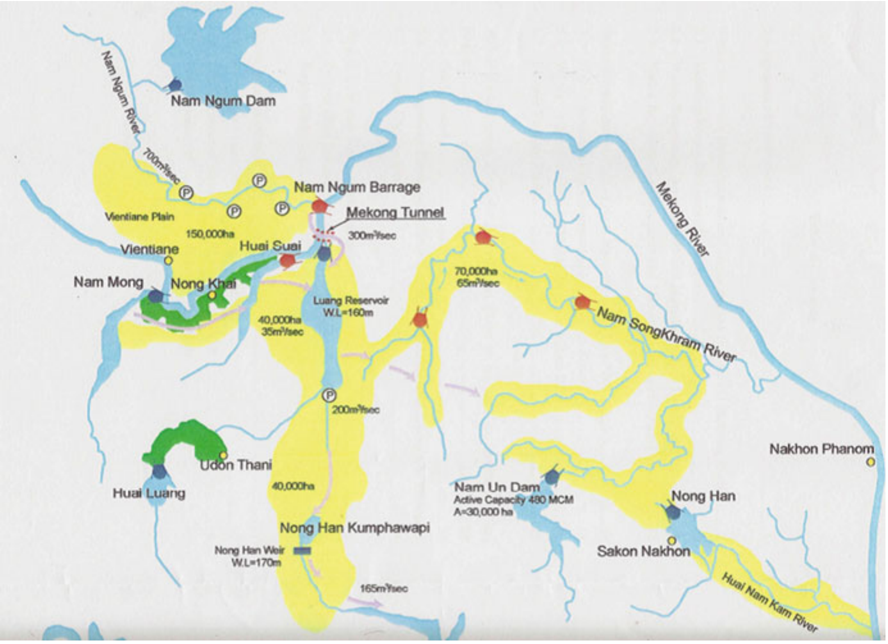

Fig. 2.8 Proposed diversion site map – Nam Ngum Water Management Project for Vientiane plain of Lao PDR and Northeast Thailand (Source: Sanyu 2004)

(MRC 2005). Additional flows from upstream reservoir operation may compensate for the reduced flows. The combined influence of proposed inter-catchment water diversions and upstream dam operations introduces the potential for both positive and negative transboundary outcomes for this stretch of the Mekong River (the Thalweg channel) that Lao PDR and Thailand share as their political boundary. Positive outcomes for Thailand relate to additional irrigation water, however Sanyu (2004) flags the potential flood hazard of reservoir operations in the wet season. For example the Huai Luang Reservoir will need to be completely emptied by the end of July in order to store the August flood waters emanating from the Huai Luang basin.

Intra-basin diversions can cause significant reductions in dry season flows in the Nam Ngum/Nam Lik tributaries as sources of diverted water. Abstractions are likely to cause more severe impacts on mainstream reaches by-passed by the diversion, especially in drier years. A constant annual diversion rate of 300 m^3/s from the Nam Ngum may potentially cause water shortages during critical dry season months, since the observed average flow (1993–2000) at Ban Pak Kannhoung (further upstream from the diversion point), was between 791 and 686 m^3/s from January to April (Sanyu 2004). The abstraction of nearly 50 % of dry season flow assigned for diversion to north-east Thailand will cause water shortages for other uses including the projected abstraction for irrigation in the Vientiane Plain.

Approximately 250 m^3/s is projected for irrigating 150,000 ha in the north and south Vientiane Plains, and at least 570 m^3/s for maintaining minimum flow in the Mekong mainstream (Sanyu 2004). However, it is expected that the planned release of controlled flows from Nam Ngum Dams 1, 2, and 3 and flows from the Nam Link development may help relieve that water shortage during critical dry season, assuming reservoir releases and operations are coordinated.

The reduction of dry season flow without compensation from other flow coupling with climate changes may potentially deteriorate salinity intrusion in Mekong delta. Table 2.6 summarises the estimated impacts of a Nam Ngum water diversion to northeast Thailand on the Mekong Water sector.

4.3 Large-Scale Mining Activities

Bauxite is one of the most economically important minerals. According to the U.S. Geological Survey, Asia contains about 17 % of the total global bauxite reserves (ranked 3rd after South America and Africa). Cambodia, Lao PDR and Vietnam are reportedly rich in mineral resources; however, the exploitation of these resources has typically been delayed due to conflict, lack of foreign investment, and limited capital and capacity to establish extensive mining operations (Lazarus 2009).

Deposits of bauxite have been prospected and explored for the last 5 years in the Bolaven plateau in southern Lao PDR (Champassak Province next to the Cambodian border, see Figure 5 Chap. 1). A commercially viable alumina refinery consumes electricity in the order of 600–800 MW, dependent on the technology applied and the scale of the operation, and large quantities of water (Sekong River and Sekong dams) (Lazarus 2009). A large concession area would be required and would have to be fully cleared along the Bolaven plateau.

Substantial water sector impacts are expected as a result of large-scale bauxite mining in the Bolaven plateau, including altered water quality, transport of sediments, soil erosion, land use change and loss of forest cover (Lazarus 2009, ADB – RETA 40082 2011). Land use change and loss of forest cover resulting from forest clearance and earth removal for mining (open cut mines, or removing the surface layers) can potentially cause significant soil erosion, sedimentation and altered runoff characteristics. Deforested areas, especially those having steep slopes and fragile soils change runoff conditions and will potentially generate deteriorated flood conditions, including sudden flash floods, and more intense drought (ADB – RETA 40082 2011).

Changes to sedimentation loads and soil erosion will affect the Mekong and Sekong Rivers although lagoons and tailing ponds may be used to reduce the amount of sediment actually reaching the rivers (Lazarus 2009, ADB – RETA 40082 2011).

It is also expected that large quantities of water will be extracted either from the river or as groundwater for the extraction and production of minerals, e.g. for washing of ores and in the production processes (Lazarus 2009, ADB – RETA 40082

Table 2.6 Summary of potential impacts from Nam Ngum water diversion

Aspects	Indicators/Variables	Changes
Hydrological changes	Water level	Intra-basin diversions can cause significant reductions in dry season flows in the mainstream reaches by-passed by the diversion. Tributaries from where water is abstracted will be more severely impacted. Potential flood hazard due to storage reservoir operation in north-east Thailand
	Flow level in dry season at specific locations	Short term water shortage for contributing to maintaining minimum flow in the Mekong, and meeting water demands in Vientiane Plain in critical months of dry seasons
	Flood timing	Flood timing is affected by dam regulation from upper catchment
	Flood duration	
	Flood area	
	Reverse flow/water level in Tonle Sap;	
	Inundated area, duration and timing	
	Storage	Series of 300 new large and medium-sized reservoirs and 25,000 community reservoirs in north-east Thailand
	Change in water quality (turbidity and relevant quality parameters)	Point-source and non-point-source pollutants are expected to substantially increase for irrigation expansion and human activities in Vientiane Plain and from return flow from Mun Chi (Thailand)
	Change in salinity intrusion – extent, duration, and concentration	May significantly contribute to worsening salinity intrusion in Mekong delta
Other water elements – geo-morphological changes	Barrier effects and disconnectivity	Habitat partitioning (locally) from water manager devices (WMD)
	Sediment and nutrients	Sediment trapping is caused by series of 4–5 dams on Nam Ngum and Nam Lik
	Changes in reservoirs	Ibid
	Downstream and critical deep pool and habitat	Some noticeable impact on landscape and habitat from diversion channel or siphon structure construction
	Mekong delta	No significant impact
	Coastal zones	No significant impact

2011). ADB – RETA 40082 (2011) estimated that one of the bauxite mines on the Bolaven plateau is expected to use about 110,000 m^3/per day, sourced from the Xe Namnoy River, equivalent to half of the river's peak flow. The local and transboundary low flow issues are likely to be amplified during the dry season and during drier years for downstream communities in both Lao PDR and Cambodia (ADB – RETA 40082 2011).

Pollution derived from mining activities affects mainly surface water and potentially groundwater. Toxic compounds and metal salts are likely to leach into extraction waters, concentrating in sediments and eventually discharged into streams and rivers. The generation of highly alkaline red mud and associated contaminants represents the most significant risk to downstream surface and groundwater sources. Poorly managed disposal will lead to deterioration of livelihoods of dependent communities in Lao PDR and Cambodia, declining public health and a decline of downstream fish stocks and aquatic life (ADB – RETA 40082 2011).

Large scale mining will trigger otheris dependent on the development of major infrastructure such as railway, road transport and energy generation. The production of aluminium requires a great deal of energy. The mining of bauxite and production of alumina require about 200–250 MW for 1 t of alumina, and a modern aluminium smelter would require about 14,000 MW to smelt 1 t of aluminium. Cheap energy is essential for cost effectiveness in aluminium production, estimated at 2.5–3.5 US cents per kilowatt. Lao PDR is currently selling hydropower generated electricity to Vietnam and Thailand at 5–6 US cents per kilowatt. At present this makes localised aluminium smelting unviable and the transporting of locally smelted alumina elsewhere for the production of aluminium a likely production strategy.

Transport infrastructure will need to be further improved through development of an east–west road corridor to connect Thailand through Lao PDR to Vietnam and north–south road corridor to connect southern China (Kunming) through Lao PDR to Thailand (Thompson Richard 2010). Table 2.7 summarise the effects of bauxite mining on the Mekong water sector.

4.4 Mekong Rail Link Within Wider Mekong Region Economic Corridor

Substantial transport infrastructure developments have been proposed for the wider Mekong Region, introducing substantial improvements in regional trading opportunities (ADB 2009). In contrast, there exist countervailing concerns regarding the construction and operation of connecting rail and road networks. Large scale transport infrastructure has the potential to introduce additional pressures on terrestrial and aquatic ecosystems and altered patterns of migration with associated social pressures.

Table 2.7 Summary of potential impacts from large-scale bauxite mining on Bolaven Plateau

Aspects	Indicators/Variables	Changes
Hydrological changes	Water level	Large quantities of water will be extracted either from the river or ground water for mining operations in the extraction and production of minerals
	Flow level in dry season at specific locations	Local and transboundary low flow issues can be escalated in dry season and drier years for the communities living downstream in Lao PDR and Cambodia
	Flood timing	
	Flood duration	Cause significant increase in local run-off
	Flood area	Deforested areas, especially those having steep slopes and fragile soils increase the runoff conditions and potentially generate stronger flood, including sudden flash floods, and stronger drought events
	Reverse flow/water level in Tonle Sap;	
	Land use changes	Large land area and forest cover will be cleared for mining, transport facility, smelter facility, and energy production and transmission line
	Storage	
	Change in water quality (turbidity and relevant quality parameters)	Pollution of surface water and potentially ground waters from: • Toxic compounds, metal salts etc. into the water and hence discharged into streams and rivers • Build up of toxic materials in the sediments. Generation of highly alkaline red mud
	Change in salinity intrusion – extent, duration, and concentration	
Other water elements – geo-morphological changes	Barrier effects and disconnectivity	Significantly large area of landscape will be disturbed
	Sediment and nutrients	Cause significant soil erosion, sedimentation and run-off changes -discharge of sediments into water courses (Mekong River and Sekong River etc.)
	Changes in reservoirs	
	Downstream and critical deep pool and habitat	Fish and wildlife habitats will be disturbed or affected by pollution from mining
	Mekong delta	
	Coastal zones	

In August 2010, Ministers from Cambodia, China, Lao PDR, Myanmar, Thailand and Vietnam adopted the plan which they called “a significant first step toward the development of an integrated railway system” (ADB 2009). The existing six Nations’ national railway systems do not connect except for a line that connects China and Vietnam. Lao PDR has no existing rail network. The rail network plan coincides with an effort by Mekong Nations to develop “economic corridors” based on new road linkages. The most viable of four possible routes cites Route 1 – which would link Bangkok to Phnom Penh, then Ho Chi Minh City and Hanoi, and finally up to Nanning and Kunming, largely using existing lines or those already under construction (ADB 2009). This Section is focused on large scale transport infrastructure, in particular the connected railway project.

By 2025, the regional railway lines in all countries will be developed (or rehabilitated) to further regional integration and connectivity in the Mekong Region.[10] (see Figure 4 Chap. 1)

Built infrastructures consist of a variety of man-made structures that contribute to modified natural and social systems. For instance, dams, weirs, irrigation schemes, and dykes can potentially alter water outflow, whilst embankments, polders, levees and roads prevent the natural exchange and movement of water fish, sediments and nutrients. Since major infrastructures are usually constructed to enhance socio-economic development, they tend to attract people and industry: therefore, river and terrestrial ecosystems containing these structures must also contend with the resulting environmental and social pressures that are independent from, and in addition to, the direct influences of built infrastructure on the physical and biological dimensions of the system (Baran et al. 2007).

The key impact will be alteration of surface hydrology due to road crossing, resulting in modified sediment deposition and increased soil erosion, and modification of water local flood patterns. The impacts can potentially be trans-national where the structures intersect key trans-boundary ecosystems and communities. Table 2.8 summarises the estimated impacts of proposed railway networks in the wider Mekong Region on the Mekong water sector.

The modification in water flows and flood patterns are the predominate threats to the ecology of floodplains by poorly designed and built roads and rail-links. The study by a Finnish group and the World Fish Centre analysed numerous experiences

[10]On going and planned projects include:

- Cambodia: rehabilitation of the railway funded by ADB and AusAID;
- China is financing the Feasibility Study for line between Phnom Penh and VN Border;
- China is building new line to the VN and Myanmar borders
- Thailand‘s high-speed train line and new links to link Lao and onward to VN;
- VN considering lines to Lao and Cambodia; and
- Railway through Lao PDR will be online in 2015 and form part of the Asian-China railway, which runs from Yunnan Province south through Lao PDR to Thailand, Malaysia and Singapore.

Table 2.8 Summary of impacts from major railway links

Aspects	Indicators/Variables	Changes
Hydrological changes	Water level	Alteration of surface hydrology crossed by roads, resulting in increased sediment and increased soil erosion mostly locally. Changes in the level of the water table
	Flow level in dry season at specific locations	Increase water levels by 40–50 cm up to 20 km upstream within local floodplain
	Flood timing	
	Flood duration	
	Inundated/Flood area	Modification in local water flows and flood patterns
	Reverse flow/water level in Tonle Sap;	
	Inundated area, duration and timing	
	Storage	
	Change in water quality (turbidity and relevant quality parameters)	Deterioration of surface water quality due to silt runoff and sanitary wastes
	Change in salinity intrusion – extent, duration, and concentration	
Other water elements – geo-morphological changes	Barrier effects and dis-connectivity	Habitat partitioning locally but with transboundary implication at cross border points. Restriction of fish and wildlife migrations (locally)
	Sediment and erosion	Increased local sediment and increased soil erosion
	Changes in reservoirs	
	Downstream and critical deep pool and habitat	
	Mekong delta	
	Coastal zones	

in tropical floodplains in Asia, Africa and South America and reviewed more than 300 journal articles, reports and books. Their review confirms the need to consider and avoid irreversible changes to water when planning infrastructure development. In particular changes affecting seasonal flooding or disrupting the natural "connectivity" between various water bodies have to be avoided when building major infrastructure in critical watershed and floodplains (see e.g. Baran et al. 2007).

4.5 Sea-Level Rise and Adaptation Strategies in Vietnam's Mekong Delta

The important aspect for the assessment is to consider water sector implications of climate change induced sea-level rise for the Vietnamese Mekong Delta. Current climate change forecasts for the Mekong delta identify increased incidents in floods and droughts together with changes to seasonal rainfall patterns and an increased incidence and severity of typhoons and storm surge.

Sea level rises combined with increased water consumption within the Mekong delta and upstream in the dry season and droughts will increase levels of inland saline intrusion.

The Vietnamese government has identified substantial increases in 'hard' water infrastructure investments (higher embankments and strengthening of dikes and roads, sluice gates) as a primary strategy to offset any direct detrimental consequences of sea level rise. Proposed structural measures will cause hydrological and morphological changes such as obstructions to flood drainage, increasing flood peaks, and increasingly localized retention of sediments. The infrastructure strategy may also decrease the amount of overbank flow across the border between Cambodia and Vietnam with some significant transboundary consequences such as back-up flooding waters into Cambodia. Couple with the flood control structures along the Viet Nam and Cambodian Border and Viet Nam Mekong Delta, additional infrastructure to mitigate seavel rise may also lead to decreasing drainage to the West Mekong Region increased drainage to the Gulf of Thailand (Shigeko 2009). Table 2.9 summarises the estimated effects of sea level rises in the Mekong delta on the Mekong water sector.

4.6 Large-Scale Rubber Plantations

It is estimated that 1.6 million hectares of additional rubber will be planted by 2030. According to various resources, there were 2.9 million hectares of rubber planted in the Mekong Region in year 2000/2002. According to Fox (2012), 4 % of current vegetation in 2000 would be replaced by rubber plantation by the year 2050. Ziegler et al. (2009) estimated that more than 500,000 ha of native vegetation may have already been converted to rubber. By 2050, the area of land dedicated to rubber and other diversified farming systems may double or triple.

There is limited literature based insights and research concerned with the affects of large-scale tree plantations on water, flora and fauna of the zones proximate to plantations (Grupo Guayubira 2011). The impacts on local lakes, streams and rivers can be severe due to hydrological modifications, forest cover changes and soil

Table 2.9 Summary of potential impacts of climate change induced sea level rises in the Mekong delta on the Mekong water sector

Aspects	Indicators/Variables	Measurable changes
Hydrological changes	Flow level in dry season at specific locations; • Times – wet and dry seasons, wet, dry or average year; • Reverse flow/water level in Tonle Sap;	
	• Delta	Sea level rising together with sea water intrusion structures obstructing directly flood discharge to sea
	Change in inundated area, duration and timing	Causing flooding in a wider area and longer flooding duration. Duration of the ending flood drainage for the entire delta would be longer
	Change in water quality (turbidity and relevant quality parameters)	Stagnation of flow affects flushing capacity. Further deterioration of water quality in the delta areas of Viet Nam
	Change in salinity intrusion – extent, duration, and concentration	
	Barrier effects and dis-connectivity	Sea water intrusion and flood control infrastructures will cause further ecological and habitat dis-connectivity in Mekong delta
	Change in sediment transport	Trapping of sediment behind dykes and road networks
Geo-morphological changes	Sedimentation and erosion rates	
	Downstream;	
	Critical sub-catchment;	
	Critical deep pool and habitat;	
	Mekong delta	Significant

erosion (Menne 2004; CSIRO 2011). Studies on forestry plantation water use confirm that plantation expansion has had an impact on catchment stream flow. The combination of changes in climate, vegetation, soil, geology and other features can make a difference to water flows. However, further studies are needed to account for variability due to tree growth and management, such as planting date and location within a catchment, which impact on stream flow and sedimentation within the transboundary context.

5 Cumulative Assessment

5.1 Current Practice of Impact Assessment in the Mekong Region

Combining identified multiple stresses, risks and various degrees of vulnerabilities in an assessment can provide critical insights for regional planning and development of the Mekong basin water and other key resources. Focused on the water sector this Chapter has attempted to account for both cross-sectoral implications of development interventions and their likely impacts on natural resources and on communities (ADB and SEI 2002; World Bank and ADB 2006).

In addition to the existing rapid pace of habitat and watershed degradation, the development and operation of large-scale hydropower, major reservoirs, increased irrigation and water diversion in different parts of the wider Mekong Region are likely to create substantial positive and negative outcomes for communities and natural resources (Pech 2010).

In spite of some attempts to create a framework for assessing the impact of various development projects in the Mekong River Basin, to date there has been no "cumulative assessment" carried out (Keskinen and Kummu 2010). The absence of such a comprehensive impact assessment and an underpinning monitoring system in the Mekong Region highlights the concern for severe cumulative impacts on resource sustainability and livelihoods.

5.2 Expert Opinion on Combined Impacts

Based on expert opinion and the evidence provided in the previous Chapter sections, this Section aims to provide an assessment of the combined impact on the water sector assuming all pending development investments were to be realised in the near future.

All projects and plans for developing hydropower, intensifying water abstraction for irrigation and large scale mining activities are likely to create region wide impacts. The construction of roads and similar structures in the watershed and floodplains, and large scale rubber plantation potentially cause further hydrological and morphological changes but mostly with local implications. The hydropower and diversion of water for agriculture across the Mekong basin are presently the most important economic activities of interest and the focus of most inter sectoral concern.

It is not feasible to assess the impacts of each and every dam and irrigation project due to the fact that they are so numerous and subject to variable data availability and reliability. It is important to note that the current modelled hydrological changes utilised by the MRC to derive conclusions on cumulative outcomes are built on a number of rough assumptions (MRC 2010b). One thing is clear that these major development projects, considered incrementally and cumulatively, will change the hydrological regime of the Mekong River Basin and associated water elements (World Bank and ADB 2006). Table 2.10 summarise the proposed cumulative effects on the Mekong water sector.

5.3 Hydrological Changes

5.3.1 Water Level

As shown in Chap. 2, the development sector will alter the hydrological regime of the entire MRB – mostly due to hydropower development, for the first time since monitoring commenced in 1915. The active storage will potentially increase by 700 % from 9.9 to 69 km^3 and about 23.7 km^3 or 36 % will be within Yunnan Province, mainly from its two largest hydropower dams with active storage about 22.2 km^3 (Xiawan and Nuozhadu) (MRC 2010e). With the construction of 11 proposed LMB mainstream projects, 55 % of the total length of the mainstream stretch between Chiang Saen (Thailand) and Kratie (Cambodia) will be converted to reservoir, transforming a “live” river to a series of managed impoundments, typified by slow water movement and highly modified flow patterns in response to dam operations (ICEM 2010)

5.3.2 Flow Level in Dry Season at Specific Locations

The increase in dry season flow will theoretically be able to meet a planned increase in irrigation abstractions over current levels depending on location along the mainstream. However, China and other LMB dams will cause an increase in the lowest and mean minimum annual dry season flows at all stations, except for Kratie where the increase is restricted to approximately 2 % and 10 % respectively (MRC 2010b; Halcrow Group 2003; Halcrow Group 2004). Dry season flow increases are the lowest in the Mekong delta, where, conversely the dry season irrigation demand is the highest. Hence, dams have strongest affect in the areas nearest to the dam sites, not in the Mekong delta where irrigation water demand is highest.

The operation of the mainstream dams can cause significant downstream fluctuations during any 1 day if they are operated as peaking projects. In this case, water level fluctuations locally may amount to typically 2–4 m or more in extreme cases (MRC 2010c) adversely affecting underprivileged farmers relying on the riverbank gardening and fisheries.

Water abstraction from the Mekong River is limited during the wet season when flow levels are high and rain water is available, however, there are many constraints on water utilisation during the dry season, especially in the drier years. The drier years pose the most severe water constraints.

Table 2.10 Summary of potential cumulative impacts

Aspects	Indicators/Variables	Foreseeable 20 years 2030 with LMB dams
Hydrologic changes	Development sector totally alter hydrologic regime of the entire basin	
	Water level	Mainstream flow fluctuation relatively slow +/–0.16 m/day at Luang Prabang, +/–0.11 m/day at Pakse and 0.09 m/day at Stung Treng. But further changes depend on dam operation and regulation (peaking vs. continuous). Areas immediately (40–50 km) below reservoirs can experience up to 3–6 m of daily flow fluctuations from peak operations and abrupt release. Potential flood hazard due to storage reservoir operation in the receiving basin
	Flow level in dry season at specific locations;	Mainstream flow change due to mainstream dams has the least positive effect to support any major water diversions from Tributaries. Tributaries from where water is abstracted will be more severely impacted. Intra-basin diversions can cause significant reductions in dry season flows in the mainstream reaches by-passed by the diversion. 25–50 or 70 % increase in dry season in Northern Lao PDR and Thailand (higher than annual deviation), but only 10 % in delta. Increase in irrigation water use coupling with sea water rising will further exacerbate water shortage in extreme drought period in delta. Large quantities of water will be extracted either from the river or as groundwater for the extraction and production of minerals → local and transboundary low flow issues can be escalated during the dry season and during drier years for downstream communities in Lao PDR and Cambodia
	Flood timing	More even hydrograph in stretch above Vientiane transition from dry to flood: 2–4 weeks shorter above Pakse, and by 1 week in Cambodian floodplains. Spates and first flushes of transition to flood no longer occur. Further reduction the length of transition period to flood season (disappearance totally above Vientiane). Emergency release due to flooding to avoid dam break will cause flooding in the immediate downstream stretches
	Flood duration	Shorter flood peak – Mostly at uppermost reaches Lower and shorter flood peak
	Flood area	Reduction of 300,000 ha in flooded area (15 %) in Thailand and Lao PDR, 5 % in Cambodia and Viet Nam 9000–150,000 ha of garden and agricultural land inundated in dam reservoir sites (54 %) in Chiang Saen to Pakse. Disappearance of floodplains and channels due to impoundment of river stretches into reservoirs. Downstream: reduction in wetland by 34 % in Lao PDR, 18 % in Thailand, 2.4 % in Cambodia

(continued)

Table 2.10 (continued)

Aspects	Indicators/Variables	Foreseeable 20 years 2030 with LMB dams
	Reverse flow/water level in Tonle Sap	Reduce flooded area by 500–600 km^2 (−5 to 10 %) – affect reverse flow in and out. Increase in dry season inundated area +5–8 % Some 82 % of the total flooded area was subject to shorter flood durations under the worst case average annual flow into TLS will be reduced by 13 % or over 430 MCM
	Inundated area, duration and timing	Significant reduction in flooded areas and wetlands in LMB floodplains and Tonle Sap. Sea water intrusion prevention in VN delta causes flooding in a wider area and longer flooding duration. Duration of the ending flood drainage for the entire delta would be longer
	Storage	700 % increase in active to store 14 % of the mean annual flow (9.9–68.8 km^3). Series of 300 new large and medium-sized reservoirs and 25,000 community reservoirs in north-east Thailand as result of water diversion schemes
	Change in water quality (turbidity and relevant quality parameters)	Reduced turbidity by 75 % Overall nutrient loading from irrigated areas increases with 85 % (N) and 100 % (P) Overall nutrient loading from wastewater discharges increases with 33 % (N and P) Considerable basin-wide increase in herbicide and pesticide/fungicide use (75 % and 59 %) Point-source and non-point source pollutants are expected to substantially increase for irrigation expansion and human activities in Vientiane plain and from return flow from Mun Chi (Thailand). Increases are largest in the Mun – Chi Basin, the 3Ss Basin (agricultural run-off and mining operations) and the Tonle Sap Basin Large-scale mining in Bolevan will cause serious water quality issue locally, but there will be long-term trans-boundary water quality issues in 3Ss region. Investment in water infrastructure for salinity intrusion prevention will reduce flushing capacity that lead to further deterioration of water quality in the delta areas of Viet Nam
	Change in salinity intrusion	Increase in dry season flow from dam operations will be offset by sea level rise by 0.3 or 1 m by 2,100
Geomorphologic changes	Barrier effects and dis-connectivity	55–66 % of the total LMR 1,760 km river distance (Sambor to Pak Beng) and 81.3 % of the watershed will be obstructed
		Major changes to sediment transport of all sizes
		Local alteration of surface hydrology crossed by roads, resulting in increased sediment and increased soil erosion
		Changes in the level of the water table
		Sea Water Intrusion and flood control infrastructures will cause further ecological and habitat dis-connectivity in Mekong delta

(continued)

Table 2.10 (continued)

Aspects	Indicators/Variables	Foreseeable 20 years 2030 with LMB dams
	From UMB	75–80 % reduction (90–20 Mt/year) Half the amount of nutrients
		Medium size sediment to Kratie-PP –TLS decrease to 0 by 2050
		Fine sized sediments reduced by another half at all locations
		Nutrient reduced by another 50 %
	Within reservoir area	Formation of deltaic type deposits at the head of each of the reservoirs
		Middle and lower parts of each reservoir will sediment during flood events, associated with reduced velocities/gradients
		Sedimentation and deltaic formation at head of reservoirs
		Sedimentation in reservoirs
	Downstream and critical deep pool and habitat	Erosion starts from Chiang Sean and progressively downstream but slowdown by deep pool
		Increased down cutting and bed and bank erosion in Vientiane-Pakse reaches
		Riverbed and bank erosion Vientiane-Pakse reaches, and Pakse-Kratie. Changes in Thalweg border lines between Lao PDR and Thailand
		Bank and bed erosion starts to be felt at Kratie to PP reaches
		No more supply of sand sized sediment to Mekong delta (not enough stream power for suspension)
		335 deep-pools continue to function, but their long-term functioning may affect
		48 % of them are lost. (About 70 % on Chiang Saen- Vientiane reaches)
	Mekong delta	Reduce in floodplain sedimentation
		§165 million tonnes per year down to 36 % in 20 years
		Stability of the delta shaping processes due to loss in sediment deposition, which are potentially further exacerbated by sea level rise
		Greater instability and erosion of channel
		Some sections of the dykes would have to be even relocated to further land due to the seashore erosion
		Rises in sea water levels combining with increased water consumption within the Mekong delta and upstream will push saline water further inland
		Higher embankments and strengthening of dikes, roads and sluice gates for salinity intrusion will lead to hydrological and morphological changes and variation (obstructions to flood drainage, increasing flood peaks, and increase sedimentation and erosion) on both sides of the Vietnamese and Cambodian border

Estimated increases in mean monthly flows due to proposed dam releases are anticipated for at least the 3 months of February to April. But in early dry season (December) most stations downstream from Vientiane are expected to experience reduced flows due to the combination of dam operations and the high demand for irrigation. If the planned large scale diversions in Thailand materialize, further reduction in base flow is expected. The dry season flow change would be more marked with the projected increase of the dry season irrigation in the area further downstream of Kratie, but may be compensated slightly by hydropower reservoir operations in the Vietnam Central Highlands.

Areas immediately below (40–50 km) reservoirs can experience up to 3–6 m of daily flow fluctuations from peak operations, and emergency releases to avoid dam failure due to flooding can cause flash flooding in the immediate downstream stretches.

Moreover, without river specific and calibrated water balance accounting the projected increase in dry season flow from upper mainstream stretches may not directly benefit any planned diversions from the tributaries. For instance, intra-basin diversions will cause significant reductions in dry season flows in source tributaries such as the Nam Ngum and Nam Lik. Opportunities exist for both positive and negative transboundary impacts, at this time mostly constrained to Lao PDR and Thailand. Positive impacts are related to the benefits of access to additional irrigation water, assuming effective infrastructure and irrigation efficiencies are in place. However wet season reservoir operation poses the risk of flood hazard and additional irrigation water can mobilise soil or groundwater salts. Mainstream reaches by-passed by the diversion are exposed to additional, cumulative risks, especially in drier years. A constant diversion potentially causes water shortages during the critical dry season months of February to May, reducing tributary contributions that maintain minimum environmental flow in the Mekong mainstream.

5.3.3 Expected Changes in Flooding Conditions

The onset of dry to flood season transition will be significantly reduced by 7–8 weeks earlier in Chiang. Saen, 2–4 weeks earlier upstream of Pakse and 1 week at Kratie. This change will see a reduction in the important freshwater '*spates*' which drive many ecosystem functions such as fish spawning, lave dripping and fish migration.

Substantially reduced irrigation needs and limited water storage capacity restrict the current level of wet season water diversions. The impact of dam and irrigation developments on flood conditions will vary at different key points of the Mekong River. Proposed mainstream dams in the LMB will provide limited flood protection to the location immediately downstream (MRC 2010b, c, d). Records from around the world indicate that revenue neutral flood protection tends to be neglected in multipurpose projects (Regional POE 2010).[11]

Reduced flood season peak flows are predicted to reduce the extent and duration of floodplain inundation and contribute to bank erosion on the critical stretches and infilling of deep pools (MRC 2009). The average annual reduction in flooded area is estimated at 7 % (309,000 ha), expected to be smaller in wet years and larger in dry years. The greatest area of reduction occurs in Cambodia (142,000 ha), Lao and Thailand (17 % and 19 % reduction respectively) (MRC 2010d; MRC 2009).

5.3.4 Reverse Flow in Tonle Sap and Impact on Water Level and Inundated Area, Duration and Timing

The changes in the Mekong flood pulse are expected to have transboundary impacts, particularly for the ecology of the Tonle Sap Lake and Mekong delta floodplains (MRC 2010c). The inundation of the Tonle Sap Lake will reduce by 5–10 % (500–600 km^2). However, seawater intrusion prevention measures in the Vietnamese delta will contribute to increased and longer duration flooding in both Cambodia and the delta. Extended flood drainage duration for the entire delta is anticipated, leading to flow stagnation and attendant reductions in water quality.

The Tonle Sap reverse flow will commence at least a week sooner, and the average days will be about 8 days shorter. Dry season inundated area is estimated to increase by 5–8 % transforming the affected seasonal terrestrial ecosystem into permanent aquatic. These changes will reduce the flooded area, flood depth and sediment inflow into the lake, influencing ecosystem and farming productivity, fish migration and sediment flushing capacity.

5.3.5 Change in Water Quality (Turbidity and Relevant Quality Parameters)

Dam sediment trapping will reduce Mekong sediment transport and attendant turbidity by 75 %. The predicted expansion and consolidation of irrigated agriculture

[11] Most of the dams have not been designed to take into consideration major natural disasters such as earthquakes or floods. Lessons from the typhoon Ketsana (end of September 2009) show that mismanagement can cause misery to vulnerable communities. Even where they have been considered, the imperatives of maximizing revenue obliged the dam operators to keep a reservoir as full as possible (and thus maximize hydropower generation as well as irrigation water availability). In recent years a number of earthquakes have taken place across Asia resulting in impacts to numerous dams (Mongabay.com 2008; Brewer 2008; Vijay and Ramesh 2005; Hough and Martin 2001). For example, the 12 May 2008 earthquake in Sichuan province of China (7.9 magnitude) seriously damaged hydroelectric dams and caused major social and economic losses. Sixty-nine dams were in danger of collapse, 310 were at "high risk," and 1,424 posed a "moderate risk" (Brewer 2008). China said it would spend more than $1.3 billion per year fixing vulnerable dams, many of which were poorly constructed (Mongabay.com, 2008; Brewer, 2008). USGS Earth Quake Hazards Project reported two major quake measuring 4.7 on the Richter scale in late February 2011 and 6.1-magnitude quake in 2007at the proposed mainstream dams near Xayaboury, Lao PDR.

will also lead to an increase in use of chemical fertilizer to offset losses in sediments, increasing variable production costs.

As a corollary a considerable basin-wide increase in herbicide and pesticide/fungicide use (75 % and 59 %) is expected and an overall increase in nutrient loading from irrigated areas (85 % (N) and 100 % (P)). The increases will be largest in the Mun – Chi Basin, the 3Ss Basin (agricultural run-off and mining operations) and the Tonle Sap Basin Increased urbanisation along the mainstream and key tributaries will lead to an 33 % increase in N and P nutrient loading from wastewater discharges.

A substantial reduction in water quality is expected as a result of large-scale mining in the Bolaven plateau. Vietnamese government investments in higher embankments, sluice gates and strengthening of dikes and roads will accentuate water quality reductions by increasing the level of flow stagnation and reduced flushing capacity.

5.3.6 Change in Salinity Intrusion: Extent, Duration, and Concentration

Vietnamese irrigators in the Mekong delta are demanding increasing volumes of water during the dry season period of April and May (MRC 2002) Predicted sea level rises and subsequent salinity intrusion will further exacerbate water shortages in periods of extreme drought. The interaction of predicted dry season flows from dam releases and salinity intrusion remains uncertain but potentially a significant determinant of aggregate agricultural production in the delta.

The return flow from the Tonle Sap during the early stage of dry season (December to February) substantially contributes to the downstream flows at Chaktomuk and eventually the Mekong delta. confirming the important role of the Tonle Sap Great Lake as a regulator of Mekong flows. A drastic change to the flow level at the Mekong delta will be expected if the flow into and from Tonle Sap is drastically reduced or delayed by upstream dams operations and diversion. Figure 2.9 illustrates the relative delta flow contributions of the Tonle Sap and upper Mekong.

The delta irrigation volumes registered in 2000 constituted 76–81 % of the available flow in the critical dry season months of April and May, correlated with the increased incidence of seawater intrusion (World Bank 2004). With a projected growth in irrigation water use in April and May serious water shortages and increased competition among water uses is anticipated, as current irrigation demand is already approaching flow availability.

Earlier MRC commissioned studies estimated that during the low flow period the Mekong delta flow requires at least 1,500 m^3/s to prevent severe sea water intrusion (Daming 1997; SMEC 1998). The MRC and Vietnamese Sub-Institute for Water Resources Planning estimated the water requirements for crops in the Vietnam's Mekong delta (year 2000) was at around 1528–1018.7 m^3 per second during February until May, when the observed mean discharge at Phnom Penh, Cambodia was measured between 1,984 and 2,769 m^3/s during that same period (MRC 2002).

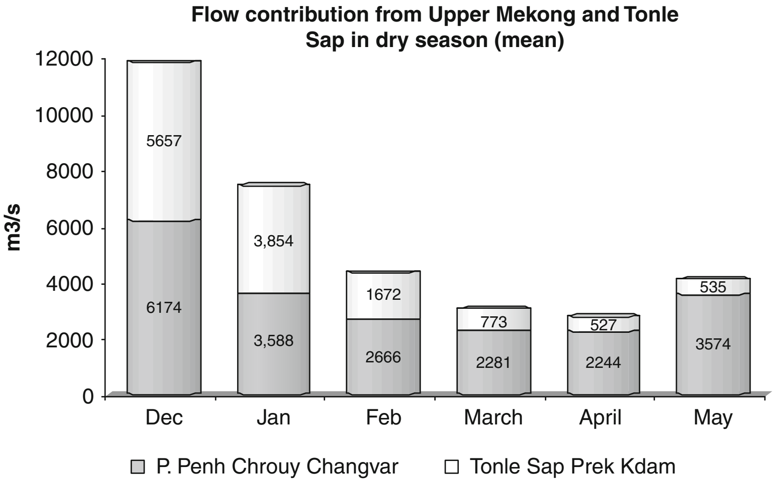

Fig. 2.9 Chaktomuk average monthly minimum flow from upper Mekong and Tonle Sap Rivers

In order to satisfy the water requirements of predicted irrigation expansion and to prevent sea water intrusion in the delta area, additional dry season flows will be required in March, April and May either from locations above Kratie or from the Tonle Sap Great Lake.

5.3.7 Geomorphologic Changes

Despite some proponent claims of benign run of river impoundments, large dams in particular are predicted to reduce sediment transport and associated nutrients, and disconnect wetlands from the river system.

Bravard and Goichot 2010 refer to four dimensions of geomorphologic change in a river system: the longitudinal, lateral, vertical and time. The downstream impacts on the longitudinal profile will trigger localized riverbank erosion and indirect effect of a higher level process that will influence the lateral dimension of the river geomorphology. Erosion of the riverbed, a reconstitution of bed load, and a reduced river bed slope are predicted due to dissipation of river energy. Consequences for the populations living on the river banks (immediately downstream in the area around Vientiane, and to a greater extend on the stretch downstream from Kratie to the Vietnamese border) will be much more critical than anticipated in the current scenario assessment (Bravard and Goichot 2010).

Incision of the river bed in alluvial stretches from Vientiane to Paske, and downstream from Kratie from a sediment hungry river are also another potential impact and will result in water table and riparian vegetation changes. Dams directly upstream of these areas will reduce bed loads and rapidly lead to significant loss of habitat diversity and reduced fisheries productions.

5.3.8 Barrier Effects and Disconnectivity

The construction of the 11 LMB mainstream projects will convert 55–66 % of the 1,760 km river distance between Chiang Saen (Thailand) and Kratie (Cambodia) to a series of managed reservoirs. From 9,000 to 150,000 ha of garden and agricultural land will be inundated in dam reservoir sites (54 %) in Chiang Saen to Pakse, and a 34 % reduction of Lao PDR wetland 18 % in Thailand, and 2.4 % in Cambodia. This change is expected to cause substantial changes in key ecological habitats and water dependent productivity.

With mainstream hydropower power projects operating, there will reduced velocity to suspend sediment particles leading to enhanced sedimentation and the formation of deltaic type reservoir deposits (MRC 2010d; ICEM 2010). Reliable estimates of reservoir sedimentation rates have been hampered by limited sediment size gradients data, except for fine sized particles, measured in the Mekong mainstream since the 1960s.

The main impact of built infrastructures in the floodplains and across Mekong basin rivers will be the alteration of surface hydrology, modified distribution of sediment loads, increased soil erosion and modified flood patterns.

5.3.9 Critical Deep Pool and Habitat

The development will also potentially reduce upper Mekong Basin fined sized sediment transport from 90 to 20 Mt/year at Chiang Sean, and from 165 to 88 Mt/year at Kratie. The reduction will result in a significant loss of floodplain nutrients in floodplains, making deep pool fish habitat at most stretches less productive, reducing fish capture harvests.

6 Conclusion

The water issues in the Mekong Region are closely related to the unequal spatial and temporal distribution of flow, and the lack of robust institutional coordination and well-informed decision making for water resources development. Much of the runoff occurs in flood events or remains inaccessible because of remote locations. The proportion of runoff and river recharge required to maintain non-extractive instream functions and other social and ecological services remains poorly defined.

Despite many Mekong Region countries being endowed with relatively high amounts of renewable water resources per capita, a number of locations currently face a series of critical water issues such as: water shortages and growing water demand; intensive salinity intrusion in the Mekong delta; fisheries reductions and degradation of natural habitats; increased frequency and intensity of floods and drought; and intensification of sectoral competition within and among the Mekong countries.

Water and ecosystem productivity and integrity in the Mekong River Basin are closely linked to the seasonal flow pattern of the river, typified by a wet season flow up to 10 m higher than the dry season. Policy deliberations will need to assess potential water sector changes based on those natural fluctuations, focusing on hydrological changes, and geomorphologic changes that modify ecosystem sustainability and sustainable livelihood. The multi-sector demand and associated dam and diversion interventions remains the key trigger of changes in the Mekong Region for the next 30 years, associated with significant transboundary implications. The extent of hydropower development remains as the primary locus of political attention and negotiation at national and supra national scales. The impact of large scale mining and processing, road and railway infrastructures, and salinity intrusion prevention and flood control structures in the floodplains and Mekong delta will have significant transboundary implication, albeit generally manifest at the local scale. The magnitude of impacts will be dependent on the number and location of dams that will be actually built and how dams are designed, built and operated.

The positive and negative impacts from selected hydropower plans and projects are well documented, although interpretation remains highly contested. However, uncertainties remain relating to the nature, extent and distribution of benefits and impacts on vulnerable communities and water dependent interest. The characteristics of the development trajectory are likely to have a significant impact on the nutritional status of the poor given the extent of the expected reduction in fisheries. This may be aggravated by increases in urban poverty from increased rural–urban migration due to a declining natural resource base and may have knock-on implications for urban poverty rates and an increase in food prices. Those displaced people losing agricultural land would not be the same people who would benefit from improved irrigation opportunities. Small scale land holders may not benefit from medium and large irrigation schemes (ICEM 2010).

It is challenging to provide defensible economic values to the loss to paddy production, fishery and other wetland services. As a general rule, hydropower developments externalise costs, transferring a large proportion to affected communities and undervalue the modification to ecosystem goods and services. Significant mitigation and compensation costs due to these developments, which are expected to be both financially and politically extensive, need to be included in the economic valuation.

There are a number of limitations and caveats regarding the analysis discussed in the Chapter. It is not possible to assess the impacts of the numerous dam and irrigation projects due to limited availability and informally collated data. It is important to note that the current hydrological changes modelled by the MRC relied on to derive these conclusions are built on a number of rough assumptions. Furthermore, in spite of some attempts to create a framework for assessing the impact of various development projects in the MRB, there has been no "cumulative assessment" carried out in the Mekong River Basin. The absence of such a comprehensive impact assessment and an underpinning monitoring system in the Mekong Region highlights the concern for severe cumulative impacts on resource sustainability and livelihoods. However, there is general agreement that these major development projects will substantially modify the hydrological regime and associated water elements in both an incremental and a cumulative manner.

References

ADB, and SEI. 2002. Strategic environmental framework: Integrating development and environment in the transport and water resources sectors, Vols. II, II and IV. Manila: Asian Development Bank and Stockholm Environment Institute.

ADB (2009), 'Annual Report of the Community of Practice on Water', (Manila: Asian Development Bank).

ADB – RETA 40082. 2011. 3S Technical sheets of key topics no 8 large scale infrastructure development in the 3Ss 8b – mining development. Accessed on line on 16 Feb 2011 at http://reta.3sbasin.org/index.php?option=com_content&view=category&layout=blog&id=142&Itemid=178&lang=en.

Baran, E. 2005. *Cambodian inland fisheries – facts, figures and context*. Penang: World Fish Centre.

Baran, E., P. Starr, and Y. Kura. 2007. Influence of built structures on Tonle Sap fisheries Cambodia National Mekong Committee and the WorldFish Centre. Phnom Penh. 44.

Bravard, J. P., and M. Goichot. 2010. Ensuring ecosystem integrity and ecosystem services: A critical review of the BDP (Basin Development Plan) environmental assessment. Critical review by International NGOs at the BDP2 3rd Stakeholders Forum, Vientiane 29–30 July 2010.

Catch and Culture. 2005. Fisheries research and development in the Mekong Region, Vol. 11, no.1, issue of May 2005, fishery programme. Vientiane: Mekong River Commission Secretariat.

CSIRO. 2011. Measuring forestry's impact on water availability. Accessed on line on 18 Feb 2011 at http://www.csiro.au/news/Measuring-forestry-impact-on-water-availability.html.

Daming, H. 1997. Sustainable development of Lancang-Mekong River Basin and integrated multi-objective utilization research of water Resources, *Journal of Chinese Geography* 7(4):9–21.

Dore, J., and X. Yu. 2004. Yunnan hydropower expansion: Update on China's energy industry reforms and the Nu, Lancang and Jinsha hydropower dams. Chiang Mai University's unit for social and environmental research, and Green Watershed.

Dosch, J., and O. Hensengerth. 2005. Sub-regional cooperation in Southeast Asia: The Mekong Basin, Brill academic publishers. *European Journal of East Asian Studies* 4(2): 263–286.

FAO. 2005. Increasing the contribution of small-scale fisheries to poverty alleviation and food security, *FAO technical guidelines for responsible fisheries*. No. 10. Rome: FAO.

Fox, J.M., J.B. Vogler, O.L. Sen, A.L. Ziegler, and T.W. Giambelluca. 2012. Simulating land-cover change in Montane Mainland Southeast Asia. *Environmental Management* 49(5): 968–979.

Grupo Guayubira. 2011. Testimonies about the impacts of large-scale tree plantations on flora and fauna, Montevideo – Uruguay Accessed on line on 18 Feb 2011 at http://www.guayubira.org.uy/english/florafauna.html.

Halcrow Group. 2003. Water utilization project component A: Hydro-ecological report (discussion paper 11). Phnom Penh: Mekong River Commission Secretariat.

Halcrow Group. 2004. Development of basin modelling package and knowledge base (WUP-A), DSF 650 technical reference report appendix A 1–6. Phnom Penh: Halcrow Group Limited, for Mekong River Commission Secretariat.

ICEM. 2010. MRC strategic environmental assessment for hydropower on the Mekong mainstream impacts assessment (opportunities and risks), discussion draft, MRC Initiative on Sustainable Hydropower (ISH). Vientiane: Mekong River Commission Secretariat.

Jiabao, W. 2005. *Opening statement – A stronger partnership for common prosperity*. Kunming: 2nd Greater Mekong Sub-region (GMS) Summit.

Keskinen, M., and M. Kummu. 2010. *Impact assessment in the Mekong – Review of Strategic Environmental Assessment (SEA) & Cumulative Impact Assessment (CIA), improving Mekong water allocation project (PN67) Challenge Program on Water and Food (CPWF)*. Finland: Water and Development Research Group, Aalto University.

Lazarus, K. 2009. *In search of aluminum: China's role in the Mekong Region*. Cambodia: Heinrich Böll Stiftung Cambodia, World Wild Fund and International Institute for Sustainable Development.

Menne, W. 2004. Timber plantations in Swaziland: An investigation into the environmental and social impacts of large-scale timber plantations in Swaziland, Timberwatch coalition member, commissioned by the World Rainforest Movement (WRM).

Miyazawa, N., K. Sunada, and S. Pech. 2008. Bank erosion in the Mekong River Basin: Is bank erosion in my town caused by activities from my neighbours? In *The modern Mekong myth book*, ed. M. Kummu, M. Keskinen, and O. Varis, 19–26. Helsinki: Finnish Academy of Sciences, Helsinki University of Technology (TKK).

Miyazawa, N., S. Kengo, and S. Pech. 2008. Book chapter: Bank erosion in the Mekong River Basin: Is bank erosion in my town caused by activities from my neighbours? In: *The modern Mekong myth book*, ed. The Matti Kummu Marko Keskinen Olli Varis, 19–26. Finnish Academy of Sciences, Helsinki University of Technology (TKK).

Molle, F., and P. Floch. 2008. The "Desert bloom" syndrome: Irrigation development, politics, and ideology in the Northeast of Thailand. Working paper. Mekong program on water, environment and resilience, Institut de Recherche pour le Développement, International Water Management Institute. M-POWER, Chiang Mai. http://www.mpowernet.org/mweb.php?pg=92

Molle, F., T. Foran, and M. Kakonen. 2009. *Contested waterscapes in the Mekong Region: Hydropower, livelihoods, and governance*. London: Earthscan.

MRC. 2002. Basin development planning regional sector overview – agriculture and irrigation report. Phnom Penh: MRC Secretariat, Basin Development Plan Programme.

MRC. 2003. State of the basin report. Phnom Penh: Mekong River Commission Secretariat. 316 pages. ISSN 1728:3248.

MRC. 2005. The MRC basin development plan – scenario for strategic planning, BDP library. Vol. 4, Vientiane, Lao PDR: Mekong River Commission Secretariat.

MRC. 2009. The modelling the flow of the Mekong, MRC management information booklet series no 3. Vientiane, Lao PDR: Mekong River Commission Secretariat.

MRC. 2010a. State of the basin report. Vientiane, Lao PDR: Mekong River Commission Secretariat.

MRC. 2010b. Assessment of basin-wide development scenarios, basin development plan programme, Phase 2. Vientiane, Lao PDR: Mekong River Commission Secretariat.

MRC. 2010c. IWRM-Based basin development strategy for the lower Mekong basin – first complete draft – 15 Sept 2010. Vientiane, Lao PDR: Mekong River Commission Secretariat.

MRC. 2010d. Impacts of climate change and development on Mekong flow regime. First assessment – 2009. MRC Technical paper no. 29. Vientiane, Lao PDR: Mekong River Commission Secretariat.

MRC. 2010e. Technical note 2 – Hydrological assessment, Vientiane, Lao PDR: Mekong River Commission Secretariat.

Nikula, J. 2008. Is harm and destruction all that floods bring? In *The modern Mekong myth book*, ed. M. Kummu, M. Keskinen, and O. Varis, 19–26. Helsinki: Finnish Academy of Sciences, Helsinki University of Technology (TKK).

Papademetriou, M.K. 2000. *Rice production in the Asia–Pacific region: issues and perspectives*, Food and agriculture organization, regional office for Asia and the Pacific, www.fao.org.

Pech, S. 2010. Cambodian and Mekong water resources governance. In *Transboundary resources and environment in mainland Southeast Asia*, ed. Sato J. Institute for advanced studies on Asia, The University of Tokyo, Japan.

Pech, S., and K. Sunada. 2006, China natural resources demand: Opportunities and challenges for Mekong sub-region, Processing of regional workshop "China in mainland Southeast Asia: Flying with the Dragon", Chiang Mai 17–19 Oct 2006.

Pech, S., and K. Sunada. 2008. Population growth and natural resources pressures in Mekong River Basin. Ambio – *A Journal of the Human Environment* XXXVII(3): 219–224

Raskin, P.D., and E. Kemp-Benedict. 2002. Global environmental outlook scenario framework. *Background paper for UNEP's third global environmental outlook report.* Boston: Stockholm Environment Institute.

Regional POE. 2010. Review of the Mekong river commission's basin development plan programme Phase 2. Vientiane: Panel of Experts Report prepared for the Mekong River Commission Secretariat, M-POWER.

Revenga, C., and G. Mock. 2000. Pilot analysis of global ecosystems: Freshwater systems and world resources 1998–99. http://earthtrends.wri.org/features/ view_feature.

Sanyu. 2004. Nam Ngum water management project for Vientiane plain of Lao PDR and northeast Thai region, by Sanya Consultants Inc. SCI, Japan.

Sarkkula et al. (2010). Juha Sarkkula, Jorma Koponen, Hannu Lauri, Markku Virtanen. Origin, fate and impacts of the Mekong sediments. Mekong River Commission, Vientiane, Lao PDR.

Shigeko. 2009. *The Mekong river delta*. Kokon Shoin Publishers

Smajgl, A., J. Ward, T. Foran, J. Dore, and S. Larson In review. Visions, beliefs and transformation:Methods for understanding cross-scale and trans-boundary dynamics in the wider Mekong Region. Global Environmental Change.

Smakhtin, V., C. Revenga, P. Döll, and R. Tharme. 2003. Giving nature its share: Reserving water for ecosystems. In Putting the water requirements of freshwater ecosystems into the global picture of water resource assessment, ed. A. Moy. Accessed on 6 Feb 2011 at http://earthtrends.wri.org/features/view_feature.php?theme = 2&fid = 38.

SMEC. 1998. Final report water utilization programme preparation project. Bangkok: SMEC/MRC Secretariat.

Thompson, R. 2010. Regional and international country experiences lessons learned, http://www.un.org.kh/undp/international-conference-on-mining/international-conference-on-mining#keynote-presentations.

UN. 2007. World population prospects: The 2006 revision, population division of the department of economic and social affairs of the United Nations Secretariat.

UNEP/GIWA. 2006. Global international waters assessment: Mekong River – GIWA regional assessment 55, University of Kalmar for United Nations environment programme.

Van Zalinge, N.P., 2002. Update on the status of the Cambodian inland capture fisheries sector with special reference to the Tonle Sap Great Lake, Mekong Fish Catch and Culture, Vol. 8 no. 2.

WRI. 2011. Earthtrends environmental information. Washington, D.C.: World Resource Insititue. http://www.wri.org/project/earthtrends/.

World Bank. 2004. Mekong Regional water resources assistance strategy – modelled observations on development scenarios in the lower Mekong basin. Vientiane: World Bank.

World Bank and ADB. 2006. Future directions for water resources management in the Mekong River Basin. Joint working paper. Vientiane: World Bank and the Asian Development Bank, 65.

Xu, A., and D. Moller. 2003. Hydropower development plan set for Lancang River. In http://www.china.org.cn/english/2003/Dec/82505.htm. Accessed on 10 Feb 2011.

Ziegler, A.D., J.M. Fox, and J. Xu. 2009. The rubber juggernaut. *Science* 324: 1024–1025.

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