

Simulated changes in water flows of the Mekong River from potential dam development and operations on the Se San and Sre Pok tributaries

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Abstract

Rapid regional growth and energy demands have driven plans to build numerous dams along the Mekong's mainstem and its tributaries prompting significant concern for potential changes in seasonal flow regimes and subsequent impacts on fisheries and biodiversity. In this paper, we demonstrate how multiple dam development and operation in the Se San and Sre Pok tributaries can affect flows in the mainstem of the Mekong. The Se San and Sre Pok tributaries were chosen because they are undergoing rapid dam development, are close to key wetlands, and because they contribute substantial flows to the Mekong. Dam operations along the Se San and Sre Pok Rivers were modelled with the HEC-HMS (Hydrological Modelling System) and HEC-ResSim (Reservoir Simulation) models. Two levels of dam development and three reservoir operation scenarios were modelled. For all operation scenarios of existing and high priority dams, daily changes in water flows and levels occur, but overall seasonal effects are low. However, substantial changes in discharge flows result when large medium priority dams are included and operated to maximize electricity generation. Dry season flows nearly double and wet season peak flows are significantly reduced, translating to changes in the order of 8% of water flows in the receiving Mekong River at Stung Treng. Changes in flows are clearly dependent on the number, size, and operation of reservoirs in the basin. However, simulation results imply that a coordinated management of dams operated under a wider set of rules to minimize changes to natural flow pulses can be a key to maximize total economic return by including the value of downstream ecosystem services. This analysis provides a methodology and basis for future work on studying changes in water levels from dam operations by which strategic options for dam development in the Mekong can be considered.

Keywords

Mekong; dams; hydro modelling; reservoir operations

INTRODUCTION

The Mekong River and its tributaries form a dynamic hydro-ecological system supporting unique biodiversity and providing food security for more than fifty million people in the Indo-Burma region (Kite, 2001). The system is undoubtedly one of the world's most diverse river ecosystems, containing over 560 endemic fish species and over 300 globally threatened vertebrate species (IUCN, 2009). The region's inland fisheries are also some of the most productive freshwater fisheries in the world yielding an estimated 2.5Mt per year (Hortel, 2007) and supplying up to 2/3 of the protein consumption in the region.

The river and its tributaries also have a large potential for hydropower generation (Bakker, K. 1999). Rapid regional growth and energy demands from neighbouring countries have prompted plans to build numerous dams along the Mekong's mainstem and its tributaries (Yu, 2003). These proposals have raised significant concern for the impacts the dams will have on biodiversity and fisheries due to changes in the flow regime. Reduced seasonal fluctuations are likely to affect wetland habitats situated on the floodplains of the Mekong and adversely impact the hydrodynamic flooding and drainage of the Tonle Sap (Cambodia's Great Lake). Preliminary results from three scenarios of cumulative dam development along the Mekong show that the predicted rise in water levels in the Tonle Sap during the dry season could range from 15 to 60 cm. This would result in a

flooding area increase of 147 to 721 km² which would cause significant impacts to the surrounding gallery forests (Kummu and Sarkkula, 2008). Studies on individual dams currently operating in the upper Mekong have shown that significant variations from pre-dam conditions occur on daily and hourly timescales (Li and He, 2008; Fu et al, 2008). Although initial impact assessments have provided remarkably different estimates on hydrological, environmental, and social aspects of the potential development (Keskinen, 2008), it is clear that how dams are operated and where they are constructed are key factors in determining flow changes and subsequent impact on downstream ecosystems services and biodiversity. In this paper we examine how multiple dam development and operation in two main tributaries to the Mekong River (Se San and Sre Pok) can affect flow regimes and water levels in the mainstem of the Mekong.

BACKGROUND INFORMATION

The Se San and Sre Pok tributaries were chosen for investigating the potential extent of impact on the Mekong from tributary dam development because of their rapid and proposed dam development, their relatively close proximity to key wetlands and the Tonle Sap, hydrological data availability, and because they contribute a substantial and important amount of flow to the Mekong mainstem.

The Se San and Sre Pok basins straddle Cambodia and Vietnam (Fig. 1). Their areas are 18,684 km² and 31,079 km² respectively, representing 7.3% of the total area of the Mekong basin at Stung Treng (675,000 km²). Annual discharges for the Se San and Sre Pok are 41 km³ yr⁻¹ and 29 km³ yr⁻¹ respectively which constitute over 17% of total annual flows of the Mekong at Stung Treng (408 km³ yr⁻¹), ranking them among the tributaries contributing the largest water flows to the Mekong river (MRC, 2005).

Both basins have been targeted for rapid development of hydropower with a series of dams being planned along both rivers. There are currently six dams operating on the Se San and Sre Pok mainstems and their principal tributaries (Fig. 1). Other minor dams not identified in Figure 1 exist in smaller tributaries. Seven dams have been designated as high priority dams, some of which are already under construction and due to be completed this year (Table 1). Six additional dams in the lower part of the basin have been designated as medium priority dams, all of which are in Cambodia. Selected information of reservoir storage and potential generation capacity is show in Table 1 for these 19 dams.

Table 1. Existing, high and medium priority dams along the Se San and Sre Pok.

ID (Fig. 1)	Name	Expected Year	Priority	Live storage (mcm)	Potential capacity (MW)
C002	Se San 2 + Sre Pok 2	2014	medium	379.00	480
C009	Lower Se San 3	N/A	medium	3120.00	243
C010	Prek Liang 1	N/A	medium	110.00	35
C011	Prek Liang 2	N/A	medium	180.00	25
C012	Lower Sre Pok 3	N/A	medium	5310.00	204
C013	Lower Sre Pok 4	N/A	medium	2700.00	143
V001	Upper Kontum	2011	high	123.00	250
V002	Plei Krong	2008	existing	948.00	100
V003	Yali	2001	existing	779.00	720
V004	Se San 3	2006	existing	4.00	260
V005	Se San 3A	2007	existing	4.00	96

V006	Se San 4	2009/10	high	264.00	360
V007	Se San 4A	2008	existing	8.00	0
V008	Duc Xuyen	N/A	high	413.00	49
V009	Buon Tua Srah	2009/10	high	523.00	86
V010	Buon Kuop	2009/10	high	15.00	280
V011	Dray Hlinh 2	2007	existing	2.00	16
V012	Sre Pok 3	2009/10	high	63.00	220
V013	Sre Pok 4	2009/10	high	10.00	70

Source: MRC (2009a).

Several data sources were available for hydrological and hydraulic modelling of the basin and dams. Spatial information included satellite imagery, a 50 m grid cell size resolution digital elevation model (DEM), and a GIS based land cover map. Rainfall data for modelling purposes was obtained from 10 stations distributed around the basins (Fig 1.). Measured flow data for the Sre Pok was available for Lumphat in Cambodia and Ban Don in Vietnam. Data for four water level measuring stations were available along the Se San and one along the Sre Pok. Data from 2003 and 2004 was used for calibration and modelling purposes.

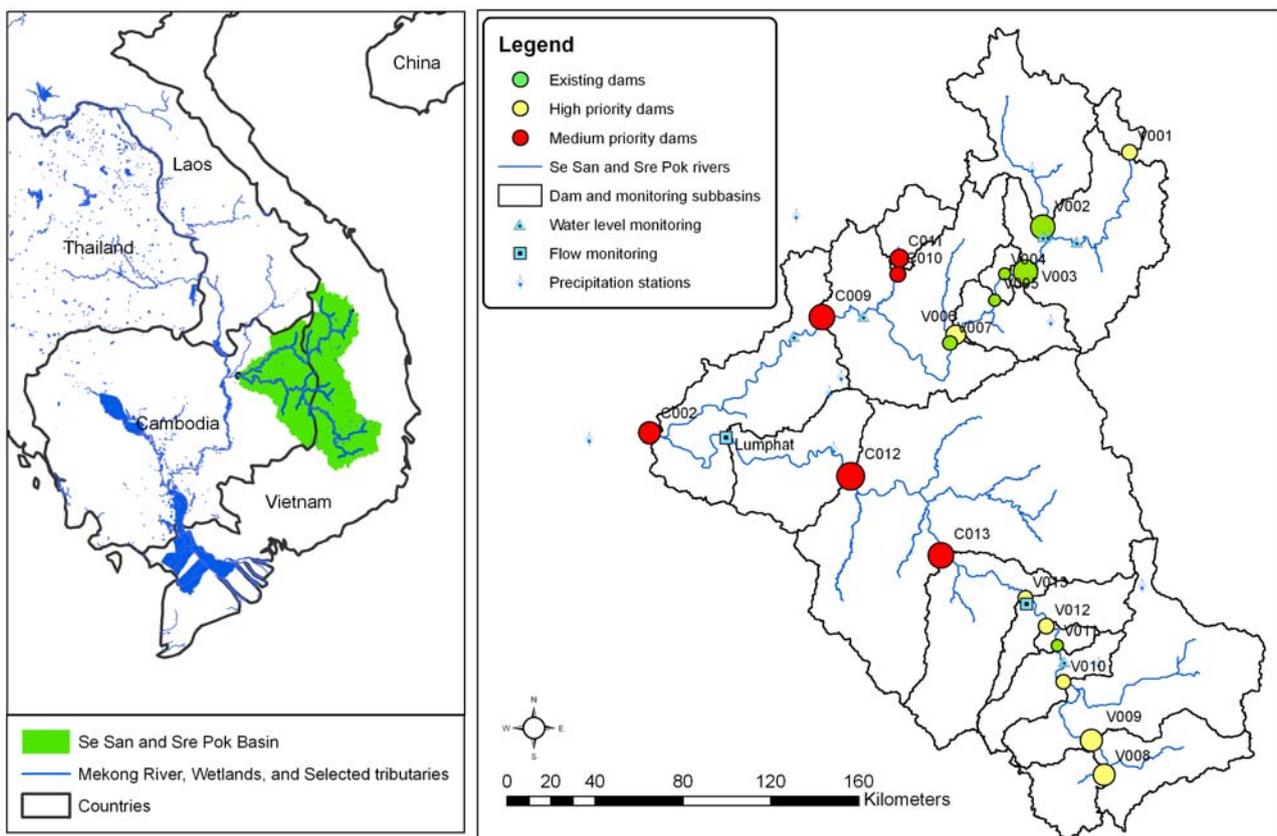


Figure 1. Location of the Se San and Sre Pok basins within Indo-burma (left). Sub-basins, dams, rainfall stations, and monitoring points are shown on the right. Dot size represents comparative reservoir live storage capacity for existing dams (green dots), high priority dams (yellow dots), and medium priority dams (red dots). Data source: MRC (2009a, b).

METHODOLOGY

The impact of the level of dam development along the Se San and Sre Pok and dam operation

scenarios were modelled with the HEC-HMS (Hydrological Modelling System) and HEC-ResSim (Reservoir Simulation) models (USACE, 2009a,b; USACE, 2007) to quantify the magnitude of potential changes to water flows and levels. All simulations were conducted on a daily time step.

The HEC-HMS model was used to model natural (unrestricted) flows and runoff contributions from sub-basins between existing or proposed dams as delineated in Fig. 1. Simulations were conducted on a daily basis using spatially distributed data from the 10 precipitation stations across the basin. Regional land use maps and soils information was used to calculate weighted SCS curve numbers for each sub-basin to predict infiltration and excess rainfall (SCS, 1971). The Clark unit hydrograph method was used to transform excess rainfall to runoff accounting for the time required for water to move to the catchment outlet (Clark, 1945). Baseflow in each river reach was modelled through a simple relationship between sub-basin area and discharge, a ratio to peak threshold type, and an exponential recession constant (k) of 0.98 which was based on typical values proposed by Pilgrim and Cordery (1992). Channel routing was modelled with the Muskingum-Cunge routing method using eight points to define channel cross-sections (Ponce, 1986). Channel parameters (slope, x-section, roughness) were estimated from DEM's, satellite imagery, and reported hydraulic observations. Channel losses or gains were not considered. Daily rainfall values from stations (shown in Fig. 1) were used in the model to generate flows throughout the basin. Calibration of the model was conducted by comparing model simulations with measured flows from Lumphat and Ban Don for the year 2003. Daily peak flows and general flow tendencies were matched by optimizing model parameters (curve numbers and baseflow variables). Model simulation of flows at the outlet of the Se San and Sre Pok basin are plotted against measured flows at the Mekong River at Stung Treng and Sre Pok River at Lumphat showing expected flow magnitudes and tendencies at the basin outlet (Fig. 2). The model was also applied and a verified with 2004 rainfall and individual simulated sub-basin flow contributions were fed to the HEC-ResSim model.

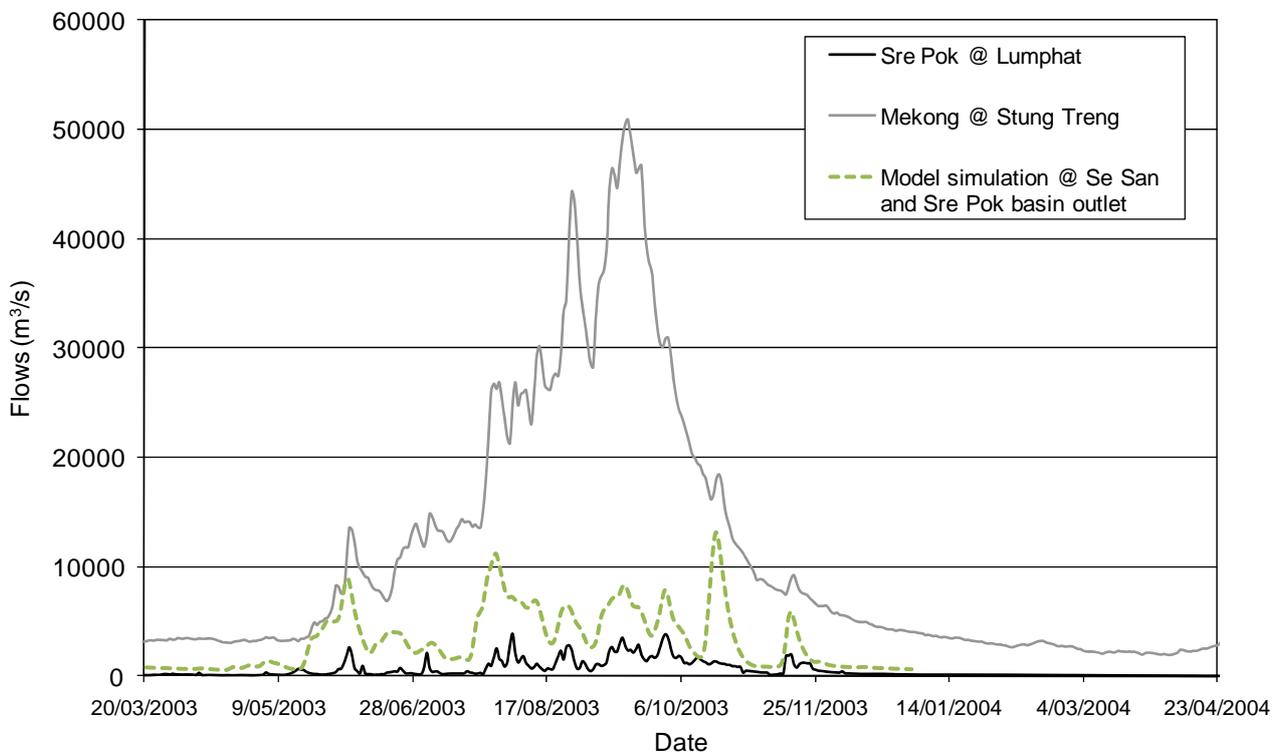


Figure 2. Observed water flows at the Sre Pok River at Lumphat and Mekong River at Stung Treng compared to model simulated flows at Se San and Sre Pok basin outlet.

HEC-ResSim is an established and widely used model for simulating reservoir systems within basins (USACE 2007). HEC-ResSim allows for modelling reservoir operations and routing of water between reservoirs. A reservoir system was developed in HEC-ResSim for the five existing dams and 14 proposed high and medium priority dams in the Sre Pok and Se San basins. For each of the 19 reservoirs, physical characteristics of the dams including location, dam height and width, spillways, power plant discharges, and associated design flows and hydropower capacity were gathered from MRC (2009a). Relationships for area storage and elevation for each modelled reservoir were calculated from the 50m DEM using spatial analyst tools. Operational zones for dead storage, active storage and flood storage were included for each dam based on available information (MRC, 2009a). Routing of water was done through the same channel network use in the HEC-HMS model.

Two levels of dam development (all 19 dams and combined existing/high priority dams) and three operation scenarios (high supply, low supply, and intermediate operation) were modelled to compare resulting changes in water flows at the outlet of the Se San and Sre Pok basin. Existing and high priority dams were combined under one development scenario because most high priority dams are under construction or nearly completed. In the low supply operation scenario, simulations were conducted under dam operation rules intended to keep all reservoirs at or above their lowest active storage level. In the high supply scenario, all simulations were conducted under dam operation rules intended to keep reservoirs at or above their highest active storage level. The intermediate scenario operated dams to i) maintain low active storage levels during the wet season, ii) maintain high active storage levels during the dry season, and iii) linearly change storage levels from low to high or vice-versa during transition months. These scenarios were intended to show the possible range of dam operations which would encompass energy-focused reservoir operations, reservoir management to minimize impact on ecosystem services, and possible levels of dam development scenarios. Operations to maintain dams above the lowest discharge flows during the dry season is analogous to operating dams to maximize electricity generation, while operating dams to maintain a high water level in reservoirs (high supply) is analogous to a more ecological conscious management of dams that would minimize seasonal changes to natural flow pulse patterns. The intermediate scenario aims to maximize energy production in both the dry and wet season.

RESULTS AND DISCUSSION

Simulation results from the low and high supply operation scenarios for all 19 dams and for 13 dams (existing/high priority) are presented in Fig. 3. For the existing and high priority dams under either low or high supply operations, daily changes in water flows and levels occur, but overall seasonal effects are low as demonstrated by the similar flow patterns. When the larger medium priority dams are included in the simulations, discharge flow changes are dependent on the operation scenario. Under the low supply operation scenario, changes in discharge flows at the outlet of the Se San and Sre Pok basin resulting from the operation of all 19 dams are substantial. Dry season flows nearly double and wet season peak flows are reduced by about 1/3 during most of the wet season. These changes will result in changes of up to 8% of water flows and corresponding water levels in the receiving Mekong River, downstream wetlands, and the Tonle Sap, where small changes in water levels can have significant ramifications in terms of gallery forest flooding (Kummu et al., 2008). However, under the high supply operation scenario, differences in discharge flows between the operations of all 19 dams compared to 13 existing/high priority dams are less pronounced, implying that the way dam operations are managed can have a significant effect on seasonal discharge flow changes.

An intermediate operation scenario is plotted against high and low supply operation scenarios for all 19 dams in Fig. 4. Although the operation range of the intermediate scenarios was in the range of the high and low water levels, the resulting change in discharge flows during the months of May, June, and July (beginning of wet season) varied significantly from either of the previous scenarios. This occurs because of changes in the timing and release of stored water. Optimization of cascading dam operations can be achieved to reduce the effect of raising water levels during the dry season and reducing levels during the wet season, but these changes will have an effect on when and how much electricity can be generated. Coordinated management and operation of dams thus becomes important and necessary to maximize economic and ecological benefits.

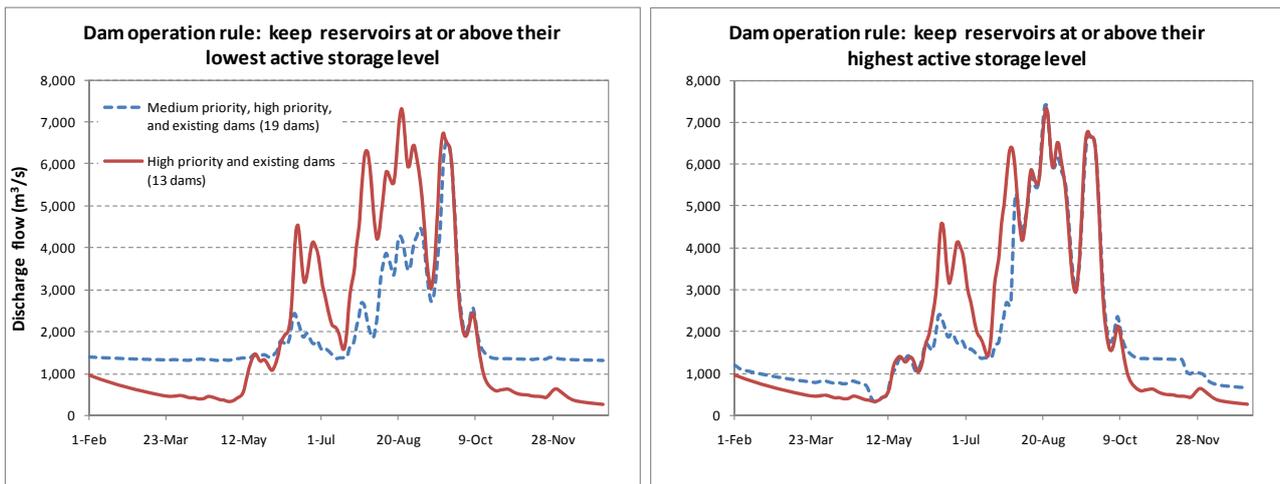


Figure 3. Comparative discharge flows for high and low supply level operation scenarios and dam development levels (all 19 dams and 13 existing/high priority dams).

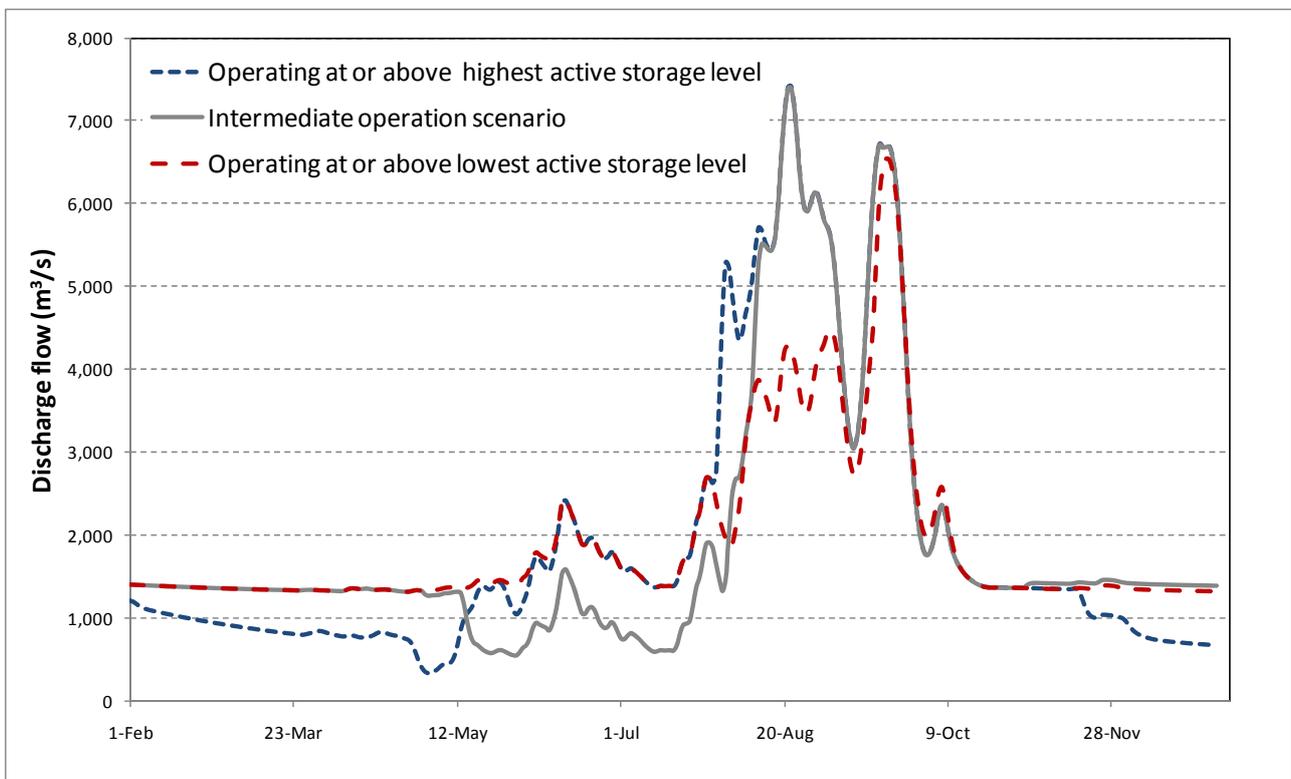


Figure 4. Comparison of three scenarios of dam operations for all 19 dams in the Se San and Sre Pok basin.

CONCLUSIONS AND FUTURE WORK

Simulations clearly show that changes in flows are dependent on the number, size, and operation of reservoirs. Large storage reservoirs, coupled with energy focused operation in the Se San and Sre Pok system will significantly increase discharge flows in dry season and reduce flows at the beginning of the wet season. Development of medium priority dams in Se San and Sre Pok tributaries will have a significant effect on water flows and levels in the Mekong River, because of their location and the large storage designed for these dams. However, simulation results imply that a coordinated management of dams operated under a wider set of rules to minimize changes to natural flow pulses can be a key to maximize total economic return by including the value of downstream ecosystem services. Downstream ecosystem services should include fisheries, natural flora and fauna, and agricultural production dependent on natural flood pulses. This analysis provides a methodology and basis for future work on studying changes in water levels (and sediment flows) from dam operations in the Mekong and its tributaries by which strategic options for dam development can be considered.

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