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# **Comparison of climate change impacts and development effects on future Mekong flow regime**

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**Abstract:** A framework of climate change (CC) analysis is developed using the Decision Support Framework models of the Mekong River Commission (SWAT hydrological, IQQM basin simulation and hydrodynamic iSIS models) to analyze impacts of CC and water resources development on Mekong flow regime. This analysis is based on six model run scenarios defined as combinations of a development scenario, either baseline or 20-year plan and a climate dataset, either observed or from regional downscaling model simulating the past in 1985-2000 or projecting the future climate in 2010-2050. The projected climate shows a slight increase in precipitation throughout the Mekong basin except in the delta. Temperature is projected to increase by 0.023°C/year. During the high-flow season, impacts of CC and development are in contrasting directions. The development brings a decrease of about -8 to -17% of river flow but CC increases +2 to +11%. The combined effect causes changes in discharge from +3% to -13% depending on CC scenarios and location of stations. In the low-flow season, both CC and development will increase river flow, with +30 to +60% due to development and +18 to +30% due to CC. The combined effect is up to +40 to +76%. While development reduces the flooded area, CC will make it larger in a wet year. Salinity intrusion area in the delta could be larger in a dry year under CC but development can reduce the affected area. The analysis shows that adaption strategies are needed to achieve the development objectives under CC conditions.

**Keywords:** Mekong River Basin; Climate change; Development impacts; Flow regime., Decision Support Framework

## **1. INTRODUCTION**

The Mekong river is one of the world's largest rivers with a length of 4,800 km and a basin area of 795,000 km<sup>2</sup> extending over six countries: China, Myanmar, Lao PDR, Thailand, Cambodia and Viet Nam (Fig. 1). In 2006, a population of over 60 million depended on the Basin resources for their livelihoods. In Cambodia, the Great Lake, linked to the Mekong River by the Tonle Sap River, covers an area varying from 3,000 km<sup>2</sup> in the dry season (November-April) to 15,000 km<sup>2</sup> in the wet season (May-October), and is considered the heart of the Mekong basin. In Viet Nam, the Mekong Delta is the most important rice producing region in the country. However, the Mekong annual volume of 475,000 million m<sup>3</sup> is irregularly distributed with about 87% in the high flow season (June-November) and only 13% in the low flow season (December-May). Because of such seasonal variations induced by the monsoonal regime, many hydropower and irrigation reservoirs have either been constructed or are being planned for redistributing water volume between the high-flow and low-flow seasons. These infrastructures are expected to significantly alter land uses and ecosystems in the basin. This paper presents a modelling framework to analyse the impacts of different development and climate change scenarios on the Mekong flow.

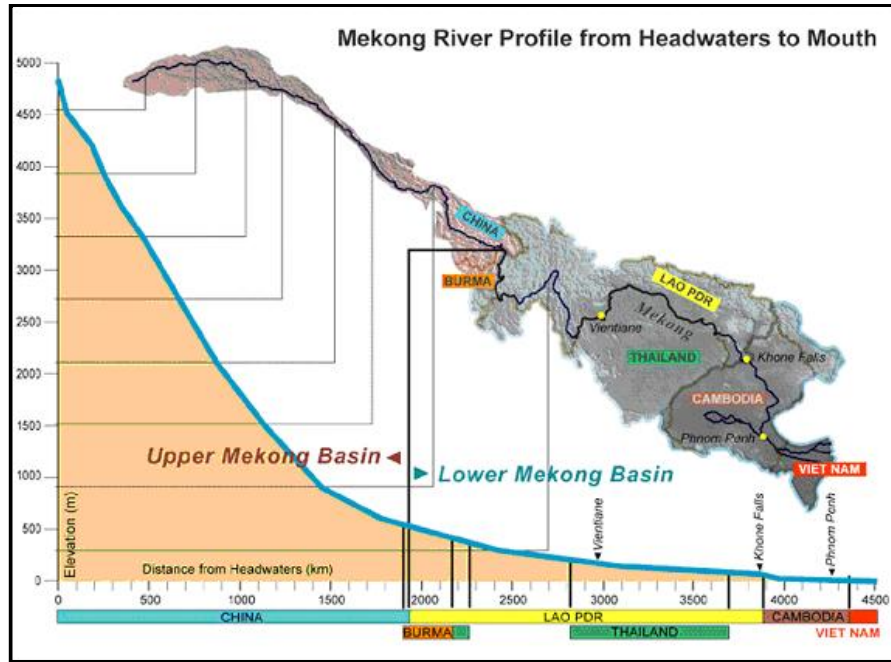


Figure 1. Mekong River Basin and longitudinal profile of the Mekong River (MRC, 2005).

## 2. MATERIALS AND METHODS

### 2.1 Framework of development and climate change scenario analysis

In the framework of climate change (CC) scenario analysis, a model run scenario is defined by a combination of a development scenario and a climate dataset. The basin development scenarios are Baseline (BL) or future 20-year development (DEV) under the Basin Development Program (BDP) of the Mekong River Commission (MRC). The climate datasets include either observed hydro-meteorological data from the past 1985 - 2000 or projected data by the regional climate model (RCM) for 1985-2000 (simulation period) or future 2010-2050 (projection period). In total, six model run scenario (Fig. 2) were implemented to provide the comparison presented in Table 1.

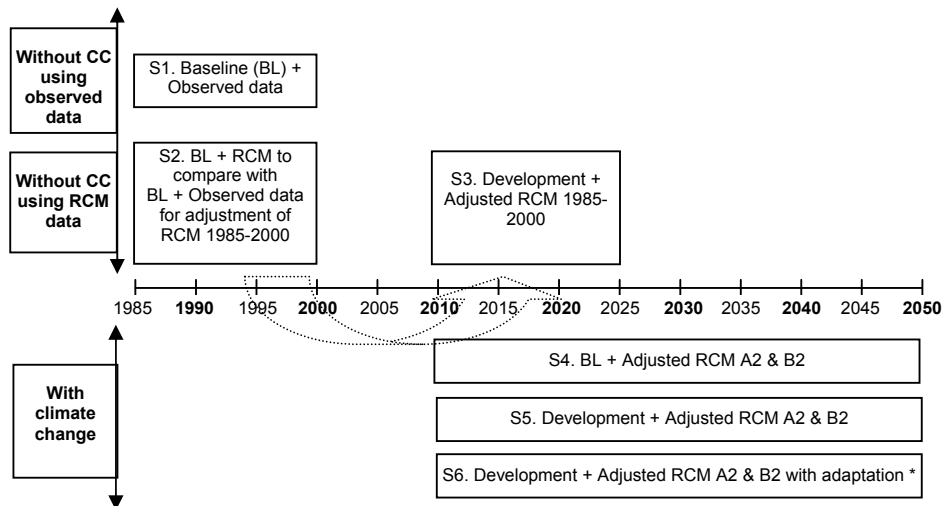


Figure 2. Framework of climate change scenario analysis.

**Table 1.** Purposes of model run comparison

Comparison	Purposes
S2 and S1	Demonstrate that the adjustment applied to the RCM data of 1985 - 2000 is appropriate for simulating the hydrological impacts in the past and could be applied for future RCM projections.
S3 with S2 <sup>a</sup>	Identify impacts of Development compared with Baseline without climate change.
S4 with S2	Identify impacts of climate change if Baseline conditions are remained in the future.
S5 with S4	Identify impacts when Development is implemented under climate change
S6 with S5 <sup>b</sup>	Analyse effects of adaptation strategies to climate change on Development

Note: <sup>a</sup> To keep same source of climate data in comparison, S2 is used instead of S1.

<sup>b</sup> This comparison is not presented in this paper because the adaptation strategies require further revision of agricultural production systems and hydropower options under new flow regime of scenario S5 that will be done under the new studies on adaptation.

## 2.2 The models

Since 2004, the Decision Support Framework (DSF) has been used at the MRC to analyse the Mekong flow regime under different development scenarios (Halcrow, 2004). The DSF integrates geo-referenced hydro-meteorological records, topographic, land use, socio-economic and environmental data. The core component of the DSF is a model package comprising 3 models: (i) the “Soil and Water Assessment Tool” (SWAT) hydrological model (Neitsch et al., 2001) which simulates runoff, including snowmelt from observed daily climate variables, topography, soils and land cover; (ii) the “Integrated Water Quantity and Quality” (IQQM) basin simulation model (Podger and Beecham, 2003) which routes catchment flows through the river system, taking into account control structures such as dams and irrigation abstractions; and (iii) the iSIS hydrodynamic model (Halcrow/HR Wallingford, 1999) which simulates the water level, discharge and salinity in the river system from Kratie (Cambodia) to the river mouths, including the Tonle Sap Lake and the Cambodia and Vietnamese Mekong Delta.

The SWAT model was set-up and calibrated to represent 190 sub-basins in the upper Mekong Basin (UMB) upstream of Chiang Saen, 510 sub-basins in the lower Mekong Basin (LMB) between Chiang Saen and Kratie and 63 sub-basins around the Great Lake in Cambodia. Runoff output from SWAT was used as input for the IQQM model to generate discharge at key stations (Fig. 3). IQQM simulated discharge at Kratie and SWAT simulated runoff around the Great Lake were used as upstream boundary conditions for the ISIS hydrodynamic model in the downstream area of the Mekong basin, including the delta.

## 2.3 The basin development scenarios

The Baseline scenario corresponds to the infrastructural, socio-economic and bio-physical conditions of the Mekong basin in 2000 (MRC, 2009). This scenario accounts for (i) physical properties of river network, climate and land use conditions, public and industrial water demand, irrigated areas, cropping patterns, storage characteristics, hydraulic conveyance, flood storage and (ii)



**Figure 3.** Location of key discharge stations along the Mekong mainstream in the Lower Mekong Basin.

water management options, including operating rule curves for storages, water allocation policies and operating rules for salinity barriers, based on available information of existing infrastructures collected by MRC. In the BL scenario, the total live storage of large reservoirs is 9.6 km<sup>3</sup>, about 2% of the annual Mekong flow (475 km<sup>3</sup>). Irrigated areas extend over 5.3 million ha during the wet season and 2.1 millions ha in the dry season.

The DEV scenario accounts for : i/ the construction of six Chinese dams in the UMB; (ii) the development of water infrastructure in the LMB tributaries since 2000 such as Nam Theun 2 and Nam Ngum 2 hydropower projects and several irrigation projects, (iii) the current development plans of the LMB countries, including 11 dams on the Mekong mainstream, realistic diversions and other developments for irrigated agriculture, flood control, domestic and industrial water supply planned for the next 20 years. The total live storage of the Chinese reservoirs and of the LMB reservoirs included in the DEV scenario are about 22.2 km<sup>3</sup> and 44.0 km<sup>3</sup> respectively. In total, all reservoirs provide a live storage of 75.8 km<sup>3</sup> (16% of Mekong water) to generate 48,807 MW. Irrigated areas are expected to expand by 8% and 18.3% in the rainy and dry season respectively. Data on China dams are limited, therefore it is assumed that they will be operated to maximize electricity production within the variability of historical inflow data. The mainstream dams in the LMB will be constructed and operated in accordance with their current preliminary designs.

#### **2.4 The PRECIS Regional Climate Model data**

The PRECIS (Providing Regional Climates for Impacts Studies, see Jones et al. 2004) appears to be one of the most frequently used regional climate models (RCM) in Southeast Asia over the last five years. This RCM was forced by the Global Climate Model (GCM) ECHAM4 at its lateral boundaries, under the IPCC SRES scenarios A2 and B2. Climate output of the PRECIS RCM includes precipitation, temperature, solar radiation and wind speed, produced by the “Southeast Asia SysTem for Analysis, Research and Training” (SEA-START) Regional Center. The downscaled grid of the PRECIS model includes 2,225 cells covering the entire Mekong River Basin at a resolution of 0.2 degree x 0.2 degree (equivalent to about 22 km x 22 km) for 1985-2000 and 2010-2050. These data were processed in three steps: (i) aggregation of data from grid cells to sub-basins; (ii) adjustment to match monthly RCM data with observed data during simulation period 1985-2000 and to fit simulated runoff and flow of model run scenario S2 with that of scenario S1; and (iii) adjustment of RCM data for projection period 2010 – 2050 by applying the same adjustment method and values in step (ii).

### **3. RESULTS AND DISCUSSIONS**

#### **3.1 Climate change projection**

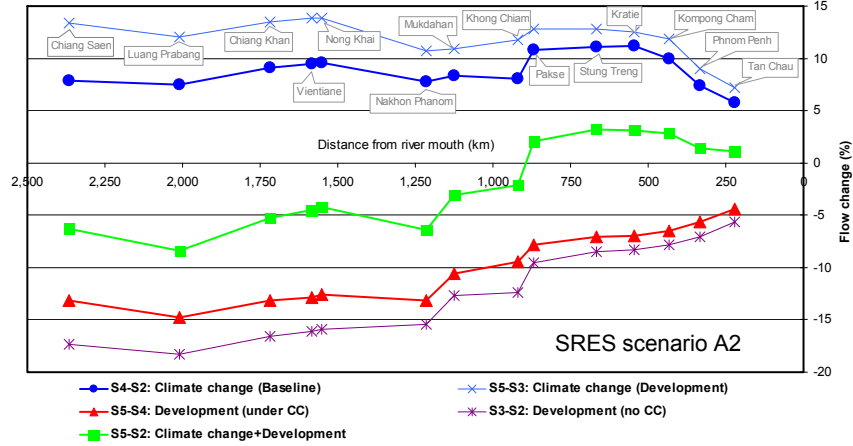
After applying the adjustment mentioned above, the RCM projection revealed a slight increase in precipitation throughout the Mekong Basin (1.2 – 1.5 mm/year), except in Cambodia and in the Vietnamese Delta during the period 2010-2050 compared with the period 1985-2000, with higher precipitation depth in scenario A2 compared to scenario B2. This implies that the rainy seasons will be wetter. Wetter dry seasons in the UMB with an increase of 0.9 mm/year are also projected, but precipitation changes in the LMB are insignificant. Temperature is projected to increase by about 0.023°C/year. These rainfall and temperature projections are similar to the results obtained by other studies implemented over the last few years (Eastham et al., 2008; Mac Sweeney et al., 2008)

#### **3.2 Impacts of development on flow regime without and with climate change**

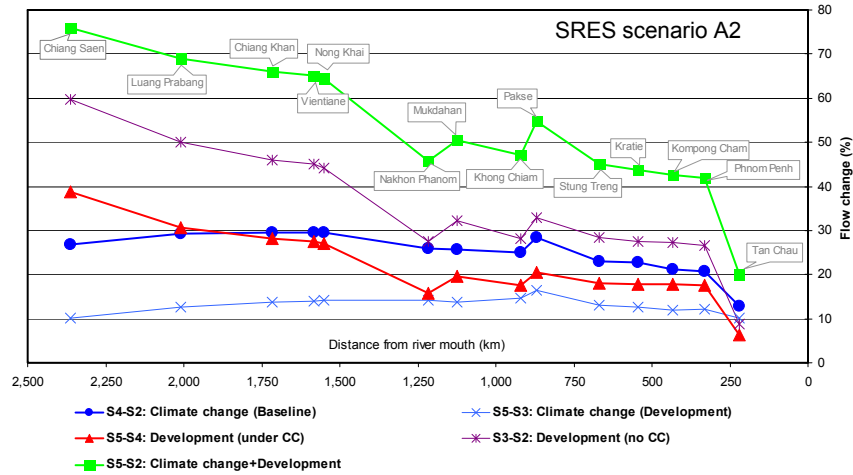
The impacts of DEV were assessed through the characterization of changes in flow regime at key discharge stations along the Mekong mainstream. The comparison of the DSF models output under scenarios S3 and S2 (DEV and BL without CC) shows that in the high-flow season, discharge decreases at all stations with a decrease rate rising from upstream to downstream, for examples, 715 m<sup>3</sup>/s decrease at Chiang Sean (the most

upstream station of LMB) and 1,787 m<sup>3</sup>/s decrease at Kratie (downstream of most hydropower reservoirs). In term of percentage, the lower values at downstream stations (S3-S2 in Fig. 4, 8% at Kratie compared to 17% at Chiang Saen) show that the proportion of water flow regulated by the reservoirs is higher at upstream.

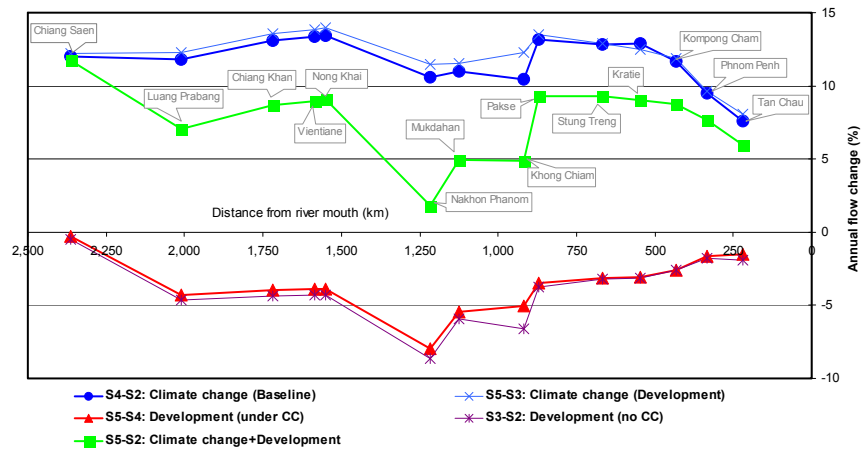
**Figure 4.** Impacts of development and climate change on high-flow season discharge.



**Figure 5.** Impacts of development and climate change on low-flow season discharge.



**Figure 6.** Impacts of development and climate change on annual discharge.



On the other hand, in the low-flow season, discharge increases at all stations but to a lesser extent than the decrease in the high-flow season, although in terms of percentage, the increase is much higher (S3-S2 in Fig. 5). On an annual basis, mean discharge decreases as a result of increased evapo-transpiration in new irrigation schemes and evaporation losses from new hydropower reservoirs under the DEV scenario (S3-S2 in Fig. 6).

With CC, the effects of DEV (S5) on flow decrease in the high-flow season and flow increase in the low-flow season (S5-S4 in Figs. 4 and 5) are less pronounced than in the absence of CC (S3-S2). However, the effect of CC on development-induced changes in annual flow is insignificant (cf. scenarios S5-S4 and S3-S2 in Fig. 6). These results are similar in both SRES scenarios A2 and B2, with lower flow changes under scenario B2.

### 3.3 Impacts of climate change with and without development

SRES scenario A2

Without further development, i.e. the BL will be remained in the future, the discharge increases in both high-flow and low-flow seasons (S4-S2 in Figs. 4 and 5). The increase in high-flow season is due to change in precipitation in the whole basin, but the increase in low-flow season is mainly explained by the increase of precipitation and snowmelt in the UMB discussed below. The percentage increase is between 20% and 30% in the low-flow season and 7% and 11% in the high-flow season, leading to an overall increase of 10 - 13% in the annual discharge at stations upstream of Kratie (S4-S2 in Fig. 6).

Under the DEV, a comparison of model run scenarios S5-S3 reveals similar impacts of CC on flow regime as S4-S2. The increase of discharge in the low-flow season is less than that found in S4-S2 because more water is available and used in the sub-basins (Fig. 5). On the other hand, the discharge increase is greater during the high-flow season than in the case of S4-S2 (Fig. 4). This indicates that the water control measures such as reservoirs and irrigation systems in the DEV do not fully take advantage of additional flows induced by CC. However, these two seasonal changes lead to a similar increase in annual discharge ranging from 11% to 14% at most stations like in S4-S2.

### 3.4 Comparison of impacts of development and climate change

Impacts of both DEV and CC on flow regime are analysed by comparing model run scenarios S5 and S2. The combined effect of both DEV and CC results in a 40-70% increase of discharge during the low-flow season at stations upstream of Kratie (S5-S2 in Fig. 5). On the other hand, flow change in the high-flow season varies according to the CC scenarios (A2 or B2). DEV and CC scenarios induce opposite hydrological impacts in this season: river flow decreases in response to DEV and increases under CC. Under scenario A2, discharge in the high-flow season decreases at upstream and increases at downstream of Pakse (S5-S2 in Fig. 4) where the effect of CC becomes stronger than that of DEV. Under scenario B2, it decreases at all stations because of lower projected precipitation. DEV and CC together result in an increase in the annual discharge at all stations ranging from 5 to 10% under scenario A2 and from 0 to 7% under scenario B2.

In summary, in the high-flow season, DEV causes a discharge decrease ranging from 5% to 18%, CC causes an increase in discharge of between 5% and 14%. The effect of decreasing high-flow season discharge by DEV under non-climate change condition (S3 - S2) is slightly higher than that under CC conditions (S5 - S4). The combined effects of DEV and CC lead to a 2 - 5% decrease (S5 - S2) in high-flow season discharge at stations upstream of Pakse, but a slightly smaller increase of 0 - 4% downstream from this station. These results indicate that the water volume controlled by DEV in non-climate change condition should be better adjusted to control high-flow season discharge under CC. Detailed analysis of water use modalities of each development system is required to identify suitable options to better adapt to CC, but taking into account the uncertainty in CC projection.

In contrast to the high-flow season, both DEV (S5 - S4) and CC (S4 - S2) result in a similar increase of 20 - 40% in the low-flow season discharge at all stations, with an exception of lower value at Tan Chau located in the Mekong delta where river water is regulated by the Great Lake through the Tonle Sap and influenced by tide in the South China Sea. The

combined effects of DEV and CC (S5 - S2) lead to a 40 - 80% increase in discharge which is higher at upstream but gradually reduces downstream. The discharge increase in the low-flow season by CC under DEV (S5 - S3) is lower than that under BL (S4 - S2) since more water is used in the sub-basins in the low-flow season under DEV.

The combination of DEV and CC results in an increase of annual discharge at all stations ranging from 2 to 12% (S5 - S2 in Fig. 6). The magnitude of CC impact on annual flows is higher (+8 to +14%) than that of the DEV (-0 to -8%). Interestingly, while there are large differences in effects of DEV on CC impacts (S5 - S3 compared with S4 - S2) and of CC on DEV impacts (S5 - S4 compared with S3 - S2) in the high- and low-flow seasons (Figs 4 and 5), these differences in the effects on the annual discharge are minor (Fig. 6). This implies that a seasonal analysis of impacts should be made as in this study rather than only looking at changes in the annual discharge.

### 3.5 Other impacts related to flow regime

Increased temperature will induce earlier melting of snow in spring in the UMB. The effect of CC on glaciers is slightly different. Within the Mekong basin, the melted glaciers (about 17.3 km<sup>3</sup>) (Eastham et al., 2008) and permafrost (about 10 km<sup>3</sup>) are equivalent to about 25 km<sup>3</sup> of water. If future global warming were to melt all these glaciers and the permafrost, the annual amount of water produced would still be insignificant in comparison to the total Mekong water of 475 km<sup>3</sup> per year (Johnston et al., 2009). The mean monthly and annual snowmelt depths calculated for all SWAT sub-basins of the UMB show 72% and 62% increase between the past 1985 – 2000 and the future climate 2010 – 2050 under scenarios A2 and B2, respectively. The snowmelt contribution to water yield at the Chinese–Lao border, currently about 5.5% might increase to 8% in 2010 - 2050. With such range, snowmelt in the UMB contributes about 7% to the annual discharge at Chiang Saen, but the percentage gradually lowers further downstream, to about 1.5% at Kratie. However, its contribution is more significant in the low-flow season, for example, estimated 68.2% and 22.2% in March during the period 1985-2000 at Chiang Saen and Kratie, respectively. With the temperature and precipitation increase under CC, the amount of March snowmelt will change, but the percentage contribution to the river discharge will not differ much because the river discharge also changes.

Attention is commonly paid to areas of the Mekong Delta which are flooded or suffered by saline intrusion in extreme years. Years with highest flow at Kratie (1998 for the past and 2048 for future periods) and years with lowest flow at Kratie (2000 for the past and 2021 for future) were selected for comparison of flood and salinity intrusion, respectively. While the DEV only reduces the total flooded area (45,000 km<sup>2</sup> under 2000 conditions) by -3.4% under non-climate change condition, CC may cause an enlargement of 3% to 8.8% depending on SRES scenarios. Under CC, the effect of DEV on reduction of flooded area becomes minor because of the limited regulation capacity at high peak flows. However, the variation by CC scenario implies that the area of flooding depends, to a large extent, on the uncertain variations of daily precipitation throughout the wet season.

The increased discharge in the low-flow season due to DEV reduces the area with salinity > 4 g/l by about 14%. However, under CC, although over a long period, the mean discharge will increase, the inter-annual variations are rather large, hence low-flow seasonal discharges may be lower than the past in certain years. This variation is shown by the 16 - 17% enlargement of saline area in scenario S4 compared to S2. By increasing discharge in the low-flow season, the DEV can help in reducing such enlargement. However, salinity intrusion in the Delta also depends on the water volume stored in the Great Lake during the high-flow season in the previous year and the tidal regime in the sea, therefore the saline area does not always correspond to the minimum monthly discharge at Kratie.

## 4. CONCLUSIONS AND RECOMMENDATIONS



The effects of DEV will cause a decrease in annual discharge of about 3 - 8% under both the past climatic conditions and the future CC projected by the PRECIS RCM. Conversely, CC would increase the river discharge by 4 - 14% under both the BL and the DEV. The effect of both CC and DEV may cause an increase in discharge of about 2 - 12%, depending on the CC scenario and the location of stations considered. However, in the high-flow season, impacts of CC and effects of DEV are in contrasting directions. The combined effects of DEV and CC may cause a decrease in discharge of up to 13% at one station, but an increase of 3% at another. Such variation reflects that the current development plan has not been prepared to adapt to CC. In the low-flow season, although impacts of CC and effects of DEV are in the same direction of increasing river flows, the combined effects are complex. The effect of both CC and DEV may cause an increase in discharge of up to 40 - 76% at different stations. These figures suggest that a seasonal analysis is needed for dealing with DEV and CC issues.

Analysis with more CC datasets would be helpful to reduce the uncertainty in climate projection. Although more observed hydro-climatic data (i.e. from more stations and of longer duration) and other data such as land use, water use, reservoir regulation rules are collected to improve the accuracy in modelling, the DSF, which was designed and set-up only for the analysis of changes in flow regime under different scenarios, should be supported by other production models and analyses in order to identify adaptation strategies dealing with flow changes.

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