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Impacts of climate change and development on Mekong flow regimes First assessment - 2009

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Meeting the Needs, Keeping the Balance

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Abbreviations and acronyms

BDP	Basin Development Plan.
CC	Climate Change.
CE	Coefficient of Efficiency.
CSIRO	Commonwealth Scientific and Industrial Research Organisation.
DSF	Decision Support Framework-MRC's suite of computer-based numerical modelling and knowledge based tools.
ECHAM4	A model based on the prevision model of the "European Centre for Medium Range Weather Forecast" (ECMWF) and modified by the German modelling centre and the Max Planck Institute to adapt it to the long term climatic simulations.
EP	Environment Programme.
GCM	General Circulation Model.
IBFM	Integrated Basin Flow Management
IKMP	Information and Knowledge Management Programme
IPCC	Intergovernmental Panel on Climate Change
IQQM	Integrated Quantity Quality Model, a hydrologic modelling tool developed by the Department of Land and Water Conservation (DLWC), New South Wales, Australia.
ISIS	ISIS a comprehensive software system developed by Halcrow and Wallingford Software, UK, for managing change in basins.
IWMI	International Water Management Institute.
KB	DSF Knowledge Base.
LMB	Lower Mekong Basin.
MQUAD	Data preparation tool for generating catchment average estimates of rainfall from point estimate rainfall.
MRB	Mekong River Basin.
MRC	Mekong River Commission.
MRCS	Mekong River Commission Secretariat.
PET	Potential Evapotranspiration.
PRECIS	Providing Regional Climates for Impacts Studies, a regional climate model system developed by Hadley Centre, UK.
RCM	Regional Climate Model.
SEA START RC	Southeast Asia SysTem for Analysis, Research and Training Regional Center.
SRES	Special Report on Emission Scenarios.
SWAT	Soil and Water Assessment Tool, US Department of Agriculture.
UMB	Upper Mekong Basin.
VR	Volume Ratio.
WUP	Water Utilisation Programme.

Summary

The waters of the Mekong River, flowing through one of the world's largest river basins, are used mainly for hydropower and irrigation. Thus the river flow regime would not only be affected by climate change but also by any hydropower or irrigation developments planned in the Basin. The Basin Development Plan (BDP) Scenarios are designed to take account of any such developments. This paper presents: (i) the framework of the climate change analysis and its application to the (BDP) Scenarios; (ii) the results of the Decision Support Framework (DSF) models for the analysis of the climate change impacts and the selected BDP Scenarios on flow regimes; and (iii) recommendations for further studies to identify suitable adaptation strategies for dealing with such impacts.

The DSF framework comprises six scenarios defined by a BDP scenario combined with a climate dataset. Three scenarios, i.e. Scenarios S1, S2 and S3, assume there is no climate change, while three, i.e. Scenarios S4, S5 and S6 assume there is climate change. The scenarios also differ in the data input; some use observed data (S1) while others use Regional Climate Model (RCM) data (S2 and S3). Other differences are those scenarios which take into account both climate change and development impacts and adaptation stepwise (S4, S5 and S6 respectively). Detailed descriptions of the various scenarios are given in Chapter 2.

In this first assessment, two BDP Scenarios, namely the Baseline Scenario and the Lower Mekong Basin (LMB) 20-Year Plan Scenario, were selected in order to compare the impacts of climate change on the flow regime. Data on climate change were the future climate projection daily data for the two Scenarios A2 and B2 from the Intergovernmental Panel on Climate Change Special Report on Emission Scenarios (IPCC SRES) as provided by the SEA START Regional Centre and based on the ECHAM4 GCM from the Max Planck Institute for Meteorology, Germany. These were downscaled to the Mekong region using the PRECIS system.

In order to project the flow changes under different climate and development options, DSF simulation models, the SWAT hydrological model, the IQQM basin simulation model and the hydrodynamic ISIS model were used. The PRECIS climate data produced for 2,225 grid 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) were processed in three steps: (i) aggregation of data from grid cells to sub-basins; (ii) adjustment to fit simulated data with observed data for 1985 – 2000; and (iii) adjustments to the projected data for 2010 – 2050.

After data from 1985 – 2000 were adjusted by a comparison with the observed data and applied to the future, the results showed changes in both precipitation and temperature. The PRECIS climate data revealed a trend of a slight increase in precipitation throughout the Mekong Basin, except in Cambodia and in the Viet Nam Delta with a 1.2 – 1.5 mm/year projected increase in precipitation from now until 2050. This means that the rainy seasons will be wetter; however the precipitation increase in Scenario B2 is less than that in Scenario A2.

Wetter dry seasons in the Upper Mekong Basin (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 projections are similar to those found by other studies.

The projections of the impacts of both climate change and development are somewhat different; mostly in terms of the level of the water flows. At times of high-water flow the impacts of climate change have an opposite effect to those of development. In Scenario S3 with the climatic conditions of 1985 – 2000, the impact of development is to decrease the river flow by 8 – 17% (the results of Scenario S3 minus those of S2), but from 2010 – 2050, the decrease is slightly less, at about 7 – 14% (the results of Scenario S5 minus those of S4). These percentages are percentages of the changes in the scenario in which it is assumed that the Baseline will continue in the future. If climate change is taken into account, then the river flow in Scenario S4 is projected to increase by 2 – 11% in comparison to that in the past (Scenario S4 – S2). The combined effect of development and climate change may cause a decrease of up to 13% in discharge at one station, but an increase of 3% at another station, depending on the climate change scenarios and the location of the stations (Scenario S5 – S2). Such variations clearly show that the current development plan will require adjustments to encompass adaptations to climate change.

In the low-flow season, both the impacts of climate change alone and the effects of development alone bring about increases in the river flow, but their combined effect is more complex. Under the climatic conditions of 1985 – 2000, the impact of development is to bring about an increase of 30 to 60% in the river discharge (Scenarios S3 and S2), but under the future climate change conditions, the effects are less at about 18 – 40% (Scenarios S5 and S4) in comparison with the assumption of the Baseline continuing in the future. In this instance river flow would increase by about 18 – 30% (Scenarios S4 and S2). The effect of both climate change and development may cause an increase of discharge of up to 40 – 76% (Scenarios S5 and S2), depending on the climate change scenarios and the location of the stations.

When a combination of the effects of climate change and development are considered in both seasons, the annual discharge will decrease by about 3 – 8% as a result of the effects of development under both the past climate conditions and the future climate change (Scenarios S3 and S2, and S5 and S4). On the other hand, climate change would increase the river discharge by 6 – 16% under both the Baseline and the Development Scenarios (Scenarios S4 and S2, and S5 and S3). The effect of both climate change and development may cause an increase in discharge of about 2 – 12% (Scenarios S5 and S2), depending on the climate change scenarios and the location of the stations considered. These changes show that a seasonal analysis is needed to deal with development and climate change issues.

The contribution of snowmelt to the annual water yield (or runoff) at the Chinese-Lao border will be slightly increased, from 5.5% to 8% under climate change. Although the contribution of snowmelt in the dry season (for example, in March) is more significant, the percentage increase in river discharge does not change significantly. Its effect becomes of minor importance at stations further downstream.

If the Baseline were to continue into the future with climate change, the number of days with a discharge higher than that of the high-flow seasonal mean is expected to increase. The effect of development is to significantly reduce this number at the upstream stations, but rather less at the downstream stations. While development can help in reducing the areas of flooding, climate change will increase these areas in worse years. Climate change could increase the areas with saline intrusion, but to a smaller extent than the increase in flooded areas, and development can help to reduce the affected areas. However, the uncertainty in the projection of future precipitation should be remembered when reaching these conclusions.

This study concludes by recommending that (i) analysis with more climate change datasets would be useful to reduce the uncertainty in climate projection; (ii) further study and testing of the adjustment methods are needed to ensure that the projection trend will be maintained properly while any bias from climate modelling is removed; (iii) more observed climate data (i.e. from more stations and of longer duration) and other data used in modelling such as land use, water use, reservoir regulation rules should be collected; (iv) in addition to the refined DSF models with more functions and improvement of simulation accuracy, supporting tools are needed to handle large datasets for climate change analysis, and simplification for a basin-wide assessment which is more focused rather than one attempting trying to cover more sub-basin details is needed; and (v) the DSF, designed and set-up only for the analysis of changes in flow regime under different scenarios, should be supported by other models and analyses or improved with new components to become an integrated modelling package for analysing changes other than just those of the flow regime.

1. Introduction

Water resources development in the Mekong River Basin

The Mekong River Basin is one of the world's largest river basins. Its length of 4,800 km makes it the twelfth longest in the world, while its area of 795,000 km^2 makes it the twenty-first in terms of size. About 22% of the Basin lies in the People's Republic of China (China), 3% in the Union of Myanmar, 25% in the Lao People's Democratic Republic (Lao PDR), 23% in the Kingdom of Thailand (Thailand), 19% in the Kingdom of Cambodia and 8% in the Socialist Republic of Viet Nam (Viet Nam). The contribution of these countries to its mean annual discharge of 475,000 million m^3 (ranked the eighth largest in the world) are 16%, 2%, 35%, 18%, 18% and 11% respectively. The LMB covers a total downstream area of about 620,000 km^2 in the countries of Lao PDR, Cambodia, Thailand and Viet Nam. Figure 1-1 illustrates a longitudinal profile of the Mekong River from its headwaters to the river mouth (MRC, 2005). In 2006, a population of over 60 million depended on the Basin resources for their livelihoods.

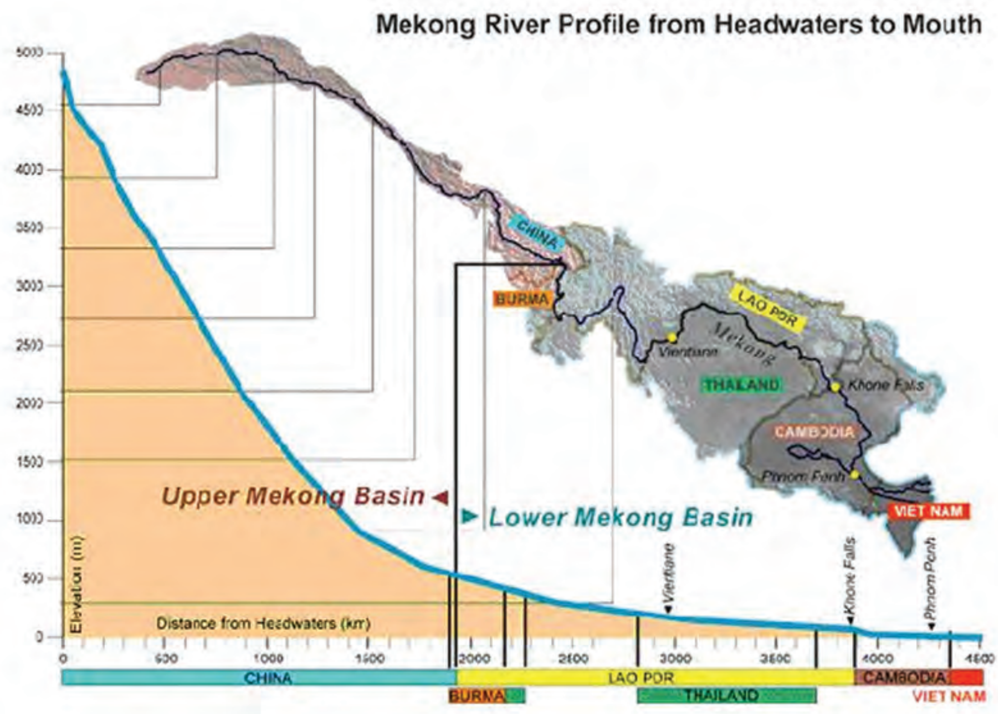

Figure 1-1 Mekong River Basin and longitudinal profile of the Mekong River (MRC, 2005).

The hydropower and irrigation sectors are the two major users of water in the Mekong Basin. Many mainstream hydropower dams have either been constructed or are being planned. These include the two existing hydropower dams, the Manwan and the Dachaosan, in the Lancang[1] mainstream, the Xiaowan and the Jinghong Dams under construction, and the Nuozhadu Dam for which preparations are being made for construction. In Thailand, six major tributary reservoirs are in operation, namely the Ubol Ratana, Chulabhorn, Sirindhorn, Pak Mun, Lam Pao and Nam Oun Dams. These dams are for hydropower and irrigation in the North East of Thailand where a significant number of irrigation systems exist and more are planned. In Lao PDR, three major tributary reservoirs, namely the Nam Ngum, Nam Theun Hinboun and Huai Ho, are hydropower dams, and others, such as Nam Ngum 2 and Nam Theun 2, are under construction. In Cambodia, the Great Lake, linked to the Mekong River by the Tonle Sap River, covers an area varying from 3,000 km^2 in the dry season to 15,000 km^2 in the wet season, and is considered the heart of the LMB. It is also the largest source of freshwater fish in South East Asia. The reverse flow from the Mekong River to the lake along the 120 km of the Tonle Sap River creates quite complicated hydraulic and ecological processes in the area. In Viet Nam, the largest existing reservoir for hydropower is the Yali Falls on the Se San River, a major tributary in the east of the Mekong Basin; an area identified as having a high hydropower potential. The Mekong Delta in Viet Nam is the most important rice producing region in the country. In the low-flow seasons, the tidal effect in the Delta is observed up to Phnom Penh in Cambodia. About 2.5 million hectares in the Delta are irrigated and drained for rice cultivation. However, in the low-flow seasons agriculture is practised only in a small fraction of this area because of insufficient freshwater and the intrusion of seawater.

Purpose of the paper

This paper aims to summarise in detail the results of the analysis under the CSIRO- MRC Project: “Reducing vulnerability of water resources, people and the environment in the Mekong Basin to climate change impacts” by providing the basic findings on the impacts of climate change and development on the Mekong River flow regimes.

The paper aims:

- To present the framework of climate change analysis and its application to the BDP Scenarios;
- To present the results from the application of the DSF models of the Mekong River Commission (MRC) in order to analyse the impacts of climate change and selected BDP Scenarios on flow regimes; and
- To determine further studies necessary to identify suitable adaptation strategies for dealing with such impacts.

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[1] *In the UMB in Yunnan in China, the Mekong River is known as the Lancang River*

The framework of the climate change scenario analysis is introduced in Chapter 2. A brief introduction to the DSF is presented in Chapter 3. Chapter 4 presents the processing of the PRECIS data for the provision of climate inputs for the analysis. The results of model runs for the Baseline Scenario with observed and PRECIS data are presented in Chapter 5. Changes in the flow regime due to both development and climate change are discussed in Chapter 6. Finally, conclusions and recommendations for further studies are presented in Chapter 7.

Limitations of the paper

In this first assessment of climate change impacts on flow regime, the analysis is based on existing climate change data downscaled to the Mekong Basin by the SEA START (South East Asia SysTem for Analysis, Research and Training) Regional Center using the PRECIS (Providing Regional Climates for Impacts Studies) Regional Climate Model developed by the Hadley Centre, a leading climate research centre in the United Kingdom. In this study, PRECIS data were adjusted against the available observed data used for setting-up and calibrating the DSF models.

The DSF models used in this study were those versions available at the end of 2008. Some difficulties were encountered when these were run over the long period of 40 years. These difficulties are discussed in the recommendations in Chapter 7. The development scenarios used in this study were provided by BDP and IKMP Modelling Teams at the end of 2008. This paper deals only with the impacts of climate change and development on the flow regime at the Basin level. Since these DSF models were not designed to include food production, the analysis of food security, another focus of the CSIRO-MRC project, is being implemented by the CSIRO team using other models. However some recommendations on adaptation strategies are included as conclusions of this paper. More detailed studies will be required in the coming years to account for newly collected observed data, updated development scenarios, including projections of land use changes, updated climate change data from RCM, and the refined DSF models currently being tested. Since the study covered the whole Mekong Basin, it could not provide a detailed analysis of certain sub-basins or areas that require more data and modelling efforts.

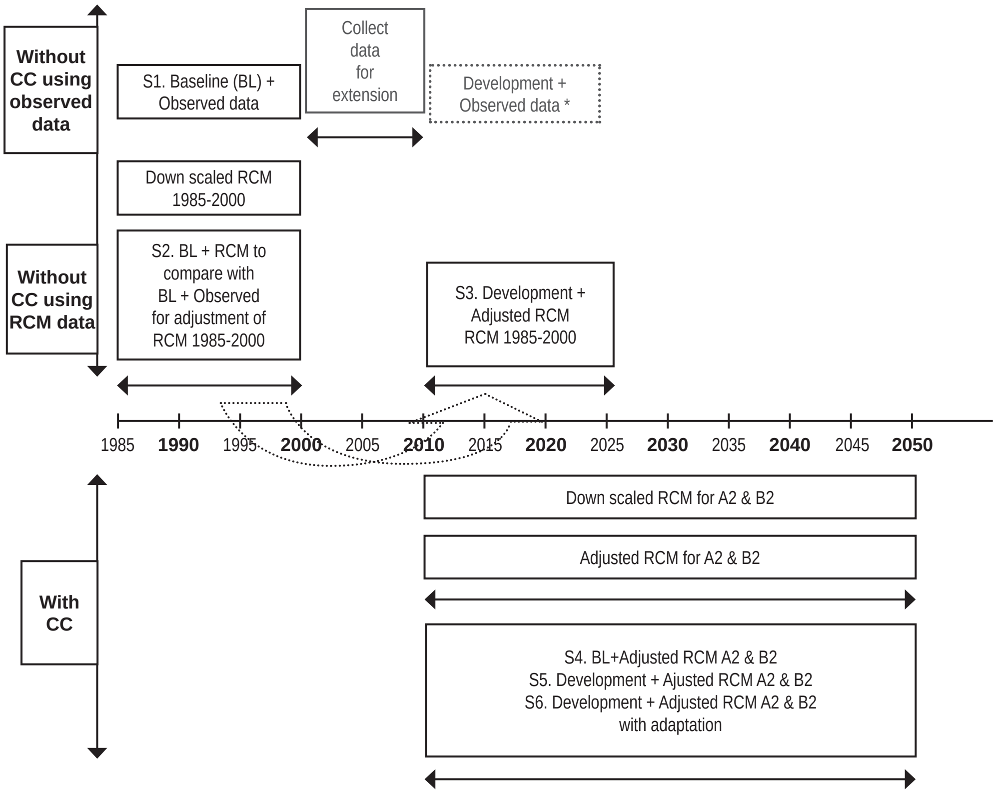
RCM data are available until 2100, but the time horizon of our analysis is up to 2050 since this is more realistic for the current BDP Development Scenarios. Because observed data in the DSF are available only for the 16 years from 1985 - 2000, and are used for the Baseline Scenario, future comparisons are also divided into 16 year periods, i.e. 2010 - 2025, 2026 - 2041, 2042 - 2050 thus covering the whole period of 2010 - 2050. The impacts of sea level rise are not considered in this paper. Since sea level rise is not a sudden event like a tsunami, its analysis should reflect the slow process. In addition, the adaptation of people and ecosystems, such as changes in river and canal configurations due to changing hydraulic conditions and human activities for strengthening the protection, and changes in the mangrove forest along the Delta coast line, will require more detailed studies which could not be covered by this project.

2. Framework for climate change scenario analysis

2.1 Methodology for climate change scenario analysis

Design of the framework for climate change scenario analysis

Figure 2-1 presents the framework of the climate change (CC) scenario analysis in this first assessment. In this framework, a scenario model run is defined by a combination of a BDP Scenario and a climate dataset. The data included observed data from 1985 - 2000 and the Regional Climate Model (RCM) data.



* This model run was under the BDP Scenario analysis but it is replaced by Scenario S3 in this climate change study.

Figure 2-1 Framework of scenario analysis for impacts of climate change.

Three groups of scenario model runs (coded S1 to S6) were implemented:

1. Scenario 1 (S1): without climate change, using observed data:
    - S1: BDP baseline scenario + observed climate data for 1985-2000.
      The model for this scenario had been calibrated by the MRC Modelling and the BDP Teams in the previous studies (Halcrow, 2004; Beecham and Cross, 2005; TSD Modelling Team, 2007).
2. Scenarios 2 and 3 (S2 and S3): without climate change, using RCM data
    - S2: BDP Baseline Scenario + adjusted RCM data for 1985-2000.
    - S3: BDP 20-year plan Scenario + adjusted RCM data for 1985-2000.
3. Scenarios 4 and 5 (S4 and S5): with climate change, using RCM data:
    - S4: BDP baseline + adjusted RCM data of A2 and B2 scenarios[2] for 2010-2050.
    - S5: BDP 20-year plan Scenario + adjusted RCM data of A2 and B2 scenarios for 2 010-2050.
4. Scenario 6 (S6):
    - S6: BDP 20-year plan Scenario + adjusted RCM data of A2 and B2 scenarios for 2010-2050 + adaptation strategies.

In scenarios S2 and S3, because simulated RCM data for A2 and B2 for the past period 1985-2000 are identical, only one RCM model dataset for A2 was used, but for scenarios S4, S5 and S6, both RCM datasets of scenarios A2 and B2 are used.

From model runs of these scenarios, the following analyses can be made:

- A comparison of S1 with S2, demonstrates that the adjustment to the RCM data of 1985 - 2000 is justifiable and appropriate for a simulation of the past hydrologic impacts and therefore the same adjustment could be applied for any future projections using RCM data.

- A comparison of S3 with S2, allows the identification of the impacts of development compared with the Baseline Scenario without climate change.

- A comparison of S4 with S2, allows a projection of the impacts of climate change if the Baseline Scenario continues in the future. Although Scenario S4 is not realistic because new development projects will be planned or implemented, it helps to show the impacts of climate change.

- A comparison of S5 with S4, allows the identification of the impacts when the Development Scenario is run under climate change conditions.

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[2] *A2 and B2 are two climate change SRES scenarios studied by IPCC (2000). In brief, A2 correspond to a storyline of high population growth with slower per capita economic growth and technological change, while B2, corresponds to a storyline of moderate population growth and economic development with less rapid and more diverse technological change.*

- A comparison of S6 with S5 allows the analysis of the effects of adaptation strategies to climate change on the development.

Preparation of climate change scenarios

Future climate projection daily data for the two IPCC SRES scenarios (A2 and B2) provided by the SEA START Regional Center were based on the ECHAM4 GCM from the Max Planck Institute for Meteorology, Germany and downscaled to the Mekong region using the PRECIS system. The PRECIS data for the Baseline 1985 - 2000 were adjusted by comparing them with the available observed data in the DSF. Adjustment methods (see Appendix) were applied in an effort to calibrate the models to match the flow regime outputs from the DSF for Scenario S2 with that from the Scenario S1 using the available observed data. Such adjustment, called bias-correction by Fujihara et al. (2008) is needed to make the downscaled monthly values of the simulated climate for the past period match the observed monthly values. Climate data were compared using: (i) point-based data, i.e. observed data at climate stations and RCM data at the same coordinates; and (ii) surface-based data, i.e. observed precipitation data at stations aggregated to sub-basins by using MQUAD program in the DSF and RCM data aggregated to sub-basins from PRECIS grid cells.

The SWAT model was run to identify the suitable adjustment methods by comparing outputs from model runs with adjusted RCM data and with observed climate data for 1985 - 2000. The adjustment was necessary because the RCM data for this period includes some extreme values, for example, daily precipitation RCM values are between 500 - 1,000 mm and some are even over 1,000 mm; values which were not recorded in the observed dataset. These values result in too high water yields and river flows in several catchments in the model outputs. The adjustment was first applied to the precipitation data, then for other parameters such as maximum and minimum temperatures, wind speed and solar radiation. After running the SWAT model for all sub-basins, the IQQM model was also run for the whole Basin, and the ISIS model was run for the Tonle Sap and the Delta.

For Scenarios S4, S5 and S6, the same adjustment methods as used for Scenario S2 were applied for both A2 and B2 future projection climate in 2010 - 2050 to minimise the bias in the climate change modelling.

2.2 BDP scenarios for climate change analysis

During the development of the DSF from 2000 - 2004 under the Water Utilisation Programme (WUP), the Consultant provided the seven demonstration scenarios (Halcrow, 2004) as shown in Table 2-1.

Inputs to each of these scenarios included:

- hydrological conditions (climate, observed river flows, rainfall – runoff relationships);
- known or assumed water demands (for irrigation, municipal or other uses); and

- information about existing or proposed infrastructure or other interventions (such as dams, diversions, embankments etc.).

Outputs were simulations of how the magnitude and pattern of river flows, and related information, such as the areas inundated by floods or suffering saline intrusion, would change in each scenario. The climate change scenario was included by simply increasing or decreasing the temperature and rainfall of the observed data by a certain percentage for the whole Basin.

Table 2-1 *Summary of existing development scenario formulations in the Mekong River Basin.*

WUP	World Bank	BDP1	IBFM
1) Baseline	1) Baseline	1) Baseline	1) Baseline Flow regime 1 (FR1)
2) Impact of climate change	2) Chinese dams	2) Upper dams	2) (BDP1-Low develop-ment) Flow regime 2 (FR2)
3) Impact of catchment change	3) Low development	3) Low development	3) (BDP1-Irrigation) Flow regime 3 (FR3)
4) High irrigation growth	4) Embankments	4) Irrigation	4) (BDP1-High develop-ment)
5) Impact of Chinese dams	5) Agriculture	5) High development	
6) Impact of LMB dams	6) High development		
7) Impact of flood embankments			

In 2004, the World Bank approached the MRCS and suggested the use of the DSF in the planning of a regional water resources development strategy. Revised development scenarios were developed as refined versions of the existing scenarios (Table 2-1). The two development sectors thought to have the most significant impacts on the Mekong flow regime are (i) hydropower, which will redistribute water from the high-flow season to the low-flow season[3] ; and (ii) irrigation, which will divert large volumes of water from the Mekong River and tributaries in both the wet and dry seasons. The results of this study were presented in two reports. The first, of November 2004, was impact assessments of the six scenarios of the Baseline, Chinese Dams, Low Development, Embankments, Agriculture and High Development (TSD Modelling Team, 2007). In the second report, the Embankments Scenario was eliminated leaving only five scenarios. Furthermore, the Agriculture Scenario was renamed the Irrigation Scenario. The Scenarios were used for the BDP1 (Table 2-1). As part of the Integrated Basin Flow Management (IBFM) study these scenarios were referred to as Baseline, FR1 (Low Development), FR2 (Irrigation), and FR3 (High Development).

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[3] *To avoid confusion between the wet season (May-October) and the dry season (November-April) based on precipitation distribution and the wet season (June-November)and the dry season (December-May) usually used in flow analysis, in this study the following terms are used:*

- *for climate analysis: rainy season (May-October) and dry season (November-April); the wet season is also used as rainy season if this term was used in a cited reference.*
- *for flow analysis: high-flow season (June-November) and low-flow season (December-May).*

Under BDP Phase 2, these scenarios were revised and new scenarios were considered as presented in Table 2-2.

Table 2-2 *Basin-wide water resource development scenarios (MRC, 2009).*

Baseline situation	Definite future situation	Foreseeable future situation	Longer-term future
1. Baseline line scenario	2. Chinese Dam Scenario 3. Definite Future Scenario	4. LMB 20-Year Plan Scenario 5. LMB 20-Year Plan Scenario without Mainstream Dams 6. LMB 20-Year Plan Scenario without Mainstream Dams in the Middle and Lower LMB 7. Mekong Delta Flood Management Scenario	8. LMB Long-term Development Scenario 9. LMB Very High Development Scenario

By the end of 2008, BDP Phase 2 provided details of fast track scenarios (MRC, 2008) that included the baseline, definite future and foreseeable future. More studies and consultations with the Mekong Countries were implemented to revise the long-term future scenarios. In this first assessment, two scenarios, namely the Baseline Scenario and the LMB 20-Year Plan Scenario (hereafter called the Development Scenario) were selected for a comparison of the impacts of climate change on flow regime: (Table 2-3). Details of sector development in these scenarios are presented in Tables 2-4 to 2-7.

The Baseline scenario represents the development conditions in the Basin in 2000 (MRC, 2009) and includes:

i) physical conditions including climate; land use; public and industrial water demand; irrigated areas, cropping patterns, and delivery infrastructure; storage characteristics; and hydraulic conveyance and flood storage; and

ii) management conditions including operating rule curves for storages; water allocation policies; and operating rules for salinity barriers.

The Baseline Scenario is used as a “reference scenario” to which the flow changes in the Development Scenario can be compared. In this Baseline Scenario, the total live storage (Table 2-4) of current large reservoirs (Figure 2-2) is 9,638 MCM (million m^3), about 2% of the annual Mekong water (475,000 MCM). Irrigation in the wet and dry seasons, 5.3 million ha and 2.1 million ha, respectively, provides an annual total irrigated area of 7.4 million ha (Figure 2-4).

The Development Scenario includes:

i) the Chinese dams being developed in the UMB;

ii) the significant water resources developments on the LMB tributaries since 2000 such as Nam Theun 2, Nam Ngum 2 hydropower projects, and several irrigation projects;

iii) the current development plans of the LMB countries, including the 11 dams on the mainstream currently being studied, realistic diversions and other developments for irrigated agriculture, flood management and mitigation, domestic and industrial water supply planned for implementation during the coming 20 years in the various BDP sub-areas.

In the Development Scenario, in addition to the storage in the Baseline Scenario, the total live storage of the Chinese reservoirs[4] is 22,189 MCM (4.7% of Mekong water) and that of the LMB reservoirs is 43,972 MCM (9.3% of Mekong water). In total, these reservoirs (Figure 2 - 2) provide live storage of 75,799 MCM (16% of Mekong water). Of the total hydropower capacity of the Mekong Basin of 40,807 MW (Table 2 - 4), Lao PDR will generate the highest percentage (36% + 7.2% shared with Thailand), higher than China (37.9%), Cambodia (12.2%), Viet Nam (6.1%) and Thailand (0.6%). However, in the total live storage to generate this capacity, Lao PDR needs over half of the total (51.6% + 0.8% sharing with Thailand), compared with China (29.3%), Cambodia (9.9%), Thailand and Vietnam (about 4.2% each). The expansion of the irrigated areas (see Figure 2-5 for the project locations) will provide an annual increase of 10.9% of which 8% and 18.3% will be in the rainy and dry season respectively. These percentages are percentages of the Baseline figures. Domestic and industrial water demand is minor, even though it would be doubled under the Development Scenario (Table 2-7).

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[4] *The Manwan reservoir in Yunnan has been in operation since 1993, but its live storage is minor (250 MCM) therefore it is included with the other Chinese reservoirs*

Table 2-3 *Selected scenarios for the first assessment of climate change impacts on flow regime (MRC, 2009)*.

Scenario	Objective	Climatic condition	Demand	Intervention (Dam and Diversion)
Baseline	For use as the "reference scenario" representing the development conditions in year 2000	1985-2000	Domestic and industrial - Lao 116 MCM - Thailand 935 MCM - Cambodia 126 MCM - Viet Nam 443 MCM Irrigation - Lao 324,000 ha - Thailand 1,422,000 ha - Cambodia 1,340,000 ha - Viet Nam 4,295,000 ha	Dams - Lao 5 dams - Thailand 12 dams - Viet Nam 1 dam
LMB 20 Year Plan	To ascertain flow regime change due to multi-sector water resource developments for next 20 years	1985-2000	Next 20 year plan Domestic and industrial - Lao 291 MCM - Thailand 1542 MCM - Cambodia 427 MCM - Viet Nam 481 MCM Irrigation - Lao 471,000 ha - Thailand 1,738,000 ha - Cambodia 1,644,000 ha - Viet Nam 4,332,000 ha	Total dams - Upper Mekong 6 dams - Lao 47 dams - Lao-Thailand 2 dams - Thailand 12 dams - Cambodia 8 dams - Viet Nam 12 dams Diversions - Thailand 2 projects

Table 2-4 *Summary of hydropower development in the Mekong Basin under 20-Year Plan (based on details in Table 2-5).*

Country	Design discharge m^3/s	Capacity MW	Annual energy GWh	% Total capacity in Mekong Basin	Storage MCM	% Total storage in Mekong Basin
Existing						
China (in Mekong)		2,900		7.1	525	0.7
Lao PDR	583	575	3,027	1.4	5,603	7.4
Thailand	1,483	258	530	0.6	3,256	4.3
Viet Nam	424	720	3,659	1.8	779	1.0
Definite future (under preparation or on-going)						
China (in Mekong)		12,550		30.8	21,664	28.6
Lao PDR	1,827	2,598	11,770	6.4	9,295	12.3
Viet Nam	3,475	1,472	6,740	3.6	1,837	2.4
20-Year Plan – mainstream						
Cambodia	21,000	4,280	19,740	10.5	2,070	2.7
Lao PDR	28,292	6,848	30,137	16.8	2,222	2.9
Lao-Thailand	17,420	2,951	13,752	7.2	614	0.8
20-Year Plan – tributaries						
Cambodia	2,478	695	695	1.7	5,404	7.1
Lao PDR	8,205	4,661	4,661	11.4	21,993	29.0
Lao-Thailand	112	299	299	0.7	536	0.7
Total by country						
Cambodia	23,478	4,975	23,097	12.2	7,474	9.9
China (in Mekong)		15,450		37.9	22,189	29.3
Lao PDR	38,907	14,682	66,720	36.0	39,113	51.6
Lao-Thailand	17,420	2,951	13,752	7.2	614	0.8
Thailand	1,483	258	530	0.6	3,256	4.3
Viet Nam	4,011	2,491	11,636	6.1	3,153	4.2
Total for Mekong Basin	85,299	40,807	115,735	100.0	75,799	100.0

Table 2-5 *List of hydropower projects in Baseline (BL) and LMB 20-Year Plan scenarios (MRC, 2009).*

Country	Project Name	Rated Head	Plant Design Discharge	Installed Capacity	Mean Annual Energy	Full Supply Level	Low Supply Level	Live Storage
		m	m^3/s	MW	GWh	mamsl	mamsl	MCM
Lao PDR (Baseline)	Nam Ngum 1	38.5	414.4	155.0	1,006.0	212.0	196.0	4,700.0
	Houayho	748.3	23.0	150.0	487.0	883.0	860.0	649.0
	Theun-Hinboun	225.5	106.0	210.0	1,327.0	400.0	395.0	15.0
	Nam Leuk	174.2	39.5	60.0	207.0	405.0	388.0	228.2
	Nam Song							11.2
Viet Nam (Baseline)	Yali	190.0	424.0	720.0	3,658.6	515.0	490.0	779.0
Thailand (Baseline)	Chulabhorn	366.0	13.3	42.0	93.0	759.0	739.0	144.5
	Nam Pung	85.0	8.6	6.3	15.0	284.0	270.0	156.3
	Pak Mun	11.6	1,320.0	141.6	280.0	108.0	105.5	125.0
	Sirindhorn	30.3	141.0	42.0	86.0	142.2	137.2	1,135.0
	Ubol Ratana	16.0		26.3	56.0	182.0	175.5	1,695.0
Chinese	Manwan			1,550.0				250.0
	Dochashan			1,350.0				275.0
	Jinghong			1,750.0				309.0
	Xiaowan			4,200.0				9,895.0
	Nuozhadu			5,850.0				11,340.0
	Gongouqiao			750.0				120.0
Lao PDR	Nam Mang 3	513.2	9.1	40.0	138.0	750.0	742.0	45.0
	Nam Theun 2	356.6	334.0	1,075.0	5,936.0	538.0	525.5	3,378.4
	Xekaman 1	99.0	336.6	290.0	1,096.0	230.0	218.0	1,683.0
	Xekaman-	12.2	378.0	32.0	123.0	122.0	122.0	0.0
	Sanxay (Xekaman2)	477.7	62.5	250.0	982.8	960.0	925.0	108.5
	Xekaman 3	246.0	28.7	76.0	309.0	813.0	803.5	9.3
	Xeset 2	146.5	448.0	615.0	2,218.0	375.0	345.0	2,994.0
	Nam Ngum 2	337.0	42.9	120.0	507.0	1,100.0	1,060.0	251.0
	Nam Ngum 5	63.0	187.0	100.0	460.0	305.0	270.0	826.0
	Nam Lik 2							
Viet Nam	Plei Krong	43.0	367.6	100.0	417.2	570.0	537.0	948.0
	Se San 3	61.0	486.0	260.0	1,224.6	304.5	303.2	3.8
	Se San 3A	22.0	500.0	96.0	475.0	239.0	238.5	4.0
	Se San 4	56.0	719.0	360.0	1,420.1	215.0	210.0	264.2
	Se San 4A	0.0	0.0	0.0	0.0	155.2	150.0	7.5
	Buon Tua Srah	47.0	204.9	86.0	358.6	487.5	465.0	522.6
	Buon Kuop	99.0	316.0	280.0	1,455.2	412.0	409.0	14.7
	Sre Pok 3	60.0	412.8	220.0	1,060.2	272.0	268.0	62.6
	Sre Pok 4	17.1	468.9	70.0	329.3	207.0	204.0	10.1
Lao PDR	Mekong at Pakbeng	31.4	4,362.0	1,230.0	5,007.0	345.0	340.0	442.4
	Mekong at Luangprabang	40.0	3,812.0	1,410.0	6,268.0	320.0	310.0	936.7
	Mekong at Xayabuly	24.4	6,018.0	1,260.0	5,186.0	275.0	270.0	224.7
	Mekong at Paklay	25.7	5,782.0	1,320.0	5,785.0	248.0	245.0	316.5
	Mekong at Don Sahong	17.0	2,400.0	360.0	2,375.0	74.5	72.0	115.0
	Mekong at Sanakham	25.0	5,918.0	1,268.0	5,516.0	220.0	215.0	186.7

Country	Project Name	Rated Head	Plant Design Discharge	Installed Capacity	Mean Annual Energy	Full Supply Level	Low Supply Level	Live Storage
		m	m^3/s	MW	GWh	mamsl	mamsl	MCM
Lao PDR-Thailand	Mekong at Sangthong Pakchom	22.0	5,720.0	1,079.0	5,318.0	192.0	190.0	217.3
	Mekong at Ban Kum	18.6	11,700.0	1,872.0	8,434.0	115.0	115.0	397.0
Cambodia	Mekong at Sambor	32.9	13,000.0	3,300.0	14,870.0	40.0	38.0	2,000.0
	Mekong at Stung Treng	15.2	8,000.0	980.0	4,870.0	55.0	50.0	70.0
Lao PDR	Theun-Hinboun	225.5	110.0	222.0	1,395.0	400.0	395.0	15.0
	expansion	47.0	88.4	60.0	294.0	455.0	420.0	2,262.0
	Theun-Hinboun	302.0	163.0	440.0	2,230.0	720.0	660.0	979.0
	exp. (NG8)	140.0	404.0	523.0	1,840.0	292.0	260.0	2,549.2
	Nam Ngum 3	136.2	230.0	260.0	1,327.0	320.0	296.0	1,191.8
	Nam Theun1	65.5	289.5	168.0	759.4	455.0	442.5	675.5
	NamNgiep 1	642.0	70.0	390.0	1,748.0	786.5	760.0	885.0
	Nam Tha 1	186.0	44.5	75.0	469.0	320.0	287.0	505.0
	Xepian-Xenamnoy	33.7	460.0	152.0	598.7	160.0	155.0	95.1
	Nam Kong 1	17.2	568.0	96.0	375.7	117.0	111.0	168.4
	Xe Kong 3up	140.0	240.0	300.0	1,901.0	290.0	270.0	3,100.0
	Xe Kong 3d	188.1	146.0	248.0	1,201.0	500.0	470.0	1,355.5
	Xekong 4	20.5	1,045.0	180.0	829.0	305.0	300.0	10.0
	Xe Kong 5	11.0	932.0	90.0	413.0	320.0	316.0	8.4
	Nam Ou 1	43.0	831.0	300.0	1,337.0	375.0	370.0	13.5
	Nam Ou 2	16.0	558.0	75.0	337.0	400.0	395.0	9.2
	Nam Ou 3	25.0	514.0	108.0	496.0	430.0	425.0	11.2
	Nam Ou 4	68.0	368.0	210.0	840.0	510.0	490.0	363.0
	Nam Ou 5	90.0	238.0	180.0	725.0	630.0	600.0	1,134.0
	Nam Ou 6	19.5	300.0	54.0	255.0	195.0	191.0	6.8
	Nam Ou 7	831.6	6.7	48.0	366.0	1,470.0	1,445.0	121.7
	Nam Lik 1	111.0	142.3	150.0	577.0	550.0	515.0	2,738.0
	Nam San 3	32.0	129.0	40.0	187.1	325.0	314.5	87.6
	Nam Pha	122.8	119.6	134.0	617.6	460.0	435.0	2,014.7
	Nam Suang 1	97.3	107.9	100.0	434.3	440.0	407.0	1,565.1
	Nam Suang 2	75.4	43.2	30.0	120.0	430.0	410.0	97.9
	Nam Nga	57.0	57.1	28.0	113.2	340.0	334.0	30.0
	Nam Beng							
	Nam Feuang 1							
Viet Nam	Upper Kontum	904.1	30.5	250.0	1,056.4	1,170.0	1,146.0	122.7
	Duc Xuyen	71.0	81.0	49.0	181.3	560.0	551.0	413.4
Cambodia	Lower Se San2 + Lower Sre Pok 2	26.2	2,119.2	480.0	2,311.8	75.0	74.0	379.4
	Battambang 1	34.0	52.0	24.0	123.2	76.0	58.0	1,040.0
	Battambang 2	450.0	5.8	36.0	187.0	670.0	658.0	110.0
	Pursat 1	115.0	99.2	100.0	442.9	200.0	185.0	690.0
	Pursat 2	23.0	57.0	17.0	91.0	50.0	41.0	295.0
	Stung Sen	19.0	145.0	38.0	201.0	43.5	35.0	2,890.0

Note: mamsl: metres above mean sea level

Figure 2-2 Location of hydropower dams (MRC, 2009).

Table 2-6. *Irrigation area (x 1000 ha) in Baseline and LMB 20-Year Plan (location of BDP subareas is shown in Figure 2-3)*

BDP subarea	Baseline			LMB 20-Year Plan			Percentage increase		
	Wet	Dry	Annual	Wet	Dry	Annual	Wet	Dry	Annual
Lao PDR									
1L+3L	22	14	36	32	20	52	45.5	42.9	44.4
4L	133	85	218	193	124	317	45.1	45.9	45.4
6L+7L	42	28	70	61	41	102	45.2	46.4	45.7
Country total	197	127	324	286	185	471	45.2	45.7	45.4
Thailand									
2T	148	13	161	180	38	218	21.6	192.3	35.4
3T	268	18	286	309	34	343	15.3	88.9	19.9
5T	850	125	975	985	192	1177	15.9	53.6	20.7
Country total	1266	156	1422	1474	264	1738	16.4	69.2	22.2
Cambodia									
6+8C	16	4	20	20	10	30	25	150	50
7C	13	0	13	14	2	16	7.7		23.1
9C	451	44	495	491	103	594	8.9	134.1	20
10C	629	203	832	711	323	1034	13	59.1	24.3
Country total	1093	247	1340	1216	428	1644	11.3	73.3	22.7
Viet Nam									
7V	123	44	167	126	78	204	2.4	77.3	22.2
10V	2,618	1,510	4128	2,618	1,510	4128	0	0	0
Country total	2,741	1,554	4,295	2,744	1,588	4,332	0.1	2.2	0.9
Basin total	5,297	2,084	7,381	5,720	2,465	8,185	8	18.3	10.9

Note: End of crop season BDP subarea irrigation (Beecham and Cross, 2005):

Lao PDR	*Wet season: 31 October*	*Dry Season: 31 March*
Thailand	*Wet season: 31 October*	*Dry Season: 30 April*
Cambodia	*Wet season: 31 December*	*Dry Season: 30 March*
Viet Nam	*Wet season: 31 October*	*Dry Season: 30 March*

Table 2-7 *Average annual domestic and industrial demands in Baseline and LMB 20-Year Plan scenarios*

Country	Baseline		LMB 20 Year Plan	
	m^3/s	MCM	m^3/s	MCM
Lao PDR	3.7	116	9.7	305
Thailand	29.6	935	49.0	1,545
Cambodia	4.0	126	12.8	404
Viet Nam	14.0	443	27.1	855
Total	51.4	1,620	98.6	3,109

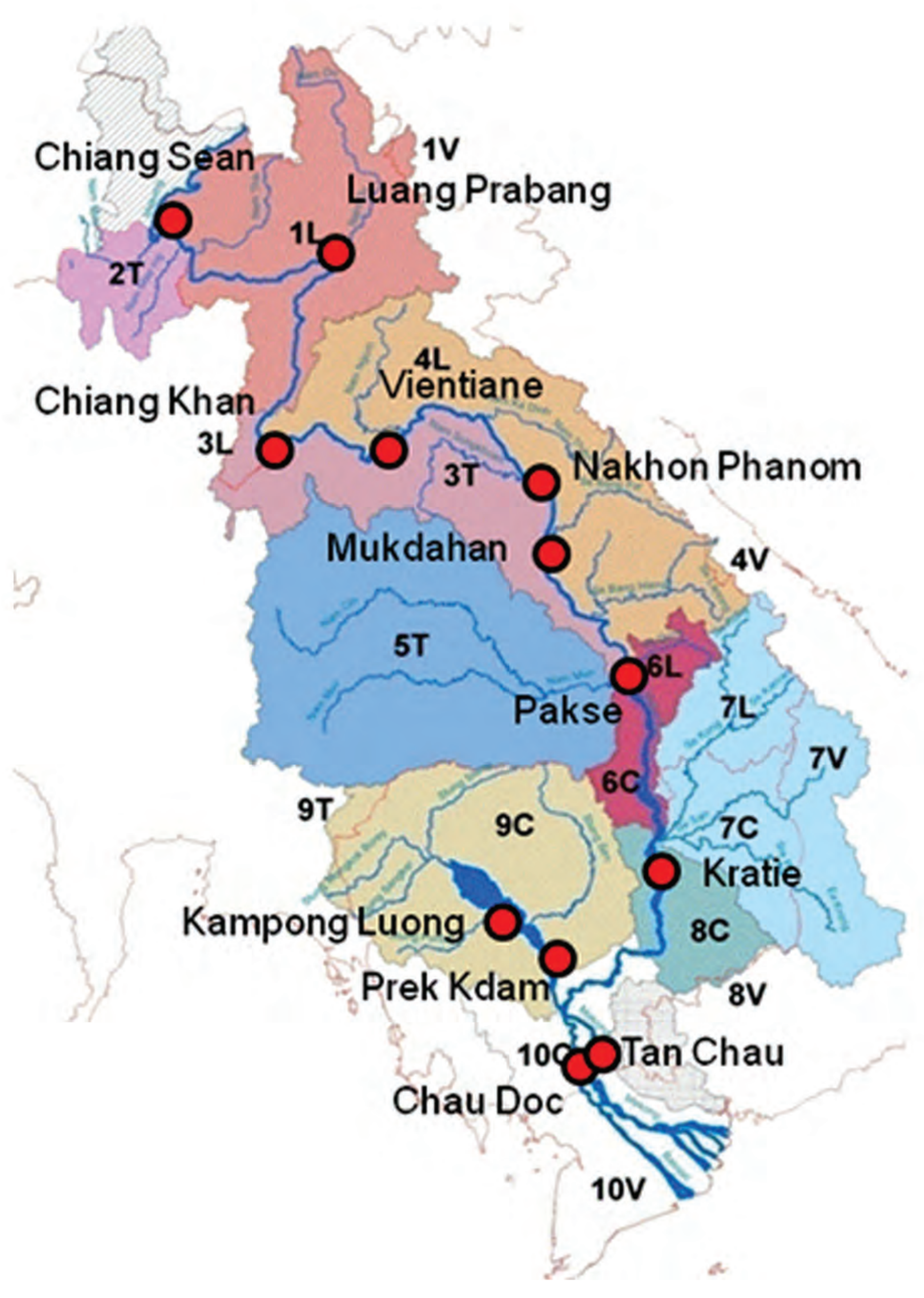


Figure 2-3 Location of BDP sub-areas.

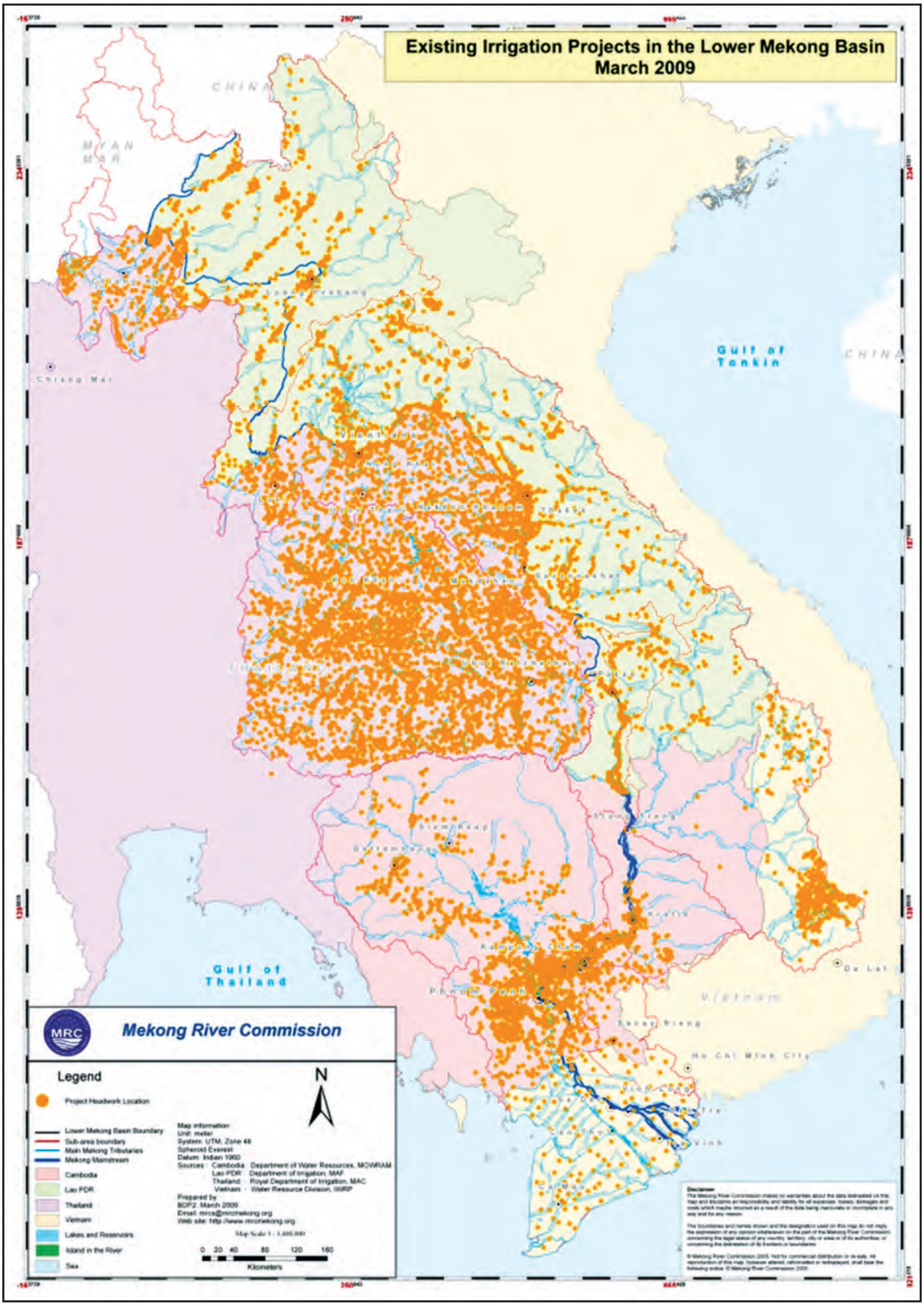


Figure 2-4 Existing irrigation projects in the LMB (MRC, 2009).

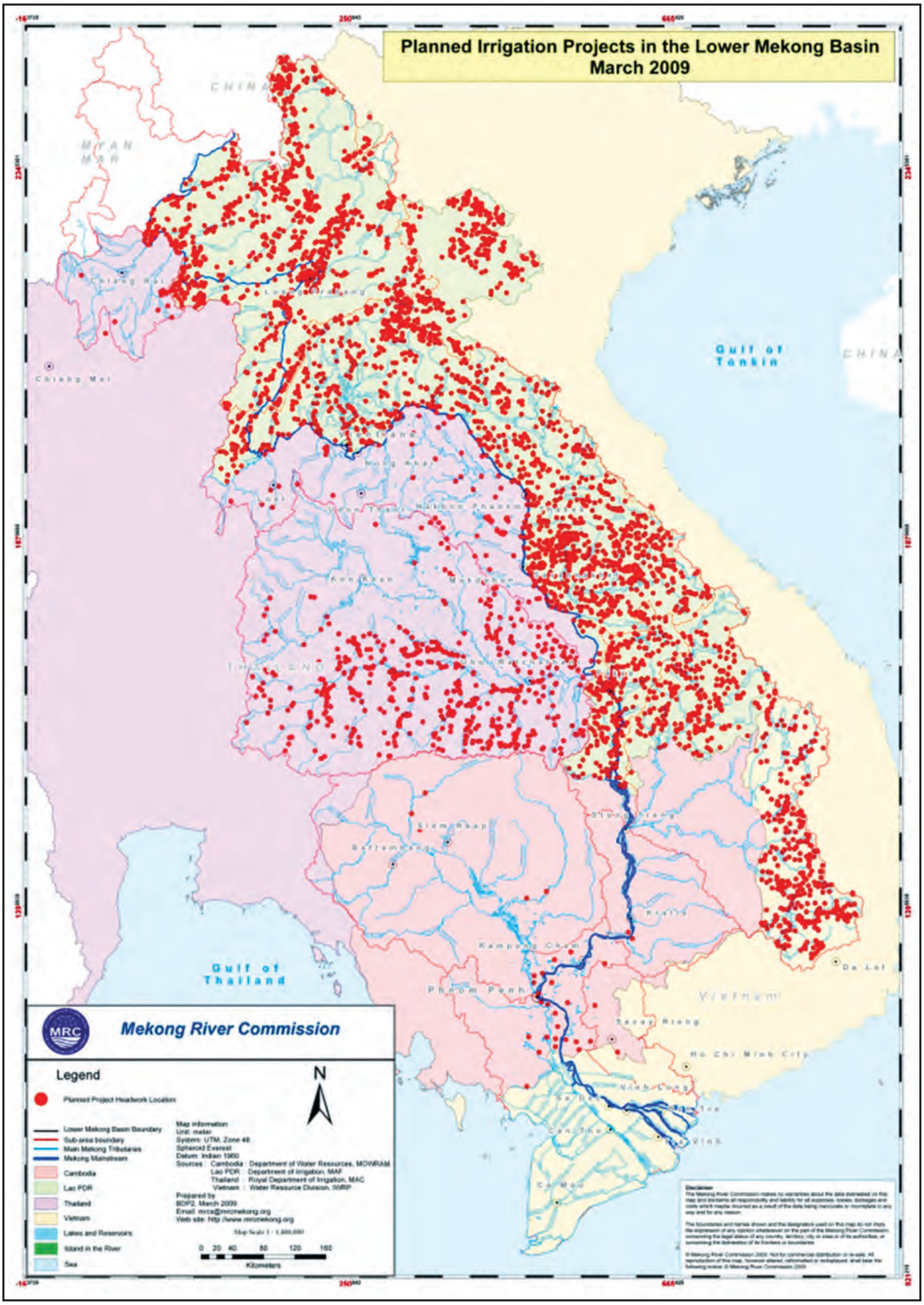


Figure 2-5 Planned irrigation projects in the LMB (MRC, 2009).

3. Brief introduction to the MRC decision support framework (DSF)

On April 5 1995 in Chiang Rai, Thailand, the four LMB countries of Cambodia, Lao PDR, Thailand and Viet Nam signed the “Agreement on the Cooperation for the Sustainable Development of the Mekong River Basin” (MRC, 1995), and so agreed. “to cooperate in a constructive and mutually beneficial manner for sustainable development, utilisation, conservation and management of the Mekong River Basin water and related resources”. Three articles, namely Article 5: Reasonable and equitable utilisation; Article 6: Maintenance of flows on the mainstream; and Article 26: Rules for water utilisation and inter-basin diversions deal with the utilisation of the Mekong water.

In 1999, the WUP was established. One of its main tasks was the development of a planning tool, known as the DSF, to assist in the implementation of Articles 5, 6 and 24 of the Agreement. In September 2001, development of the DSF began, and was completed in March 2004 (Halcrow, 2004).

3.1 Structure of Decision Support Framework (DSF)

The Decision Support Framework (DSF) comprises a knowledge base (KB) and a DSF User Interface and Tools giving access to a Basin Simulation Modelling Package. The Interface also gives access to Impact Analysis Tools (IAT) and Reporting Tools. Details of the structure are shown in Figure 3-1.

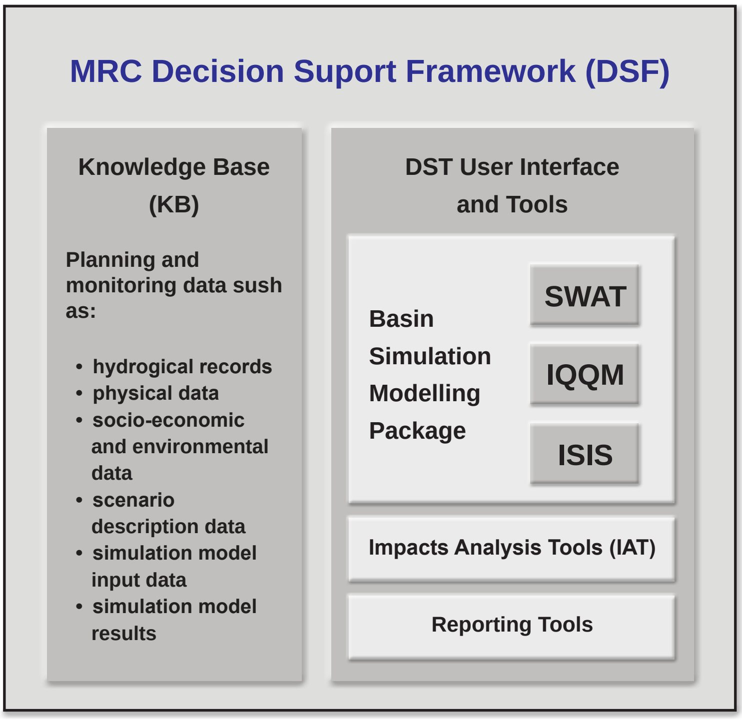


Figure 3-1 Structure of the DSF.

1. The **Knowledge Base** contains information on the hydrologic and meteorological historic records, topographic data of the river network, land use, socio-economic and environmental conditions, scenario description and model input data as well as model outputs for the projection of changes in the flow regime under the different scenarios.

2. The **Simulation Models** enable the projection of flow changes under different climate and development options within the Basin. This element comprises three models, namely:

   - **A Hydrological Model**

   The Soil and Water Assessment Tool (SWAT), a hydrological model developed by the US Department of Agriculture, has been set up under the DSF to simulate runoff based on certain parameters: observed daily climatic data, topography, soils and land cover of each sub-basin. Although the SWAT model is also able to investigate nutrient and sediment flows, at present, these cannot be analysed at a basin scale because of the limited availability of data.

   - **A Basin Simulation Model**

   The SWAT model also provides inputs to the Integrated Water Quantity and Quality Model (IQQM), originally developed for the Murray-Darling Basin in Australia but used for the LMB. This simulation model routes catchment flows through the river system, taking account of any control structures such as dams and irrigation obstructions. Daily discharges are generated throughout the river system and, in particular, at the primary outfalls of Kratie on the mainstream and the Great Lake in the Tonle Sap Basin.

   - **A Hydrodynamic Model**

   The ISIS, a hydrodynamic model, developed by HR Wallingford and Halcrow, is used to simulate the water level, discharge and salinity in the river system from Kratie to the river mouth, and includes the Tonle Sap Lake and the East Vaico in Viet Nam. The model represents the complex interactions caused by tidal influences, flow reversal in the Tonle Sap River and the over-bank flow during the flood season.

3. **Impact Analysis Tools** enable the projection of environmental and socio-economic impacts in response to changes in flow regimes by using Time Series Impact Analysis Tools. In addition, the DeltaMapper in the DSF is used to interpolate water level and salinity outputs at the ISIS nodes to grid-based flood depth, flood duration, salinity and salinity duration maps.

3.2 Application of the Decision Support Framework Models

Since 2004 the DSF Models have been used to analyse the Mekong flow regime under different scenarios. In the beginning, the full set of three DSF models was used for the entire LMB. The SWAT model was used for the area from the Chinese – Lao border to Kratie in

Cambodia (Figure 3-2) by dividing this area into 8 sub-models with 121 sub-basins, while the IQQM model was designed to receive inputs on water yield and runoff as calculated by the SWAT. Inflow from China at the uppermost point of the IQQM model was estimated from the observed flow at Chiang Saen. Discharge at Kratie, as simulated by the IQQM, was used as the upstream boundary condition for the ISIS hydrodynamic model for the downstream area. SWAT was also applied to 16 sub-models (corresponding to the 16 sub-basins) around the Tonle Sap Great Lake in Cambodia, and the East and West Vaico Rivers in Viet Nam. The IQQM model was also set up for this area (Figure 3-2) to provide upstream boundary conditions around the Tonle Sap Great Lake for the ISIS model, and to estimate water abstractions for irrigation in the eight provinces of Kratie, Kompong Cham, Kandal, Prey Veng, Kompong Speu, Ta Keo, Kampot and Svay Rieng in Cambodia. Another IQQM model was set-up to estimate the water abstractions from 120 irrigation sectors in the Viet Nam Delta. These abstractions were used in the ISIS model. The ISIS model, thus, starts from Kratie and continues down to the South China Sea, and includes the floodplains along the Mekong mainstream, the Tonle Sap Great Lake, the Tonle Sap River and the Viet Nam Delta (Figure 3-2).

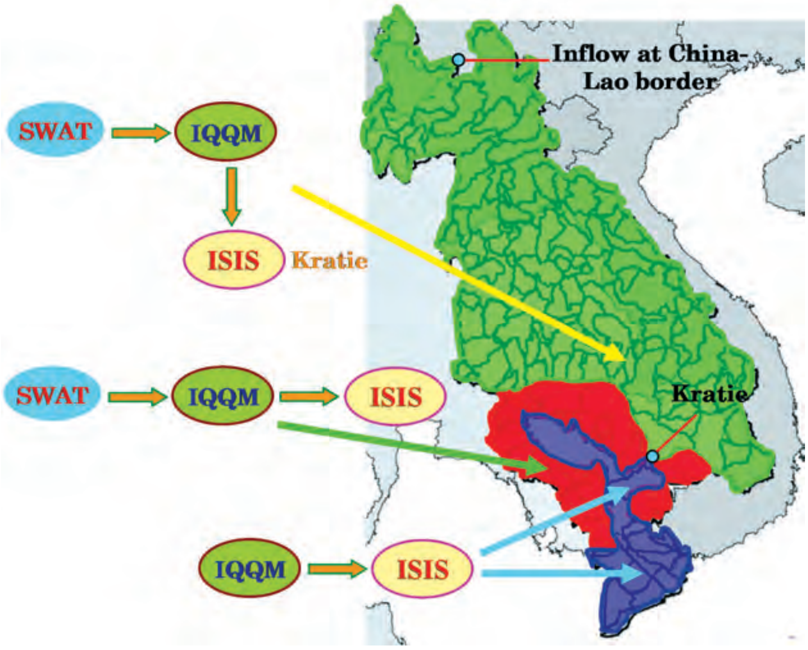


Figure 3-2 Application areas of DSF models.

Between 2005 and -2006, the SWAT was re-calibrated by the MRC Modelling Team to represent more detailed topography, land use and soil conditions by dividing the upstream Kratie area into 510 sub-basins (Table 3-1) and the Tonle Sap Great Lake area into 63 sub-basins (Table 3-2). In addition, multiple Hydrological Response Units (HRUs) were set up in each sub-basin in stead of only one dominant HRU as in the previous version. In 2007, a preliminary SWAT model with 190 sub-basins for the Upper Mekong Basin (UMB) was set-up using secondary data and information from the web to compute the inflow to the LMB under snowmelt, land use change, operations of existing and planned dams, and possible climate change. Thus two options were available for scenario analysis, either by using the model for the UMB or by using the discharge data from Chiang Saen as in the previous BDP scenario analysis. These newer models are used for this climate change study.

Table 3-1 *LMB SWAT models from Chinese – Lao border to Kratie. (Locations in Figure 3-3).*

"SWAT Model Code"	Model Name	"Number of Subbasins"	"Model Coverage Area (km^2)"
LMB1	China-Lao border to Chiang Saen	30	31,479
LMB2	Chiang Saen to Luang Prabang	60	80,549
LMB3	Luang Prabang to Vientiane	36	30,035
LMB4	Vientiane to Mukdahan	94	90,138
LMB5	Mukdahan to Pakse	59	66,195
LMB6	Pakse to Kratie	118	101,133
LMB7	Chi up to Yasothon	62	46,608
LMB8	Mun up to Rasi Salai	51	44,665
	Total	510	490,802

Table 3-2 SWAT model around the Tonle Sap Great Lake (locations are given in Figure 3-3)

SWAT	Model Name	Number of Sub-basins	Model Coverage Area (km^2)
Model	China-Lao border to Chiang Saen	4	6,563
Code	Model Name	4	15,632
Subbasins	Model	3	4,171
Coverage	Vientiane to Mukdahan	3	2,306
Area (km^2)	Mukdahan to Pakse	5	3,089
GLK1	Stung Chinit	3	9,530
GLK2	Stung Sen	6	14,718
GLK3	Stung Staung	5	5,131
GLK4	Stung Chikreng	5	3,494
GLK5	Stung Siem Reap	3	5,531
GLK6	Stung Sreng	11	7,445
GLK8	Stung Mongkol Borey (included Stung Sisophon)*	3	5,806
GLK10	Stung Battambang (included Stung Sangker)*	2	4,302
GLK11	Stung Dauntri	3	5,363
GLK12	Stung Pursat	1	835
GLK13	Stung Boribo	2	4,135
GLK14	Prek Thnot	63	98,051
GLK15	Prek Te	2	4,302
GLK16	Prek Chhlong	3	5,363
GLK17	East Vaico	1	835
GLK18	West Vaico	2	4,135
	Total	63	98,051

*Note: * GLK 7 and GLK 9 were combined into GLK 8 and GLK 10, respectively, therefore they are not in this list.*

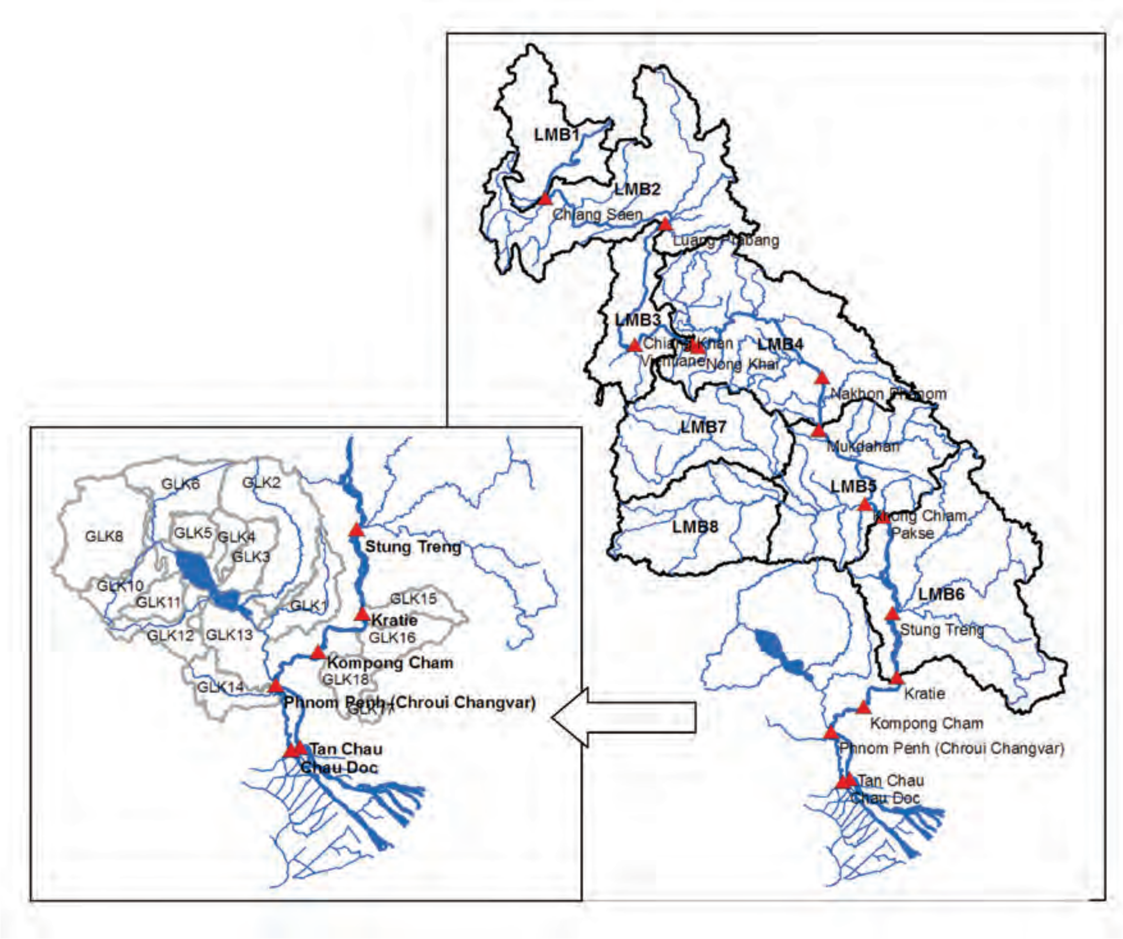


Figure 3-3 SWAT models in the Lower Mekong Basin and key stations in flow analysis.

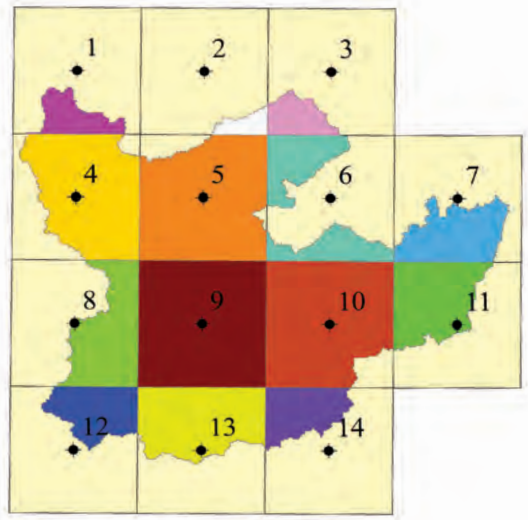
4. PRECIS data processing

The PRECIS data were produced by the SEA START Regional Center for 2,225 grid cells covering the entire Mekong River Basin with resolution of 0.2 degree x 0.2 degree (equivalent to about 22 km x 22 km). These data comprise two data sets for ECHAM4 SRES Scenarios A2 and B2, each of which includes daily precipitation, maximum and minimum temperatures, solar radiation and wind speed. The data set for Scenario A2 is for 1960 – 2004 and 2010 – 2050 while that for Scenario B2 is only for 2010 – 2050 since the data for 1960 – 2004 are identical to those for Scenario A2.

The three steps in processing the PRECIS data are: (i) aggregation of data from grid cells to sub-basins; (ii) adjustment of the simulated data to fit the observed data for 1985 - 2000; and (iii) application of the adjustment to the projected data for 2010 - 2050.

4.1 Aggregation of PRECIS data to sub-basins

For the SWAT model of the UMB, the area from Chinese – Lao border to Kratie and the Tonle Sap Great Lake, subbasin PRECIS data were obtained from grid-based data by using grid area-weighted average. For example, precipitation of a SWAT subbasin covering 14 PRECIS grid cells (Figure 4-1) is calculated by using the equation 4-1.



$$CM_{sub} = \frac{\sum_{i=1}^{n} (A_{itsc,i} CM_j / A_i)}{\sum_{i=1}^{n} (A_{itsc,i} / A_i)} \qquad (4\text{-}1)$$

CM_{sub} = SWAT subbasin climate data

$A_{itsc,i}$ = Area of grid i in the SWAT subbasin

CM_i = Climate data of grid i

A_i = Area of grid cell varying by latitude of the cell

n = Number of overlaid grids, in this example $n = 14$

Figure 4-1 A SWAT sub-basin covers all or a part of 14 PRECIS grid cells.

For the IQQM and ISIS models of the Tonle Sap Great Lake and the Delta (downstream of Kratie), the PRECIS data for specific locations were assigned from the PRECIS data at the closest grid cell. However the PRECIS precipitation data were aggregated into 120 irrigation sub-areas of the Viet Nam Delta IQQM model.

4.2 Adjustment of PRECIS data based on observed data

Although the PRECIS data were generated by dynamic downscaling methods that took into account the regional characteristics, when these are used for modelling at the sub-basin level, the outputs from the RCM should be compared with observed data for any further adjustment to make sure that the model outputs from the PRECIS data will fit with those obtained from observed data for 1985 - 2000. Assuming that the same bias occurs for the whole dataset provided by the RCM, including future data, such adjustment, is also applied for 2010 - 2050 as illustrated in Figure 4-2.

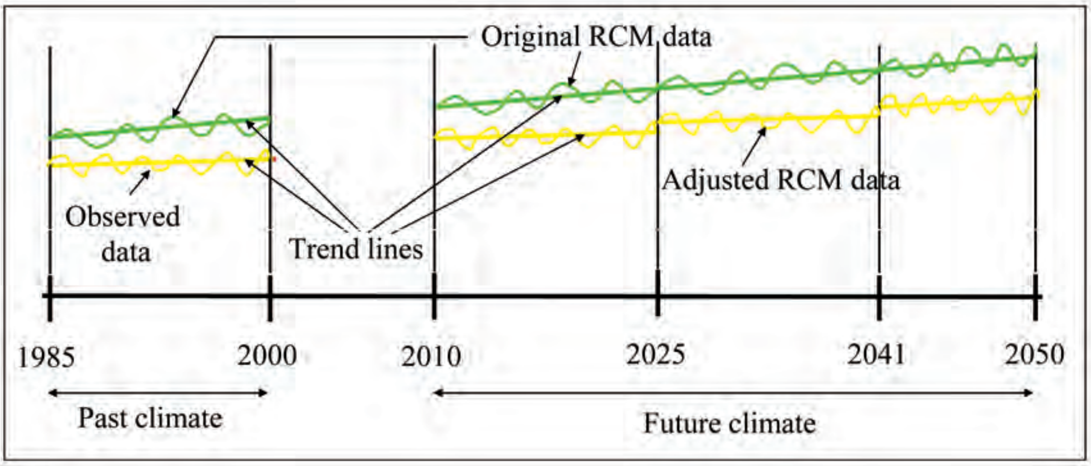


Figure 4-2 Conceptual schematization for adjustment of PRECIS data.

Adjustment of precipitation data

In the DSF, observed sub-basin precipitation is generated by using the MQUAD, a tool for aggregating data at stations in or around the sub-basin to its precipitation. The PRECIS data of sub-basins for 1985 - 2000 were adjusted by comparison with the MQUAD data.

As shown in Table 4-1, in Scenario A2, the mean annual precipitation for 2010 – 2050 in the UMB, the LMB and throughout the entire Basin increases by 10.9%, 4.5% and 5.3%, respectively, compared to that of 1985 – 2000. Under Scenario B2, these increases are smaller at 9.1%, 2.4% and 3.2%, respectively. The percentage increases in the dry season from November to April (i.e. 27.5%, 7.9% and 10.7% in Scenario A2, respectively), are much higher than those in the wet season from May to October (7.7%, 4.0% and 4.5% respectively in Scenario A2). However, the total precipitation in the dry season is only about 11 - 13% of the annual precipitation. Figure 4-3 reveals that highest increase in the mean annual sub-basin precipitation may reach 44 - 45% in the UMB in Scenarios A2 and B2. In most of the LMB sub-basins, precipitation will increase from 1 - 10%, except in some sub-basins in northern Lao PDR and central Viet Nam. On the other hand, precipitation will decrease, up to 8% in some areas of the Delta.

When these results are compared with the results from using data from 11 GCMs but selecting only one year (2030) as presented in Eastham et al. (2008), the adjusted PRECIS monthly data show larger variations in many months during 2010 - 2050 (Figure 4-4) but the highest value of 437 mm is less than that of 500 mm from the 11 GCMs for 2030. A possible explanation is that the GCM data used by Eastham et al. were not adjusted by comparison with the observed data in the past. The variation and the mean of the monthly data throughout the whole period are within the range and the mean of the 11 GCM data for 2030. However, the monthly PRECIS data for 2030 in both Scenarios A2 and B2 show that data in a single year may not give a good picture of the long-term trend of future climate change impacts.

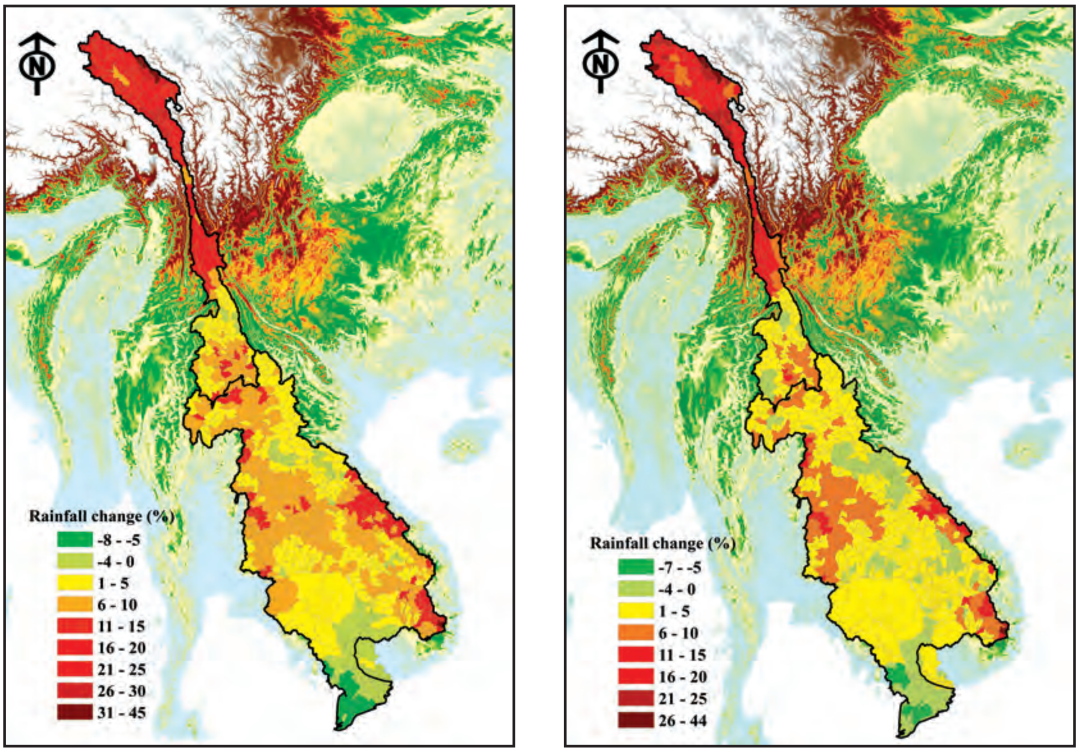
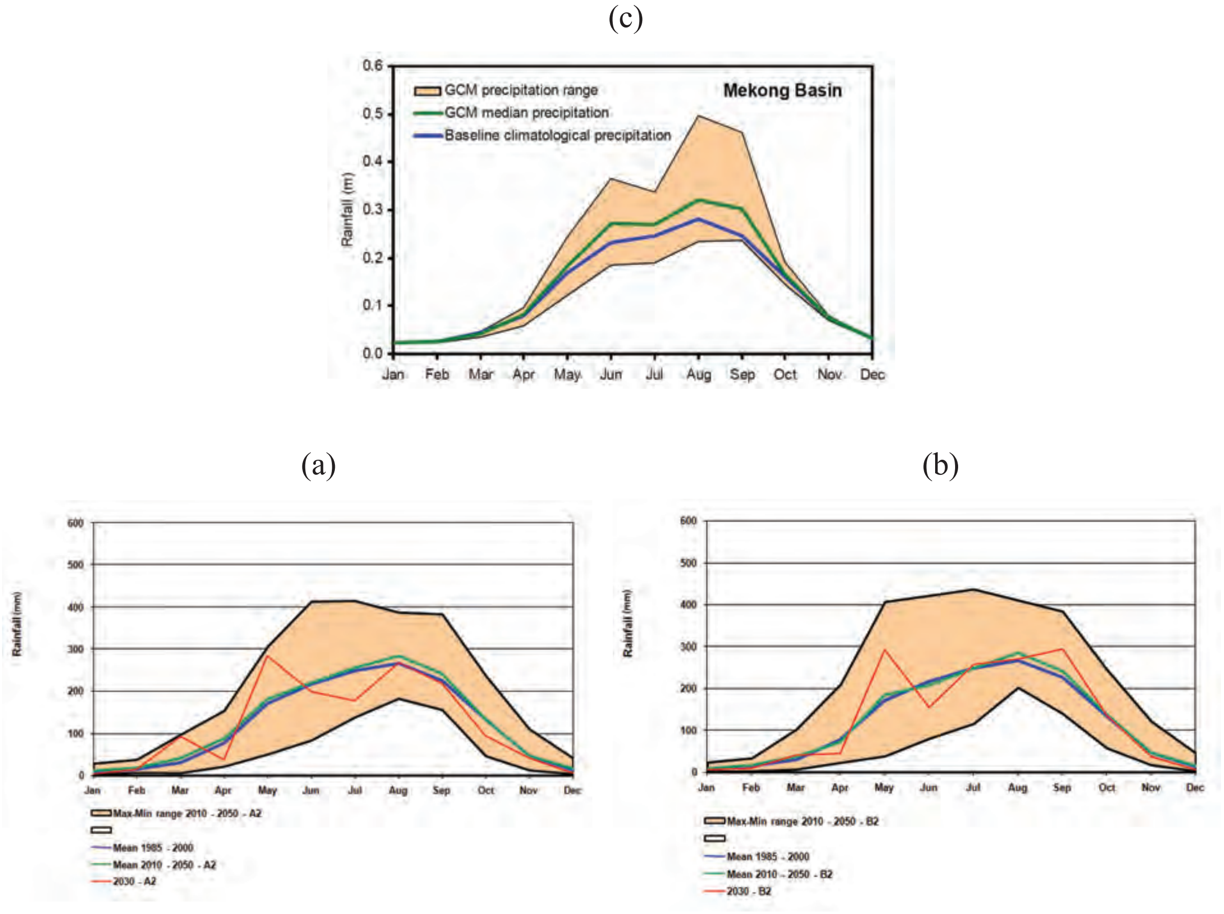


Figure 4-3 Change in mean annual sub-basin precipitation (%) during 2010 - 2050 compared to that for 1985–2000 for Scenario A2 (left) and Scenario B2 (right).


(c)

(a)

(b)

Figure 4-4 Changes in monthly precipitation in Scenario A2 (a) and Scenario B2 (b) compared with change in 2030 (c) versus 1951 - 2000 indicated by Eastham et al., 2008.

Table 4-1 *Mean annual, rainy (May-October) and dry (November - April) seasonal precipitation in Scenarios A2 and B2 compared with 1985 – 2000 for UMB, LMB and the entire Mekong Basin.*

Mekong Region	ECHAM4 Scenario	Mean Annual Precipitation (mm)					Change of Mean Annual Precipitation (mm)				Change of Mean Annual Precipitation (%)				Rate (mm/yr)
		1985 - 2000	2010 - 2025	2026 - 2041	2042 - 2050	2010 - 2050	2010 - 2025	2026 - 2041	2042 - 2050	2010 - 2050	2010 - 2025	2026 - 2041	2042 - 2050	2010 - 2050	
Upper Mekong	A2	901	979	1,008	1,019	999	78	108	119	99	8.7	12.0	13.2	10.9	+2.56
Lower Mekong	A2	1,598	1,647	1,671	1,707	1,670	49	73	109	72	3.0	4.6	6.8	4.5	+1.86
Entire Mekong	A2	1,458	1,512	1,538	1,568	1,535	55	80	111	77	3.7	5.5	7.6	5.3	+2.00
Upper Mekong	B2	901	965	1,000	982	982	65	100	81	82	7.2	11.1	9.0	9.1	+2.12
Lower Mekong	B2	1,598	1,628	1,680	1,573	1,636	30	82	-25	38	1.8	5.1	-1.6	2.4	+0.98
Entire Mekong	B2	1,458	1,494	1,543	1,454	1,504	37	85	-4	47	2.5	5.8	-0.3	3.2	+1.21

Mekong Region	ECHAM4 Scenario	Mean Wet Season Precipitation (mm)					Change of Mean Wet Season Precipitation (mm)				Change of Mean Wet Season Precipitation (%)				Rate (mm/yr)
		1985 - 2000	2010 - 2025	2026 - 2041	2042 - 2050	2010 - 2050	2010 - 2025	2026 - 2041	2042 - 2050	2010 - 2050	2010 - 2025	2026 - 2041	2042 - 2050	2010 - 2050	
Upper Mekong	A2	765	794	844	838	823	29	79	74	59	3.8	10.4	9.6	7.7	+1.52
Lower Mekong	A2	1,390	1,416	1,453	1,488	1,446	26	63	98	56	1.8	4.5	7.1	4.0	+1.46
Entire Mekong	A2	1,264	1,290	1,330	1,357	1,321	26	66	93	57	2.1	5.2	7.4	4.5	+1.47
Upper Mekong	B2	765	791	822	817	809	26	57	53	44	3.4	7.5	6.9	5.8	+1.14
Lower Mekong	B2	1,390	1,423	1,467	1,400	1,435	33	77	10	45	2.4	5.6	0.7	3.3	+1.18
Entire Mekong	B2	1,264	1,296	1,337	1,283	1,309	32	73	19	45	2.5	5.8	1.5	3.6	+1.17

Mekong Region	ECHAM4 Scenario	Change of Mean Dry Season Precipitation (mm)					Change of Mean Dry Season Precipitation (%)				Change of Mean Dry Season Precipitation (%)				Rate (mm/yr)
		1985 - 2000	2010 - 2025	2026 - 2041	2042 - 2050	2010 - 2050	2010 - 2025	2026 - 2041	2042 - 2050	2010 - 2050	2010 - 2025	2026 - 2041	2042 - 2050	2010 - 2050	
Upper Mekong	A2	138	184	165	184	176	45	27	46	38	32.9	19.3	32.9	27.5	+0.99
Lower Mekong	A2	208	230	221	219	224	22	14	11	16	10.6	6.6	5.5	7.9	+0.43
Entire Mekong	A2	194	220	210	212	214	27	16	18	21	13.8	8.5	9.4	10.7	+0.54
Upper Mekong	B2	138	174	180	162	174	35	42	24	35	25.5	30.2	17.1	25.5	+0.92
Lower Mekong	B2	208	205	217	169	202	-2	9	-38	-6	-1.1	4.3	-18.4	-2.8	-0.15
Entire Mekong	B2	194	199	209	168	196	5	16	-26	2	2.7	8.1	-13.3	1.2	+0.06

Note: The rate of change (in mm/year) = difference between the 1985-2000 and the 2010-2050 periods / 38.5 years from 1992.5 to 2030 as the mid-year of these two periods.

Adjustment of temperature data

The sub-basin temperature was adjusted in the same way as the sub-basin precipitation. However, since in the current DSF, observed temperature data are limited in terms of stations and records, the data of one station in a certain year or period were assigned to many sub-basins. The results after adjustment (Table 4 - 2) show that the mean annual average temperature will increase 0.9°C, 0.7°C and 0.7°C for the UMB, LMB and the entire Mekong Basin respectively, in Scenario A2 and 1.0°C, 0.8°C and 0.8°C respectively, in scenario B2. Similar changes are also observed for the maximum and minimum temperatures. Figure 4-5 shows that highest temperature increase will be in the uppermost part of the UMB. The increase will be less in the LMB but slightly higher in the lower part of the LMB and the Delta.

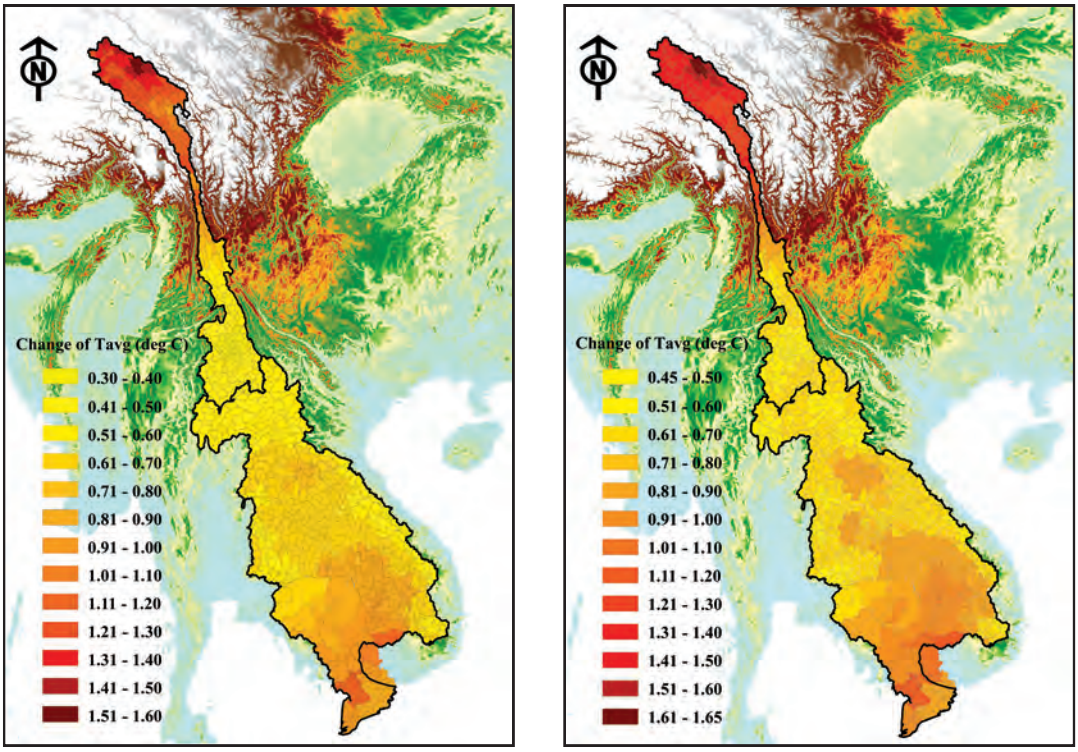


Figure 4-5 Increase in mean annual sub-basin average temperature during 2010-2050 compared with 1985-2000 for Scenario A2 (left) and Scenario B2 (right).

Adjustment of other climate parameters

An adjustment method similar to that for temperature was used for solar radiation and wind speed although the observed data for these parameters are very limited. However, model outputs are less sensitive to these parameters than they are to precipitation and temperature. Details of these parameters are not presented in this paper.

4.3 Comparison of climate change projection with other studies

A comparison of changes in precipitation and temperature in the Mekong Basin in the future compared to the past is presented in Table 4-3. While most studies provide a common projected increase of temperature of about 0.020 - 0.023°C/year, the projected changes in precipitation vary. The annual and seasonal precipitation increases or decreases depending on the selection of the GCM or RCM, the SRES scenarios, the duration of the past and future periods and the data (observed data in the basin, data from the global database or data from models). This comparison shows the high degree of uncertainty in projecting precipitation. This should be borne in mind when using results from any climate change scenario analysis.

Table 4-2 *Mean annual maximum, minimum and average temperatures in 2010 - 2050 under Scenarios A2 and B2 compared to 1985 - 2000 for the UMB, the LMB and the entire Mekong Basin.*

Mekong Region	ECHAM4 Scenario	Mean Annual Maximum Temperature (°C)					Change of Mean Annual Maximum Temperature (°C)			
		1985 - 2000	2010 - 2025	2026 - 2041	2042 - 2050	2010 - 2050	2010 - 2025	2026 - 2041	2042 - 2050	2010 - 2050
Upper Mekong	A2	18.3	18.8	19.1	20.0	19.2	0.5	0.8	1.7	0.9
Lower Mekong	A2	30.7	31.0	31.5	32.0	31.4	0.3	0.7	1.3	0.7
Entire Mekong	A2	28.1	28.4	28.9	29.5	28.8	0.3	0.8	1.4	0.7
Upper Mekong	B2	18.3	18.9	19.3	20.2	19.3	0.6	1.0	1.9	1.0
Lower Mekong	B2	30.7	31.1	31.4	32.3	31.5	0.4	0.7	1.5	0.8
Entire Mekong	B2	28.1	28.5	28.9	29.7	28.9	0.4	0.8	1.6	0.8

Mekong Region	ECHAM4 Scenario	Mean Annual Minimum Temperature (°C)					Change of Mean Annual Minimum Temperature (°C)			
		1985 - 2000	2010 - 2025	2026 - 2041	2042 - 2050	2010 - 2050	2010 - 2025	2026 - 2041	2042 - 2050	2010 - 2050
Upper Mekong	A2	5.4	5.9	6.2	7.2	6.3	0.5	0.8	1.8	0.9
Lower Mekong	A2	21.5	21.7	22.2	22.8	22.1	0.2	0.7	1.3	0.6
Entire Mekong	A2	18.1	18.3	18.8	19.5	18.8	0.3	0.7	1.4	0.7
Upper Mekong	B2	5.4	6.0	6.4	7.4	6.4	0.6	1.0	2.0	1.0
Lower Mekong	B2	21.5	21.8	22.1	23.1	22.2	0.3	0.7	1.6	0.8
Entire Mekong	B2	18.1	18.4	18.8	19.8	18.9	0.4	0.7	1.7	0.8

Mekong Region	ECHAM4 Scenario	Mean Annual Average Temperature (°C)					Change of Mean Annual Average Temperature (°C)			
		1985 - 2000	2010 - 2025	2026 - 2041	2042 - 2050	2010 - 2050	2010 - 2025	2026 - 2041	2042 - 2050	2010 - 2050
Upper Mekong	A2	11.9	12.4	12.7	13.6	12.8	0.5	0.8	1.8	0.9
Lower Mekong	A2	26.2	26.4	26.9	27.5	26.8	0.3	0.7	1.3	0.7
Entire Mekong	A2	23.3	23.6	24.0	24.7	24.0	0.3	0.8	1.4	0.7
Upper Mekong	B2	11.9	12.5	12.9	13.8	12.9	0.6	1.0	1.9	1.0
Lower Mekong	B2	26.2	26.6	26.9	27.8	27.0	0.4	0.7	1.6	0.8
Entire Mekong	B2	23.3	23.7	24.1	25.0	24.1	0.4	0.8	1.7	0.8

Table 4-3 *Comparison of projected climate change from different studies.*

Authors	Snidvongs et al. (2003)	Hoanh et al. (2003)	Ruosteenoja et al. (2003)	Water Development & Research Group of Helsinki University and START (2008)	Eastham et al. (2008)	Mac Sweeney et al. (2008a & 2008b)	ADB (2009)	Johnston et al. 2009	This study
Location	Lower Mekong catchment	Mekong Basin	Southeast Asia	Lower Mekong catchment	Lower Mekong catchment	Cambodia, Viet Nam	Thailand, Viet Nam	Greater Mekong Subregion	Mekong Basin
Models	CCAM	HADC	7 GCMs	ECHAM4-PRECIS	11 GCMs	15 GCMs	MAGICC (GCM)	PRECIS/ ECHAM4	PRECIS/ ECHAM4
Scenarios	No specific	A2, B2	A1F1, A2, B1, B2	A2	A1B	A2, A1B, B1	A1F1, B2	A2, B2	A2, B2
Period	From [1×CO2] to [2×CO2]	1960-2099	1961-2095	1960-2099	1951-2000 and 2030	1970-2090	1990-2100	1960-2049	1985-2050
Projected changes in annual rainfall	Not explicitly quantified	-1.64 to +4.36 mm/y	Either >0 or <0, depends on models and scenarios. Almost always insignificant	Increase (not explicitly quantified)	+0.1 to +9.9 mm/y	+0.3 to +0.6 mm/y	1990-2050: +1.26 to -1.62 mm/y (B2); 0.66 to -1.14 mm/y (A1F1) 1990-2100: +3.27 to +4.91 mm/y (A1F1) and -1.63 to -2.45 mm/y (B2)	No significant change at the whole GMS scale	+ 1.2 (B2) to +2 (A2) mm/y
Changes in seasonal rainfall pattern	Dry season drier and longer 1-month delayed rainy season		Dry season drier and longer 1-month delayed rainy season	Dry season drier and longer 1-month delayed rainy season	Wetter rainy season (+1.7 to +6.1 mm/y) Drier dry season (-0.3 mm/y – not significant)	Wetter rainy season : +0.8 to +1.5 mm/y (C); +0.4 to +1.5 mm/y (VN) Drier dry season: -0.7 to -0.1 mm/y (C); -0.3 to -0.1 mm/y (VN)		Wetter rainy season in North Myanmar and Gulf of Thailand (From +0.2 to +0.6 mm/y) Drier dry season on both sides of Gulf of Thailand (-2.5 to -2.8 mm/y)	Wetter rainy season: +1.2 (B2) to +1.5 (A2) mm/y Wetter dry season in UMB +0.9 mm/y and insignificant change in LMB
Temperature	+ 1 to +3°C (over 100 year period)	+0.026 to +0.036°C/y	+0.01 to +0.05°C/y	Increase (not explicitly quantified)	+0.012 to +0.014°C/y	0.00 to +0.06°C/y	+0.03 to +0.06°C/y	+0.03 to +0.06°C/y	+0.020 to +0.023°C/y

5. Baseline scenario with observed and PRECIS climate data

In the scenario analysis, outputs (such as water yield from sub-basins generated by the SWAT, simulated flow and irrigation extraction at key stations generated by the IQQM, water level and salinity generated by the ISIS) from the Development Scenario with and without climate change are compared with outputs from the Baseline Scenario to analyse impacts of both development and climate change. Because PRECIS data are used for scenarios with future climate change, for a proper comparison simulated PRECIS data for 1985 - 2000 are also used to replace the observed data in providing the outputs of the Baseline Scenario, i.e. outputs in Scenario S2 will be used in the comparison with the future projection instead of Scenario S1. Another objective of the model run of Scenario S2 for the Baseline with these PRECIS data is to identify the adjustment needed to make sure that the outputs from the DSF by using simulated PRECIS data for 1985 - 2000 match the outputs from the same scenario using observed data.

The DSF models and data for the Baseline Scenario formulated and calibrated by IKMP and BDP Teams were adopted for use in this climate change study. The DSF models include eight Lower Mekong SWAT Models upstream of Kratie, 16 Tonle Sap Great Lake SWAT Models, three IQQM Models (upstream of Kratie, the Tonle Sap Great Lake and the Viet Nam Delta) and one ISIS model downstream of Kratie. In addition a SWAT Model for the UMB was used.

The process of model runs for adjustment of RCM data by running the SWAT models is shown in Figure 5-1. First, water yield outputs from SWAT models for the Baseline with RCM data (model run Scenario S2) were compared with outputs for the Baseline with observed data and different adjustment methods (see Appendix) were applied until the differences were minor and acceptable.

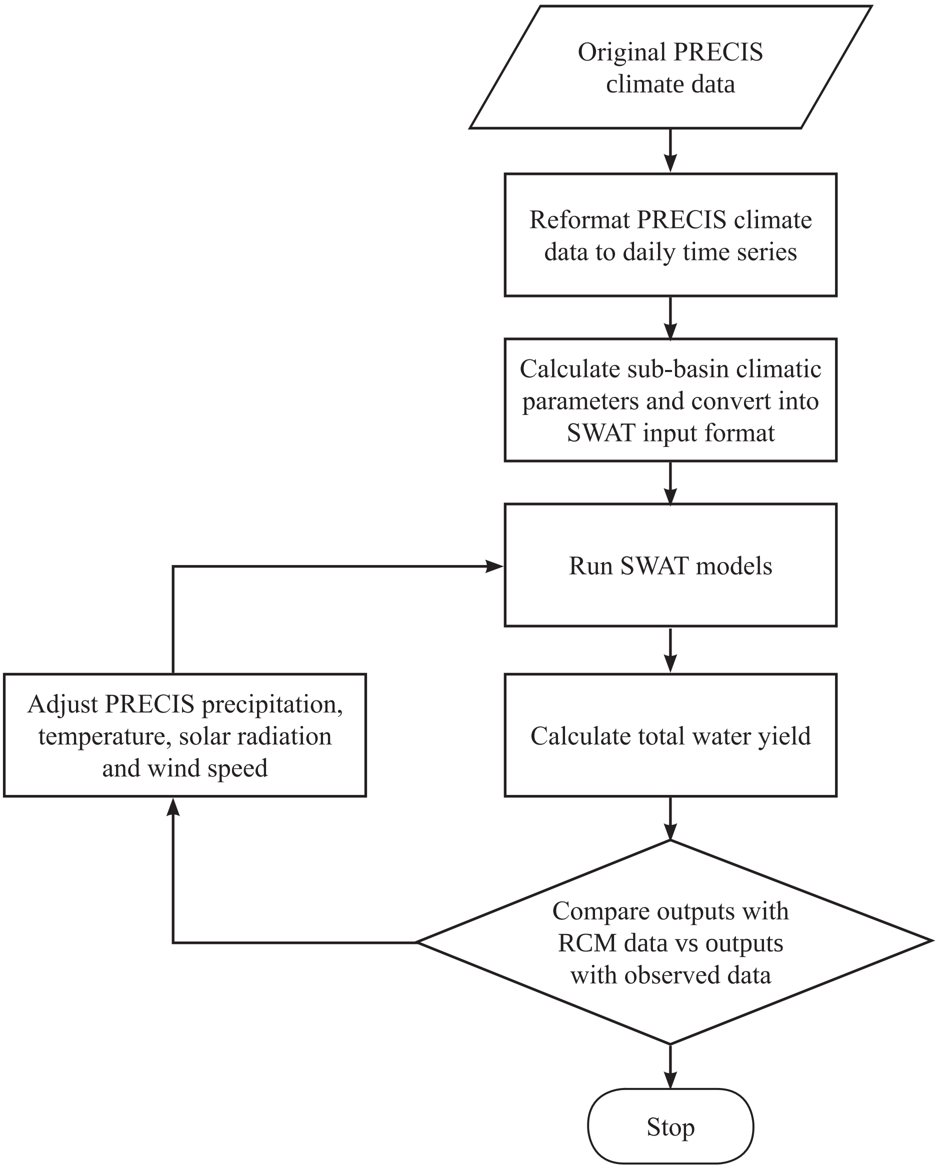
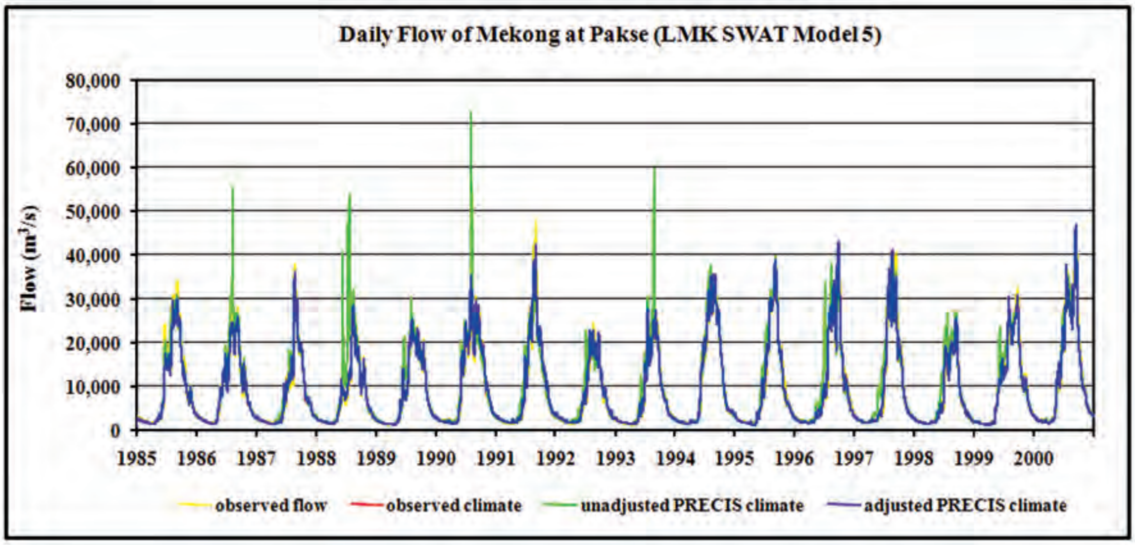


Figure 5-1 Flow chart for the adjustment of PRECIS data by running SWAT models.

5.1 Verification of water yields from SWAT models

As examples of model outputs, daily and monthly discharges from the LMB SWAT Model 5 (river reach from Mukdahan to Pakse) are presented in Figures 5-2 and 5-3. These clearly demonstrate that the peaks of the daily and monthly river discharges using the unadjusted PRECIS climate data as inputs are much higher than those of either the observed discharges or those computed from the observed climate data. However the graph shows that both the daily and monthly river discharge hydrographs computed from the adjusted PRECIS climate data fit well with those from both the observed climate data and the observed discharge hydrographs.



Note: In this figure and the following Figures 5-3, 5-4 and 5-5, outputs from model runs using the observed climate data cannot be seen clearly because they fit too well with the outputs from the model run using adjusted PRECIS data.

Figure 5-2 Comparison of daily observed discharge with outputs from model runs with observed climate data, unadjusted and adjusted PRECIS data for LMB SWAT Model 5.

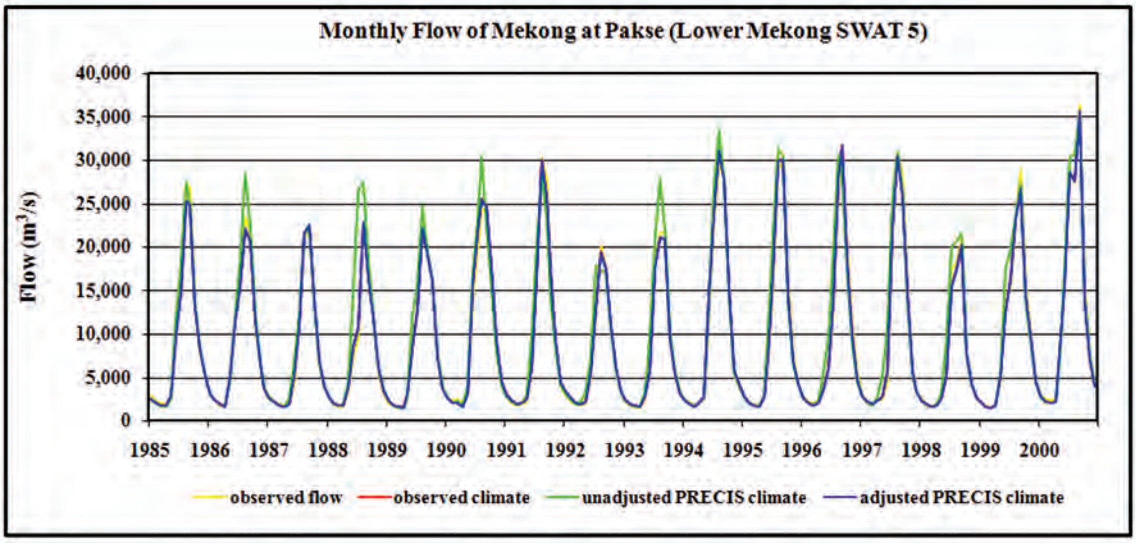


Figure 5-3 Comparison of monthly water yield from model runs with observed climate data, unadjusted and adjusted PRECIS data for LMB SWAT Model 5.

In the same way, total daily and monthly water yields generated from Scenario S2 were also compared with those of Scenario S1. These are shown in Figures 5-4 and 5-5 which show that the daily and monthly water yields calculated by using unadjusted PRECIS data are much higher than those calculated from the observed data. After adjustment, the daily and monthly water yields using adjusted PRECIS data as inputs fit well with those from using observed data.

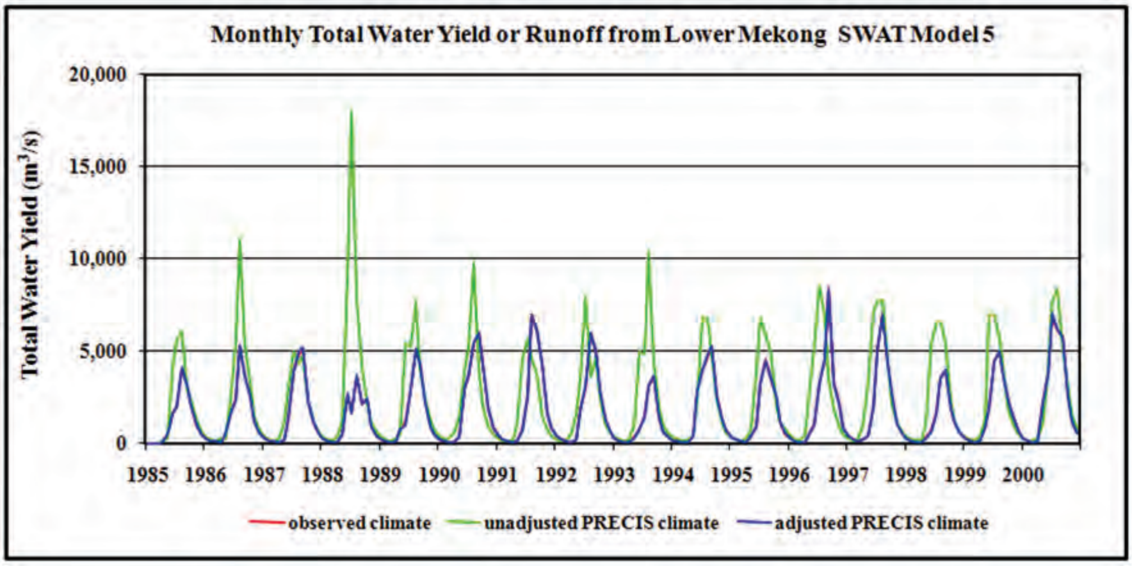


Figure 5-4 Comparison of daily water yields from model runs with observed climate data, unadjusted and adjusted PRECIS data for LMB SWAT Model 5.

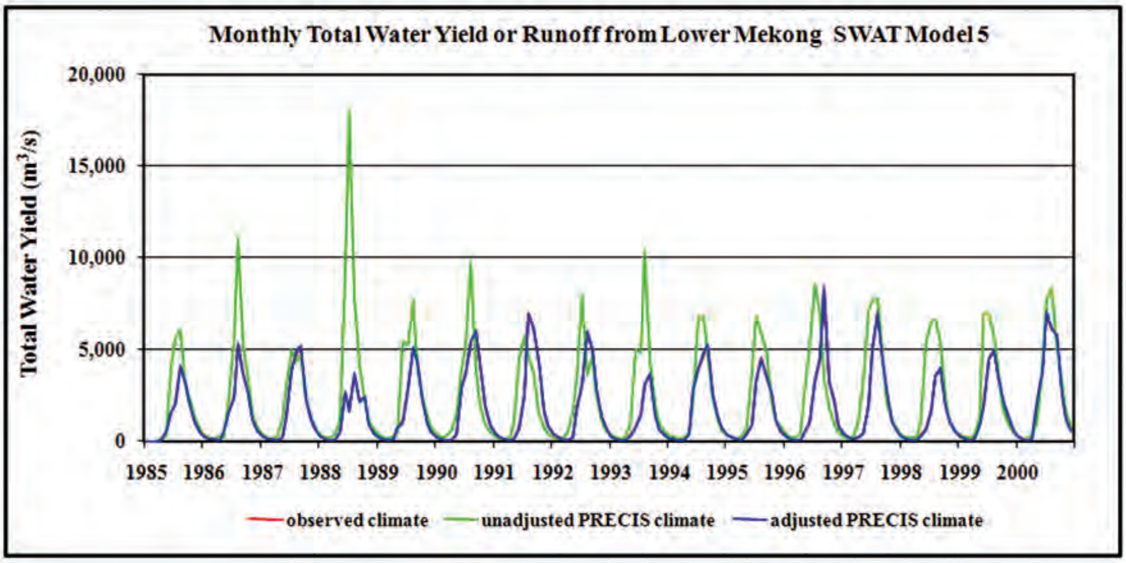


Figure 5-5 Comparison of monthly observed discharges with outputs from model runs with observed climate data, unadjusted and adjusted PRECIS data for LMB SWAT Model 5.

The evaluation results for all SWAT models upstream of Kratie and around the Tonle Sap Great Lake are presented in Tables 5-1 and 5-2. In the model run with unadjusted PRECIS data, values of Coefficient of Efficiency (CE) are much lower than those values using observed data as inputs. The high values of Volume Ratio (VR) of all models (all over 100%) reflect an overestimation of precipitation in the unadjusted PRECIS data. With the adjusted PRECIS data, the CE and VR values show that outputs are very close to those from the model run with observed data. Figure 5-6 shows a very similar spatial distribution of mean annual sub-basin water yields from model runs with observed and adjusted PRECIS data for the upstream area of Kratie.

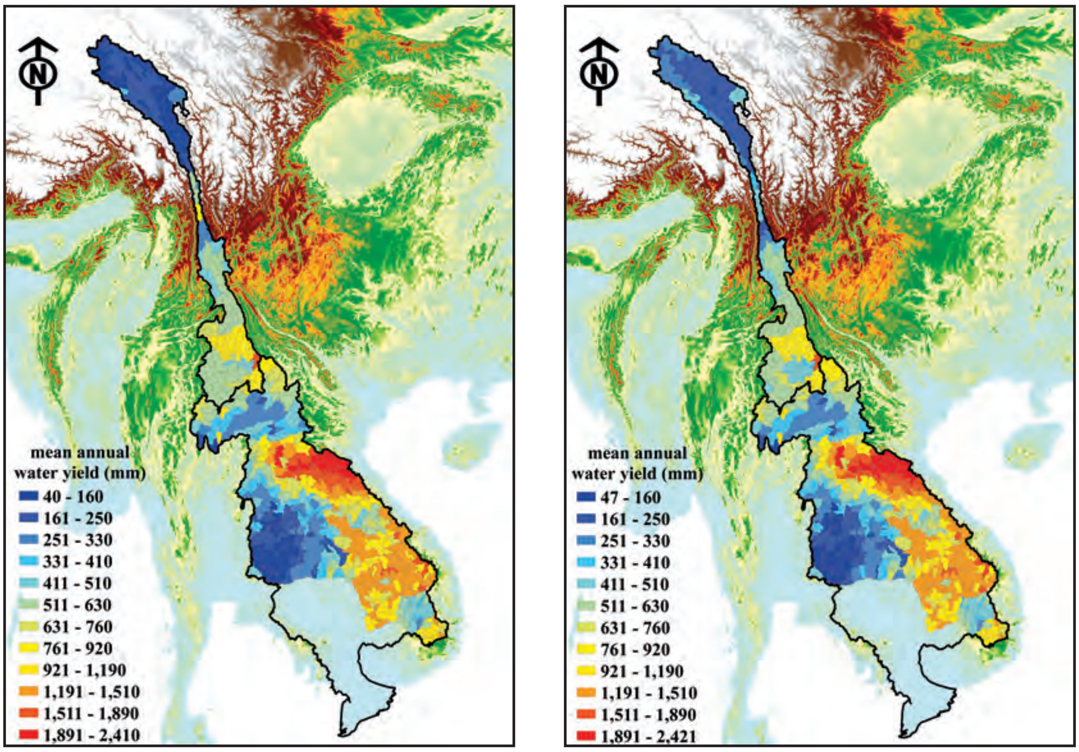


Figure 5-6 Mean annual sub-basin water yields during 1985 – 2000 from model runs with observed (left) and adjusted PRECIS (right) data.

Table 5-1 *Comparison of results of SWAT models upstream of Kratie with different climate datasets.*

Model Code	Evaluation point	Observed data		Unadjusted PRECIS data				Adjusted PRECIS data				Mean Annual Precipitation (mm)		
		River discharge		River discharge		WYLD		River discharge		WYLD				
		CE	VR (%)	CE	VR (%)	CE	VR (%)	CE	VR (%)	CE	VR (%)	Observed	Unadjusted	Adjusted
UMB	Chiang Saen	0.68	101.8	0.50	120.2	0.50	122.1	0.63	98.8	0.98	96.9	901	986	901
LMB1	Chiang Saen	0.58	102.2	0.50	105.2	-0.76	113.3	0.58	101.9	1.00	98.7	1,474	1,634	1,474
LMB2	Luang Prabang	0.95	100.2	0.82	107.4	-0.24	123.5	0.94	99.4	1.00	97.9	1,576	1,724	1,576
LMB3	Vientiane	0.94	101.0	0.86	108.8	-3.02	164.9	0.94	100.8	1.00	98.5	1,361	1,674	1,361
LMB4	Mukdahan	0.94	104.5	0.84	107.1	0.50	102.1	0.94	104.1	1.00	99.2	2,140	2,130	2,140
LMB5	Pakse	0.98	99.6	0.89	107.9	-1.18	144.4	0.98	99.5	1.00	99.1	1,706	2,158	1,706
LMB6	Kratie	0.93	100.5	0.74	107.1	-1.82	124.0	0.93	100.6	1.00	100.3	1,875	2,351	1,875
LMB7	Yasothon	0.62	100.3	-1.70	150.7	-1.08	173.8	0.61	99.9	1.00	97.8	1,122	1,381	1,122
LMB8	Rasi Salai	0.38	99.9	-3.29	160.6	-2.22	159.7	0.41	98.1	0.99	98.4	1,049	1,315	1,072

Notes:

CE = *Nash and Sutcliffe Coefficient of Efficiency, calculated as:*

$$CE = 1 - \frac{\sum_{i=1}^{n}(A_{itsc,i}\,O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2}$$

with n as number of values, Oi as observed, Pi as predicted values, as mean of all Oi values

VR = *Total Simulated Volume / Total Observed Volume for 16 years 1985-2000*

WYLD = *Water yield, SWAT terminology for runoff*

Table 5-2 *Evaluation of SWAT models with PRECIS data around the Great Lake* .

Model Code	SWAT Model Name	Unadjusted PRECIS data WYLD		Adjusted PRECIS data WYLD	
		CE	VR (%)	CE	VR (%)
GLK01	Stung Chinit	0.08	112.71	1.00	97.96
GLK02	Stung Sen	0.01	105.42	1.00	98.25
GLK03	Stung Staung	-0.53	101.55	0.99	96.41
GLK04	Stung Chikreng	-1.20	122.39	1.00	93.43
GLK05	Stung Siem Reap	-1.14	91.07	1.00	97.64
GLK06	Stung Sreng	-0.77	111.35	0.92	95.85
GLK08	Stung Mongkol Borey	-3.68	166.28	1.00	98.79
GLK10	Stung Battambang	-0.63	117.32	1.00	100.14
GLK11	Stung Dauntri	0.08	79.29	1.00	98.62
GLK12	Stung Pursat	-0.59	102.42	1.00	99.34
GLK13	Stung Boribo	-1.42	123.33	1.00	99.40
GLK14	Prek Thnot	-0.79	108.92	1.00	101.54
GLK15	Prek Te	-1.65	197.08	0.99	90.74
GLK16	Prek Chhlong	-6.92	236.16	1.00	97.98
GLK17	East Vaico	-0.87	201.30	1.00	99.44
GLK18	West Vaico	-0.14	118.89	1.00	98.36

5.2 Verification of river discharge from IQQM model

In this verification, the daily total water yield from the SWAT model for the UMB was used as the inflow at Chinese – Lao border for the model run of Scenario S2 using PRECIS data, but for the model run of Scenario S1, using observed climate data, the observed inflow at Chiang Saen was used to rebuild the inflow at the Chinese – Lao border (as used in previous BDP studies). The influence of the China inflow on the Mekong mainstream discharge becomes smaller at locations further downstream. The verification of the model performance was carried out by comparing the daily river discharge computed from the model run of Scenarios S1 and S2. Table 5-3 presents the evaluation results at the key stations along the Mekong mainstream and at some selected points on the tributaries, while Figure 5-7 shows the comparison of the discharge at Kratie in Scenarios S1 and S2 as an example. With CE values close to 1.00 and VR values close to 100%, it can be concluded that the IQQM model using adjusted PRECIS data as inputs in Scenario S2 produced similar outputs to Scenario S1 using observed data.

Table 5-3 *Evaluation of IQQM model results upstream of Kratie in the model run of Scenario S2 using PRECIS data.*

Station Name	CE	VR (%)	Station Name	CE	VR (%)
Mekong at Chiang Saen	0.73	100.2	Se Bang Hieng at Ban Keng Done	1.00	97.9
Mekong Luang Prabang	0.90	99.4	Se Bang Hieng at Tchepon	1.00	99.8
Mekong at Chiang Khan	0.92	99.2	Se Done at Saravanne	1.00	100.6
Mekong at Vientiane	0.93	99.2	Se Done at Souvannakhili	1.00	99.0
Mekong at Nong Khai	0.93	99.2	Nam Mun at Ubon	0.99	96.9
Mekong at Nakhon Phanom	0.98	99.1	Nam Leak at Ban Hin Heup	1.00	99.2
Mekong at Mukdahan	0.98	99.2	Nam Ngum at Ban Pak Khanoung	1.00	99.0
Mekong at Pakse	0.99	99.2	Nam Oon at Ban Pok Yai	0.99	95.3
Mekong at Stung Treng	0.99	99.5	Nam Songkhram at Ban Tha Kok Daeng	1.00	99.2
Mekong at Kratie	0.99	99.5	Nam Ngiep at Muong Mai	1.00	98.9
Nam Mun at Rasi Salai	0.98	97.4	Se Bang Fai at Mahaxai	1.00	99.2
Nam Mun at Satuk	0.97	98.9	Nam Theun at Ban Signo	1.00	98.5
Lam Pao at Kamalasai	0.97	95.4	Nam Ou at Muong Ngoy	1.00	97.8
Nam Chi at Ban Chot	0.99	101.5	Nam Ing at Thoeng	1.00	99.1
Nam Chi at Yasothon	0.98	91.4	Nam Kok at Chiang Rai	0.99	95.8
Sre Pok at Lomphat	1.00	101.6	Nam Lao at Ban Tha Sai	0.99	98.0
Se Chomphone at Ban Keng Kok	1.00	96.3	Nam Khan at Ban Mout	1.00	97.4
Se Lanong at Muong Nong	1.00	99.3			

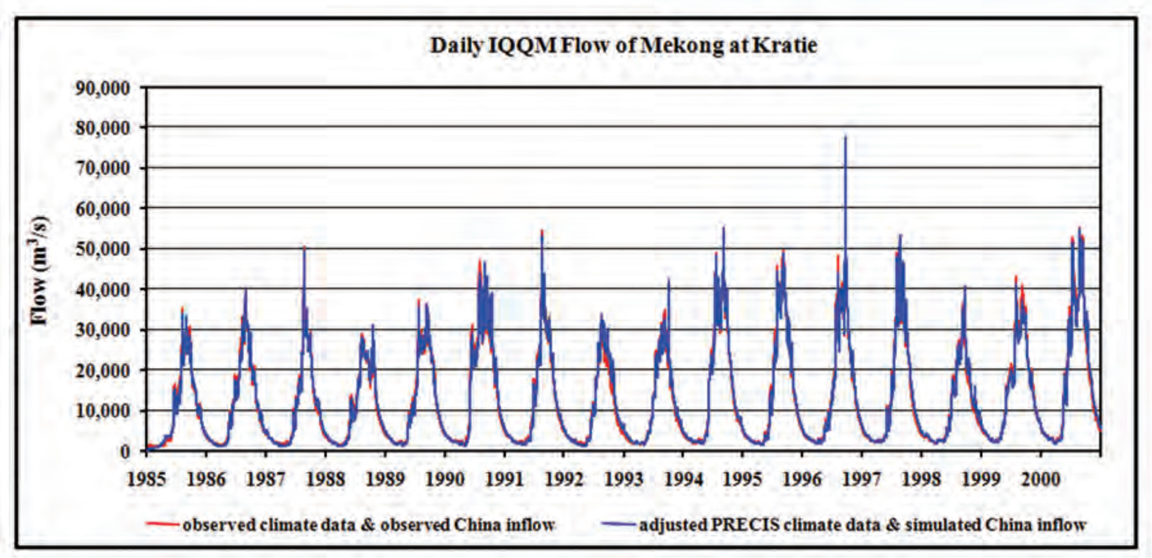


Figure 5-7 Comparison of the daily discharge at Kratie in two model runs of Scenarios S1 and S2.

5.3 Verification of flood and salinity from ISIS model

Because, over a long period, more attention is usually paid to the maximum levels of flooding and salinity intrusion than to their average levels, the comparison of flood and salinity conditions is based on a specific year when the flooding depth or salinity is the highest. Table 5-4 compares the flooded areas based on maximum flood depths at each river and canal node of a model run of Scenarios S1 and S2 in 2000 (a high flood year). The difference in the flooded areas in these two model runs is small, maximum -1.9% for the flooding depth > 3.0 m. Similarly Table 5-5 compares salinity intrusion areas based on maximum salinity at each river and canal node in these two model runs in 1998 (a high salinity year due to low river discharge). Most saline areas show increases of about 1 - 2%, except for those areas with salinity > 32 g/l where the increase is 6.7%, but this is only in a narrow area along the coastline with high salinity. Therefore, it can be concluded that the ISIS model run for Scenario S2 using adjusted PRECIS data is able to produce similar results to the model run for Scenario S1 using observed data.

Table 5-4 *Comparison of flooded areas in 2000 in two model runs of Scenarios S1 and S2.*

Maximum Depth	Flood Area of Maximum Flood Depth (km^2)		Difference in Flood Area (km^2)	
	Adjusted PRECIS Data	DSF Observed Climate	+/- (km^2)	+/- (%)
> 0.0 m	60,729	60,732	-3	0.0
> 0.5 m	41,317	40,939	378	0.9
> 1.0 m	36,393	36,211	182	0.5
> 1.5 m	30,923	31,132	-209	-0.7
> 2.0 m	26,347	26,769	-422	-1.6
> 2.5 m	21,971	22,352	-381	-1.7
> 3.0 m	17,977	18,328	-351	-1.9
> 3.5 m	15,198	15,384	-186	-1.2
> 4.0 m	13,570	13,749	-179	-1.3

Table 5-5 *Comparison of salinity intrusion areas in 1998 in two model runs of Scenarios S1 and S2.*

"Concentration (g/l)"	Salinity Area for Maximum Concentration (km^2)		Difference in Saline Area (km^2)	
	Adjusted PRECIS Data	DSF Observed Climate	+/- (km^2)	+/- (%)
> 0 g/l	41,150	41,332	-182	-0.4
> 4 g/l	20,744	20,224	520	2.6
> 8 g/l	15,451	15,377	74	0.5
> 12 g/l	12,944	13,042	-98	-0.8
> 16 g/l	10,953	11,102	-149	-1.3
> 20 g/l	9,378	9,241	137	1.5
> 24 g/l	7,064	7,197	-133	-1.8
> 28 g/l	4,923	4,873	50	1.0
> 32 g/l	2,852	2,673	179	6.7

This verification of the SWAT, IQQM and ISIS outputs from Scenario S2 also helped with the conclusion that the adjustment methods applied to the PRECIS data are appropriate in making the RCM simulation for 1985 - 2000 match with the observed data, and these methods can be applied to the adjustment of PRECIS data for the future period of 2010 - 2050.

6. Impacts of development and climate change on the Mekong flow regime

6.1 Mekong flow under development and climate change

Although water yield and river flow for many sub-basins and nodes can be generated from the SWAT, IQQM and ISIS models this paper deals with the changes in discharge at 11 key stations in the Mekong mainstream upstream of Kratie (see Table 6-1 and Figure 3-3 for the their locations). These discharges were generated by the IQQM model. The discharge at the three stations of Kampong Cham, Phnom Penh and Tan Chau downstream of Kratie, generated by the ISIS model were analysed. Discharge at these stations in the high-flow season is not a true reflection of all the water flowing in the Mekong mainstream because some water drains to the sea through the large tributary of the Bassac, and through many other smaller rivers and canals. Therefore values of the high-flow season and annual discharges at these stations could be lower than those at Kratie.

The mean discharge in both the high- and low-flow seasons, and the annual discharges at these stations in Scenarios A2 and B2 are presented in Tables 6-1 to 6-6. The corresponding model runs of scenarios and years of simulation are also shown to indicate the development scenario and climate dataset used to generate the river flow. All climate data used in these scenarios are the adjusted PRECIS data, for either 1985 - 2000 or 2010-2050. For comparison, in addition to the mean value for 2010 - 2050, the mean value of each 16 year period (only 9 years in the last part of 2042 - 2050) were also calculated to show the possible future variations.

As previously described, since the PRECIS simulation data for 1985 – 2000 for Scenarios A2 and B2 are identical, the discharge outputs in the different tables are also identical. In general, climate change will result in higher discharge in both the high- and low-flow seasons at all stations in the future. The development of hydropower dams in the Development Scenario will result in a lower discharge in the high-flow season but the discharge will be higher than that of the Baseline both without climate change (1985 - 2000) and with climate change (2010 - 2050). However, these changes will vary from year to year, as shown by the higher discharge during 2026 - 2041 than that in the other 16 year periods. Such variations in flow regime also imply that high climate variability, in particular the variability of precipitation, will continue in the future as shown in Table 4-1, and changes in the flow regime do not only depend on the total precipitation but also on its distribution throughout the year. Furthermore, there is also variation by space, development scenario and climate change scenario. For example, between 2010 and 2025 in the A2 Baseline Scenario, high-flow season discharge decreases at Nakhon Phanom, Mukdahan and Khong Chiam but increases at all other stations (Table 6-1) but in the B2 Baseline Scenario, high-flow season discharge increases at Pakse, Stung Treng, Kratie and Kompong Cham and decreases at all other stations. Such differences in the A2 and B2 Climate Scenarios are also found between 2042 and 2050 in the Development Scenario.

Despite these variations, the common trend in flow regime, i.e. higher in both seasons due to climate change, and lower in high-flow season/higher in low-flow season due to development, can be observed at most stations. The detailed analysis of the flow changes by comparing different pairs of scenarios are discussed in the next Sections.

Table 6-1 *Mean high-flow season discharge at 14 key stations along the Mekong River in the Baseline and Development Scenario without and with climate change A2 Scenario.*

	Station	Baseline Scenario: Mean high-flow season discharge (m^3/s)					Development Scenario: Mean high-flow season discharge (m^3/s)				
		1985-2000	2010-2025	2026-2041	2042-2050	2010-2050	1985-2000	2010-2025	2026-2041	2042-2050	2010-2050
	Scenario	S2	S4	S4	S4	S4	S3	S5	S5	S5	S5
1	1985-2000	4,127	4,213	4,668	4,498	4,453	3,412	3,616	4,080	3,936	3,867
2	Luang Prabang	6,008	6,087	6,861	6,400	6,458	4,912	5,138	5,891	5,471	5,505
3	Chiang Khan	6,636	6,798	7,624	7,344	7,240	5,536	5,848	6,652	6,410	6,285
4	Vientiane	6,837	7,021	7,861	7,653	7,488	5,734	6,067	6,885	6,711	6,527
5	Nong Khai	6,947	7,138	7,986	7,802	7,614	5,843	6,182	7,008	6,859	6,653
6	Nakhon Phanom	11,601	11,514	13,232	12,962	12,502	9,812	9,884	11,566	11,345	10,861
7	Mukdahan	12,522	12,425	14,392	14,137	13,568	10,939	10,992	12,940	12,723	12,132
8	Khong Chiam	14,444	14,223	16,434	16,457	15,610	12,656	12,808	14,972	15,035	14,141
9	Pakse	15,827	15,993	18,396	18,736	17,533	14,319	14,627	16,995	17,384	16,156
10	Stung Treng	20,827	21,353	24,297	24,286	23,146	19,055	19,738	22,603	22,677	21,501
11	Kratie	21,549	22,064	25,065	25,046	23,890	19,762	20,428	23,352	23,437	22,229
12	Kompong Cham	20,935	21,382	24,123	24,009	23,028	19,301	19,884	22,579	22,559	21,523
13	Phnom Penh	20,217	20,460	22,702	22,175	21,711	18,797	19,194	21,484	21,048	20,495
14	Tan Chau	14,435	14,511	15,823	15,618	15,266	13,614	13,793	15,156	14,997	14,589

Table 6-2 *Mean low-flow season discharge at 14 key stations along the Mekong River in the Baseline and Development Scenario without and with climate change A2 Scenario.*

	Station	Baseline Scenario: Mean Low-flow season discharge (m^3/s)					Development Scenario: Mean Low-flow season discharge (m^3/s)				
		1985-2000	2010-2025	2026-2041	2042-2050	2010-2050	1985-2000	2010-2025	2026-2041	2042-2050	2010-2050
	Scenario	S2	S4	S4	S4	S4	S3	S5	S5	S5	S5
1	Chiang Saen	1,157	1,439	1,463	1,519	1,467	1,847	2,012	2,040	2,069	2,035
2	Luang Prabang	1,499	1,882	1,952	2,001	1,937	2,247	2,475	2,560	2,578	2,532
3	Chiang Khan	1,613	2,026	2,104	2,170	2,089	2,356	2,609	2,707	2,745	2,678
4	Vientiane	1,640	2,057	2,138	2,212	2,124	2,377	2,635	2,739	2,785	2,709
5	Nong Khai	1,668	2,091	2,174	2,252	2,160	2,403	2,668	2,773	2,823	2,744
6	Nakhon Phanom	2,172	2,637	2,757	2,855	2,733	2,771	3,068	3,204	3,269	3,166
7	Mukdahan	2,220	2,691	2,814	2,925	2,792	2,935	3,235	3,377	3,449	3,339
8	Khong Chiam	2,386	2,876	2,994	3,139	2,984	3,060	3,394	3,545	3,648	3,510
9	Pakse	2,506	3,112	3,201	3,430	3,218	3,333	3,769	3,882	4,063	3,879
10	Stung Treng	3,515	4,219	4,400	4,371	4,325	4,511	5,029	5,142	5,154	5,101
11	Kratie	3,622	4,323	4,497	4,446	4,420	4,621	5,143	5,259	5,212	5,204
12	Kompong Cham	3,650	4,328	4,501	4,447	4,423	4,643	5,159	5,264	5,192	5,208
13	Phnom Penh	3,718	4,391	4,577	4,514	4,492	4,708	5,226	5,336	5,267	5,279
14	Tan Chau	5,052	5,591	5,807	5,696	5,700	5,502	5,981	6,132	6,096	6,066

Table 6-3 *Mean annual discharge at 14 key stations along the Mekong River in the Baseline and Development Scenario without and with climate change A2 Scenario.*

	Station	Baseline Scenario: Mean annual discharge (m^3/s)					Development Scenario: Mean annual discharge (m^3/s)				
		1985-2000	2010-2025	2026-2041	2042-2050	2010-2050	1985-2000	2010-2025	2026-2041	2042-2050	2010-2050
	Scenario	S2	S4	S4	S4	S4	S3	S5	S5	S5	S5
1	Chiang Saen	2,642	2,826	3,066	3,008	2,960	2,629	2,814	3,060	3,002	2,951
2	Luang Prabang	3,754	3,985	4,406	4,200	4,197	3,580	3,806	4,226	4,024	4,018
3	Chiang Khan	4,125	4,412	4,864	4,757	4,665	3,946	4,228	4,680	4,577	4,482
4	Vientiane	4,239	4,539	5,000	4,932	4,806	4,056	4,351	4,812	4,748	4,618
5	Nong Khai	4,308	4,615	5,080	5,027	4,887	4,123	4,425	4,890	4,841	4,698
6	Nakhon Phanom	6,887	7,075	7,995	7,909	7,618	6,292	6,476	7,385	7,307	7,014
7	Mukdahan	7,371	7,558	8,603	8,531	8,180	6,937	7,113	8,159	8,086	7,735
8	Khong Chiam	8,415	8,550	9,714	9,798	9,297	7,858	8,101	9,259	9,341	8,826
9	Pakse	9,167	9,553	10,799	11,083	10,376	8,826	9,198	10,439	10,723	10,018
10	Stung Treng	12,171	12,786	14,348	14,328	13,735	11,783	12,384	13,873	13,915	13,301
11	Kratie	12,585	13,193	14,781	14,746	14,155	12,192	12,786	14,305	14,325	13,717
12	Kompong Cham	12,292	12,855	14,312	14,228	13,726	11,972	12,521	13,921	13,875	13,365
13	Phnom Penh	11,967	12,426	13,639	13,345	13,102	11,753	12,210	13,410	13,158	12,887
14	Tan Chau	9,743	10,051	10,815	10,657	10,483	9,558	9,887	10,644	10,546	10,328

Table 6-4 Mean high-flow season discharge at 14 key stations along the Mekong River in the Baseline and Development Scenario without and with climate change B2 Scenario.

	Station	Baseline Scenario: Mean high-flow season discharge (m^3/s)					Development Scenario: Mean high-flow season discharge (m^3/s)				
		1985-2000	2010-2025	2026-2041	2042-2050	2010-2050	1985-2000	2010-2025	2026-2041	2042-2050	2010-2050
	Scenario	S2	S4	S4	S4	S4	S3	S5	S5	S5	S5
1	Chiang Saen	4,127	4,042	4,479	4,157	4,238	3,412	3,435	3,914	3,513	3,639
2	Luang Prabang	6,008	5,804	6,767	5,800	6,179	4,912	4,855	5,808	4,807	5,216
3	Chiang Khan	6,636	6,488	7,623	6,538	6,942	5,536	5,536	6,659	5,542	5,976
4	Vientiane	6,837	6,706	7,894	6,768	7,183	5,734	5,750	6,924	5,765	6,211
5	Nong Khai	6,947	6,827	8,029	6,881	7,308	5,843	5,870	7,058	5,877	6,335
6	Nakhon Phanom	11,601	11,456	13,064	11,243	12,037	9,812	9,830	11,413	9,537	10,383
7	Mukdahan	12,522	12,428	14,089	12,181	13,022	10,939	10,998	12,648	10,678	11,571
8	Khong Chiam	14,444	14,198	15,981	14,029	14,857	12,656	12,760	14,530	12,515	13,397
9	Pakse	15,827	16,044	17,865	15,640	16,666	14,319	14,673	16,474	14,188	15,269
10	Stung Treng	20,827	21,185	23,247	20,663	21,875	19,055	19,560	21,623	18,927	20,226
11	Kratie	21,549	21,939	23,979	21,366	22,609	19,762	20,290	22,341	19,605	20,940
12	Kompong Cham	20,935	21,248	23,161	20,712	21,877	19,301	19,747	21,681	19,113	20,362
13	Phnom Penh	20,217	20,195	21,920	19,824	20,787	18,797	18,951	20,735	18,474	19,542
14	Tan Chau	14,435	14,392	15,391	14,047	14,706	13,614	13,702	14,687	13,310	14,000

Table 6-5 *Mean low-flow season discharge at 14 key stations along the Mekong River in the Baseline and Development Scenario without and with climate change B2 Scenario.*

	Station	Baseline Scenario: Mean low-flow season discharge (m^3/s)					Development Scenario: Mean low-flow season discharge (m^3/s)				
		1985-2000	2010-2025	2026-2041	2042-2050	2010-2050	1985-2000	2010-2025	2026-2041	2042-2050	2010-2050
	Scenario	S2	S4	S4	S4	S4	S3	S5	S5	S5	S5
1	Chiang Saen	1,157	1,383	1,522	1,332	1,426	1,847	1,966	2,073	1,959	2,007
2	Luang Prabang	1,499	1,770	2,038	1,713	1,862	2,247	2,382	2,613	2,387	2,474
3	Chiang Khan	1,613	1,903	2,214	1,848	2,013	2,356	2,509	2,786	2,518	2,619
4	Vientiane	1,640	1,935	2,255	1,879	2,048	2,377	2,536	2,824	2,547	2,652
5	Nong Khai	1,668	1,971	2,297	1,911	2,086	2,403	2,571	2,864	2,577	2,687
6	Nakhon Phanom	2,172	2,484	2,982	2,440	2,670	2,771	2,945	3,385	2,964	3,122
7	Mukdahan	2,220	2,536	3,055	2,489	2,729	2,935	3,104	3,578	3,131	3,296
8	Khong Chiam	2,386	2,693	3,276	2,652	2,912	3,060	3,246	3,786	3,281	3,465
9	Pakse	2,506	2,941	3,552	2,861	3,163	3,333	3,627	4,195	3,621	3,848
10	Stung Treng	3,515	3,933	4,716	3,741	4,197	4,511	4,772	5,497	4,667	5,033
11	Kratie	3,622	4,042	4,830	3,816	4,301	4,621	4,900	5,616	4,758	5,149
12	Kompong Cham	3,650	4,073	4,797	3,818	4,300	4,643	4,924	5,581	4,750	5,143
13	Phnom Penh	3,718	4,148	4,833	3,889	4,359	4,708	4,991	5,622	4,808	5,198
14	Tan Chau	5,052	5,401	5,970	5,225	5,586	5,502	5,725	6,336	5,497	5,914

Table 6-6 *Mean annual discharge at 14 key stations along the Mekong River in the Baseline and Development Scenarios without and with climate change B2 Scenario.*

	Station	Baseline Scenario: Mean annual discharge (m^3/s)					Development Scenario: Mean annual discharge (m^3/s)				
		1985-2000	2010-2025	2026-2041	2042-2050	2010-2050	1985-2000	2010-2025	2026-2041	2042-2050	2010-2050
	Scenario	S2	S4	S4	S4	S4	S3	S5	S5	S5	S5
1	Chiang Saen	2,642	2,713	3,001	2,744	2,832	2,629	2,701	2,994	2,736	2,823
2	Luang Prabang	3,754	3,787	4,403	3,756	4,021	3,580	3,619	4,210	3,597	3,845
3	Chiang Khan	4,125	4,195	4,918	4,193	4,477	3,946	4,022	4,722	4,030	4,298
4	Vientiane	4,239	4,320	5,075	4,324	4,616	4,056	4,143	4,874	4,156	4,432
5	Nong Khai	4,308	4,399	5,163	4,396	4,697	4,123	4,221	4,961	4,227	4,511
6	Nakhon Phanom	6,887	6,970	8,023	6,842	7,353	6,292	6,387	7,399	6,250	6,753
7	Mukdahan	7,371	7,482	8,572	7,335	7,876	6,937	7,051	8,113	6,904	7,434
8	Khong Chiam	8,415	8,445	9,629	8,340	8,885	7,858	8,003	9,158	7,898	8,431
9	Pakse	9,167	9,492	10,708	9,251	9,914	8,826	9,150	10,334	8,905	9,559
10	Stung Treng	12,171	12,559	13,982	12,202	13,036	11,783	12,166	13,560	11,797	12,630
11	Kratie	12,585	12,991	14,404	12,591	13,455	12,192	12,595	13,979	12,181	13,045
12	Kompong Cham	12,292	12,661	13,979	12,265	13,089	11,972	12,335	13,631	11,932	12,753
13	Phnom Penh	11,967	12,172	13,376	11,856	12,573	11,753	11,971	13,178	11,641	12,370
14	Tan Chau	9,743	9,897	10,681	9,636	10,146	9,558	9,713	10,511	9,403	9,957

6.2 Impacts of development on the Mekong flow regime

As described in Chapter 2, a comparison of Scenarios S2 with S3 or S5 with S4, allows the analysis of the impacts of development on the flow regime under the same climate conditions, either with or without climate change.

Impacts of development without climate change

To analyse the impacts of development assuming no future climate change, discharge at key stations in Scenario S3 (Development + PRECIS data for 1985 - 2000) was compared to that at the stations in Scenario S2 (Baseline + PRECIS data for 1985 - 2000) (see Table 6-7). In the high-flow season, discharge decreases at all stations. The amount of the decrease gradually increases with the downstream distance. The decrease, at the upstream station of Chiang Saen is 715 m^3/s and 1,787 m^3/s at the downstream Kratie. There are some variations at Mukdahan and Pakse because of the water use in these reaches. Downstream from Kratie, the values decrease again because, as previously described, these downstream stations do not reflect the total amount of the Mekong water. In the low-flow season, the reverse is true with discharge increasing at all stations but to a lesser extent than the corresponding decrease in the high-flow season. Thus, the annual discharge, the sum of the high- and low-flow seasons, shows an overall decrease. This decrease in annual discharge reflects more water use in the Basin by new hydropower reservoirs and for irrigation in the future in the Development Scenario. When expressed as percentages, the decreases, in the discharge in the high-flow season and increases in the low-flow season gradually reduce from upstream to downstream. These variations lead to variations in the decreases of the annual discharge, with the highest percentage decrease of 8.6% occurring at Nakhon Phanom, and smaller percentages at Mukdahan and Khong Chiam (5.9% and 6.6% respectively), and less than 5% at other stations.

Table 6-7 *Flow changes due to development without considering climate change.*

	Station	Flow Change (+/- m^3/s)			Flow Change (+/- %)		
		1985-2000	1985-2000	1985-2000	1985-2000	1985-2000	1985-2000
		High-flow season	Low-flow season	Annual	High-flow season	Low-flow season	Annual
	Scenario	S3-S2	S3-S2	S3-S2	S3-S2	S3-S2	S3-S2
1	Chiang Saen	-715	690	-12	-17	60	-0.5
2	Luang Prabang	-1,097	748	-174	-18	50	-4.6
3	Chiang Khan	-1,100	742	-179	-17	46	-4.3
4	Vientiane	-1,103	738	-183	-16	45	-4.3
5	Nong Khai	-1,104	736	-184	-16	44	-4.3
6	Nakhon Phanom	-1,789	599	-595	-15	28	-8.6
7	Mukdahan	-1,584	716	-434	-13	32	-5.9
8	Khong Chiam	-1,788	674	-557	-12	28	-6.6
9	Pakse	-1,508	826	-341	-10	33	-3.7
10	Stung Treng	-1,772	996	-388	-9	28	-3.2
11	Kratie	-1,787	1,000	-394	-8	28	-3.1

	Station	Flow Change (+/- m^3/s)			Flow Change (+/- %)		
		1985-2000	1985-2000	1985-2000	1985-2000	1985-2000	1985-2000
		High-flow season	Low-flow season	Annual	High-flow season	Low-flow season	Annual
	Scenario	S3-S2	S3-S2	S3-S2	S3-S2	S3-S2	S3-S2
12	Kompong Cham	-1,634	994	-320	-8	27	-2.6
13	Phnom Penh	-1,419	990	-215	-7	27	-1.8
14	Tan Chau	-821	450	-185	-6	9	-1.9

Impacts of development under climate change

Table 6-8 presents the flow changes resulting from development and climate change in Scenarios A2 and B2 (S5) compared to those in the Baseline (S4) in 2010 - 2050. The changes are similar to the changes assuming no climate change i.e. decreases in discharge in the high-flow season greater than the increases in the low-flow season leading to an overall decrease of 5% in the annual flow with decreases of between 5% and 8% at Nakhon Phanom, Mukdahan and Khong Chiam, and less than 4.5% at other stations.

Table 6-8 *Flow changes due to development under climate change.*

	Station	Flow Change (+/- m^3/s)						Flow Change (+/- %)					
		A2			B2			A2			B2		
		2010-2050	2010-2050	2010-2050	2010-2050	2010-2050	2010-2050	2010-2050	2010-2050	2010-2050	2010-2050	2010-2050	2010-2050
		High-flow season	Low-flow season	Annual	High-flow season	Low-flow season	Annual	High-flow season	Low-flow season	Annual	High-flow season	Low-flow season	Annual
	Scenario	S5-S4	S5-S4	S5-S4	S5-S4	S5-S4	S5-S4	S5-S4	S5-S4	S5-S4	S5-S4	S5-S4	S5-S4
1	Chiang Saen	-586	569	-9	-599	580	-9	-13.2	38.8	-0.3	-14.1	40.7	-0.3
2	Luang Prabang	-953	595	-179	-962	611	-176	-14.8	30.7	-4.3	-15.6	32.8	-4.4
3	Chiang Khan	-955	589	-183	-966	607	-180	-13.2	28.2	-3.9	-13.9	30.1	-4.0
4	Vientiane	-960	585	-188	-972	603	-184	-12.8	27.6	-3.9	-13.5	29.5	-4.0
5	Nong Khai	-962	584	-189	-973	602	-186	-12.6	27.0	-3.9	-13.3	28.9	-4.0
6	Nakhon Phanom	-1,641	433	-604	-1,654	452	-601	-13.1	15.8	-7.9	-13.7	16.9	-8.2
7	Mukdahan	-1,436	547	-445	-1,451	567	-442	-10.6	19.6	-5.4	-11.1	20.8	-5.6
8	Khong Chiam	-1,469	526	-471	-1,460	553	-454	-9.4	17.6	-5.1	-9.8	19.0	-5.1
9	Pakse	-1,377	661	-358	-1,396	685	-356	-7.9	20.5	-3.5	-8.4	21.7	-3.6
10	Stung Treng	-1,644	777	-434	-1,649	836	-406	-7.1	18.0	-3.2	-7.5	19.9	-3.1
11	Kratie	-1,660	785	-438	-1,669	848	-410	-6.9	17.8	-3.1	-7.4	19.7	-3.1
12	Kompong Cham	-1,506	784	-361	-1,515	843	-336	-6.5	17.7	-2.6	-6.9	19.6	-2.6
13	Phnom Penh	-1,216	786	-215	-1,244	839	-203	-5.6	17.5	-1.6	-6.0	19.2	-1.6
14	Tan Chau	-677	366	-155	-706	329	-189	-4.4	6.4	-1.5	-4.8	5.9	-1.9

6.3 Impacts of climate change on flow regime

Assuming the Baseline Scenario will hold good for the future, the impacts of climate change on flow regime, can be analysed by a comparison of Scenario S4 (Baseline + PRECIS data for 2010 -2050) with Scenario S2 (Baseline + PRECIS data for 1985 - 2000) as shown in Table

6-9. With climate change, the discharge increases in both seasons. The increases are about 2 - 3 times greater in the high-flow season than those in the low-flow season at downstream stations in Scenario A2 but less in Scenario B2. In Scenario A2, the percentage increase in discharge 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 to 13% in the annual discharge at stations upstream of Kratie. In Scenario B2, the increase in the low-flow season is still high, between 19% and 25%, but much less, only 2 to 5%, than that in the high-flow season, therefore the overall increase, of only 5 to 9%, in the annual discharge is less than that in Scenario A2,

Table 6-9 *Flow change resulting from climate change in the Baseline Scenario.*

	Station	Flow Change (+/- m^3/s)						Flow Change (+/- %)					
		A2			B2			A2			B2		
		2010-2050	2010-2050	2010-2050	2010-2050	2010-2050	2010-2050	2010-2050	2010-2050	2010-2050	2010-2050	2010-2050	2010-2050
		High-flow season	Low-flow season	Annual	High-flow season	Low-flow season	Annual	High-flow season	Low-flow season	Annual	High-flow season	Low-flow season	Annual
	Scenario	S4-S2	S4-S2	S4-S2	S4-S2	S4-S2	S4-S2	S4-S2	S4-S2	S4-S2	S4-S2	S4-S2	S4-S2
1	Chiang Saen	326	310	318	111	270	190	7.9	26.8	12.0	2.7	23.3	7.2
2	Luang Prabang	449	438	443	170	364	267	7.5	29.2	11.8	2.8	24.3	7.1
3	Chiang Khan	604	476	540	305	399	352	9.1	29.5	13.1	4.6	24.8	8.5
4	Vientiane	650	484	567	346	408	377	9.5	29.5	13.4	5.1	24.9	8.9
5	Nong Khai	667	493	580	361	418	389	9.6	29.6	13.5	5.2	25.1	9.0
6	Nakhon Phanom	901	561	731	436	498	467	7.8	25.9	10.6	3.8	22.9	6.8
7	Mukdahan	1,046	572	809	500	509	504	8.4	25.8	11.0	4.0	22.9	6.8
8	Khong Chiam	1,166	598	882	413	526	469	8.1	25.1	10.5	2.9	22.0	5.6
9	Pakse	1,706	712	1,209	839	656	748	10.8	28.4	13.2	5.3	26.2	8.2
10	Stung Treng	2,318	810	1,564	1,048	682	865	11.1	23.0	12.8	5.0	19.4	7.1
11	Kratie	2,341	798	1,569	1,060	679	870	11.2	22.7	12.9	5.1	19.3	7.1
12	Kompong Cham	2,094	774	1,434	942	650	796	10.0	21.2	11.7	4.5	17.8	6.5
13	Phnom Penh	1,495	775	1,135	570	642	606	7.4	20.8	9.5	2.8	17.3	5.1
14	Tan Chau	832	648	740	272	534	403	5.8	12.8	7.6	1.9	10.6	4.1

A comparison of Scenario S5 (Development + PRECIS data for 2010 - 2050) with Scenario S3 (Development + PRECIS data for 1985 - 2000) reveals similar impacts of climate change on flow regime in the Development Scenario (Table 6-10). The increase of discharge in the low-flow season is less than that found in the Baseline because more water is available in the Development Scenario in the sub-basins in the low-flow seasons and so more will be used. On the other hand, the greater increase in the discharge in the high-flow season in comparison to that in the Baseline Scenario shows that the water control measures in the Development Scenario have not taken into account the increase in water yield due to climate change. However, these two changes lead to a similar change in annual discharge in the Baseline Scenario at most stations. Once again, the annual discharge increase of 11 to 14% in Scenario A2 is slightly higher than that of 7 to 9% in Scenario B2.

Table 6-10 *Flow change due to climate change in the Development Scenario.*

	Station	Flow Change (+/- m^3/s)						Flow Change (+/- %)					
		A2			B2			A2			B2		
		2010-2050	2010-2050	2010-2050	2010-2050	2010-2050	2010-2050	2010-2050	2010-2050	2010-2050	2010-2050	2010-2050	2010-2050
		High-flow season	Low-flow season	Annual	High-flow season	Low-flow season	Annual	High-flow season	Low-flow season	Annual	High-flow season	Low-flow season	Annual
	Scenario	S5-S3	S5-S3	S5-S3	S5-S3	S5-S3	S5-S3	S5-S3	S5-S3	S5-S3	S5-S3	S5-S3	S5-S3
1	Chiang Saen	456	188	322	228	160	194	13.4	10.2	12.2	6.7	8.6	7.4
2	Luang Prabang	593	284	439	305	226	266	12.1	12.7	12.3	6.2	10.1	7.4
3	Chiang Khan	749	323	536	439	264	352	13.5	13.7	13.6	7.9	11.2	8.9
4	Vientiane	793	332	563	477	274	376	13.8	14.0	13.9	8.3	11.5	9.3
5	Nong Khai	810	341	575	492	284	388	13.9	14.2	14.0	8.4	11.8	9.4
6	Nakhon Phanom	1,049	395	722	571	351	461	10.7	14.3	11.5	5.8	12.7	7.3
7	Mukdahan	1,193	403	798	633	360	497	10.9	13.7	11.5	5.8	12.3	7.2
8	Khong Chiam	1,485	450	967	741	405	573	11.7	14.7	12.3	5.9	13.2	7.3
9	Pakse	1,838	546	1,192	951	515	733	12.8	16.4	13.5	6.6	15.5	8.3
10	Stung Treng	2,446	590	1,518	1,171	522	847	12.8	13.1	12.9	6.1	11.6	7.2
11	Kratie	2,468	583	1,525	1,178	528	853	12.5	12.6	12.5	6.0	11.4	7.0
12	Kompong Cham	2,222	564	1,393	1,062	500	781	11.8	12.0	11.9	5.6	10.6	6.6
13	Phnom Penh	1,698	571	1,134	745	490	617	9.0	12.1	9.6	4.0	10.4	5.3
14	Tan Chau	975	564	770	386	413	399	7.2	10.2	8.1	2.8	7.5	4.2

6.4 Comparison of development and climate change impacts

Impacts of both development and climate change on flow regime are analysed by comparing Scenario S5 (Development + PRECIS data 2010 - 2050) with Scenario S2 (Baseline + PRECIS data 1985 - 2000) as shown in Table 6-11. Discharge in the low-flow season increases significantly (by 40 - 70% at stations upstream of Kratie) in both Scenarios A2 and B2 because of the contribution of both development and climate change. On the other hand, flow change in the high-flow season varies with the climate change scenario. In Scenario A2, discharge in this season decreases at upstream stations, but increases downstream from Pakse. In Scenario B2, it decreases at all stations, but to a lesser extent than the increase in the low-flow season. Development and climate change together result in an increase in the annual discharge at all stations. The increase of 5 to 10% in Scenario A2 is greater than that of 0 to 7% in Scenario B2 with the exception of the slight decrease of 1.9% at Nakhon Phanom.

Table 6-11 *Flow change due to both development and climate change.*

Station		Flow Change (+/- m^3/s)						Flow Change (+/- %)					
		A2			B2			A2			B2		
		2010-2050	2010-2050	2010-2050	2010-2050	2010-2050	2010-2050	2010-2050	2010-2050	2010-2050	2010-2050	2010-2050	2010-2050
		High-flow season	Low-flow season	Annual	High-flow season	Low-flow season	Annual	High-flow season	Low-flow season	Annual	High-flow season	Low-flow season	Annual
	Scenario	S5-S2	S5-S2	S5-S2	S5-S2	S5-S2	S5-S2	S5-S2	S5-S2	S5-S2	S5-S2	S5-S2	S5-S2
1	Chiang Saen	-260	879	310	-487	850	181	-6.3	76.0	11.7	-11.8	73.5	6.9
2	Luang Prabang	-503	1,033	265	-792	975	91	-8.4	68.9	7.0	-13.2	65.0	2.4
3	Chiang Khan	-351	1,065	357	-661	1,006	173	-5.3	66.0	8.6	-10.0	62.4	4.2
4	Vientiane	-310	1,069	380	-626	1,012	193	-4.5	65.2	9.0	-9.2	61.7	4.6
5	Nong Khai	-295	1,076	391	-612	1,020	204	-4.2	64.5	9.1	-8.8	61.1	4.7
6	Nakhon Phanom	-740	994	127	-1,218	950	-134	-6.4	45.8	1.8	-10.5	43.7	-1.9
7	Mukdahan	-390	1,119	364	-951	1,076	62	-3.1	50.4	4.9	-7.6	48.5	0.8
8	Khong Chiam	-303	1,124	411	-1,047	1,079	16	-2.1	47.1	4.9	-7.3	45.2	0.2
9	Pakse	329	1,372	851	-557	1,342	392	2.1	54.8	9.3	-3.5	53.5	4.3
10	Stung Treng	674	1,586	1,130	-601	1,518	458	3.2	45.1	9.3	-2.9	43.2	3.8
11	Kratie	681	1,582	1,132	-609	1,528	459	3.2	43.7	9.0	-2.8	42.2	3.6
12	Kompong Cham	588	1,558	1,073	-572	1,493	460	2.8	42.7	8.7	-2.7	40.9	3.7
13	Phnom Penh	278	1,561	920	-674	1,480	403	1.4	42.0	7.7	-3.3	39.8	3.4
14	Tan Chau	155	1,014	584	-435	862	214	1.1	20.1	6.0	-3.0	17.1	2.2

Figures 6-1 to 6-6 show comparisons of the impacts in the paired scenarios on the high- and, low-flow seasons, and the annual discharges in Scenarios A2 and B2, while Figure 6-1 shows clearly the contrasting trends of development and climate change in the high-flow season. While development causes a decrease in discharge of between 5% and 18%, climate change causes an increase in discharge of between 5% and 14%. The effect of decreasing high-flow season discharge by development under non-climate change conditions (Scenario S3 and S2) is slightly higher than that under climate change conditions (Scenario S5 and S4). On the other hand, the effect of the increase in the high-flow season discharge in climate change with development (Scenario S5 and S3) is slightly higher than that in the Baseline (S4 and S2). This poses questions as to the efficiency of development, designed and operating in non-climate change conditions, in controlling the high-flow season discharge under climate change. More detailed analysis will be needed to identify suitable options in adapting to climate change. The combined effects of development and climate change lead to a 2 to 5% decrease (Scenario S5 and S2) in high-flow season discharge at stations upstream of Pakse, but a slightly smaller increase of 0 to 4% downstream from this station.

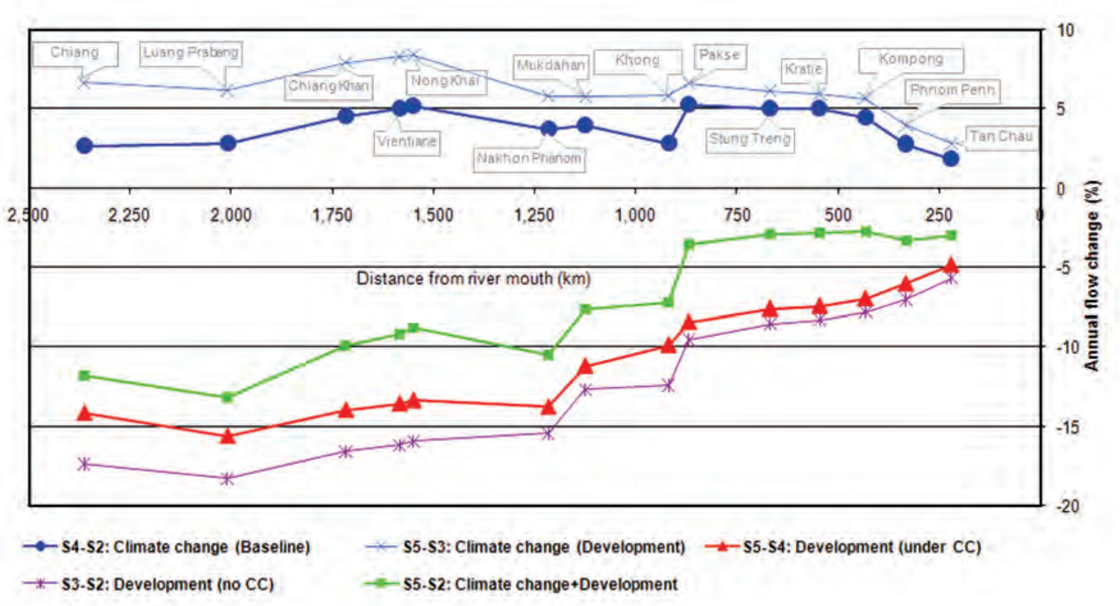


Figure 6-1 Impacts of development and climate change on high-flow season discharge under Scenario A2.

In contrast to the high-flow season, development (Scenario S5 and S4) and climate change (Scenario S4 and S2) result in a similar increase of 20 - 40% in the low-flow season discharge at all stations, with the exception of Tan Chau (Figure 6-2). The increase resulting from climate change is mainly explained by the increase of precipitation and snowmelt in the UMB discussed below. The combined effects of development and climate change (Scenario S5 and S2) lead to a 40 - 80% increase in discharge which is higher at upstream but gradually reduces downstream. The increase in the low-flow season discharge by development under non-climate change conditions (Scenario S3 and S2) is higher than that under climate change conditions (Scenario S5 and S4). In contrast, the increasing low-flow season discharge by climate change in the Development Scenario (Scenario S5 and S3) is lower than that in the Baseline (Scenario S4 and S2) since more water is used in the sub-basins in the low-flow season under the Development Scenario.

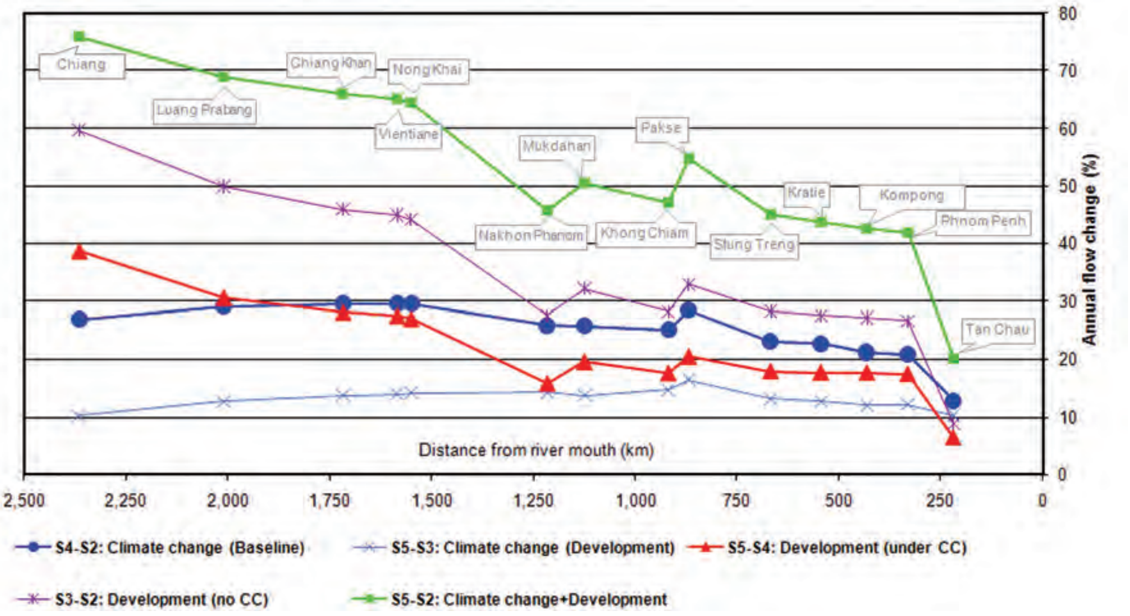


Figure 6-2 Impacts of development and climate change on low-flow season discharge under Scenario A2.

Development and climate change increase the total annual discharge at all stations by 2 to 12% (Scenario S5 and S2 in Figure 6-3). In this combination, the impact of climate change is stronger giving an 8 to 14% increase in the annual discharge while the impact of development is lower with, 0 to 8% decrease. Interestingly, while there are large differences in effects of development on climate change impacts (Scenario S5 and S3 compared with S4 and S2) and of climate change on development impacts (Scenario S5 and S4 compared with S3 and S2) in the high-and low-flow seasons as already discussed (Figures 6-1 and 6-2), these differences in the effects on the annual discharge are minor. This implies that a seasonal analysis of impacts should be made rather than one which only look at the annual discharge.

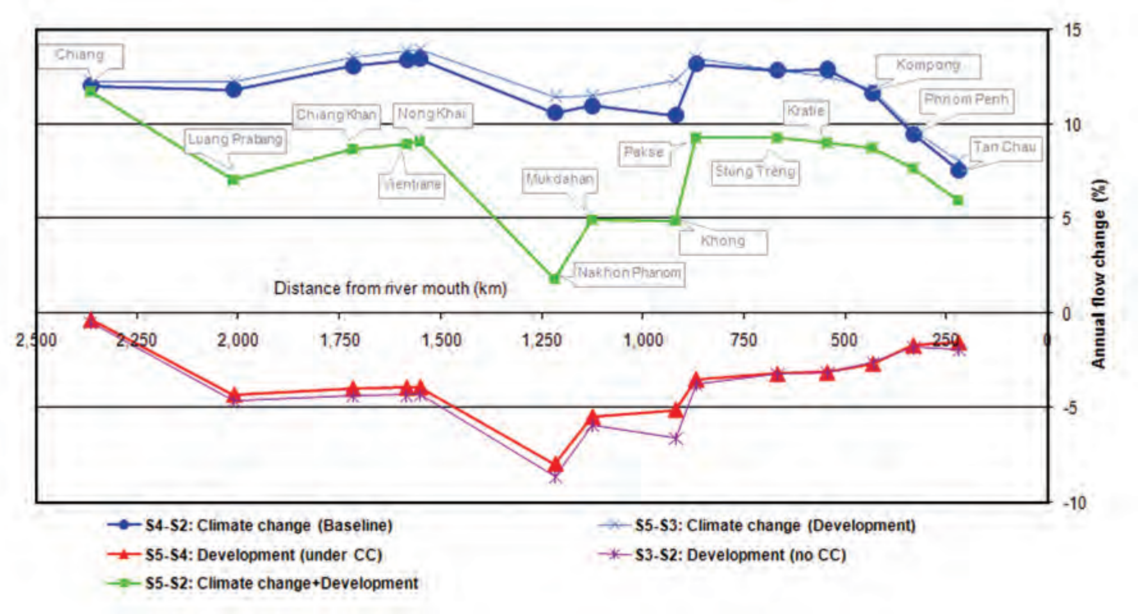


Figure 6-3 Impacts of development and climate change on annual discharge under Scenario A2.

Under Scenario B2, similar results for the high-flow season, low-flow season and annual discharges are presented in Figures 6-4, 6-5 and 6-6 respectively. In Scenario B2, the impact of climate change on the high-flow season discharge (Figure 6-4) is less (2 - 8%) than that in Scenario A2 (5 - 14%), while the impact of development is the same as that in Scenario A2. This results in their combined impacts bringing about a decrease in the high-flow season discharge at all stations, with a 7 - 13% increase upstream of Pakse and a 3 - 4% increase downstream from this station. In contrast, in Scenario B2, the impacts of both development and climate change on low-flow season discharge (Figure 6-5) are similar to those in Scenario A2 (Figure 6-2). The combined impacts in both seasons result in an increase in annual discharge, but the increase is smaller in Scenario A2 at 0 - 7% compared to 2 - 12% in Scenario B2. This trend occurs at all stations, with the exception of a slight decrease of 2% at Nakhon Phanom.

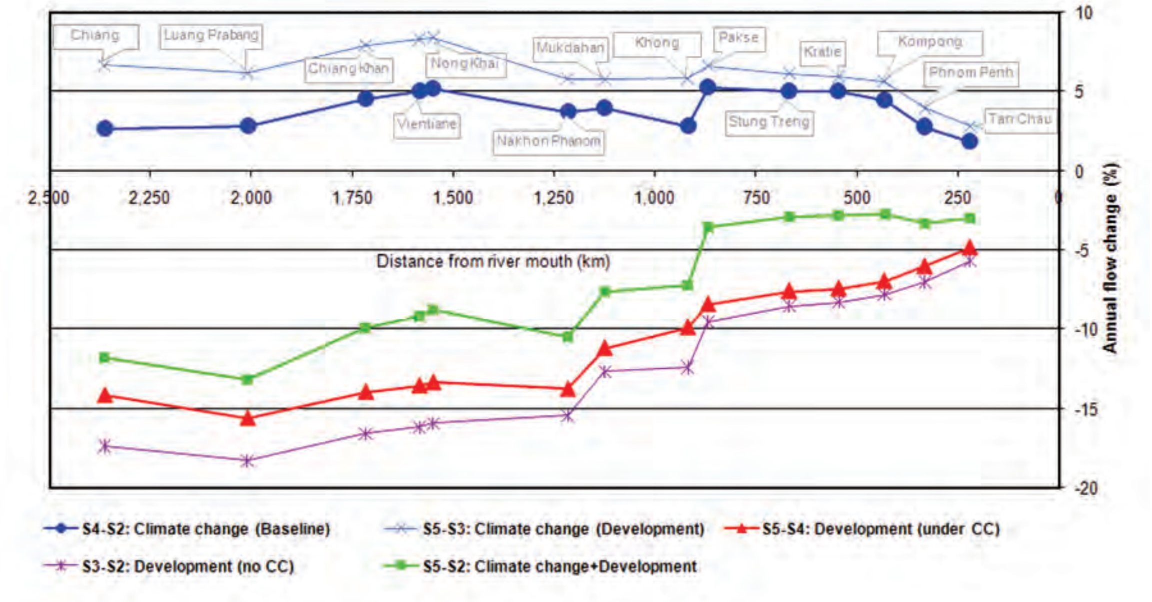


Figure 6-4 Impacts of development and climate change on high-flow season discharge under Scenario B2.

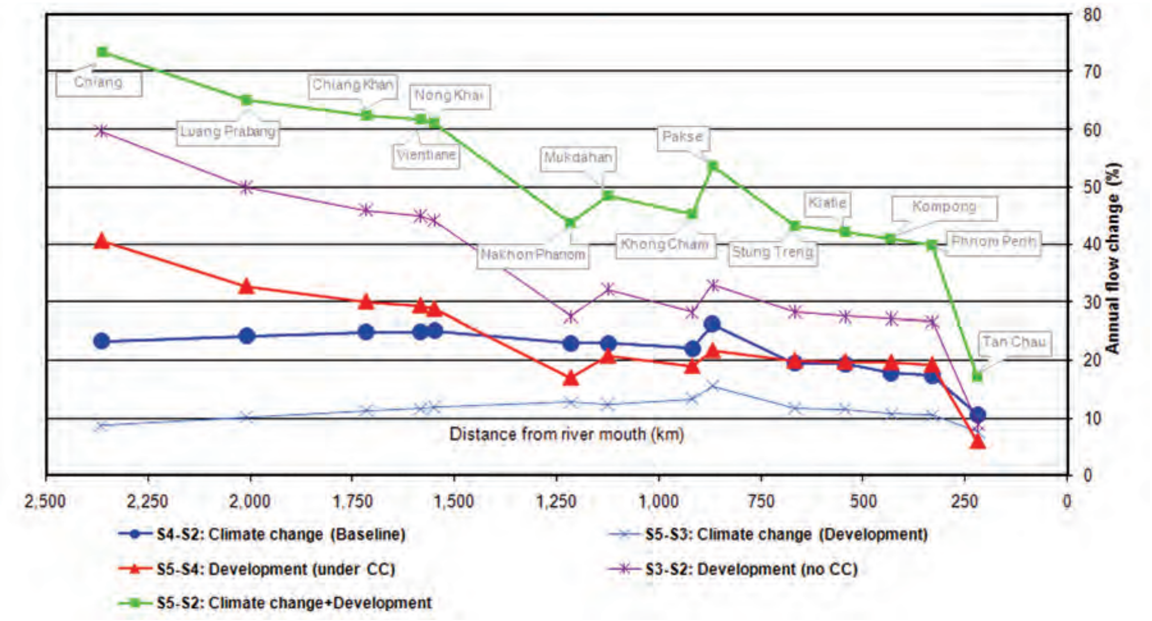


Figure 6-5 Impacts of development and climate change on low-flow season discharge under Scenario B2.

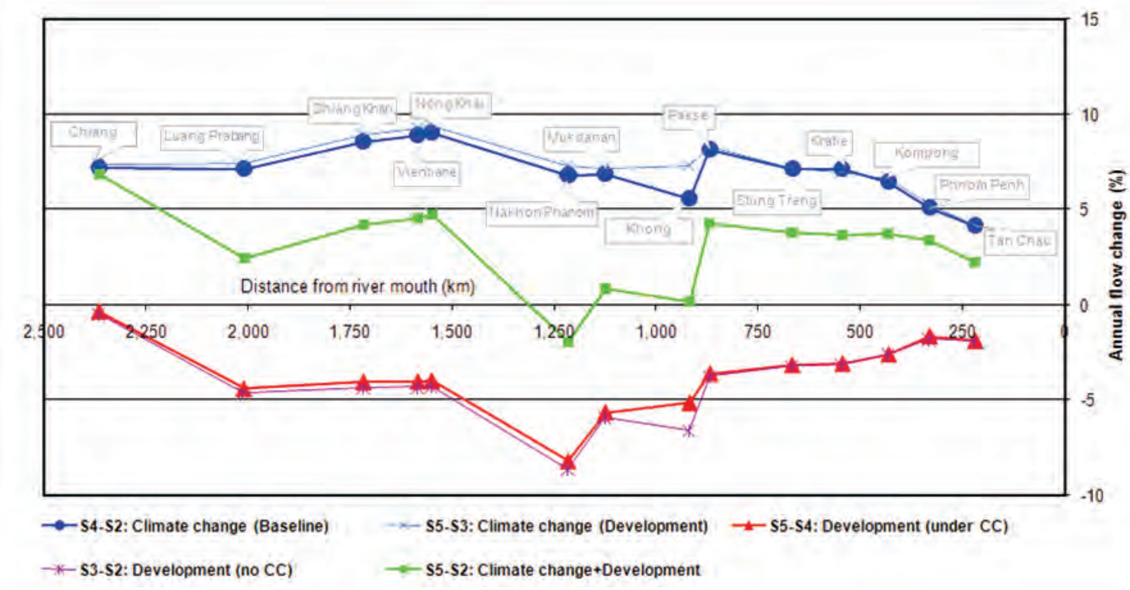


Figure 6-6 Impacts of development and climate change on annual discharge under scenario B2.

6.5 Contribution of snowmelt under climate change

Climate change and its effects on snowmelt in the UMB could result in changes in the flow regime of the Mekong River. The increased temperature will mean the earlier melting of snow in the UMB. This is not the same as the effects of climate change on the melting of glaciers. Within the Mekong catchment, glaciers with a volume of 17.3 km^3 and permafrost of 10 km^3 cover 50,000 km^2 of the Tibetan part of the catchment contain about 25,000 million m^3 of water, (Eastham et al., 2008). 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 475,000 million m^3 per year (Johnston et al., 2009).

The mean monthly and annual snowmelt depths in millimetres were calculated for all SWAT sub-basins of the UMB. Figure 6-7 presents the changes in the future (2010 – 2050) of the mean annual sub-basin snowmelt depths compared to those of 1985 – 2000. The maximum increase is around 40 mm in both Scenarios A2 and B2. The mean annual snowmelt depths over the entire UMB are 23.2, 39.9 (a 72% increase) and 37.5 (a 62% increase) mm/year for the baseline climate of 1985 – 2000, and the future climate of 2010 – 2050 under Scenarios A2 and B2, respectively.

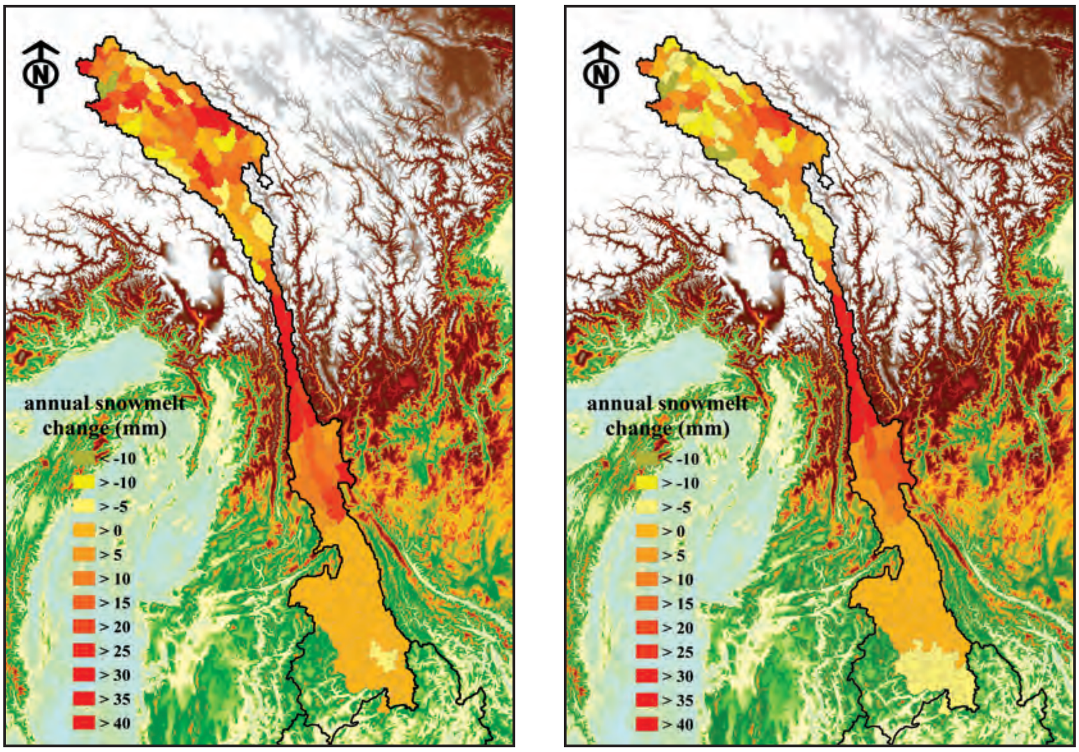


Figure 6-7 Changes of mean annual snowmelt depths in 2010 – 2050 of Scenario A2 (left) and B2 (right) relative to the mean depth of 1985 – 2000.

Table 6-12 shows that snowmelt currently contributes around 5.5% to the total water yield at the Chinese – Lao border and this might increase to 8% in 2010 - 2050 in Scenarios A2 and B2. Snowmelt in the UMB contributes about 7% at Chiang Saen to the Mekong discharge, but the percentage gradually lowers further downstream, to about 1.5% at Kratie.

In 1985 - 2000, at the time of the greatest snowmelt in March, its contribution to river discharge is significant, contributing 68.2% and 22.2% at Chiang Saen and Kratie respectively. With the temperature and precipitation increase under the climate change scenario, the amount of March snowmelt will change, but the percentage contribution to the river discharge will not differ by much, because the river discharge also changes.

Table 6-12 *Mean annual snowmelt contribution to water yield in the UMB under Scenarios A2 (upper part) and B2 (lower part).*

Period	Mean Annual Water Yield or Runoff (mm)	Mean Annual Snowmelt (mm)	Snowmelt Contribution to Water Yield (%)	Snowmelt Increase Relative to 1985 - 2000 (mm)	Snowmelt Increase Relative to 1985 - 2000 (%)	Average Snowmelt Rate (m^3/s)
1985 - 2000	417.8	23.2	5.5			120.0
2010 - 2025	443.6	43.4	9.8	20.2	87.3	224.7
2026 - 2041	487.6	39.5	8.1	16.4	70.6	204.7
2042 - 2050	483.6	34.8	7.2	11.7	50.3	180.4
2010 - 2050	469.5	39.9	8.5	16.7	72.3	206.7

Period	Mean Annual Water Yield or Runoff (mm)	Mean Annual Snowmelt (mm)	Snowmelt Contribution to Water Yield (%)	Snowmelt Increase Relative to 1985 - 2000 (mm)	Snowmelt Increase Relative to 1985 - 2000 (%)	Average Snowmelt Rate (m^3/s)
1985 - 2000	417.8	23.2	5.5			120.0
2010 - 2025	432.1	41.1	9.5	17.9	77.2	212.6
2026 - 2041	473.5	36.6	7.7	13.5	58.2	189.8
2042 - 2050	446.5	33.0	7.4	9.8	42.4	170.9
2010 - 2050	451.4	37.5	8.3	14.3	61.8	194.1

6.6 Irrigation extraction under development and climate change

In comparison with 1985 - 2000, the higher temperatures in 2010 – 2050 are likely to lead to increased demands for water for agriculture which in turn lead to the projection of more water diversions for irrigation.This increase could also be due to higher river discharge, particularly in the dry season as a result of an expansion of areas under crops and diversions for irrigation. Another reason could be the change in the precipitation pattern making more supplementary irrigation necessary in the wet season. More detailed analysis will be needed to confirm these assumptions.

Table 6-13 summarises changes in the total diversions for irrigation in the different scenarios. The current demand of 36,074 million m^3 in Scenario S2 (Baseline + PRECIS data for 1985 - 2000), diversions under in Scenarios S3 (Development + PRECIS data for 1985 - 2000) or S4 (Baseline with A2 and B2 PRECIS data for 2010 -2 050) increases to about 40,000 million m^3 (an 11 - 12% increase). In both development and climate change scenarios, about 45,000 million m^3 (a 24 - 25% increase) more water is diverted for irrigation. However, this increase depends to a large extent on the assumptions of the way in which irrigation schemes will be implemented in different sub-areas (Table 6-13). For example, in the sub-area 10V (Viet Nam Delta), no irrigation expansion is assumed in the Development Scenario (Table 2-6), therefore irrigation in Scenarios S2 and S3 remains the same under the same climate conditions. However, in the climate change scenarios, diversions for irrigation in this sub-area increase significantly, by about 2,600 - 2,900 million m^3, or about 60% of the total increase.

Table 6-13 *Changes in net irrigation diversions of BDP subarea due to development and climate change.*

BDP Subarea	Past period 1985-2000			A2: 2010-2050				B2: 2010-2050			
	Base line	Development	+/- (%)	Base line	Development	+/- (%)	+/- (%)	Base line	Development	+/- (%)	+/- (%)
Scenario	S2	S3	S3-S2	S4	S5	S5-S4	S5-S2	S4	S5	S5-S4	S5-S2
1L	243	357	46.5	280	406	45.0	66.8	288	419	45.2	71.9
2T	543	742	36.8	538	739	37.4	36.2	557	761	36.5	40.1
3L	25	37	44.9	31	46	46.0	80.8	31	46	45.8	81.8
3T	947	1,291	36.3	1,153	1,546	34.0	63.2	1,104	1,498	35.7	58.1
4L	1,669	2,438	46.1	1,918	2,809	46.5	68.3	1,946	2,854	46.7	71.0
5T	5,823	8,044	38.1	5,878	8,218	39.8	41.1	5,546	7,845	41.4	34.7
6C	200	288	44.3	233	335	43.9	67.8	242	348	44.0	74.4
6L	147	216	46.2	166	241	45.0	63.2	174	253	45.4	71.4
7C	122	151	24.6	160	195	21.6	60.6	167	204	21.8	67.6
7L	139	204	46.8	161	235	46.0	69.5	170	249	46.0	79.1
7V	625	1,008	61.4	699	1,100	57.5	76.2	725	1,124	55.0	80.0
8C	219	296	34.9	267	353	32.3	61.0	265	352	32.9	60.5
9C	2,009	2,015	0.3	2,261	2,268	0.3	12.9	2,133	2,145	0.5	6.7
10C	3,634	3,634	0.0	3,931	3,931	0.0	8.2	3,989	3,989	0.0	9.8
10V	19,728	19,795	0.3	22,858	22,889	0.1	16.0	22,657	22,694	0.2	15.0
Total	36,074	40,515	12.3	40,533	45,311	11.8	25.6	39,995	44,779	12.0	24.1

6.7 Impacts of development and climate change on flood and salinity intrusion

Change in flood frequencies will require detailed analysis at the sub-basin level. At the basin-wide level, change is analysed simply by comparing the change in the number of days with discharge higher than the mean in the high-flow season under development and climate change scenarios (Table 6-14). In the Development Scenario (S3), in comparison with the Baseline with the climate conditions of 1985 – 2000 (Scenario S2), the number of days with high discharge at Chiang Saen decreases by 52% but this percentage gradually decreases to about 12% at Tan Chau. However in the Baseline, climate change (Table 6 – 14, column S4 - S2) increases the number of days with high discharge by about 5 - 19% in Scenario A2, but by about only 0 – 10% in Scenario B2. The decrease in the number of days with high discharge in the Development Scenario is smaller with climate change, of about 30% and 41% at Chiang Saen under Scenarios A2 and B2 respectively. This percentage gradually decreases at the downstream stations. The percentage variations by station and by climate change scenario indicates that the current development plan has not yet been adapted for climate change, as shown by the input data and the reservoir rules and regulation used in the current DSF models.

Table 6-14 *Average number of days per year with discharge higher than mean discharge in high-flow season.*

Station		Mean dis-charge in high-flow season 1985-2000	Average number of days per year with discharge higher than mean discharge in high-flow season.						Change (%)				
			No CC		A2		B2		No CC	A2		B2	
			1985-2000	1985-2000	2010-2050	2010-2050	2010-2050	2010-2050	1985-2000	2010-2050	2010-2050	2010-2050	2010-2050
	Scenario		S2 – Base line	S3 - Dev	S4 – Base line	S5 - Dev	S4 – Base line	S5 - Dev	S3-S2	S4-S2	S5-S2	S4-S2	S5-S2
1	Chiang Saen	4,127	97	47	106	68	97	57	-52.1	9.6	-30.4	-0.2	-41.3
2	Luang Prabang	6,008	89	43	102	67	96	59	-51.1	15.1	-24.3	7.6	-34.0
3	Chiang Khan	6,636	89	46	105	74	97	65	-48.6	17.9	-17.4	9.1	-27.6
4	Vientiane	6,837	89	48	105	76	97	66	-46.6	18.6	-14.6	9.6	-25.3
5	Nong Khai	6,947	89	48	106	76	98	68	-45.9	19.1	-13.9	10.4	-23.6
6	Nakhon Phanom	11,601	87	59	94	71	90	68	-31.4	8.1	-17.6	4.0	-21.2
7	Mukdahan	12,522	86	66	93	76	90	73	-23.7	7.6	-12.2	3.8	-15.3
8	Khong Chiam	14,444	86	68	91	77	86	74	-20.3	6.1	-10.5	0.9	-13.3
9	Pakse	15,827	86	72	92	81	88	78	-16.5	6.5	-6.7	2.2	-10.3
10	Stung Treng	20,827	88	72	93	83	89	79	-18.5	5.0	-6.3	0.4	-10.6
11	Kratie	21,549	88	73	93	83	89	80	-17.4	5.5	-5.4	1.1	-9.0
12	Kompong Cham	20,935	91	76	95	85	91	83	-16.4	4.4	-6.4	-0.3	-8.9
13	Phnom Penh	20,217	93	79	98	88	93	85	-14.7	5.3	-5.3	0.1	-8.5
14	Tan Chau	14,435	105	93	118	106	111	100	-11.9	12.0	1.0	5.6	-4.7

Attention is commonly paid to areas of the Mekong Delta which are flooded or suffer saline intrusion in extreme years, therefore, for the period of 1985 - 2000, 1998 was selected since it was a low discharge year with high salinity intrusion and 2000 was selected since it was a year of high floods. The selection of the extreme years for 2010 - 2050 is based on the daily flow at Kratie. The years of 2048 and 2047 in Scenarios A2 and B2, respectively, were selected for flood analysis because of the high daily discharge in the high-flow season. For the salinity analysis the years of 2021 and 2022 were selected for Scenarios A2 and B2, respectively.

In Baseline Scenario S2 in 2000 the total flooded area was about 45,000 km^2 (Table 6-15), while in Development Scenario S3 with the same climate data of 2000, this area was reduced to 43,000 km^2 (-3.4%) because the peak flow was lower. However, under climate change with the Baseline (Scenario S4), the total flooded area increased to 49,000 km^2 (+8.8%) in Scenario A2 and to 46,000 km^2 (+3.1%) in Scenario B2, corresponding to very high peak flows (Figure 6-8). The difference in the two climate change scenarios implies that the area of flooding depends, to a large extent, on the highly uncertain future distribution of the daily precipitation throughout the wet season. Water control under Development Scenario S5 can reduce the total flooded area by only less than 1% of the total flooded area in Scenarios A2 and B2 (comparing Scenario S5 - S2 with Scenario S4 - S2) because of the limited decrease in peak flows. In all the Scenarios, the percentage increase (Scenario S4 - S2, and Scenario S5 - S2) or decrease (Scenario S3 - S2) is higher at higher flood depth levels (except some at depths of > 3 m), but the absolute values of flooded areas are lower.

Table 6-16 shows a comparison of the duration of flooding in areas with flood depths higher than 0.5 m in the different Scenarios. The climate conditions of 1985 - 2000 and development reduced the duration of flooding by about 6 - 9% (see column S3-S2), while the impacts of climate change vary a great deal from one Scenario to another with an increase of 14 - 23% at different duration levels in Scenario A2 but either a decrease or increase of 0 - 5% in Scenario B2 because the peak flow in Scenario B2 is very high, and the high flow period is short compared with that of the year 2000 and Scenario A2. The effects of development on the duration of flooding under climate change also vary depending on the different Scenarios (columns S5-S2).

Changes in the salinity intrusion in the different scenarios are shown in Table 6-17. In the Development Scenario the increased discharge in the low-flow season reduces the salt intrusion area for salinity concentrations > 4 g/l by about 14% (column S3-S2). However, under climate change, although, over a long period, the mean discharge will increase, the annual variation is rather large, hence low-flow seasonal discharges may be lower than in the certain past years, although the long term average discharge in the low-flow season may increase as previously discussed. This variation is shown by the 16 - 17% increase of those areas of salinity > 4 g/l) in Scenario S4 in the years of 2021 and 2022 for Scenarios A2 and B2, respectively. Development can compensate for climate variability causing low minimum monthly discharges as shown in column S5-S2. However, salinity intrusion in the Delta also depends on the water volume stored in the Tonle Sap 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, as shown in the cases of Scenarios A2 and B2 of Scenario S5.

Table 6-15 *Flooded areas under different development and climate change scenarios.*

Maximum Flood Depth (m)	Flood Area based on Maximum Flood Depth (km²)						Difference in Flooded Area (+/- km²)					Difference in Flooded Area (+/- %)				
	Baseline 2000	Baseline 2048 A2	Baseline 2047 B2	Dev 2000	Dev 2048 A2	Dev 2047 B2	Baseline 2048 A2	Baseline 2047 B2	Dev 2000	Dev 2048 A2	Dev 2047 B2	Baseline 2048 A2	Baseline 2047 B2	Dev 2000	Dev 2048 A2	Dev 2047 B2
	S2	S4	S4	S3	S5	S5	S4-S2	S4-S2	S3-S2	S5-S2	S5-S2	S4-S2	S4-S2	S3-S2	S5-S2	S5-S2
Peak daily discharge at Kratie (m^3/s)	*54,922**	*95,293*	*90,117*	*50,807*	*92,922*	*92,569*	*40,370*	*35,195*	*-4,116*	*38,000*	*37,647*	*73.5*	*64.1*	*-7.5*	*69.2*	*68.5*
> 0.0 m	44,654	48,579	46,037	43,121	48,295	45,753	3,925	1,383	-1,533	3,642	1,099	8.8	3.1	-3.4	8.2	2.5
> 0.5 m	41,317	46,915	42,657	39,541	46,599	42,253	5,598	1,340	-1,776	5,282	936	13.5	3.2	-4.3	12.8	2.3
> 1.0 m	36,393	43,917	38,311	33,352	43,457	37,620	7,524	1,918	-3,041	7,065	1,227	20.7	5.3	-8.4	19.4	3.4
> 1.5 m	30,923	40,563	33,061	27,946	40,003	32,355	9,641	2,138	-2,976	9,081	1,432	31.2	6.9	-9.6	29.4	4.6
> 2.0 m	26,347	36,459	28,993	22,975	35,703	28,334	10,112	2,645	-3,372	9,356	1,987	38.4	10.0	-12.8	35.5	7.5
> 2.5 m	21,971	32,783	24,924	19,060	31,951	24,212	10,812	2,953	-2,912	9,980	2,241	49.2	13.4	-13.3	45.4	10.2
> 3.0 m	17,977	29,006	20,934	15,767	28,211	20,275	11,028	2,957	-2,210	10,234	2,298	61.3	16.4	-12.3	56.9	12.8
> 3.5 m	15,198	25,501	17,439	13,897	24,588	17,136	10,302	2,241	-1,301	9,390	1,938	67.8	14.7	-8.6	61.8	12.7
> 4.0 m	13,570	21,422	15,656	12,152	20,424	15,433	7,852	2,086	-1,418	6,854	1,863	57.9	15.4	-10.5	50.5	13.7

*Note: * Observed daily peak discharge at Kratie in 2000 was 56,273 m^3/s, slightly higher than the simulated value.*

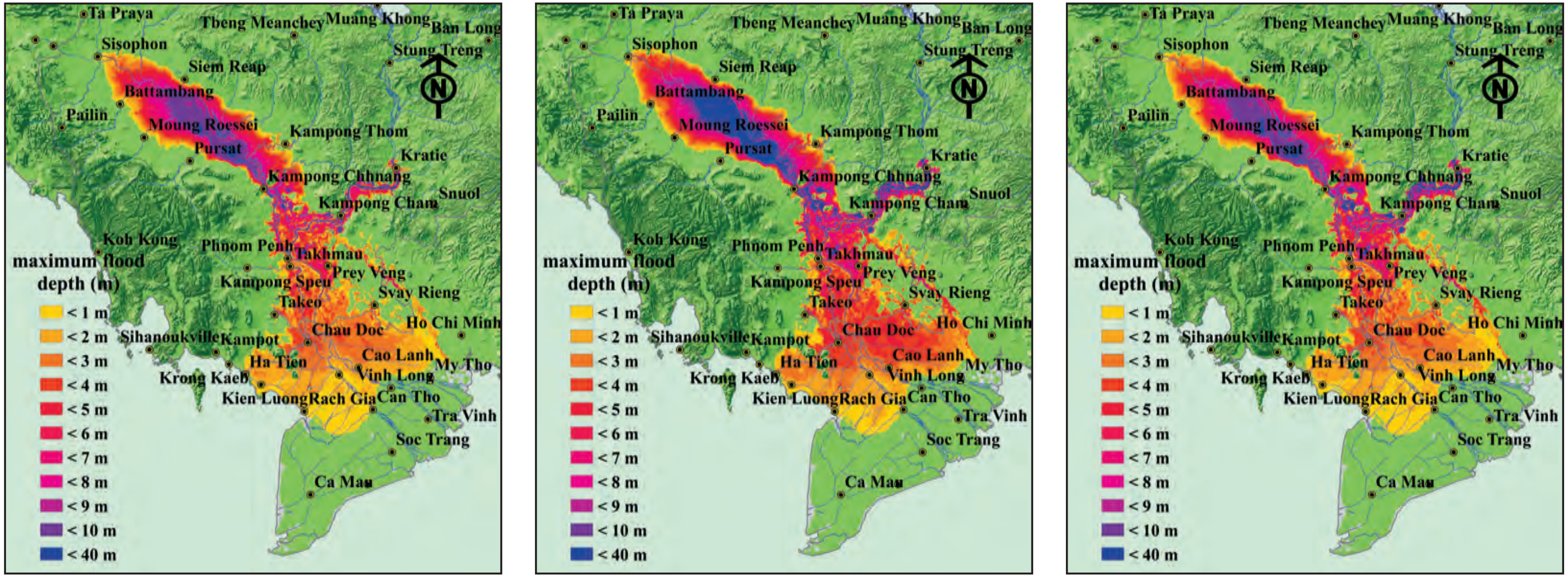


Figure 6-8 Flooded areas in 2000 under Scenario S2 (left), in 2048 under Scenario S5 A2 (middle) and in 2047 under Scenario S5 B2 (right).

Table 6-16 *Flood duration under different development and climate change scenarios.*

Flood duration (months)	Flood duration based on flood depth > 0.5 m (km^2)						Difference in flooded area (+/- km^2)					Difference in flooded area (+/- %)				
	Baseline 2000	Baseline 2048 A2	Baseline 2047 B2	Dev 2000	Dev 2048 A2	Dev 2047 B2	Baseline 2048 A2	Baseline 2047 B2	Dev 2000	Dev 2048 A2	Dev 2047 B2	Baseline 2048 A2	Baseline 2047 B2	Dev 2000	Dev 2048 A2	Dev 2047 B2
	S2	S4	S4	S3	S5	S5	S4-S2	S4-S2	S3-S2	S5-S2	S5-S2	S4-S2	S4-S2	S3-S2	S5-S2	S5-S2
< 1 month	2048 A2	Dev	42,657	39,541	46,599	42,253	5,598	1,340	-1,776	5,282	936	13.5	3.2	-4.3	12.8	2.3
>= 1 month	2047 B2	44,640	36,568	35,933	43,998	35,506	6,474	-1,598	-2,233	5,832	-2,660	17.0	-4.2	-5.9	15.3	-7.0
>= 2 months	34,434	42,536	32,464	32,341	41,927	30,812	8,102	-1,970	-2,093	7,493	-3,621	23.5	-5.7	-6.1	21.8	-10.5
>= 3 months	30,087	37,797	29,544	27,592	36,953	27,346	7,709	-544	-2,496	6,866	-2,741	25.6	-1.8	-8.3	22.8	-9.1
>= 4 months	25,907	30,690	25,892	24,030	29,546	24,210	4,784	-15	-1,876	3,640	-1,696	18.5	-0.1	-7.2	14.0	-6.5
>= 5 months	19,173	22,302	19,923	17,640	20,354	18,213	3,129	750	-1,533	1,181	-960	16.3	3.9	-8.0	6.2	-5.0
>= 6 months	12,287	14,002	12,496	11,172	12,109	10,852	1,715	209	-1,115	-178	-1,435	14.0	1.7	-9.1	-1.4	-11.7

Table 6-17 *Saline area under different development and climate change scenarios.*

Maximum salinity (g/l)	Saline area (km^2)						Difference in saline area (+/- km^2)					Difference in saline area (+/- %)				
	Baseline 1998	Baseline 2021 A2	Baseline 2022 B2	Dev 1998	Dev 2048 A2	Dev 2047 B2	Baseline 2048 A2	Baseline 2047 B2	Dev 2000	Dev 2048 A2	Dev 2047 B2	Baseline 2048 A2	Baseline 2047 B2	Dev 2000	Dev 2048 A2	Dev 2047 B2
	1998	Dev	S4	S3	S5	S5	S4-S2	S4-S2	S3-S2	S5-S2	S5-S2	S4-S2	S4-S2	S3-S2	S5-S2	S5-S2
Minimum monthly discharge at Kratie (m^3/s)	2021 A2	Dev	1,510	3,433	2,529	3,314	-1,786	-753	1,170	266	1,051	-78.9	-33.3	51.7	11.8	46.4
> 0 g/l	2022 B2	Baseline 2021 A2	Baseline 2022 B2	Dev	18,101	19,734	3,409	3,526	-2,892	-2,643	-1,009	16.4	17.0	-13.9	-12.7	-4.9
> 4 g/l	1998	Dev	24,270	17,852	18,101	19,734	3,409	3,526	-2,892	-2,643	-1,009	16.4	17.0	-13.9	-12.7	-4.9
> 8 g/l	2021 A2	Dev	18,231	14,288	14,395	15,552	2,104	2,780	-1,163	-1,056	101	13.6	18.0	-7.5	-6.8	0.7
> 12 g/l	2022 B2	Baseline 2021 A2	Baseline 2022 B2	Dev	11,967	12,583	724	811	-826	-977	-361	5.6	6.3	-6.4	-7.5	-2.8
> 16 g/l	1998	Dev	11,075	10,289	10,114	10,387	305	122	-664	-839	-566	2.8	1.1	-6.1	-7.7	-5.2
> 20 g/l	2021 A2	Dev	9,164	8,874	8,213	8,713	-172	-214	-504	-1,165	-665	-1.8	-2.3	-5.4	-12.4	-7.1
> 24 g/l	2022 B2	6,735	6,597	6,666	5,986	6,441	-329	-468	-398	-1,078	-623	-4.7	-6.6	-5.6	-15.3	-8.8
> 28 g/l	4,923	4,406	5,006	4,732	4,144	4,768	-517	83	-190	-778	-155	-10.5	1.7	-3.9	-15.8	-3.1
> 32 g/l	2,852	2,633	2,967	2,797	2,563	2,992	-219	115	-56	-289	140	-7.7	4.0	-1.9	-10.1	4.9

*Note: * Observed monthly lowest discharge at Kratie in 1998 was 2,190 m^3/s, slightly lower than the simulated value.*

7. Conclusions and recommendations for future studies

7.1 General conclusions

In general, after the adjustments made by comparing the scenario data with the observed data in the past and applying this to the future, the PRECIS climate data shows a trend of a slight increase in precipitation throughout the Mekong Basin, except in Cambodia and Viet Nam. The projection shows wetter rainy seasons from now to 2050 with a precipitation increase of 1.2 - 1.5 mm/year. The increase in Scenario B2 is less than that in Scenario A2. Wetter dry seasons in the UMB, with an increase of 0.9 mm/year, are also projected, but the change in precipitation in the LMB is insignificant. Temperatures are projected to increase by about 0.023°C/year. These projections are similar to the assessments from other studies.

In the high-flow season, impacts of climate change and effects of development are in opposite directions. Under the same climate conditions as in 1985 - 2000, development brings about a decrease of 8 -17% in river flow (Scenario S3 and S2), but under the future climate change in 2010 - 2050, the effects are less at about 7 - 14% (Scenario S5 and S4) in comparison with the assumption of the future continuation of the Baseline. Climate change would bring about an increase of about 2 - 11% in river flows when compared to that in the past (Scenario S4 and S2). The combined effects of development and climate change may cause a decrease in discharge of up to 13% at one station, but an increase of 3% at another, depending on the climate change scenarios and the location of stations (Scenario S5 and S2). Such variation is a good reflection of the fact that the current development plan has not been prepared to adapt to climate change.

In the low-flow season, although impacts of climate change and effects of development are changes in the same direction of increasing river flows, the combined effects are complex. Under the same climate conditions as in 1985 - 2000, development brings about an increase of 30 - 60% of in river discharge (Scenario S3 and S2), but climate change results in a smaller increase of about 18 - 40% (Scenario S5 and S4) in comparison to the assumption that the Baseline continues in the future. Climate change increases river flow by about 18 - 30% (Scenario S4 and S2). The effect of both climate change and development may cause an increase in discharge of up to 40 - 76% (Scenario S5 and S2), depending on the climate change scenarios and the location of stations.

The effects of development will be to cause decrease in the overall annual discharge of about 3 - 8% under both the past climatic conditions and the future climate change (Scenarios S3 and S2, and S5 and S4). Conversely, climate change would increase the river discharge by 6 - 16% under both the Baseline and the Development Scenarios (Scenarios S4 and S2, and S5 and S3). The effect of both climate change and development may cause an increase in discharge of about 2 - 12% (Scenario S5 and S2), depending on the climate change scenario and the location of the stations. These changes show that a seasonal analysis is needed for dealing with development and climate change issues.

Climate change will bring about a slight increase of about 5.5 - 8% in the contribution of snowmelt to the annual water yield at the Chinese-Lao border. Although the contribution of snowmelt in the dry season (such as in March) is more significant, its percentage contribution to the river discharge does not change by a great deal, and becomes even smaller at stations further downstream.

Assuming that the Baseline will continue to hold good in the future, climate change will bring about an increase in the number of days with discharges above the mean of the high-flow season. Development can help to significantly reduce this number of days at upstream stations, but the effect is somewhat less at downstream stations. Development can also help reducing the areas of flooding but climate change will increase these areas in worse years. Climate change could also increase the extent of the areas with saline intrusion but the increase in these areas is smaller than that of the areas of flooding. In contrast, development can help in reducing these affected areas. However, the uncertainties in any projection of future precipitation should be borne in mind when reaching these conclusions.

7.2 Recommendations for further studies

Although this paper analyses several impacts of climate change on the flow regime of the Mekong River, the results should be considered as a preliminary assessment. We present some suggestions for further efforts to improve the assessment which include:

- An analysis using more climate change datasets would be helpful considering the uncertainties involved in any climate projection, and use should be made of the great efforts currently being made at the global level to reduce the uncertainty of the GCMs and RCMs. This is in spite of the fact that the use of a single climate change projection dataset of ECHAM4 GCM, downscaled to the Mekong Basin by using PRECIS system in the current analysis yields projected climate change results in the range indicated by other studies.

- Daily data are required for the DSF model analysis of changes in flow regime. However, since the daily simulated data vary considerably in comparison with the observed data, adjustment methods are needed. Further study and testing of these methods are needed to ensure that proper projection trends will be maintained. Any analysis of extreme events, such as floods and droughts, requires the daily distribution of precipitation, but the projection of daily variation is still improved by RCMs.

- More observed climate data (involving more stations and covering a longer period) and other data used in modelling, such as land and water use, reservoir regulations and rules and so on, should be collected in order to improve climate change analysis. Most of the data currently available are for single or specific years, and these are interpolated or assumed to be the same for the whole of the study period. However, since climate change is a long process, records covering longer periods are required in analysing any variations. The Baseline and Development Scenarios used in this study were the BDP Scenarios defined by the end of 2008, and more information and data have been provided to the MRC by the national agencies to update the Scenarios. This updated information and data should be used in the next assessment of climate change.

- The DSF models (SWAT, IQQM and ISIS) used in this study are those versions which were available at the end of 2008. Although these are specialist models of a high standard, there are several difficulties in their application to climate change study in a large and complex basin such as that of the Mekong. For the long period of 40 years, the input and output datasets are quite large (about 20 GB for SWAT and IQQM models, and 400 GB for the ISIS model). Supporting tools are needed to handle such large datasets for analysis. Although some tools have been developed, with this amount of data, the time taken for re-runs and analysis is too long. The direction of the modelling is to try to include as many details as possible (such as more sub-basins, reservoirs and irrigation systems) and this may not work for a basin-wide assessment. Therefore simplification of the Mekong model and development of sub-models for groups of sub-basins are needed, because even when more sub-basins are included, the models cannot be calibrated and validated for all sub-basins. The DSF models are also being refined to include more functions and for an improvement of the simulation accuracy, therefore new versions have been provided or are under preparation. Updating to the new versions is a challenge for the modellers, particularly for model running with large datasets. For example, very often the ISIS model stops when running for a long period of 40 years without user-friendly debug functions.

- The DSF was designed and set-up for the analysis of changes in flow regime in different scenarios to support Articles 5, 6 and 26 of the 1995 Mekong Agreement. Other parameters required for adaptation analysis such as food and energy production have not been generated, so Scenario S6 (Development + PRECIS data 2010 - 2050 + Adaptation strategies) has not yet been analysed. This can only be done after there are sufficient outputs from other models and analyses based on outputs of the DSF, or with the new components of the DSF that are being improved at the MRC to provide an integrated modelling package that not only focuses on flow changes but also on other changes.

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Appendix: Methods for adjustment of GCM based on observed data

A. Algorithm for Climate Change Model data adjustment

Deviations of climate model outputs from the observed climate cannot be avoided and should not be neglected. To keep the outputs from baseline scenario using climate model data as inputs coinciding with the outputs from the same scenario but using the observed climate data as inputs, an adjustment or correction needs to be employed. In this climate change study, the methodologies proposed by Hoanh et al. (2006) were adopted with slight modifications for adjusting the climate data synthesised by the PRECIS Regional Climate Model (RCM) system.

A.1 Adjustment of precipitation

Due to the deviation of the precipitation data generated by the PRECIS system from the observed precipitation, and to keep the outputs from baseline scenario SWAT models as close as possible to the observed flows at major monitoring points, the PRECIS sub-basin precipitation needs to be adjusted. For 1985 – 2000, the monthly precipitation time series for all SWAT sub-basins were adjusted against the sub-basin precipitation used for SWAT model calibration (derived by the MQUAD program in the DSF using observed point - rainfall data as input). The approach adopted here is similar to the method 3 proposed by Hoanh et al. (2006) and can be explained as follows:

$$P_{adjCMM\,(\,sub\_i,\ month\_j\,)} = P_{CMM\,(\,sub\_i,\ month\_j\,)} - f \times \left(P_{CCM\,(\,sub\_i,\ month\_j\,)} - P_{calib\,(\,sub\_i,\ month\_j\,)}\right)$$

where:

$P_{adjCMM\,(\,sub\_i,\ month\_j\,)}$ = Adjusted Climate Change Model monthly precipitation for sub-basin *i* in month *j* during 1985–2000

$P_{CMM\,(\,sub\_i,\ month\_j\,)}$ = Simulated Climate Change Model monthly precipitation for sub-basin *i* in month *j* during 1985–2000

$P_{calib\,(\,sub\_i,\ month\_j\,)}$ = Monthly precipitation used for SWAT model calibration (observed data) for sub-basin *i* in month *j* during 1985 – 2000

f = Adjustment factor (1.0 for complete adjustment)

After monthly precipitation variables had been adjusted fitted to the sub-basin precipitation used for SWAT model calibration (observed data), the daily precipitation values were generated. To generate the daily precipitation values and to keep the daily precipitation pattern of Climate Change Model data as much as possible, the daily patterns from either observed data or Climate Change Model data were conditionally applied as follows:

$$P_{adjCMM\,(sub\_i,\ month\_j,\ day\_k\,)} = P_{adjCMM\,(\,sub\_i,\ month\_j\,)} - \times P_{part\,(sub\_i,\ month\_j,\ day\_k\,)}$$

When $\left(P_{CMM\,(sub\_i,\ month\_j\,)} - P_{calib\,(\,sub\_i,\ month\_j\,)}\right) < 0$

$$P_{pat\,(sub\_i,\ month\_j,\ day\_k\,)} = P_{calib\,(\,sub\_i,\ month\_j,\ day\_k\,)} \,/\, P_{calib\,(\,sub\_i,\ month\_j\,)}$$

when $\left(P_{CMM\,(sub\_i,\ month\_j\,)} - P_{calib\,(\,sub\_i,\ month\_j\,)}\right) \leq 0$

$$P_{pat\,(sub\_i,\ month\_j,\ day\_k\,)} = P_{CCM\,(\,sub\_i,\ month\_j,\ day\_k\,)} \,/\, P_{CCM\,(\,sub\_i,\ month\_j\,)}$$

where:

$P_{adjCMM\,(sub\_i,\ month\_j,\ day\_k\,)}$ = Adjusted daily Climate Change Model precipitation for sub-basin *i* in month *j* and day *k* during 1985 - 2000

$P_{adjCMM\,(sub\_i,\ month\_j)}$ = Adjusted monthly Climate Change Model precipitation for sub-basin *i* in month *j* during 1985 - 2000

$P_{pat\,(sub\_i,\ month\_j,\ day\_k\,)}$ = Daily pattern for sub-basin *i* in month *j* and day *k* during 1985 - 2000

$P_{CCM\,(\,sub\_i,\ month\_j\,)}$ = Monthly Climate Change Model precipitation for sub-basin *i* in month *j* during 1985 - 2000

$P_{calib\,(\,sub\_i,\ month\_j\,)}$ = Monthly precipitation used for SWAT model calibration (observed data) for subbasin i in month *j* during 1985 - 2000

$P_{CCM\,(\,sub\_i,\ month\_j,\ day\_k\,)}$ = Daily Climate Change Model precipitation for subbasin *i* in month *j* and day *k* during the past period of 1985 - 2000

$P_{calib\,(\,sub\_i,\ month\_j,\ day\_k\,)}$ = Daily precipitation used for SWAT model calibration (observed data) for sub-basin i in month *j* and day *k* 1985 – 2000

For 1985 - 2000, first the daily PRECIS precipitation data were adjusted using both types of daily precipitation patterns based on the aforementioned conditions. However the outputs from few Great Lake SWAT models have shown rather high deviations from their outputs using observed climate data. Hence finally only the patterns from daily observed precipitation were adopted. For all SWAT models, the adjustment factor of 1.0 was adopted except for the Lower Mekong SWAT Model 8 (Mun up to Rasi Salai), as the model output compared to the output from observed climate data was significantly underestimated, therefore the factor of 0.9 was adopted.

For 2010 - 2050, the monthly PRECIS precipitation data for every 16 years were adjusted using the monthly adjustment values obtained from 1985 – 2000 and subsequently the daily PRECIS precipitation data were adjusted using daily precipitation patterns from future PRECIS data.

A.2 Adjustment of spikes in daily precipitation data

Option 1: Due to the original PRECIS Regional Climate Model data containing a number of days with extremely high daily precipitation values or spikes in several grid-cells (details mentioned in the full report), and the fact that these spikes still remain even after the calculation of sub-basin precipitation is performed, these spikes embedded into the precipitation data may cause the existence of an abrupt anomalous increase in the water yield hydrograph. This section explains an algorithm applied to adjust extremely high daily precipitation values or spikes by introducing so called "monthly threshold" and "day with rainfall". Monthly threshold is defined as the historical maximum daily precipitation in each month. Spikes will be reduced to the monthly threshold and the excess rainfall will be redistributed to the rainfall of the preceding and following days, assuming that these are "day with rainfall" to make sure that this excess rainfall will not be lost through evaporation or percolation if it is redistributed to a day without rainfall.

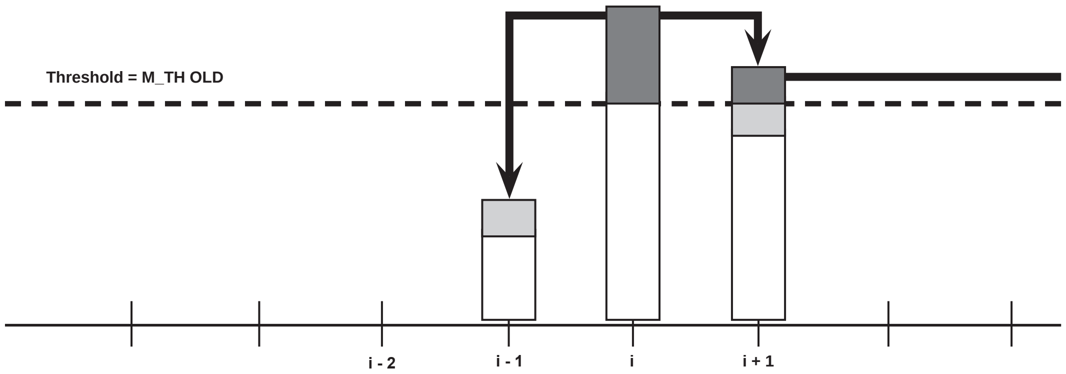

Figure A-1 Algorithm for adjustment of spikes in daily precipitation data.

Normally, the algorithm should be applied after monthly precipitation volumes have been adjusted using the method mentioned in the previous section. The following steps are applied for each calendar month to adjust spikes down to the monthly threshold.

Step 1) Calculate the excess rainfall to be distributed to the preceding and following days by using the rainfall weighted average approach. Suppose for the day *i* in a specific month in which the spike needs to be adjusted, first the excess rainfall will be calculated by

$$EXC\_PCP = P_i - M\_THOLD$$

$$EXC\_PCP1 = \frac{P_{i-1}}{P_{i-1} + P_{i+1}} EXC\_PCP$$

$$EXC\_PCP2 = \frac{P_{i+1}}{P_{i-1} + P_{i+1}} EXC\_PCP$$

Where:

EXC_PCP = Total excess rainfall for the day *i* incorporating spike

M_THOLD = Threshold value for precipitation in the month

P_i, P_{i-1}, P_{i+1} = Daily precipitation for day *i* incorporating spike, preceding and following days respectively

EXC_PCP1 = Excess rainfall to be distributed to preceding days

EXC_PCP2 = Excess rainfall to be distributed to following days

Step 2) Distribute any excess rainfall or to the preceding day with rainfall. If the excess rainfall occurs in the day after redistribution, the excess rainfall in that day will be distributed to the other preceding days with rainfall.

Step 3) Distribute to the following day in the same way as used for the preceding days in step 2.

Step 4) In case the excess rainfall distributed to the preceding days reaches the first day of the month, or that distributed to the following days reaches the last day of the month, but the rainfall on that day is still over the monthly threshold, the distribution will be continued in reverse direction.

Usually, a spike will be absolutely dropped to corresponding monthly threshold after passing these steps, and the procedure will be repeated for the next spikes in the month. It should be noted that after adjusting the spikes in a particular month, the monthly rainfall volume is still unchanged.

Option 2: This simple approach is applied before adjustment of the monthly rainfall volume. The daily sub-basin rainfall from PRECIS RCM exceeding the corresponding monthly threshold will be dropped to the monthly threshold value. After comparing two options in this climate change study, finally this option 2 was selected to handle the spikes in the daily PRECIS rainfall data.

A.3 Adjustment of maximum and minimum temperatures

The Climate Change Model maximum and minimum temperatures during 1985-2000 also deviate from historical records, and in order to keep the outputs from baseline scenario SWAT models close to those using observed temperature data, the maximum and minimum temperatures obtained from PRECIS Regional Climate Model need to be adjusted. To adjust maximum and minimum temperatures, monthly values are adjusted against the observed and subsequently the monthly adjustment value for a specific month is used to adjust the daily temperature values in that month. The following equations are applied to adjust maximum and minimum temperatures.

$$T_{diff\,(sub\_i,\ month\_j\,)} = \bar{T}_{CMM\,(\,sub\_i,\ month\_j\,)} - \bar{T}_{calib\,(sub\_i,\ month\_j\,)}$$

$$T_{adjCCM\,(sub\_i,\ month\_j\,)} = \bar{T}_{CMM\,(\,sub\_i,\ month\_j\,)} - \bar{T}_{diff\,(sub\_i,\ month\_j\,)}$$

$$T_{adjCCM\,(sub\_i,\ month\_j,\ day\_k\,)} = T_{CCM\,(\,sub\_i,\ month\_j,\ day\_k)} - T_{diff\,(sub\_i,\ month\_j\,)}$$

where:

$T_{diff\,(sub\_i,\ month\_j\,)}$ = Monthly temperature adjustment value for a particular sub-basin *i* in month *j* during 1985 - 2000

$\bar{T}_{CCM\,(\,sub\_i,\ month\_j\,)}$ = Monthly Climate Change Model temperature for a particular sub-basin *i* in month *j* during 1985 - 2000

$\bar{T}_{calib\,(\,sub\_i,\ month\_j\,)}$ = Monthly observed temperature for a particular sub-basin *i* in month *j* during 1985 - 2000

$\bar{T}_{adjCCM\,(\,sub\_i,\ month\_j\,)}$ = Adjusted monthly Climate Change Model temperature for a particular sub-basin *i* in month *j* during 1985 - 2000

$\bar{T}_{adjCCM\,(sub\_i,\ month\_j,\ day\_k)}$ = Adjusted daily Climate Change Model temperature for a particular sub-basin *i* in month j and day *k* during 1985 - 2000

$T_{CCM\,(sub\_i,\ month\_j,\ day\_k)}$ = Daily Climate Change Model temperature for a particular sub-basin *i* in month *j* and day *k* during 1985 - 2000

There are some DSF temperature stations in particular those stations in Viet Nam, for only observed daily mean temperature data are available. In the DSF, KB and the SWAT models have been set-up using daily mean temperature for both maximum and minimum temperatures. Therefore, both sub-basin PRECIS maximum and minimum temperatures were adjusted against the observed daily mean temperature. For adjustment for 2010 - 2050, the monthly adjustment values obtained from 1985 - 2000 were applied to adjust the future monthly temperature values and subsequently the daily values for every 16 years.

A.4 Adjustment of solar radiation and wind speed

To adjust the two climatic parameters of solar radiation and wind speed, firstly the monthly values were adjusted against the monthly observed data using the monthly ratios or factors between them, and subsequently these adjustment factors were applied to adjust the daily values in the month. The monthly ratios or factors have been selected as from testing, and the monthly deviation values may produce negative adjusted values for solar and wind speed. The adjusted monthly and subsequently daily values can be calculated from:

Solar radiation,

$$f_{r\,(sub\_i,\ month\_j)} = R_{calib\,(sub\_i,\ month\_j)} / R_{CCM\,(sub\_i,\ month\_j)}$$

$$R_{calibCCM\,(sub\_i,\ month\_j)} = f_{r\,(sub\_i,\ month\_j)} \times R_{CCM\,(sub\_i,\ month\_j)}$$

$$R_{adjCCM\,(sub\_i,\ month\_j,\ day\_k)} = f_{r\,(sub\_i,\ month\_j)} \times R_{CCM\,(sub\_i,\ month\_j,\ day\_k)}$$

where:

$f_{r\,(sub\_i,\ month\_j)}$ = Monthly adjustment ratio or factor for solar radiation of sub-basin *i* in month *j*

$R_{CCM\,(sub\_i,\ month\_j)}$ = Monthly Climate Change Model solar radiation for sub-basin *i* in month *j* during 1985 - 2000

$R_{calib\,(sub\_i,\ month\_j)}$ = Monthly solar radiation used for SWAT model calibration (observed data) for sub-basin *i* in month *j* during 1985 - 2000

$R_{adjCCM\,(\,sub\_i,\ month\_j\,)}$ = Adjusted monthly Climate Change Model solar radiation for sub-basin *i* in month *j* during 1985 - 2000

$R_{CCM\,(\,sub\_i,\ month\_j,\ day\_k\,)}$ = Daily Climate Change Model solar radiation for sub-basin *i* in month *j* and day *k* during 1985 - 2000

$R_{adjCCM\,(\,sub\_i,\ month\_j,\ day\_k\,)}$ = Adjusted daily Climate Change Model solar radiation for sub-basin *i* in month *j* and day *k* during 1985 – 2000

For wind speed:

$$f_{w\,(sub\_i,\ month\_j\,)} = W_{calib\,(\,sub\_i,\ month\_j\,)} \,/\, W_{CCM\,(\,sub\_i,\ month\_j\,)}$$

$$W_{calibCCM\,(\,sub\_i,\ month\_j\,)} = f_{w\,(sub\_i,\ month\_j\,)} \times W_{CCM\,(\,sub\_i,\ month\_j\,)}$$

$$W_{adjCCM\,(\,sub\_i,\ month\_j,\ day\_k\,)} = f_{w\,(sub\_i,\ month\_j\,)} \times W_{CCM\,(\,sub\_i,\ month\_j,\ day\_k\,)}$$

where:

$f_{w\,(sub\_i,\ month\_j\,)}$ = Monthly adjustment ratio or factor for wind speed of sub-basin *i* in month *j*

$W_{CCM\,(\,sub\_i,\ month\_j\,)}$ = Monthly Climate Change Model wind speed for sub-basin *i* in month *j* during 1985 - 2000

$W_{CCM\,(\,sub\_i,\ month\_j\,)}$ = Monthly wind speed used for SWAT model calibration (observed data) for sub-basin *i* in month *j* during 1985 - 2000

$W_{adjCCM\,(\,sub\_i,\ month\_j\,)}$ = Adjusted monthly Climate Change Model wind speed for sub-basin *i* in month *j* during 1985 - 2000

$W_{CCM\,(\,sub\_i,\ month\_j,\ day\_k\,)}$ = Daily Climate Change Model wind speed for sub-basin *i* in month *j* and day *k* during 1985 - 2000

$W_{adjCCM\,(\,sub\_i,\ month\_j,\ day\_k\,)}$ = Adjusted daily Climate Change Model wind speed for subbasin *i* in month *j* and day *k* during 1985 - 2000

To adjust the solar radiation and wind speed for 2010 - 2050, the same monthly adjustment ratios from 1985 - 2000 were employed to adjust the monthly and subsequently the daily values of the original PRECIS climate data for every 16 years.

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