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Assessment of Environmental Flow Under Climate Change Scenario

Case Study of Stung Chinit Sub-basin

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Abstract: Water is fundamental to all aspects of human and economic development, so protecting riverine ecosystem is vital. Environmental flow assessment is widely applied to describe how much a river ecosystem changes with alterations to its natural flow regime. This study aimes to assess the environmental flow of Stung Chinit basin, one among the 12 tributaries contributing to Tonle Sap Great Lake, caused by the changes in river flow regimes under future climate change scenarios. Two models were used in this study; SWAT and ERFA, to assess the ecological risk due to flow alterations. The calibration and validation of SWAT model on daily time step for the period of 2000-2009 and 2010-2013, respectively, show good performances based on their statistics indictors (NSE = 0.76, PBIAS = -6.25%, and RSR = 0.48 for calibration; and NSE = 0.81, PBIAS = -23.37%, and RSE = 0.42 for validation). The model was then used to perform the simulation from 3 GCMs (GFDL-CM3, GISS-E2-R and IPSL-CM5A-CC) under two emission scenarios (RCP 4.5 and RCP 8.5) and two time slices (2050s and 2090s). Environmental flow is assessed using ERFA model which calculates the difference in MFRIs between scenario and baseline to derive ERFA classes (no, low, medium and high risks). Overall, the ecosystem of Chinit River might have been affected by the flow alteration as the risk level varied significant across the 3 GCMs of the 2 RCPs for the both time slices. GFDL-CM3 produce highest risk level in high flow while GISS-E2-H and IPSL-CM5A-MR produce higher risk level in low flow. Three GCMs mainly show that the level of risk in 2090s are higher than in 2050s. The change of flow regime under climate change could thread the ecological systems of Stung Chinit river, especially the low flow, which is necessary to take the risk level into account and shall be maintained to minimize the risk.

Keywords: environmental flow; climate change; SWAT; ERFA; Stung Chinit basin

1. INTRODUCTION

Water is fundamental to all aspect of human and economic development, so protecting riverine ecosystems is vital. The central importance of water for meeting social and economic development objectives and the anticipated impacts of climate change are such that across the globe, many of the effects of climate change will be felt through water (WorldBank, 2010). River exploitation has become a widespread concern for conservation and restoration of healthy river ecosystem as the exploitation can cause an extensive ecological degradation and loss of biological diversity (Schmutz & Sendzimir, 2018) . Diversion weirs, run-off-river abstraction and exploitation of aquifers for the primary uses of irrigated agriculture, hydropower generation, industry and domestic supply, are the water resource development impacts to riverine ecosystems caused by the altered natural hydrological regime (Rosenberg, et al., 2000).

Climate change has become one of the most important topics to scientists, the public, and governments around the world. The past 30 years (1983–2012) were probably the hottest in the Northern Hemisphere in the last 1400 years, with the warmest being the first 10 years of the 21st century (IPCC, 2009). Regionally, mean temperature is expected to rise 0.79 ºC by the year 2030 compared to 1951–2000 in the Mekong River Basin (Eastham, J., et al., 2008). Furthermore, the average temperature is projected to increase over 1 °C under a RCP 2.6 (low-emission scenario), and over 4 °C under RCP 8.5 (high-emission scenario) (Bajracharya, et al.,

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2018). This will lead to a more vigorous hydrological cycle, with changes in precipitation and evapotranspiration rates regionally variable and it will affect water availability and runoff and thus may also affect the discharge regime of rivers (Middelkoop, H., et al., 2001). In addition, the global climate is projected to continue to change over this century and beyond (Wuebbles, et al., 2017).

Environmental flow assessment has become an essential part of Integrated Water Resources Development, and the demand to include environmental and subsistence consideration into decision making process on water resource development have been rapidly increasing in recent years. The assessment included some form of scenario analysis and some were integrated with socio-economic aspect (MRC, 2014). There is a range of methods for assessing river environmental flow requirements. Some are tailored to specific environments, such as freshwater flows to estuaries. Others incorporate different options for addressing the same issue: flow needs of river ecosystems. Many methods follow the natural flow paradigm (Poff, et al., 1997) that assumes a river's flow regime, comprising key components of variability, magnitude, frequency, duration, timing and rate of change, is central to sustaining biodiversity and ecosystem integrity. All elements of the flow regime are important for some aspect of river ecosystems.

It is especially true for Cambodia that the central for meeting social and economic development objectives and the anticipated impacts of climate change will be felt through water. Because of Cambodia's central location in the Mekong River system, the country's water resource management has a trans-boundary dimension. Cambodia, although this is most clearly typified by the Tonle Sap, the great lake fed by, and at different times draining to, the Mekong River, the central role of water resources is replicated in numerous smaller river systems in which the monsoon flood provides water for irrigated agriculture and supports extensive fisheries. Seasonality in hydrological conditions drives much of the ecological diversity within Cambodia's (and indeed wider Southeast Asia's) aquatic ecosystems. The change of river flow in Cambodia's river basin currently result from:

- Human activities: through hydropower dams, irrigation, consumption, and industrial needs.
- Climate change: through the variation or change in precipitation and evaporation (temperature, wind speed, humidity…etc)

(Poff, et al., 1997) recognized there are scientific limits to how precisely the natural flow regime for a particular river can be defined as it is possible to have only an approximate knowledge of the historic condition of a river. This illustrates that there still has a research gap about this particular field. Moreover, the studies of flow regime and environmental flow seems to be limited as many studies focused on large scale or region rather than a specific catchment of Cambodian rivers. This study will assess the environmental flow of a particular sub-catchment area of Tonle Sap, Stung Chinit basin respond to the change of flow regime under future climate scenarios. This aim was achiever through three objectives:

- To predict future streamflow of Stung Chinit river basin based on SWAT (Soil Water Assessment Tool) model;
- To predict streamflow due to climate change scenarios (RCP4.5 and RCP8.5) from three GCMs; and
- To apply environmental flow model (ERFA) to assess level of risk due to climate change scenarios.

2. STUNG CHINIT SUB-BASIN

Stung Chinit River, is major tributary of the Tonle Sap River. The catchment lies mainly in Kampong Thom province and falls partially in Kampong Cham, Kratie, Stung Treng and Preah Vihear province. The river's length is approximately 264km and loops out and into the Tonlé Sap system. Its width varies in the range of 60–90m over a total river stretch of 110km. The river drains a catchment area approximate of 5,600 km^2 including the catchment of 1,150 of its tributary, the Stung Tang Krasaing, up to its outflow into Tonlé Sap Lake. The catchment located at the east of Tonle Sap lake between longitude 12°31′38″N to 104°27′31″E and latitude 13°32′N to 105°47′E. The average annual precipitation recorded is 1,590mm with heavy rains recorded from April to October and produce average flow rate of 44.1 m3/s. The basin has climatic parameters record at Kampong Thmar station.

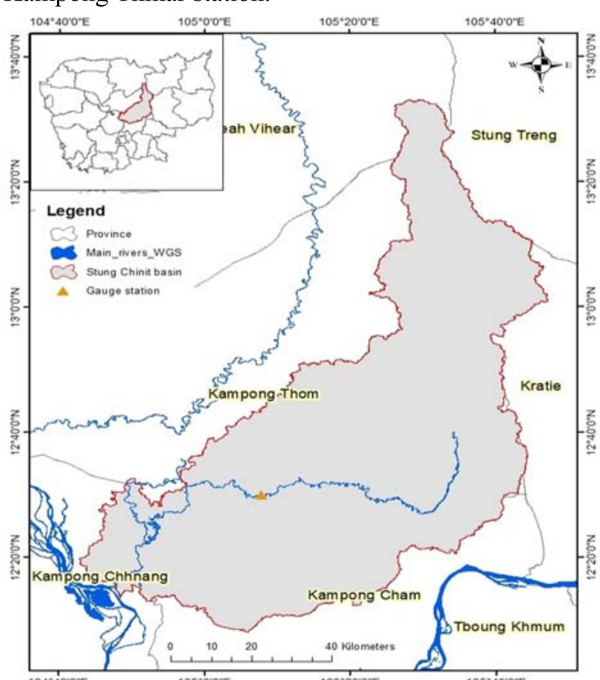

Figure 2.1: Map of study area- Stung Chinit basin

3. METHODOLOGY

3.1. Data acquisition

- SWAT input

SWAT is a physically based model requires much specific information about the basin in order to be able to represent a complex hydrological process. Thus, the minimum required data of SWAT model are topography, land-use, soil properties and weather data which were collected from different sources and databases which is summarized in Table 3.1.

Table 3.1: Input data for SWAT model setting up

Data	Description	Information	Period	Source
Topography	DEM	SRTM 1 Arc-Second Global	-	USGS
Land Use	Shapefile		2015	CNMC
Soil type	Shapefile		2003	FAO
Meteorological data	Rainfall (GCPC-v1.3)	0.15ºx0.15º	1998-2017	GPCP
	Solar radiation, wind speed, temperature, relative humidity	25º x 25º	1995-2014	Global weather for SWAT
Hydrological data	Stream flow observation	Daily	2000-2013	MoRAM

- Climate change scenarios

Monthly data of projected temperature and precipitation time slice for RCP 4.5 and RCP 8.5 scenarios were derived from Royal Netherlands Meteorological Institute (KNMI) Climate Explorer. The delta factor method was used for this study to derive future projected mean temperature and precipitation. Two time slices: 2041-2060 (referred to as the 2050s) and 2081-2100 (referred to as the 2090s) to produce climate change projections and 20-year period (1991-2010) was used as baseline period for deriving the delta factors. The delta factors which, applied across the entire basin, expressed in percentage (%) for precipitation and in Celsius (ºC) for temperature. The factors vary within the basin.

3.2. Data processing

Geospatial data and weather data were input in SWAT model for watershed delineation and simulation. Daily time step was run to project the streamflow from 2000 to 2015 with 5 warm-up years. Then, SWAT parameters calibration is required in order to have appropriate streamflow simulation. The daily observed streamflow, used for calibration, were divided into two periods; 2000-2009 for calibration and 2010-2013 for validation. Before that, sensitive analysis was done to identify the sensitive parameters which can reduce the calibration effort. Both sensitive analysis and calibration were done by SWAT Calibration Uncertainty Procedure (SWAT-Cup). Once getting satisfied result, calibrated SWAT model was used to simulate the future streamflow under different climate change scenarios. The output of SWAT model was then used for the environmental flow assessment by a new model called "TERFRIC ERFA". In TERFRIC ERFA; calibrated SWAT simulation is used as baseline, and future streamflow simulations under climate change are used as scenarios to assess the environmental flow based on the threshold set. The model output appears on interface indicating the level of risk based the number of indicators with the color-code. The ERFA model aggregates the results using a risk of ecological change classification based on how many MRFIs differ significantly from the baseline. The risk was expressed in color-code shown in Table 3.4 and Figure 3.2.

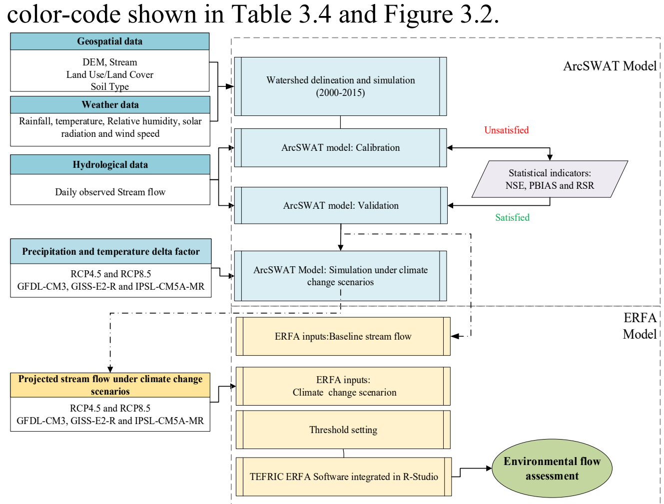

Figure 3.1: flow chart of study

Table 3.2: Performance ratings of recommended statistics for streamflow simulation

Performance Rating	NSE	RSR	PBIAS
Unsatisfactory	NSE ≤ 0.5	RSR > 0.7	PBIAS ≥ ±25
Satisfactory	0.5 < NSE ≤ 0.65	0.6 < RSR ≤ 0.7	±15 ≤ PBIAS < ±25
Good	0.65 < NSE ≤ 0.75	0.5 < RSR ≤ 0.6	±10 ≤ PBIAS < ±15
Very Good	0.75 < NSE ≤ 1	0.5 < RSR ≤ 0	PBIAS < ±10

Table 3.3: Setting and threshold for Stung Chinit study

Parameter	Description	Value
hthreshold_mediqr	Median/IQR threshold for high flow	0.3
hthreshold_mode	Mode threshold for high flow	1
water_year_start	Start of water year	3
threshold_low_flow	Low flow threshold	0.05
threshold_high_flow	High flow threshold	0.95
lthreshold_mediqr	Median/IQR threshold for low flow	0.3
lthreshold_mode	Mode threshold for low flow	1

Table 3.4: Summary of ERFA's class

Number of MRFIs exceeding thresholds	Coded color	Risk level
0	Blue	No risk
2-3	Green	Low risk
4-5	Orange	Medium risk

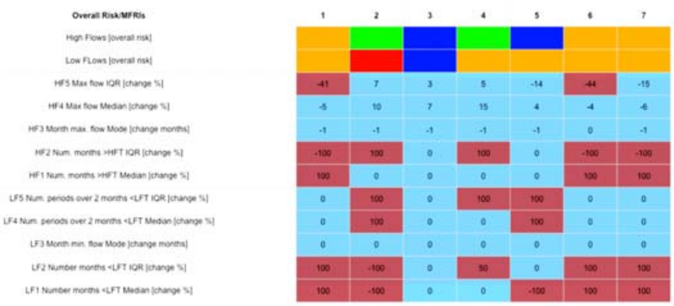

Figure 3.2: The example of ERFA Matrix plot for environmental flow risks (Model Mannual)

4. RESULTS AND DISCUSSION

4.1. SWAT model setup

With the availability data consist of ASTER30 DEM, land use/soil type/slope, weather data (temperature, relative humidity, wind speed and solar radiation) and satellite rainfall with the threshold area of 10000 hectares and threshold value of 10% for HRU definition for land use/siol type/slope, SWAT finally run on daily time step for 16 simulation year (2000-2015) with 5 warm-up years (1995-1999). Consequently, SWAT delineated a basin of 7381 square kilometers and divided into 45 sub-basins and 725 HRUs were created for Stung Chinit basin.

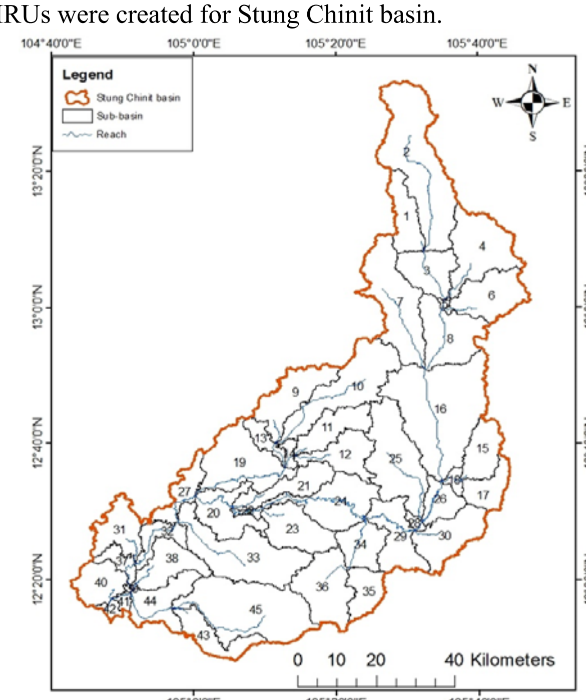

Figure 4.1: Delineated of Stung Chinit basin

4.2. Sensitive analysis

p-Value is used as key indicator to evaluate sensitiveness of each parameter. Parameter is identified to be sensitive when p-Value is less than 0.05 and the smaller its p-Value indicates that parameter is more sensitive (Abbaspour K. C., 2013). A 250 runs was performed by SWAT-CUP on SUFI-2 method has identify 5 sensitive parameters with it rank as presented in Table 4.1.

Table 4.1: Sensitive parameters for Stung Chinit basin

Parameter	t-Value	p-Value	Rank	Fitted value
CH_K2.rte	10.7161359	0.0000000	1	260.000
CN2.mgt	-8.7373778	0.0000000	2	-0.219
ALPHA_BF.gw	-4.3556959	0.0000024	3	0.466
SOL_K.sol	-3.6771927	0.0071903	4	660.000
SOL_AWC.sol	-2.2212821	0.0272896	5	-0.003

4.3. SWAT model performance

Once the sensitive parameters related to the streamflow were identified, automical and manual calibration and validation were applied with daily time step of 2000-2009 and 2010-2013 respectively. Good result were obtained for calibration based on statistical indicators; NSE = 0.762, PBIAS = -6.251 and RSR = 0.488. The result was slightly different for validation period according to its statistic indicators which NSE = 0.817, PBIAS = -23.37 and RSR = 0.428. Figure 4.2 illustrate the calibrated and validation streamflow compare to the observed streamflow for daily time step. Model is well captured of flow variation and show an acceptable streamflow except in 2000 and 2005 for calibration period and in 2012 for validation period which are overestimated of peak flow.

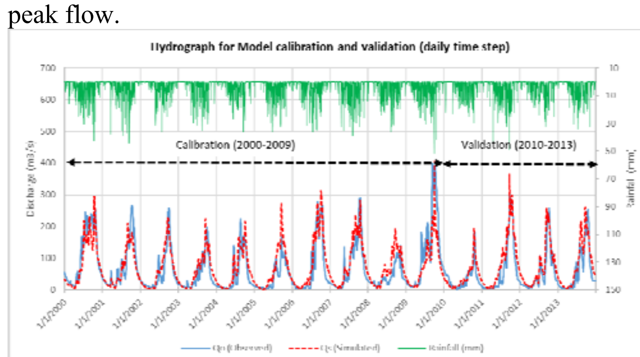

Figure 4.2: The hydrograph of daily simulated and observed flow for calibration and validation

Table 4.2: Calibration and validation performance for daily time-step

Statistic Indicators	Calibration	Rating	Validation	Rating
NSE	0.762	Very Good	0.817	Very Good
PBIAS	-6.251	Very Good	-23.370	Satisfaction
RSR	0.488	Very Good	0.428	Very Good

4.4. Projected streamflow under climate change scenarios

Projected streamflow under different climate change scenarios was simulated by SWAT model. The model was force to run with three GCMs; GFDL-CM3, GISS-E2-R and IPSL-CM5A-MR, under two emission scenario; RCP4.5 (medium) and RCP8.5 (high) for two time slices; 2050s and 2090s. The three GCMs provide significant variation of discharge under two emission scenarios, especially in rainy season. The peak discharges were projected in October for all scenarios, which approximate 350m^3/s for 2050s and 400m^3/s for 2090s, except GFDL-CM3 under RCP4.5 for 2090s time slice shows that peak flow happened in September (Figure 4.3-b). Among three GCMs; GFDL-CM3 mainly provided highest flow while GISS-E2-R gave the lowest except under scenario RCP4.5 for 2050s which GFD-CM3 signs the lowest flow and IPSL-CM5A-MR denotes a highest flow (Figure 4.3-a). It is noticed that, GISS-E2-R produced lower flow to the baseline while both GFDL-CM3 and IPSL-CM5A-MR produce the higher one.

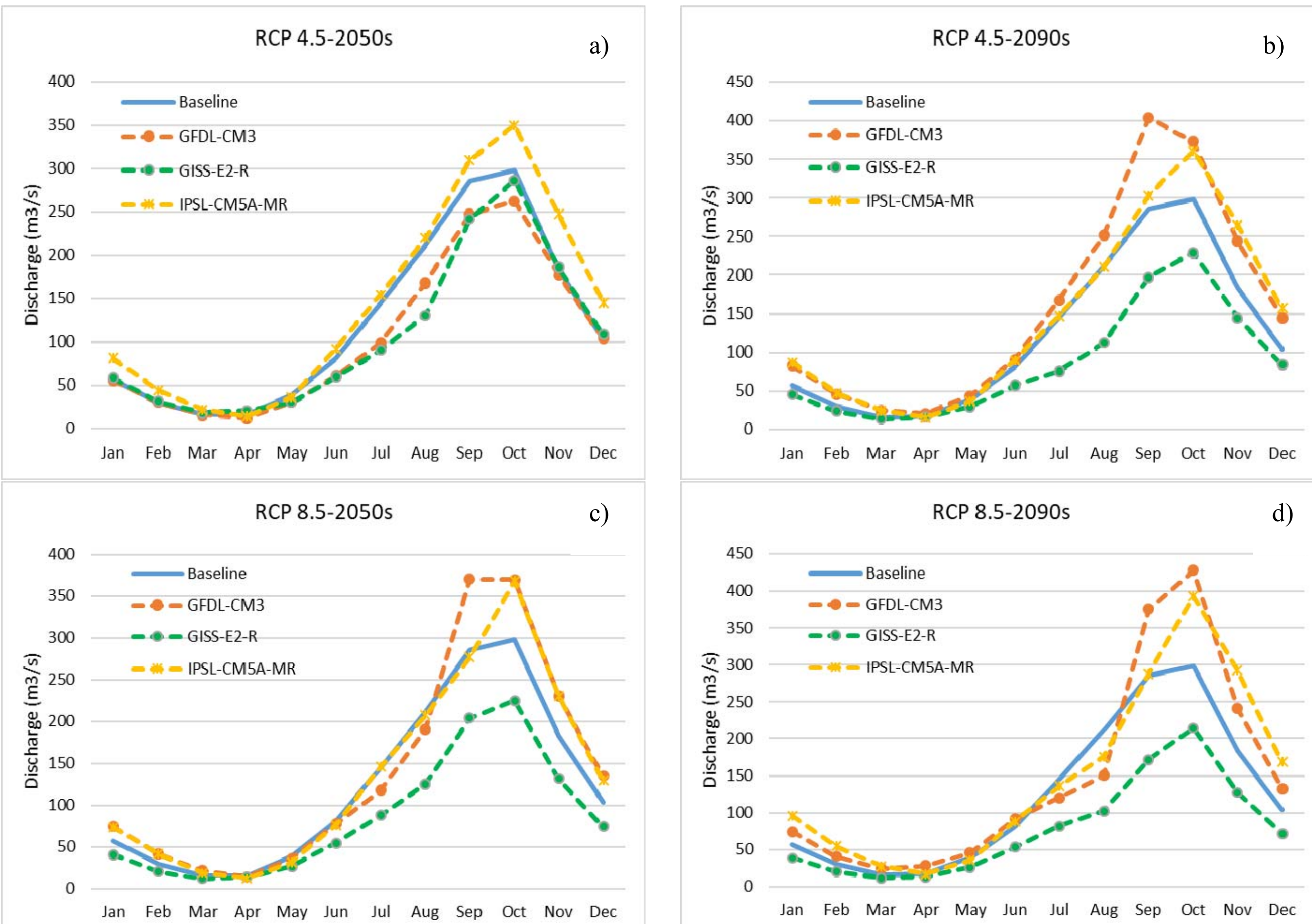

Figure 4.3: Monthly projected streamflow under 2RCPs from 3GCMs for 2050s and 2090s at outlet of basin (sub-basin 42)

4.5. Ecological Risk due to Flow alteration

Flow regime of three GCMs are significantly altered from the baseline scenario in term of RCP, time slice. As well level of risk produced by three GCMs are also altered in term of high and low flow. In term of high flow, GFDL-CM3 is one GCM which is considered produce higher risk level to other. Only GFDL-CM3 which produces high risk with RCP8.5 while GISS-E2-R and IPSL-CM5A-MR point low and medium risk for both RCPs. Meanwhile, GISS-E2-R demonstrate lower level of risk to other in term of high flow. In 2050s with RCP4.5, GISS-E2-R mainly shows no risk occurred and low risk. In term of low flow, GISS-E2-R signs highest level risk to other and follow by IPSL-CM5A-MR. Both GCMs mainly indicate high and medium risk while GFDL-CM3 more highlight low and medium level of risk for both RCPs. In general, GCMs provide higher risk in 2090s than in 2050s.

Figure 4.4 illustrate geographical location of ERFA classes of high flows in the 2050s for both RCPs. It is clearly indicate that only GFDL-CM3 which produces high risk to river with RCP8.5 at down-stream. Meanwhile, IPSL-CM5A-MR show medium risk for both RCPs and GISS-E2-

R show no risk occurred with RCP4.5 and low risk with RCP8.5 majority part of basin.

Figure 4.5 illustrate geographical location of ERFA classes of high flows in the 2090s for two RCPs. It is noticed that, in term of high flow GFDL-CM3 highly altered from the baseline. Haft of basin at the down-stream has high risk for RCP8.5 and mostly medium risk for RCP4.5. As mention above, GFDL-CM3 is one GCM which has highest altered flow regime compare to other. Then, it is followed by IPSL-CM5A-MR which indicate majority of medium risk and small part at the middle of basin has high risk. The lowest risk level produce by GISS-E2-R, low and medium.

Figure 4.6 illustrate ERFA classes in term of low flow in 2050s for both RCP. Both GFDL-CM3 and IPSL-CM5A-MR mainly point medium risk for both RCPs (4.5 and 8.5). The significant change for GISS-E2-R. This GCM signs no and low risk for RCP4.5 but medium and high risk for RCP8.5 where the high risk mostly happened at the downstream of the basin.

According to Figure 4.7 Geographical location of ERFA classes of low flows in the 2090s for both RCPs, GISS-E2-R produce the highest risk level among three GCMs. In term of low flow, GISS-E2-R produces high risk at up-stream and middle of basin for RCP4.5 and RCP8.5 accordingly. Beside this, IPSL-CM5A-MR also points high risk in major part of basin for RCP4.5. As well, the same GCM provide vary of risk level (no risk, medium and high) with RCP8.5. In contrary, GFDL-CM3 provides low and medium risk level in vary part of basin.

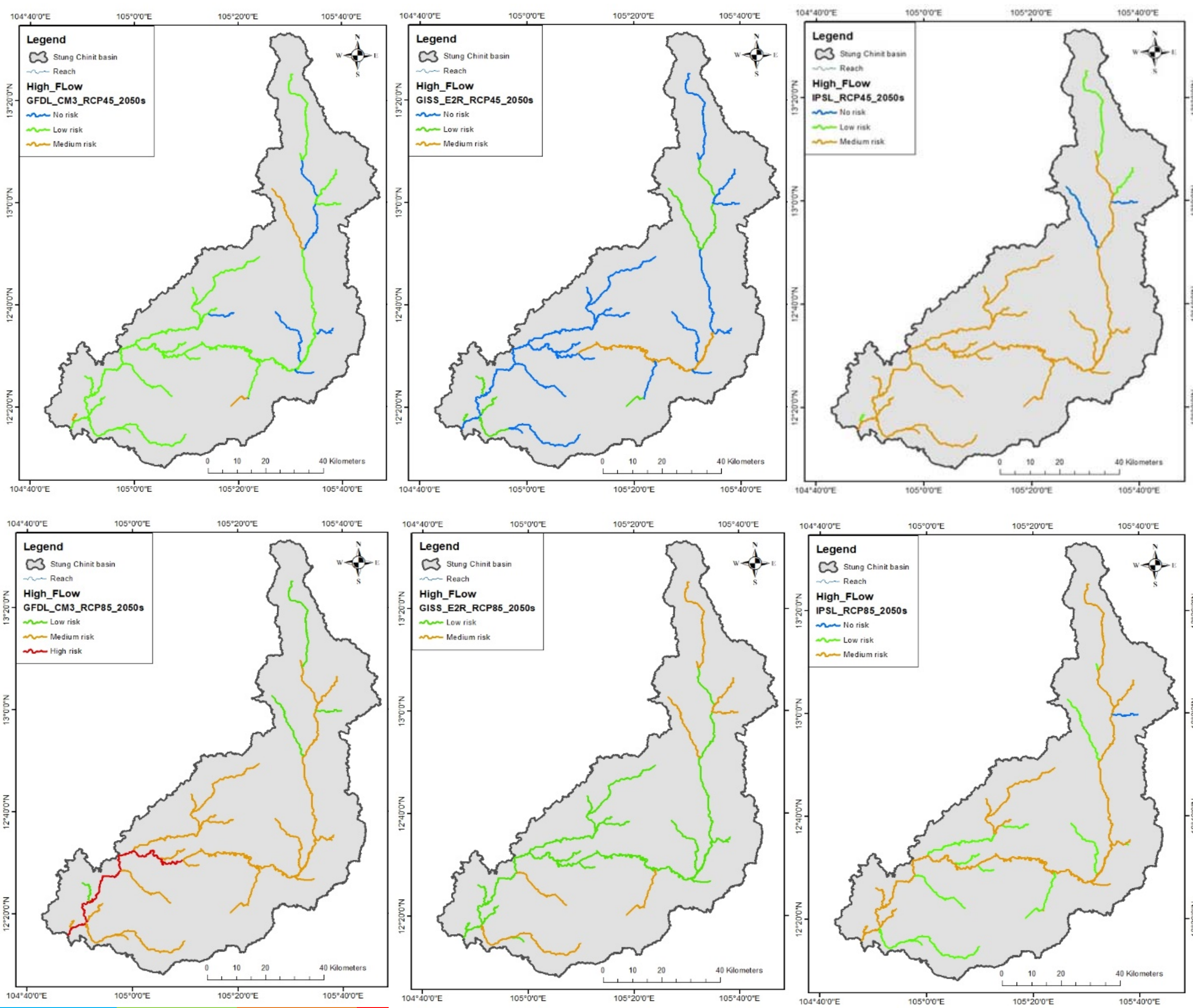

Figure 4.4 Geographical location of ERFA classes of high flows in the 2050s for both RCPs

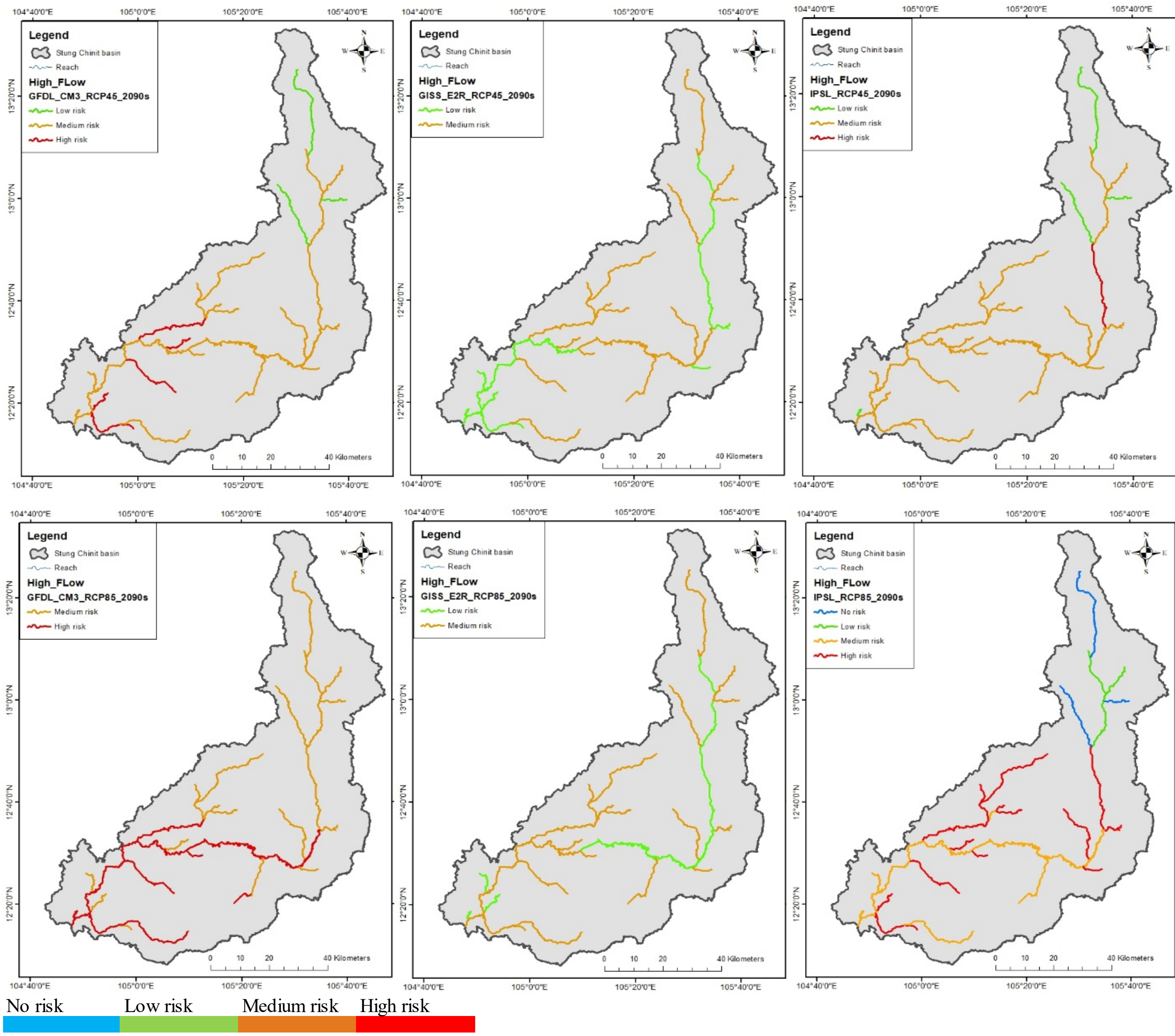

Figure 4.5: Geographical location of ERFA classes of hgh flows in the 2090s for both RCPs

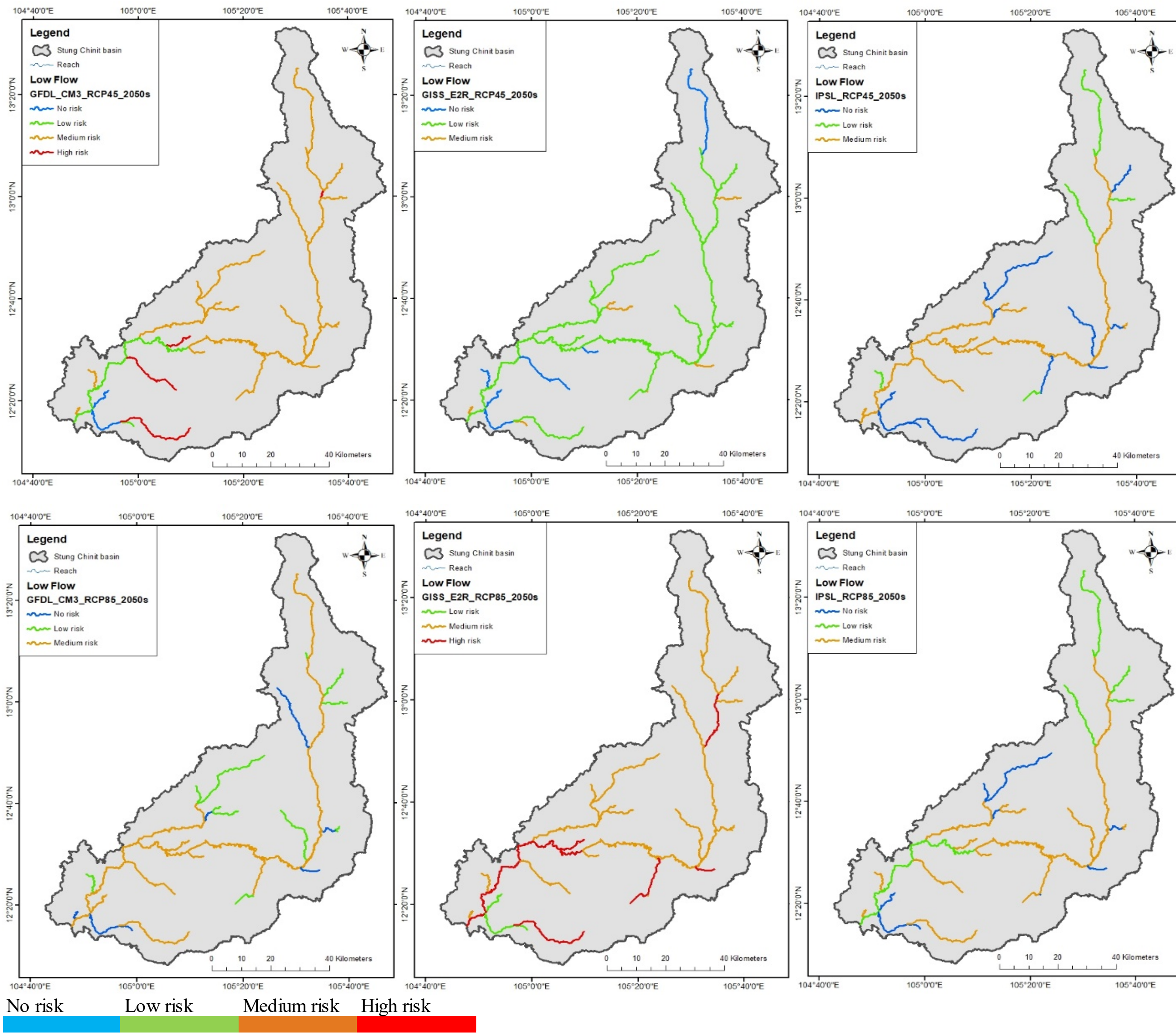

Figure 4.6: Geographical location of ERFA classes of low flows in the 2050s for both RCPs

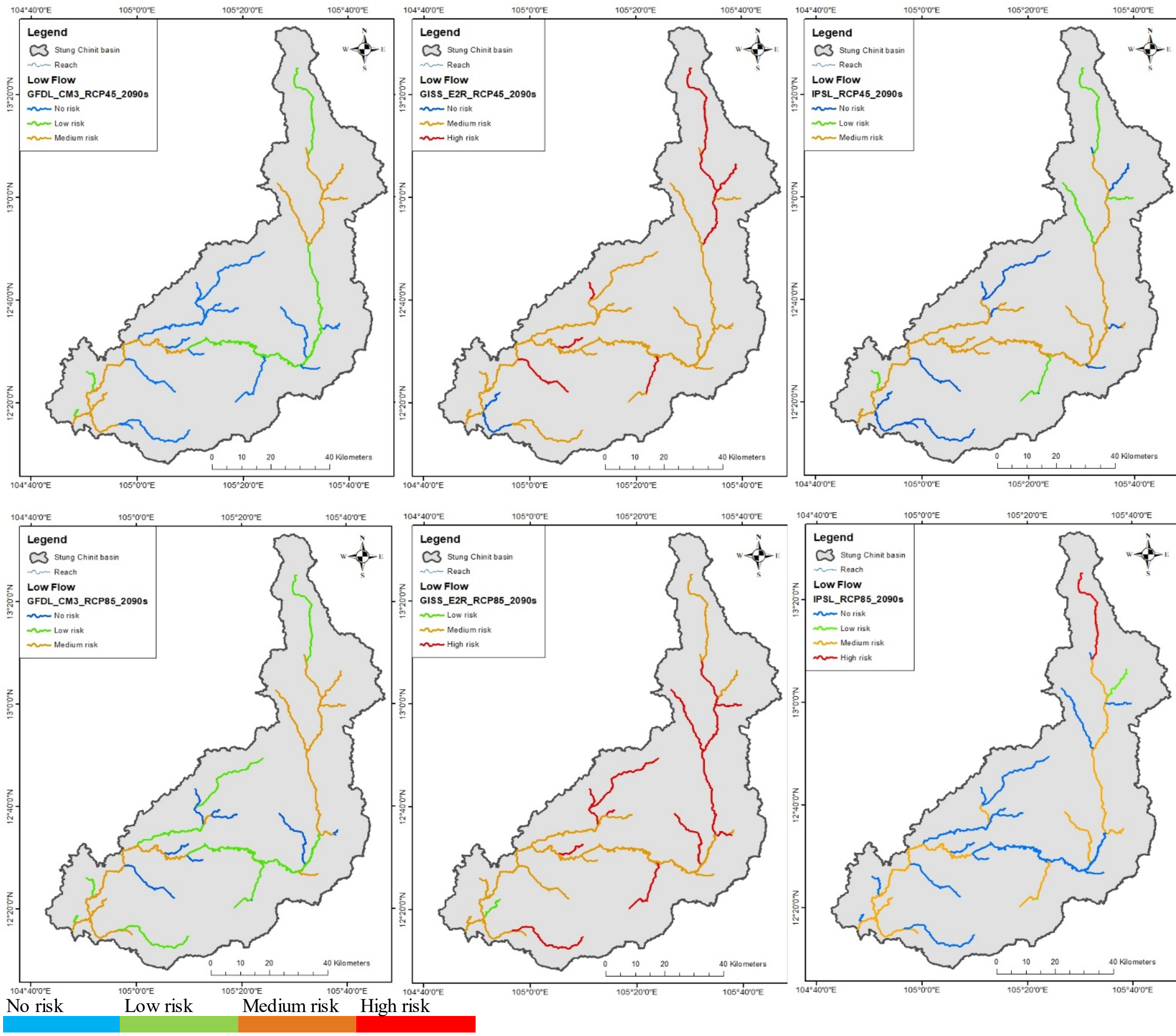

Figure 4.7: Geographical location of ERFA classes of low flows in the 2090s for both RCPs

5. CONCLUSIONS

The SWAT model has delineated a basin of 7,381square kilometers and divided into 45 sub-basins, and reached satisfied results of model performance which its statistical performances give "very good" and "satisfactory" for calibration and validation respectively for both daily time step and monthly time step. Calibrated SWAT model was forced to project the stream flow from three GCMs; GFDL-CM3, IPSL-CM5A-MR and GISS-E2-R under two emission scenarios; RCP4.5 and RCP8.5 with the two time slices of 2050s and 2090s. The climate change data (precipitation and temperature) were derived by using delta factor method.

The three GCMs show significant variation of discharge under two emission scenarios. GFDL-CM3 mainly provided highest flow while GISS-E2-R gave the lowest except under scenario RCP4.5 for 2050s which GFD-CM3 sign the lowest flow and IPSL-CM5A-MR denotes a highest flow. The peak discharges mainly happened in October for all scenarios, which approximate 350m^3/s for 2050s and 400m^3/s for 2090s which exceeded the baseline which its peak discharge stand at around 300m^3/h, except GISS-E2-R which is underestimation to the baseline. These projected flows were used to assess the environmental flow of Stung Chinit river. Three GCMs provide variation of risk level under different RCPs (RCP4.5 and RCP8.5) and time slices (2050s and 2090s) in term of high flow and low flow. In term of high flow, GFDL-CM3 produces the highest risk level, which is the only one GCM demonstrate high level of risk while the other two only produce no risk occurred to low to medium risk. In contrary, GISS-E2-R and IPSL-CM5A-Mr produce the higher level of risk in low flow. As well, three GCMs mainly show that level of risk in 2090s are higher than in 2050s.

It is necessary to take the risk level into account, especially the low flows of Stung Chinit river should be maintained as there is a high risk level. Assessment of environmental flow at a specific area shall be done more as it is useful for decision maker to identify possible solution to overcome the risk such as prevention, planning and adaptation. Due to data limitation, the stydy has narrowed down to mainly focus on availability data. Anthopogenic shall be included in the next study as it has significant impact to not only model performance but also influence the environmental flow assessment.

Acknowlegement

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REFERENCES

Abbaspour, K. C., 2013. SWAT Calibration and Uncertainty Program—A User Manual, SWAT-CUP 2012.

Bajracharya, A. R., Bajracharya, S. R., Shrestha, A. B., Maharjan, S. B., 2018. Climate change impact assessment on the hydrological regime of the Kaligandaki Basin-Nepal. Science of the Total Environment, 625, 837-848.

Eastham, J., Mpelasoka, F., Mainuddin, M., Ticehurst, C., Dyce, P., Hodgson, G., Kirby, M., 2008. Mekong River Basin Water Resources Assessment: Impacts of Climate Change. Water for a Healthy Country National Research Flagship Report; CSIRO: Canberra, Australia.

IPCC, 2009. Climate Change 2013 - The Physical Science Basis by Intergovernmental Panel on Climate Change. Cambridge University Press (CUP): Cambridge, UK.

Middelkoop, H., Daamen, K., Gellens, D., Grabs, W., Kwadijk, J. C., Lang, H., & Wilke, K., 2001. Impact of climate change on hydrological regimes and water resources management in the Rhine basin. Climatic change, 49(1-2), 105-128.

MRC, 2014. Study on The Sustainable Management and Development of the Mekong River, Including Impacts of Mainstream Hydropower Projects.

Poff, N. L., Allan, J. D., Bain, M. B., Karr, J. R., Prestegaard, K. L., Richter, B. D., & Stromberg, J. C., 1997. The natural flow regime. BioScience, 47(11), 769-784.

Rosenberg, D. M., McCully, P., Pringle, C. M., 2000. Global-scale environmental effects of hydrological alterations: introduction. BioScience, 50(9), 746-751.

Schmutz, S., and Sendzimir, J., 2018. Riverine ecosystem management. Springer International Publishing Switzerland.

WorldBank, 2010. Development and Climate Change. Washington, DC: World Bank.

Wuebbles, D. J., Fahey, D. W., Hibbard, K. A., 2017. fourth national climate assessment. Climate science special report: volume I.