IMPACTS OF CLIMATE CHANGE ON WATER RESOURCES AND ADAPTATION MEASURES

FINAL REPORT

Hanoi, 11/2010

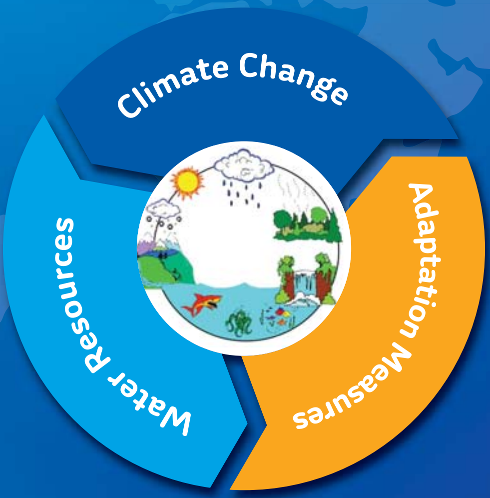
DANISH INTERNATIONAL DEVELOPMENT AGENCY (DANIDA)
EMBASSY OF DENMARK IN VIET NAM

MINISTRY OF NATURAL RESOURCES AND ENVIRONMENT (MONRE)
VIETNAM INSTITUTE OF METEOROLOGY,
HYDROLOGY AND ENVIRONMENT

PROJECT

Impacts of Climate Change on Water Resources and Adaptation Measures

FINAL REPORT



Implementing Agency : **Vietnam Institute of Meteorology, Hydrology and Environment**
Supporting Agency : **Embassy of Denmark in Viet Nam**

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LIST OF ABBREVIATIONS AND ACRONYMS

CC	Climate Change
DHI	Danish Hydraulic Institute
DANIDA	Danish International Development Agency
GCM	Global Circulation Models/ Climate Models or General Circulation Models
IMHEN	Viet Nam Institute of Meteorology, Hydrology and Environment
IPCC	Intergovernmental Panel on Climate Change
MAGICC/SCENGEN	Model for the Assessment of Greenhouse-gas Induced Climate Change/ Regional Climate SCENario GENerator
MARD	Ministry of Agriculture and Rural Development
MONRE	Ministry of Natural Resources and Environment
MOST	Ministry of Science and Technology
MRC	Mekong River Commission
PRECIS	Providing REgional Climates for Impacts Studies
ROMS	Regional Ocean Model System
RCM	Regional Circulation Models
SLR	Sea Level Rise
SEA START	Southeast Asia SysTem for Analysis, Research and Training
UNFCCC	United Nations Framework Convention on Climate Change

FOREWORD

Our Earth is gradually warming from the impacts of climate change (CC) due to the increasing concentration of greenhouse gases in the atmosphere.

Vietnam is one of the five countries affected most severely by climate change because of the long shoreline and the delta lowlands, particularly Red – Thai Binh (Hong – Thai Binh) River Delta and Cuu Long Delta, where the majority of economic activities and population are concentrated, but the infrastructure is not fully developed.

With assigned mandate, Viet Nam Institute of Meteorology, Hydrology and Environment under the Ministry of Natural Resources and Environment have undertaken much research on climate change. The project "Impact of climate change on water resources and adaptation measures" sponsored by the Government of the Kingdom of Denmark was undertaken with the participation of consulting experts from the Danish Hydraulic Institute (DHI) and the participation of many agencies in the country. This is one of several specific studies undertaken by IMHE regarding climate change issues.

The research project focuses on climate change impacts on water resources of the seven major river basins of the Red - Thai Binh, Ca, Thu Bon, Ba, Dong Nai and Cuu Long River. The total water volume of the seven river basins constitutes 87% of Vietnam's rivers. In particular, the basins of the Red River, Ca River and Cuu Long River have great parts of their catchment areas outside the territory, highlighting the difficulties and limitations of the project. This report presents the findings for the high and medium emission scenarios (A2, B2), and is divided into sections as follows:

Chapter I: provides an overview and context for the project including the objectives.

Chapter II: presents a summary of all results and conclusions of the project. This can be considered a summary of independent projects.

Chapter III: analyzes and compares the effects of climate change impacts on water resources for the studied basins.

Chapter IV: proposes adaptive measures.

Annexes and technical reports for experts and technicians are also provided.

In the framework of the project, due to the large areas under research, it was not possible to carry out a detailed analysis of the impacts of climate change on water resources and subsequent consequences on the socio-economic aspects. The project has addressed the most fundamental issues of concern for each basin, and suggested suitable adaptation measures as a basis for policy management.

The results of the project have provided basic information on the impacts of climate change on water resources of Vietnam for "The 2nd National Communication to UNFCCC". The results of the project are important foundations to assess the trend of changes in national water resources in the future under the impacts of climate change, providing scientific basis for more in-depth studies. This Project is one of the practical activities in the process of implementing the National Target Program (NTP) in response to climate change.

We gratefully acknowledge the support and contributions of the Government of the Kingdom of Denmark, Ministry of Foreign Affairs of Denmark, the Danish Royal Embassy in Hanoi, the Ministry of Natural Resources and Environment, and all concerned organizations and individuals.

We are especially grateful to Mrs. Helene Bjerre Jordans, Environment & Culture Counselor, Mr. Lasse Melgaard, Counselor of Environment, Climate Change and Energy; Mrs. Nguyen Thuy Trang and Mrs. Tran Hong Viet, Climate Change Program Officers, Royal Embassy of Denmark in Hanoi, who for practical guidelines and supervisions during the project.

We are especially grateful for the group of international experts from DHI for their most valuable technical support and contributions to project activities.

Special gratefulness is expressed to IMHEN for timely and lucid guidance and encouragement.

Many thanks to the national experts for their valuable study works which contributed to the main outputs of the project.

We appreciate the comments and contributions to the report by the technical experts, research centers, and institutes in Vietnam, as well as international experts and the Danish Royal Embassy in Ha Noi.

It is my honor to introduce these results.

Prof. Dr. Tran Thuc

Project Director
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Chapter 1 | INTRODUCTION

1.1. Background and justification

Vietnam has abundant water resources with total annual river flow volume of about 847 km^3; the amount of flow generated outside Vietnam's territory is about 507 km^3, accounted for 60%. However, water availably varies considerably throughout the year and is unevenly distributed across areas as well as river systems. For example, flow volumes in Cuu Long and Red River systems occupy 63.9% of total flow.

Vietnam is rated as one of five countries that will suffer most severely by climate change. The impacts of climate change are already and will increasingly during the 21st century be reflected in the following aspects:

- There is increased rainfall in the rainy season and decreased rainfall during the dry season. The number of rainy days will decreased markedly, while out of season and anomaly heavy rainfall will occur more often;
- The frequency of large floods will increase in the Central and Southern of VietNam;
- Droughts occur every year in most areas of the country;
- The typhoon tracks have the tendency of moving southward and typhoon season tends to end later;
- The frequency of cold fronts in northern VietNam declined sharply over the last three decades. The number of days of extreme and damaging cold surges has reduced remarkably. However, anomalous events can occur more frequently;
- The number of hot days in the decade 1991-2000 has become more frequently relative to the period of 1961-1990, particularly in the central and southern regions of Vietnam.

In addition, the sea level may rise between 0.65 m to 1.0 m by 2100, therefore Cuu Long, Red River deltas and coastal areas in the central part will be subject to inundation, flooding and salinity intrusion.

On the other hand, population growth and socio - economic development increase significantly water demand, especially during the dry season when the river flow is often quite low. In the context of climate change, water availability in the dry season can decrease dramatically, leading to the risk of water shortages becoming more acute.

Therefore, it is necessary to carry out studies to assess fully the impact of climate change to water resources based on climate change scenarios in Vietnam to actively implement appropriate adaptation measures.

1.2. Objectives of the project

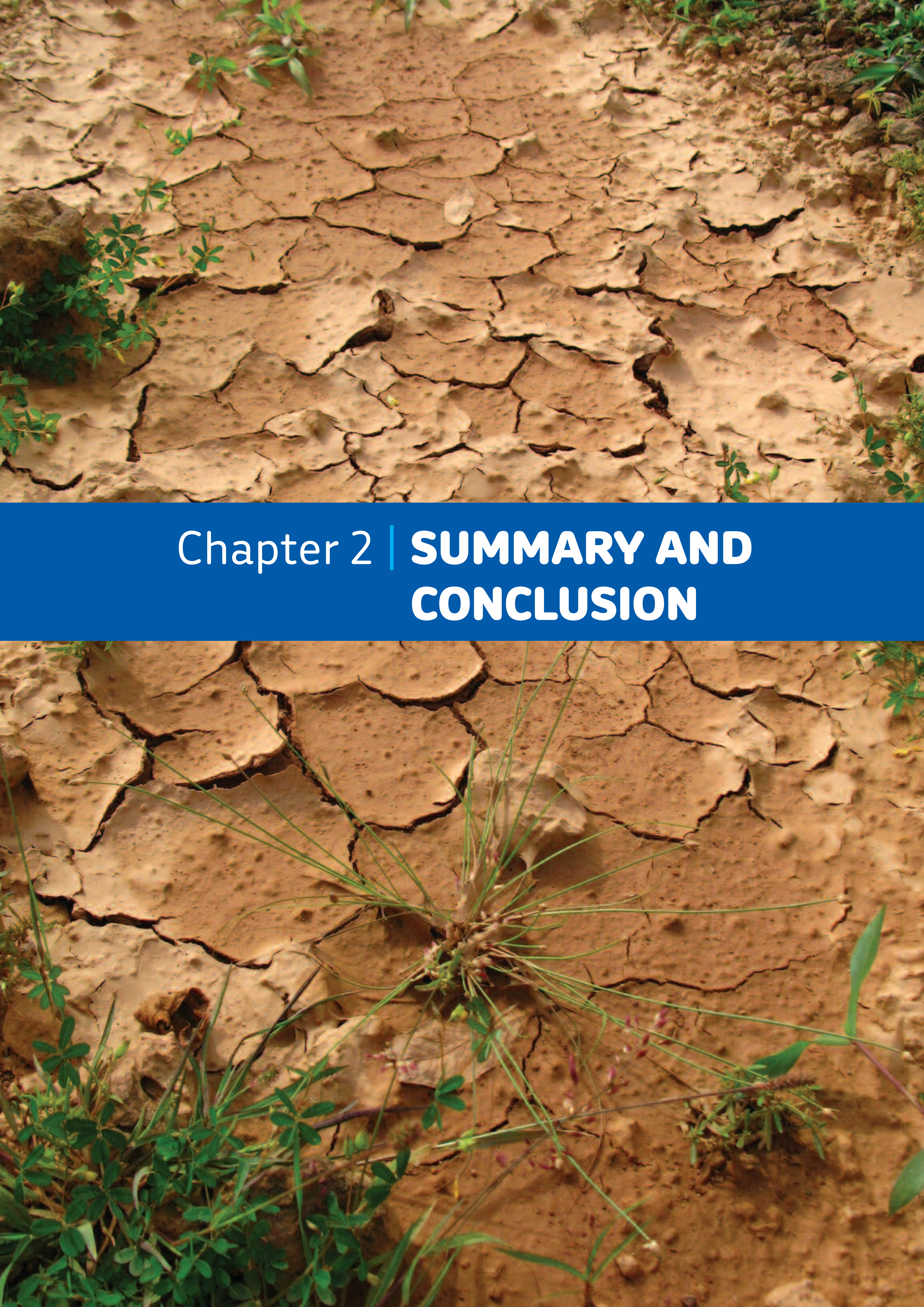
General objective

The longterm objective of the project is to strengthen the capacity of the sectors, organizations and Vietnamese people to adapt and response to climate change impacts on water resources in order to minimize the negative impacts and losses and effectively recover from their effects, or by taking advantage of positive impacts.

Immediate objectives

The immediate objectives are:

- To assess the impacts of climate change on water resources in seven main river basins of Vietnam (Red, Thai Binh, Ca, Thu Bon, Ba, Dong Nai and Cuu Long Delta).
- To propose measures adapting to water resources changing due to climate change.



Chapter 2 | SUMMARY AND CONCLUSION

The project has analyzed the situation of climate change (rainfall and temperature changes) on 7 of Vietnam largest river basins (Fig. 2-1): Red - Thai Binh, Ca, Thu Bon, Ba, Dong Nai Rivers and Cuu Long Delta with high (A2) and medium (B2) emissions scenarios. Together the seven basins are deemed to be representative of the climate change effects in the Country. Some results are summarised in the tables 2-1 to 2-4.

Table 2-1. Change in annual mean temperature (°C) relative to the period 1980-1999, medium emission scenario (B2)

River basin/area	Decades in the 21st Century								
	2020	2030	2040	2050	2060	2070	2080	2090	2100
Red and Thai Binh	0.50	0.73	1.03	1.33	1.63	1.90	2.10	2.35	2.55
Ca	0.58	0.83	1.15	1.50	1.83	2.13	2.43	2.65	2.85
Thu Bon	0.50	0.70	1.03	1.33	1.63	1.90	2.10	2.35	2.55
Ba	0.48	0.73	1.03	1.33	1.60	1.88	2.10	2.30	2.50
Dong Nai	0.35	0.53	0.75	0.98	1.15	1.33	1.55	1.70	1.80
Cuu Long Delta	0.35	0.50	0.75	0.98	1.20	1.35	1.58	1.70	1.85

River basin/area	Decades in the 21st Century								
	2020	2030	2040	2050	2060	2070	2080	2090	2100
Red and Thai Binh	0.55	0.75	0.98	1.28	1.63	2.00	2.35	2.80	3.25
Ca	0.60	0.85	1.13	1.48	1.80	2.23	2.68	3.15	3.65
Thu Bon	0.55	0.73	0.98	1.28	1.60	2.00	2.38	2.80	3.23
Ba	0.55	0.75	0.98	1.25	1.58	1.95	2.35	2.78	3.18
Dong Nai	0.38	0.55	0.68	0.93	1.15	1.43	1.73	2.03	2.33
Cuu Long Delta	0.40	0.50	0.73	0.95	1.15	1.45	1.73	2.05	2.35

River basin/area	Decades in the 21st Century								
	2020	2030	2040	2050	2060	2070	2080	2090	2100
Red and Thai Binh	0.8	1.3	1.9	2.6	3.4	4.1	4.8	5.4	6.0
Ca	1.3	2.0	2.8	3.6	4.3	5.1	5.7	6.3	6.8
Thu Bon	0.6	0.9	1.2	1.6	1.9	2.3	2.5	2.8	3.0
Ba	0.6	0.9	1.3	1.7	2.1	2.4	2.7	3.0	3.2
Dong Nai	0.3	0.5	0.7	0.9	1.1	1.3	1.4	1.6	1.7
Cuu Long Delta	0.4	0.9	1.3	1.7	2.1	2.3	2.5	2.5	2.5

Figure 2-2. Location of study basins

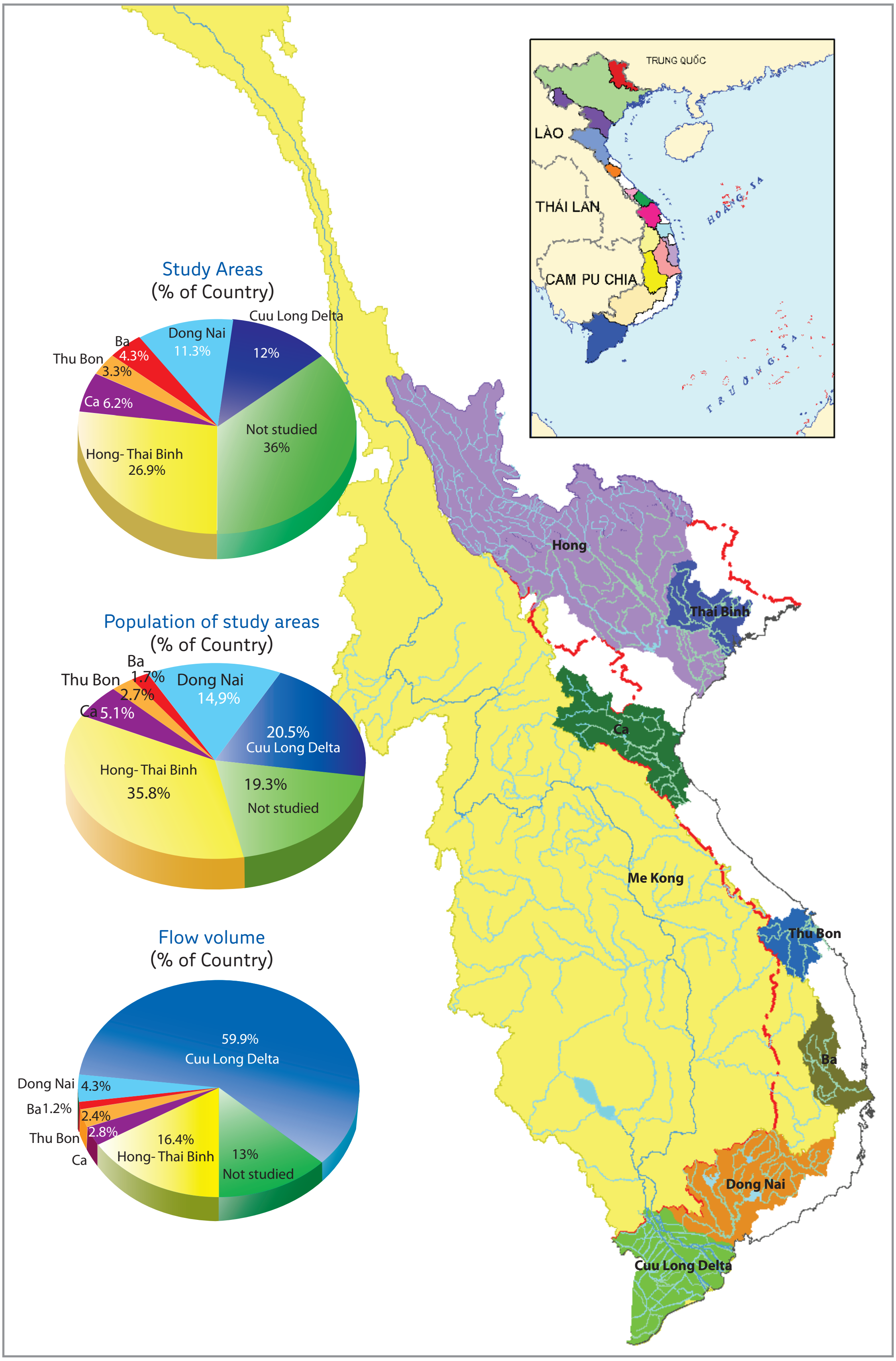


Table 2-4. Change in annual rainfall (%) relative to the period 1980-1999, high emission scenario (A2)

River basin/area	Decades in the 21st Century								
	2020	2030	2040	2050	2060	2070	2080	2090	2100
Red and Thai Binh	0.9	1.4	1.9	2.5	3.2	4.1	5.1	6.1	7.2
Ca	1.4	2.0	2.6	3.4	4.3	5.3	6.4	7.5	8.7
Thu Bon	0.6	0.9	1.2	1.5	1.9	2.4	2.8	3.3	3.9
Ba	0.7	1.0	1.2	1.6	2.0	2.5	3.0	3.6	4.1
Dong Nai	0.4	0.5	0.7	0.8	1.1	1.3	1.6	1.9	2.2
Cuu Long Delta	0.5	1.0	1.4	1.8	2.2	2.5	2.7	2.8	2.9

Combining temperature and rainfall data with the sea level rise scenarios built in the project **"Sea level rise scenarios and possible disaster risk reduction in Vietnam"**, this project estimated and assessed the impact on water resources for the 7 study River basins.

Change in the river water resources

By comparing with average flows of the period 1980-1999 some outputs obtained as follow:

Annual flow: For the climate change scenarios A2 and B2, flows in Red - Thai Binh, Ca, Ba, and Thu Bon River basins tended to increase by less than 2% in the period 2040-2059 and up to 2÷5% in the period 2080-2099, with the greatest increase in flow up to 5.8%. The average flow of the Mekong River into Cuu Long Delta in the period 2010-2050 increases about 4÷6% over 1985-2000 period.

In contrast, the flows of La tributary of Ca River and Dong Nai River system trend downward, reducing by 3%. Flow decrease in Dong Nai River system is from 3% to 6% in the middle 21st century and 5% to 7.5% in the late 21st century.

Flood flow: most of flows of Red, Thai Binh, Ca, Ba and Thu Bon Rivers tend to increase compared with present, but to varying degrees, generally from 2% to 4% in the period 2040-2059 and from 4% to 10% in the period 2080-2099. Particularly in Thu Bon River and Ngan Sau River, flood flow changes less than 2% in the period 2040-2059 and less than 3% in the period 2080-2099.

Meanwhile, the flow in flood season of Dong Nai River system falls by 2.5% to 6% and by 4% to 8% in two periods mentioned above.

For the Mekong River, compared with the period 1985-2000, the average flood flow at Kratie station of period 2010-2050 increases only about 5% to 7%.

Apart from Dong Nai River basin, the peak flow and total volume of the big floods increased in almost all basins. Flood peak values increase from 6% to 27%. In the basins with heavy rainfall in the rainy season such as Ba River, the branches of Da river system (in Red River basin), flood peaks rise up to more than 15%. The peak flow of Dong Nai River basin decreases slightly, less than 1.5% at the end of the 21st century.

Dry season flows: Climate change can lead into decreasing dry season flow. Comparing with baseline period, dry season flows decrease by 2% to 9% in the period 2040-2059 and by 4% to 12% in the period 2080-2099.

However, compared to the period 1985-2000, average dry season flow of period 2010-2050 of the Mekong River in Tan Chau has an increasing tendency of about 10%, while the smallest monthly flow decreases by 5% in scenarios B2 and increases by 3% in scenarios A2.

Some main impacts

Climate change impacts are observed to be greatest in Cuu Long Delta and Red - Thai Binh River Delta.

In Cuu Long Delta, the saliferous area (salinity concentration >1‰) accounts for over 2,500,000 ha in 2050. With increased flooding projected in the mid-21st century, the inundated area of Cuu Long River Delta increases to over 3,500,000 ha, accounting for nearly 90% of its area.

In Dong Nai River Basin, the flow decreases significantly with the impact of sea level rise. By the end of the 21st century, 300,000 ha downstream flooding due to upstream floods and saltwater encroachment will average more than 10 km. These considerably affect the socio-economic development, especially in Ho Chi Minh City.

In Red- Thai Binh River Deltas, saltwater intrusion into the land ranges more than 3÷9 km by 2100. Upstream floods are bigger. The flood peak of 1% ($Q_{max1\%}$) increases from 8% to 10% in 2050 and possibly up to 11% to 25% by 2100. This greatly affects the safety of all upstream reservoir systems and nearly 2700 km of dyke system protecting the whole delta.

Thu Bon and Ba Rivers are under strong pressured from water exploitation, and dense hydroelectric power systems. Under the impact of climate change, conflicts between water users would be more critical. At the same time, greater flooding leads to marked increase in flooded area of about 4% in 2050 and up to 9% in 2100. In the dry season, water shortage in downstream occurs more frequently. Salinity intrusion is threatening downstream plains with deeper saltwater encroachment about 3 km from sea in Ba river catchment and possibly up to 8 km in some branches of Thu Bon River in 2100.

Ca River is affected less but the basin here has the highest temperature increase. Annual flow in La branch is reduced, especially in the dry season, by 10% by 2100. Flood peak increases by 4% to 15% in the end of century, which affects the dyke system protecting the downstream delta. In the main flow, salinity intrusion is 4km to 5km further inland.

Proposed Adaptation measures

1) Red-Thai Binh River Basin

- Continue to develop multi-purpose reservoirs
- Build the dams, sluices to shut off saltwater for downstream in the North Delta.
- Upgrade river and sea dyke systems.
- Restore forest.
- Save water in various sectors, especially in agriculture.
- Promote and realize cooperation with China in water resources management.

2) Ca River Basin

- Carry out the construction of planned multi-purpose reservoirs. Develop operating rules for reservoir systems.
- Upgrade inland drainage systems.
- Develop water supply systems.
- Strengthen cooperation with Lao PDR in the integrated water resources management to share water upstream of Ca River in Laos territory.

3) Thu Bon River Basin

- Continue to develop reservoir system with different volumes, including multi-purpose reservoirs and reservoirs of specific objectives.
- Establish operating rules for reservoir systems.
- Upgrade and build water supply plan for domestic and industrial uses.
- Maintain small water supply systems and

develop priority water supply systems for districts with concentrated population and industry.

- Strengthen the capacity of gravity drainage systems to reduce the impact of inundation.
- Construct dams and sluices to prevent saltwater.
- Construct houses to evacuate people from flooding in sever inundation areas.

4) Ba River Basin

- Review planning of projects for water resources development based on integrated planning of river basins.
- Preserve and afforest at upstream, implement coordinated land-use planning, soil protection, erosion control.
- Maintain environmental flow downstream of projects.
- Implement flood prevention measures in the basin, particularly in the middle and downstream areas.
- Set up fair principles of water resources allocation between upstream and downstream areas.

5) Dong Nai River Basin

- Continue to construct reservoirs with adjusted design parameters by considering the impact of climate change.
- Set up mechanism of water resources sharing.
- Strengthen water supply through the construction of water plants pumping water from rivers.
- Develop irrigation and drainage projects, including pump stations for expanding irrigation areas.
- Build dykes and sluices to prevent saltwater intrusion.
- Strengthen measures to conserve water quality, prevent pollution from industrial activities and wastes.

6) Cuu Long Delta

- Complete and consolidate planning works for flood protection in Cuu Long Delta, taking into account the impacts of climate change.
- Plan and progressively build sea dyke system along the East Sea and West Sea.
- Construct sluices to prevent saltwater intrusion.
- Shift crop and livestock pattern based on land-use planning.
- Harvest fresh water (rain water in rainy seasons) by family size.
- Apply measures for environment conservation and water pollution prevention.
- Promote activities in the Mekong River Commission on issues relating to water resources of river basins.

Chapter 3

IMPACTS OF CLIMATE CHANGE ON WATER RESOURCES IN THE STUDIED RIVER BASINS

3.1. Climate change scenarios in the study basins

In the project, the software MAGICC / SCENGEN 5.3 and Statistical Dowscaling methods were used to develop climate change scenarios for Vietnam in general and the study river basins in particular. For parts of Red River, Ca River and Mekong River basins that are external to Vietnam, of the Dynamic Dowscaling Model (PRECIS) was used instead, due to lack of meteorological data and constraining timing.

Scenarios of greenhouse gas emissions were selected to build climate change scenarios for the low emissions scenario (B1), the medium emission scenario (B2) and high emissions scenarios (A2). The baseline period was 20 years, from 1980 to 1999.

Two important meteorological elements, rainfall and air temperature, were computed and analyzed for each scenario. In addition to the changes of climatic factors, sea level rise was also taken into account to assess the extent of flooding and salinity intrusion. The pressure of increased future water demand due to climate change was also considered in the project.

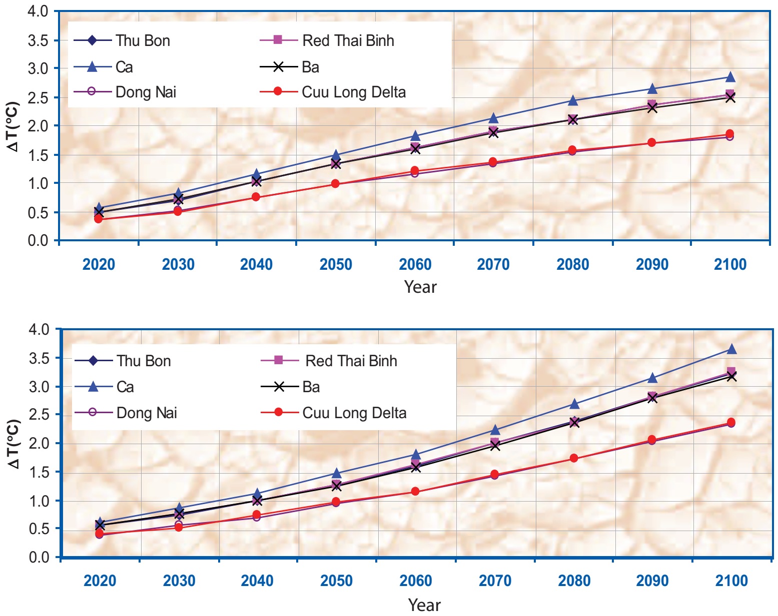
3.1.1. Air temperatures

In all scenarios for the 7 study basins, temperature increase throughout the 21st century. In the B2 scenario, annual mean temperature increases about 0.9 to 1.5 °C in the mid- 21st century and up to 1.8to 2.8°C by the end of 21st century (Fig. 3-1). In the A2 scenario, the increase is more significant. The annual mean temperature increases 1.0°C to 1.5°C by the mid 21st century and up to 2.3 °C to 3.6°C by the late 21st century (Fig. 3-1). After 2050, the difference in the extent of temperature change between the scenarios is more evident (Fig. 3-2).

In Ca River basin, temperatures rises at the highest rate, followed by Red -Thai Binh River basin. In Thu Bon and Ba River basins, temperatures have similar increases in the medium term. In Dong Nai River basin and Cuu Long Delta, temperatures increase less, with Dong Nai River basin has the smallest temperature rise.

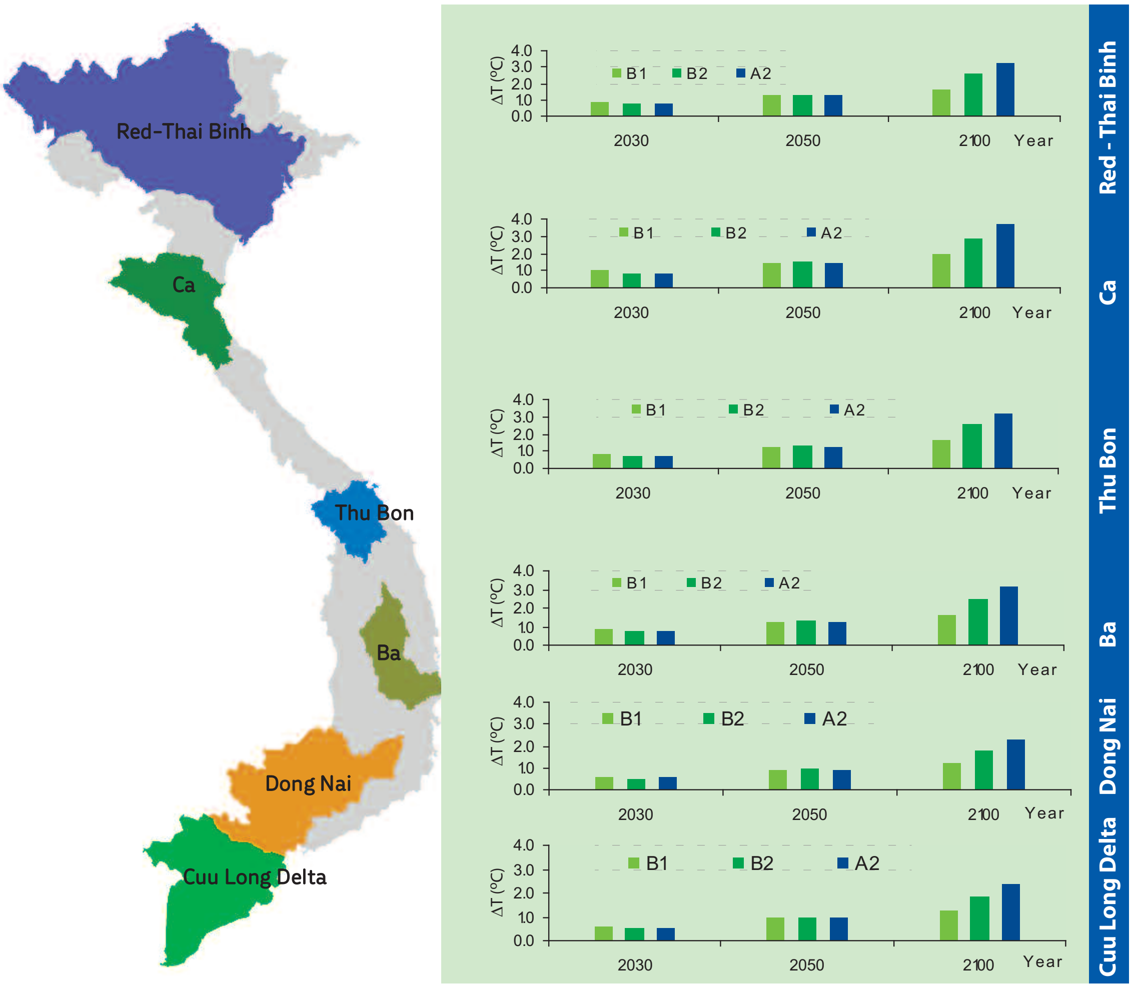
In general, in the rainy season, on the river basins from Red-Thai Binh to Ba River basin, temperature rises less than in dry season, but on Dong Nai River basin and Cuu Long Delta, there is an opposite trend.

Figure 3-1. Changes in annual mean temperature relative the period 1980 – 1999, A2 and B2 scenarios


Scenarios B2

Scenarios A2

Figure 3-2. Change in mean annual temperature relative to the period 1980-1999 (°C)



3.1.2. Rainfall

The change of rainfall in seasons can be seen throughout the 21st century (Fig. 3-3). Rainfall may increase in the rainy season and decrease in the dry season. The general trend of change in precipitation depends on geographical location of river basins. In the north of Vietnam, on the basins of Red - Thai Binh River system and Ca River basin, precipitation changes are quite similar in trend: Rainfall reduces –between March and May and increases in the remaining months, with the greatest increases – between June and August. In other basins, rainfall decreases from December to May and increases between June and November, with rainfall –from September to November increasing more than in other months (Figs. 3-4, 3-5).

Figure 3-3. Change in annual rainfall relative to the period 1980-1999 (%) in study basins.

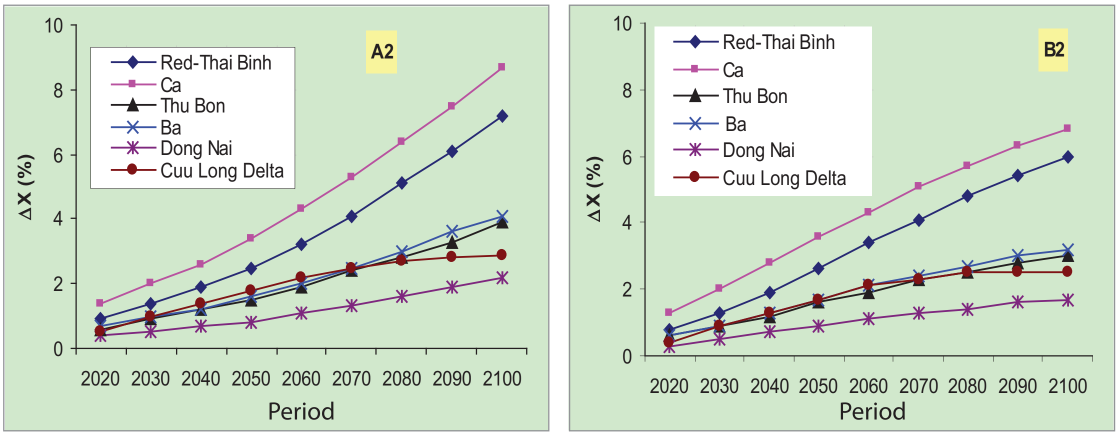
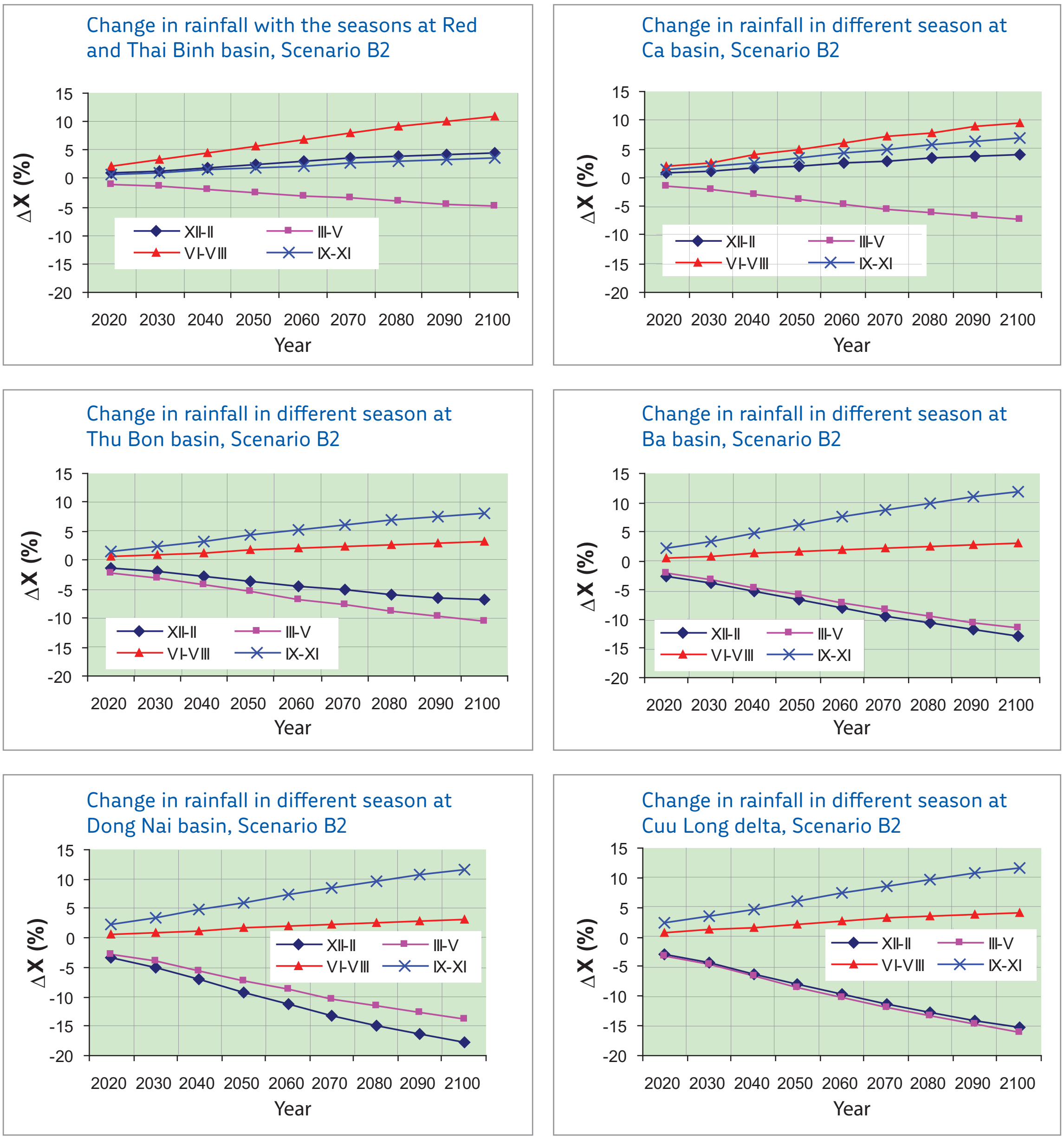


Figure 3-4. Changes in rainfall in seasons (%) compared to the period 1980-1999 in river basins/regions



Change in rainfall with the seasons at Red and Thai Binh basin, Scenario B2

Change in rainfall in different season at Ca basin, Scenario B2

Change in rainfall in different season at Thu Bon basin, Scenario B2

Change in rainfall in different season at Ba basin, Scenario B2

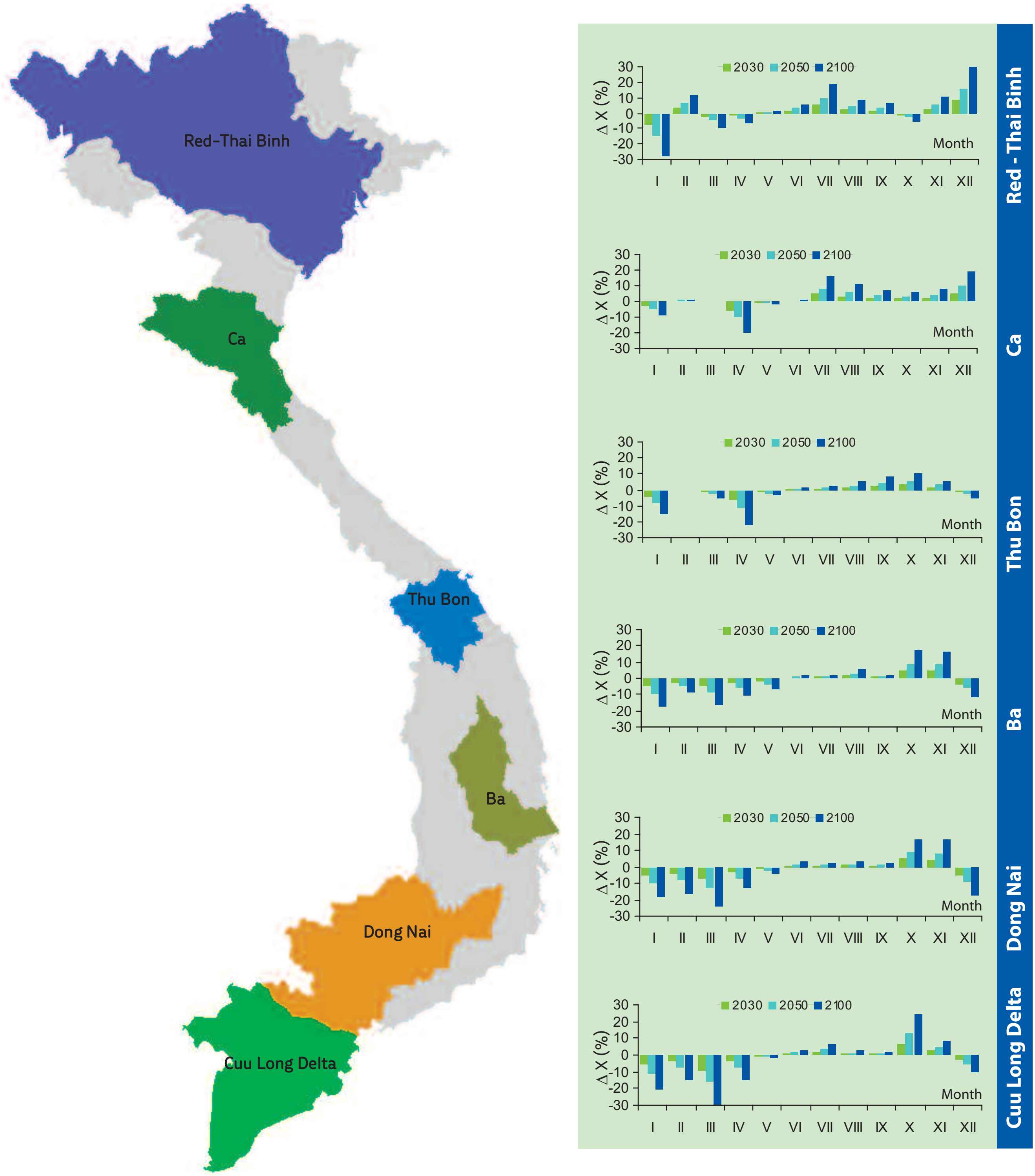
Change in rainfall in different season at Dong Nai basin, Scenario B2

Change in rainfall in different season at Cuu Long delta, Scenario B2

The decrease in rainfall from Thu Bon basin down to Cuu Long Delta is much larger than in Red Thai Binh River and Ca River. In 2100, in Thu Bon, Ba, Dong Nai and Cuu Long River basins, rainfall could reduce between 10 and 23% in the drier months. Meanwhile, in Red - Thai Binh and Ca River basins, the reduction in rainfall is only about 6% to 10% from March to May (Figure 3-4). This decrease in rainfall and increase in temperature means that drought could become more severe.

Rainfall increases most in the months of July and August in Red-Thai Binh and Ca River basins and in September and October in Thu Bon, Ba, Dong Nai River basins and Cuu Long Delta (Figs. 3-4, 3-5). This leads to a trend of increasingly larger floods.

Figure 3-5. Change in mean monthly rainfall relative to the period 1980-1999 (%), scenario B2

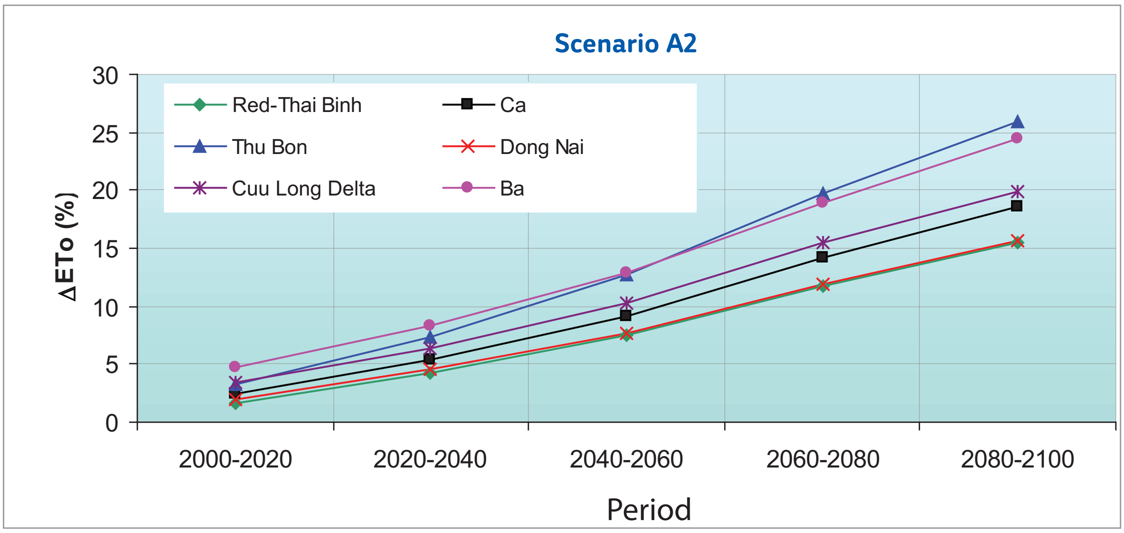


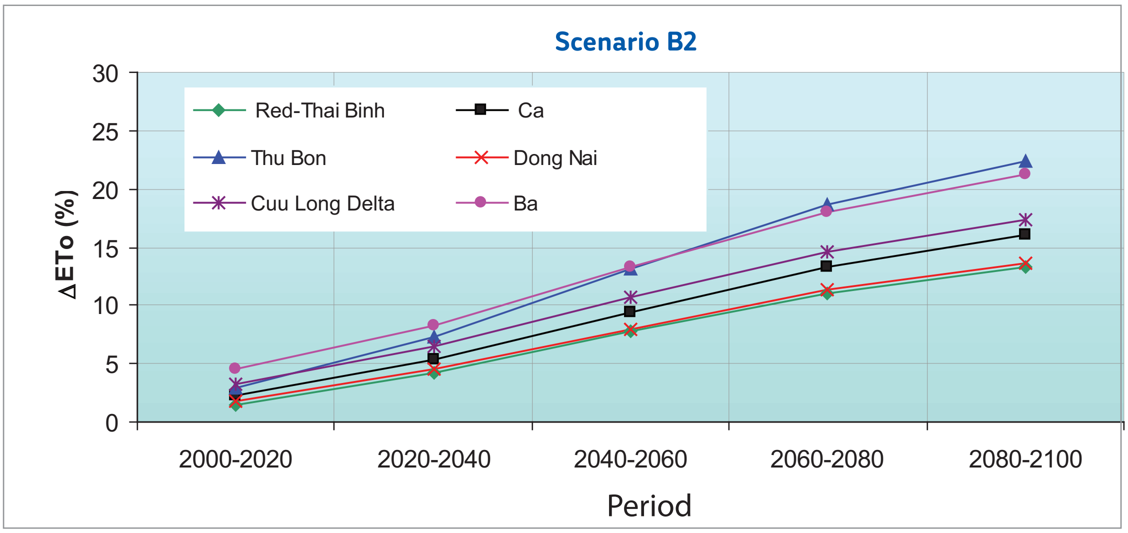
3.1.3. Potential evapotranspiration (ETo)

The change in air temperature resulting from climate change can lead to significantly changes in evapotranspiration in a basin. Evapotranspiration is an important factor involved in direct hydrological cycle that causes changes in flow in the basin. Potential evapotranspiration (ETo) is the ability to evaporate, and depends only on meteorological conditions, sand is an important factor in the assessment of changed water balance of a basin. ETo is computed according to different scenarios to assess the change of evapotranspiration in a basin.

As with changes in temperature and rainfall, the difference in ETo between scenarios is greater after 2050 (Figure 3-6).

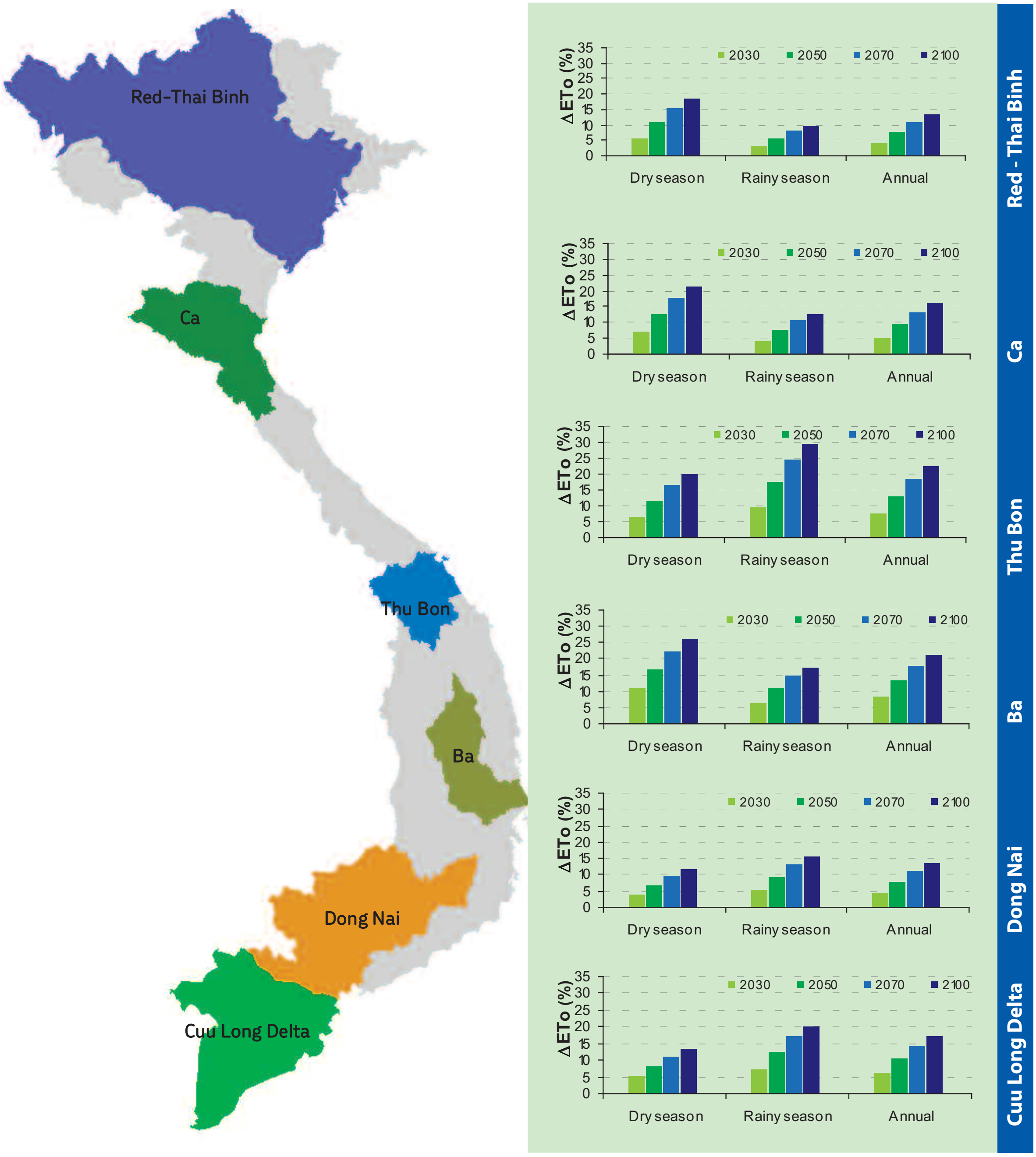
Figure 3-6. Changes in average annual potential evapotranspiration (%) compared to the period 1980-1999, scenarios B2 and A2





The change in potential evapotranspiration depends significantly on the degree of temperature increase. In Ba and Thu Bon basins, the increase in ETo is greatest while the ETo in Red-Thai Binh basin changes less. This is entirely consistent with the high year-round heat and low humidity of the air in the central region of Vietnam. In the dry season, averaging over the study basins, ETo increases between 8% and 10% in the mid-21st century and up to about 25% by 2100 (Fig. 3-7). The increase in evapotranspiration causes increasing moisture loss on the basin when rainfall in the dry months decrease in general, resulting in reduces low flows. Meanwhile, with increased water demand for irrigation, water shortage will be more serious.

Figure 3-7. Change in potential evapotranspiration relative to the period 1980 – 1999, scenario B2



3.1.4. Sea level rise

Under the impacts of climate change, along with the change of meteorological factors is sea level rise (SLR). According to observed data from tidal gauges along the Vietnam coast, the rate of sea level rise was approximately about 3mm/year during the period of 1993-2008, which is comparable with global trends. In the past 50 years, sea level at Hon Dau station has risen about 20 cm.

With a long coastline and the extended flat delta areas in Red-Thai Binh and Cuu Long Delta systems, sea level rise will threaten both the population and the land fertility of important areas of Vietnam.

Sea level rise scenarios for Vietnam were computed according to the lowest (B1), the medium (B2) and the highest (A1FI) emission scenarios.

Results computed by scenarios show that, by mid-21st century sea levels may rise about 28 cm to 33 cm and by the end of the 21st century sea level may rise between 65 cm and 100 cm above the baseline period 1980 - 1999 (Table 3-1).

Table 3-1. Sea level rise (cm) relative to the period of 1980-1999

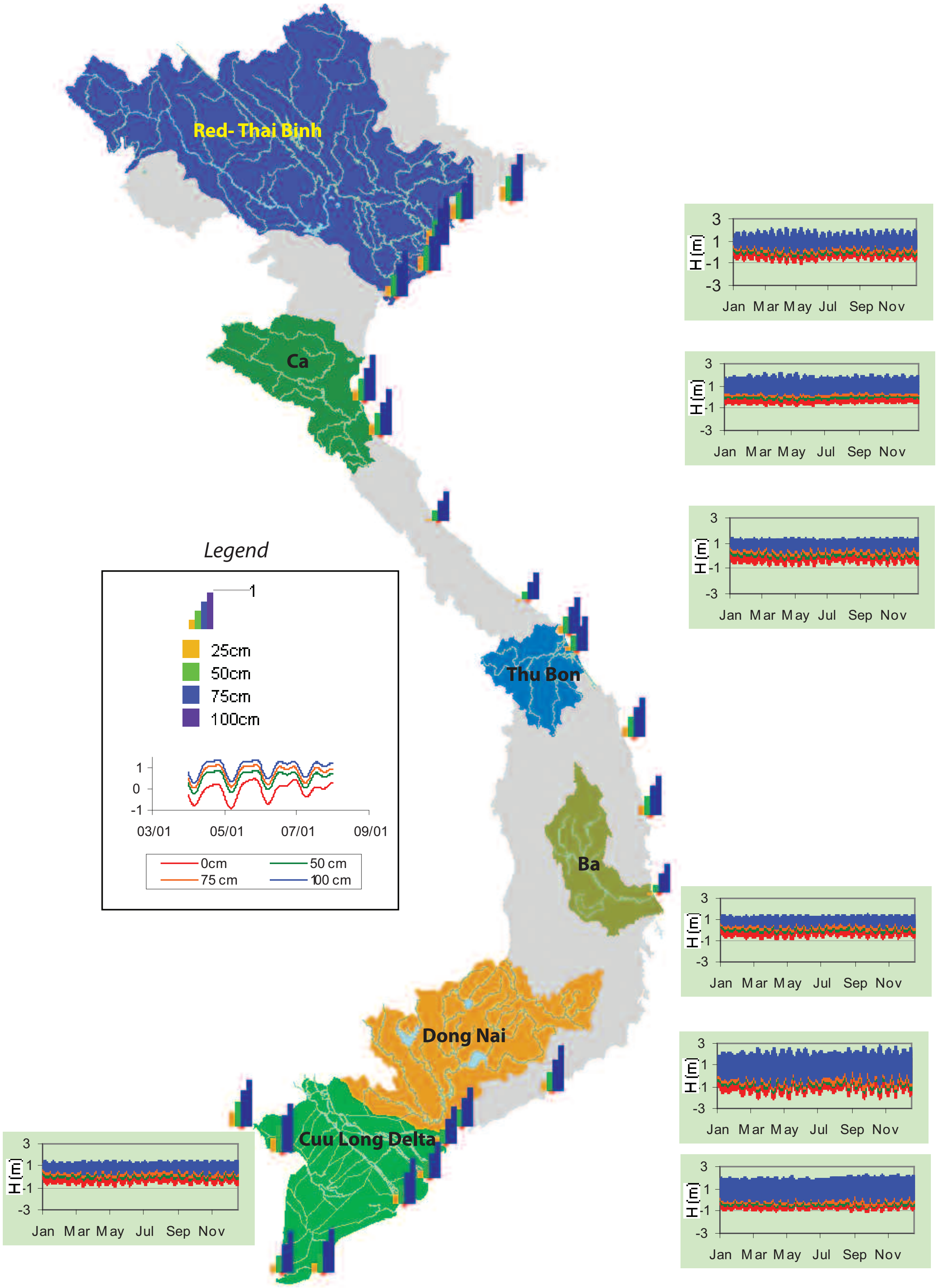
Source: Climate change, sea level rise scenarios for Viet Nam, MONRE Jun-2009

Scenarios	Decades in the 21st Century								
	2020	2030	2040	2050	2060	2070	2080	2090	2100
Low emission scenario (B1)	11	17	23	**28**	35	42	50	57	**65**
Medium emission scenario (B2)	12	17	23	**30**	37	46	54	64	**75**
High emission scenario (A1FI)	12	17	24	**33**	44	57	71	86	**100**

Depending on local conditions, tidal regimes and the climate change over the East Sea, sea level rise is very different for coastal locations. The highest sea level rise is found in Ganh Hao, Bo De River mouth of Ca Mau province, followed by the coastal line from Quang Ninh to Thua Thien Hue. The lowest sea level rise is discovered in Quang Nam, Quang Ngai, Kien Giang provinces and South Central coastal lines (Figure 3-8).

With the above sea level rise, many regions in the North delta will be affected by seawater intrusion (with a total area of about half a million hectares), as the sea will encroach inland more than 10 km. In Cuu Long Delta, there will be about 1.5 million hectares (37.8% of total area) submerged with sea level rise at 1 m. The central coastal plain will also be subject to sea level rise that may be close to the foot of Truong Son Mountain range in some areas. In addition, hydraulic and hydrological regimes in coastal zones will change significantly with greater duration, extension and depth of flood, erosion of river banks and shore lines, and more saltwater intrusion. Such change would lead to a reduction in the area of cultivated land, destroying ecosystems and biodiversity.

Figure 3-8. Sea level rise along coastal line of Vietnam



3.2. Impacts of Climate Change on water resources of study basins

Rivers are products of topographi and climate and climate change have significant impacts on river flows. Using the two climate change scenarios (B2, A2) and sea level rise scenarios, the project simulated and assessed the impacts of climate change on water resources in 7 study river basins on the following specific characteristics: river flow, such as annual, flood, dry season flows, flood peak and flooding situation, and saltwater intrusion from the sea in the future ... The project also considered the impacts of climate change on hydropower, and water demand for various sectors, especially water supply for irrigation.

The impacts of climate change on the characteristics of the river flow in future periods are simulated by the Rainfall-Runoff Model under climate change scenarios A2 and B2 as previously mentioned.

In the project, the time series of the average daily river flow for future periods at key hydrological stations in the river systems was simulated by a model with rainfall and ETo corresponding to climate change scenarios.

The following discussion provides comments regarding the impacts of climate change to river flow in Vietnam, as seen from model outputs corresponding to the future climate change scenarios (2000-2039, 2040-2059, 2060-2079, 2080-2099) at hydrology stations on the study river basins.

3.2.1. Annual flow

The Annual Flows reflects the total available water resources at various locations of the river systems. Hence these flows are important parameters for evaluating the adequacy of storage facilities and operation of reservoirs under changed climate conditions. The impacts of climate change on annual flows varies between regions and river systems across Vietnam. Tables 3-2 to 3-4 present the changes in average annual flow for the period 2040-2059 and 2080-2099 under two scenarios (A2 and B2) at typical hydrology stations in the river basins. The trend of annual flow changes in the 21st century at hydrology stations for selected rivers is shown in Fig. 3-9.

From Table 3-2 to 3-4 opposite trends in changes to annual flow can be seen between the rivers in the north (North Vietnam and North Central – Thanh Hoa and Nghe An) and the river in the south of Viet Nam (Southern part of North Central, South Central, Central Highlands and South Vietnam). The annual flow of rivers in the North and rivers in the northern part of North Central tend to increase in general by less than 2% in 2040-2059 and by up to 2% to 5% in the period 2080-2099; there is little difference between the two scenarios A2 and B2.

In contrast, the projected annual flow of rivers from southern Ha Tinh and further south tends to decrease. In the B2 scenario, the reduction in annual flow is usually less than 4% in the period 2040-2059 and less than 7% in the period 2080-2099. The decrease is relatively little in La, Thu Bon River basins and upstream of Ba River (less than 2%). In Dong Nai River basin, annual flow reduces by 5% in the period 2040-2059 and 7% in the period 2080-2099 in downstream Be River at Phuoc Hoa Station.

The impacts of climate change will also increase the annual flow of the Mekong River. According to calculation of the Mekong River Commission, the increase of the average annual flow of the Mekong River in the period 2010-2050 at Kratie and Tan Chau is about 7% and 4% for scenario B2 and 12.5% and 7.6% for the A2 scenario compared to the period 1985 – 2000. If considering the development of water use and exploitation in the basin, average annual flow in the period 2010-2050 at Kratie and Tan Chau could also increase, but at smaller rate, increasing by only 3.7% and 2.2% for scenario B2 and 9% and 6% for scenario A2 compared to the period 1985 – 2000 (Table 3-2).

Table 3-2. Change in average annual flow relative to the period 1985 – 2000 at selected stations in Mekong River basin, under climate change and water use scenarios

Climate Change Scenarios	Station	Annual flow Baseline scenario(m^3/s)		Annual flow Development scenario (m^3/s)	Change in average annual flow (m^3/s)		Change in average annual flow (%)	
		1985-2000	2010-2050	2010-2050	Baseline scenario: 2000	Development scenario: 2020	Baseline scenario: 2000	Development scenario: 2020
A2	Kratie	12,585	14,155	13,717	1,570	1,132	12.5	9.0
	Kompong Cham	12,292	13,726	13,365	1,434	1,073	11.7	8.7
	Phnom Penh	11,967	13,102	12,887	1,135	920	9.5	7.7
	Tan Chau	9,743	10,483	10,328	740	585	7.6	6.0
B2	Kratie	12,585	13,455	13,045	870	460	6.9	3.7
	Kompong Cham	12,292	13,089	12,753	797	461	6.5	3.8
	Phnom Penh	11,967	12,573	12,370	606	403	5.1	3.4
	Tan Chau	9,743	10,146	9,957	403	214	4.1	2.2

The equation of average annual natural water balance calculated for some basins shows the impacts of climate change on the natural water balance:

$$Yo=Xo-Eo$$

Where Yo represents flow, Xo represents rainfall, and Eo represents evapotranspiration (here ETo was used instead).

Although annual rainfall increases, the loss of water due to evapotranspiration in the basin increases greatly because of increased temperatures, which leads to a low rate of flow increase, or even flow decreases as seen in most of the annual flows in Central Vietnam. Through the factors of natural water balance, the most difference in flows in various basins can be explained by the impacts of climate change (Fig. 3-10).

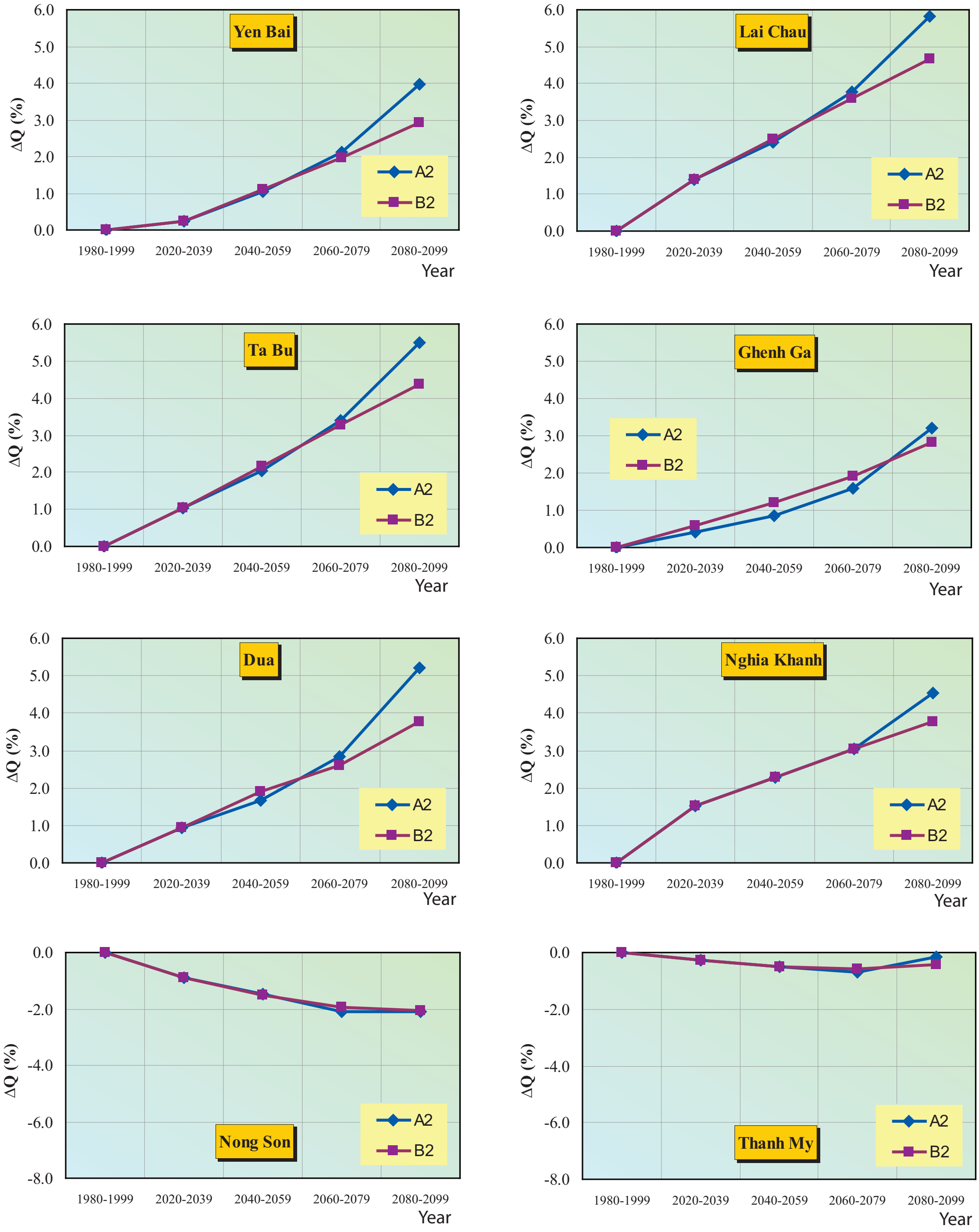
Table 3-3. Average annual flow change at selected hydrology stations in the study basins relative to the period 1980-1999, scenario A2

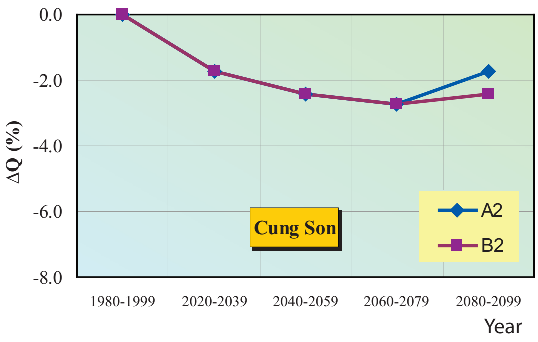
No	Station	River	Basin Area (km²)	Average annual flow in periods (m³/s)				The change relative to the period of 1980 - 1999					
				1980-1999	2020 - 2039	2040-2059	2080-2099	2020-2039		2040-2059		2080-2099	
								m³/s	%	m³/s	%	m³/s	%
1	Yen Bai	Thao	48,000	711	713	718	739	1.62	0.2	7.45	1.1	28.2	4.0
2	Lai Chau	Da	33,800	1,132	1,147	1,159	1,198	15.7	1.4	27.3	2.4	65.9	5.8
3	Ta Bu	Da	45,900	1,529	1,545	1,560	1,613	15.9	1.0	31.2	2.0	83.9	5.5
4	Ha Giang	Lo	8,298	163	165	166	171	2.43	1.5	3.39	2.1	8.08	5.0
5	Ham Yen	Lo	11,900	375	374	376	386	-1.55	-0.4	0.67	0.2	10.4	2.8
6	Ghenh Ga	Lo	29,600	808	811	815	834	3.25	0.4	6.99	0.9	26.0	3.2
7	Vu Quang	Lo	36,790	1,086	1,090	1,095	1,119	3.5	0.3	8.4	0.8	33.1	3.0
8	Chiem Hoa	Gam	16,500	388	393	394	403	5.02	1.3	6.63	1.7	15.4	4.0
9	Bao Yen	Chay	4,960	139	140	140	143	0.43	0.3	0.99	0.7	3.90	2.8
10	Thac Buoi	Cau	2,220	54.4	54.7	55.2	57.0	0.37	0.7	0.86	1.6	2.67	4.9
11	Chu	Luc Nam	2,090	42.6	42.7	43.0	44.4	0.03	0.1	0.39	0.9	1.73	4.1
12	Dua	Ca	20,800	423	427	430	445	4.00	1.0	7.00	1.7	22.0	5.2
13	Nghia Khanh	Hieu	4,024	132	134	134	138	1.54	1.2	2.43	1.8	6.00	4.5
14	Nong Son	Thu Bon	3,155	282	279	277	276	-2.50	-0.9	-4.10	-1.5	-5.90	-2.1
15	Thanh My	Cai	1,850	117	117	116	117	-0.30	-0.3	-0.60	-0.5	-0.20	-0.2
16	An Khe	Ba	1,440	35.8	35.2	35.1	35.3	-0.60	-1.7	-0.70	-2.0	-0.50	-1.4
17	Cung Son	Ba	12,800	291	286	284	286	-5.00	-1.7	-7.0	-2.4	-5.0	-1.7
18	Tri An	Dong Nai	14,800	505	490	484	475	-14.7	-2.9	-20.9	-4.1	-30.0	-6.0
19	Ta Pao	La Nga	2,010	93.1	91	90	88.4	-2.10	-2.3	-3.10	-3.3	-4.70	-5.1
20	Phuoc Long	Be	2,370	89.6	87.4	86.7	86	-2.20	-2.5	-2.90	-3.2	-4.10	-4.6
21	Phuoc Hoa	Be	5,240	281	268	265	261	-12.4	-4.4	-15.7	-5.6	-19.3	-6.9

Table 3-4. Average annual flow change at selected hydrology stations in the study basins relative to the period 1980-1999, scenario B2

No	Station	River	Basin Area (km²)	Average annual flow in periods (m³/s)				The change relative to the period of 1980 - 1999					
				1980-1999	2020 - 2039	2040-2059	2080-2099	2020-2039		2040-2059		2080-2099	
								m³/s	%	m³/s	%	m³/s	%
1	Yen Bai	Thao	48,000	711	713	719	732	1.79	0.3	7.94	1.1	20.8	2.9
2	Lai Chau	Da	33,800	1,132	1,148	1,160	1,184	15.7	1.4	28.3	2.5	52.7	4.7
3	Ta Bu	Da	45,900	1,529	1,545	1,562	1,596	15.8	1.0	32.8	2.1	66.7	4.4
4	Ha Giang	Lo	8,298	163	165	166	169	2.42	1.5	3.51	2.2	6.40	4.0
5	Ham Yen	Lo	11,900	375	375	378	386	-0.27	-0.1	3.14	0.8	10.9	2.9
6	Ghenh Ga	Lo	29,600	808	812	818	831	4.65	0.6	9.71	1.2	22.9	2.8
7	Vu Quang	Lo	36,790	1,086	1,091	1,098	1,114	5.10	0.5	11.3	1.0	28.0	2.6
8	Chiem Hoa	Gam	16,500	388	393	394	400	5.09	1.3	6.80	1.8	12.0	3.1
9	Bao Yen	Chay	4,960	139	140	140	142	0.44	0.3	1.04	0.8	2.79	2.0
10	Thac Buoi	Cau	2,220	54.4	54.7	55.3	56.4	0.37	0.7	0.91	1.7	2.07	3.8
11	Chu	Luc Nam	2,090	42.6	42.7	43.0	43.9	0.05	0.1	0.42	1.0	1.25	2.9
12	Dua	Ca	20,800	423	427	431	439	4.24	1.0	7.50	1.8	16.2	3.8
13	Nghia Khanh	Hieu	4,024	132	134	135	137	1.54	1.2	2.51	1.9	4.77	3.6
14	Nong Son	Thu Bon	3,155	282	279	277	276	-2.50	-0.9	-4.30	-1.5	-5.80	-2.1
15	Thanh My	Cai	1,850	117	116.7	116.4	116.5	-0.30	-0.3	-0.60	-0.5	-0.50	-0.4
16	An Khe	Ba	1,440	35.4	34.8	34.7	34.7	-0.59	-1.7	-0.70	-2.0	-0.69	-2.0
17	Cung Son	Ba	12,800	291	286	283	284	-5.00	-1.7	-8.0	-2.8	-7.00	-2.4
18	Tri An	Dong Nai	14,800	505	490	484	468	-14.4	-2.9	-20.8	-4.1	-36.5	-7.2
19	Ta Pao	La Nga	2,010	93.1	91.1	90.0	87.8	-2.00	-2.2	-3.10	-3.3	-5.30	-5.7
20	Phuoc Long	Be	2,370	89.6	87.4	86.8	84.7	-2.20	-2.5	-2.80	-3.1	-4.90	-5.5
21	Phuoc Hoa	Be	5,240	281	268	265	260	-12.3	-4.4	-15.8	-5.6	-20.6	-7.3

Figure 3-9. Average annual flow change (%) at selected hydrology stations in study basins relative to the period 1980 - 1999

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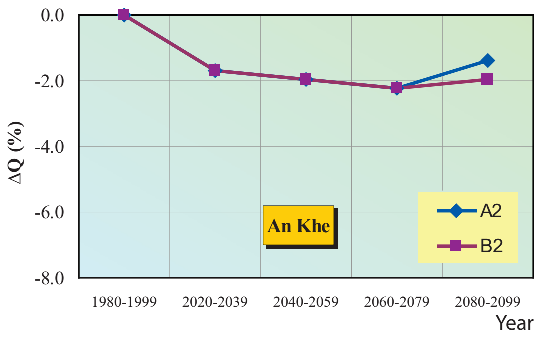
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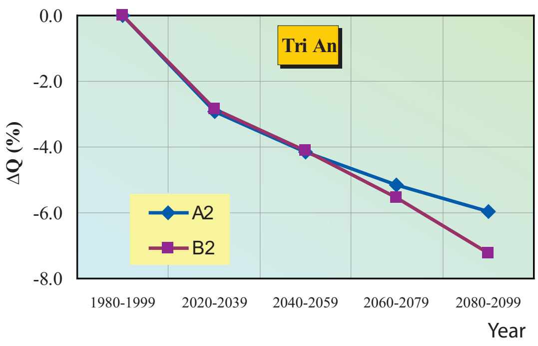
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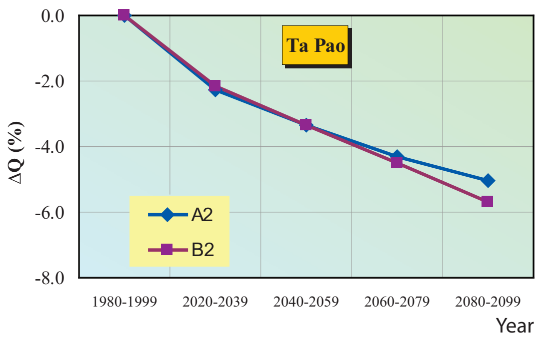
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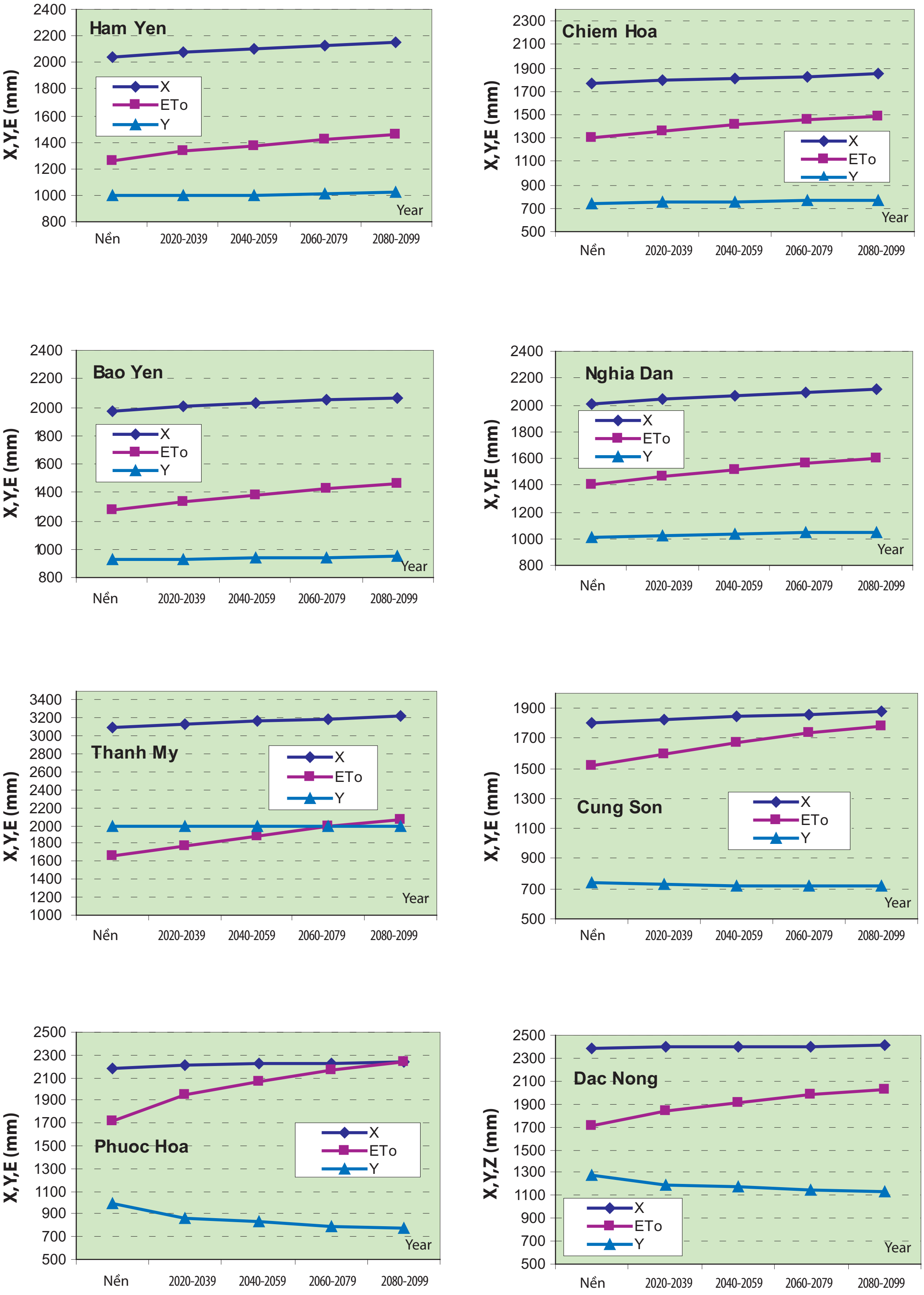
2060-2079
2080-2099
Year

Figure 3-10. Change in annual Rainfall (X) - Evapotranspiration (Z) - Runoff (Y) in some catchments, Scenario B2



3.2.2. Flow in flooding season

Under the impacts of climate change, flood flows of most rivers tend to increase compared with the period 1980-1999, except for Dong Nai River basin, where flood flow decrease. There is no significant difference between the two scenarios B2 and A2 (Tables 3-5, 3-7 and figure 3-11). For the B2 scenario in the period 2040-2059, the average flow in flood season increases by approximately about 2% to 4% on Red - Thai Binh and Ca River systems and only about 0.9% to 1.5% for Thu Bon and Ba River basins . For the period 2080-2099, the average flood flows increase by 5% to 10% in the Red and Ca Rivers and from 1% to 2.5% in Thu Bon and Ba river systems and to about 8.5% at Yen Bai station on the Thao River, where the flood flow increases considerably. However, the flood flow in Dong Nai River falls by between 4% and 7%, with the greatest decreases in downstream of Be River at Phuoc Hoa station.

Under the impacts of climate change, flood flow in Mekong River Basin will also increase. Compared with the period 1985-2000, the average flood flow for 2010-2050 under scenario B2 at Kratie and Tan Chau increases by 5% and 2% respectively, and by 11% and 5.8% under scenario A2 (Table 3-7).

However, for the period 2010-2050, due to reservoir regulation built on the Mekong River (development scenario of water exploitation and use), the average flow in flood season at Kratie and Tan Chau is projected to increase only slightly under scenario A2, at a lower rate of 3.2% and 1.1%, while flood season flows are projected to decrease under scenario B2 (Table 3-7).

Table 3-5. Change in flood season flows at selected hydrology stations in the study basins relative to the period 1980-1999, scenario A2

No	Station	River	Basin area (km²)	Average flow in flood season for periods (m³/s)				The change relative to the period of 1980-1999					
				1980-1999	2020 - 2039	2040-2059	2080-2099	2020-2039		2040-2059		2080-2099	
								m³/s	%	m³/s	%	m³/s	%
1	Yen Bai	Thao	48,000	1,188	1,209	1,229	1,292	20.3	1.7	40.4	3.4	103	8.7
2	Lai Chau	Da	33,800	2,566	2,611	2,646	2,754	44.2	1.7	79.3	3.1	187	7.3
3	Ta Bu	Da	45,900	3,389	3,442	3,488	3,633	53.1	1.6	99.3	2.9	245	7.2
4	Ha Giang	Lo	8,298	346	352	355	369	5.60	1.6	9.25	2.7	23.0	6.6
5	Ham Yen	Lo	11,900	769	777	786	817	7.25	0.9	16.3	2.1	47.4	6.2
6	Ghenh Ga	Lo	29,600	1,384	1,401	1,416	1,470	16.4	1.2	31.5	2.3	85.6	6.2
7	Vu Quang	Lo	36,790	2,098	2,121	2,144	2,225	23.8	1.1	46.3	2.2	128	6.1
8	Chiem Hoa	Gam	16,500	640	650	657	683	9.98	1.6	16.8	2.6	42.2	6.6
9	Bao Yen	Chay	4,960	231	234	237	246	2.80	1.2	5.40	2.3	14.6	6.3
10	Thac Buoi	Cau	2,220	114	116	117	123	1.60	1.4	3.25	2.9	8.70	7.6
11	Chu	Luc Nam	2,090	74,9	76,0	77,3	81,4	1.07	1.4	2.39	3.2	6.52	8.7
12	Dua	Ca	20,800	741	758	770	813	16.6	2.2	29.0	3.9	72.2	9.7
13	Nghia Khanh	Hieu	4,024	216	220	223	232	4.27	2.0	7.07	3.3	16.4	7.6
14	Nong Son	Thu Bon	3,155	802	807	809	819	5.20	0.7	7.20	0.9	16.8	2.1
15	Thanh My	Cai	1,850	319	321	321	326	1.60	0.5	2.10	0.7	6.40	2.0
16	An Khe	Ba	1,440	105	105	106	109	0.30	0.3	1.00	1.0	4.18	4.0
17	Cung Son	Ba	12,800	627	631	635	654	4.00	0.6	8.00	1.3	27.0	4.3
18	Tri An	Dong Nai	14,800	889	863	853	839	-25.3	-2.9	-35.6	-4.0	-49.9	-5.6
19	Ta Pao	La Nga	2,010	157	154	153	151	-3.00	-1.9	-4.20	-2.7	-5.80	-3.7
20	Phuoc Long	Be	2,370	158	154	153	151	-4.00	-2.5	-5.20	-3.3	-7.10	-4.5
21	Phuoc Hoa	Be	5,240	489	467	462	457	-22.0	-4.5	-27.3	-5.6	-32.6	-6.7

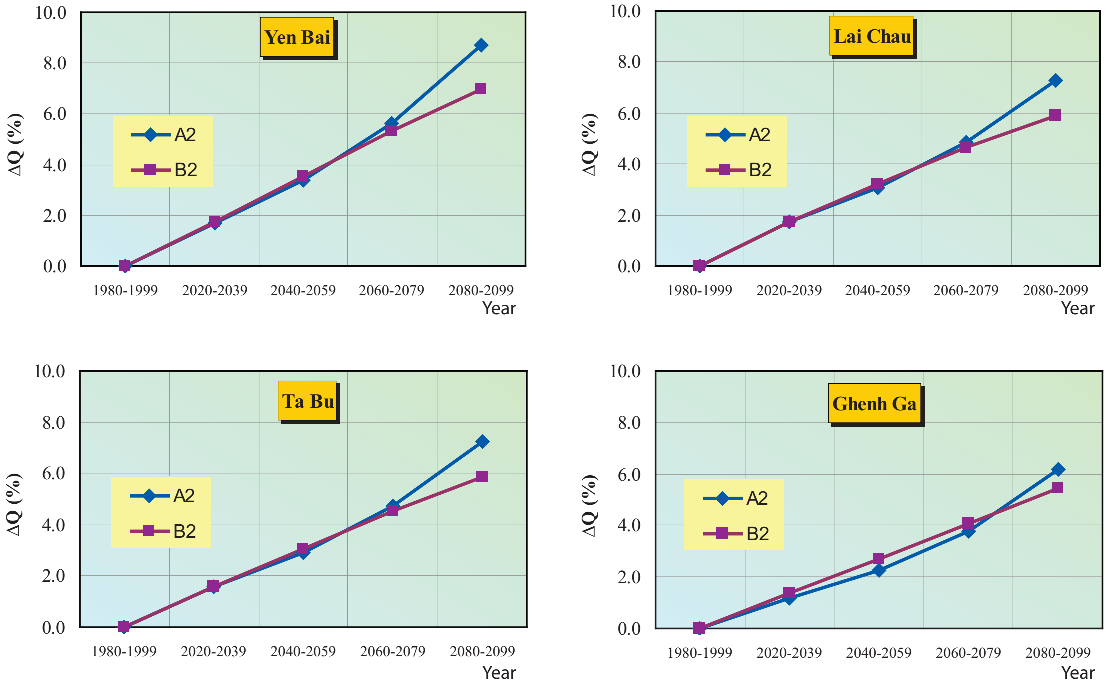
Table 3-6. Change in flood season flows at selected hydrology stations in the study basins relative to the period of 1980-1999, scenario B2

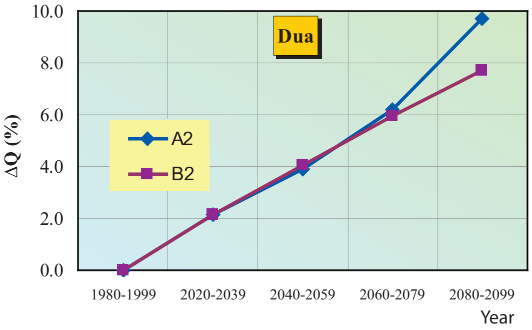
No	Station	Sông	Basin area (km²)	Average flow in flood season for periods (m³/s)				The change relative to the period 1980-1999					
				1980-1999	2020 - 2039	2040-2059	2080-2099	2020-2039		2040-2059		2080-2099	
								m³/s	%	m³/s	%	m³/s	%
1	Yen Bai	Thao	48,000	1,188	1,209	1,231	1,271	20.5	1.7	42.1	3.6	82.7	7.0
2	Lai Chau	Da	33,800	2,566	2,611	2,649	2,718	44.3	1.7	82.5	3.2	152	5.9
3	Ta Bu	Da	45,900	3,389	3,442	3,493	3,587	53.0	1.6	104	3.1	199	5.9
4	Ha Giang	Lo	8,298	346	352	356	365	5.57	1.6	9.65	2.8	18.5	5.4
5	Ham Yen	Lo	11,900	769	780	792	816	10.2	1.3	22.3	2.9	46.2	6.0
6	Ghenh Ga	Lo	29,600	1,384	1,404	1,422	1,460	19.1	1.4	37.4	2.7	75.4	5.5
7	Vu Quang	Lo	36,790	2,098	2,125	2,152	2,208	27.1	1.3	53.9	2.6	110	5.2
8	Chiem Hoa	Gam	16,500	640	651	658	674	10.1	1.6	17.5	2.7	33.5	5.2
9	Bao Yen	Chay	4,960	231	234	237	243	2.80	1.2	5.64	2.4	11.5	5.0
10	Thac Buoi	Cau	2,220	114	116	118	121	1.60	1.4	3.40	3.0	6.97	6.1
11	Chu	Luc Nam	2,090	74,9	76,0	77,4	80,1	1.09	1.5	2.49	3.3	5.18	6.9
12	Dua	Ca	20,800	741	758	771	798	16.7	2.3	30.3	4.1	57.2	7.7
13	Nghia Khanh	Hieu	4,024	216	220	223	229	4.24	2.0	7.30	3.4	13.4	6.2
14	Nong Son	Thu Bon	3,155	802	807	809	815	5.20	0.7	7.30	0.9	13.2	1.7
15	Thanh My	Cai	1,850	319	320	321	324	1.60	0.5	2.20	0.7	4.70	1.5
16	An Khe	Ba	1,440	105	105	106	108	0.27	0.3	1.05	1.0	3.08	2.9
17	Cung Son	Ba	12,800	627	630	635	654	3.0	0.5	8.00	1.3	27.0	4.3
18	Tri An	Dong Nai	14,800	889	864	853	826	-24.6	-2.8	-35.2	-4.0	-63.0	-7.1
19	Ta Pao	La Nga	2,010	157	154	153	149	-2.90	-1.9	-4.20	-2.7	-7.40	-4.7
20	Phuoc Long	Be	2,370	158	154	153	149	-3.90	-2.5	-5.20	-3.3	-9.00	-5.7
21	Phuoc Hoa	Be	5,240	489	468	462	453	-21.8	-4.5	-27.8	-5.7	-36.4	-7.4

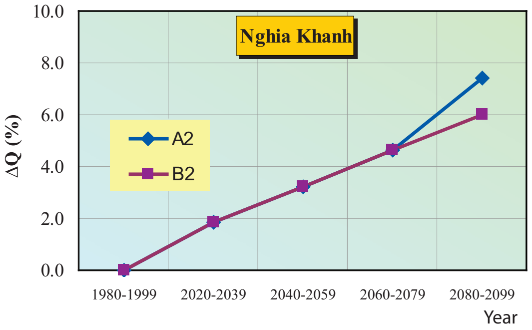
Table 3-7. Change in flood season flows at selected hydrology stations in Mekong River basin relative to the period 1980 – 1999, under climate change and water use scenarios

Climate Change Scenarios	Station	Flow in flood season Baseline scenario(m^3/s)		Flow in flood season Development scenario (m^3/s)	Change in flow (m^3/s)		Change in flow (%)	
		1985-2000	2010-2050	2010- 2050	Baseline scenario: 2000	Development scenario: 2020	Baseline scenario: 2000	Development scenario: 2020
A2	Kratie	21,549	23,890	22,229	2,341	680	10.9	3.2
	Phnom Penh	20,217	21,711	20,495	1,494	278	7.4	1.4
	Tan Chau	14,435	15,266	14,589	831	154	5.8	1.1
B2	Kratie	21,549	22,609	20,940	1,060	-609	4.9	-2.8
	Phnom Penh	20,217	20,787	19,542	570	-675	2.8	-3.3
	Tan Chau	14,435	14,706	14,000	271	-435	1.9	-3.0

Figure 3-11. Changes in flood flow (%) relative to the period 1980-1999 at selected hydrology stations, scenario A2 and B2




Dua
A2
B2
ΔQ (%)
10.0
8.0
6.0
4.0
2.0
0.0
1980-1999
2020-2039
2040-2059
2060-2079
2080-2099
Year


Nghia Khanh
A2
B2
ΔQ (%)
10.0
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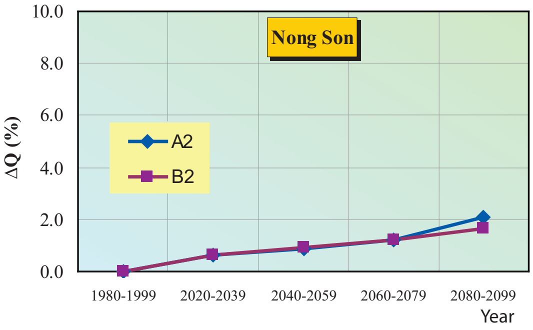
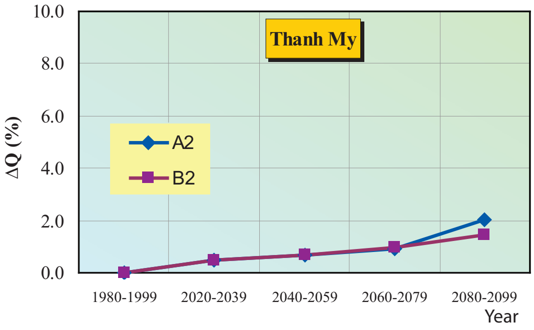
6.0
4.0
2.0
0.0
1980-1999
2020-2039
2040-2059
2060-2079
2080-2099
Year


Nong Son
A2
B2
ΔQ (%)
10.0
8.0
6.0
4.0
2.0
0.0
1980-1999
2020-2039
2040-2059
2060-2079
2080-2099
Year


Thanh My
A2
B2
ΔQ (%)
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6.0
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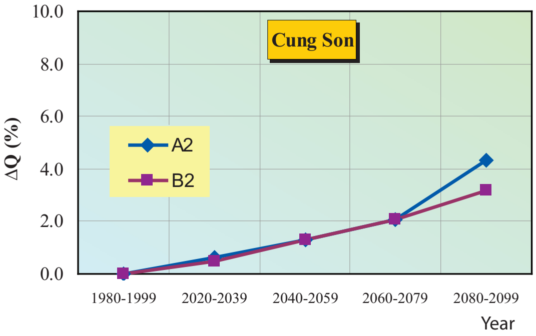
0.0
1980-1999
2020-2039
2040-2059
2060-2079
2080-2099
Year


Cung Son
A2
B2
ΔQ (%)
10.0
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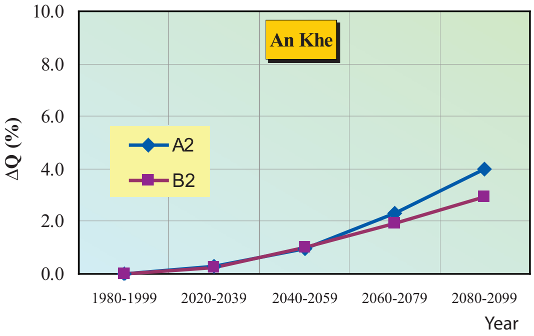
6.0
4.0
2.0
0.0
1980-1999
2020-2039
2040-2059
2060-2079
2080-2099
Year


An Khe
A2
B2
ΔQ (%)
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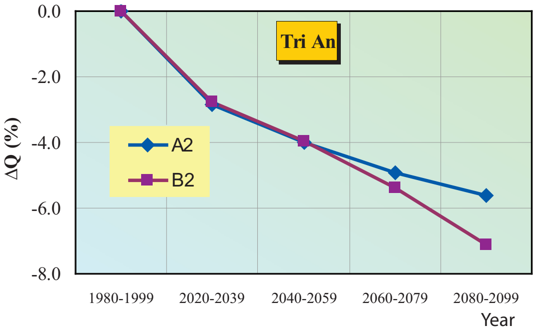
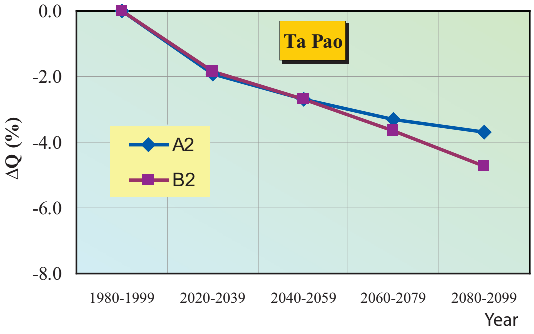
4.0
2.0
0.0
1980-1999
2020-2039
2040-2059
2060-2079
2080-2099
Year


Tri An
A2
B2
ΔQ (%)
0.0
-2.0
-4.0
-6.0
-8.0
1980-1999
2020-2039
2040-2059
2060-2079
2080-2099
Year


Ta Pao
A2
B2
ΔQ (%)
0.0
-2.0
-4.0
-6.0
-8.0
1980-1999
2020-2039
2040-2059
2060-2079
2080-2099
Year

Flood peak

In general, the impacts of climate change will increase the risk of flooding with increasing of flood peaks and flood volume. Tables 3-8 and 3-9 give the change in maximum annual flood peak corresponding to a 1% and 5% frequency at selected hydrology stations.

In general, the value of maximum flood peak (Q_{max}) corresponding to various frequencies follows an increasing trend for most rivers, with higher flows corresponding for low frequency. On for tributaries of Dong Nai and La Nga Rivers do Q_{max} decreases.

For the B2 scenario, in the period 2040-2059, Q_{max} values corresponding to 1% frequency ($Q_{max1\%}$) increase by approximately 1% to 5% compared to the period 1980-1999 for most rivers, with higher increase strongly in some tributaries of Red River (about 9% at Yen Bai, Vu Quang), and with decreases in La Nga River (-0.29% at Ta Pao) and upstream Be River (-1% at Phuoc Long). In the period 2080-2099, the increase of $Q_{max\,1\%}$ on most of the rivers is about 5÷15%, with greater increase in downstream of Ba River (18.5% at Cung Son), Thao River (21.7% at Yen Bai), and Lo River (19% at Ghenh Ga). However, in La Nga River and upsteam of Be River, $Q_{max1\%}$ reduces by approximately 0.5% to 2.5% during the period 2080-2099.

For the A2 scenario, Q_{max} values for most rivers follow an increasing trend compared to 1980-1999, but Q_{max} values decrease in La Nga River and upper part of Be basin, with the rate of change of Q_{max} is greater than for scenario B2. Moreover, the rate of change of Q_{max} corresponding to a 1% frequency is greater than for a 5% frequency. It shows that the rate of change of small floods is less than that of big and extreme floods (Fig. 3-12).

On the Mekong River, the maximum daily flow ($Q_{max-day}$) at Kratie in all climate change scenarios in each decade from 2010 to 2050 increases. However, the differences between the A2 and B2 scenarios are only significant after 2030. To mid 21st century, $Q_{max-day}$ could increase by over 50% compared to flood peak in 2000 (Fig. 3-13).

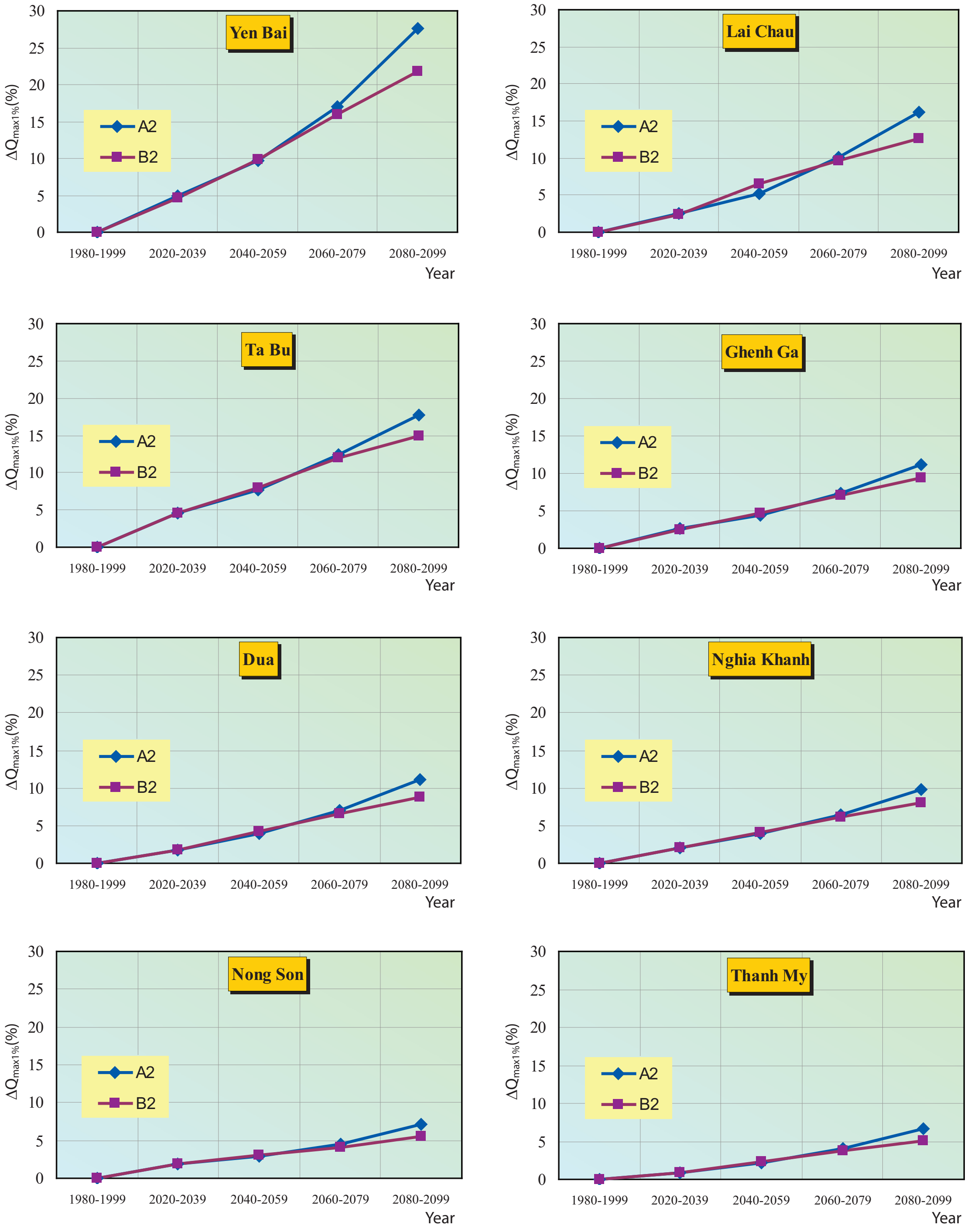
Table 3-8. Change in Flood peak (Q_{max}) corresponding to exceeding frequency of 1% and 5% at selected hydrology stations, scenario A2

Station	River	Basin area (km²)	Q_{max} (m³/s)		Q_{max} corresponding with exceeding frequencies for periods (m³/s)						Change Q_{max} relative 1980 - 1999					
			1989-1999		2020-2039		2040-2059		2080-2099		2020-2039		2040-2059		2080-2099	
			1%	5%	1%	5%	1%	5%	1%	5%	1%	5%	1%	5%	1%	5%
Yen Bai	Thao	48,000	10,418	8,611	10,932	8,937	11,423	9,285	13,298	10,573	4.9	3.8	9.7	7.8	27.6	22.8
Lai Chau	Da	33,800	14,130	12,230	14,653	12,645	15,025	12,958	16,274	14,010	3.7	3.4	6.3	6.0	15.2	14.6
Ta Bu	Da	45,900	21,837	17,515	22,502	18,134	23,056	18,597	24,758	20,012	3.1	3.5	5.6	6.2	13.4	14.3
Ha Giang	Lo	8,298	2,979	2,502	3,103	2,579	3,216	2,654	3,544	2,872	4.2	3.1	8.0	6.1	19.0	14.8
Ham Yen	Lo	11,900	6,601	5,161	6,773	5,286	6,964	5,427	7,517	5,807	2.6	2.4	5.5	5.2	13.9	12.5
Ghenh Ga	Lo	29,600	9,359	8,146	9,756	8,444	10,161	8,699	11,482	9,591	4.2	3.7	8.6	6.8	22.7	17.7
Vu Quang	Lo	36,790	12,549	9,270	13,211	9,762	13,864	10,144	15,989	11,508	5.3	5.3	10.5	9.4	27.4	24.1
Chiem Hoa	Gam	16,500	7,014	5,755	7,193	5,912	7,379	6,066	8,153	6,676	2.6	2.7	5.2	5.4	16.2	16.0
Bao Yen	Chay	4,960	3,357	2,447	3,536	2,559	3,674	2,639	4,081	2,897	5.3	4.6	9.4	7.9	21.6	18.4
Thac Buoi	Cau	2,220	3,371	2,611	3,525	2,724	3,630	2,809	3,971	3,085	4.6	4.3	7.7	7.6	17.8	18.1
Chu	Luc Nam	2,090	4,094	3,256	4,200	3,337	4,277	3,392	4,549	3,586	2.6	2.5	4.5	4.2	11.1	10.1
Dua	Ca	20,800	11,955	8,989	12,163	9,166	12,429	9,366	13,281	10,005	1.7	2.0	4.0	4.2	11.1	11.3
Nghia Khanh	Hieu	4,024	6,766	4,911	6,905	5,010	7,030	5,100	7,426	5,383	2.1	2.0	3.9	3.8	9.8	9.6
Nong Son	Thu Bon	3,155	9,347	7,460	9,545	7,584	9,649	7,666	10,079	8,008	2.1	1.7	3.2	2.8	7.8	7.4
Thanh My	Cai	1,850	5,628	4,206	5,676	4,247	5,753	4,304	6,011	4,498	0.9	1.0	2.2	2.3	6.8	6.9
An Khe	Ba	1,440	3,280	25,00	3,510	2,590	3,590	2,650	3,810	2,850	7.0	3.6	9.5	6.0	16.2	14.0
Cung Son	Ba	12,800	23,400	16,460	24,500	17,070	25,120	17,480	28,470	19,700	4.7	3.7	7.4	6.2	21.7	19.7
Tri An	Dong Nai	14,800	3,620	3,300	3,619	3,293	3,617	3,281	3,600	3,250	0.0	-0.2	-0.1	-0.6	-0.6	-1.5
Ta Pao	La Nga	2,010	1,112	932	1,110	931	1,110	931	1,106	928	-0.1	-0.1	-0.2	-0.2	-0.5	-0.5
Phuoc Long	Be	2,370	1,416	1,176	1,407	1,173	1,404	1,173	1,385	1,170	-0.6	-0.3	-0.9	-0.3	-2.2	-0.6
Phuoc Hoa	Be	5,240	2070	1682	2069	1681	2067	1680	2051	1668	0.0	-0.1	-0.2	-0.1	-0.9	-0.9

Table 3-9. Change in Flood peak (Q_{max}) corresponding to exceeding frequency of 1% and 5% at selected hydrology stations, scenario B2

Station	River	Basin area (km²)	Q_{max} (m³/s)		Q_{max} corresponding with exceeding frequencies for periods (m³/s)						Change in Q_{max} (%) relative to 1980 - 1999					
			1989-1999		2020-2039		2040-2059		2080-2099		2020-2039		2040-2059		2080-2099	
			1%	5%	1%	5%	1%	5%	1%	5%	1%	5%	1%	5%	1%	5%
Yen Bai	Thao	48,000	10,418	8,611	10,902	8,915	11,448	9,300	12,682	10,133	4.7	3.5	9.9	8.0	21.7	17.7
Lai Chau	Da	33,800	14,130	12,230	14,638	12,640	15,068	12,991	15,925	13,714	3.6	3.4	6.6	6.2	12.7	12.1
Ta Bu	Da	45,900	21,837	17,515	22,524	18,138	23,110	18,639	24,129	19,550	3.2	3.6	5.8	6.4	10.5	11.6
Ha Giang	Lo	8,298	2,979	2,502	3,099	2,578	3,223	2,658	3,466	2,818	4.0	3.0	8.2	6.2	16.4	12.6
Ham Yen	Lo	11,900	6,601	5,161	6,772	5,285	6,976	5,436	7,347	5,667	2.6	2.4	5.7	5.3	11.3	9.8
Ghenh Ga	Lo	29,600	9,359	8,146	9,743	8,439	10,198	8,721	11,136	9,357	4.1	3.6	9.0	7.1	19.0	14.9
Vu Quang	Lo	36,790	12,549	9,270	13,306	9,823	13,885	10,142	14,551	10,564	6.0	6.0	10.7	9.4	16.0	14.0
Chiem Hoa	Gam	16,500	7,014	5,755	7,185	5,908	7,468	6,131	7,899	6,471	2.4	2.7	6.5	6.5	12.6	12.4
Bao Yen	Chay	4,960	3,357	2,447	3,531	2,559	3,687	2,644	3,969	2,812	5.2	4.6	9.8	8.1	18.2	14.9
Thac Buoi	Cau	2,220	3,371	2,611	3,524	2,723	3,641	2,817	3,876	3,009	4.5	4.3	8.0	7.9	15.0	15.2
Chu	Luc Nam	2,090	4,094	3,256	4,194	3,335	4,288	3,399	4,478	3,533	2.5	2.4	4.7	4.4	9.4	8.5
Dua	Ca	20,800	11,955	8,989	12,163	9,166	12,455	9,385	13,001	9,795	1.7	2.0	4.2	4.4	8.8	9.0
Nghia Khanh	Hieu	4,024	6,766	4,911	6,902	5,008	7,041	5,107	7,309	5,299	2.0	2.0	4.1	4.0	8.0	7.9
Nong Son	Thu Bon	3,155	9,347	7,460	9,546	7,585	9,656	7,672	9,912	7,875	2.1	1.7	3.3	2.8	6.0	5.6
Thanh My	Cai	1,850	5,628	4,206	5,676	4,247	5,758	4,309	5,922	4,431	0.9	1.0	2.3	2.5	5.2	5.4
An Khe	Ba	1,440	3,280	2,500	3,410	2,560	3,450	2,620	3,580	2,710	4.0	2.4	5.2	4.8	9.2	8.4
Cung Son	Ba	12,800	23,400	16,460	24,140	16,830	25,130	17,400	27,730	19,050	3.2	2.3	7.4	5.7	18.5	15.7
Tri An	Dong Nai	14,800	3622,5	3295,9	3,619	3,289	3,616	3,276	3,581	3,235	-0.1	-0.2	-0.2	-0.6	-1.2	-1.9
Ta Pao	La Nga	2,010	1,112	932	1,110	931	1,109	930	1,099	926	-0.2	-0.2	-0.3	-0.2	-1.1	-0.7
Phuoc Long	Be	2,370	1,416	1,176	1,406	1,172	1,402	1,171	1,377	1,165	-0.7	-0.3	-1.0	-0.4	-2.7	-1.0
Phuoc Hoa	Be	5,240	2,070	1,682	2,069	1,679	2,065	1,678	2,045	1,663	-0.1	-0.2	-0.3	-0.2	-1.2	-1.1

Figure 3-12. Change in flood peak (%) corresponding to exceeding 1% frequency relative to the period 1980-1999 at selected hydrology stations



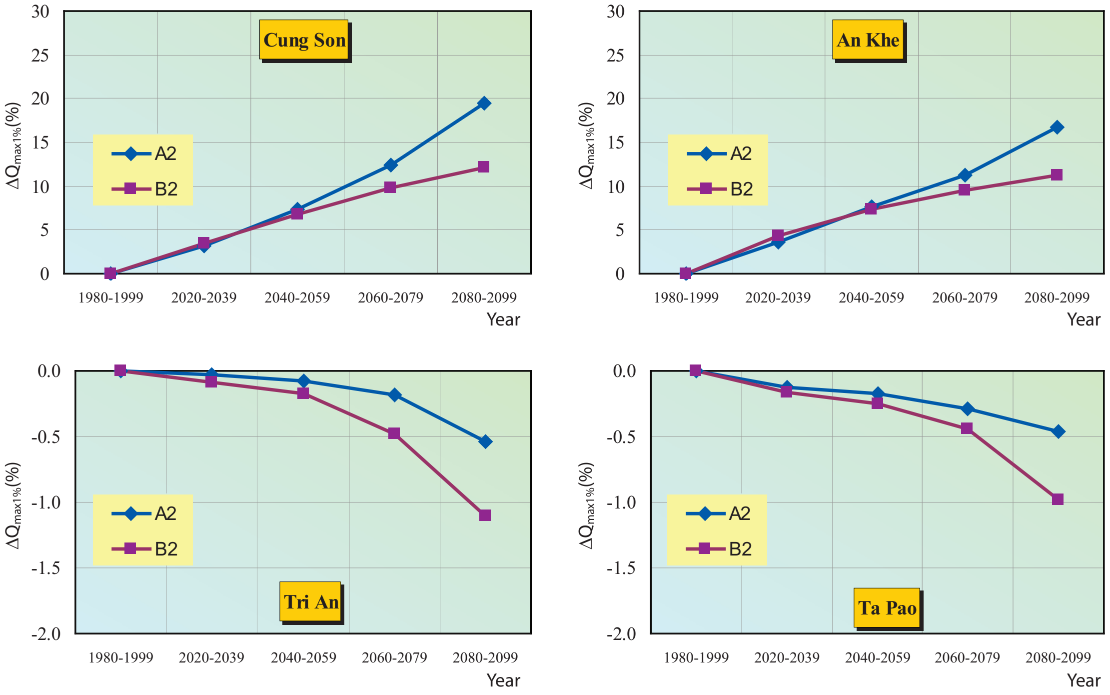
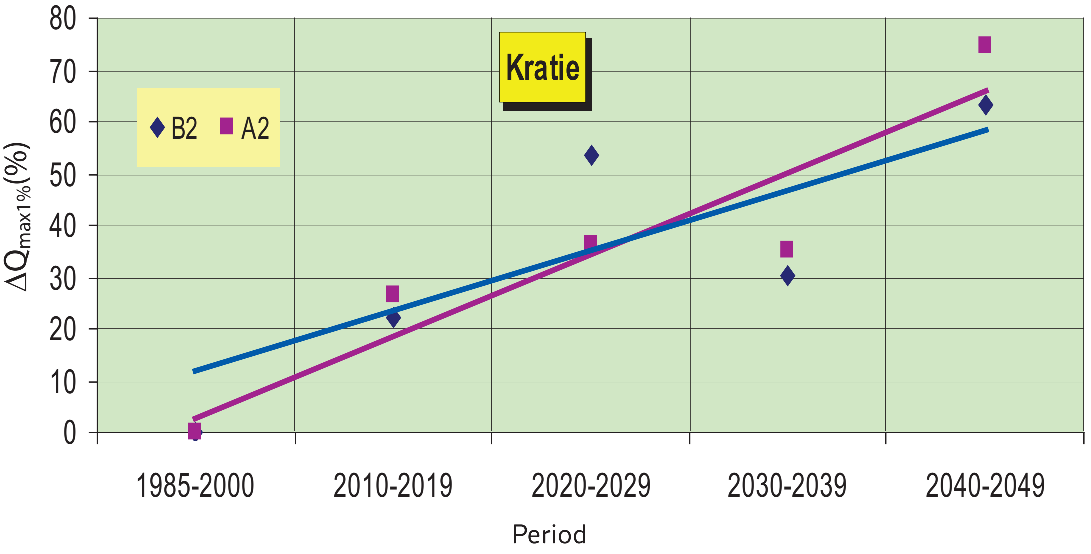


Figure 3-13. Change in daily flood peak (%) at Kratie relative to the period 1985 - 2000



3.2.3. Flow in dry season

Unlike annual and flood flows, flow in the dry season of all rivers within Vietnam will decrease due to the impacts of climate change. However, the decreases are quite different between rivers, and are even different between upstream, middle and downstream of one river. In addition, results from the A2 scenario show a greater decrease in dry weather flows than those in the B2 scenario.

In the period 2040-2059, the magnitude of decrease of average dry weather flow varies from below 1.5% in Da, Gam and Hieu Rivers to over 10% in Ba River; and for most rivers is in the range 3% to10% (Tables 3-11, 3-12, Fig. 3-14).

According to calculation by MRC, as a result of climate change the average flow in the dry season In the Mekong River increases by approximately 20% at Kratie and 10% at Tan Chau by the mid 21st century. While the average flows in the three driest months in the period 2010-2050 still tend to increase such increase is limited to 10% in both scenarios at Tan Chau and Chau Doc. In 2010-2050, the average flow for one dry month at Tan Chau station decreases by approximately 5% in scenario B2 and increases approximately 3% in scenario A2. When considering regulation effect of reservoir systems in combination with the future impacts of climate change, the average flow in the dry season may increase by approximately 40% at Kratie and about below 20% at Tan Chau (Table 3-10).

Table 3-10. Change in dry season flows at selected hydrology stations of the Mekong basin relative to the period 1980 – 1999, under climate change and water use scenarios

Climate Change Scenarios	Station	Flow in dry season Baseline scenario (m^3/s)		Flow in dry season Development scenario (m^3/s)	Change in flows (m^3/s)		Change in flows (%)			
		1985-2000	2010-2050	2010-2050	Low-flow Baseline scenario 2000	Low-flow Dev scenario 2020	Low-flow Baseline scenario 2000	Low-flow Dev scenario 2020	3-month minimum flow, Dev scenario 2000	1-month minimum flow, Dev scenario 2020
A2	Kratie	3,622	4,420	5,204	798	1,582	22.0	43.7	5.5	-0.1
	Phnom Penh	3,718	4,492	5,279	774	1,561	20.8	42.0	7.0	1.4
	Tan Chau	5,052	5,700	6,066	648	1,014	12.8	20.1	7.1	1.3
B2	Kratie	3,622	4,301	5,149	679	1,527	18.7	42.2	2.9	-4.6
	Phnom Penh	3,718	4,359	5,198	641	1,480	17.2	39.8	1.7	-4.4
	Tan Chau	5,052	5,586	5,914	534	862	10.6	17.1	1.4	-4.8

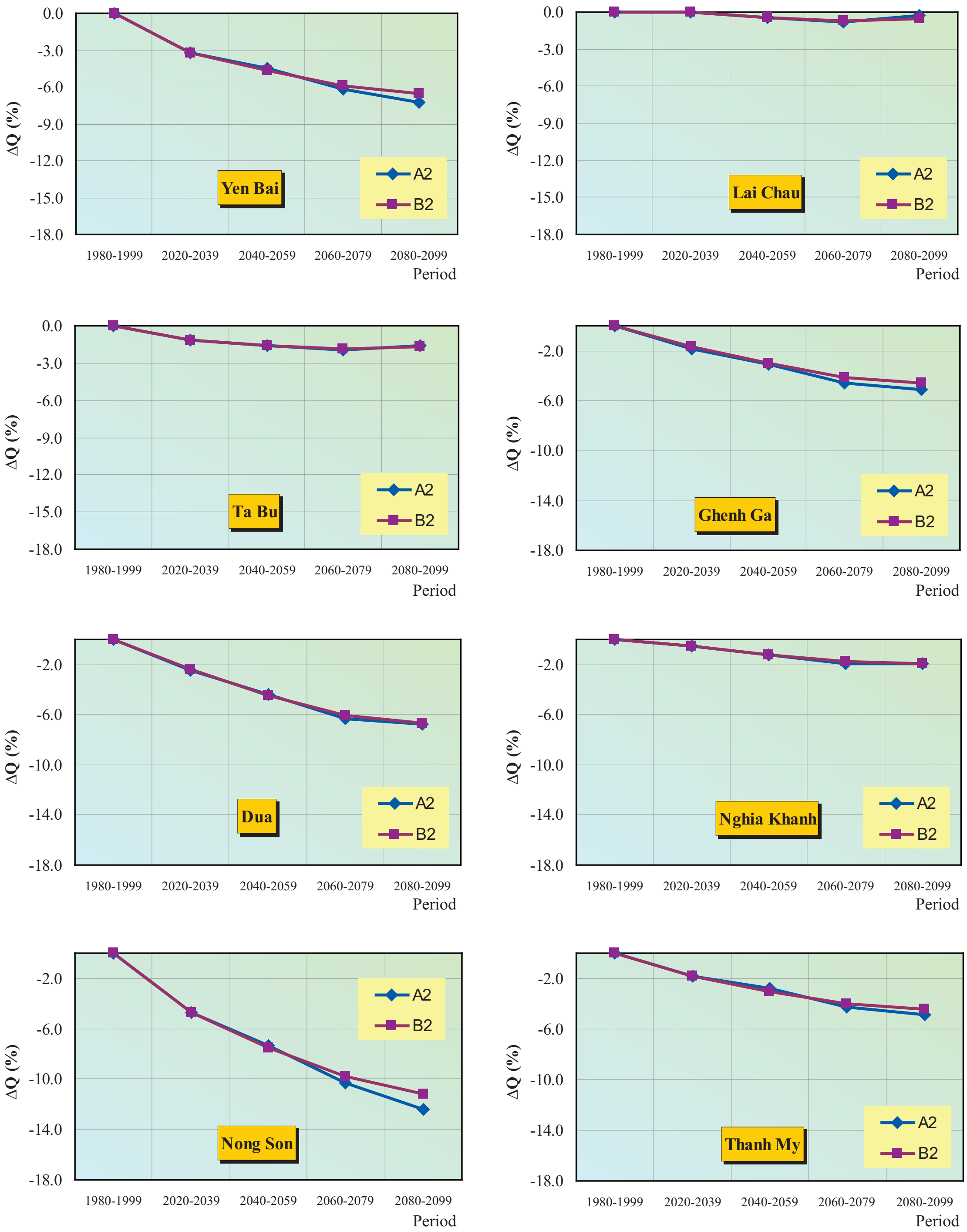
Table 3-11. Change in dry season flows at selected hydrology stations of the study basins relative to the period 1980-1999, high emissions scenario A2

No	Station	River	Basin area (km²)	Average flow in dry season for periods (m³/s)				The change relative to the period of 1980-1999					
				1980-1999	2020 - 2039	2040-2059	2080-2099	Period 2020-2039		Period 2040-2059		Period 2080-2099	
								m³/s	%	m³/s	%	m³/s	%
1	Yen Bai	Thao	48,000	364	352	348	338	-11.9	-3.3	-16.4	-4.5	-26.3	-7.2
2	Lai Chau	Da	33,800	361	361	360	360	-0.10	0.0	-1.50	-0.4	-1.03	-0.3
3	Ta Bu	Da	45,900	498	492	490	490	-5.60	-1.1	-7.80	-1.6	-7.86	-1.6
4	Ha Giang	Lo	8,298	62.8	63.5	62.9	62.5	0.69	1.1	0.11	0.2	-0.27	-0.4
5	Ham Yen	Lo	11,900	145	138	136	133	-7.05	-4.9	-8.99	-6.2	-12.1	-8.3
6	Ghenh Ga	Lo	29,600	366	360	355	348	-6.64	-1.8	-11.4	-3.1	-18.9	-5.2
7	Vu Quang	Lo	36,790	487	478	472	462	-8.93	-1.8	-15.0	-3.1	-24.8	-5.1
8	Chiem Hoa	Gam	16,500	188	189	187	183	1.15	0.6	-1.27	-0.7	-5.24	-2.8
9	Bao Yen	Chay	4,960	69.1	67.8	66.8	65.1	-1.34	-1.9	-2.30	-3.3	-4.07	-5.9
10	Thac Buoi	Cau	2,220	20.4	20.1	19.9	19.5	-0.37	-1.8	-0.57	-2.8	-0.90	-4.4
11	Chu	Luc Nam	2,090	15.0	14.2	13.8	12.8	-0.80	-5.3	-1.22	-8.1	-2.17	-14.5
12	Dua	Ca	20,800	196	191	187	183	-4.86	-2.5	-8.55	-4.4	-13.3	-6.8
13	Nghia Khanh	Hieu	4,024	72.6	72.1	71.7	71.1	-0.41	-0.6	-0.88	-1.2	-1.41	-1.9
14	Nong Son	Thu Bon	3,155	108	103	100	94.6	-5.10	-4.7	-7.90	-7.3	-13.4	-12.4
15	Thanh My	Cai	1,850	49.6	48.7	48.2	47.2	-0.90	-1.8	-1.40	-2.8	-2.40	-4.8
16	An Khe	Ba	1,440	12.8	12.0	11.5	10.7	-0.84	-6.6	-1.27	-9.9	-2.07	-16.2
17	Cung Son	Ba	12,800	122	113	109	101	-9.00	-7.4	-13.0	-10.7	-21.0	-17.2
18	Tri An	Dong Nai	14,800	121	117	114	110	-4.10	-3.40	-6.30	-5.2	-10.3	-8.53
19	Ta Pao	La Nga	2,010	29.4	28.2	27.5	25.9	-1.20	-4.1	-1.90	-6.5	-3.50	-11.9
20	Phuoc Long	Be	2,370	21.3	21	20.9	20.4	-0.30	-1.4	-0.40	-1.9	-0.90	-4.2
21	Phuoc Hoa	Be	5,240	71.9	69	67.8	65.9	-2.90	-4.0	-4.10	-5.7	-6.00	-8.3

Table 3-12. Change in dry season flows at selected hydrology stations of the study basins relative to the period 1980-1999, medium emissions scenario B2

Nº	Station	River	Basin area (km²)	Average flow in dry season for periods (m³/s)				The change relative to the period of 1980-1999					
				1980-1999	2020 - 2039	2040-2059	2080-2099	Period 2020-2039		Period 2040-2059		Period 2080-2099	
								m³/s	%	m³/s	%	m³/s	%
1	Yen Bai	Thao	48,000	364	352	347	340	-11.7	-3.2	-16.8	-4.6	-24.0	-6.6
2	Lai Chau	Da	33,800	361	361	360	359	-0.05	0.0	-1.67	-0.5	-2.03	-0.6
3	Ta Bu	Da	45,900	498	492	490	489	-5.56	-1.1	-7.92	-1.6	-8.55	-1.7
4	Ha Giang	Lo	8,298	62.8	63.5	62.9	62.4	0.69	1.1	0.08	0.1	-0.35	-0.6
5	Ham Yen	Lo	11,900	145	138	137	135	-6.72	-4.6	-8.58	-5.9	-10.6	-7.3
6	Ghenh Ga	Lo	29,600	366	360	355	350	-6.23	-1.7	-11.1	-3.0	-16.7	-4.6
7	Vu Quang	Lo	36,790	487	478	472	464	-8.49	-1.7	-14.8	-3.1	-22.2	-4.6
8	Chiem Hoa	Gam	16,500	188	189	187	184	1.19	0.6	-1.44	-0.8	-4.62	-2.5
9	Bao Yen	Chay	4,960	69.1	67.8	66.7	65.4	-1.33	-1.9	-2.38	-3.5	-3.72	-5.4
10	Thac Buoi	Cau	2,220	20.4	20.1	19.9	19.6	-0.37	-1.8	-0.58	-2.8	-0.85	-4.1
11	Chu	Luc Nam	2,090	15.0	14.2	13.7	13.0	-0.79	-5.3	-1.25	-8.4	-1.94	-12.9
12	Dua	Ca	20,800	196	191	187	183	-4.68	-2.4	-8.79	-4.5	-13.0	-6.7
13	Nghia Khanh	Hieu	4,024	72.6	72.2	71.7	71.2	-0.39	-0.5	-0.91	-1.3	-1.39	-1.9
14	Nong Son	Thu Bon	3,155	108	103	100	95.9	-5.10	-4.7	-8.10	-7.5	-12.1	-11.2
15	Thanh My	Cai	1,850	49.6	48.7	48.1	47.4	-0.90	-1.8	-1.50	-3.0	-2.20	-4.4
16	An Khe	Ba	1,440	12.8	12.0	11.5	10.9	-0.84	-6.6	-1.32	-10.3	-1.91	-15.0
17	Cung Son	Ba	12,800	122	113	109	103	-9.00	-7.4	-13.0	-10.7	-19.0	-15.6
18	Tri An	Dong Nai	14,800	121	117	114	111	-4.20	-3.5	-6.30	-5.2	-10.0	-8.3
19	Ta Pao	La Nga	2,010	29.4	28.2	27.5	26.2	-1.20	-4.1	-1.90	-6.5	-3.20	-10.9
20	Phuoc Long	Be	2,370	21.3	21.0	20.9	20.7	-0.30	-1.4	-0.40	-1.9	-0.60	-2.8
21	Phuoc Hoa	Be	5,240	71.9	69.0	68.0	67.0	-2.90	-4.0	-3.90	-5.4	-4.90	-6.8

Figure 3-14. Change in dry season flows (%) at selected stations relative to the period 1980-1999



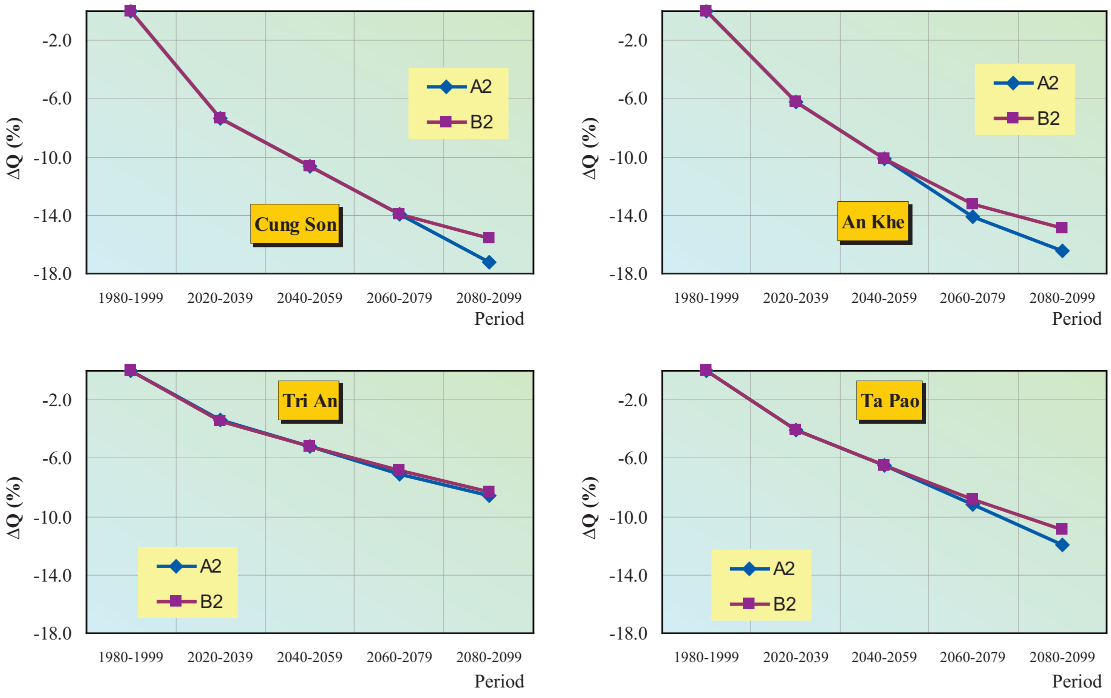
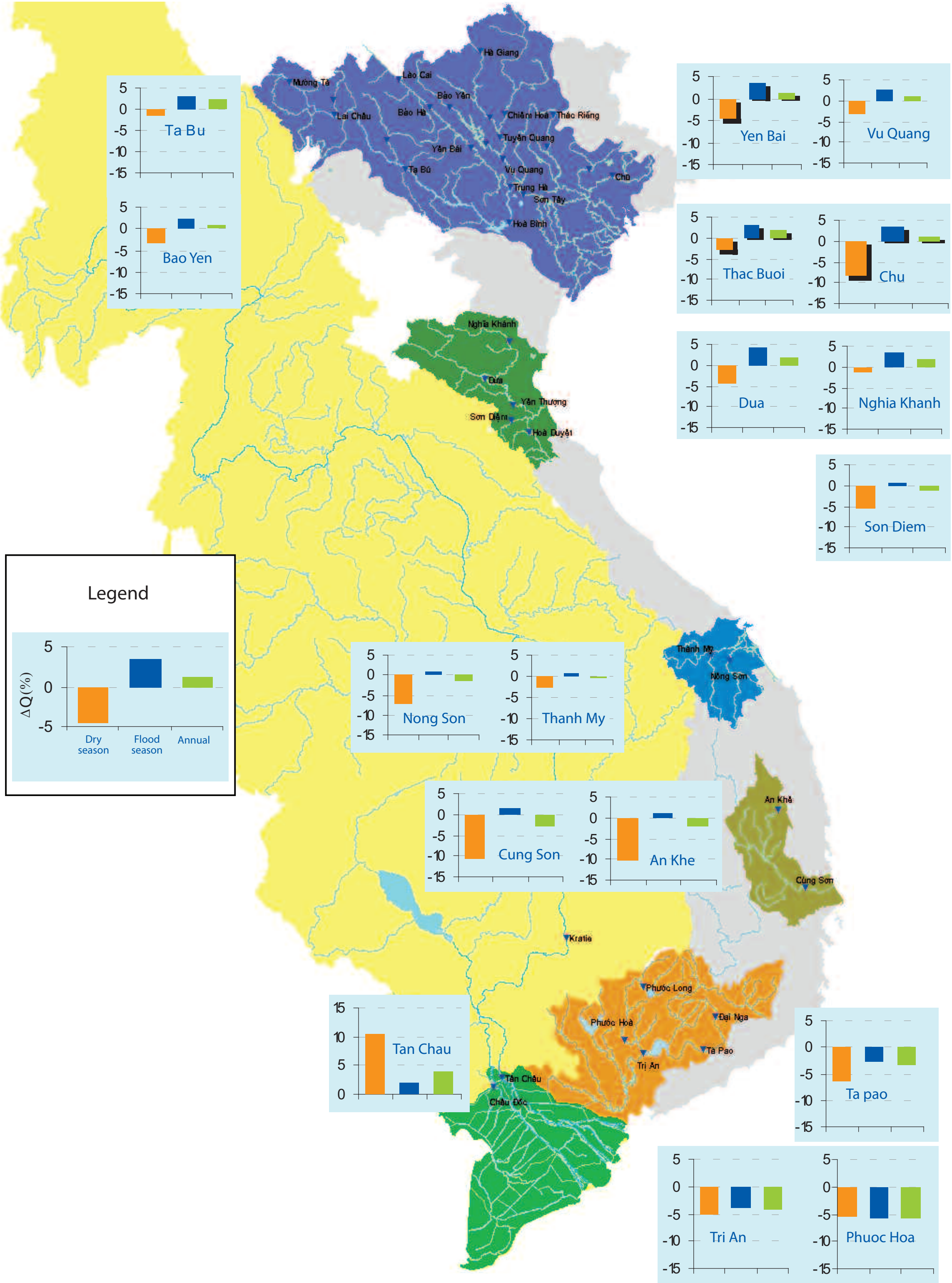

Cung Son
ΔQ (%)
-2.0
-6.0
-10.0
-14.0
-18.0
A2
B2
1980-1999
2020-2039
2040-2059
2060-2079
2080-2099
Period
An Khe
ΔQ (%)
-2.0
-6.0
-10.0
-14.0
-18.0
A2
B2
1980-1999
2020-2039
2040-2059
2060-2079
2080-2099
Period
Tri An
ΔQ (%)
-2.0
-6.0
-10.0
-14.0
-18.0
A2
B2
1980-1999
2020-2039
2040-2059
2060-2079
2080-2099
Period
Ta Pao
ΔQ (%)
-2.0
-6.0
-10.0
-14.0
-18.0
A2
B2
1980-1999
2020-2039
2040-2059
2060-2079
2080-2099
Period

Figure 3-15. Changes in flows by the middle of 21st century at selected hydrology stations



3.2.4. Flooding

Of all study basins, Red-Thai Binh and Ca river basins are protected by large reservoir and dyke systems. Therefore, for these two basins inundation was not calculated; instead, the maximum water levels on the rivers were calculated based on large floods that occurred during the baseline period 1980-1999. With the impacts of climate change, flood flows and flood peak tend to increase, leading to a greater possibility occurrence of big flood in the future. The historical flood was simulated with an increasing rate of maximum average daily flow and total flood volume that corresponded to the climate change scenarios for each time period. In combination with sea level rise, the increase in upstream flooding will lead to higher water levels along the river, threatening reservoirs and dyke systems.

It was assumed that reservoirs would regulate floods by using the full volume of the reservoir for flood protection, and by discharging the remaining water downstream, as simulated by hydraulic model downwards to the sea. The highest water levels at some positions along the rivers are presented in table 3-13.

Table 3-13. Maximum water level (H_{max}) at locations on Red- Thai Binh River and Ca River according to scenarios

River system	Location	Maximum water of big flood at periods (m)			
		1980-1999	2020 - 2039	2040 - 2059	2080 - 2099
Scenario A2					
Red and Thai Binh	Viet Tri	15.85	15.99	16.06	16.36
	Trung Ha	17.28	17.44	17.51	17.85
	Son Tay	14.51	14.65	14.71	15.02
	Ha Noi	11.42	11.55	11.62	11.92
	Hung Yen	7.26	7.35	7.4	7.62
	Thuong Cat	11.4	11.54	11.61	11.9
	Trieu Duong	6.58	6.68	6.73	6.97
	Pha Lai	6.29	6.41	6.47	6.71
	Ben Binh	5.07	5.19	5.24	5.47
Ca	Do Luong	19.4	19.4	19.5	20.0
	Outlet of Giang river	16.3	16.3	16.4	16.7
	Dung	14.3	14.4	14.4	14.8
	Yen Thuong	11.4	11.4	11.4	11.7
	Outlet of Gang river	10.5	10.5	10.5	10.8
	Nam Dan	9.59	9.62	9.62	9.83
	Yen Xuan bridge	6.93	6.95	6.98	7.14
	Cho Trang	6.56	6.57	6.61	6.76
	Ben Thuy port	5.24	5.26	5.29	5.48
	Hung Hoa	4.43	4.50	4.53	4.72
	Rao Dung	3.08	3.12	3.15	3.50

River system	Location	Maximum water of big flood at periods (m)			
		1980 - 1999	2020 - 2039	2040 - 2059	2080 - 2099
Scenario B2					
Red and Thai Binh	Viet Tri	15.85	15.96	16.07	16.2
	Trung Ha	17.28	17.39	17.51	17.7
	Son Tay	14.51	14.62	14.72	14.9
	Ha Noi	11.42	11.52	11.63	11.8
	Hung Yen	7.26	7.33	7.41	7.53
	Thuong Cat	11.4	11.51	11.61	11.8
	Trieu Duong	6.58	6.66	6.74	6.88
	Pha Lai	6.29	6.4	6.48	6.62
	Ben Binh	5.07	5.17	5.24	5.38
Ca	Do Luong	19.4	19.5	19.5	19.8
	Outlet of Giang river	16.3	16.3	16.4	16.6
	Dung	14.3	14.4	14.4	14.7
	Yen Thuong	11.4	11.4	11.4	11.6
	Outlet of Gang river	10.5	10.5	10.5	10.7
	Nam Dan	9.59	9.63	9.65	9.77
	Yen Xuan bridge	6.93	6.96	6.97	7.07
	Cho Trang	6.56	6.56	6.59	6.69
	Ben Thuy port	5.24	5.26	5.28	5.40
	Hung Hoa	4.43	4.48	4.52	4.63
	Rao Dung	3.08	3.09	3.13	3.37

In Red – Thai Binh River system, the historical flood event of 1996 on Da River was selected as the typical flood. The reservoirs used for flood regulation include Son La, Hoa Binh, Thac Ba and Tuyen Quang.

In Ca River basin, the historical flood event of 1988 was selected as the typical flood, with flood regulation by the reservoirs at Ban Ve, Ban Mong, Ngan Tuoi and Thac Muoi.

Although floods are regulated by the reservoirs, larger floods combined with sea level rise will mean that by the end of the 21st century, the highest flood level in Hanoi would still exceed the Alarm Level III (11.5m) by about 0.5m if the flood event of 1996 occurs. Similarly, on Ca River, with the flood event of 1988, the water level at Nam Dan would exceed Alarm Level III at about 1.8m.

The basins of Thu Bon, Ba, Dong Nai and MeKong Rivers would have serious inundation in dounstream areas due to increasing flood flows combined with sea level rise. Results of simulations of historical flood events under the impacts of climate change (including sea level rise) show that the flooding duration, depth and area increase markedly (Fig. 3-16).

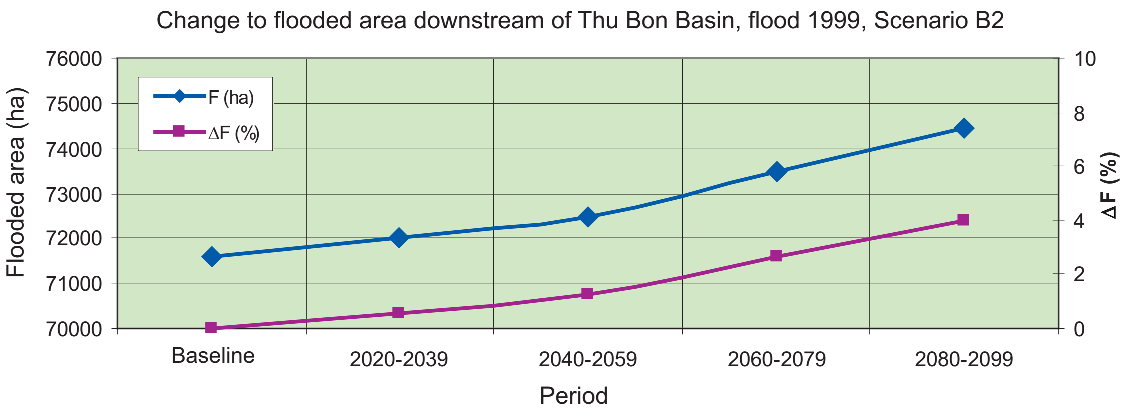
In Thu Bon River, if a flood similar to the historical level in 1999 occurs in 2050 and 2100, the flooded area will increase from between 1.5% and 4% compared to the present, even with regulation by hydropower reservoirs.

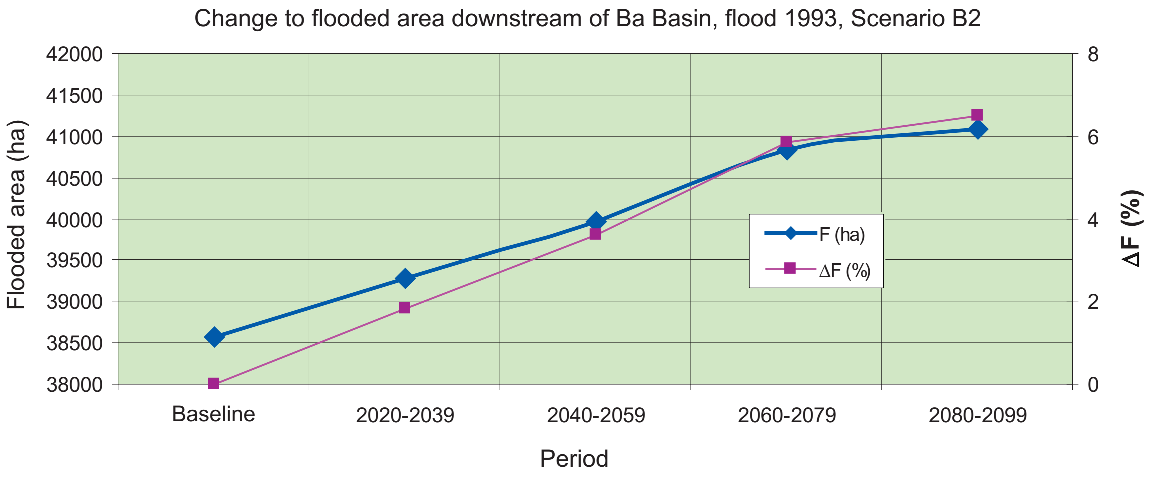
In Ba River, if a flood similar to the historical level of 1993 occurs, the flooded area will increase by 3.5% in 2050 and up to 6.5% in 2100 under scenario B2 and by 3.6% to 8.2% under scenario A2, even with regulation by hydropower reservoirs.

In Dong Nai River, the flooding area for a large flood similar to the one of 2000 will increase by 13% in 2050 to 18% in 2100. Although the Dau Tieng reservoir assists in preventing creek flooding, when the effects of sea level rise and upstream flood are taken into account, serious inundation will occur in downstream areas.

Details are presented in Figs. 3-16, 3-18 and Tables 3-14 to 3-19.

Figure 3-16. Change to flooded area downstream of study basins for big flood, scenario B2





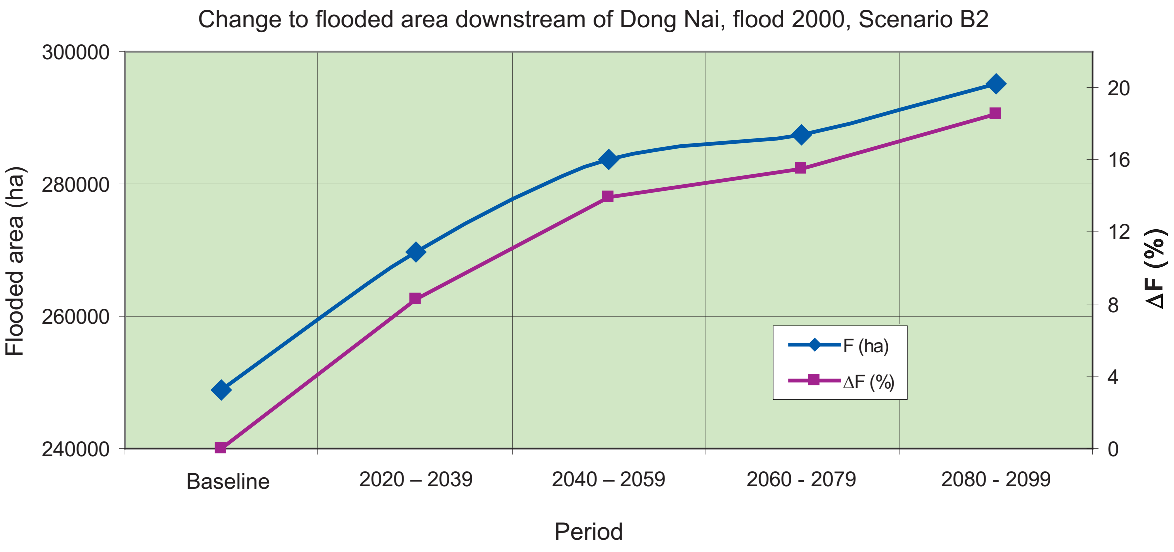


Table 3-14. Area and population affected by flooding, flood shape in 1999, with reservoir regulation, Thu Bon basin, scenario A2

Period	Depth classification (m)	Flooded area (ha)					Population
		Total	Industry and living	Agriculture	Aquaculture	Others	
1980 - 1999	<0.5	13,950	4,539	7,405	0	2,006	3,374
	0.5 - 1	13,880	4,387	7,745	0	1,748	8,147
	1-2	30,710	10,064	16,892	0	3,754	20,193
	2-3	10,680	2,989	6,191	0	1,501	22,042
	3-4	981	261	604	0	116	17,211
	>4	1,375	376	654	0	345	78,498
	Total	**71,576**	**22,615**	**39,491**	**0**	**9,470**	**149,465**
2020 - 2039	<0.5	14,360	4,673	7,621	0	2,066	3,155
	0.5 - 1	13,690	4,325	7,641	0	1,724	7,032
	1-2	30,870	10,118	16,980	0	3,772	20,284
	2-3	10,840	3,034	6,283	0	1,524	22,027
	3-4	1,026	273	632	0	121	16,745
	>4	1,430	391	680	0	359	81,632
	Total	**72,216**	**22,813**	**39,836**	**0**	**9,567**	**150,877**
2040 - 2059	<0.5	14,570	4,741	7,733	0	2,096	3,239
	0.5 - 1	13,860	4,378	7,736	0	1,746	6,390
	1-2	30,990	10,155	17,046	0	3,789	20,745
	2-3	11,330	3,171	6,567	0	1,593	22,997
	3-4	1,057	281	650	0	125	18,525
	>4	1,478	404	703	0	371	79,647
	Total	**73,285**	**23,129**	**40,436**	**0**	**9,720**	**151,544**
2060 - 2079	<0.5	14,840	4,826	7,877	0	2,137	3,059
	0.5 - 1	14,050	4,438	7,842	0	1,770	5,724
	1-2	31,180	10,213	17,152	0	3,815	20,562
	2-3	11,450	3,204	6,636	0	1,609	22,788
	3-4	1,107	295	681	0	131	18,474
	>4	1,552	424	738	0	390	82,546
	Total	**74,179**	**23,401**	**40,926**	**0**	**9,852**	**153,151**
2080 - 2099	<0.5	15,030	4,888	7,980	0	2,162	2,987
	0.5 - 1	14,250	4,502	7,953	0	1,796	5,197
	1-2	31,600	10,349	17,384	0	3,868	23,707
	2-3	11,670	3,267	6,763	0	1,640	21,561
	3-4	1,208	322	743	0	142	18,330
	>4	1,664	455	791	0	418	86,766
	Total	**75,422**	**23,782**	**41,614**	**0**	**10,026**	**158,548**

Table 3-15. Area and population affected by flooding, flood shape in 1999, with reservoir regulation, Thu Bon basin, scenario B2

Period	Depth classification (m)	Flooded area (ha)					Population
		Total	Industry and living	Agriculture	Aquaculture	Others	
1980 - 1999	<0.5	13,950	4,539	7,405	0	2,006	3,374
	0.5 - 1	13,880	4,387	7,745	0	1,748	8,147
	1-2	30,710	10,064	16,892	0	3,754	20,193
	2-3	10,680	2,989	6,191	0	1,501	22,042
	3-4	981	261	604	0	116	17,211
	>4	1,375	376	654	0	345	78,498
	Total	**71,576**	**22,615**	**39,491**	**0**	**9,470**	**149,465**
2020 - 2039	<0.5	14,040	4,568	7,453	0	2,020	3,143
	0.5 - 1	13,870	4,382	7,741	0	1,746	7,067
	1-2	30,870	10,118	16,979	0	3,773	20,253
	2-3	10,820	3,028	6,272	0	1,520	22,008
	3-4	1,001	267	616	0	118	16,799
	>4	1,399	382	665	0	351	81,650
	Total	**72,000**	**22,744**	**39,726**	**0**	**9,530**	**150,921**
2040 - 2059	<0.5	14,250	4,637	7,563	0	2,050	3,234
	0.5 - 1	13,940	4,403	7,781	0	1,756	6,364
	1-2	30,830	10,102	16,959	0	3,769	20,760
	2-3	11,010	3,081	6,381	0	1,548	22,987
	3-4	1,006	268	619	0	119	18,496
	>4	1,420	388	675	0	356	79,747
	Total	**72,456**	**22,880**	**39,978**	**0**	**9,599**	**151,588**
2060 - 2079	<0.5	14,420	4,692	7,654	0	2,075	3,142
	0.5 - 1	14,130	4,463	7,887	0	1,780	5,827
	1-2	30,980	10,149	17,041	0	3,791	20,626
	2-3	11,330	3,170	6,567	0	1,593	22,541
	3-4	1,107	295	681	0	131	18,919
	>4	1,534	419	729	0	385	81,870
	Total	**73,501**	**23,188**	**40,559**	**0**	**9,754**	**152,923**
2080 - 2099	<0.5	14,610	4,752	7,756	0	2,103	3,043
	0.5 - 1	14,230	4,495	7,942	0	1,792	5,403
	1-2	31,280	10,244	17,207	0	3,829	21,128
	2-3	11,450	3,205	6,636	0	1,609	22,383
	3-4	1,208	322	743	0	143	18,537
	>4	1,651	452	785	0	415	82,900
	Total	**74,429**	**23,469**	**41,070**	**0**	**9,891**	**153,395**

Table 3-16. Area and population affected by flooding, flood shape in 1993, with reservoir regulation, Ba basin, scenario A2

Period	Depth classification (m)	Flooded area (ha)					Population
		Total	Industry and living	Agriculture	Aquaculture	Others	
1980 - 1999	<0.5	1,355	197	955	0	204	5,946
	0.5 - 1	2,550	376	1,831	0	342	12,062
	1-2	5,480	677	3,830	0	973	25,418
	2-3	5,747	552	3,827	0	1,368	26,611
	3-4	4,866	459	2,517	0	1,890	16,661
	>4	18,583	1,021	9,760	0	7,802	57,946
	Total	**38,582**	**3,282**	**22,720**	**0**	**12,579**	**144,646**
2020 - 2039	<0.5	1,196	184	789	0	222	5,355
	0.5 - 1	2,556	370	1,783	0	403	11,704
	1-2	5,210	648	3,592	0	970	23,883
	2-3	5,991	531	3,965	0	1,495	28,345
	3-4	4,602	459	2,340	0	1,803	16,146
	>4	19,723	1,106	10,193	0	8,424	61,413
	Total	**39,279**	**3,299**	**22,663**	**0**	**13,317**	**146,847**
2040 - 2059	<0.5	1,050	164	690	0	195	4,654
	0.5 - 1	2,404	351	1,656	0	396	10,543
	1-2	5,104	697	3,461	0	945	23,687
	2-3	5,944	576	3,906	0	1,462	28,284
	3-4	4,511	449	2,440	0	1,622	16,459
	>4	20,895	1,199	10,740	0	8,957	65,154
	Total	**39,908**	**3,437**	**22,893**	**0**	**13,578**	**148,781**
2060 - 2079	<0.5	932	143	594	0	195	4,200
	0.5 - 1	2,146	313	1,485	0	347	9,168
	1-2	5,120	716	3,436	0	968	23,319
	2-3	5,601	596	3,741	0	1,264	26,834
	3-4	4,638	442	2,537	0	1,659	18,264
	>4	22,320	1,323	11,454	0	9,542	69,470
	Total	**40,756**	**3,533**	**23,247**	**0**	**13,976**	**151,255**
2080 - 2099	<0.5	857	157	499	0	200	3,681
	0.5 - 1	1,830	292	1,175	0	363	8,234
	1-2	5,104	720	3,426	0	957	22,344
	2-3	5,415	564	3,633	0	1,217	24,289
	3-4	4,793	414	2,742	0	1,636	19,994
	>4	23,744	1,453	12,134	0	10,157	76,255
	Total	**41,742**	**3,601**	**23,611**	**0**	**14,531**	**154,799**

Table 3-17. Area and population affected by flooding, flood shape in 1993, with reservoir regulation, Ba basin, scenario B2

Period	Depth classification (m)	Flooded area (ha)					Population
		Total	Industry and living	Agriculture	Aquaculture	Others	
1980 - 1999	<0.5	1,355	197	955	0	204	5,946
	0.5 - 1	2,550	376	1,831	0	342	12,062
	1-2	5,480	677	3,830	0	973	25,418
	2-3	5,747	552	3,827	0	1,368	26,611
	3-4	4,866	459	2,517	0	1,890	16,661
	>4	18,583	1,021	9,760	0	7,802	57,946
	Total	**38,582**	**3,282**	**22,720**	**0**	**12,579**	**144,646**
2020 - 2039	<0.5	1,198	186	790	0	222	5,368
	0.5 - 1	2,560	370	1,786	0	404	11,741
	1-2	5,208	647	3,590	0	970	23,866
	2-3	5,990	531	3,964	0	1,495	28,327
	3-4	4,598	459	2,339	0	1,800	16,127
	>4	19,727	1,106	10,194	0	8,427	61,421
	Total	**39,281**	**3,300**	**22,664**	**0**	**13,318**	**146,850**
2040 - 2059	<0.5	1,082	166	691	0	225	4,670
	0.5 - 1	2,406	349	1,660	0	396	10,553
	1-2	5,118	698	3,466	0	954	23,693
	2-3	5,949	576	3,911	0	1,462	28,298
	3-4	4,516	448	2,448	0	1,620	16,437
	>4	20,900	1,201	10,730	0	8,968	65,143
	Total	**39,971**	**3,439**	**22,907**	**0**	**13,625**	**148,794**
2060 - 2079	<0.5	1,086	176	703	0	207	4,788
	0.5 - 1	2,252	333	1,524	0	395	9,774
	1-2	5,236	692	3,528	0	1,016	23,546
	2-3	5,810	570	3,938	0	1,302	28,043
	3-4	4,632	439	2,469	0	1,724	17,444
	>4	21,823	1,271	11,125	0	9,428	68,055
	Total	**40,839**	**3,482**	**23,286**	**0**	**14,071**	**151,650**
2080 - 2099	<0.5	883	142	538	0	203	3,937
	0.5 - 1	2,002	302	1,339	0	361	8,358
	1-2	5,220	742	3,508	0	970	23,473
	2-3	5,664	579	3,752	0	1,333	26,567
	3-4	4,862	414	2,749	0	1,699	19,833
	>4	22,450	1,384	11,469	0	9,597	70,063
	Total	**41,081**	**3,564**	**23,354**	**0**	**14,162**	**152,233**

Table 3-18. Area and population affected by flooding, flood shape in 2000, with reservoir regulation, Dong Nai basin, scenario A2

Period	Depth classification (m)	Flooded area (ha)					Population
		Total	Industry and living	Agriculture	Aquaculture	Others	
1980 - 1999	<0.5	181,922	28,289	107,989	410	45,234	2,820,000
	0.5 - 1	64,936	9,394	29,199	0	26,343	800,000
	1-2	2,038	267	1,462	0	309	250,000
	2-3	0	0	0	0	0	0
	3-4	0	0	0	0	0	0
	>4	99	78	0	0	21	0
	Total	**248,995**	**38,028**	**138,650**	**410**	**71,907**	**3,870,000**
2020 - 2039	<0.5	115,338	20,448	82,795	111	11,984	1,530,000
	0.5 - 1	83,313	16,943	41,063	411	24,896	2,290,000
	1-2	69,614	6,097	28,156	0	35,361	510,000
	2-3	3,305	1,559	1,104	0	642	0
	3-4	0	0	0	0	0	0
	>4	102	80	0	0	22	0
	Total	**271,672**	**45,127**	**153,118**	**522**	**72,905**	**4,340,000**
2040 - 2059	<0.5	121,415	21,410	90,055	92	9,857	1,520,000
	0.5 - 1	83,095	16,523	47,408	361	18,803	2,310,000
	1-2	77,490	9,024	24,834	69	43,563	790,000
	2-3	3,514	1,621	1,110	0	783	0
	3-4	0	0	0	0	0	0
	>4	102	80	0	0	22	0
	Total	**285,616**	**48,658**	**163,408**	**522**	**73,028**	**4,630,000**
2060 - 2079	<0.5	57,317	12,181	40,663	92	4,380	880,000
	0.5 - 1	106,958	21,473	76,722	0	8,764	2,450,000
	1-2	123,601	15,292	48,310	430	59,570	1,480,000
	2-3	3,844	1,877	1,120	0	847	0
	3-4	0	0	0	0	0	0
	>4	102	80	0	0	22	0
	Total	**291,822**	**50,902**	**166,815**	**522**	**73,582**	**4,800,000**
2080 - 2099	<0.5	30,176	4,419	17,503	92	8,162	1,510,000
	0.5 - 1	119,844	22,037	92,001	0	5,805	810,000
	1-2	162,210	26,541	74,201	430	61,038	2,970,000
	2-3	5,662	3,142	2,271	0	249	110,000
	3-4	0	0	0	0	0	0
	>4	268	221	0	0	47	0
	Total	**318,160**	**56,360**	**185,976**	**522**	**75,302**	**5,400,000**

Table 3-19. Area and population affected by flooding, flood shape in 2000, with reservoir regulation, Dong Nai basin, scenario B2

Period	Depth classification (m)	Flooded area (ha)					Population
		Total	Industry and living	Agriculture	Aquaculture	Others	
1980 - 1999	<0.5	181,922	28,289	107,989	410	45,234	2,820,000
	0.5 - 1	64,936	9,394	29,199	0	26,343	800,000
	1-2	2,038	267	1,462	0	309	250,000
	2-3	0	0	0	0	0	0
	3-4	0	0	0	0	0	0
	>4	99	78	0	0	21	0
	Total	**248,995**	**38,028**	**138,650**	**410**	**71,907**	**3,870,000**
2020 - 2039	<0.5	112,018	16,583	82,277	19	13,139	1,390,000
	0.5 - 1	84,687	17,288	41,483	411	25,504	2,050,000
	1-2	70,198	9,488	27,479	0	33,232	470,000
	2-3	2,715	1,169	1,000	0	546	0
	3-4	0	0	0	0	0	0
	>4	102	81	0	0	21	0
	Total	**269,720**	**44,610**	**152,239**	**430**	**72,441**	**3,910,000**
2040 - 2059	<0.5	117,975	24,742	88,161	92	4,980	1,460,000
	0.5 - 1	85,745	12,015	48,422	361	24,946	2,260,000
	1-2	76,920	10,063	24,544	69	42,244	790,000
	2-3	2,834	1,264	1,000	0	570	0
	3-4	0	0	0	0	0	0
	>4	102	81	0	0	21	0
	Total	**283,576**	**48,166**	**162,128**	**522**	**72,760**	**4,520,000**
2060 - 2079	<0.5	56,755	12,325	40,529	92	3,809	890,000
	0.5 - 1	114,995	22,200	79,380	19	13,397	2,470,000
	1-2	112,000	13,466	42,563	411	55,560	1,330,000
	2-3	3,675	1,800	1,336	0	539	0
	3-4	0	0	0	0	0	0
	>4	102	81	0	0	21	0
	Total	**287,527**	**49,872**	**163,808**	**522**	**73,325**	**4,680,000**
2080 - 2099	<0.5	20,894	6,720	10,930	92	3,152	780,000
	0.5 - 1	145,476	27,545	104,814	0	13,116	1,370,000
	1-2	123,820	14,478	51,886	430	57,027	2,570,000
	2-3	4,785	2,297	1,885	0	603	40,000
	3-4	0	0	0	0	0	0
	>4	102	81	0	0	21	0
	Total	**295,077**	**51,121**	**169,516**	**522**	**73,918**	**4,760,000**

Especially for Cuu Long Delta, every year in flood season, the Mekong River flood inundates nearly 2 million hectares, lasting 3-5 months. In years with bigger floods, significant human and property losses occur. However, flooding also brings alluvial soils to fertilise the land, abundant aqua-product and good effects in sanitary for rice fields. Large floods in the mid 21st century combined with sea level rise of about 30 cm would increase the flooded area by 25% greater than that of the historical flood of 2000. The flooded area would occupy almost 90% of all natural area of Cuu Long Delta. The flooded area (>0.5m deep) would be 2,660,000 ha (accounting for 68.3% area of Cuu Long Delta), an increase of 1,160,000 ha (equivalent to 29.5% natural area) compared to the flood in 2000. The flooded area (>1.0m deep) would be approximately 1,500,000 ha (accounting for 40% area of Cuu Long river delta), an increases of 500,000 ha (equivalent to 14% natural area) compared to the flood in 2000.

Floods would inundate the areas of Dong Thap Muoi and Long Xuyen quadrangle, with particularly serious flooding occurring in the area between the two rivers Tien and Hau. Apart from the cities and towns that are currently regularly flooded, such as Chau Doc, Long Xuyen and Cao Lanh, additional cities and towns would be flooded, including Sa Dec, Vinh Long, Tan An, My Tho, Can Tho, Vi Thanh, Soc Trang, Rach Gia and Ha Tien, which are inundated at more than 1.0 m. Among these towns, the most serious flooding occurs at Can Tho and Vinh Long.

Sea level rise also makes the drainage in My Tho, Ben Tre, Tra Vinh, Bac Lieu and Ca Mau more difficult.

Increasing upstream flooding and rising sea levels will limit the drainage on Mekong River system and lead to more serious inundation. This leads to earlier flooding and late easing of floodwaters, which can make drainage difficult and make planting and harvesting of crops difficult. Assuming similar land uses in 2100 as in 2010, the biggest inundated area in agriculture could reach 2,100,000 ha, which is 53% of the natural area of Cuu Long Delta, while flooding in industry and residences could reach 500,000 ha (12.6% of land area) and flooding in aquaculture 250,000 ha (6.3%). Details are provided in Tables 3-20 and 3-21 and in Figs. 3-17 and 3-18.

Figure 3-17. Change in flooded area in Cuu Long delta, scenario B2

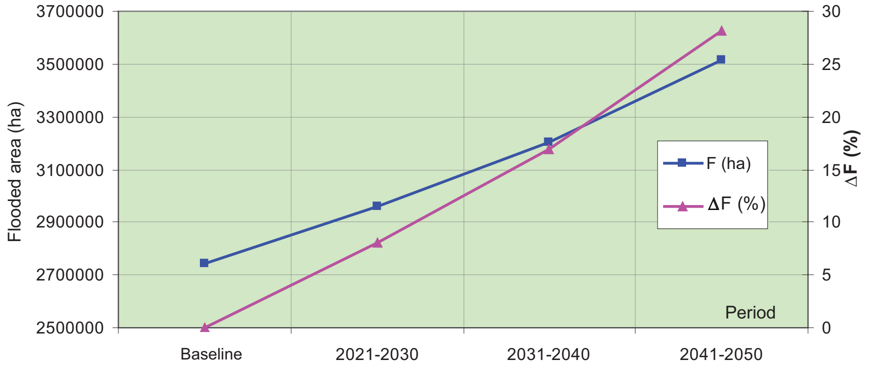


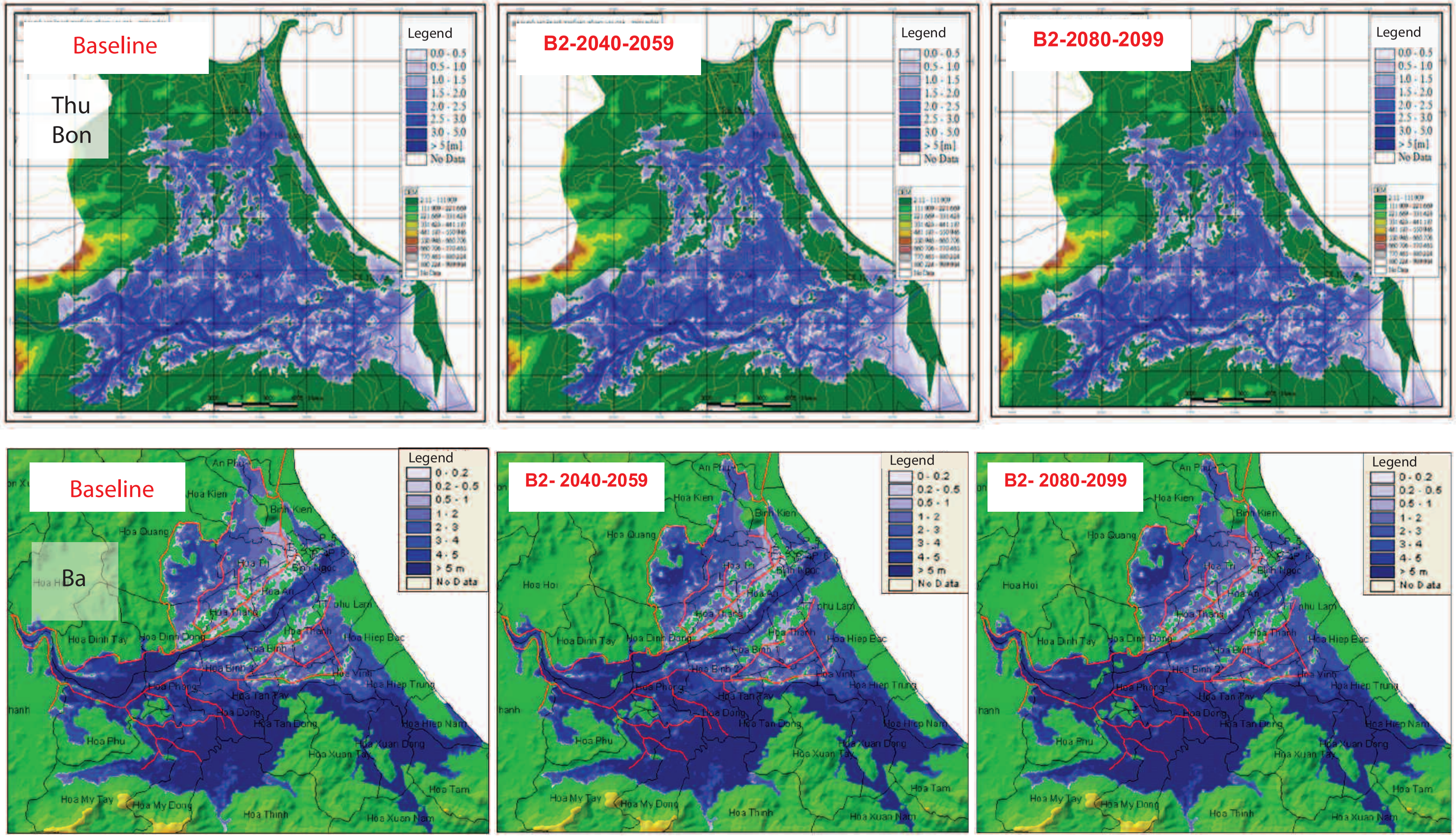
Table 3-20. Area and population affected by flooding, Cuu Long Delta, scenario A2

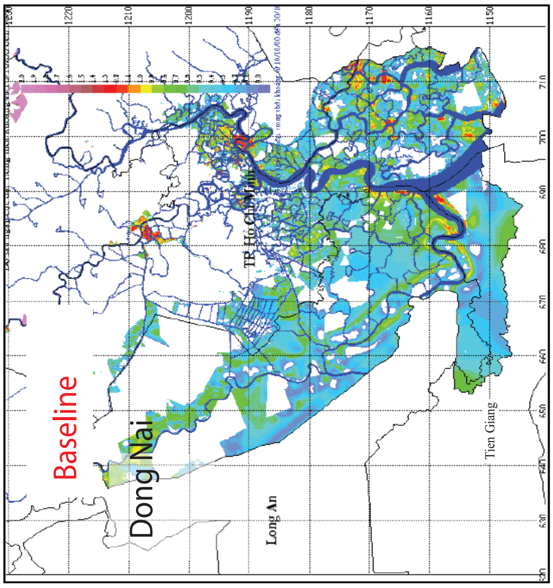
Period	Depth classification (m)	Flooded area (ha)						Population
		Total	Living and Industry	Agriculture	Aquaculture	Agriculture combined with aquaculture	Others	
2000	<0.5	1,210,551	474,885	197,069	218,073	248,239	735,666	4,010,000
	0.5 - 1	510,763	242,175	69,921	45,263	108,118	268,588	2,710,000
	1-2	534,572	337,642	69,122	17,269	40,451	196,930	2,160,000
	2-3	365,145	250,420	41,219	5,249	21,589	114,725	1,480,000
	3-4	112,044	82,832	8,697	1,052	2,850	29,212	432,000
	>4	7,843	3,551	1,167	0	0	4,292	44,000
	Total	**2,740,919**	**1,391,506**	**387,196**	**286,906**	**421,247**	**1,349,413**	**10,800,000**
2020-2029	<0.5	1,247,594	307,553	210,746	265,668	237,702	940,042	5,520,000
	0.5 - 1	707,179	426,101	122,735	93,787	163,257	281,078	3,480,000
	1-2	570,869	361,445	69,908	13,531	38,713	209,424	2,180,000
	2-3	353,942	23,512	17,485	2,087	9,881	330,431	1,460,000
	3-4	124,390	2,598	2,116	1,549	228	121,792	435,000
	>4	7,894	435	7	0	0	7,459	45,000
	Total	**3,011,868**	**1,121,644**	**422,997**	**376,620**	**449,782**	**1,890,224**	**13,100,000**
2030-2039	<0.5	1,028,156	357,500	171,174	267,076	165,109	670,656	4,300,000
	0.5 - 1	901,002	372,096	143,246	111,642	217,766	528,907	4,350,000
	1-2	692,562	422,611	86,964	36,141	72,639	269,951	3,040,000
	2-3	388,906	261,692	49,334	7,772	22,719	127,214	1,660,000
	3-4	197,562	144,462	16,013	1,482	6,714	53,100	677,000
	>4	11,219	5,415	1,673	0	1	5,804	61,000
	Total	**3,219,407**	**1,563,775**	**468,404**	**424,113**	**484,947**	**1,655,632**	**14,100,000**
2040-2049	<0.5	847,654	260,893	133,946	248,593	118,967	586,761	3,220,000
	0.5 - 1	1,144,046	413,549	178,983	211,373	232,520	730,497	4,900,000
	1-2	923,021	574,444	135,748	72,610	139,739	348,577	4,650,000
	2-3	387,695	257,632	48,894	4,455	25,494	130,062	1,680,000
	3-4	200,696	132,985	15,728	1,947	5,508	67,712	710,000
	>4	11,290	4,746	1,759	0	43	6,544	63,000
	Total	**3,514,403**	**1,644,250**	**515,058**	**538,978**	**522,272**	**1,870,153**	**15,200,000**

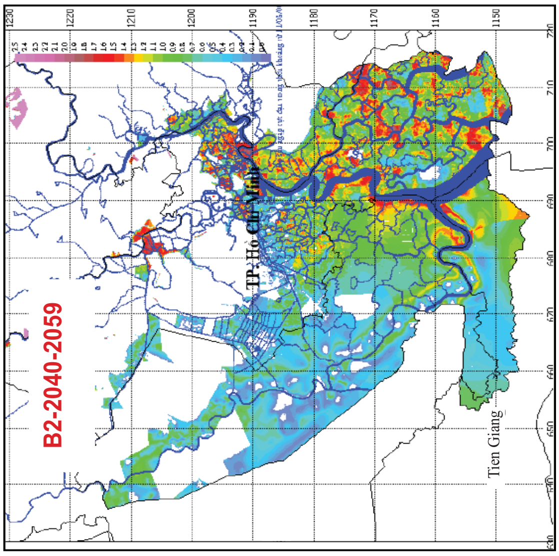
Table 3-21. Area and population affected by flooding, Cuu Long Delta, scenario B2

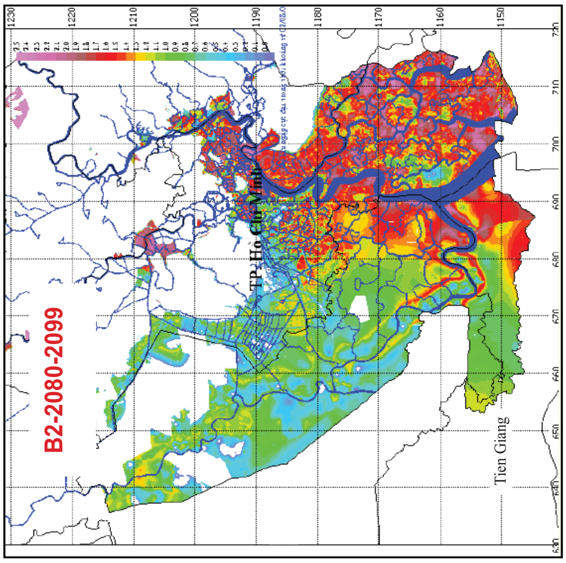
Period	Depth classification (m)	Flooded area (ha)						Population
		Total	Living and Industry	Agriculture	Aquaculture	Agriculture combined with aquaculture	Others	
2000	<0.5	1,210,551	474,885	197,069	218,073	248,239	735,666	4,010,000
	0.5 - 1	510,763	242,175	69,921	45,263	108,118	268,588	2,710,000
	1-2	534,572	337,642	69,122	17,269	40,451	196,930	2,160,000
	2-3	365,145	250,420	41,219	5,249	21,589	114,725	1,480,000
	3-4	112,044	82,832	8,697	1,052	2,850	29,212	432,000
	>4	7,843	3,551	1,167	0	0	4,292	44,000
	Total	2,740,919	1,391,506	387,196	286,906	421,247	1,349,413	10,800,000
2020-2029	<0.5	1,343,392	460,831	202,799	267,231	237,730	882,561	5,250,000
	0.5 - 1	595,224	320,113	100,535	82,009	142,626	275,111	3,520,000
	1-2	541,600	372,760	74,447	20,601	47,279	168,840	2,450,000
	2-3	360,614	243,614	41,133	2,791	21,254	117,000	1,490,000
	3-4	112,935	91,218	9,612	1,427	3,008	21,718	459,000
	>4	7,907	3,611	1,165	0	0	4,295	44,000
	Total	2,961,673	1,492,146	429,691	374,059	451,898	1,469,526	13,200,000
2030-2039	<0.5	1,162,840	418,291	193,174	279,549	199,598	744,549	4,810,000
	0.5 - 1	884,471	378,653	132,624	105,498	199,057	505,818	4,360,000
	1-2	651,902	412,013	82,799	35,576	57,565	239,890	2,730,000
	2-3	369,154	251,283	43,204	4,649	22,708	117,871	1,550,000
	3-4	129,021	92,385	10,024	1,549	3,398	36,636	497,000
	>4	8,195	3,740	1,209	0	0	4,456	46,000
	Total	3,205,585	1,556,364	463,034	426,821	482,327	1,649,220	14,000,000
2040-2049	<0.5	822,728	271,111	141,018	250,801	125,808	551,616	3,420,000
	0.5 - 1	1,119,506	422,545	181,854	212,146	248,221	696,961	5,120,000
	1-2	991,947	539,448	124,261	69,340	117,126	452,500	4,160,000
	2-3	381,317	259,308	49,895	7,792	25,200	122,009	1,670,000
	3-4	187,069	143,318	16,446	1,928	6,630	43,751	710,000
	>4	11,182	5,495	1,683	0	1	5,687	60,000
	Total	3,513,749	1,641,224	515,157	542,006	522,986	1,872,524	15,100,000

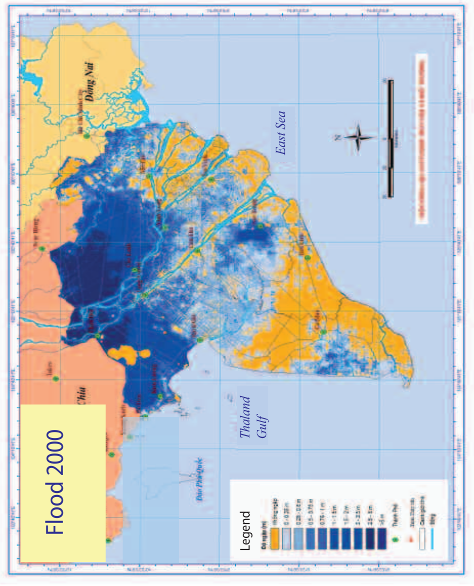
Figure 3-18. Flooded map of study basins

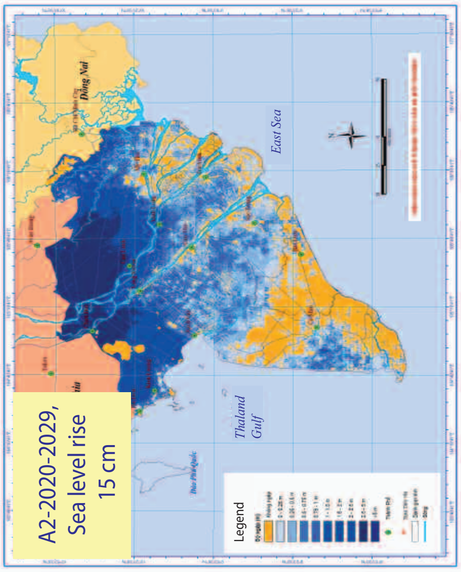


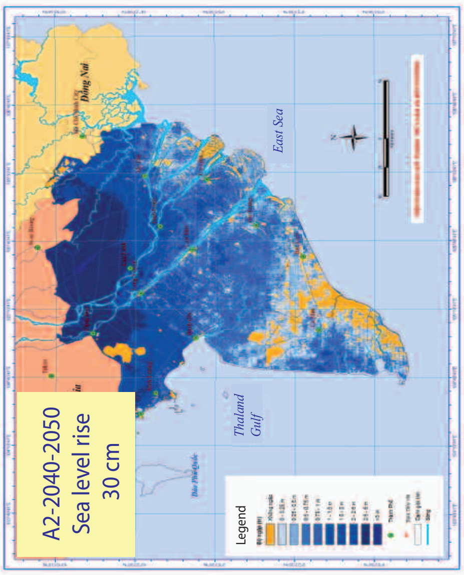

Baseline
Dong Nai
Long An
TP. Ho Chi Minh
Tien Giang


B2-2040-2059
TP. Ho Chi Minh
Tien Giang


B2-2080-2099
TP. Ho Chi Minh
Tien Giang


Flood 2000
Dong Nai
East Sea
Thaland Gulf
Legend


A2-2020-2029, Sea level rise 15 cm
Dong Nai
East Sea
Thaland Gulf
Legend


A2-2040-2050 Sea level rise 30 cm
Dong Nai
East Sea
Thaland Gulf
Legend

3.2.5. Salinity intrusion

Sea level will rises an average of 30 cm in 2050 and 75 cm in 2100. This, together with the decrease in low flow from upstream, means that salinity will intrude further into the mainland. The impact of climate change and sea level rise on salinity intrusion in the downstream areas of the river systems was assessed on the basis of calculation by hydraulic models with the upper boundaries being the average flow of the driest month of every 20-year period and with the corresponding sea level rise at each river mouth. Tables 3-22 and 3-23 show the depth of salinity intrusion at 1‰ and 4‰ downstream of corresponding river with various rates of sea level rise and scenarios A2 and B2. Tables 3-24 and 3-25 show the area (according to the map of land use planning as in 2010) under salinity intrusion at >1‰ and >4‰.

The map of salinity isoline (Figures 3-19 to 3-21) and calculation results show that under the effect of sea level rise and changes in water availability upstream due to climate change, salinity intrudes deeper into the mainland of Cuu Long Delta, downstream Dong Nai and Thai Binh Rivers than for other rivers. By the end of the 21st century, the depth of salinity intrusion at 1‰ may increase more than 10 km in Dong Nai, Tien, Hau and Thai Binh river.

Salinity intrusion will be quite severer for the Cuu Long River Delta. Over the next 30 years, the area under salinity intrusion at >4‰ is about 1,605,200 ha occupied 41% area of all Cuu Long Delta more 255,100 ha than baseline. The area under salinity >1‰ is 2,323,100 ha (59% of natural area), increasing 193,200 ha compared with present time. In the next 20 years, land use area under salinity intrusion >4‰ is 1,851,200 ha (47% of natural are), larger than baseline (1991-2000) about 439,200 ha. With salinity >1‰, the affected area is 2,524,100 ha (64% of natural are), more than baseline about 456,100 ha.

The 1‰ salinity boundary on Co Chien is 5 km far from Vinh Long city (deeper 9.5km than baseline), it is 3 km far from Can Tho city (deeper 8.8km than baseline) on Hau River.

The distances for 4‰ salinity boundary are 9.2 km deeper than present on Co Chien River and 8.4 km deeper than baseline on Hau River.

Nearly four-fifths of the area of the Ca Mau peninsular is under salinity intrusion (except the western part of Hau River). The entire area of projects Go Cong, Bao Dinh, North Ben Tre, Mo Cay, South Mang Thit and Tiep Nhat are surrounded and intruded by salinity.

Apart from the cities and towns of Ben Luc, Rach Gia and Ha Tien, others will also be affected by deeper salinity intrusion. These include My Tho, Vinh Long and Can Tho.

Table 3-22. Change in distance of salinity intrusion corresponding to salinity of 1‰ and 4‰ at the rivers of the 7 study basins, scenario A2

River System	River	Distance of salinity intrusion corresponding to salinity of 1‰ at period (km)				Distance of salinity intrusion corresponding to salinity of 4‰ at period (km)				Change in distance of salinity intrusion corresponding to 1‰ relative to the period 1980-1999 (km)			Change in distance of salinity intrusion corresponding to 4‰ relative to the period 1980-1999 (km)		
		1980-1999	2020-2039	2040-2059	2080-2099	1980-1999	2020-2039	2040-2059	2080-2099	2020-2039	2040-2059	2080-2099	2020-2039	2040-2059	2080-2099
Red and Thai Binh	Day	24.1	25.4	26.4	28.6	19.2	20.7	21.9	23.8	1.3	2.3	4.5	1.5	2.7	4.6
	Ninh Co	24.9	27.5	27.7	29.7	21.3	22.5	22.8	24.5	2.6	2.8	4.8	1.2	1.5	3.2
	Red	26.8	28.1	29.5	33.6	22.0	22.6	24.0	26.5	1.3	2.7	6.8	0.6	2.0	4.5
	Tra Ly	27.3	29.0	29.2	30.2	21.0	22.7	22.9	23.4	1.7	1.9	2.9	1.7	1.9	2.4
	Thai Binh	36.0	37.5	41.2	45.0	27.5	28.5	29.2	31.3	1.5	5.2	9.0	1.0	1.7	3.8
	Van Uc	30.8	32.4	35.9	39.0	25.0	25.6	28.2	31.4	1.6	5.1	8.2	0.6	3.2	6.4
	Lach Tray	25.6	26.6	29.6	32.5	19.5	20.5	22.3	24.3	1.0	4.0	6.9	1.0	2.8	4.8
	Kinh Thay	43.2	44.7	45.5	49.4	36.0	39.2	40.5	45.5	1.5	2.3	6.2	3.2	4.5	9.5
	Da Bach	30.3	32.0	33.2	34.5	25.4	27.0	27.6	29.1	1.7	2.9	4.2	1.6	2.2	3.7
Ca	Ca	37	37.7	39.8	43.8	29.4	30.5	31	33.4	0.7	2.8	6.8	1.1	1.6	4.0
Thu Bon	Vu Gia	22.7	24.5	26.5	27.8	18.4	19.9	20.2	22.3	1.8	3.8	5.1	1.5	1.8	3.9
	Thu Bon	20.9	24.9	25.6	30.6	18.1	22.5	23.3	27.2	4.0	4.7	9.7	4.4	5.2	9.1
Ba	Ba	8.36	8.99	9.74	12.55	7.45	7.79	8.39	11.14	0.6	1.4	4.2	0.3	0.9	3.7
Dong Nai	Sai Gon	84.3	85.4	86.3	92.3	73.8	74.8	75.4	81.7	1.1	2.0	8.0	1.0	1.6	7.9
	Dong Nai	78.3	79.1	79.8	83.1	71.1	72.0	72.6	75.9	0.8	1.5	4.8	0.9	1.5	4.8
Cuu Long Delta	Hau	62.5	67.3	71.3		49.9	54.4	58.3		4.8	8.8		4.5	8.4	
	Co Chien	62.8	67.9	72.3		50.3	55.3	59.5		5.1	9.5		5.0	9.2	
	My Tho	63.1	70.2	73.0		51.0	57.8	60.5		7.1	9.9		6.8	9.5	
	Vam Co Tay	120	124.6	129.3		95.0	99.2	104.0		4.6	9.3		4.2	9.0	

Table 3-23. Change in distance of salinity intrusion corresponding to salinity of 1‰ and 4‰ at the rivers of 7 study basins, scenario B2

River System	River	Distance of salinity intrusion corresponding to salinity of 1‰ at period (km)				Distance of salinity intrusion corresponding to salinity of 4‰ at period (km)				Change in distance of salinity intrusion corresponding to 1‰ relative to the period 1980-1999 (km)			Change in distance of salinity intrusion corresponding to 4‰ relative to the period 1980-1999 (km)		
		1980-1999	2020-2039	2040-2059	2080-2099	1980-1999	2020-2039	2040-2059	2080-2099	2020-2039	2040-2059	2080-2099	2020-2039	2040-2059	2080-2099
Red and Thai Binh	Day	24.1	25.4	26.3	27.4	19.2	20.6	21.5	23.5	1.3	2.2	3.3	1.4	2.3	4.3
	Ninh Co	24.9	27.4	27.4	28.9	21.3	22.6	22.6	23.9	2.5	2.5	4.0	1.3	1.3	2.6
	Red	26.8	28.1	29.4	31.1	22.0	22.4	23.6	24.9	1.3	2.6	4.3	0.4	1.6	2.9
	Tra Ly	27.3	29.2	28.5	29.7	21.0	22.6	22.5	23.1	1.9	1.2	2.4	1.6	1.5	2.1
	Thai Binh	36.0	37.5	40.8	44.2	27.5	28.4	29.1	30.7	1.5	4.8	8.2	0.9	1.6	3.2
	Van Uc	30.8	32.1	35.5	38.5	25.0	25.6	27.8	30.9	1.3	4.7	7.7	0.6	2.8	5.9
	Lach Tray	25.6	26.6	29.3	32.1	19.5	20.4	22.3	24.1	1.0	3.7	6.5	0.9	2.8	4.6
	Kinh Thay	43.2	44.1	44.5	46.0	36.0	38.4	39.6	41.7	0.9	1.3	2.8	2.4	3.6	5.7
	Da Bach	390.3	32.1	32.4	34.2	25.4	26.9	27.3	28.4	1.8	2.1	3.9	1.5	1.9	3.0
Ca	Ca	37	37.6	39.8	43.3	29.4	30.2	30.7	33.2	0.6	2.8	6.3	0.8	1.3	3.8
Thu Bon	Vu Gia	22.7	24.6	26.6	27.4	18.4	19.9	20.2	21.9	1.9	3.9	4.7	1.5	1.8	3.5
	Thu Bon	20.9	24.4	25.3	28.5	18.1	22	23	25.5	3.5	4.4	7.6	3.9	4.9	7.4
Ba	Ba	8.36	8.9	9.51	10.99	7.45	7.77	8.3	9.55	0.5	1.2	2.6	0.3	0.9	2.1
Dong Nai	Sai Gon	84.3	85.3	86.1	88.9	73.8	74.6	75.3	78.2	1.0	1.8	4.6	0.8	1.5	4.4
	Dong Nai	78.3	78.9	79.6	81.5	71.1	71.8	72.5	74.2	0.6	1.3	3.2	0.7	1.4	3.1
Cuu Long Delta	Hau	62.5	67.1	71.1		49.9	54.1	58.1		4.6	8.6		4.2	8.2	
	Co Chien	62.8	67.6	72.0		50.3	55	59.2		4.8	9.2		4.7	8.9	
	My Tho	63.1	69.8	72.7		51.0	57.5	60.2		6.7	9.6		6.5	9.2	
	Vam Co Tay	120.0	124.0	129.0		95.0	98.8	103.7		4.0	9.0		3.8	8.7	

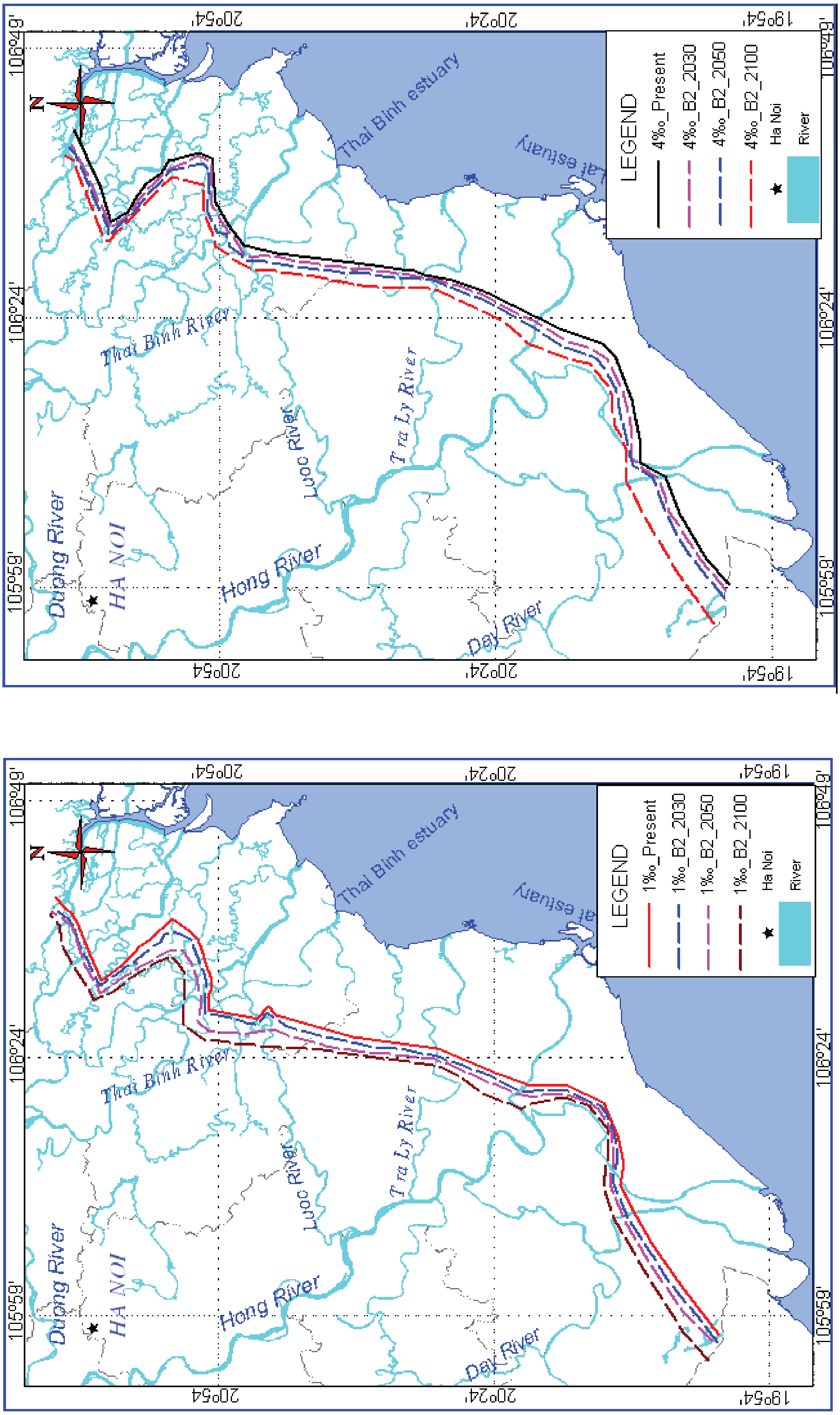


Figure 3-19. Salt water intrusion map of Red and Thai Binh Delta

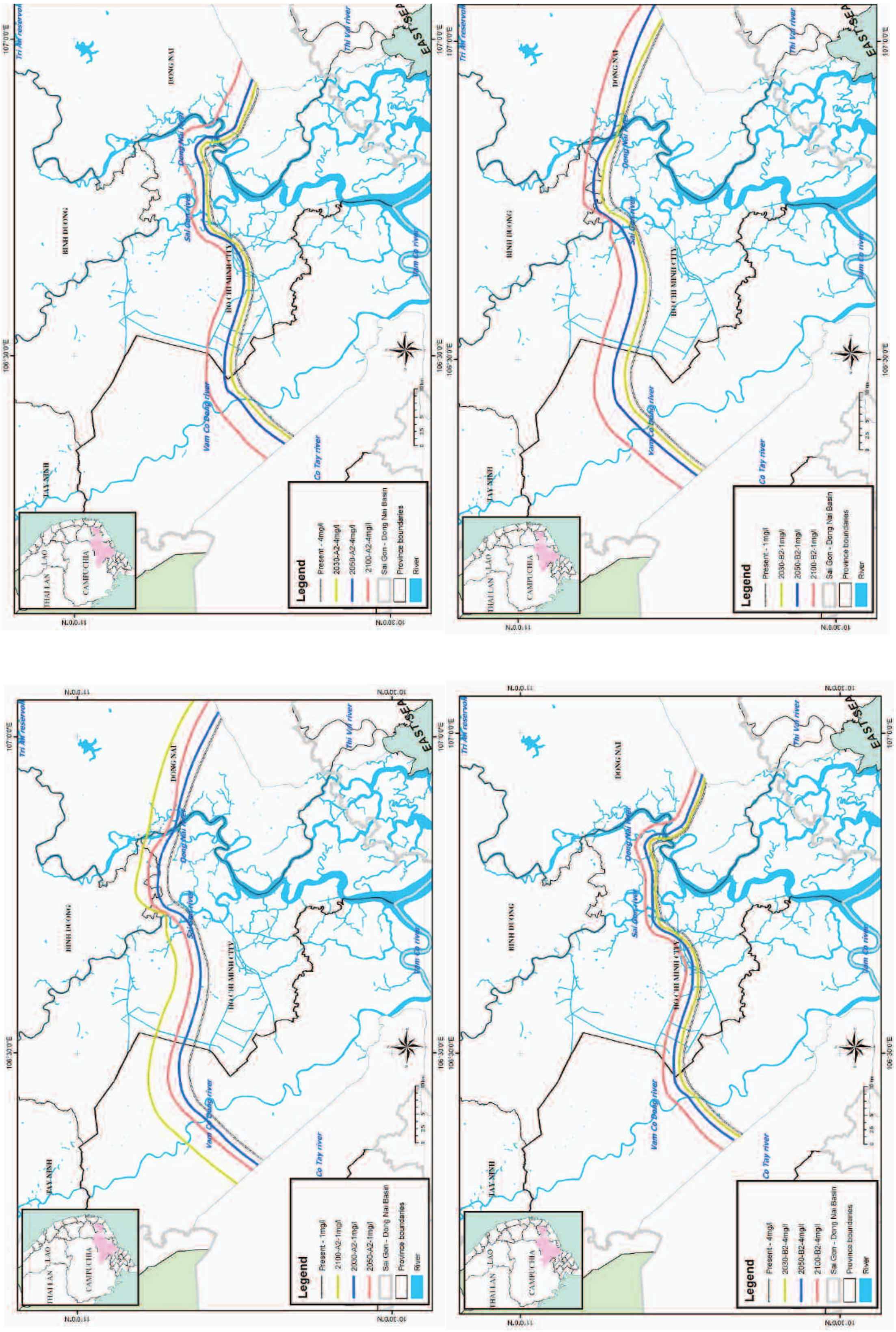


Figure 3-20. Salt water intrusion map of downstream of Dong Nai River basin

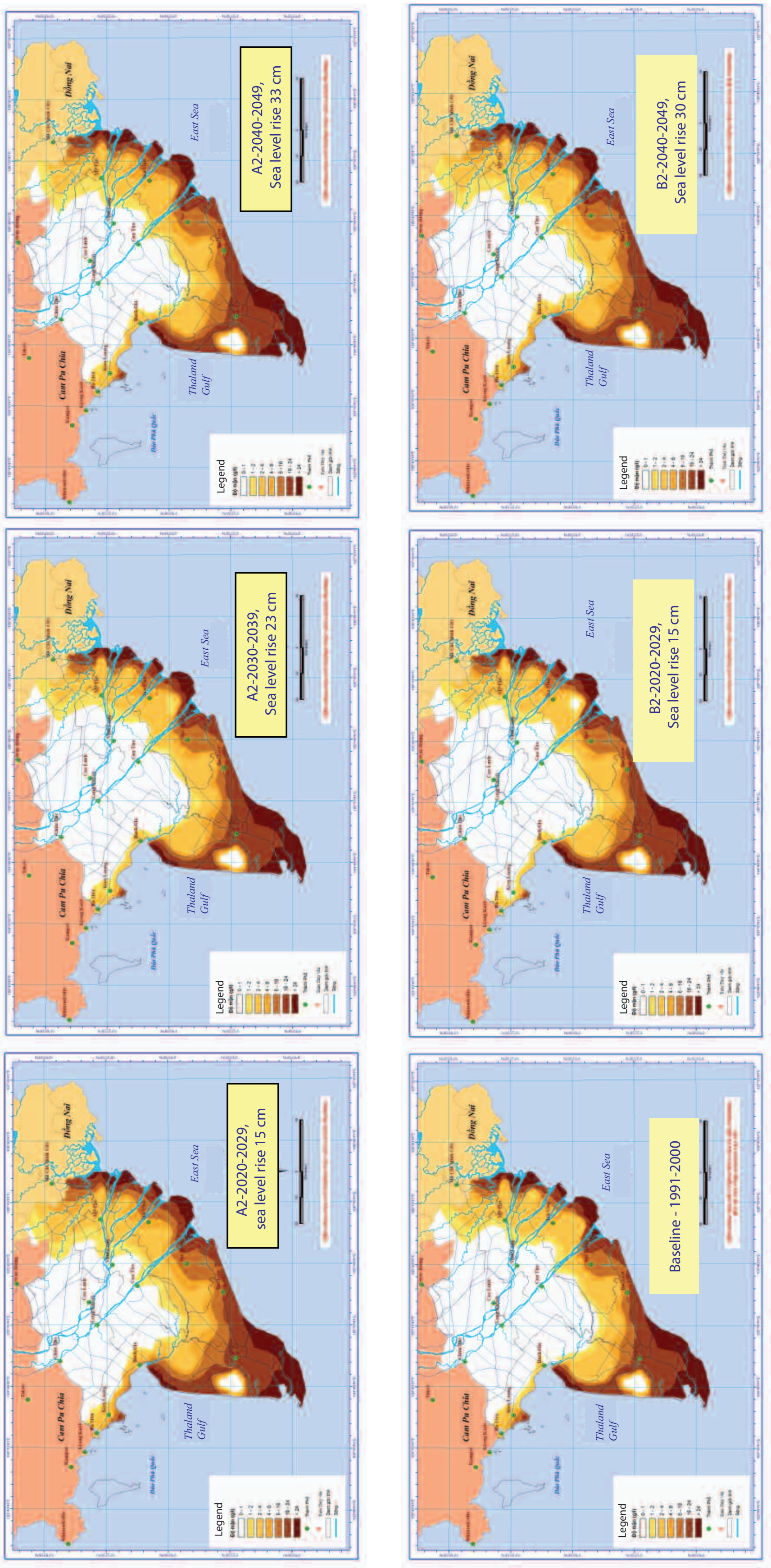


Figure 3-21. Salt water intrusion map of Cuu Long Delta

Table 3-24. Area and population affected by salinity concentration 1‰

River System	Scenario	Period	Salinity intrusion area (ha)				Population (10^6)
			Total	Living and industry	Agriculture combined with aquaculture	Agriculture	
Red - Thai Binh	Baseline	1980 - 1999	316,611	60,357	10,070	144,100	3.426
	A2	2020 - 2039	338,510	65,695	10,190	157,700	3.682
		2040 - 2059	353,404	68,767	10,280	166,800	3.854
		2080 - 2099	378,151	73,462	10,440	181,600	4.130
	B2	2020 - 2039	334,834	65,652	10,170	155,400	3.639
		2040 - 2059	349,465	68,106	10,260	164,400	3.809
		2080 - 2099	373,951	72,639	10,410	179,000	4.081
Dong Nai	Baseline	1980 - 1999	411,713	90,990	3100,0	190,000	5.701
	A2	2020 - 2039	426,612	97,250	3103,0	198,000	6.201
		2040 - 2059	447,413	106,200	3151,0	208,400	6.757
		2080 - 2099	485,965	118,300	3473,0	321,200	7.410
	B2	2020 - 2039	423,361	95,260	3103,0	195,900	6.034
		2040 - 2059	442,256	103,600	3103,0	205,600	6.642
		2080 - 2099	478,431	115,000	3,410	226,800	7.286
Cuu Long Delta	Baseline	1985 - 2000	2,068,000	312,300	181,400	759,300	8.415
	A2	2010 - 2019	2,194,000	332,200	207,500	825,800	8.941
		2020 - 2039	2,323,000	352,600	238,000	889,500	9.485
		2040 - 2059	2,524,100	387,700	293,700	987,200	10.395
	B2	2010 - 2019	2,153,000	325,300	199,300	801,100	8.760
		2020 - 2039	2,243,200	339,200	218,200	849,900	9.151
		2040 - 2059	2,426,300	372,600	266,300	939,800	9.949

Table 3-25. Area and population effected by salinity concentration 4‰

River System	Scenario	Period	Salinity intrusion area (ha)				Population (10^6)
			Total	Living and industry	Agriculture combined with aquaculture	Agriculture	
Red - Thai Binh	Baseline	1980 - 1999	269,806	50,347	9,808	113,400	2.873
	A2	2020 - 2039	286,947	54,730	9,969	123,900	3.089
		2040 - 2059	289,730	55,361	9,188	127,700	3.135
		2080 - 2099	322,245	62,185	10,140	146,700	3.488
	B2	2020 - 2039	283,412	53,781	9,943	121,700	3.045
		2040 - 2059	295,660	56,784	10,020	129,300	3.191
		2080 - 2099	318,908	61,480	10,120	146,600	3.450
Dong Nai	Baseline	1980 - 1999	317,067	56,170	2,315	143,600	2.318
	A2	2020 - 2039	325,266	59,990	2,315	146,700	2.578
		2040 - 2059	336,762	64,620	2,344	152,400	2.968
		2080 - 2099	373,445	75,750	2,715	170,600	4.251
	B2	2020 - 2039	322,718	58,940	2,315	146,200	2.518
		2040 - 2059	332,484	62,960	2,316	150,700	2.852
		2080 - 2099	353,014	69,660	2,461	160,600	3.583
Cuu Long Delta	Baseline	1985 - 2000	1,412,000	215,900	667,940	443,300	5.456
	A2	2010 - 2019	1,528,100	233,900	696,150	509,700	6.089
		2020 - 2039	1,605,200	254,700	729,800	576,300	6.743
		2040 - 2059	1,851,200	282,300	778,400	665,900	7.703
	B2	2010 - 2019	1,489,200	228,400	687,780	487,400	5.860
		2020 - 2039	1,574,300	241,000	705,400	535,000	6.342
		2040 - 2059	1,795,300	275,900	763,200	640,200	7.417

3.2.6. Impacts on water demand for agriculture

Temperature rise and the corresponding rise in potential evapotranspiration, together with a decrease in dry season rainfall in all basins, will lead to increasing irrigation water demand (Fig. 3-22, Table 3-26). In Dong Nai River basin, water demand for irrigation increases the most, up 50% by the end of the 21st century as a result of a low increase in rainfall (about 2%), combined with a high increase in potential evapotranspiration (about 15%) and a decrease in river flow in both the flood season and the dry season.

Table 3-26. Water requirements for irrigation in study basins

Scenarios	Climate Change Scenarios	Period	Water requirement for irrigation ($10^9 m^3$/year)				
			Red and Thai Binh	Ca	Thu Bon	Ba	Dong Nai
Present Irrigation Area, year 2000	Baseline	1980-1999	9.04	1.156	0.757	0.403	5.90
	A2	2020-2039	9.18	1.165	0.915	0.403	7.40
		2040-2059	9.43	1.175	0.964	0.430	8.11
		2060-2079	9.75	1.184	1.014	0.457	8.98
		2080-2099	10.05	1.196	1.057	0.483	10.10
	Baseline	1980-1999	9.04	1.156	0.757	0.403	5.90
	B2	2020-2039	9.18	1.165	0.862	0.403	7.01
		2040-2059	9.45	1.175	0.908	0.426	7.62
		2060-2079	9.70	1.183	0.912	0.444	8.23
		2080-2099	9.88	1.194	0.944	0.459	9.01
Development Irrigation Area, year 2020	Baseline	1980-1999	11.26	1.307	0.795	0.802	5.60
	A2	2020-2039	11.59	1.318	0.918	0.846	6.95
		2040-2059	11.86	1.329	0.967	0.898	7.63
		2060-2079	12.24	1.339	1.021	0.954	8.48
		2080-2099	12.59	1.351	1.069	1.006	9.52
	Baseline	1980-1999	11.26	1.307	0.795	0.802	5.60
	B2	2020-2039	11.59	1.317	0.877	0.840	6.50
		2040-2059	11.88	1.328	0.926	0.890	7.02
		2060-2079	12.18	1.337	0.969	0.934	7.65
		2080-2099	12.40	1.349	1.005	0.965	8.27

Figure 3-22. Change in water requirement for irrigation in study basins, senario B2

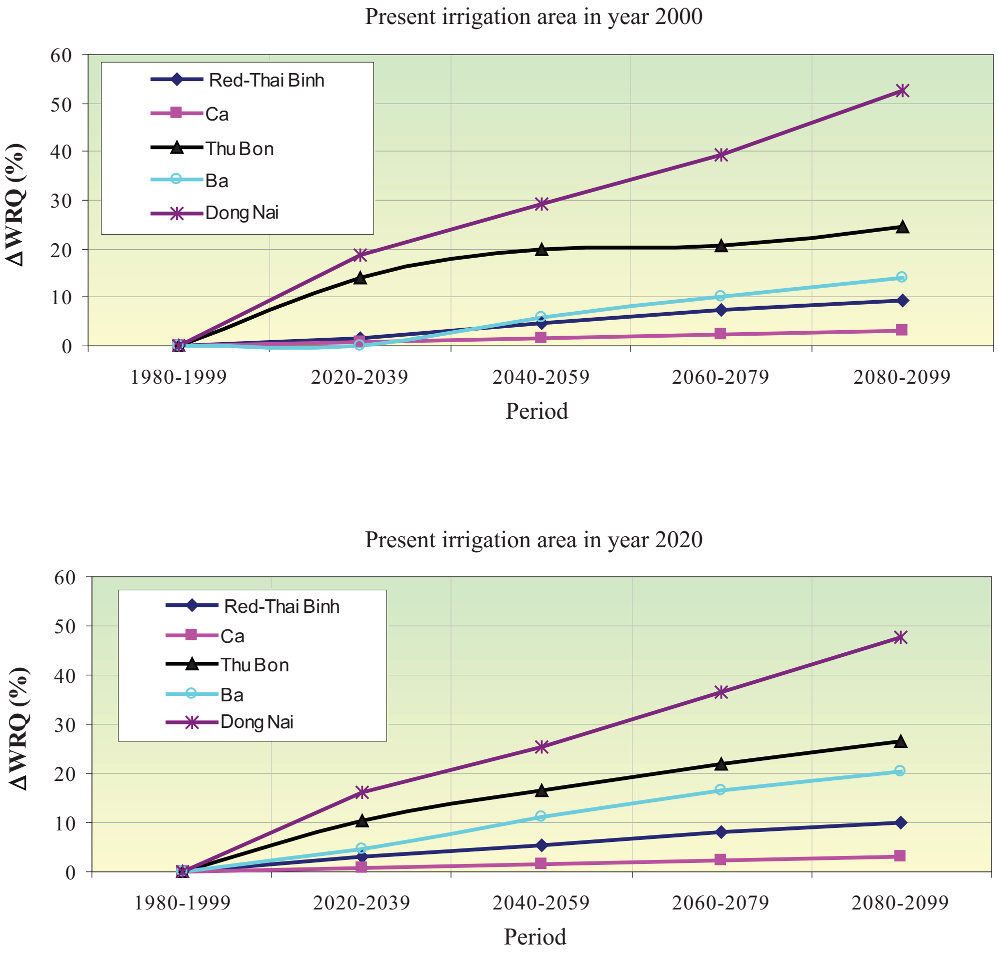
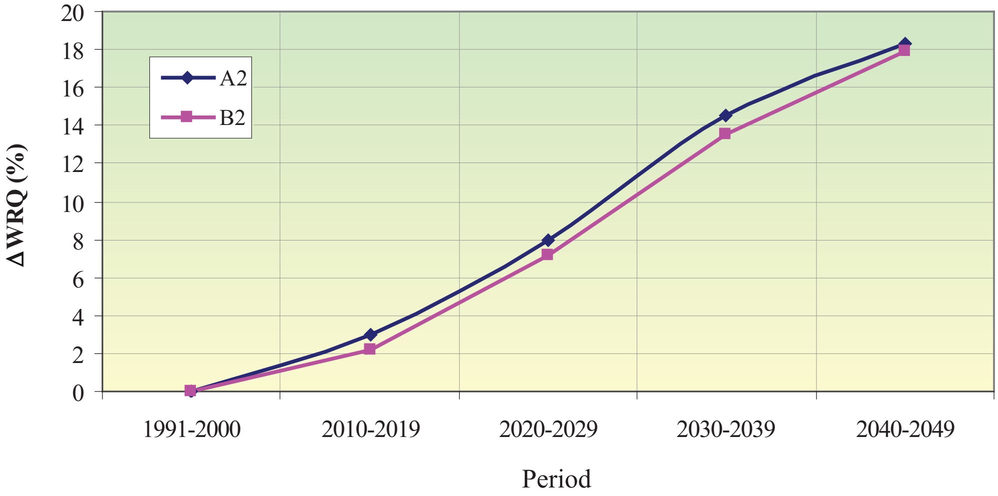


Table 3-27. Water requirement for irrigation of Cuu Long Delta

Period	Water requirement (10^9 m^3/year)		Change in water requirement (%)	
	A2	B2	A2	B2
1991-2000	18.94	18.94	0	0
2010-2019	19.50	19.36	2.94	2.18
2020-2029	20.44	20.30	7.93	7.17
2030-2039	21.69	21.51	14.50	13.58
2040-2049	22.42	22.33	18.35	17.87

Figure 3-23. Change in water requirement for irrigation in Cuu Long Delta



3.2.7. Impacts on hydropower

Table 3-8 lists the large existing hydropower reservoirs, hydropower reservoirs under construction, and hydropower reservoirs under the electricity planning scheme VI approved by the Government that were included in the calculations.

Table 3-28. Reservoirs taken into account

River basin	Reservoirs
Red-Thai Binh	Hoa Binh, Son La, Lai Chau, Tuyen Quang, Thac Ba
Ca	Ban Ve, Ban Mong, Thac Muoi, Ngan Truoi, Khe Bo
Ba	Song Ba Ha, Song Hinh, Krong H'Nang, An Khe-Kranak, Yaun Ha
Thu Bon	A Vuong, Song Bung 2, Song Bung 4, Dak My 4 level 1 and Song Tranh 2
Dong Nai	Tri An, Thac Mo, Da Nhim, Ham Thuan, Can Don, Sroc Phu Mieng, Dai Ninh, Dong Nai 2, Dong Nai 3, Dong Nai 4, Dong Nai 5, Dong Nai 6

As in analysis, changes to river flows as a result of climate change will affect the output of hydropower plants in the long term (hereafter electricity means hydropower). On Red - Thai Binh and Ca River basins, where flows increase, the average annual electricity outputs also increase, especially in Ca River basin where electricity generation increases by almost 3% by the mid 21st century. Of the remaining basins, the average annual electricity outputs decline by about 3% in mid 21st century and are 6% lower by the end of the 21st century (Table 3-29, Fig. 3-24). Electricity output decreases for Thu Bon, Ba and Dong Nai River basins are mainly due to large reduction in flow during the nine months of dry season, and the minimal output increases during the three months of the flood season (Table 3-30).

Table 3-29. Total annual capacity of hydro-power plants of study basins (MW)

River Basin	Capacity (MW), scenario B2				Change in Capacity ΔN (%)			
	1980-19999	2020-2039	2040-2059	2080-2099	1980-19999	2020-2039	2040-2059	2080-2099
Red- Thai Binh	2586	2592	2595	2600	0	0,2	0,3	0,5
Ca	143	145	147	151	0	1,4	2,8	5,6
Thu Bon	250	249	248	246	0	-0,1	-0,6	-1,6
Ba	211	205	204	200	0	-2,6	-3,0	-4,9
Dong Nai	514	503	500	493	0	-2,1	-2,7	-4,1

River Basin	Capacity (MW), scenario A2				Change in Capacity ΔN (%)			
	1980-19999	2020-2039	2040-2059	2080-2099	1980-19999	2020-2039	2040-2059	2080-2099
Red- Thai Binh	2586	2594	2597	2604	0	0,3	0,4	0,7
Ca	144	146	149	153	0	1,4	3,5	6,3
Thu Bon	250	249	248	245	0	-0,1	-0,6	-1,8
Ba	211	205	204	199	0	-2,7	-3,2	-5,6
Dong Nai	514	502	499	491	0	-2,3	-2,9	-4,5

Figure 3-24. Change in annual capacity of study basins

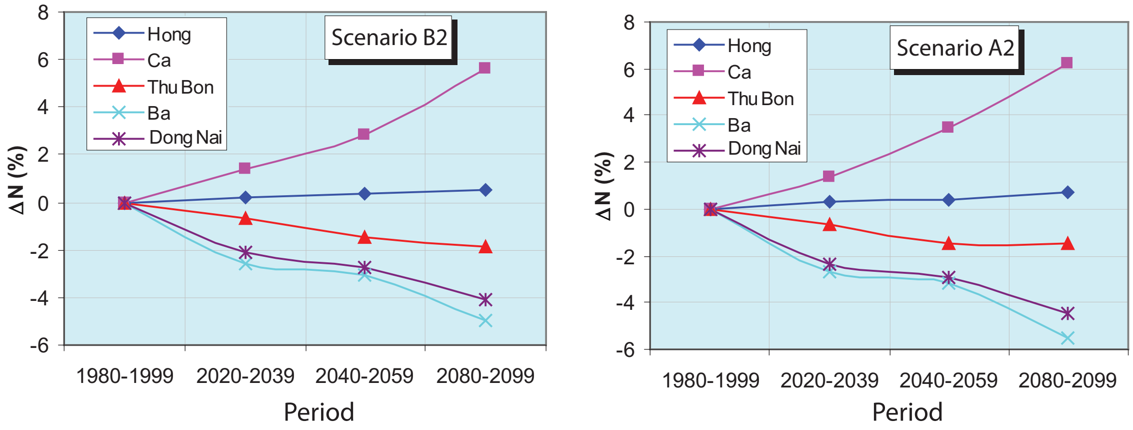


Table 3-30. Change in monthly capacity of hydro-power plants in study basins

Scenario A2

Basin	Period	Monthly capacity (MW)											
		I	II	III	IV	V	VI	VII	VIII	I X	X	XI	XII
Red – Thai Binh	1980-1999	1.626	1.515	1.148	1.065	1.152	3.190	3.529	3.798	4.027	4.175	3.856	1.953
	2020-2039	1.628	1.407	1.006	957	1.132	3.162	3.624	3.897	4.136	4.286	3.923	1.967
	2040-2059	1.641	1.420	1.011	952	1.127	3.152	3.625	3.897	4.136	4.287	3.940	1.974
	2080-2099	1.647	1.460	1.049	956	1.120	3.136	3.627	3.897	4.136	4.288	3.951	1.983
Ca	1980-1999	82	64	53	53	71	127	201	279	284	237	152	111
	2020-2039	84	65	54	53	65	119	205	289	289	243	155	113
	2040-2059	85	66	55	52	62	114	208	298	293	245	162	115
	2080-2099	95	69	56	52	57	103	216	321	308	254	172	131
Ba	1980-1999	208	140	120	109	113	131	143	200	253	339	408	364
	2020-2039	206	139	119	109	108	123	130	184	240	332	408	362
	2040-2059	211	139	120	111	108	119	125	177	238	330	409	361
	2080-2099	214	139	120	110	105	104	115	158	220	329	414	360
Thu Bon	1980-1999	295	219	198	184	170	168	145	123	156	313	529	495
	2020-2039	298	218	198	184	170	162	141	116	151	312	542	500
	2040-2059	302	218	198	183	168	158	137	110	149	312	543	500
	2080-2099	302	217	195	182	163	149	128	101	145	315	547	498
Dong Nai	1980-1999	342	375	375	369	440	486	528	650	767	780	685	370
	2020-2039	333	368	362	346	416	469	502	639	767	779	680	365
	2040-2059	333	366	356	339	404	465	499	638	766	779	678	365
	2080-2099	330	354	341	322	389	455	494	632	763	776	676	364

Scenario B2

Basin	Period	Monthly capacity (MW)											
		I	II	III	IV	V	VI	VII	VIII	I X	X	XI	XII
Red – Thai Binh	1980-1999	1.626	1.515	1.148	1.065	1.152	3.190	3.529	3.798	4.027	4.175	3.856	1.953
	2020-2039	1.625	1.409	1.006	956	1.127	3.161	3.624	3.897	4.136	4.284	3.919	1.963
	2040-2059	1.635	1.423	1.012	952	1.121	3.149	3.624	3.897	4.136	4.286	3.939	1.972
	2080-2099	1.645	1.447	1.035	954	1.118	3.132	3.626	3.897	4.136	4.287	3.946	1.982
Ca	1980-1999	82	64	53	53	71	127	201	279	284	237	152	111
	2020-2039	84	65	55	52	63	116	206	292	291	245	156	114
	2040-2059	86	67	55	51	57	107	209	302	296	248	165	117
	2080-2099	93	69	57	51	51	94	214	320	306	255	174	134
Ba	1980-1999	208	140	120	109	113	131	143	200	253	339	408	364
	2020-2039	206	139	119	109	108	124	131	185	241	332	408	362
	2040-2059	211	139	120	111	108	119	125	179	239	331	409	361
	2080-2099	213	139	119	111	106	107	118	166	225	329	411	360
Thu Bon	1980-1999	295	219	198	184	170	168	145	123	156	313	529	495
	2020-2039	299	218	198	184	170	161	140	116	150	310	543	502
	2040-2059	303	218	198	183	168	158	137	110	148	309	543	502
	2080-2099	303	218	196	181	164	152	131	103	145	311	544	500
Dong Nai	1980-1999	342	375	375	369	440	486	528	650	767	780	685	370
	2020-2039	333	368	362	348	419	470	504	639	767	779	680	365
	2040-2059	333	367	360	339	407	466	500	638	766	779	679	365
	2080-2099	331	361	347	328	393	457	494	634	764	777	676	364


Hội thảo khoa học
ng của biến đổi khí hậu lên tài nguyên nước
các biện pháp thích ứng
f Climate Change on Water Resources and Adaptation Measures
I NGUYÊN NƯỚC
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SỐNG, CHIẾN ĐẤU, LA


BỘ NGOẠI GIAO ĐAN MẠCH
CƠ QUAN PHÁT TRIỂN QUỐC TẾ ĐAN MẠCH
BỘ TÀI NGUYÊN VÀ MÔI TRƯỜNG
VIỆN KHOA HỌC KHÍ TƯỢNG THỦY VĂN VÀ MÔI TRƯỜNG
HỘI THẢO
TÁC ĐỘNG CỦA BIẾN ĐỔI KHÍ HẬU LÊN TÀI NGUYÊN NƯỚC
VÀ CÁC BIỆN PHÁP THÍCH ỨNG
Quảng Ngãi, ngày 14 thá năm 2010

Chapter 4

PROPOSED ADAPTATION MEASURES

Principal orientations:

- Awareness raising and human resources development;
- Enhancement of International Cooperation;
- To mainstream climate change issue into socio-economic development strategies. Strengthening the capacities of organization, institution and policy on climate change;
- Development of action plans of Ministries, sectors and localities to respond to climate change;
- Use water source in a scientific, economic, reasonable and effective way to secure the safety and adequacy of water supply for all requirements;
- Build and enhance the frameworks of legal documents in accordance with laws and under law documents. Amend and improve related mechanisms and policies;
- Relevant ministries and sectors consolidate their organisation in management, exploitation and use of water resources in different levels in the context of climate change;
- Develop programs and plans of adaptation to climate change in the fields of management, exploitation and use of water resources in different sectors and levels;
- Define appropriate scientific and technological solutions such as: integrated planning of a river basin, changing technical standards of constructions for water exploitation and use, measures to save and use water source in an economic and effective way, maintain and protect water source, control water pollution, drainage of flood and inundation, protection against salinity intrusion and preserve fresh water.

4.1. Red – Thai Binh River basin

4.1.1. Main impacts of climate change on water resources in the river basins

Water volumes increases in the flooding season but decreases in the dry season.

Sea level rise results in salt intrusion deeper in the river mouth (further inland).

4.1.2. Consequences

Increase in water demand, especially in the dry season.

Increase in flooding area.

In present conditions, in flood seasons, maximum water level at river mouth can reach the top of dyke. Due to high flood combined with sea level rise, the risk of overflow is greater.

Salinity intrusion increases.

4.1.3. Adaptation measures

a) Construction of multi-purpose reservoirs

The construction of reservoirs that ensure flood regulation and appropriate water allocation can meet the requirements of downstream flood defense in the flood season and water supply in the dry season. This is a traditional measure, which has a long history of application before the appearance of climate change issues and is very effective.

There are a number of large reservoirs in Red - Thai Binh River basin, namely Son La, Hoa Binh, Tuyen Quang and Thac Ba, and a number are under construction such as Ban Chat and Huoi Quang. In addition, there are many medium and small-scale reservoirs used for agriculture. These reservoirs can be more effective through their optimal operation.

b) Construction of salinity barriers

The construction of salinity barriers at the river mouths of Hoa, Do Han and Tra Ly Rivers can mitigate salt intrusion in the dry season, ensuring essential fresh water availability for users, primarily domestic and agricultural uses.

c) Improvement of sea and river dyke systems

Improvement to sea and river dyke systems in the provinces of Hai Phong, Nam Dinh, Thai Binh and Ninh Binh can prevent high flood and sea water intrusion.

The available sea dike systems in the area of Red – Thai Binh River Delta are still low and are not strong enough to cope with typhoons level 10 or above. Therefore, this necessary measure needs to be implemented in the near future as part of the natural disaster prevention and mitigation program of this area.

d) Enhancement of afforestation

According to the Food and Agriculture Organization (FAO), forests are one of the most important environments to store greenhouse gases on the planet.

Priority should be given to poor forest or bare areas to protect the soil and retain or slow water flows in the flood season, especially in the northwest (provinces Son La, Dien Bien and Lai Chau) where there is serious reduction in forest vegetation. It is necessary to strengthen the protection of existing forests, especially primeval forests and surface humus layer, acting as a large reservoir to regulate and retain flood flows in the rainy season for the dry season. At the same time, it is important to raise awareness for cultivation and living in permanent settlements, improve the living standard and changing the habits of local people, especially ethnic minority people.

e) Implementing efficient use of water

Recommendations for efficient water use vary for different water users.

Agriculture use: Red – Thai Binh Delta is an important area in the lower basin. This delta is a main area for rice cultivation in the north, which requires a huge amount of water. In the future, agriculture is still expected to be the biggest water user. Therefore, efficient use of water is necessary. The following measures are recommended:

- Continue concreting irrigation channels to minimize water loss.
- Apply advanced water techniques such as drip irrigation. This is very efficient but requires big investment and high technology, so it may be used for large, specialized concentrated production areas.

Industry use: Water use in this sector is significant. In the near future (by 2020), Vietnam is expected to be an industrial country with strong development of large industry zones, and therefore industry is expected to be the biggest water user. Additionally, industry might be the main cause of water pollution and degradation of water quality. Therefore, the following measures need to be applied in order to use water efficiently:

- Give priorities to reuse of water (recycling)
- Treat waste water from production enterprises to meet the new standards before disposing into environment (for example, river or lake).
- Enforce regulations, severely punishing those who do not meet treatment standards

Domestic use: Although amount of water for this user is not considerable, water treatment is required to ensure water quality is high. Therefore, water saving has an economic significance. Moreover, reducing distribution losses is a priority. There are two main solutions as follows:

- Improve the quality of the pipeline system to avoid leakage.
- Regularly monitor the pipeline to avoid illegal extraction of water.

f) International cooperation

International cooperation in Red and Thai Binh Rivers focuses on strengthening cooperation with China in management and protection of water resources in the upstream areas of the rivers Da, Thao and Lo (including upper part of Gam and Chay rivers), and sharing water resources in exploitation and use.

This is a difficult but necessary issue. Until a bilateral agreement is signed, it is necessary to have basic agreements on water resources protection in each relevant country, as well as the benefit balance derived from water use for users located at upstream and downstream areas. Particularly, the information of inflow and current state of water extraction needs to be available.

4.2. Ca River basin

4.2.1. Main impacts of climate change on water resources in Ca River basin

The average potential evapotranspiration of the basin increases around 12% to 19% by the end of the century. The potential evapotranspiration increase in Ngan Pho and Ngan Sau River basin is between 20.8% and 24.1%. Ca and Hieu River's upstreams have the evapotranspiration increase of about 22% and 19 %.

Total rainfall in the basin in the late 21st century tends to increase by 1% to 7.5% over the period of 1980-1999. During the rainy season, rainfall may increase by 10.5%, with the greatest increase in precipitation within a month almost reaching 30%. Dry season rainfall reduces by 9.5% and may reduce by more than 28% in several months in some areas.

The increasing trend in total annual flow in Ca River is a result of climate change. For the main river, the average annual flow by the end of the 21st century increase by 5%. Meanwhile, the average annual flow in the Ngan Sau and Ngan Pho rivers is 0.9% less than in the period of 1980-1999 as the increase in evapotranspiration is greater than the increase in rainfall.

In the flood season, the average flow increases by approximately 10% on Ca River and 3.5% on Ngan Pho and Ngan Sau Rivers. During the flooding season, the average monthly flow can increase by up to 17% on the main rivers, and 3% to 4% for the tributaries. The increase in flood peak can reach up to 15%. As a result, the height of Ca River's dyke system needs to increase by 0.5 m by the end of the century.

The reduction in dry season flow mostly occurs during the last months of the dry season, particularly in May when the flow decreases by more than 20%.

Also, in the dry season, salt water is predicted to penetrate more than 10 km inland by the late 21st century. Increasing evapotranspiration and decreasing flows and precipitation combine to result in a rise in water demand and increased water shortages in the basin. By the end of the century, the deficit of water required for irrigation increases to more than 50% compared to today.

Hence, the changes in water resources as a result of climate change are significant for La River basin.

4.2.2. Consequences

Increase in flood risk that causes serious human and property damages.

In the dry season, increasing temperature and evapotranspiration will lead to increased water demand, while water resources are reduced. This causes issues in water management and shortages of water.

Salt intrusion increases in downstream areas and estuaries.

4.2.3. Adaptation measures

a) Construction of reservoirs

Construction of multi-purpose reservoirs in the basin can serve as flood defense for downstream, water storage in flooding season and water supply in dry season.

By 2020, the additional reservoirs of Ban Ve, Ban Koh, Nhac Hac, Thac Muoi, Ngan Truoi, Cam Trang, Chuc A, Kim Cuong, Da Gam, Khe Bo, and Ban Mong will be built.

Development of inter-reservoir operations and regulation, particularly for the flood season, can ensure the safety for downstream areas.

b) Consolidation and supplementation of internal water drainage

Rao Dung culvert is built to drain water for Nghi Loc sandy area, Northern Vinh industrial park, Vinh and Cua Lo.

Thap, Gai, Hoang Cam and Vinh canals are dredged and improved. Dien Hoa canal is dredged and Dien Thuy and Dien Thanh culverts are modernized. Hung Chau, Hung Loi, Bau Non pumping stations are improved. New pumping stations are built for water drainage in Rao Nay, Thanh Chuong and Huong Son.

c) Construction of water supply work

In industrial parks

Water extraction works to take water directly from Ca, Hieu, Ngan Sau, and Ngan Pho Rivers and supply industrial zones in districts such as Muong Xen, Tuong Duong, Anh Son, Con Cuong, Quy Chau, Quoc Phong, Do Luong, Huong Son, Huong Khe and Vu Quang will be built.

Water extraction work will be built to take water from Ca River at Do Luong in order to supply water for Hoang Mai residential area and area along national road No. 1 from Hoang Mai to Dien Chau.

Nam Dan culvert should be widened, Thap and Gai canals should be dredged and Cau Mieu pumping station should be built to supply water for the southern area of Cam River, Vinh, Cua Hoi and Cua Lo.

Xuan Hoa reservoir should be built to supply water for Nghi Xuan industrial park.

Finally, building Cam Trang dam would supply water for Thach Khe industrial park.

In irrigational areas (agriculture)

Hung Nguyen-Nghi Loc area: Tho Son and Hung Dong pumping stations should be built and Nghi Quang-Ben Thy culvert put into operation.

Dien-Yen-Quynh area: The main canals of the Do Luong drainage system should be strengthened, internal irrigational canals should be consolidated, and Hiep Hoa siphon should be built.

Thanh Chuong area: Thac Muoi reservoir and other small reservoirs should be built to irrigate 27,000 ha of cultivated land.

Downstream of Hieu River: Ban Mong reservoir should be built to irrigate more than 32,000 ha of land in Bai Tap area. The reservoir in Sao River and smaller reservoirs upstream of Dinh River should be completed.

Downstream Ngan Sau-Ngan Pho Rivers: This area is considered to be severely impacted by climate change, particularly as water shortages in dry season become more acute.

Trai Doi reservoir, Da Han and Dong Tren dams and other smaller reservoirs and pumping station dams should be built.

d) International cooperation

Cooperation with Laos should be strengthened in the management and protection of water resources in order to share water resources reasonably in the upstream region of Ca River (in Laos). It is recommended that an international commission for Ca River Basin be established.

4.3. Thu Bon River basin

4.3.1. Main impacts of climate change on water resources in Thu Bon River basin

Rainfall increases in the rainy season and decreases in the dry season. The biggest increase of rainfall is seen in September and October about 16% while the biggest decrease is in January and April can reach 26%. The average monthly rainfall may increase by approximately 6% for scenario A2 and by 5% for scenario B2. Potential evapotranspiration increases greatly under both climate change scenarios, possibly by 29% at the end of the 21st century.

The dry season lasts up to nine months from January to September with flow decreasing by approximately 8.5%. The flood season is only in three months from October to December, the amount of flow in flood season grow up 1.6% by the late 21st century. The total annual flow across Thu Bon system trends down in all scenarios with a fall of about 2% by the end of the 21st century. The total annual flow across Thu Bon - Vu Gia system trends down in all scenarios with a fall of about 2% by the end of the 21st century.

4.3.2. Consequences

Even in current conditions, the inequality in water distribution leads to a lack of water for various purposes in the dry season each year. This phenomenon will be more severe in the context of climate change impacts and water demand in the dry season.

The decrease in water inflows in the dry season along with sea level rise will result in tide and salt intrusion of 5 km to 8 km further inland than present.

Natural disasters such as floods will occur more frequently and be more severe, especially in downstream areas. Damages caused by flooding will be therefore even greater. Areas flooded by larger floods will increase by approximately 3% to 8% compared with the present status.

4.3.3. Adaptation measures

a) Development of reservoirs system

The building of reservoirs systems, including multi-purpose reservoirs and specific purpose reservoirs (for example, power generation, water supply, or flood defense), such as Song Bung 2 and 4, A Vuong, Song Con 2, Song Giang, Dak Mil 1 and 4 and Song Tranh, should be continued.

Upgrading and building of new water works (reservoirs and impoundment dams) should continue. Across the river basin, 58 irrigational constructions serving 7,669 ha (4,435 ha for rice and 3,234 ha for cash crops) need to be upgraded. 143 new reservoirs providing irrigation for 9,088 ha (7,081 ha for rice and 2,070 ha for cash crop) need to be built.

Water supply plants also need to be upgraded and built.

Da Nang city:

Upgrade the capacity of Son Tra water supply plant from 8,000 m^3/day to 10,000 m^3/day. The water source is from streams in SonTra peninsula.

Upgrade the capacity of Cau Do water supply plant from 50,000 m^3/day to 240,000 m^3/day. The water source is from Vu Gia River. Move the inlet for water (now at upstream of Duong Sat bridge) to the upstream of An Trach dam on the Yen river.

Build the Xuan Thieu water supply plant with a capacity of 200,000 m^3/day. The water source is taken from Cu De River through Hoa Bac reservoir supplying for Northern Da Nang, Hoa Khanh and Lien Chieu industrial parks and people in Lien Chieu district. Ho Bac reservoir basin is expected to cover 272 km^2 with a volume of 31 million m^3.

Hoi An town:

Build the water supply plant with a capacity of 55,000 m^3/day taking water from Vinh Dien River, and supplying water for Hoi An town, tourism areas and industrial parks in Dien Ngoc and Dien Nam.

Rural areas:

Together with the use of small water supply works, priority is given to the development of centralized water supply systems to serve populous towns, industrial parks and coastal communes.

Water supply system supplying water for centres of Tay Giang, Dong Giang and Phuoc Son districts with a capacity of 3,000 m^3/day to each district, taking water from Bung and Cai Rivers.

Water supply system supplying water for the centre of Dai Loc District and other small industrial parks with a capacity of 10,000 m^3/day, taking water from Vu Gia River.

Water supply system supplying water for industrial parks of An Hoa-Nong Son with a capacity of 80,000 m^3/day, taking water from Thu Bon River.

Water supply system supplying water for centres of Tra Mi, Tien Phuoc and Hiep Duc districts with a capacity of 3,000 m^3/day to each district, taking water from Tranh and Khang Rivers.

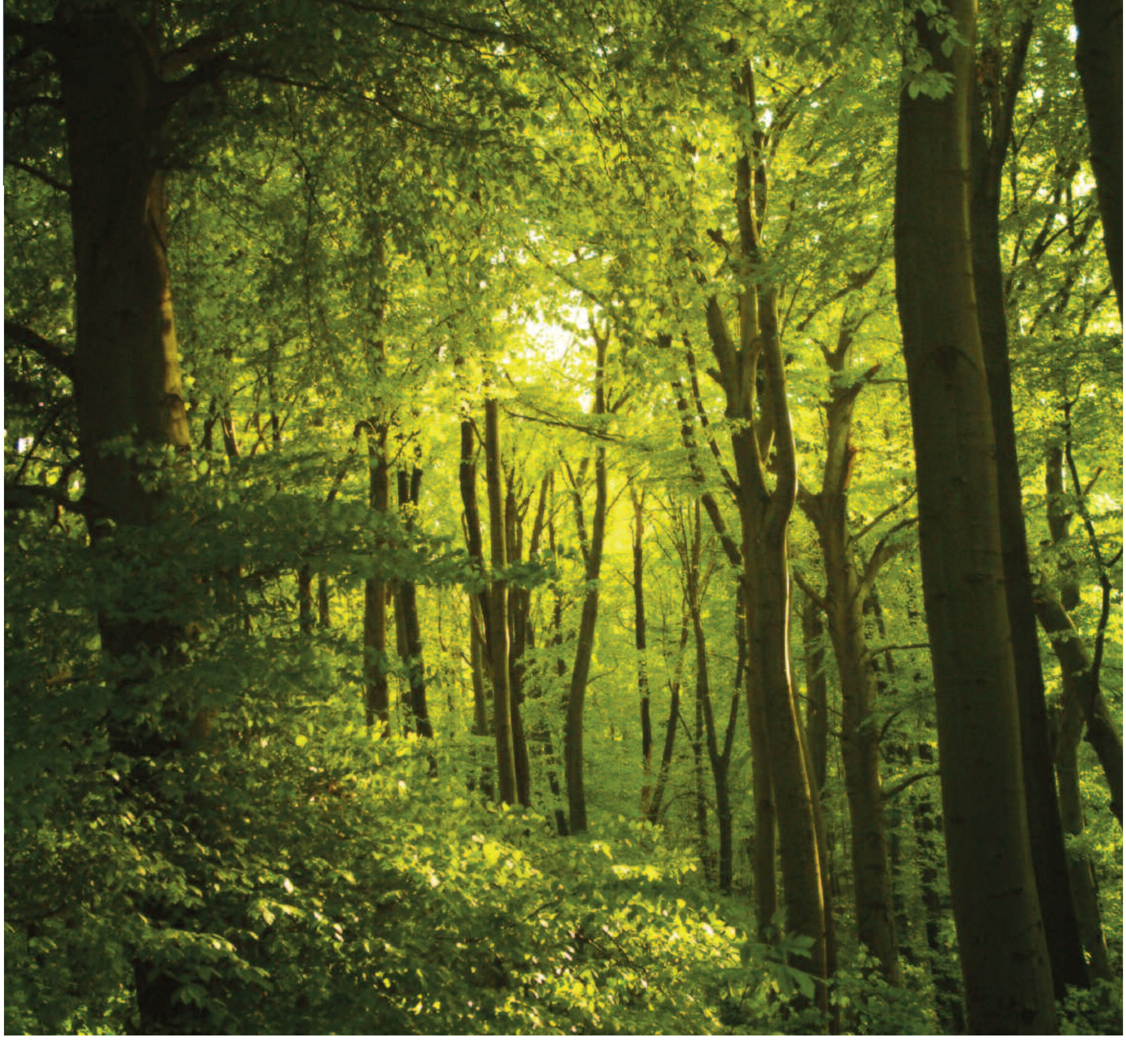
b) Strengthen the capacity of gravity drainage system and mitigate the impact of inundation.

It is necessary to strengthen the capacity of water drainage networks at the Han and Dai River mouths to solve the inundation in flood season. Based on its topographic condition, the downstream area can be divided into 2 parts:

The area between Vu Gia River and Thu Bon River: This area is surrounded by Vu Gia River to the north, Quang Hue River to the west, Thu Bon River to the south and Vinh Dien River to the east. The area of this region is over 16,000 ha consisting of the communes Hoa Chau, Hoa Tien, Hoa Xuan, and Hoa Phuoc in the Hoa Vang District, the communes Dien An, Dien Phuoc, Dien Tho, Dien Hong, Dien Tien, Dien Hoa, and Dien Thang in the Dien Ban District, and Dai Hoa Commune and Ai Nghia Town in the Dai Loc District.

The key solution for flooding is gravity drainage to the Yen, La Tho, Thanh Quyt, Thu Bon and Vinh Dien rivers through improving current available canals and culverts, and particularly the culverts under roads.

Eastern area of Vinh Dien River: This area starts from Han River to Hoi An consisting of Ngu



Hanh Son District, Dien Ngoc, Dien Duong, Dien Nam, Dien Phuong, Dien Minh communes, Vinh Dien Town of Dien Ban District and Hoi An City.

The solution to inundation in this area is also drainage by gravity into Vinh Dien River to the west, Hoi An River to the south, Ha Xau and Cau Bien rivers to the east.

c) Manage and protect available forest

Forests should be planted on bare land and hills to increase the vegetation coverage from the current level of 33% to 50% in 10-15 years. Illegal logging must be prohibited, particularly upstream of Quang Nam and Kon Tum provinces.

d) Other solutions

Salinity barriers at estuaries such as Han and Dai should be built.

Operational regulations for inter-reservoirs should be established to meet the requirements of water supply and flood protection for downstream.

Shelters for evacuation in case of flood should be built in the area of high risk of flood in Quang Nam Province.

4.4. Ba River basin

4.4.1. Main impacts of climate change on water resources in Ba River basin

Potential evapotranspiration in almost all places on Ba River basin increases, with the greatest increase up to 25.65%.

While annual rainfall tends to increase, during the dry months it tends to decrease. For the B2 scenario, it increases by 0.7% to 3.2%, in some places up to 7.0%; for the A2 scenario it increases by 0.7% to 4.1%, and in some places up to 8.4%. In the rainy season, rainfall increases up to 11.2% at most, while in the dry season, rainfall decreases by 20% at most.

Due to the impacts of climate change, annual flow in Ba River basin tends to decrease and only increases in the flooding season. In the upstream area, the average annual flow decreases between 1.6% and 2. 5%, with the average flood flow increasing between 0.3% and 2.7%, and the average dry season flow decreasing between 6.8% and 15.5%. In the downstream area, the average annual flow decreases between 1.8% and 2.5%, with the average flood flow increasing between 0.5% and 3.0%, and the average dry season flow decreasing between 7.7% and 15.3%.

The flood peak flow of 1% can increase by 16.7% in the upstream area and 21.8% in the downstream area.

The flooded area increases from 1.5% to 7% for larger floods by the end of the 21st century.

In the last period of the 21st century, salinity intrusion into the river is quite deep. The maximum intrusion distance of 1 ‰ salinity may increase approximately 4.2 km and with 4 ‰ salinity the distance is approximately 3.7 km.

The water demand of economic sectors increases significantly, among which the biggest increase is in irrigation. Irrigation demand could increase up to 25.5%. The shortage of water would also increases significantly, for irrigation it can reach 37.1%.

4.4.2. Consequences

The dryness and water shortages for living and production increase in the dry season, particularly in Gia Lai and lower areas of An Khe town, the area where the river flows through Krong H'nang (Krong H'nang tributary) and the area between downstream Dong Cam dam and estuary.

The magnitude of tidal influence and salt intrusion increases at estuaries in the dry season.

The occurrence of flash floods and soil erosion at upper part of streams and rivers tends to be more frequent and more severe, while big floods cause large extended inundation in lower areas.

4.4.3. Adaptation measures

a) Planning review

A review of the planning of construction of water resources development work should be done on the basis of integrated planning of the river basin, ensuring that construction meets the requirements of hydropower generation in the dry season and flood protection for downstream areas.

Apart from Dong Cam dam which has existed since 1932, there is currently a lot of construction of water infrastructure, namely Ayun Ha, Song Hinh, Song Ba Ha, Krong Hnang, and An Khe-Kanak reservoirs. In addition, a series of overflow-type dams and small reservoirs are distributed within the basins of tributaries.

There should be regulations to coordinate the operation of these works in order to balance benefits and reasonable allocation of water, to maximize the efficiency of the works, as well as the exploitation of water resources and protection of the river basin environment.

b) Protection and development forest

Forests at upper parts of the catchment should be protected and enlarged; land use planning should be established and implemented. Furthermore, the protection of soil from erosion should be carried out.

The protection and enlargement of upper catchment forests should be carried out simultaneously in all 4 sub-basins: An Khe, Ayun, Krong H'nang and Hinh. Care should be taken when planning the changes of land use and planting patterns together with closely monitoring the implementation of the planting.

c) Maintenance of environmental flow in river reaches

In activities of water exploitation and use, the maintenance of environmental flow in reaches is a compulsory requirement. This is particularly pertinent downstream of hydro-power dams, and downstream of Dong Cam dam should be managed to avoid dead segments in the dry season.

This is a very important solution to prevent the degradation of water sources and maintain aquatic ecosystems in the dry season, while at the same time preventing salinity intrusion at estuaries.

d) Implementation of measures for flood protection within the basin, focusing on the middle and lower areas of the river

Severe consequences to people and the environment in the basin show the importance of measures for flood defense; mainly in the middle and lower catchment areas due to the possible increase in intensity and frequency of rainfall and flooding in the context of climate change.

Together with protection and enlargement of upper catchment forests (within the area of provinces Gia Lai and Kon Tum), it is necessary to carry out the flood peak depression using proper inter-reservoir operation regulation in order to protect areas from flooding based on the flood forecast information. One such measure to protect Tuy Hoa City is to build the surrounding dyke.

The dredging of bed sediment at the river reach behind Dong Cam dam and estuaries must be implemented annually to facilitate flood conveyance.

4.5. Dong Nai River basin

This is one of the well-developed centres of the country. For this reason, the water demand increases rapidly under the limitation of water resources in the context of climate change. The expansion of centralized industrial parks, especially downstream in Binh Duong Province, Ho Chi Minh City and Dong Nai City is always accompanied by increasing water pollution which makes degrades water quality. Therefore, the protection of water sources and environmental protection are two major issues in the basin.

4.5.1. Main impacts of climate change on water resources in Dong Nai River basin

Mean annual temperature rises approximately 1.4°C to 2.2°C.

Rainfall in the dry season (December to May) reduces approximately 10% to 20%, but increases approximately 1.1% to 8.5% in the rainy season.

Annual flow reduces about 7%: flood season reduction of 5% to 7%, and a dry season reduction of 6% to 10%.

4.5.2. Consequences

Flow reduction, water shortages in the future.

Increase in water demand for domestic and other users.

Downstream inundation increases in combination with sea level rise.

Increase in salinity intrusion at coastal estuaries.

Increase in water pollution, especially in dry season when the water level in river is low. Contradiction in water use between sectors and areas becomes more acute.

4.5.3. Adaptation measures

a) Planning aspect

Integrated river basin planning should be completed immediately in order to establish a legal mechanism for water allocation and sharing among users, and efficient use and protection of water resources in the basin. This task is expected to be easy for Dong Nai River as its entire basin falls within Vietnam's territory. As a consequence, the extraction and use of water is not affected by foreign partners.

b) Reservoir system

The construction of reservoir systems (for irrigation and hydropower) should be continued according to planning, in order to serve as flood protection downstream, storage of water for dry season, and prevention of salinity intrusion downstream in the dry season. Building mechanisms are also required to share water resources rationally, because this is the basin having the biggest water transfer to outside the basin.

c) Strengthen the capacity of water supply to meet the increasing demand

More water supply plants taking water from Dong Nai River should be built at the same time as improvements to the existing plants Ben Than, Thu Dau Mot, Hoa An and Binh An are made.

Construction of culverts and pumping stations are required, especially at upper Vam Co Dong River locations such as Goc Oi, Hoa Hoi, Ben Soi, Tra Cu and Ben Dinh stations.

d) Construction of dyke for tide and salinity prevention

Dyke system should be built in Can Gio District and Nha Be estuary. Also the existing dykes in Nha Be District should be consolidated.

e) Strengthen measures for water quality protection

This task should be conducted especially at the industrial developed areas such as Binh Duong, Ho Chi Minh and Dong Nai. Moreover, waste water must be treated to attain acceptable criteria before disposing into receiving sources. Sources of waste water disposal must be investigated regularly. Heavy fine should be given to the illegal disposal.

4.6. Cuu Long Delta

4.6.1. Main impact of climate change on water resources in Cuu Long Delta.

- Mean annual flow increases gradually.
- Mean flood season flow increases in accordance with the average annual flow. Average maximum monthly flow (often in September) also increases gradually.
- Mean dry season flow into Vietnam increases and average minimum monthly flow tends to decrease.
- Inundation area in Cuu Long River Delta expands. Inundation by flooding is earlier and lasts about one month.
- Salinity intrusion is wider and deeper by approximately 5 km to 8 km.

4.6.2. Consequences

Increase in flood season flow combined with sea level rise will result in the longer water drainage times, expansion of the flooding area, and deeper and longer floods.

Because of tidal influence, saline water will intrude farther from two directions, the sea and Thailand Gulf in dry season. Water demand (for domestic and agricultural use) increases in dry season.

Water is polluted because of salinity and waste water from people and industry, causing more difficulties in supplying fresh water to users.

4.6.3. Adaptation measures

a) Planning aspect

Water works approved in flood planning programs for Cuu Long Delta should be completed and consolidated. These include works for flood protection and flood conveyance, including the building of residential areas to avoid flooding, surrounding dykes in An Giang, Dong Thap and Long An provinces, and dredging and widening of canals for water drainage to Thailand gulf and Tien river.

b) Construction of sea dyke

Sea dykes along East Sea and West Sea should be built to prevent salinity intrusion in case of sea level rise.

c) Study measures for salinity prevention

A study of measures for preventing salinity intrusion in the dry season need to be implemented, and should include the building of salinity barrier sluices at effective places.

d) Study the change of crop patterns and livestock

The study should be based on planning of land use under the condition of sea level rise.

Areas unaffected by tide and salinity: Plants and livestock that do not require large amount of water should be considered. Water saving technologies should be applied.

Areas recently affected by tide and salinity: reasonably distribute areas for crops and aquaculture. Priority should be given to plants and animals that can adapt to brackish and salt water. Mangrove forest at coastal estuaries (Ben Tre, Hau Giang and Ca Mau) should be protected and enlarged.

e) Use of fresh water storage measures

Devices such as large jars or pots should be used to store rain water by each family. This water can be used in the dry season. The measure has proved to be efficient in coastal areas (Ben Tre, Bac Lieu, Soc Trang, and Ca Mau) where fresh water from the river is limited in the dry season because of tidal influences.

f) Environmental protection

Strengthening of environmental protection measures against water pollution should be carried out. Treatment and disposal of waste water from industrial parks should be monitored regularly and strict punishment should be applied to polluters.

g) International cooperation

International cooperation includes promotion of activities on water resources within the MRC, focusing on:

- Sharing of water resources in dry season among riparian countries.
- Opposing the launch of the project on water conveyance from the Mekong River to other areas.

Constructing reservoirs in various locations (within territory of Laos and Cambodia) to store water in flood season for later use in dry season (in downstream).

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APPENDICES

Methodology and tool

In order to assess the impacts of climate change on water resources in studied area, tasks can be grouped in a diagram that has an interactive connection shown in figure PL1.

Figure PL1. Process for assessment of climate change impact on water resources

Basing on the diagram, main tasks are implemented by work groups and experts of the project.

1. Climate change and sea level rise scenarios development

1.1. Methodology and tool for developing climate change scenarios

There are many methods have been developed to create scenarios of global climate change such as using the global climate model (GCM), using the regional climate model (RCM), and using the statistical methods. The GCM model is the most approximate model for addressing climate change scenarios. But the most dynamic global models (GCM) have relatively coarse resolution (about 250-600 km), it is difficult to use direct product of this model to evaluate for each small area. To get a more detailed climate change scenarios for small regions based on global climate change scenarios, the solution was need to develop methods based on the local conditions. A number of methods can be used to develop climate change scenarios for a small area:

- Using directly GCMs's outputs,

- Using the statistical downscaling methods;

- Using the local factor method with software MAGICC/SCENGEN developed with the cooperation of NCAR/USA and CRU/UK;

- Using the regional dynamic model (RCM) such as RegCM3 of NCAR, USA and the PRECIS model of the Hadley Centre, UK.

Based on criteria on the reliability of original climate change scenarios (GCM, integration method); details of climate change scenarios (need to ensure the details to serve the assessment of impacts of climate change, at least the details of climatic regions); the inheritance (inheriting and updating information of the First National Communication and the draft Second National Communication...); the updating of information for scenarios, local relevance such as the trends of temperature and rainfall in Vietnam; the adequacy of scenarios including the high, medium, low scenarios corresponding to greenhouse gases emission scenarios and the ability to update proactively climate change scenarios, we selected climate change scenarios for climatic regions of Vietnam which have been developed based on the application of software MAGICC / SCENGEN 5.3 and the statistical Downscaling method.

1.2. MAGICC/SCENGEN software

MAGICC is one of the models has been used by IPCC since 1990 to predict global average temperature and sea level rise in the future. Until now, the MAGICC/SCENGEN software have been studied and improved to Version 5.3 with 2.5x2.5°C degrees lat/lon in 2007:

MAGICC - Model for Assessment of Greenhouse Gas Induced Climate Change - is a complex model of gases cycles, climate and ice melt, allowing estimate the global average temperature and the consequences of rising sea levels under the different emissions of greenhouse gases and sol (mainly sulfur dioxide). MAGICC was designed by the Climate Research Unit (CRU), UK and National Center for Atmospheric Research (NCAR), USA, in which two main authors are T. Wigley and S. Raper. CRU and NCAR are two main units provide research results for IPCC.

SCENGEN - Regional Climate Scenarios Generator - is a model for generating regional climate change scenarios, based on using associatively the MAGICC's result and results of GCM model, coupled with an model ocean – atmosphere (AOGCM), linking them with climate observed data for regions to create the very diverse results of climate change for these regions in the 21st century. The baseline period for model is from 1961 to 1990. SCENGEN's results are formatted in grid data with the resolution of 2.5x2.5 degree lat/lon. IPCC recommended using the MAGICC/SCENGEN as an effective tool supporting countries and areas for developing climate change scenarios suitable to their local conditions.

There are 24 models in the CMIP3 data base, but only 20 models have gathered enough necessary data for using SCENGEN.

SCENGEN's results is a change of object on each prediction grid cell size 2.5 × 2.5 latitude longitude in the forecast period should correspond to emission scenario chosen. Results are shown as: change, error, Mod. Change, Mod. Base, obs. Base, obs. Change. Value in each cell of the SCENGEN's grid can be for each month of the year, meteorological seasons: winter (XII - II), spring (III - V), summer (VI - VIII), autumn (IX - XI) and an annual. The object is projected in SCENGEN: temperature, rainfall, sea level rise, sea level pressure average - MSLP.

1.3. Statistical downscaling method (SD)

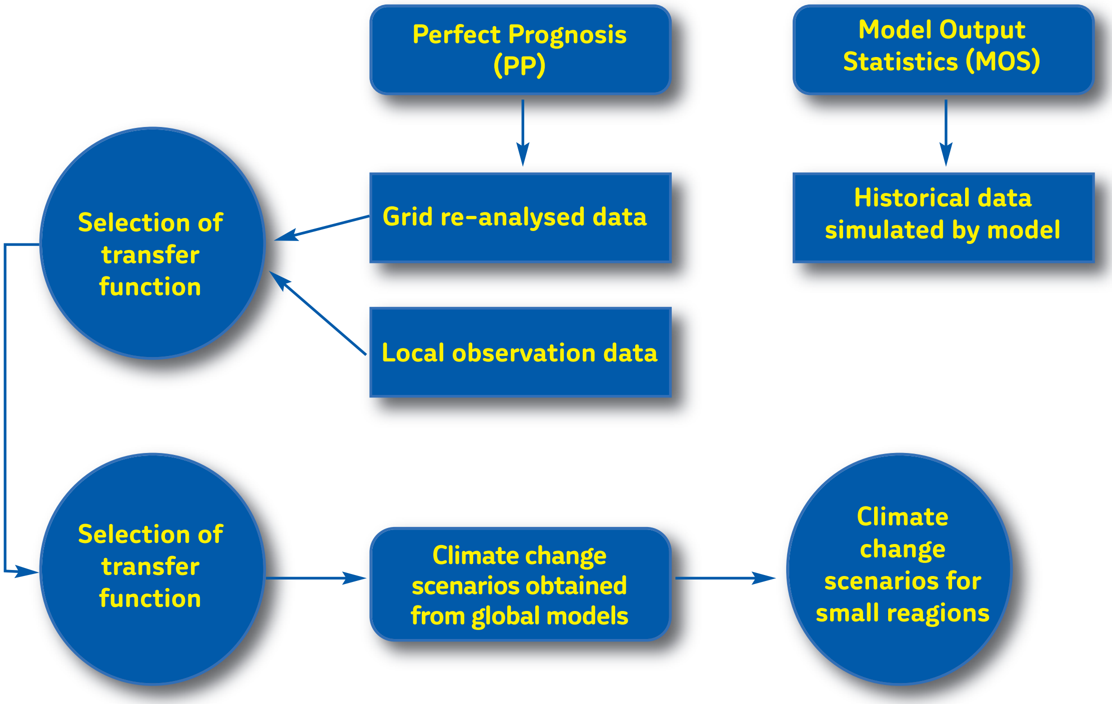
Downscaling is a method to get information of climate or climate change with high resolution from global climate models (GCMs) with relatively coarse resolution. Although GCMs are improved increasingly over space and time, they still cannot ensure the assessment of the impacts of climate change for a small area. For example, there are important differences between reality and modeling of GCMs, and not many small scale conditions such as topography and surface conditions which have great effects on local climate appear in GCMs.

Statistical Downscaling (SD) is a tool for developing the quantitative relationship between large-scale atmospheric variables, acting as forecast factors and the variables of local surface – the forecast objects. Until now, statistical Downscaling has developed quite rapidly in forecasting in general and long range forecast in particularly. The application of SD for developing scenarios on climate change is considered as a special case of SD in long range forecast. The development of SD for building scenarios on climate change has been paid attention to in many countries in recent years. There are three methods in SD:

- Regression models;
- Weather Classification schemes or Weather Typing;
- Weather Generators;

In studies for developing forecast models in general and climate change scenarios in particular; two main approaches are used as mentioned in figure PL2.

Figure PL2. Diagram of building the transfer function following the PP and MOS approaches



– "Model Output Statistics", symbol MOS. This method uses the output of model in the past combined with the data observed at stations to develop regression equations. After that these regression equations are used to transfer scenarios from models to future detailed for regions studied.

– "Perfect Prognosis", symbol PP. This method the "re-analysed" data combined with corresponding observation data to build the model. Because the "re-analysed" data are considered the data close to reality and similar to observation data, the relation between them is near to the practical one. Using this relation for future forecast is not quite compatible. Therefore, we must assume that the later forecasted results are perfect like the "re-analysed" data. That is why this method is called Perfect Prognosis. In reality, when there are only forecasted data or future climate change scenarios here, without results accumulated or re-run for the past, PP is an unavoidable method. Due to this assumption, the reliability of MOS is often higher than PP.

When developing and selecting transfer function, it is necessary to assess the reliability and criteria to make the choice. According to the length and characteristics of data series used in development of model, we select method to create and verify the relevant model.

2. Development of climate change scenarios for Vietnam and study areas

2.1. Inside Vietnam

Results of the hydrodynamic model PRECIS of Hadley center has some limitations such as great error for rainfall estimation. That needs to be studied further. Therefore, in this study, the method of statistical downscaling is applied to generate scenarios for river basins of Thu Bon, Ba, Dong Nai and a part in Vietnam territory of Red, Ca and MeKong River.

The followings are advantages and disadvantages of the method:

Advantages:

- Results are comparable with climate change scenarios shown in the report of MONRE submitted Vietnam Government;
- Meteorological factors were compared with baseline period 1980-1999 and were determined based on observation data;
- Numbers of climate change scenarios can be controlled;

Disadvantages:

- Statistical downscaling method can only generate mean monthly variations of rainfall and temperature;
- The change of maximum and minimum values and rainfall intensity cannot be seen

Scenarios for greenhouse gas emission selected for developing climate change for Vietnam are a low emission scenario (B1), amedium scenario (B2) and a medium scenario with thin the group of high emission (A2).

The following section shows the results obtained from application of statistical downscaling method to develop climate change scenarios for river basins based on scenarios generated by MAGICC/SCEGEN 5.3 model. The transfer function method is used in this study.

Transfer function is a linear regression equation y=ax+b; where y is temperature (rainfall) observed at station in a certain duration, x is temperature (rainfall) in the grid cell at the coordination of station, and a and b are constants.

137 regression equations for mean monthly temperature and rainfall were established based on observed data at 137 meteo-hydro stations. Details of the stations are shown in the table below. Results show a close relation between observed and reanalysis temperature data at the same station. Most stations have correlation coefficients above 0.5, about 0.7-0.8. Correlation coefficients in case of rainfall data are lower than that of temperature. The transfer function is used to adjust results obtained from MAGICC/SCENGEN model. In case the transfer function has a low correlation coefficient, results will be directly taken from MAGICC/SCENGEN model, then regression coeficients a=1, b=0. List of representative station for Vietnam is in the table PL1.

Climate change scenarios for temperature and rainfall for 7 climatic regions were based on scenarios developed for meteorology stations: Northwest (B1), Northeast (B2), Northern Delta (B3), North Central (B4), South Central (N1), Highland (N2) and South (N3). Data in the period of 1980-1999 was chosen as baseline.

Information about climate change at above stations is basic for developing CC scenarios for studied areas.

Table PL1. List of meteorology stations used for development of climate change scenarios

No.	Station	Latitude	Longitude	Climatic region	No.	Station	Latitude	Longitude	Climatic region
1	Dien Bien	21,4	103,0	B1	31	Bao Lac	22,9	106,5	B2
2	Muong Te	21,4	102,8	B1	32	Trung Khanh	22,8	106,5	B2
3	Tuan Giao	21,6	103,4	B1	33	Cho Ra	22,5	105,7	B2
4	Sin Ho	21,4	103,3	B1	34	Ngan Son	22,5	106,0	B2
5	Lai Chau	22,1	103,2	B1	35	Lang Son	21,8	106,8	B2
6	Pha Din	21,6	103,5	B1	36	That Khe	22,3	106,5	B2
7	Tam Duong	22,4	103,5	B1	37	Bac Son	21,9	106,2	B2
8	Son La	21,3	103,9	B1	38	Dinh Lap	21,5	107,1	B2
9	Quynh Nhai	21,8	103,6	B1	39	Huu Lung	21,5	106,3	B2
10	Yen Chau	21,1	104,3	B1	40	Bac Can	22,1	105,8	B2
11	Moc Chau	20,9	104,6	B1	41	Dinh Hoa	21,9	105,6	B2
12	Song Ma	21,1	103,7	B1	42	Thai Nguyen	21,6	105,8	B2
13	Co Noi	21,1	104,2	B1	43	Phu Ho	21,5	105,2	B2
14	Phu Yen	21,3	104,7	B2	44	Tam Dao	21,5	105,6	B2
15	Sa Pa	22,3	103,8	B2	45	Minh Dai	21,2	105,1	B2
16	Bac Ha	22,5	107,3	B2	46	Mong Cai	23,5	108,0	B2
17	Luc Yen	22,1	104,7	B2	47	Tien Yen	21,3	107,4	B2
18	Than Uyen	22,0	103,9	B2	48	Uong Bi	21,0	106,8	B2
19	Yen Bai	21,7	104,9	B2	49	Cua Ong	21,0	107,3	B2
20	Van Chan	21,6	104,5	B2	50	Hon Gai	20,5	107,1	B2
21	Pho Rang	21,3	104,5	B2	51	Bac Giang	21,3	106,2	B2
22	Bac Quang	22,5	104,8	B2	52	Luc Ngan	21,4	106,6	B2
23	Ha Giang	22,8	105,0	B2	53	Son Dong	21,3	106,8	B2
24	H, Su Phi	22,8	104,7	B2	54	Hiep Hoa	21,4	106,0	B2
25	Bac Me	22,7	105,4	B2	55	Bac Yen	21,3	104,4	B3
26	Chiem Hoa	22,2	105,3	B2	56	Viet Tri	21,3	105,4	B3
27	Ham Yen	22,1	105,0	B2	57	Vinh Yen	21,4	105,6	B3
28	T, Quang	21,8	105,2	B2	58	Lang	21,0	105,9	B3
29	Cao Bang	22,7	106,2	B2	59	Son Tay	21,1	105,5	B3
30	Nguyen Binh	22,7	105,9	B2	60	Ba Vi	21,1	105,6	B3

No.	Station	Latitude	Longitude	Climatic region	No.	Station	Latitude	Longitude	Climatic region
62	Ha Dong	21,0	105,8	B3	100	Tra Mi	15,4	108,2	N1
63	Hoa Binh	20,8	105,3	B3	101	Tam Ky	15,6	108,5	N1
64	Kim Boi	20,7	105,5	B3	102	Quy Nhon	13,8	109,2	N1
65	Chi Ne	20,5	105,3	B3	103	Hoai Nhon	14,5	109,0	N1
66	Lac Son	20,5	105,5	B3	104	Ba To	14,8	108,7	N1
67	Hai Duong	20,9	106,3	B3	105	Quang Ngai	15,1	108,8	N1
68	Hung Yen	20,7	106,1	B3	106	Nha Trang	12,3	109,2	N1
69	Phu Lien	20,8	106,6	B3	107	Tuy Hoa	13,1	109,3	N1
70	Thai Binh	20,5	106,4	B3	108	Son Hoa	13,1	109,0	N1
71	Phu Ly	20,5	105,4	B3	109	Phan Thiet	10,9	108,1	N1
72	Nam Dinh	20,4	106,2	B3	110	Playcu	14,0	108,0	N2
73	Nho Quan	20,3	105,7	B3	111	Dac To	14,7	107,8	N2
74	Ninh Bình	20,3	106,0	B3	112	An Khe	13,9	108,6	N2
75	Van Ly	20,1	106,3	B3	113	Kon Tum	14,3	107,6	N2
76	Thanh Hoa	19,8	105,8	B3	114	Ayunpa	13,4	108,9	N2
77	Bai Thuong	19,9	105,4	B3	115	B, Me Thuot	12,7	108,1	N2
78	Yen Dinh	20,0	105,7	B3	116	Buon Ho	12,9	108,3	N2
79	Hoi Xuan	20,3	105,1	B3	117	MDRak	12,7	108,8	N2
80	Nhu Xuan	19,6	105,6	B3	118	Dac Nong	12,0	107,7	N2
81	Tinh Gia	19,5	105,8	B3	119	Da Lat	11,9	108,4	N2
82	Tay Hieu	19,3	105,4	B3	120	Lien Khuong	11,8	108,4	N2
83	Quy Chau	19,7	105,1	B3	121	Bao Loc	11,5	107,8	N2
84	Vinh	18,7	105,7	B4	122	Phuoc Long	11,8	106,9	N2
85	Do Luong	18,9	105,3	B4	123	Ham Tan	10,7	107,8	N3
86	Tuong Duong	19,3	104,4	B4	124	Dong Phu	10,5	107,0	N3
87	Quynh Luu	19,1	105,6	B4	125	Tay Ninh	11,3	106,1	N3
88	Quy Hop	19,3	105,1	B4	126	Vung Tau	10,3	107,1	N3
89	Con Cuong	19,1	105,9	B4	127	Moc Hoa	10,8	105,9	N3
90	Huong Khe	18,2	105,7	B4	128	Ba Tri	10,0	106,6	N3
91	Ha Tinh	18,4	105,9	B4	129	Cang Long	10,0	106,2	N3
92	Dong Hoi	17,5	106,6	B4	130	My Tho	10,3	106,4	N3
93	Nam Dong	16,2	107,7	B4	131	Can Tho	10,0	105,8	N3
94	Hue	16,4	107,7	B4	132	Soc Trang	9,6	106,0	N3
95	Ba Don	17,8	106,4	B4	133	Cao Lanh	10,5	105,6	N3
96	Tuyen Hoa	17,8	106,1	B4	134	Phu Quoc	10,2	104,0	N3
97	Dong Ha	16,8	107,8	B4	135	Rach Gia	10,0	105,1	N3
98	A Luoi	16,2	107,4	N1	136	Chau Doc	10,8	105,1	N3
99	Da Nang	16,0	108,2	N1	137	Ca Mau	9,2	105,3	N3

Figure PL3. Map of Meteorlogy stations used to develop Climate Change Scenarios

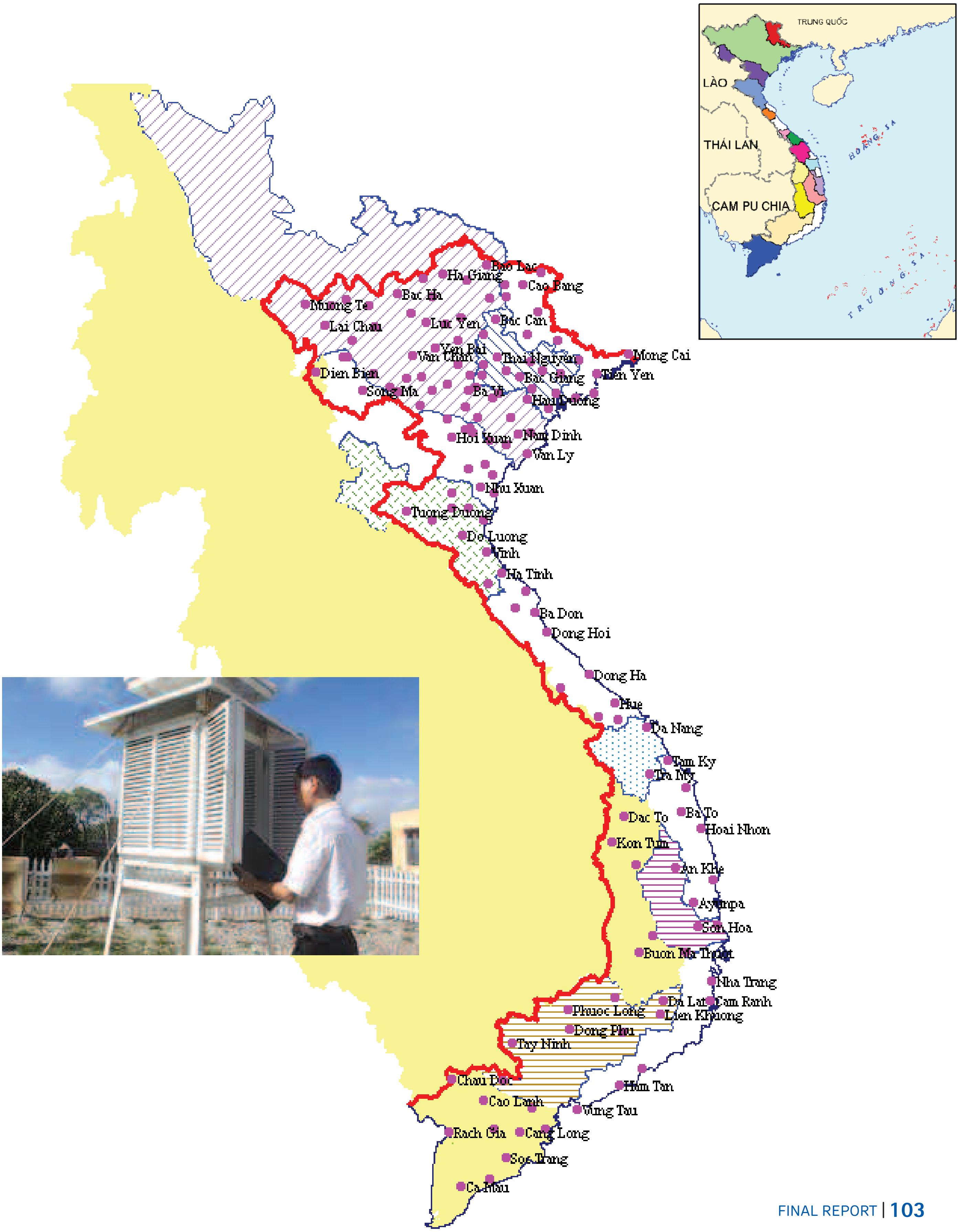
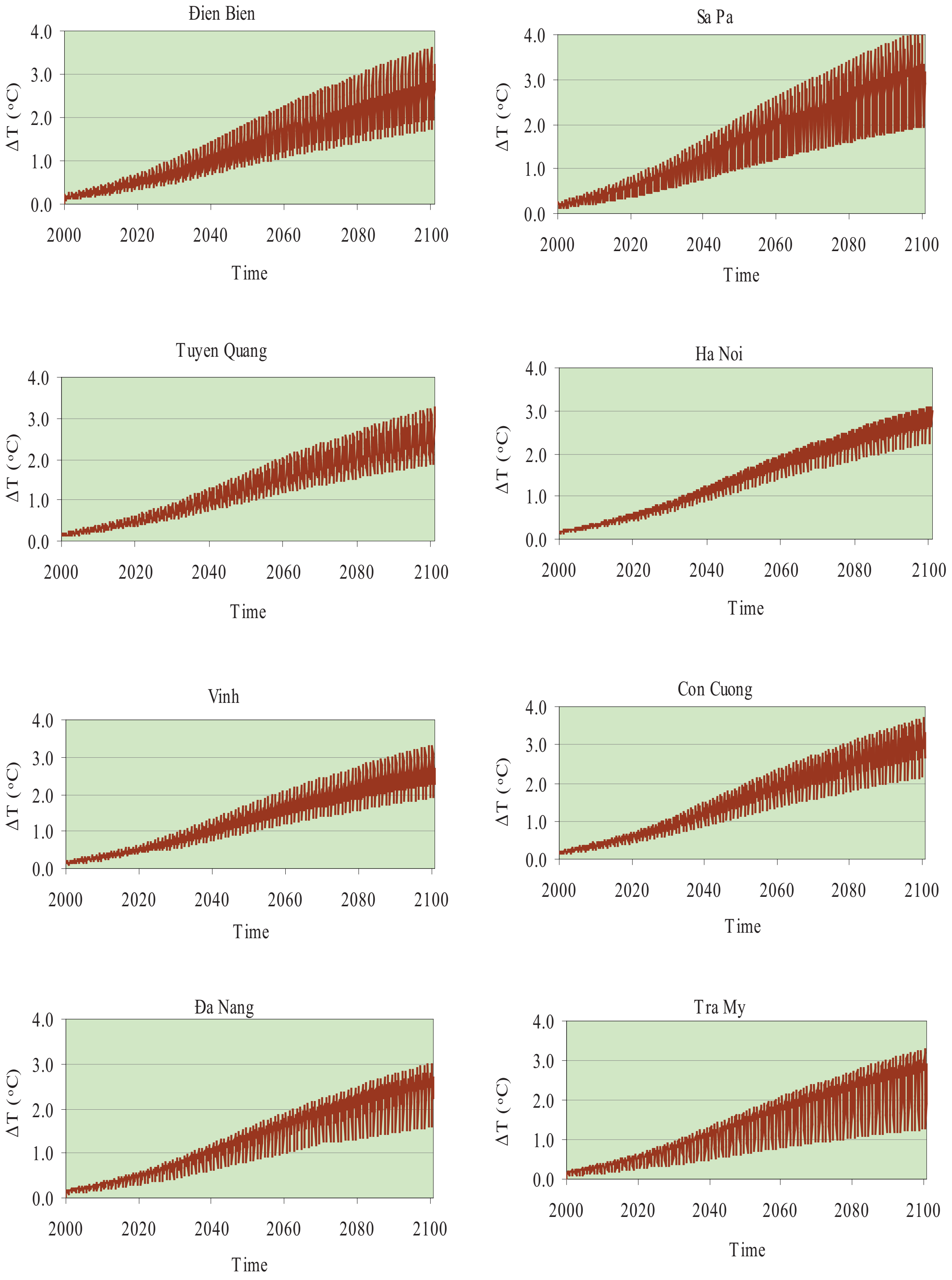
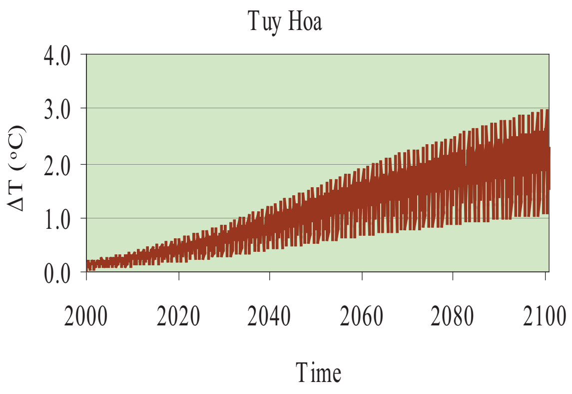


Figure PL4. Change of mean monthly temperature (^{0}C) relative to the period 1980 – 1999 at selected stations, scenario B2

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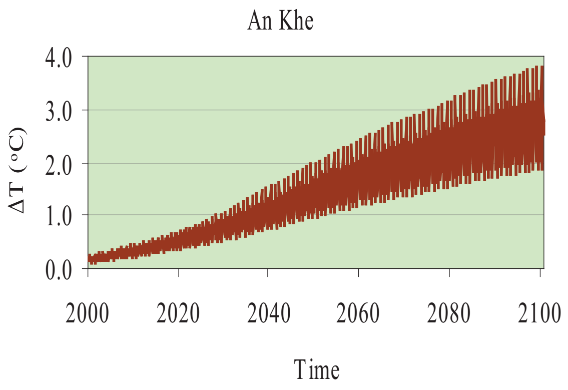
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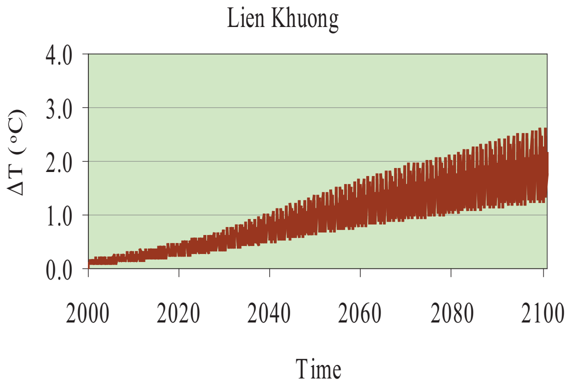
Lien Khuong
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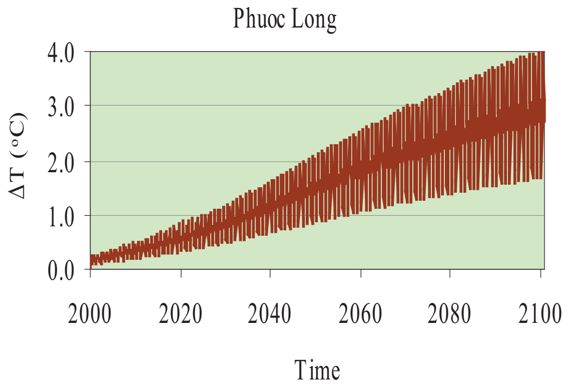
Phuoc Long
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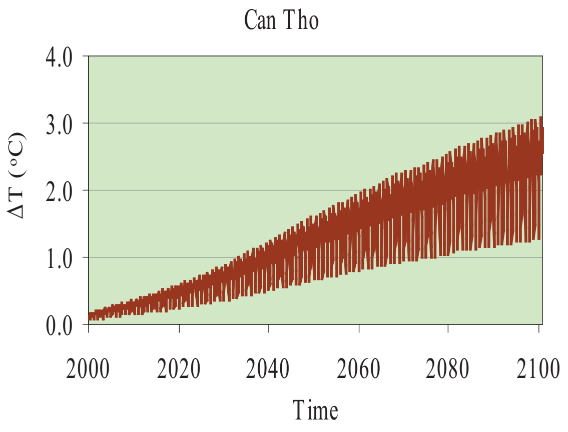
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2100
Time

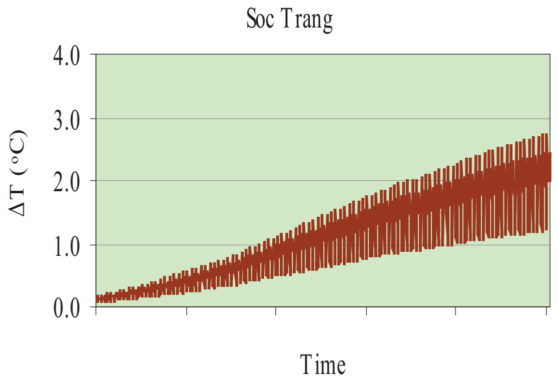
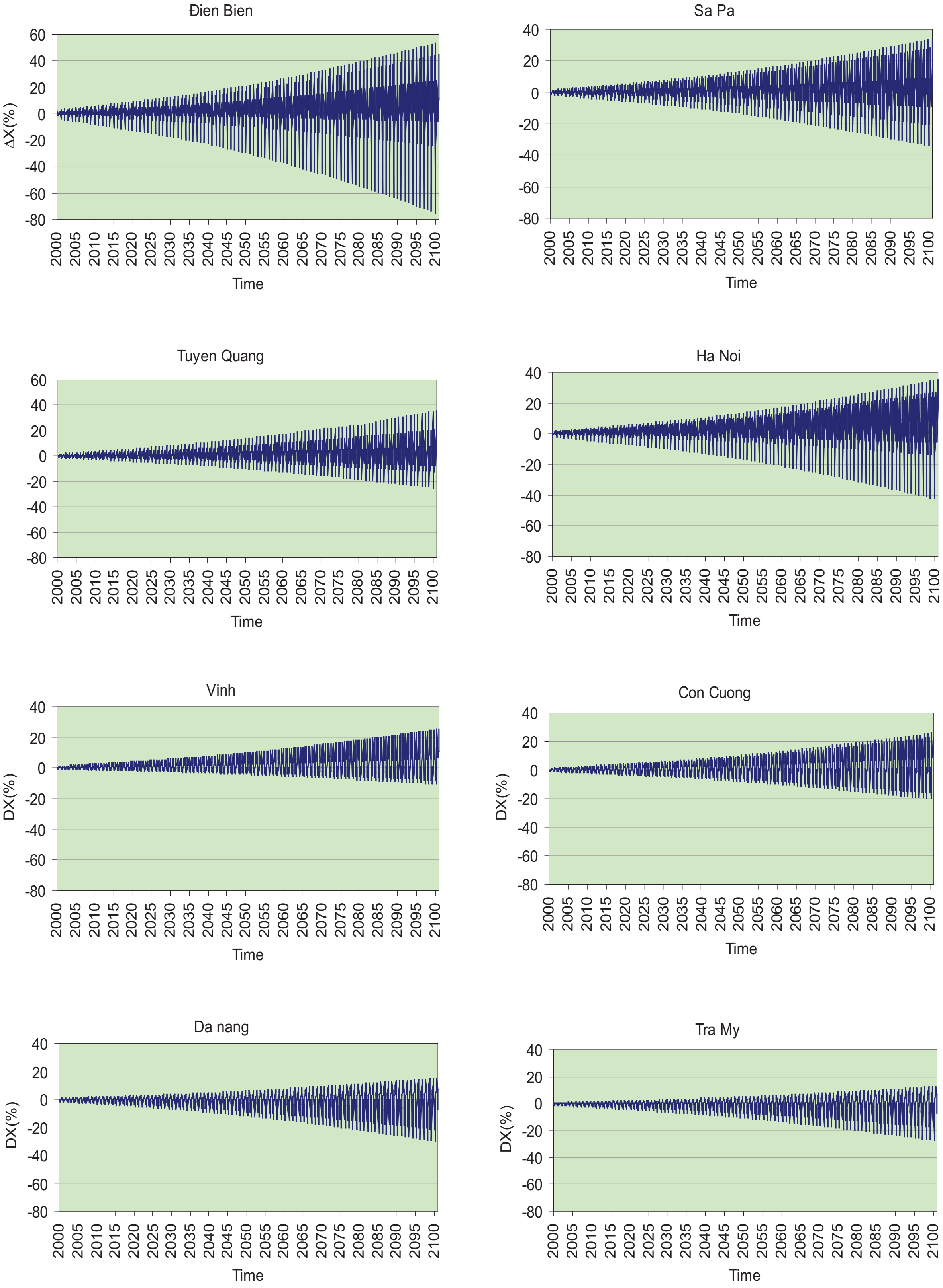
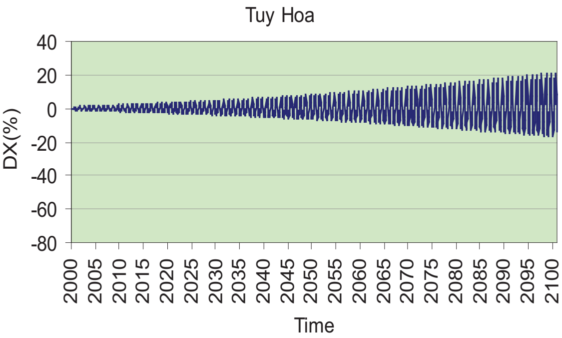
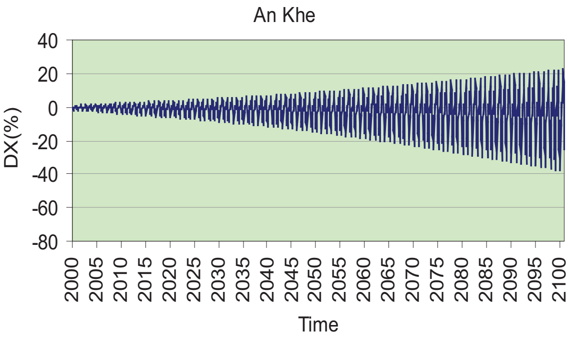
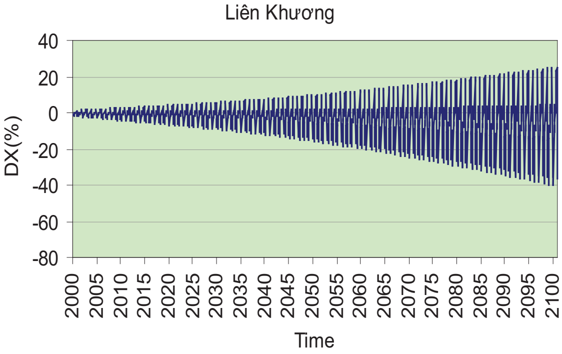

Soc Trang
ΔT (°C)
4.0
3.0
2.0
1.0
0.0
Time

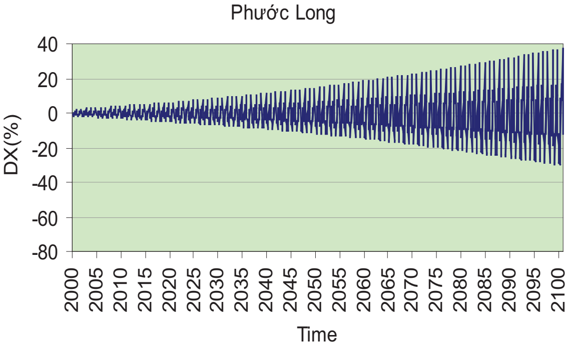
Figure PL5. Change of mean monthly rainfall (%),relative to the period 1980 – 1999 at selected stations, scenario B2

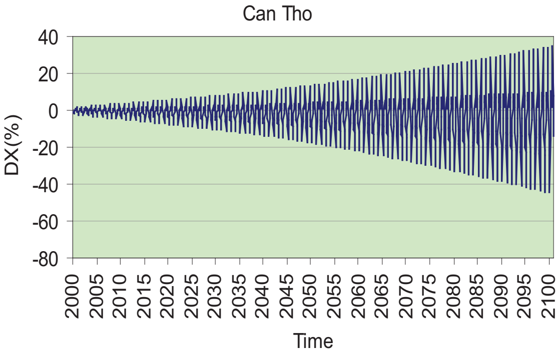


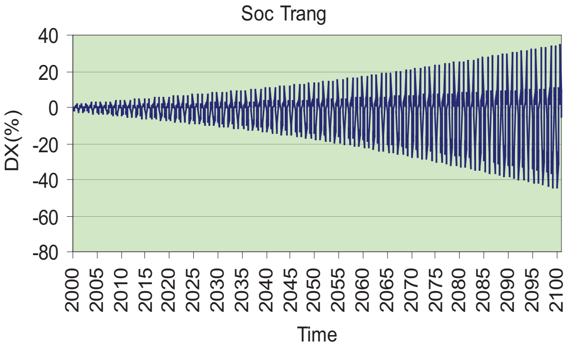

Tuy Hoa
40
20
0
-20
-40
-60
-80
DX(%)
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050
2055
2060
2065
2070
2075
2080
2085
2090
2095
2100
Time


An Khe
40
20
0
-20
-40
-60
-80
DX(%)
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050
2055
2060
2065
2070
2075
2080
2085
2090
2095
2100
Time


Liên Khương
40
20
0
-20
-40
-60
-80
DX(%)
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050
2055
2060
2065
2070
2075
2080
2085
2090
2095
2100
Time


Phước Long
40
20
0
-20
-40
-60
-80
DX(%)
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050
2055
2060
2065
2070
2075
2080
2085
2090
2095
2100
Time


Can Tho
40
20
0
-20
-40
-60
-80
DX(%)
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050
2055
2060
2065
2070
2075
2080
2085
2090
2095
2100
Time


Soc Trang
40
20
0
-20
-40
-60
-80
DX(%)
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050
2055
2060
2065
2070
2075
2080
2085
2090
2095
2100
Time

Meteorology station belonging each river basin is determined among 137 stations. Values of rainfall and temperature in climate change scenarios for each river basin are averaged of stations in the basin. (Fig. PL5)

In general, correlation coefficients of temperature vary from 0.65 to 0.95 and in winter they are higher than in summer, in the North higher than in the South.

Correlation coefficients of rainfall are lower than that of temperature, ranging between 0.2 and 0.7. Correlation coefficients in winter are higher than in summer, in the North higher than in the South.

2.2. Outside Vietnam

Statistical Downscaling method to develop climate change scenarios could not be applied for the area outside Vietnam due to the lack of observation data. At the time of the project, there have been already the results from PRECIS model for Southeast Asia region by application of SEASTART with resolution of 25 km for the basins outside Vietnam of the Red, Ca and Mekong Rivers. The applied scenarios are A2 and B2 throughout the 21st century with baseline period 1980-1999.

Therefore, we inherited the products which are compatible to the study of MRC and overcame the lack of data from observation stations outside Vietnam, in Laos and China.

2.3. Conclusions

Change in temperature: temperature increases in the basins Hong-Thai Binh, Ca, Thu Bon and Ba. Basins in the South such as Dong Nai have a smaller increase in temperature. Ca River basin may have highest increase in temperature while Dong Nai has smallest increase of all main river basins in Vietnam.

Change in rainfall: the seasonal change of rainfall in the 21st century is quite clear. Rainfall can increase in wet season but decrease in dry season. The change in rainfall volume depends on geographic location of river basins. Change in rainfall patterns is relatively similar in Hong-Thai Binh and Ca River basins: rainfall amout reduces in dry season (Mar-May) and rises in wet season (Jun-Aug). Rainfall in the rest of river basins has a same trend, reducing from December to May and increasing from June to November, with rainfall from September to November increasing more than from June to August.

Figure PL6. Map of change in mean annual temperature (^0C) relative to period 1980–1999, scenario B2

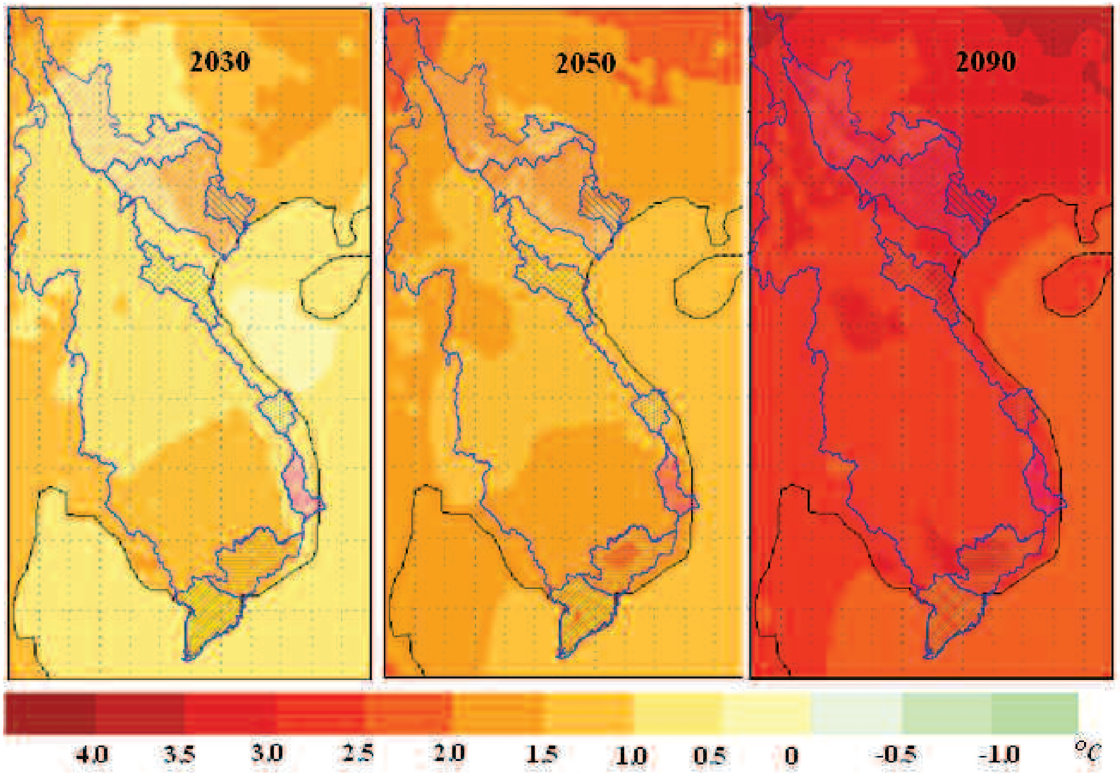


Figure PL7. Map of change in annual rainfall (%) relative to the period 1980– 1999, scenario B2

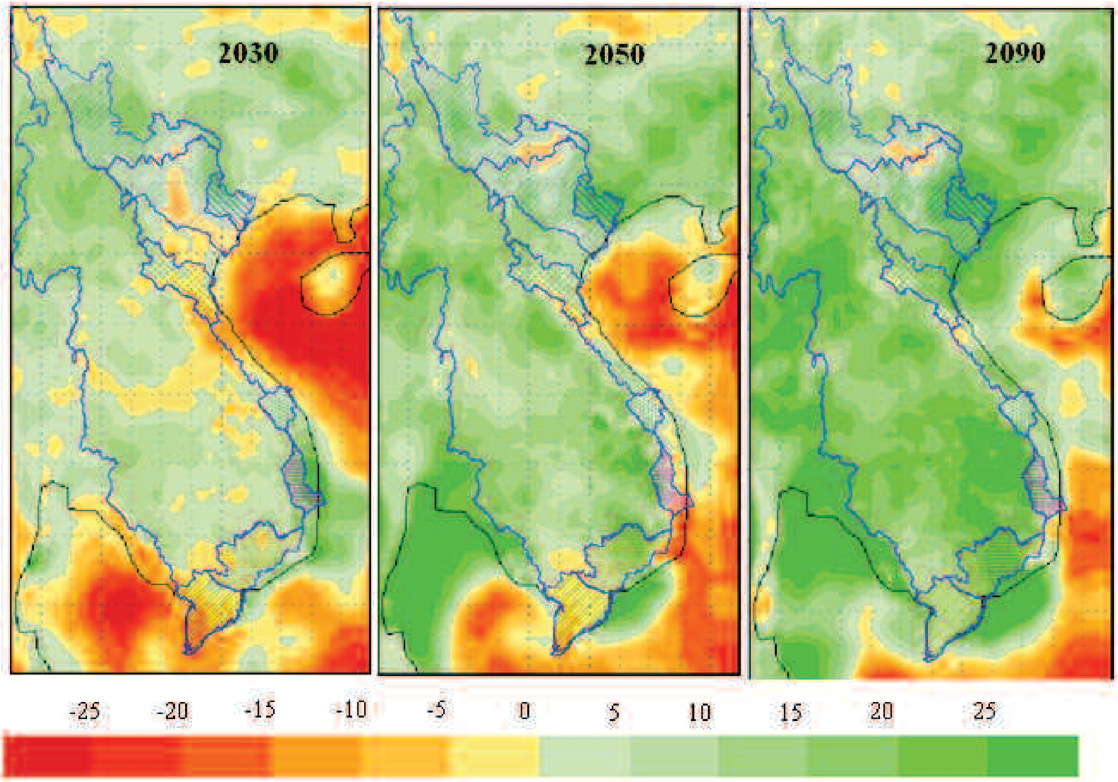
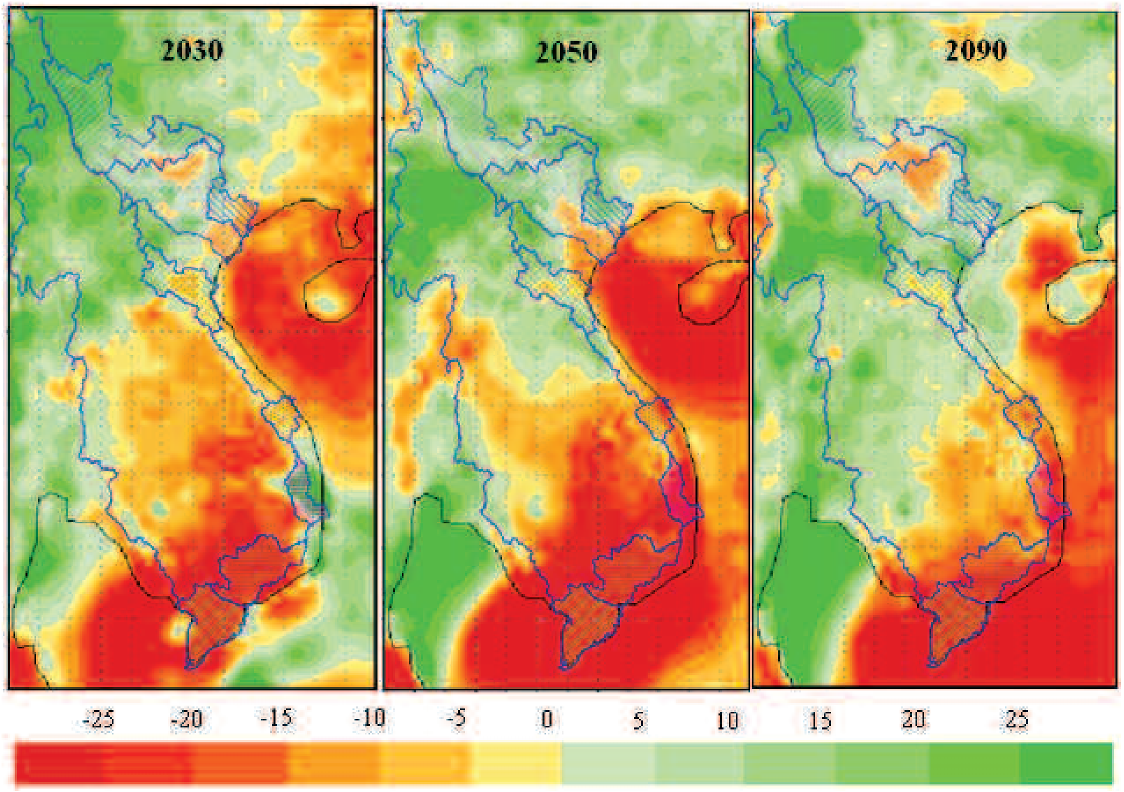


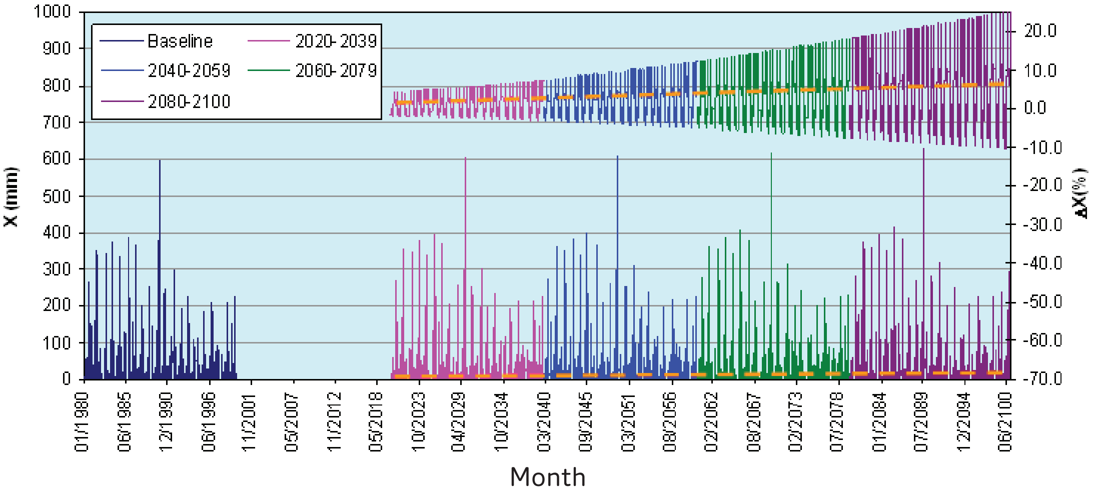
Figure PL8. Map of change in rainfall from November to April (%) relative to the period 1980-1999, scenario (B2)



2.4. Method of estimation for future daily rainfall, temperature for meteorology stations in studied areas

Statistical downscaling method can generate differences in monthly temperature (ΔT °C) and monthly rainfall (ΔX %) from 2020 to 2100 compared to baseline period (1980-1999). The monthly difference in temperature and rainfall is considered as dayly difference and rainfall distribution is assumed unchanged in the future. Values of rainfall and temperature can be estimated for periods 2020-2039; 2040-2059; 2060-2079; 2080-2099 based on the difference between values in these periods and in the baseline period (1980-1999) and observation (rainfall/temperature) in reference period (see figure PL9).

Figure PL9. Prediction rainfall in the future



2.5. Method for potential evapotranspiration (ETo) estimation

Climate change is presented through changes of climatic factors especially rainfall, temperature etc. Temperature increasing results growing evapotranspiration throughout the basin, affecting generation of flow and rising water demand for irrigation. Estimation of actual evapotranspiration under the impacts of climate change is impossible. Therefore, impact of climate change on items in the water balance equation is assessed using potential evapotranspiration insteaded, which is affected by meteorological conditions.

Potential Evapotranspitation (PET) is defined **"Potential evapotranspiration (PET) is the maximum amount of water that could be evaporated and transpired if there was plenty of water available"**. (Pecman, 1948).

Potential evapotranspiration can be estimated by various methods:

- Penman-Monteith method recommended by FAO;

- Hargreaves method;

- Blaney - Griddle method, this method can be applied in case of the availability of air temperature, cloudiness, radiation, wind speed and air moisture.

- Pecman method, only use when temperature, air moisture, wind speed, sunshine hours or radiation are available.

- Pan evaporation;

- Method applied for equatorial regions: ETo = 0,5 x Rg/59

where + Rg: Total radiation (cal/cm^2/day).

+ 59 and 0.5 are coefficients

The Penman–Monteith method is widely used over the world. However, this method is complicated and requires a lot of input data, which is beyond the scope of this study. Instead, the Hargreaves method was used, as it only requires temperature and is recommended by FAO when limited data is available.

To assess the change of potential evaporation in next century (from 2000 to 2100) under scenarios of climate change, the Hargreaves formula is used to simplify the ETo calculation, it is possible to calculate ETo in the region which insufficient data. On the other hand, in the climate change scenarios in the future, we fully expected the average air temperature and Hargreaves method is suitable for ETo calculation at river basins in Vietnam in the future.

Hargreaves method:

ETo = 0.0023(Ttb + 17.8) (Tmax - Tmin)$^{0.5}$ Ra

Where:

ETo - reference evapotranspiration (mm);

Ttb - daily mean air temperature (°C);

Tmax - daily maximum air temperature (°C);

Tmin - daily minimum air temperature (°C);

Ra - extraterrestrial radiation;

$$R_a = \frac{24(60)}{\pi} G_{sc} d_r [\omega_s \sin(\varphi)\sin(\delta) + \cos(\varphi)\cos(\delta)\sin(\omega_s)]$$

Where:

G_{sc} - solar constant = 0.082 MI/m^2.min;

dr nverse relative distance Earth-sun, is given by;

$$d_r = 1 + 0.033\cos\left(\frac{2\pi}{365}J\right)$$

J - the number of the day in the year between 1 (1 January) and 365;

ω_s - sunset hour angle (rad), is given by:

$$\omega_s = \arccos[-\tan(\varphi)\tan(\delta)]$$

φ - latitude (rad);

δ - solar decimation (rad), is given by:

$$\delta = 0.409\sin\left(\frac{2\pi}{365}J - 1.39\right)$$

However, to ensure reliability when calculating the ETo at stations on the river basin in Vietnam, we compare the results calculated by the Penman – Monteith method (at some representative stations have sufficient data) and the Hargreaves method, then the ETo calculation results by Hargreaves method in the basin were adjusted.

The representative meteorological stations used to adjust ETo data are:

- Red - Thai Binh river basin: Lai Chau, Viet Tri, Ha Noi station;

- Ca River basin: Vinh station;
- Thu Bon River basin: Da Nang station;
- Ba River basin: Tuy Hoa station;
- Dong Nai River basin: Dac Nong and Xuan Loc station;
- Sesan River basin: Buon Ma Thuot station;
- CuuLong Delta: Can Tho station;

The ETo calculating adjustment equation of Hargreaves method on basins in Vietnam was as per table PL2:

Conclusion: Correlation coefficients show that:

– A close relation between ETo(s) calculated by two methods exits.

– The results calculated by Hargreaves method and adjusted results by equations mentioned above ensured the reliability when assessing the changing of ETo under scenarios of climate change in Vietnam.

To calculate the ETo based on climate change scenarios in the future, we built the relationship between the average air temperature and calculated and adjusted ETo in the base period (1980-2000) was measured for of all meteorological stations on seven river basins. Based on the predicted average air temperature at meteorological stations and correlative equation, the ETo at those stations under climate change scenarios was calculated.

Table PL2. Adjustment equation for ETo estimated by Hargreaves method on the study basins

River basin/region	Correlation equation	Correlation coefficient R
Red - Thai Binh River basin	y = 0,7449x + 274,69	0,86
+ Middle stream:	y = 0,7759x + 192,81	0,87
+ Lower section:	y= 0,9708x – 253,35	0,83
- Ca River basin:	y = 0,8331x + 183,18	0,91
- Thu Bon River basin:	y = 0,975x + 35,791	0,99
- Ba River basin:	y = 1,6279x – 962,43	0,89
- Dong Nai River basin:	y = 0,8373x + 244,26	0,91
- CuuLong Delta:	y = 1,5767x - 835	0,83

Where: y - adjustment coefficien ETo
x - ETo calculated by Hargreaves method
R – Correlation coefficient between ETo calculated by Penman - Monteith method and ETo calculated by Hargreaves method.

The correlation equation between average air temperature and ETo in the base period is as follow:

$$ETo = aT_{tb} + b$$

For each station, coefficients a and b are different, as shown in table PL3

Table PL3. Correlation coefficient equation between average air temperature and ETo in the baseline period

Stations	a	b	Correlation coefficient
An Khe	9.92	-115.78	0.86
Ayunpa	9.76	-115.50	0.84
Bac Can	7.00	-48.96	0.99
Bac Giang	5.93	-38.53	0.98
Bac Lieu	4.98	-16.26	0.70
Bac Quang	7.59	-65.69	0.98
Bai Chay	5.30	-29.62	0.99
Bao Loc	7.35	-26.90	0.77
Ba Tri	13.65	-257.17	0.88
Buon Ho	10.93	-112.08	0.85
Buon Ma Thuot	12.60	-154.30	0.85
Ca Mau	12.34	-208.45	0.72
Cang Long	14.17	-261.76	0.84
Can Tho	13.52	-239.21	0.81
Cao Lanh	12.58	-220.85	0.69
Chau Doc	11.97	-202.37	0.79
Chiem Hoa	7.26	-55.88	0.98
Chi Ne	6.86	-54.29	0.98
Con Cuong	8.27	-81.94	0.96
Dac Nong	11.05	-102.31	0.69
Dac To	6.14	3.89	0.77
Da Lat	10.92	-106.58	0.73
Da Nang	11.21	-161.78	0.94
Dinh Hoa	6.71	-46.46	0.98
Do Luong	7.74	-78.36	0.97
Ha Dong	6.24	-46.78	0.98
Ha Giang	7.25	-58.19	0.98
Hai Duong	5.62	-36.28	0.98
Ha Nam	6.08	-44.13	0.97
Ha Tinh	7.21	-73.18	0.97
Hiep Hoa	6.08	-41.93	0.99
Hoa Binh	7.06	-56.30	0.97
Hung Yen	6.08	-48.16	0.93
Huong Khe	8.22	-81.30	0.97
Kim Boi	7.37	-60.89	0.99
Kim Cuong	7.71	-67.31	0.97

Stations	a	b	Correlation coefficient
Kon Tum	10.06	-95.19	0.82
Lai Chau	6.94	-38.13	0.87
Lang	6.38	-51.86	0.97
Lao Cai	6.75	-48.70	0.97
Lien Khuong	9.52	-67.42	0.68
Mdrack	11.39	-151.49	0.89
Moc Chau	5.77	-10.69	0.92
Moc Hoa	13.83	-259.61	0.72
Mong Cai	5.14	-20.63	0.99
Mu Cang Chai	5.38	4.89	0.89
Muong Te	6.86	-29.51	0.84
My Tho	10.45	-158.10	0.86
Nam Dinh	5.98	-43.80	0.97
Ninh Binh	6.08	-47.79	0.97
Phu Ho	6.85	-57.14	0.98
Phu Lien	5.97	-41.35	0.98
Pleiku	8.56	-63.98	0.76
Quy Chau	7.27	-59.05	0.94
Quy Hop	6.52	-53.91	0.97
Rach Gia	7.07	-82.98	0.74
Sapa	4.20	2.49	0.93
Shin Ho	4.58	11.67	0.87
Soc Trang	13.16	-228.14	0.80
Son Dong	5.93	-31.02	0.99
Son Hoa	11.55	-168.24	0.90
Son La	5.99	-12.62	0.91
Tay Hieu	7.46	-62.02	0.96
Tay Ninh	15.08	-255.57	0.88
Thai Binh	5.80	-40.64	0.99
Thai Nguyen	6.67	-52.93	0.99
Tra My	15.39	-238.97	0.94
Tuong Duong	8.80	-79.95	0.94
Tuyen Quang	6.92	-56.16	0.98
Tuy Hoa	11.65	-192.50	0.92
Van Chan	6.96	-48.05	0.98
Viet Tri	6.57	-53.67	0.98
Vinh	7.07	-67.24	0.96
Vinh Yen	6.54	-54.89	0.98
Yen Bai	6.98	-58.11	0.99

2.6. Method for developing sea level rise scenarios for Vietnam

In the project, Regional Ocean Model System (ROMS) model has been used to simulate the water level variations and hydro-dynamic fields. Water level variations according to calculation at Hon Dau and Vung Tau stations were compared to real-time data. In the future, under the impacts of climate change, when average global sea level rises, the average sea levels of various regions on global oceans are also different due to changes in circulations, temperature and salinity (IPCC4). At the same time, the long wave resonance also has different changes in every region due to increase of the depth and especially in horizontal direction, as the sizes of the seas have increasing tendency. ROMS model simulates the future tide variations through modeling the hydrodynamic process under some assumptions on the effects of average global sea level rise (or average regional sea level rise if possible)

Tide variations along the coast of Vietnam with grid points 10x10 km were calculated for future with various rates of sea level rise.

3. Simulation models

Mathematical models have proved to be useful tools for simulation and assessment of climate change impacts on water resources in the future when projected climatic information is available. The list of models is shown in table PL4.

Detail models can be referred in technical reports and these following addresses.

http://www.mikebydhi.com/

http://www.halcrow.com/isis/

http://swatmodel.tamu.edu/

http://www.mrcmekong.org/programmes/wup/DSF/DSF_Introduction.htm

Table PL4.List of used models

basins/regions	Models		
	Rainfall - runoff	Water balance	Hydraulic
Hong	NAM	MIKE BASIN	MIKE 11
Thai Binh	NAM	MIKE BASIN	MIKE 11
Ca	NAM	MIKE BASIN	MIKE 11
Thu Bon	NAM	MIKE BASIN	MIKE 11
Ba	NAM	MIKE BASIN	MIKE 11
Dong Nai	NAM	MIKE BASIN	HydroGIS
Cuu Long Delta	SWAT	IQQM	ISIS

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