THE POTENTIAL IMPACTS OF CLIMATE CHANGE ON FLOOD FLOW IN NHUE – DAY RIVER BASIN

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Abstract: In this study, the impacts of climate change on flood flow on Nhue-Day river basin are examined using the climate projection from the regional climate model RegCM3, the third version of the International Centre for Theoretical Physics (ICTP, Italy), nested into the global climate simulations of the Community Climate System Model version 3.0 followed the IPCC SRES A1B and A2 scenarios. Naturally, the Nhue-Day river basin is often affected by tropical cyclones from the northwest Pacific Ocean and the South China Sea. Moreover, this basin is impacted by the socio-ecomonic development of Hanoi capital nearby. With global warming, those impacts would be more serious over this area. In order to analyze the potential impacts of climate change on flood flow in this basin in the future, firstly the RegCM3 was set up with a configuration of 36 km horizontal resolution and 18 vertical levels over the domain of $5^oS – 27^oN$, $85^oE – 130^oE$ for the 20th century climate simulation in 1970-1999 and for the future climate projection in 2010-2050. The daily precipitation and evaporation simulated by the RegCM3 was interpolated to so-called observation stations over the area and then was used as input of NAM rainfall-runoff module of the MIKE11 river modelling system, a deterministic, lumped and conceptual rainfall-runoff model representing various components of the rainfall – runoff process by continuously accounting for the water content in up to 4 different storages and mutually interrelated storages, developed by the Department of Hydrodynamics and Water Resources at the Technical University of Denmark. Scenarios have been simulated for 8 subbasins covering the Nhue-Day river basin. Changes in extreme high values have been analysed, and further the statistical return periods of future extremes in a design situation has been shown.

Keywords: *Climate change,CCSM,GCM, RegCM3, NAM, Nhue-Day river basin, flood flow*

1. Introduction

Global climate change has been widely accepted to be happening and the issue of water resources under climate change impacts is no longer new, they are paid much attention by early works such as Namec & Schaake (1982), Gleick (1987), Bultot et al. (1988), Cohen (1991). The approaches on this aspect are therefore also diversified, for example, HadCM2 experiment, one of the Hadley Centre's Second Generation Coupled Ocean-Atmosphere GCMs was directly used to simulate the potential effects of changing climate on water resources off – line by Reynard et al. (2001) and using the global integrated water model WaterGAP calculate the water balance of each grid cell globally

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at a spatial resolution of 0.5^o longtitude and 0.5^o latitude can be found in the work by Lehner B. et al. (2006). However, there were limitations in hydrological models as well as in climate change projections, but the main sources of uncertainty lies in the climate change scenarios.

Today the science literature is full of examples of climate change impact study on water related fields such as on peak or flood flow - an important and significant hydrologic parameter in hydrological cycle and water resources management as well. As such, many studies have focused on understanding the variability of that parameter. Vietnam in contrast, while most studies on climate change have been conducted over large scale of river basin and concentrated on average values, analyses the impacts on extreme of flow regime whether floods or droughts are relatively rare.

In this study, the global climate simulations of the Community Climate System Model (CCSM) version 3.0 was used to generate IPCC SRES A1B and A2 scenarios. The climate projection from the regional climate model RegCM3, the third version of the International Centre for Theoretical Physics (ICTP, Italy), was then used to obtain future possible local meteorological variables including evaporation and precipitation in the study area. However, RegCM3 outputs are generally gridded data, while rainfall runoff model used in this study acquires the station data. The downscaled data was therefore interpolated to so-called observation stations in this area and was used as input of NAM model which is set up for Nhue – Day river basin. Although precipitation of the GCMs was about 30% less than what was observed (Phan Van Tan et al., 2011), a reason for the hydrological model tended to underestimate runoff in this study, this approach could be informative which has ability to express the fluctuation in climatic factors.

Nhue – Day is a watershed which plays a key role for the economic developments along with the Red River plain. The current water resources of river basin are suffering huge pressures from human and nature in which populous and urbanized factors is judged as one of the important causes of the worse impacts. In the whole Nhue – Day river basin, only observed runoff data at Ba Tha station are available, therefore individual calibration of the NAM model was not done for every subbasin. As such the parameter values had been calibrated and verified for NDI will be used for 6 remain subbasins (from NDII to NDVII).

2. Strategy and methods

2.1. Downscaling

In this study, we will use the output data from atmosphere component (ATM) of the Community Climate System Model (CCSM) in order to provide future climate conditions based on the medium (A1B) and high (A2) emission scenarios of GHGs. The regional climate model, RegCM3 was driven by boundary conditions from a GCM to derive finer resolution. The model runs with 18 vertical σ-levels, in which 6 levels are under 850 mb in the planetary boundary layer and the top layer is at 50 mb. The model domain centered at 11.5^{o}N and 108.0^{o}E with 145 and 105 grid-points in west-east and south-north directions, respectively, and with a horizontal resolution of 36 km for both directions. A more detailed description of these climate models is given in Phan Van Tan et al. (2010).

2.2. Interpolation method

The station data was estimated by using the simple bilinear interpolation (Fig.1) following Eq. 1. Bilinear interpolation is an extension of linear interpolation for interpolating functions of two variables on a regular grid. The key idea is to perform linear interpolation first in one direction, and then again in the other direction. Although each step is linear in the sampled values and in the position, the interpolation as a whole is not linear but rather quadratic in the sample location.

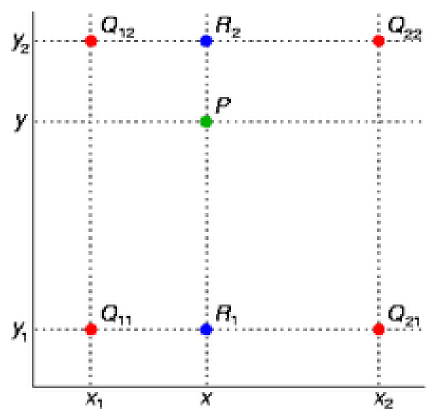

Figure 1. Bilinear interpolation scheme. The four red dots show the data points and the green dot is the point at which we want to interpolate.

$$\begin{aligned} f(x,y) \approx & \frac{f(Q_{11})}{(x_2-x_1)(y_2-y_1)}(x_2-x)(y_2-y) \\ & + \frac{f(Q_{21})}{(x_2-x_1)(y_2-y_1)}(x-x_1)(y_2-y) \\ & + \frac{f(Q_{12})}{(x_2-x_1)(y_2-y_1)}(x_2-x)(y-y_1) \\ & + \frac{f(Q_{22})}{(x_2-x_1)(y_2-y_1)}(x-x_1)(y-y_1). \end{aligned} \quad (1)$$

2.3. The hydrology model

The "Nedbor-Afstromnings Model" NAM (Danish Hydraulic Institute, 1982) is a deterministic, lumped conceptual rainfall-runoff model developed at the Technical University of Denmark. NAM has been used worldwide in a variety of climatic and hydrologic settings to simulate runoff from precipitation events. The model can be used independently, dynamically with MIKE 11, or to develop input time series for MIKE Basin catchment nodes. NAM is a rainfall-runoff model that operates by continuously accounting for the moisture content in three different and mutually interrelated storages that represent overland flow, interflow, and baseflow (DHI, 2007). As NAM is a lumped model, it treats each sub-catchment as one unit, therefore the parameters and variables considered represent average values for the entire sub-catchments. Water use associated with irrigation or groundwater pumping can also be accounted for in NAM. The precipitation in the form of snow was not considered in the paper because of the climate condition in this study area.

The result is a continuous time series of the runoff from the catchment throughout the modelling period. Thus, the NAM model provides both peak and base flow conditions that accounts for antecedent soil moisture conditions over the modelled period. Basic data requirements of NAM model include catchment area, initial conditions, and concurrent time series of precipitation, potential evapotranspiration, and stream discharge. Calibration of the NAM model involves adjusting the coefficients for the exchange of water between storage units and the storage unit depth so that simulated and observed discharges match as best as possible. A minimum of 3 years including periods of above-average precipitation is recommended for calibration, with longer periods resulting in a more reliable model (DHI, 2004). Disparity between simulated and observed discharge arise due to quality of time series data or other attributes. For ungaged streams, parameters developed for another catchment with similar topographic, climatic, geologic, vegetative, and land use characteristics can be applied.

3. Results and discussion

3.1. Calibration and verification of the rainfall-runoff model NAM

Based on the topography of the study area, the basin was divided into 7 subbasins as showed in Fig.2. An auto-calibration routine was used which aimed to maximise NSE (Nash–Sutcliffe efficiency) whilst keeping the water balance error low. NAM model was tested for the periods 1971-1973 and 1976-1978. The accumulated water balance error was 0.0%: the model predicted exactly equal to the observed total water volume and the NSE were 0.819 (Fig.3). This parameter set was verified with discharge data in 1976-1978 and also showed the good agreement between simulated and observed results (Fig.4).

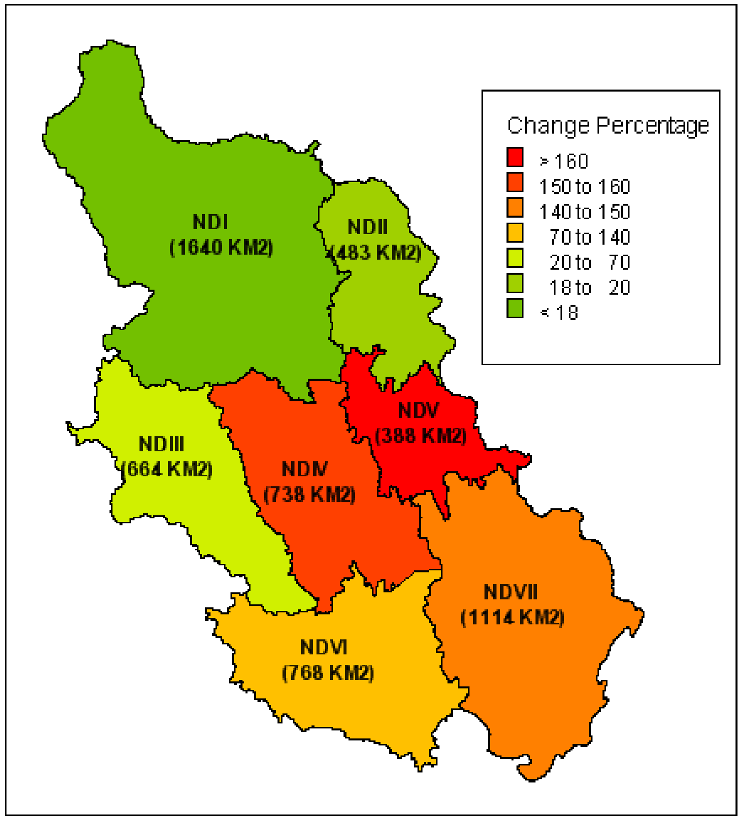

Figure 2. Spatial Change in the average flow in 6 months of the wet season in Nhue – Day catchment according to A2 scenarios

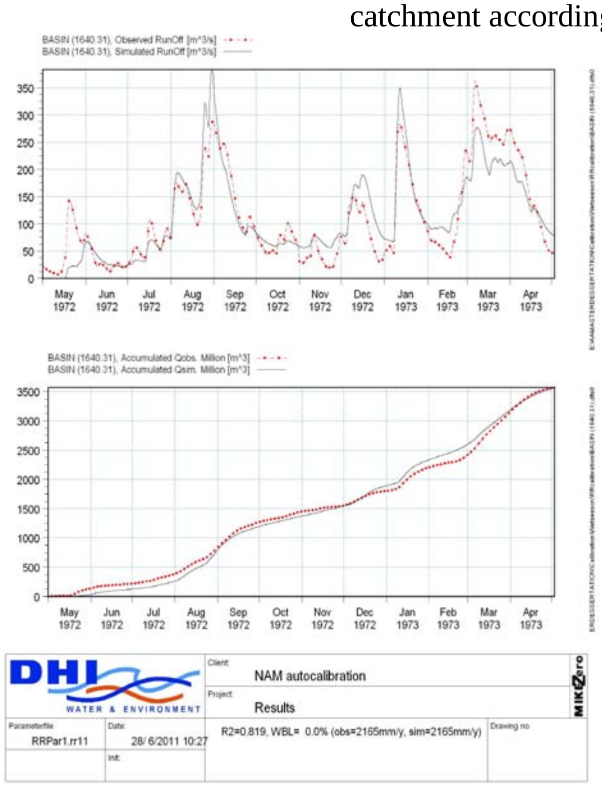

Figure 3. Calibration of the NAM model set up on the Ba Tha outlet station shown for the year 1971-1973. Accumulated water balance error = 0.0%, and NSE=0.819.

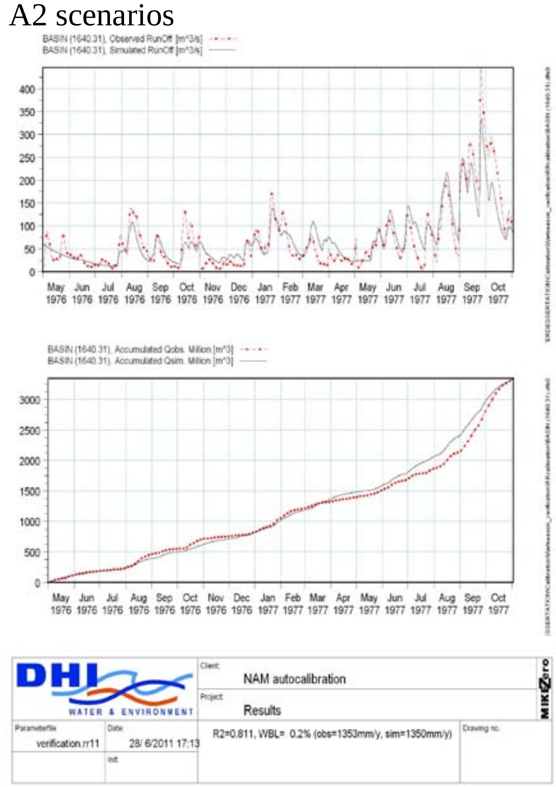

Figure 4. Verification of the NAM model set up on the Ba Tha outlet station shown for the year 1976-1978. Accumulated water balance error = 0.2%, and NSE=0.811.

3.2. Changes in flood characteristics

The climate-change impacts on runoff from subbasin within the entire Nhue – Day river basin were evaluated by applying the NAM model with climate data for the control period (1970–1999) as baseline information and then for the scenario period (2010–2050), respectively.

In this analysis, flood season occurs from May 1 until October 31 which have been distributed by Nguyen Thanh Son et al. (2011). Modelled flood runoff varies considerably between subbasins. Percentage changes in the average runoff of 6 months in the wet season for different subbasins vary from likely decrease 75.2% to increase of 31.7% according to A1B scenrios. Meanwhile, the flood flow under impacts of the A2 scenario is likely increases of 15.9% to around 169%. Although these are neighboring subcatchments they have distinctly different responses to precipitation as shown in Figure 2 and Figure 5. It showed the biggest increase in the centre, NDV subbasin, where it is likely to increase by 169% in 2050, and the lowest increase in the north of river basin, 15.9% in NDI subbasin.

The flood pattern is expected to change significantly. In the northern subbasins, peak flows occur later with greater peak flows and longer duration of flooding compared with baseline condition. In contrast, it happens earlier in the southern subbasins in comparison to baseline period in Nhue - Day (Fig. 5). Moreover, flood in those upper subbasins vary more complicated, i.e the start and end values on the flood period in both scenarios are lower than that of baseline condition, but there is a strong increase in peak values. In the south, flows in those subbasins follow the linear variation, there is an increase or a decrease during flood period depending on scenarios.

The other finding is that average flood runoff likely increase under the projected climate following A2 scenario, while projected runoff for A1B is significant lower in comparison with baseline scenario except in subbasin NDI and NDII. The A2 projections suggest that runoff of most all subbasins will increase in most all months of the wet season except in June of three headwater subbasins. The largest increases are projected to occur in July, with runoff increases of 100% or greater. The monthly runoff of most all subbasins following the A1B projections will decrease in most all months of the wet season and get the biggest decrease in June, about 36% or greater.

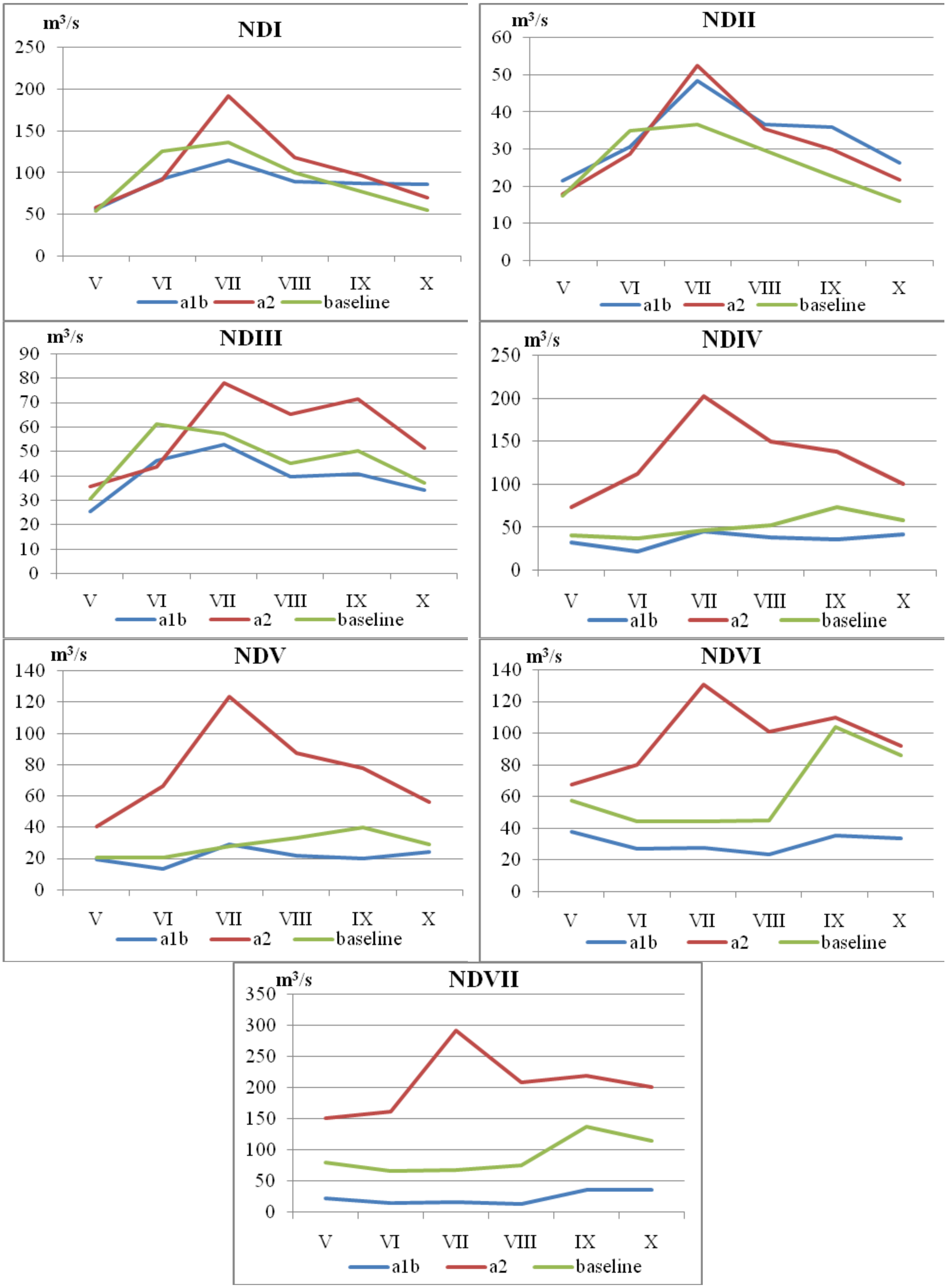

Figure 5. Distribution of the projected change in mean flood flow compared with baseline (1970-1999) mean high flow for all subbasins of Nhue Day river basin

Table 1. Estimated change in frequency distribution of average flood flow

Subbasin	NDI			NDV			NDVI		
P	Baseline	A1B	A2	Baseline	A1B	A2	Baseline	A1B	A2
1%	575	225	2822	201	366	1361	715	266	1331
2%	488	192	2014	168	289	1032	576	221	1049
5%	375	148	1075	125	191	628	400	162	692
10%	280	113	508	93	121	363	273	118	446

In term of frequency analyses, frequency software TSTV2002 of the Water Resources University, based on Pearson III probability distribution function, were used. The results suggested that the spatial variation of frequency is also similar with monthly flow in this river basin and the more frequent floods are affected less by the changes in climate (Table 1). For example, magnitude of the 100 year maximum peak of NDV subbasin increase approximately 6 times while magnitude of the 10 year maximum peak increase 4 times following A2 projections. While under A1B scenario, magnitude of 100 year event and 10 year event in the same subbasin is 1.8 and 1.3 higher respectively. The return period of a given flood might be shorter due to the climate change impacts following A2 scenarios but has an uncertain change following A1B scenario (Table 1). In detail, event with an intensity of today's 50 year floods may recur every 10 years by the 2050s according to A2 scenario in NDI subbasin.

4. Conclusion

The scenarios are produced by a combination of CCSM, RegCM3 and simple bilinear interpolation in the form of time series of so-called observation stations in Nhue – Day river basin to applying the hydrological model, NAM. Although several questions remain to be solved in order to use finer resolution scenarios for assessment of the future state of water resources in Nhue – Day catchment. And one way to overcome these problems would be to integrate the hydrological model into the climate model through developing a hydrological model with grid-scale inputs.

Generally, the climate change scenario A2 caused an increase in the magnitude and frequency of flooding, increased the flows of a given return period flood by up to 4 times or greater and therefore reduced the return period of a given flow by the 2050s. While following the A1B scenario, it showed an uncertain changes in the magnitude and frequency of flooding, magnitude and the return period of given flow.

The impacts of scenarios have been observed to cause a major shift in the flow regimes, particular at the more extreme flood in northern subbasins and those impacts is lower with more frequent floods.

These findings, though interim and preliminary, highlight the growing challenges for water resources managers. In particular, the results address the importance of mitigation and adaptation strategies at Nhue – Day river basin. They can form the basis for mapping the areas most vulnerable to flooding. Moreover, it may be employed to guide further development of regional management plans.

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Reference

1. Bultot et al. (1988), Estimated annual regime of energy-balance components, evapotranspiration and soil moisture for a damage basin in the case of CO2 doubling, Clim Change 12: 34 – 56
2. Cohen, SJ. et al. (1991) *Possible impacts of climate warming scenarios on water resources in the Saskatchewan River subbasin*, Canada, Clim Change 12: 39 – 56
3. DHI (2007) – MIKE 11 Reference Manual – DHI software 2007.
4. DHI (2004) – *Rainfall-Runoff Modeling Report for the Upper Salmon and East Fork Salmon River Basins*.
5. Lehner B. et al. (2006). *Estimating the impact of global change on flood and drought risks in Europe: A continental, integrated analysis*, Climatic Change 75: 273 – 299.
6. Gleick, PH. et al. (1987) *Regional hydrologic consequences of increases in atmospheric CO2 and other trace gases*, Clim Change 10: 127 – 161.
7. Lehner, B. et al. (2006) *Estimating the impact of global change on flood and drougnt risks in Europe: a continental integrated analysis*, Climatic Change 75: 273 – 299.
8. Namec J, Schaake J (1982) Sensitive of water resources systems to climate variation Hdrol Scie J 27: 327 – 343
9. Reynard, NS. et al. (2001), *The flood characteristics of large U.K. rivers: potential effects of changing climate and land use*. Climate Change 48: 343 – 359.
10. Nguyen Thanh Son et al., (2011). "*Survey the status of water resource in Nhue-Day river basin*", Vietnam National University Journal of Science, Natural Sciences and Technology, Vol. 27 (1S), p. 227. In Vietnamese.
11. Phan Van Tan et al. (2011). "*Study the impacts of Global Climate Change on extreme events in Vietnam, forecast ability and response solutions*", Final Report KC08.29/06-10. In Vietnamese.