

## DEVELOPING A REGIONAL METHODOLOGY FOR CLIMATE ADAPTATION IN THE NILE BASIN

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### EXTENDED ABSTRACT

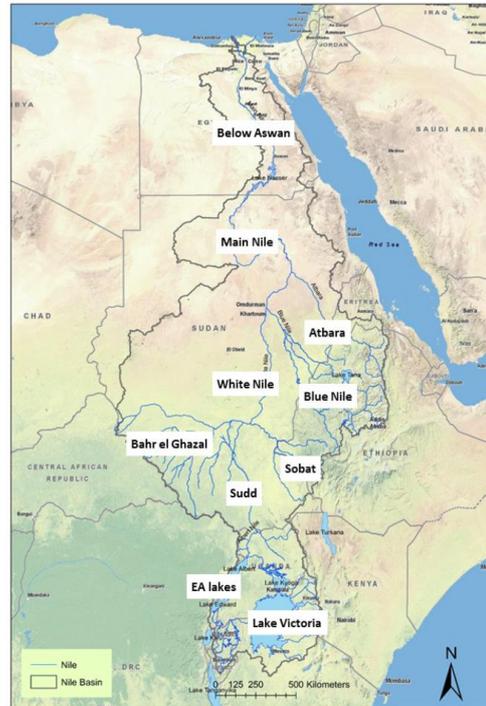
The Nile Basin is the main source of water in the North Eastern Region of Africa and represents one of the most critical and perhaps most important shared water basins in Africa. Runoff is generated in less than a third of the basin. On average 86 percent of the annual flow is generated in the Ethiopian highlands – a region known for its high seasonal and inter-annual variability. The region is facing rising levels of water scarcity, high population growth, watershed degradation and loss of environmental services. Many past studies have demonstrated that modelling current and future changes in river runoff presents a number of challenges; the large size of the basin, the complexity of the hydrology – the Nile Basin exhibits one of the most extensive system of lakes and wetlands in the world with little known hydrology, the relative scarcity of data, its geographical location and the corresponding dramatic variety of climatic conditions. On top of these hydrological challenges, the climate projections are inherently uncertain. Nevertheless decision-makers in the region need to evaluate and implement climate adaptation measures. Within trans-boundary basins like the Nile, the implementation of such measures may need to address the basin as a whole and evaluate alternatives to avoid regrettable outcomes. Therefore tools and information are required to understand climate change and adaptation impacts at the regional scale.

A modelling framework to support climate adaptation on a regional scale has been developed by DHI and the UK Met Office for the project “Adapting to climate change induced water stress in the Nile River Basin”. This project was launched in March 2010 as a partnership between the United Nations Environment Programme (UNEP) and the Nile Basin Initiative (NBI), sponsored by the Swedish International Development Cooperation Agency (SIDA), for assessing climate change impacts and adaptation potential for floods and droughts within the basin. The methodology exploits a novel perturbed physics ensemble of climate models recently developed at the UK Met Office. A systematic procedure was followed to identify a representative sub-set from a larger GCM ensemble based on the ability of the members to reproduce the key climatic processes in a number of regions of Africa while representing the range of outcomes of the full ensemble. These were then downscaled using a regional climate model with the resulting projections used together with a regional hydrological model, to assess the impacts of climate change on flow extremes and water scarcity. In this paper we present both the framework and initial results of climate changes on the flow characteristics in the basin.

**Keywords:** Climate change, regional scale modelling, regional scale adaptation, Nile River basin, floods, water scarcity.

## 1. INTRODUCTION

The Nile River, the longest river in the world (UNEP, 2010), extends from approximately latitude 4°S to 32°N. Due, in part, to the large range in latitude, the Nile basin's climate varies significantly from extreme aridity in the north, including Egypt and Sudan, to the tropical rainforests in Central and East Africa and parts of Ethiopia (Figure 1).

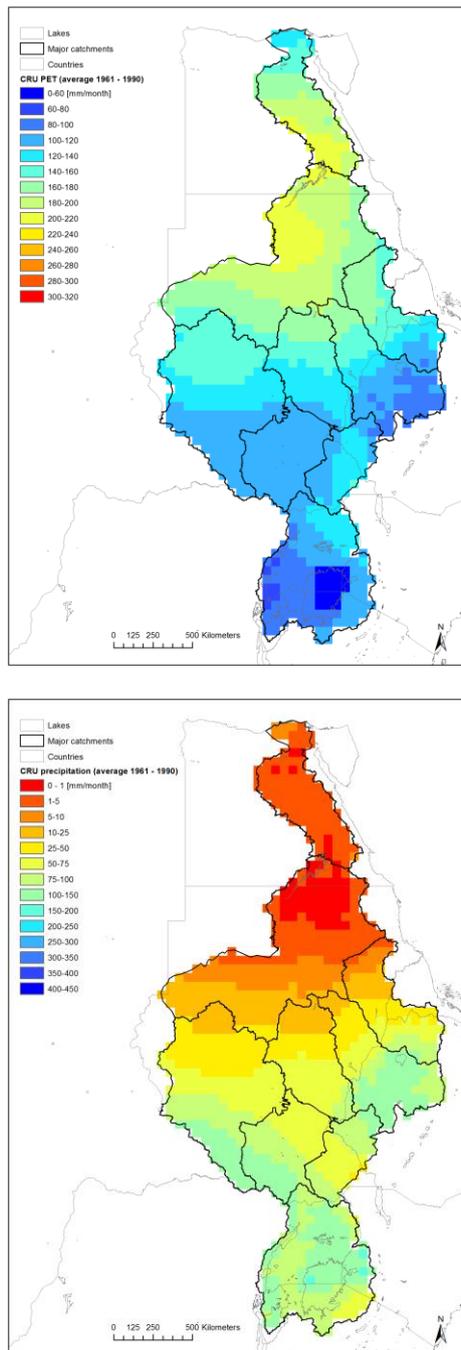


**Figure 1.** Overview of the Nile River Basin

The distribution of the precipitation over the basin when seen on a regional scale is primarily in two distinct regions; the Equatorial (or East African) lakes and the Ethiopian highlands (Figure 2) and these are the most important contributors to the flow (Sutcliffe and Parks, 1999); the Ethiopian highlands alone contribute about 86% of the annual flow to the High Aswan Dam in Egypt. As a result, one of the unusual characteristics of the basin is the contrast between the size of the basin and the relatively small volume of runoff. Furthermore, there are significant differences in the wet and dry period distribution over the Nile, with some of the areas in the tropical region of Nile Basin exhibiting a bimodal rainfall season. The natural variability of the climate and the sensitivity of the runoff to changes in climate (Conway et al., 2007; Elshamy et al., 2009) in the region are also reflected in the significant inter-annual and inter-decadal variability in the Nile flow. This has important implications for the management of water resources in the Nile (Conway, 2005). It is expected that future climate change may exacerbate the level of water stress across the basin and it therefore important to assess and manage the potential effects of such changes.

The population within the Nile basin corresponds to nearly 25% of Africa's population (UNEP, 2010) while the basin accounts for only around 10 % of the continental landmass. The Nile is a crucial resource for the economy of eastern and north-eastern Africa. Agriculture, energy production and livelihoods all depend strongly on the river flow. Managing and developing the water resources within the basin must not only address different water uses but also the trade-off between developments upstream and water

use downstream, between different countries and sectors (agriculture vs. energy, environmental quality vs. agriculture, etc.). In addition, the region is facing rising levels of water scarcity, high population growth, watershed degradation and loss of environmental services. Any future changes in the water quantity and quality and their distribution in space and time will have important impacts on the local and basin wide economies and environment. It is important therefore to obtain quantitative assessments of projected changes in climate and water demand as the basis for water resources management and climate adaptation strategies.

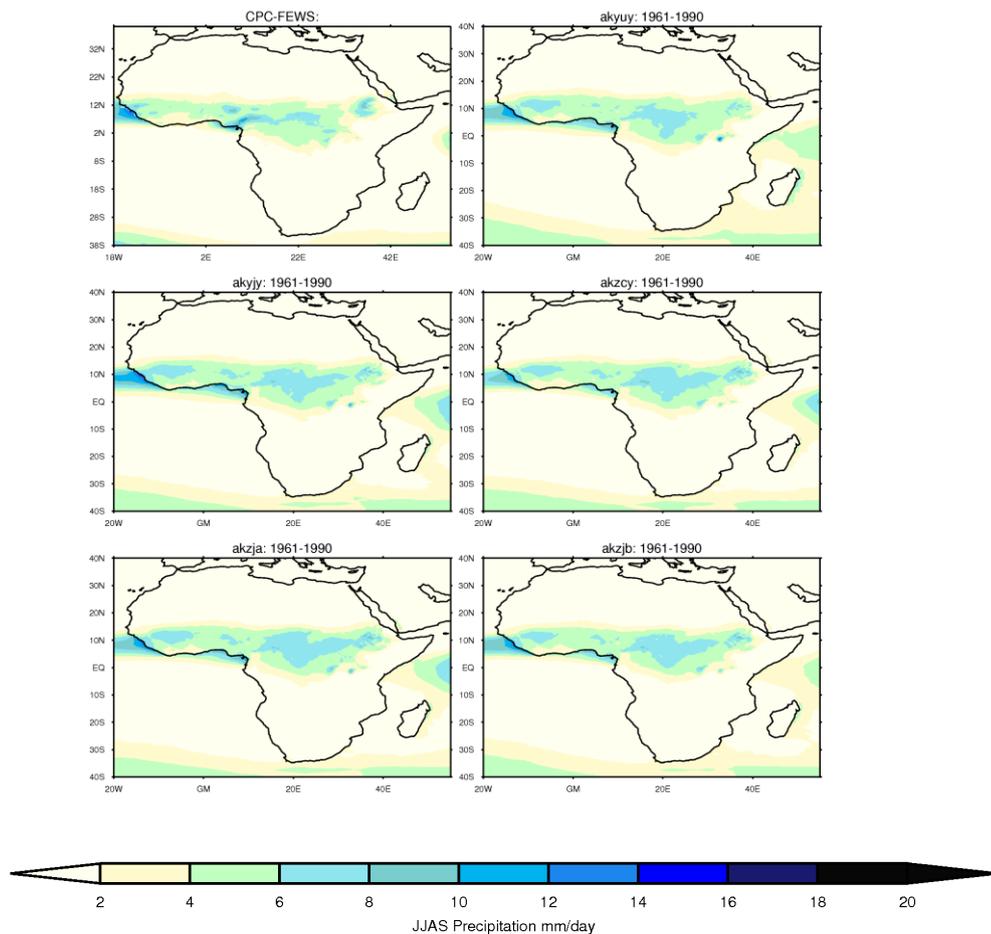


**Figure 2.** The distribution of annual average rainfall (left) and potential evapotranspiration (right) expressed in mm/month. The figures are derived from the CRU (<http://www.cru.uea.ac.uk/data>) data for the reference period 1961-1990 of the Nile River Basin

To address these challenges, managers and decision-makers require tools and information at all levels, from local to national to regional, to support their decisions. The key goal of this work is to support their efforts and inform their decision-making at the regional level by development a regional scale framework for assessing climate change effects that includes regional scale climate and hydrological modelling. This framework is being applied within the UNEP/NBI project “Adaptation to climate change induced water stress in the Nile River Basin” funded by SIDA.

## 2. REGIONAL CLIMATE MODELLING

It is now widely recognized within the climate community that assessments of climate change should be based on multiple model projections or ensembles (Collins and Knight, 2007; Buontempo et al., 2011). This is motivated by the inherent uncertainty in climate projections. Different Global Circulation Models (GCM’s) project different responses to climate change (Giorgi and Francisco, 2000) and there is no methodology for determining which is correct. The prevailing view is that no single “true” model can be found. Results from multiple global climate models, multiple parameterisations of the same model (Murphy et al., 2004; Stainforth et al, 2005) and multiple GCM-RCM combinations (Christensen et al.; 2007, Hewitt, 2005) are now available and represent the current state of the art in terms of climate change assessment.

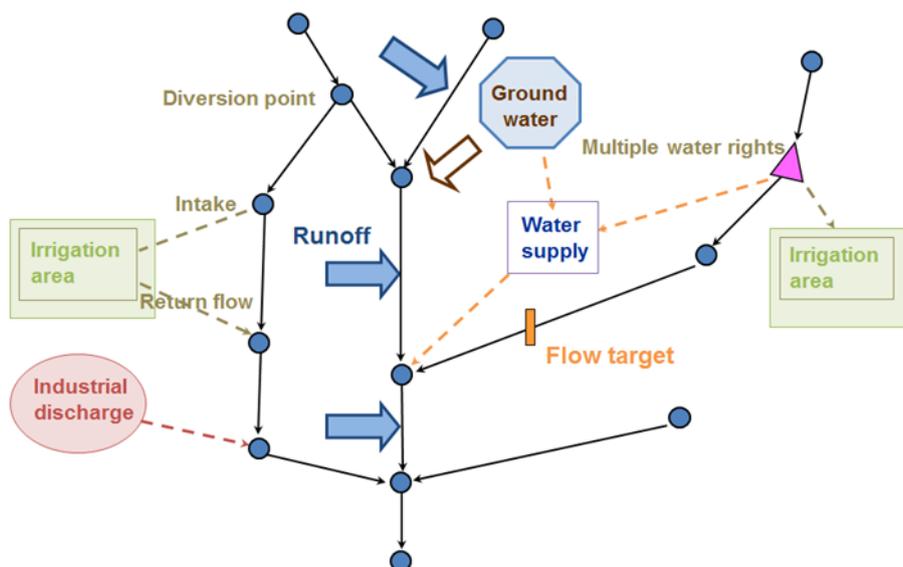


**Figure 3.** Comparison of the observed and simulated precipitation for Africa for the period June-September (JJAS). The observations are from CPC- FEWS (Love et al., 2004) cover the period 1983-2012 while the simulations cover the 1961-1990.

In this study, the Perturbed Physics Ensemble (PPE) approach is used. The PPE approach (Collins et al., 2006) represents the uncertainties or variability in climate projections by perturbing uncertain parameters to create new versions of the climate model. Each of these versions is characterised by different values for a set of parameters that describe the basic unresolved physical processes (Collins and Knight, 2007; Palmer and Williams 2008). This approach was used to generate a large ensemble and here we apply a recently published systematic methodology (McSweeney et al, 2012) to select a subset of 5 GCM ensemble members based on their ability to reproduce important features of the present-day climate over Africa while capturing the range of outcomes from the GCM ensemble. The ability of the selected ensemble to reproduce the rainfall patterns over Africa is illustrated in Figure 3. To obtain high resolution information suitable for assessing climate change impacts on flows in the Nile, these GCM's were dynamically downscaled, i.e. lateral boundary conditions from the GCM's are used to drive the regional HadRM3P on the 50km resolution Africa CORDEX (Giorgi et al, 2009) domain. On the basis of these new RCM simulations, change factors were derived for all 5 ensembles, for temperature, potential evapotranspiration and precipitation and for two periods 202-2049 and 207-2099.

### 3. REGIONAL HYDROLOGICAL MODELLING

To represent the flows and water resources on the regional scale, both for climate change impact assessment and for climate adaptation scenarios, distributed hydrological modelling is required. In this study, a sub-basin based modelling approach using MIKE HYDRO (DHI, 2013) was adopted. MIKE HYDRO is a general water resources modelling framework developed specifically to identify and assess water resource management measures and constraints. This model includes rainfall-runoff processes using the NAM model as described below, a river network that links catchment inflows from different sub-basins to the river and links the different tributaries to the main river, routing along the river reaches (Figure 4).



**Figure 4.** Schematic of the MIKE HYDRO network model including different water activities and water users.

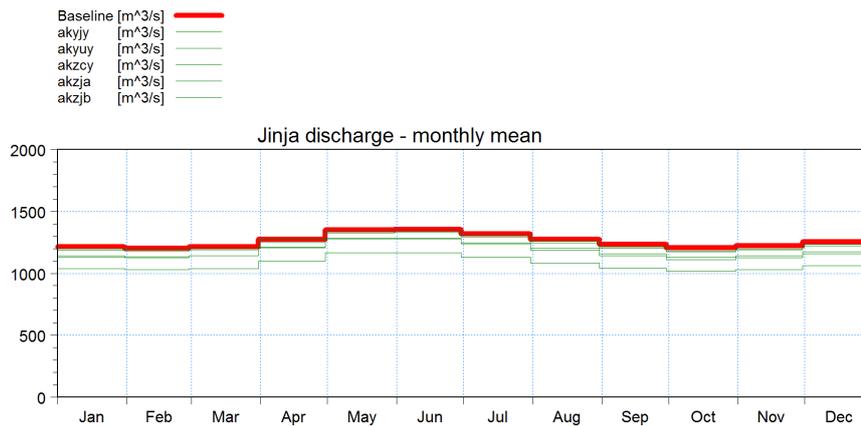
The NAM rainfall-runoff model is a conceptual rainfall-runoff model that has been extensively used in a wide range of applications and hydro-climatic conditions, (Butts et al., 2007; Butts et al., 2004; Madsen, 2000; Havnø et al., 1995). When applied to a single catchment, NAM can be characterised as a deterministic, lumped conceptual model that operates by continuously accounting for the moisture content in a number of different but mutually interrelated storages. However in most applications, the basin of interest is divided into a number of sub-basins in order to represent the spatial variations in either the meteorological forcing or sub-basin characteristics. The runoff from these basins then becomes the inflow to the river or channel network representation used in MIKE HYDRO (Figure 4).

This model represents rivers and their main tributaries as a network consisting of branches and calculation nodes. Branches represent the individual river sections, while the nodes represent either a confluence or a location where certain water activities occur. These include, for instance, multipurpose reservoirs, withdrawals for water supply or irrigation, effluent discharges, diversion canals and systems, gauging stations, low flow control points and priority-based allocations. Simple routing along the branches is used between these nodes. Withdrawals from the river or reservoir are specified as irrigation water users and/or regular water users (e.g. domestic or industrial).

MIKE HYDRO accommodates multiple multi-purpose reservoir systems. Individual reservoirs can simulate the performance of specified operating policies using associated operating rule curves. These define the desired storage volumes, water levels and releases at any time as a function of current water level, the time of the year, demand for water, and losses and gains. The irrigation module may be used to simulate agricultural water use (Riegels et al., 2011). Crop water requirements are calculated based on meteorological data and user-specified crop information such as crop coefficients and growth stage lengths. Soil water storage and uptake of water from soil are also modelled based on the FAO-56 methodology (FAO, 1998). Crop yields as a function of water use are modelled according to FAO-33 methodology (FAO, 1979), which links yields to cumulative water supply over the growing season. These capabilities make MIKE HYDRO well-suited not only for regional scale assessments of the impacts of climate change on regional water resources but also for subsequent assessment of regional scale climate adaptation options.

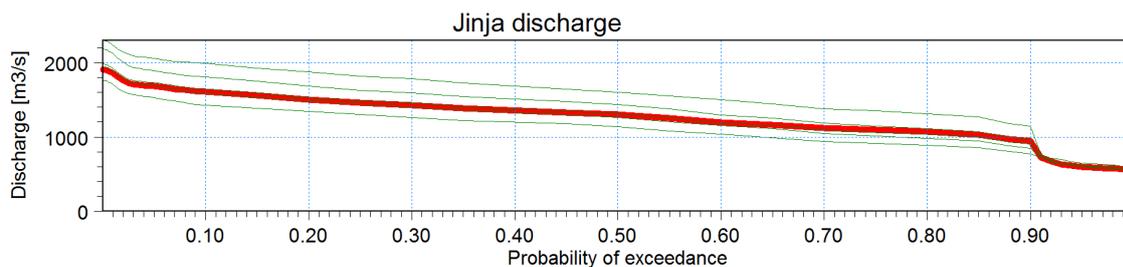
#### **4. PRELIMINARY RESULTS**

The regional hydrological model has been developed and calibrated against available discharge data within the period 1960 to 1980. This period of twenty-one years is assumed in this analysis to be representative of the variability for the reference period (1961-1990). The MIKE HYDRO model was then run using bias-corrected values for rainfall and PET over the same period. All other factors such as the operation and operation strategies of the reservoirs, the extractions for irrigation, etc. were kept fixed. The resulting changes are therefore solely as a result of projected changes in the climate.



**Figure 5.** Projected changes in the average monthly flows for 2020-2049 for the Jinja station. The solid (red) line shows the baseline levels (1961-1990) and the thin green lines show the variability among the RCM ensemble members.

Figures 5 and 6 present some preliminary results for the Jinja station that illustrate the type of assessment being carried out. The Jinja station is located at the outlet of Lake Victoria. It is an important control point with the Owen Falls dam located just downstream. The releases follow the so-called “Agreed Curve” to provide releases that resemble the natural outflows from the lake prior to its construction (Kite, 1982). One of the key features that determine the hydrology of the lake is the high contribution (85%) of rainfall directly over the lake to total lake inflow. This suggests that lake levels and the long-term outflow will be highly sensitive to climatic change. The operational policies of the Kiira and Nalubaale hydropower stations at Jinja control the outflow from the lake and attenuate seasonal and annual variability in lake inflows. The flow projections developed here indicate reductions in the flows for the near future (2020-2049) but with different magnitudes among the 5 ensemble members (Figure 5). For the far future (2070-2099) both increasing and decreasing trends are seen (Figure 6). More detailed analyses of these results are being carried out throughout the basin.



**Figure 6.** Projected changes in the flow duration curves for 2070-2099 (right) for the Jinja station. The solid (red) line shows the baseline levels (1961-1990) and the thin green lines show the variability among the RCM ensemble members.

## 5. CONCLUSIONS

A regional scale modelling framework has been developed to address the need for regional scale tools and information that can support and inform decision-making for large trans-boundary river basins like the Nile. The framework incorporates the state of the art Perturbed Physics Ensemble approach for climate change modelling and appropriate hydrological modelling using MIKE HYDRO. As a result the framework can provide an assessment of climate change impacts, an indication of the uncertainties and can be

used for regional scale adaptation. This framework is currently being applied to an assessment of the effects of climate change on extreme flows and water scarcity as part of the project “Adapting to climate change induced water stress in the Nile River Basin”.

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