

## **Significance of Past Climatic Records in Terrestrial Sediments for Assessing Current and Future Conditions**

**Giday WoldeGabriel  
Earth Environmental Sciences Division  
Los Alamos National Laboratory  
Los Alamos, NM 87545 USA**

Since the 1970s, the Nile River Basin has been subjected to multiple catastrophic drought and flooding conditions that greatly impacted millions of people and the environment. With increased population and degraded ecological conditions, there is a greater need today to learn more about paleoclimatic records in order to evaluate current and future climatic changes and to mitigate their potential impacts on Nile Basin communities and the environment they live in. Pleistocene sediments deposited in rift valleys, lakes, and other depositional settings within the Nile River drainage system preserve robust paleoclimatic and paleohydrologic records. In addition to past climatic and hydrologic archives, these sedimentary deposits provide information about variations in sediment supply, types of sediments, sedimentation rates, and the tectonic history of the depositional environments. In the Nile drainage basin, natural forces related to climatic changes and tectonic uplift mostly control sediment supply. However, anthropogenic effects (e.g., deforestation and primitive farming practices) in the last several centuries have also greatly contributed to the amount of sediment load in rivers mostly from the upper riparian highlands.

Given the widespread occurrences of long-lived, rift- and plateau-bound lakes and other depositional environments (e.g., swamps and wetlands and volcanic depressions) throughout the Nile River drainage system, it is imperative to investigate and temporally constrain the nature and impacts of past climate and climate-induced hydrological changes and the recent dramatic anthropogenic effects in the basin. The latest international drilling project in Lake Malawi is a testimony to the importance of terrestrial lake sediments in the study of continuous records of past climate change in the southern tropics of East Africa (Johnson et al., 2005). However, low-cost small-scale shallow drilling of lake sediments could also provide equally important data relevant for investigating and documenting past local and regional climatic and environmental conditions. For example, excellent core recoveries from recent exploratory shallow (80 m) drilling within the dry floor of the 1.2 Ma Valles caldera in the southwestern United States penetrated volcanoclastic mud, silts, silty clays, gravel, and thin layers of interbedded basal late Pleistocene (0.55 Ma) primary and reworked ash layers (Fawcett et al., 2007; WoldeGabriel et al., 2007). Five glacial and interglacial cycles of late Pleistocene age (0.40-0.52 Ma) that are consistent with climatic records reported from Lake Baikal, Antarctica, and marine sediments were identified (Fawcett et al., 2007). Work is in progress to determine the sedimentological, volcanic, and climatic records in the shallow core samples.

Paleoclimatic and paleohydrological investigations of a shallow core (10.6 m) from Lake Albert, a rift-bound lake in northwestern Uganda indicate at least three periods of reduced

inflow to the Nile in the late Pleistocene (30,000 years) because of drier conditions (Beuning et al., 1997). Sediments from two shallow lakes in Ethiopia outside but close to the Nile River drainage divide also provide information about Holocene climatic conditions in eastern Africa. An investigation of a shallow (~16 m) core from a lake located above 3000 m in the southeastern highlands (Bale Mountains) of Ethiopia revealed the presence of a retreating high-altitude glacier at about 17,000 years ago with ice melting ending between 12,600 and 11,800 years (Tiercelin et al., 2007, in press). A similar study of a shallow core (12.6 m) from a rift-bound saline-alkaline lake indicated a glacial-interglacial transition at about 12,700-12,000 calibrated years before present (Chalié and Gasse, 2002). This observation is temporally consistent with glacier melting and retreating reported from lake sediments in the nearby Bale Mountains located to the east of the rift floor (Tiercelin et al., 2007, in press). The lake sediments from the rift-bound Lake Abiyata also indicate early to middle Holocene wet episode (12,000-5,400 calibrated years before present) in the region (Chalié and Gasse, 2002).

Despite different elevations and geographic locations, results from the three shallow cores of lake sediments from eastern Africa provide consistent local and regional climatic records. Similar studies of shallow sedimentary cores from Lake Tana in Ethiopia, the Lake region of eastern central Africa, the Sudd in southern Sudan, the Nile Delta, and other depocenters in between could provide more detailed and more complete basin-wide paleoclimatic and paleohydrological data for the Nile River. Such basin-wide effort could engender broader cooperation among concerned scientists of the Nile River Basin and their colleagues from the developed world.

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## Estimating environmental flow requirements downstream of the Chara Chara weir on the Abay (Blue Nile) River

Matthew P. McCartney<sup>1</sup>, Abeyu S.Yilma<sup>2</sup> and Yilma Seleshi<sup>3</sup>

<sup>1</sup> International Water Management Institute, P.O. Box 5689, Addis Ababa, Ethiopia.

[m.mccartney@cgiar.org](mailto:m.mccartney@cgiar.org)

<sup>2</sup>P.O.Box 31769 Addis Ababa, Ethiopia., [abiyushif@yahoo.com](mailto:abiyushif@yahoo.com)

<sup>3</sup> Department of Civil Engineering, University of Addis Ababa, P.O. Box 150241 Addis Ababa, Ethiopia, [yilmash@ceng.aau.edu.et](mailto:yilmash@ceng.aau.edu.et)

### Abstract

In the last decade flow in the Abay River (i.e., the Ethiopian Blue Nile) has been regulated by operation of the Chara Chara weir, located at the outlet of Lake Tana. This has resulted in increased dry season and reduced wet season flows. However, the most conspicuous impact, caused by diversions to the Tis Abay hydropower station (situated 38km downstream of the weir) has been significantly reduced flows over the Tis Issat Falls, throughout the year. This paper presents the findings of a hydrological study conducted to estimate environmental flows (i.e., the flows required to maintain a river in a specified ecological condition) downstream of the Chara Chara weir. The *desktop reserve model* was used to determine both high and low flow requirements in the reach immediately upstream of the Falls. The results indicate that to maintain the basic ecological functioning of the reach requires an average annual allocation of 1,198 Mm<sup>3</sup> (i.e. equivalent to 30% of the mean annual flow) and the absolute minimum mean monthly flow should not be less than approximately 5.7 m<sup>3</sup>s<sup>-1</sup>. These estimates make no allowance for maintaining the aesthetic quality of the Falls, which are popular with tourists. The study demonstrated that, in the absence of ecological information, hydrological indices can be used to provide a first estimate of environmental water requirements. However, to ensure proper management, much greater understanding of the relationships between flow and the ecological condition of the riverine ecosystem is needed.

**ASSESSMENT OF CLIMATE CHANGE IMPACTS ON THE HYDROLOGY OF GILGEL ABBAY  
CATCHMENT IN LAKE TANA BASIN, ETHIOPIA**

Abdo K. S.<sup>a</sup>, Rientjes, T.H.M.<sup>b</sup> and Gieske, A. S. M.<sup>b</sup>

<sup>a</sup>SNNPR Water Resources Development Bureau, Awassa, P.O.Box 925, Ethiopia.

E-mail: [abdokedir@yahoo.com](mailto:abdokedir@yahoo.com)

<sup>b</sup>Department of Water resources, ITC, P.O.Box 6, 7500AA, Enschede, The Netherlands.

**Abstract:** Climate scenarios differ substantially due to uncertainties with regard to climate forcing caused by greenhouse emissions, uncertainties caused by imperfect representation of the process in the models and uncertainties with regard to initial condition. The General Circulation Models (GCMs) which are considered as the most advance tools for estimating future climate change scenarios operate on a coarse scale. However, the climate impact studies in hydrology often require climate change information at fine spatial scale. Therefore the output from a GCM has to be downscaled to obtain information relevant to hydrological studies.

This research presents the results of a study on downscaling large scale atmospheric variables simulated with General Circulation Models (GCMs) to meteorological variables at local scale in order to investigate the hydrological impact of possible future climate change in Gilgel Abbay catchment (Ethiopia). Statistical DownScaling Model (SDSM) was employed to convert the GCM output into daily meteorological variables appropriate for hydrological impact studies. The meteorological variables (minimum temperature, maximum temperature and precipitation) downscaled from SDSM were used as input to the HBV hydrological model which was calibrated ( $R^2=0.86$ ) and validated ( $R^2=0.76$ ) with historical data to investigate the possible impact of climate change in the catchment. The results obtained from this investigation indicate that there is significant variation in the seasonal and monthly flow. In the main rainy season (June-September) the runoff will be reduced by 12% in the 2080s. The result from synthetic (incremental) scenario also indicates that the catchment is sensitive to climate change. As much as 33% of the seasonal and annual runoff will be reduced if an

increment of 2°C in temperature and reduction of 20% rainfall occur simultaneously in the catchment.

**Key words:** Climate change, GCM, HBV, SDSM

# **BLUE NILE BASIN HYDROLOGY RELATIONSHIP TO CLIMATIC INDICES**

Wossenu Abteu<sup>1</sup>, Assefa M. Melesse<sup>2</sup> and Tibebe Dessaiegne<sup>3</sup>

<sup>1</sup>Principal Engineer, South Florida Water Management District, West Palm Beach, USA;  
email:wabtew@sfwmd.gov

<sup>2</sup>Assistant Professor, Department of Environmental Studies, Florida International  
University

<sup>3</sup>Senior Engineer, BEM Systems

## **ABSTRACT**

Climatic teleconnections to regional rainfall and stream flows have been correlated and respective predictions have become part of water management decision in regions such as South Florida in the United States. As changes in the climate is expected to have dramatic changes in temperature and precipitation, the ability to predict and make water resources management decisions is more critical than ever. For some parts of the world, these hydrologic changes may present major challenges to continue to provide for human water needs while balancing concerns about ecological integrity. Studies have shown that climatic indices associated with the prevailing climate have a very strong correlation to regional hydrology. Climatic teleconnections to the Blue Nile River Basin, Ethiopia, hydrology was evaluated using spatial average basin rainfall and Blue Nile flows at Bahir Dar. The El Niño Southern Oscillation index (ENSO) relationship using sea surface temperature (SST) anomalies in region Niño 3.4 and variation in air pressure between the western and eastern tropical pacific was used for analysis. The analysis indicates that the Blue Nile Basin rainfall and flows are connected to the ENSO index. High rainfall and high flows are likely to occur during La Niña years and dry years are likely to occur during El Niño years at a confidence level of 90 to 95 percent. Extreme dry and wet years are very likely to correspond with ENSO event as given above. The great Ethiopian famine of 1888-1892 corresponds to one of the strongest El Niño years, 1888. The recent drought years of 1965, 1972, 1983, 1987 and 1997 in Ethiopia

correspond to strong El Niño years. In this paper a new approach is proposed on how to classify the strength of ENSO events. A cumulative SST index value  $\geq 5$  and cumulative southern oscillation index value of  $\leq -7$  indicate strong El Niño. A cumulative SST index value of  $\leq -5$  and cumulative southern oscillation index of  $\geq 7$  indicate strong La Niña.

Key words: Blue Nile River, teleconnections, El Niño, ENSO, La Niña, climatic indices

# ANALYSIS OF HYDROLOGY AND WATER RESOURCES OF THE UPPER NILE RIVER BASIN UNDER CLIMATE CHANGE

**Ungtae Kim and Jagath Kaluarachchi**

College of Engineering  
Utah State University  
Logan, UT 84322-4100  
USA

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The work conducted at Utah State University (USU) included the evaluation of climate change impacts on both hydrologic regimes and water resources systems of the upper Blue Nile River Basin in Ethiopia where hydrologic data are limited. The downstream countries of the Nile River Basin are sensitive to the variability of runoff from the study area. Climate change affects water availability of the Nile Basin and the situation will worsen with increasing water demands from various sectors. To analyze and evaluate the future changes in hydrology and water resources of the study area, data-parsimonious, yet reliable, methodologies and models are required. Typical climate change impact studies compare the simulation results under future climate change scenarios with those under a baseline climate scenario that represents current climate conditions. High uncertainty is normally expected in climate change studies due to imperfect data and conceptualization.

This work presents four major steps for analyzing climate change impacts on hydrology and water resources: First task is the construction of the baseline climate scenario. Accurate reproduction of current climatic conditions (typically, 1961-1990) is a key to this step. The conditional generation method is proposed for this purpose. The second task is the construction of the future climate change scenarios. The outcomes of general circulation models (GCMs) are generally used for this step. This study uses six GCMs' outcomes for the 2050s to explore a range of predictions due to inter-model differences. These outcomes are weighted to provide a plausible change. Third task is the simulation of runoff using the proposed hydrologic model under different climate scenarios. Model evaluation and parameter regionalization for ungauged basins is an important task given the limited data and information available. The final step integrates the results produced from hydrologic modeling and suggests several indices to evaluate climate change impacts on hydrology and water resources. This research work presents hydrologic sensitivity to climate change and suggests the potential changes in drought, flow regimes, and performance (reliability, resiliency, and vulnerability) of water resources for the 2050s. The impacts of dam operations for hydropower generation under climate change scenarios on downstream countries are also assessed.

## **Contact Information**

Prof. Jagath Kaluarachchi  
Associate Dean  
College of Engineering  
Utah State University  
Logan, UT 84322-4100  
[jkalu@engineering.usu.edu](mailto:jkalu@engineering.usu.edu) Tel: (435) 797-3918

## Climate change predictions for East Africa – certainty, uncertainty, and recommendations

G. L. Geernaert  
Los Alamos National Laboratory

### EXTENDED ABSTRACT:

During “average” years, the Nile River basin drains about 3.3 million km<sup>2</sup> terrain that includes 81,500 km<sup>2</sup> lakes and 70,000 km<sup>2</sup> swamps in the 10 riparian nations of Burundi, DR Congo, Egypt, Eritrea, Ethiopia, Kenya, Rwanda, Sudan, Tanzania, and Uganda. The mean annual rainfall is estimated at 2,000 billion m<sup>3</sup>, resulting in an annual flow of about 84 billion m<sup>3</sup> at Aswan Dam in southern Egypt. Very little Nile River water reaches the Mediterranean Sea; and there is tremendous interannual variability in rainfall amounts.

Interannual variability is enormous. In most regions of the Nile Basin, the typical interannual rainfall variability is of order 50%; compounded with sequential dry years, the available water for agriculture, energy, and other activities is slowly diminishing and with a large interannual variability.

Climate predictions for East Africa mirror most of the rest of the world, i.e., a general warming of up to 2C in 2050 and by 5C in 2100. The warming will not be homogeneously distributed; e.g., western parts of Ethiopia are expected to warm more rapidly than the eastern part of Ethiopia; and both Sudan and Egypt are likely to experience a warming of order 2C by 2050. For precipitation, most models suggest that Sudan and northern Ethiopia will experience severe drying; these precipitation predictions, however, are based on tremendous uncertainty. Since water supplies represent the ultimate indicator of regional stability, we will attempt in this presentation to explore the dynamics governing East African precipitation variability, based on a combination of climate predictions and future changes in population pressure on water resources.

Precipitation in the horn of Africa is governed in large part by the interconnectivity of the dynamics related meteorological phenomena, e.g.:

- (a) the Somali jet and sea surface temperature patterns, that in turn exhibit an ENSO correlation;
- (b) the Mascarene High Pressure system over the Indian Ocean, that in turn exhibits an ENSO correlation;
- (c) The African Easterly Jet, with origins in tropical southeast Asia;
- (d) the South Atlantic High Pressure system (St. Helena High); and
- (e) midlatitude low pressure systems that sweep towards tropical Africa.

The challenge is to build conceptual models of the drivers that affect future climate states in east Africa, e.g., ENSO, Somali jet, etc. Once the conceptual models are collectively tested in GCMs of sufficient spatial resolution will the community be capable of refining more certain statements of the future climate and impact on water resources.