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   c. University of Minnesota (UMN)  
   d. Columbia University (Columbia)  
   e. Stanford University (Stanford)  
   f. University of Washington (UW)  
    g. Georgia Institute of Technology (Georgia Tech)  
     h. University of Illinois at Urbana-Champaign (UIUC)  
    i. University of Texas at Austin (UT)  
    j. University of California, Santa Barbara (UCSB)  
    k. University of Colorado at Boulder (UCB)  
    l. University of Michigan (UM)  
    m. University of Rochester (UR)  
    n. University of Washington, Seattle (UWS)  
    o. University of California, Davis (UCD)  
    p. University of California, Santa Cruz (UCSC)  
    q. University of California, Riverside (UCR)  
    r. University of California, Los Angeles (UCLA)  
    s. University of California, Irvine (UCI)  
    t. University of California, San Diego (UCSD)  
    u. University of California, Berkeley (UCB)  
    v. University of Southern California (USC)  
    w. University of Texas at Austin (UT)  
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    x. University of California, Los Angeles (UCLA)  
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   z. University of Southern California (USC)  
   **Total:** 62
1. Decision Making Activity – Description

We propose to develop a Decision Support System (DSS) aimed at optimizing reservoir operations for hydropower production in Africa. The DSS will allow hydropower schedulers and other water resource managers to develop reliable seasonal (30 – 180 day) reservoir planning that will guide the reservoir operation. Optimal reservoir operations ensure maximum energy production efficiency as well as continuous energy production during both wet and dry periods, and minimize sudden releases and loss of lives. The main components of the proposed DSS are shown in Fig. 1.

Figure 1. The main components of the proposed DSS for hydropower reservoir operation.

Africa provides an excellent opportunity to advance the usability of satellite remote sensing products for optimal reservoir operation for hydropower production for a number of reasons. First, Africa is currently experiencing a proliferation of new hydropower dam development, with several more in the planning stages. Just a few months ago, President Obama announced the “Power Africa” Initiative to double power supply in Sub-Saharan Africa, mainly Ethiopia, Nigeria, Tanzania, Kenya, Ghana, and Liberia. Second, reliable DSS has substantial and immediate economic and societal benefits since existing hydropower systems in Africa are performing far below their optimal potential, in some cases as low as 30% of the design capacity. Ineffective water resource management can also lead to increased regional suffering. In 2012, water released from the Lagdo reservoir dam located in northern Cameroon flooded areas around the dam including Adamawa State in Nigeria, the flooding resulted in over 10 deaths and left more than 10,000 homes submerged for more than two weeks. Third, satellite remote sensing data is most beneficial to Africa because satellite-based estimates (instead of ground-based observations) are, and will probably be, the only available data sources for most hydrologic variables for the foreseeable future.

We focus on the following 10 major hydropower systems in East and West Africa (see Table 1). Figure 2 shows the location of some of the hydropower systems. These sites represent the diverse hydro-climatic regimes of Africa and the different Decision Support Systems being used in those regions.
Table 1. Features of the Hydropower Systems

<table>
<thead>
<tr>
<th>Reservoir Features</th>
<th>Niger River Basin, Nigeria, Cameroon</th>
<th>Gibe River Basin, Ethiopia</th>
<th>Pangani, Tanzania</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kainji, Nigeria</td>
<td>Gibe I</td>
<td>Nyumba ya Mungu</td>
</tr>
<tr>
<td></td>
<td>Jebba, Nigeria</td>
<td>Gibe II</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Shiroro, Nigeria</td>
<td>Gibe III</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lagdo, Cameroon</td>
<td>Gibe IV</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gibe V</td>
<td></td>
</tr>
<tr>
<td>First year of</td>
<td>1968</td>
<td>2004</td>
<td>2016</td>
</tr>
<tr>
<td>operation</td>
<td>1984</td>
<td>2010</td>
<td>2016</td>
</tr>
<tr>
<td>Inst. Capacity, (MW)</td>
<td>760</td>
<td>210</td>
<td>662</td>
</tr>
<tr>
<td>Max. Stor. (Mm³)</td>
<td>12,000</td>
<td>840</td>
<td>600</td>
</tr>
</tbody>
</table>

The Gibe basin is a major hydropower development site in Ethiopia. It accounts for more than 50% of the Ethiopia’s power production, and has been and will continue to be the main supplier of electricity for Ethiopia and neighboring countries (Djibouti, Sudan and Kenya). The Niger River is the third longest river in Africa, passing through ten African countries. There are four major hydropower reservoirs in Niger: Kanji, Jebba and Shiroro (all three Nigeria) and Lagdo (Cameroon). The Pangani river basin in Tanzania consists of cascades of three hydropower plants with one reservoir called Nyumba ya Mungu. The Pangani basin is among two of the main hydropower development sites in Tanzania, accounting for 17% of the country’s power production.

As shown in Table 2, the current decision making practices do not use realistic seasonal streamflow forecasts and do not optimize the joint operation of cascades of reservoirs, leading to sub-optimal decisions and low efficiency of energy production. It is clear that a small improvement in operation for a system of such size will translate into enormous benefits. There is an urgent need to develop a DSS that will take full advantage of inflow forecasts.
By way of improving the seasonal (80-120 day) climate and hydrologic forecasts, incorporating optimization tools in a user–friendly Graphical User Interface (GUI), and fully automating the process, the proposed DSS has potential to substantially improve hydropower reservoir operation leading to maximum and sustained energy production and reliable flood control. For maximum impact, we are collaborating with key regional and continental organizations that have mandate to develop and disseminate climate and water resource forecasts across Africa and manage several hydropower reservoirs.

Table 2. Decision making practices of the hydropower systems

<table>
<thead>
<tr>
<th>Site</th>
<th>Reservoir planning/operation decision making practice</th>
<th>Limitations of the current decision making practice</th>
<th>Decision Maker</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gibe I, II, III, IV, and V</td>
<td>For a particular season the total amount of seasonal water at the reservoirs for the current year is expected to be the same as the total recorded for the prior year</td>
<td>Does not use any climate forecast information, and thus, is subject to large errors given the substantial large inter-annual rainfall variability Does not use optimal operation model for joint operation of cascade of reservoirs</td>
<td>Ethiopian Electric Power Corporation (EEPCO)</td>
</tr>
<tr>
<td>Kanji, Jebba; Shiroro, Lagdo</td>
<td>The streamflow rate recorded at a gauging station further upstream of the reservoir (with travel time of 2 months from station to reservoir) is routed through MIKE BASIN hydrologic model</td>
<td>Ignores rainfall over last 2 months Does not use optimal operation model for joint operation of cascade of reservoirs</td>
<td>Niger Basin Authority (NBA) in collaboration with local companies in each country</td>
</tr>
<tr>
<td>Nyumba ya Mungu</td>
<td>For a particular season the total amount of seasonal water at the reservoirs for the current year is expected to be the same as the total recorded for the prior year</td>
<td>Does not use any climate forecast information, and thus, is subject to large errors given the substantial large inter-annual rainfall variability</td>
<td>Tanzania Electric Company (TANESCO)</td>
</tr>
</tbody>
</table>

2. Earth Science Products and Results

Table 3 provides a list of earth science products and data to be used in the proposed DSS. The current decision-making practices in the study region do not utilize the vast majority of existing datasets that are proven to significantly improve the quality of climatic and hydrologic forecasts and subsequent decision making. The proposed DSS offers an excellent opportunity to infuse earth science observations and models into operational hydropower reservoir decisions.

Table 3. Earth science data and models to be used in the DSS.

<table>
<thead>
<tr>
<th>Data/model</th>
<th>Product or Model Type</th>
<th>Product or Model Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DATA</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rainfall</td>
<td>TMPA, CMORPH, and emerging GPM</td>
<td>NASA</td>
</tr>
<tr>
<td>Soil Moisture</td>
<td>ASCAT, AMSR2, SMOS</td>
<td>NASA, NESDIS, ESA</td>
</tr>
<tr>
<td>Evaporation, Temperature</td>
<td>MODIS, Landsat</td>
<td>NASA</td>
</tr>
<tr>
<td>Vegetation Index</td>
<td>MODIS</td>
<td>NASA</td>
</tr>
<tr>
<td>Reservoir Level</td>
<td>JASON, ENVISAT</td>
<td>NASA, ESA</td>
</tr>
<tr>
<td><strong>MODEL</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MIKE BASIN</td>
<td>Streamflow</td>
<td>DHI</td>
</tr>
<tr>
<td>MERRA</td>
<td>Atmospheric reanalysis</td>
<td>NASA</td>
</tr>
<tr>
<td>CFS</td>
<td>Ensemble climate forecasts</td>
<td>NOAA</td>
</tr>
<tr>
<td>NMME</td>
<td>North American Multi-Model Ensemble</td>
<td>NOAA and Canada CMC</td>
</tr>
</tbody>
</table>
Satellite rainfall data are particularly useful for calibrating climate forecasts and driving hydrologic simulations. Previously we have extensively evaluated the accuracy of rainfall products in Africa (e.g., Bitew and Gebremichael 2010; Hirpa et al. 2010; Romilly and Gebremichael 2011; Bitew and Gebremichael 2011a, b; Bitew et al. 2012). In a recent effort (Gebremichael et al. 2014a), we established the first international GPM GV site in Africa, equipping the complex-terrain site with high-quality ground-based rainfall observational networks. Our results indicate that TMPA-RT and CMORPH satellite products have the potential to generate reliable information on rainfall, but require careful calibration with appropriate rain gauge data particularly in low-elevation areas. Furthermore, our results indicate that the TMPA-RP product (which combines satellite data with GTS rain gauge datasets) has lower performance than satellite-only products. This suggests that the TMPA-RP algorithm’s bias-adjustment technique does not work properly in complex-terrain regions subject to varying satellite-rainfall bias characteristics in low- and high-elevation areas and a sparse rain gauge network (see Gebremichael et al. 2014a,b for detailed information).

Our recent study on assimilation of surface and root zone soil moisture from satellite-based passive and active microwave sensors demonstrated that a river discharge enhancement can be achieved by assimilating the remotely sensed soil moisture into a hydrologic model (Hirpa et al. 2014). Reservoir evaporation is a key variable in estimating and forecasting reservoir water storage. Recently, we developed a technique that combines data from a polar-orbiting satellite (MODIS/Terra) and a geostationary satellite (SEVIRI/MSG) to estimate daily evapotranspiration over Africa (Sun et al. 2012). USDA routinely generates Lake Height variation data for Kainji and several other lakes around the world using satellite altimetry data, and the study conducted by Salami and Nnadi (2012), among others, indicate that the satellite altimetry data offer great potential for Kainji Lake level monitoring. The altimetry data would provide updates to current conditions for the reservoir water storage estimation and optimization DSS.

These data and other emerging data from new missions (e.g., GPM) products will be used in the proposed research. The inclusion of these remote sensing data will markedly improve the quality of climate and hydrologic forecasts. Furthermore, the near-real-time availability of the data products makes them suitable for the DSS, where ground-based data gathering and quality assurance are challenging. The project team members have demonstrable experience and a keen interest in advancing the use of NASA remote sensing products in water resource applications.

3. Project Elements

3.1 Objectives

The objective of this proposal is to utilize remote sensing data and seasonal climate forecasts in a Decision Support System (DSS) to optimize reservoir operation for hydropower production. The key features of the DSS include: improved seasonal (30-180 day) climate and hydrologic forecasts, employment of reservoir operation optimization tools and methods, and fully automated software with GUI. These are reflected in the DSS components: (1) Climate System – for accessing, calibrating against remote sensing data, and integrating climate forecasts; (2) Hydrologic and Water Resource System – for integrating climate forecasts, remote-sensing hydrological products (rainfall, soil moisture, evapotranspiration, and reservoir levels), and
Optimizing Reservoir Operations for Hydropower Production in Africa

observations (streamflow, reservoir levels, flow from upstream reservoirs) into a hydrologic model; and (3) Optimization System - tools and methods for selecting the most optimal reservoir operations to maximize energy production. The three components of the DSS, working together, constitute an end-to-end information processing system and a closed feedback loop that takes climate forecasts and remote sensing observations as inputs and produces “actionable” knowledge necessary for optimal hydropower multi-reservoir operation. Tremendous progresses have been made in the last decade towards the development of each of the major components of the DSS. In this project, these components will be systematically connected to help decision makers in optimal reservoir operating decisions.

**Climate System – NCAR:** Drs. Hopson and Hacker have conducted extensive research in the context of ensemble climate and weather forecast generation and data assimilation, with applications over Africa and elsewhere. Hopson has generated statistically-based seasonal forecasts of the West African Monsoon (Broman et al. 2014), and developed approaches to utilize dynamical ensemble climate models for Mediterranean precipitation forecasting (Wu et al. 2012). Hopson has also utilized ensemble season and medium-range weather forecasts to generate forecasting systems of meningitis outbreaks (Pandya et al. 2014) and river flow (Hopson and Webster 2010; Webster et al. 2010). Hacker developed skillful approaches to data assimilate hydrologic surface layer parameters to improve atmospheric forecasts (Hacker and Rostkier-Edelstein 2007; Hacker 2010; Hacker and Angevine 2013). They will contribute their proven expertise, models, and software in the areas of ensemble climate forecasting, data assimilation, and interfacing with hydrologic modeling.

**Hydrologic and Water Resource System – UCLA:** Dr. Gebremichael has extensive experience in assessing the accuracy of satellite hydrological products mainly in Africa and elsewhere (e.g., Hirpa et al. 2010; Zeweldi et al. 2010; Romilly and Gebremichael 2011, Sun et al. 2013), pioneering new models that characterize errors in satellite rainfall estimates (e.g., Yang and Gebremichael 2009; Gebremichael et al. 2011; Woody et al. 2014), identifying the utility and potential of satellite products for hydrologic modeling (e.g., Zeweldi et al. 2011; Bitew and Gebremichael 2011a, b; Bitew et al. 2012, Hirpa et al. 2013), and training a large number of African researchers in the use of satellite remote sensing data for water resource applications (e.g., Atkinson and Gebremichael 2012). He will contribute his proven methods of using satellite products for streamflow simulations, and statistical models for adjusting the streamflow simulations. Dr. G. Robert Brakenridge, a Director of the Dartmouth Flood Observatory at University of Colorado in Boulder, has conducted extensive research in estimating lake height variations around the world using satellite data. Dr. Brakenridge will contribute his proven expertise of developing and providing real-time and historic estimates of changes in reservoir levels calculated using NASA remotely-sensed data.

**Optimization System - UCLA:** Dr. Yeh has developed large-scale optimization models that utilize systems analysis techniques, such as linear programming, dynamic programming and nonlinear programming, to plan, manage, and operate several of the nation’s large-scale hydrosystems, including the California Central Valley Project (CVP) (Becker and Yeh 1974; Becker et al. 1976; Yeh et al. 1979). His optimization models have been adopted throughout the world, most notably in Brazil, Korea, Taiwan, and the People's Republic of China (Yeh et al. 1992; Barros et al. 2003; Zambon et al. 2012). Most recently, Dr. Yeh assisted the People's Republic of China in
the development of an optimization model for hydro unit commitment for the Three Gorges Project (TGP) (Li et al. 2013). TGP is the world largest hydropower plant with an installed capacity of 22,500 MW. Dr. Yeh is very familiar with the needs of the end-users and decision-making organizations from his past experience in working with water resources agencies in the US and around the world. He will contribute to the development of the hydropower optimization model as well as the overall DSS.

We will examine the benefits of the proposed DSS (improved seasonal climate forecasts and hydrologic and water resource forecasts, and utilization of optimization models) with respect to the currently used DSS. We will identify a range of time-scales where improvements can be made in climate forecasting, water resource allocation, and power generation. The improvements could then be used by our collaborative partners (African Centre for Meteorological Applications for Development [ACMAD] and National Meteorological Agency of Ethiopia [NMA]) and those organizations participating in African regional seasonal outlook forums (annually sponsored by the World Meteorological Organization and ACMAD), and in river authority operational decision-making (Ethiopian Electric Power Corporation [EEPCO], Tanzania Electricity Company [TANESCO], and Niger Basin Authority [NBA]).

**Relevance to NASA and Solicitation**
Several aspects of the proposed work directly address the main themes of the solicitation requirements and are aligned with NASA’s Strategic Goals and Outcomes (specifically NASA Earth Science Objectives 2 and 7) as highlighted below. We propose to:

- work with key public and private river basin organizations and power supply companies (NBA, EEPCO, TANESCO) in Africa that are in charge of many hydropower systems including the ten systems considered in this study, and national, regional and continental organizations in charge of developing and disseminating climate and water-supply forecasts (ACMAD, NMA, NBA),
- enhance the ability of these organizations to use a number of earth system science observational capabilities (satellite rainfall, satellite soil moisture, satellite evapotranspiration, satellite vegetation index, and satellite reservoir level), and modeling capabilities (NASA’s MERRA, NOAA’s CFS, NOAA’s NMME, and DHI’s MIKE SHE hydrologic model) in order to respond effectively to water-related challenges (e.g., optimal reservoir operation for maximum energy production, sustained energy supply, flood control) that are difficult to address with the operational water management tools,
- improve upon seasonal forecast anomalies in water supply conditions (rainfall, streamflow, reservoir water storage) at seasonal weather forecasts at 30 – 180 day lead times for Africa currently available at our partner institutions: ACMAD, NMA, NBA, and
- integrate data and modeling systems into DSS, with a user-friendly GUI, to increase the adaptability of this state-of-the-art DSS to end users in Africa.

### 3.2 Methodology

The methodologies involved in each component of the DSS are discussed below.
(a) Climate System

The climate forecasting system of this proposal is designed to improve upon seasonal weather forecasts at 1-6 month lead times for East and West Africa currently available at our partner institutions: ACMAD, NMA, NBA). These improvements will stem from three facets: 1) integration of proven statistical climate forecast generation techniques developed by team members (Broman et al. 2014; Riddle and Wilks 2012; Diro et al. 2010) with multi-model state-of-the-art numerical weather prediction (NWP) produced ensemble seasonal forecasts (Kirtman et al. 2013; Saha et al. 2014); 2) further improvements will be achieved through provision of additional computational power and (currently bandwidth-limited) access to ACMAD of the full suite of NWP fields available at our NOAA-CPC partner institution (Co-I Collins) through a designated NCAR-housed server; 3) and through statistical tailoring of these climate forecasts for the specific hydrologic modeling applications designated in this proposal (Hopson and Webster 2010; Webster et al. 2010; Wu et al. 2012; Dutra et al. 2012).

NASA satellite data plays an important role in this piece of the overall DSS through the reliance of the seasonal forecasts on its calibration products. For rainfall, we propose to use the NASA TMPA-RT satellite-based rainfall estimation product. For all other surface weather variables (T, RH, ET, etc.), the NASA Modern –Era Retrospective Analysis for Research and Applications will be used (Rienecker et al. 2011).

Addressing facet 1), for both statistical and dynamical forecasts to have skill for this application, there must be persistent predictable connections with large-scale geophysical features that can be leveraged. For East Africa, the Madden Julien Oscillation, the Somali Jet formation and strength (which mediates an additional connection between Ethiopian summer rainfall and Indian monsoon strength (Bhatt 1989; Camberlin 1997; Riddle and Wilks 2012)), and sea surface temperatures over the Indian Ocean and the Pacific all significantly influence eastern African rainfall. Mainly because of the ENSO relationship, boreal fall (Oct-Nov) seasonal rainfall totals over Ethiopia can be relatively well predicted at a few months lead using statistical and NWP models (Korecha and Barnston, 2007; Diro et al. 2010; Dutra et al. 2012). For predicting West African monsoonal rainfall variability and limits on predictability, the location of the West African heating low (WAHL; Haarsma (2005)), mean sea-level pressure over the Sahara, and in situ soil moisture recycling all play a strong part in sustaining a strong West African Monsoon (Eltahir and Gong 1996; Haarsma 2005; Nieto et al. 2006). Focusing on the transition period between onset and retreat of the WAM, a recent study by Broman et al. (2014) has shown skillful seasonal statistical forecasts of regional moisture levels can be made out to three months in advance through connections to the large-scale geophysical controls (Figure 3), primarily from the WAHL strength and South Atlantic anticyclone.
Figure 3. Monsoon onset (15 May – 30 June) lagged correlation plots with significant global predictors in January for Gulf of Guinea regional moisture: (a) surface temperature, (b) mean sea level pressure, (c) 200hPa Zonal Winds, (d) 600hPa meridional winds. Correlations greater than 0.35 (less than -0.35) are significant at 95%, and correlations greater than 0.30 (less than -0.30) are significant at 90%.

Addressing facet 2), the designated NCAR-based server will allow ACMAD access to the full suite of current NOAA CFS (Saha et al. 2014) and North American Multi-Model Ensemble (NMME) ensemble forecasts, along with their associated seasonal hindcasts, available for 1982-2010 with a frequency of four runs per day. There is substantial evidence that use of multi-model ensembles improves the skill of seasonal prediction systems over single model ensembles (Krishnamurti et al. 2000; Weishheimer et al. 2009; Hagedorn et al. 2005; Doblas-Reyes et al. 2005; Palmer et al. 2004).

Addressing facet 3), techniques developed by Hopson and Webster (2010) and Webster et al. (2010) have shown the utility of tailoring ensemble seasonal climate forecasts for seasonal river flow forecasting applications. More recent work developed by Wu et al. (2012) used analogue approaches along with the NOAA CFS ensemble forecasts to meet Mediterranean water resource applications. Additional tailoring will be done on the ensemble climate forecasts to provide weather forcing sequences that preserve temporal and spatial covariances appropriate for driving basin models for seasonal streamflow prediction.

(b) Hydrologic and Water Resource System

This component of the DSS is aimed at using the available satellite remote sensing observations (rainfall, soil moisture, evapotranspiration, vegetation index and Leaf Area Index) in conjunction with the seasonal climate forecasts to simulate seasonal streamflow flowing into the reservoir. The simulated streamflow, the evaporation forecast and the initial satellite-observed reservoir level will then be used to forecast the seasonal water storage in the reservoir (Fig. 4). The hydrological model will be run in retrospective mode (past 30 – 180 day) to obtain the performance statistics of the streamflow simulations, and in forecasting mode (future 30 – 180 day) to simulate seasonal streamflow forecasts adjusted based on the performance statistics. To assess the accuracy of our approach, we will use historical datasets to perform runs in both “retrospective/training” and “forecasting” modes.
In retrospective mode, the hydrological model will be run with two different forcings: (1) climate forecasts, and (2) all available observations (mainly, satellite rainfall, satellite soil moisture, satellite vegetation index and Leaf Area Index, and any available ground-based observation). The satellite soil moisture data and any available streamflow measurements will be used in data assimilation framework, while the remaining datasets such as satellite rainfall will be used as model inputs. Our experience shows that the Ensemble Kalman Filter method is the most practically feasible and accurate approach in assimilating satellite soil moisture and available streamflow measurement into a hydrologic model for streamflow simulation (see, for example, Hirpa et al. 2014). We propose to use MIKE BASIN hydrologic model, the same model either currently used in reservoir planning decision for the hydropower systems in Niger or planned for use in the other hydropower systems. Using the same hydrologic model that our end-users use is the best way to ensure implementation of the proposed DSS. Our research group has extensive experience working with this model (e.g., Bitew and Gebremichael 2011a, b). By comparing the two streamflow simulations (i.e. (1) and (2) above), we will develop statistical model(s) to convert the less-reliable estimate (i.e. (1) above) to the more-reliable estimate (i.e. (2) above). We will explore the applicability of our new approach that uses an extreme value statistical model and a distributional transformation technique to transform a less reliable set of hydrological estimates to a more reliable set of estimates (Woody et al. 2014).

In forecast mode, the hydrologic model will be forced with climate forecasts. The resulting streamflow simulations will be transformed into (or adjusted to) a more-accurate streamflow simulations using the transformation method just described. The transformation methods (involving model parameters or non-parametric relationships) may vary from season to season, so caveat will be exercised to ensure appropriate transformation methods are applied to the streamflow simulations.

Figure 4. Hydrologic and water resource system illustrating the use of satellite remote sensing data products in improving reservoir inflow predictions

(c) Optimization System

Optimization of reservoir operation for hydropower production requires advanced scheduling of water releases through the turbines, accurate inflow forecasts that serve as input data, and an optimization model that utilizes forecast information to the best advantage (Yeh 1985). This implies frequent information updating and rapid transmittal to the system operator and consequent release policy re-optimization.
We propose the following nonlinear programming (NLP) formulation for hydropower optimization. The time periods considered will be either months or days. The objective function is minimizing loss of the stored potential energy (Becker and Yeh 1974; Barros et al. 2003):

\[
\min f = \sum_{i} \sum_{t} (c_i^p R'_{i,t} + c_i^n R''_{i,t})
\]

where \( R'_{i,t} \) = power release from reservoir \( i \) during time period \( t \), in cms (m\(^3\)/sec); \( R''_{i,t} \) = non-power release from reservoir \( i \) during time period \( t \) (cms); and \( c_i^p \) and \( c_i^n \) are the weighting coefficients for power release and non-power release (spill), respectively. To minimize the non-power release, a large value of \( c_i^n \) is assigned. The constraint set includes the following types: 1) Energy demand \( \sum_i \xi_{i,t} R'_{i,t} \geq d_t \), where \( \xi_{i,t} \) is the energy production function and \( d_t \) is the demand; 2) Turbine capacity; 3) Flow continuity; 4) Maximum storage variation; 5) Minimum and maximum (including flood control reservation) storages; 6) Minimum and maximum power releases; and 7) Bounds on non-power release.

The decision variables in the NLP model are \( S_{i,t} \) (storage), \( R'_{i,t} \) and \( R''_{i,t} \). The model is nonlinearly constrained with a nonlinear objective function. This is because the energy production function is a nonlinear function of storage as well as power and non-power releases. We will use either GAMS (2010) or LINDO (<http://www.lindo.com/>) to solve the formulated NLP problem. We can also consider other objective functions in consultation with the end users.

The monthly model and the daily model employ the same formulation. We will use the monthly model to optimize the monthly decision variables over six months (180 days) utilizing monthly inflow forecasts. The daily model optimizes the daily decision variables up to one month using the daily inflow forecasts. Outputs (ending storage vector) from the monthly model are used as inputs to the daily model, iterating and updating whenever new information on inflow forecasts and system state becomes available. Note that only results for the first time period are adopted for decision making. For each succeeding time period, as new information becomes available, the system is updated and re-optimized. This updating and re-optimizing procedure for a moving horizon is particularly suited for real-time operation (Becker and Yeh 1974; Barros et al. 2013).

(d) DSS Software

We will develop a DSS software that (1) automates the entire process (i.e. downloads data from the ftp sites, runs the models, applies statistical models) to produce results, (2) provides options to simulate the system with special operation rules defined by the user, (3) has a very powerful visualization tool, and (4) a Graphical User Interface (GUI) to manipulate the input data, run outputs, and generate maps, graphs and tables. The DSS software has the ability to connect to data services over the internet. The software can also be accessible from anywhere on the internet, either as a Java application or a browser-based web application. It may be restricted to specific users by IP address or login, as determined. The software can run on a standard desktop computer with any of the leading contemporary operating systems, Windows, Macintosh, and Linux performance, with the caveat that performance will be dependent on the network speed. The DSS software development will build from the previously-developed UCAR African Decision Information System ADIS (Fig. 5).
3.3 Transition Approach

Organizational/Management Approach

The end-state of the DSS will be an operational system (software) with models, databases and graphical user interface for direct use by end users involved in the planning and operation of hydropower reservoirs. The DSS will build directly on infrastructure such as MIKE BASIN hydrologic model currently used by users for hydropower reservoir operation decision making. By adding connections to NASA and non-NASA earth system science products, statistical and optimization models, and graphical user interface (visualization tools and user-driven user-friendly interface), the proposed project will substantially enhance the power and use of the existing tools, hence providing invaluable assistance to hydropower schedulers and water resource managers for increasing hydropower production. The software will be fully automated and easy to use – once the users specify their needs (e.g., seasonal climate forecast, seasonal reservoir water storage forecast, optimal seasonal reservoir planning for maximum energy production). The software will be designed to have the capability of completing the process from end-to-end (i.e. download NASA and other products, run the hydrologic model, and apply the statistical and optimization tools, and generate results).

In years 1-3, the DSS will be developed and tested on a dedicated computer server purchased as part of the Google project, for the purpose of supporting data access for ACMAD. This computer is housed at the NCAR campus in Boulder, Colorado, but cryptocard access has been established for ACMAD’s use. In year 4, the DSS will be transferred to the end users (EEPPO, National Meteorological Agency of Ethiopia, ACMAD, TANESCO, NBA), and will be operationally deployed and used by the decision makers.

Our transition plan includes technical support via (1) workshops and instruction sessions at the Regional Climate Outlook Forum for East and West Africa, (2) coaching and trainings as needed via various ways (U.S. researchers visiting the end-user organizations, end users visiting UCLA and NCAR, skype meetings), and (3) extensive web-based instructions provided through the DSS community workspace. We also plan to acquire more powerful dedicated servers for the DSS housed at the end-user organizations. Recently, PI Gebremichael acquired a powerful server...
from IBM as a donation to his capacity building project in Ethiopia, and plans to submit a similar request to IBM for this project. The software at NCAR’s dedicated server will also continue to work and get accessed by the end users, mainly to serve as a backup for the end users in case their server fails.

**Application Readiness Level (ARL)**

- The **Start-of-Project ARL Metric is 3** (Viability established),
- The **End-of-Project ARL Metric is 8** (Application Completed and Qualified, Functionally Proven).

The main components of the DSS have been tested and validated in independent studies conducted during the last decade (see Objectives Section). These components will be adapted, customized as necessary, to the Sub-Saharan African conditions. Eventually, these components will be systematically integrated in this project to form “one-stop” software that automatically does all the tasks starting from input data downloading to hydrologic model implementation to optimization. The state-of-the art software will make it easier for decision makers to make well-informed decisions without having to deal with the sophisticated processes underlying the computational results. Expected outcomes of this project include: (1) improved seasonal climate forecast, (2) improved seasonal streamflow forecast, (3) improved seasonal reservoir water storage forecast, (4) employment of optimization tool, and (5) fully-automated, end-to-end, user-friendly DSS software.

**Challenges and Risks**

Our end users and their collaborators have broader mandate to disseminate climate forecasts to stakeholders across Africa and manage several hydropower reservoirs. While this is a big benefit that is going to be gained from the proposed project, the successful implementation of the DSS for hydropower reservoirs outside of the ones included in this study could be challenging as it requires trained professionals who understand the DSS and are able to make appropriate adjustments to suit the DSS to other reservoirs. To address this challenge, we will (1) develop a users’ guide on “How to use the DSS and adapt it to other reservoirs”, (2) deliver training on this topic to relevant participants of the Regional Climate Outlook Forum, and (3) post the recorded training lectures and notes on the DSS community’s workspace for training and references.

**Issues Affecting Use of Earth Science Products**

Lack of reliable internet connection is generally an issue when dealing with any software run that requires the download of data from ftp sites. The issue won’t be that critical for our project given that our DSS will not be run that frequently (i.e. our results are on seasonal (30-180 day) timescales). Work is underway in both countries to substantially improve the internet connectivity, so we expect that the issue may not be significant once the DSS goes live. In case of lack of internet connectivity or local server failure, the DSS installed at NCAR can be used as an alternative solution until the problem is fixed.

4. **Anticipated Results**

The proposed project is built on the hypotheses that (1) improving the seasonal climate and
Optimizing Reservoir Operations for Hydropower Production in Africa

Optimizing reservoir operations for hydropower production in Africa requires three key steps: (1) improving hydrological forecasts through the use of earth system observations and models, (2) employing optimization tools, and (3) automating the process from end-to-end. These measures enable hydropower schedulers to make optimal reservoir operation decisions that maximize energy production and control floods effectively. Currently, reservoir operations are conducted without the use of advanced data like climate and hydrologic forecast information, scenario analysis tools, and optimization tools; instead, seasonal streamflow data from previous years or further upstream stations are used to guide decision-making. To achieve improved reservoir performances, integrating earth system models and observations into existing reservoir systems is necessary. The improvements include (1) better estimates of seasonal climate forecasts, (2) improved seasonal hydrologic forecasts, (3) tools to analyze the impact of various operations on energy production, and (4) optimization tools to identify the most optimal reservoir operation for maximizing hydropower production and minimizing sudden releases.

The anticipated results of this project are related to improving reservoir operation decisions for maximizing hydropower production and minimizing loss of life. Our analysis quantifies the impacts of the proposed DSS on hydropower generation. The overall system solution diagram of the project is shown in Fig. 6. The broader benefits include innovative applications of satellite remote sensing data for hydropower reservoir operations in regions with scarce and timely unavailable ground-based hydrological data.

5. Project Management

5.1 Management Approach and Structure

The project management structure will consist of Advisory Group and Research Groups. The Advisory Group, comprising user representatives (EEPCO, TANESCO, ACMAD, NMA, NBA) and US agencies with international mandates (USAID, USGS), will oversee the project. The advisory group will meet at least once every six months. The Research Groups will be responsible for different components of the Decision Support System. Each Research Group will define the technology, process, and knowledge required to gather data, develop models, and identify communication channels. Graduate students will assist with project implementation.
implementation. A “virtual community” website will be created to allow team members as well as other interested parties to test and use the latest versions of data and tool services as well as to submit comments. Annual participation at the African Regional Climate Outlook Forums is also planned to provide an excellent opportunity for the research group to share the project with participants drawn from all over Africa. Given the broad interests in the climate forecasts for various applications, it is anticipated that our climate forecast outputs will be used by other groups for various other applications.

5.2 Roles and Responsibilities of Team Members

The project will achieve its goals by connecting the components of the DSS. Each component will be led by a Research Group, described below.

The Climate System Group will develop the climate system component of the work. Group members and roles:
- Co-I Thomas Hopson (NCAR) will serve as a Group Leader
- Co-I Joshua Hacker (NCAR) will assist with the proposed work
- Co-I Andre Kamga Foamouhoue (ACMAD) will provide ACMAD’s climate forecasts, and test and use and disseminate our climate forecast products
- Co-I Diriba Korecha (NMA) will provide NMA’s climate forecast, and test and use and disseminate our climate forecast products

The Hydrology and Water Resource System Group will develop the hydrology and water resource system component of the work. Group members and roles:
- PI Mekonnen Gebremichael (UCLA) will serve as a Group Leader
- Co-I Brakenridge (University of Colorado, Boulder) will be responsible for providing real-time and historic estimates of changes in reservoir levels calculated using NASA remotely-sensed data.
- Co-Is, Mekuria Lemma (EEPCO), Philipo Patrick (TANESCO), and Henri-Claude Enoumba (NBA), will provide data on hydrology, reservoir operation, water storage, and energy production for the hydropower reservoirs in Gibe, Pangani, and Niger river basins, respectively.
- Co-Is Andre Kamga Foamouhoue (ACMAD) and Diriba Korecha (NMA) will provide in-situ meteorological observations

The Optimization System Group will develop the optimization algorithms for hydropower production. Group members and roles:
- Co-PI William Yeh (UCLA) will serve as a Group Leader
- Co-Is, Mekuria Lemma (EEPCO), Philipo Patrick (TANESCO), and Henri-Claude Enoumba (NBA), will provide data on reservoir operation, water storage, and energy production for the hydropower plants.

The DSS Software Development and Implementation Group will develop and implement the DSS at the end users’ organizations
- Co-I Thomas Hopson (NCAR), PI Mekonnen Gebremichael (UCLA) and Co-PI William Yeh (UCLA) will work together in the DSS software development and implementation.
Project coordination and Integration: The project management is based largely on the “System of systems” principles of GEOSS. The project will have clear deliverables from each Group Leader. The responsibility for overall coordination and for delivery of the function DSS will be that of the PI Mekonnen Gebremichael. Gebremichael has extensive experience in project management of international and multi-stakeholder research and educational activities. As a PI of a major USAID Grant “US-Ethiopia Collaborations in Sustainable Water Resources: Capacity Building in Research, Education and Outreach”, he has directed a program that established Ethiopia’s first water resource research institute, developed a number of graduate (MSc and PhD) degree programs in Water Resources in Ethiopia, and designed and executed a number of outreach programs to stakeholders.

Plan of Work: Years 1 and 2 will be devoted to the development of the DSS components and the software. Year 3 will be devoted to the integration of all the DSS components via the DSS software with GUI. Year 4 will be devoted to the operational deployment of the DSS software and use in Decision Making.

6. Schedule with Milestones

Table 4. Scheduled of proposed work

<table>
<thead>
<tr>
<th></th>
<th>Y1</th>
<th>Y2</th>
<th>Y3</th>
<th>Y4</th>
</tr>
</thead>
<tbody>
<tr>
<td>All climate forecasts and hindcasts archived and staged for further model development</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>All hydrology and water resource data collected and pre-processed</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>The nonlinear hydropower optimization model formulated for the selected hydropower system.</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specification of DSS feature requirements completed</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Completed merger of statistical and dynamical climate forecasting approaches</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Automation of climate processing completed</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>First level climate ADIS of data products on-line accessible</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Development of a hydrology and water resource system developed that integrates the modeling, data assimilation, statistical model, and various data inputs</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Automation of hydrology and water resource system</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Verification of hydropower optimization model against historical operation records</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Development of forecast and updating procedure, utilizing streamflow forecasts for real-time operation</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prototype software with GUI completed</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Completed tailoring of climate forecasts to hydrologic applications</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Automation of climate-to-hydrologic processing – to reservoir optimization completed. All DSS components linked to the software with GUI</td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>All data products of DSS on-line accessible</td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Co-hosting of a joint Climate Outlook Forum at ACMAD, Niamey, Niger, including training to partner institutions</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Climate forecast and DSS technology transfer to partner user institutions</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>
## Performance Measures

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Assessment Tool</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Forecast Accuracy and DSS Performance</strong></td>
<td></td>
</tr>
<tr>
<td>Improvement in seasonal climate forecast accuracy</td>
<td>Quantify the difference in seasonal climate forecast before and after the DSS is implemented, before and after the dynamic and statistical corrections are applied. The differences will be used to quantify water savings and translate into benefits. Measures include traditional “measures-oriented approaches”, “distributions-oriented approaches”, and user-defined criteria that end users employ to assess their decision making and services. Examples of specific measures: RMSE, NSE, threshold-based (e.g., Brier, ROC, etc), as well as ensemble-based (e.g., rank histograms, CRPSS, etc).</td>
</tr>
<tr>
<td>Improvement in seasonal hydrologic forecast accuracy</td>
<td>Quantify the difference in seasonal hydrologic forecast before and after the DSS is implemented, before and after satellite rainfall inputs are incorporated before and after soil moisture data are assimilated before and after statistical models are applied The differences will be used to quantify water savings and translate into benefits. See measures above.</td>
</tr>
<tr>
<td>Improvement in seasonal reservoir storage forecast accuracy</td>
<td>Quantify the difference in seasonal hydrologic forecast before and after the DSS is implemented, and before and after satellite initial reservoir level observations are used</td>
</tr>
<tr>
<td>Improvement in hydropower production</td>
<td>Quantify the difference in hydropower production before and after the DSS is implemented, and before and after optimizations before and after reservoir water storage forecasts The differences will be translated into benefits.</td>
</tr>
<tr>
<td>Improvement in flood control</td>
<td>Compare results with historical flood control reservations. Metrics include inventory of flood damages.</td>
</tr>
</tbody>
</table>

**User Acceptance and organizational Assimilation of the DSS system**

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Assessment Tool</th>
</tr>
</thead>
<tbody>
<tr>
<td>Users perspectives on forecast usefulness, ease of understanding, tools for processing, new capabilities gained, and user satisfaction</td>
<td>Survey of end users on these aspects compared to their own DSS The extent of use of the proposed DSS</td>
</tr>
<tr>
<td>Compatibility with real-time operations</td>
<td>The extent of the acceptance by the system operators.</td>
</tr>
<tr>
<td>Climate forecast user operability</td>
<td>Stand-alone improved-system climate forecast generation by ACMAD by end of 4th year</td>
</tr>
<tr>
<td>Climate DSS ADIS display operability</td>
<td>Stand-alone ADIS usage and updating by ACMAD and other end users by end of 4th year</td>
</tr>
</tbody>
</table>

**Research and Team Management Productivity**

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Assessment Tool</th>
</tr>
</thead>
<tbody>
<tr>
<td>Journal articles and conference pres.</td>
<td>Numbers and citations</td>
</tr>
<tr>
<td>Meeting milestones</td>
<td>Tracking milestones</td>
</tr>
<tr>
<td>Outreach efforts</td>
<td>Extent of outreach efforts, # stakeholders using the DSS</td>
</tr>
</tbody>
</table>
Statements of Commitments

University of California, Los Angeles (UCLA)
William W.G. Yeh, Co-PI

National Center for Atmospheric Research (NCAR)
Joshua Hacker, Co-I/Institutional PI
Thomas Hopson, Co-I/Institutional PI

University of Colorado-Boulder
Robert Brakenridge, Co-I/Institutional PI

National Oceanic and Atmospheric Administration (NOAA) Climate Prediction Center
Dan Collins, Co-I/Institutional PI

Niger Basin Authority
Henri-Claude Enoumba, Co-I/Institutional PI (non-US organization only)

African Centre for Meteorological Applications for Development (ACMAD)
Andre Kamga Foamouhoue, Co-I/Institutional PI (non-US organization only)

National Meteorological Agency of Ethiopia
Diriba Korecha, Co-I/Institutional PI (non-US organization only)

Ethiopian Electric Power Corporation
Mekuria Lemma, Co-I/Institutional PI (non-US organization only)
April 20, 2014

Mekonnen Gebremichael
Associate Professor
Civil & Environmental Engineering Department
UCLA
420 Westwood Plaza, 5732F Boelter Hall, Box 951593
Los Angeles, CA 90095-1593

Re: Proposal titled “Optimizing Reservoir Operations for Hydropower Production in Africa through the use of Remote Sensing Data and Seasonal Climate Forecasts”

Dear Dr. Gebremichael:

I acknowledge that I am identified by name as Co-Principal Investigator to the investigation, entitled < Optimizing Reservoir Operations for Hydropower Production in Africa through the use of Remote Sensing Data and Seasonal Climate Forecasts >, that is submitted by Dr. Mekonnen Gebremichael to the NASA Research Announcement NNH13ZDA001N-WATER, and that I intend to carry out all responsibilities identified for me in this proposal. I understand that the extent and justification of my participation as stated in this proposal will be considered during peer review in determining in part the merits of this proposal. I have read the entire proposal, including the management plan and budget, and I agree that the proposal correctly describes my commitment to the proposed investigation.

Sincerely yours,

William Yeh
Richard G. Newman AECOM Distinguished Professor of Civil Engineering
Mekonnen Gebremichael  
Associate Professor  
Civil & Environmental Engineering Department  
UCLA  
420 Westwood Plaza, 5732F Boelter Hall, Box 951593  
Los Angeles, CA 90095-1593

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Sincerely,

[Signature]

Dr. Joshua Hacker  
Scientific Project Manager, National Security Applications Program  
Research Applications Laboratory  
National Center for Atmospheric Research
Mekonnen Gebremichael  
Associate Professor  
Civil & Environmental Engineering Department  
UCLA  
420 Westwood Plaza, 5732F Boelter Hall, Box 951593  
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Sincerely,

Dr. Thomas Hopson  
Research Scientist  
Research Applications Laboratory  
National Center for Atmospheric Research
Prof. Mekonnen Gebremichael  
Civil & Environmental Engineering Department  
UCLA, 420 Westwood Plaza, 5732F Boelter Hall, Box 951593  
Los Angeles, CA 90095-1593  

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Dear Prof. Gebremichael:

I acknowledge that I am identified by name as Co-investigator to this proposal that is submitted to the NASA Research Announcement NNH13ZDA001N-WATER, and that I intend to carry out all responsibilities identified for me in this proposal.

I understand that the extent and justification of my participation as stated in this proposal will be considered during peer review in determining in part the merits of this proposal. I have read the entire proposal and agree that the proposal correctly describes my commitment to the proposed investigation. My participating organization is the University of Colorado.

Sincerely,

[Signature]

Professor G. Robert Brakenridge  
Director, Dartmouth Flood Observatory  
CSDMS.INSTAAAR, University of Colorado
April 28, 2014

From: Dan C. Collins, Ph.D.
NOAA Climate Prediction Center
NCWCP (W/NP5)
5830 University Research Court
College Park, MD, 20740 – 3818
Telephone: 301-683-3452

To: Mekonnen Gebremichael
Associate Professor
Civil & Environmental Engineering Department
UCLA
420 Westwood Plaza, 5732F Boelter Hall, Box 951593
Los Angeles, CA 90095-1593

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Sincerely,

Dr. Dan Collins
Research Scientist
Climate Prediction Center
National Oceanic and Atmospheric Administration
Mekonnen Gebremichael  
Associate Professor  
Civil & Environmental Engineering Department  
UCLA  
420 Westwood Plaza, 5732F Boelter Hall, Box 951593  
Los Angeles, CA 90095-1593  

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I understand that the extent and justification of my participation as stated in this proposal will be considered during peer review in determining in part the merits of this proposal.

I have read the entire proposal, including the management plan and budget, and I agree that the proposal correctly describes my commitment to the proposed investigation. My participating organization is the Niger Basin Authority as well as the proposed investigation of Optimizing Reservoir Operations for Hydropower Production in Africa through the use of Remote Sensing Data and Seasonal Climate Forecasts constitutes a solution allowing the Niger Basin Authority among others to modernize its activities, with better adaptation to the economic situation of the member countries and to intensify cooperation and coordination between them, fostering truly integrated management of water and other natural resources and truly cooperative combat of drought flood hazards and related diseases.

Sincerely,

Dr. Henri-Claude ENOUMBA  
Senior Mining Engineer  
Head of Research & Planning Division  
Niger Basin Authority
Mekonnen Gebremichael
Associate Professor
Civil & Environmental Engineering Department
UCLA
420 Westwood Plaza, 5732F Boelter Hall, Box 951593
Los Angeles, CA 90095-1593

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Sincerely,

[Signature]

Dr. Andre Kama FOAMOYOUHE
Chief, Climate and Environment Department
African Centre for Meteorological Applications for Development (ACMAD)
85, Avenue des Ministères
P.O. Box 13 184
Niamey, Niger
Mekonnen Gebremichael  
Associate Professor  
Civil & Environmental Engineering Department  
UCLA  
420 Westwood Plaza, 5732F Boelter Hall, Box 951593  
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Sincerely,

Diriba Korecha (PhD)  
Director,  
Meteorological Forecast and Early Warning Directorate  
National Meteorological Agency  
P.O. Box 1090  
Addis Ababa, Ethiopia
Mekonnen Gebremichael  
Associate Professor  
Civil & Environmental Engineering Department  
UCLA  
420 Westwood Plaza, 5732F Boelter Hall, Box 951593  
Los Angeles, CA 90095-1593  

Re: Proposal titled “Optimizing Reservoir Operations for Hydropower Production in Africa through the use of Remote Sensing Data and Seasonal Climate Forecasts”

Dear Dr. Gebremichael:

I acknowledge that I am identified by name as Co-Investigator to the investigation, entitled < Optimizing Reservoir Operations for Hydropower Production in Africa through the use of Remote Sensing Data and Seasonal Climate Forecasts >, that is submitted by Dr. Mekonnen Gebremichael to the NASA Research Announcement NNH13ZDA001N-WATER, and that I intend to carry out all responsibilities identified for me in this proposal. I understand that the extent and justification of my participation as stated in this proposal will be considered during peer review in determining in part the merits of this proposal. I have read the entire proposal, including the management plan and budget, and I agree that the proposal correctly describes my commitment to the proposed investigation.

Sincerely,

[Signature]

MEKURIA LEMMA  
Strategy and Investment Head
Letters from End-User Organizations

*African Centre for Meteorological Applications for Development (ACMAD)*

*Ethiopian Electric Power Corporation*

*Niger Basin Authority*

*Tanzania Electricity Company (TANESCO)*
Mekonnen Gebremichael, Ph.D.  
Civil & Environmental Engineering Department  
University of California, Los Angeles  
420 Westwood Plaza  
5732F Boelter Hall, Box 951593  
Los Angeles, CA 90095-1593  

Dear Dr. Mekonnen Gebremichael,

On behalf of the African Center of Meteorological Application for Development (ACMAD), I am pleased to confirm my commitment to the successful implementation of the project proposal titled “Optimizing Reservoir Operations for Hydropower Production in Africa through the use of Remote Sensing Data and Seasonal Climate Forecasts”.

Created in 1987 by the United Nations Economic Commission for Africa (UNECA), the World Meteorological Organization (WMO), and its 54 African Member States, ACMAD is the designated weather and climate center for developing and maintaining African continental-scale competence. ACMAD's mission is the provision of weather and climate information and the promotion of sustainable development of Africa in the fields of agriculture, water resources, health, public safety and renewable energy.

There are many instances over the last decades where loss of life and loss of property has occurred as a result of mis-communicated hydropower reservoir releases that occurred as a result of unanticipated upstream inflows into the reservoirs. ACMAD, as the designated continental center for climate-related public safety information, is well positioned to provide leadership with hydropower institutional partners in ways to mitigate such tragedies through advanced forecasts of extreme water inflows. Such forecasts can be derived through ACMAD’s effective use of climate forecasts and access to advanced hydrologic modeling tools, which this proposal is desirous to support.

In addition to advanced climate and hydrologic modeling tools, this proposed project aims at developing a Decision Support System (DSS) that supports the visualization of the climate and hydrologic forecasts. The proposed project is therefore highly relevant to ACMAD. The proposed DSS will significantly strengthen our ability to generate user-friendly visualization tools to inform our citizens well ahead of time so that they are better prepared in situations of water resource related dangers.

The proposed project contains a transition plan aimed at enabling ACMAD to fully utilize the ensemble climate forecasts, hydrologic modeling, and the implementation of the DSS. On our end, we are fully committed to working with you in the development and successful implementation of planning of the DSS. To this end, we confirm our commitment to ensuring utilization of generated products (seasonal forecasts, stream flow forecasts) to provide advice to decision making and action to optimize hydropower dams.

Sincerely,

Adama Ahmada SANIOU  
Director General
Mekonnen Gebremichael, Ph.D.
Associate Professor
Civil & Environmental Engineering Department
University of California, Los Angeles
420 Westwood Plaza
5732F Boelter Hall, Box 951593
Los Angeles, CA 90095-1593

Dear Dr. Mekonnen Gebremichael:

On behalf of the Ethiopian Electric Power (EEP), I am pleased to confirm my commitment to the successful implementation of the project proposal titled “Optimizing Reservoir Operations for Hydropower Production in Africa through the use of Remote Sensing Data and Seasonal Climate Forecasts”.

EEP is a government owned utility responsible for the generation, transmission, distribution and sales service of electric energy throughout Ethiopia. EEP’s goal is to provide quality electric service to Ethiopia and neighboring countries primarily using hydropower plants. To realize this goal, EEP has built and is currently building a number of hydropower dams. One of the biggest challenges EEP is facing is managing hydropower reservoir operations to generate reliable hydropower energy. Our current reservoir operation and planning practice is based on the assumption that flow volume of any current year will be the same as the year before. However, we know from our experiences that this constant flow assumption most often does not hold true due to the inherent large inter-annual rainfall variabilities in Ethiopia. Realistic flow forecasting is key to efficient and reliable hydropower reservoir management and operations.

The proposed project aims at developing a Decision Support System (DSS) that uses realistic climate and hydrologic forecast system and provides optimal solutions for cascade of reservoirs within the Gibe basin. The proposed project is therefore highly relevant to EEP, and comes at a time when EEP is striving to find solutions to the inefficient hydropower generation. The proposed DSS will significantly strengthen our ability to plan and operate our reservoirs for maximum and continuous energy production efficiency, and to inform our customers well ahead of time so that they are better prepared in situations of power shortage. The DSS you have proposed will also enable EEP to make use of satellite datasets for all its hydropower reservoir operations in Ethiopia.

The proposed project contains a transition plan aimed at enabling EEP implement the DSS. On our end, we are fully committed to working with you in the development and successful implementation of the DSS. To this end, we confirm our commitment to ensuring access to all our datasets (such as reservoir actual conditions and reservoir operation policy), and fully working with you in all aspects of the project activities from its inception to its successful implementation at EEP.

Sincerely,

[Signature]

MEKURIA LEEMA
Strategy and Investment Head

ETHIOPIAN ELECTRIC POWER

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20 JULY 2006

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Mekonnen Gebremichael, Ph.D.  
Civil & Environmental Engineering Department  
University of California, Los Angeles  
420 Westwood Plaza, 5732F Boelter Hall, Box 951593  
Los Angeles, CA 90095-1593

Dear Dr. Mekonnen Gebremichael:

On behalf of the Niger Basin Authority (NBA), I am pleased to confirm my commitment to the successful implementation of the project proposal titled “Optimizing Reservoir Operations for Hydropower Production in Africa through the use of Remote Sensing Data and Seasonal Climate Forecasts”.

Created in 1964, the NBA is one of Africa’s oldest Intergovernmental Organizations. Our purpose is the promotion of cooperation among member countries to ensure integrated development of resources, most notably, but not limited to, the Niger River. Our nine member nations are: Benin, Burkina Faso, Cameroon, Chad, Côte d’Ivoire, Guinea, Mali, Niger and Nigeria. The NBA harmonizes the member countries in their development of energy, agriculture, forestry, transport, communications, and industrial resources, in addition to its primary focus on water and hydroelectric resources.

One of the biggest challenges facing the African continent is in effective and safe management of hydropower reservoir operations to generate reliable hydropower energy, and at the same time, protect downstream civilians and farmers from unanticipated sudden reservoir releases. There are many instances over the last decades where loss of life and property occurred as a result of mis-communicated sudden hydropower reservoir releases, occurring as a result of unanticipated upstream inflows. The NBA, as the designated authority for trans-boundary water resource planning, is well positioned to provide leadership with our hydroelectric institutional partners in ways to mitigate such tragedies through advanced forecasts of extreme water inflows, while still optimizing water resource use for hydroelectric generation. These are the topics this proposed project plans to strengthen, through the provision of advanced climate and hydrologic inflow forecasts, and the development of a Decision Support System (DSS) to support their visualization. The proposed project is therefore highly relevant to both NBA and to our hydroelectric institutional partners.

The proposed project contains a transition plan aimed at enabling NBA, in partnership with its sister climate organization, the African Centre of Meteorological Application for Development (ACMAD), to utilize the ensemble climate forecasts, hydrologic modeling, and the implementation of the associated DSS. On our end, we are committed to working with you in the development and successful implementation of this proposal’s goals. To this end, we commit to (1) providing budget and technical staff to implement the DSS, (2) ensuring utilization of generated datasets (such as climate and hydrologic forecasts), and (3) working with you and ACMAD in all aspects of the project activities from its inception to its successful implementation.

Sincerely,

Dr. Henri-Claude Enoumba  
Head of Research & Planning Division  
Niger Basin Authority  
Niamey, Niger