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The Role of Climate Change in Modulating Hydroelectric Power Generation over the River Nile Basin

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Abstract: The flow of the White Nile over Eastern Africa, and hence the productivity of its hydroelectric power dams is primarily determined by the level of Lake Victoria. Nalubaale Dam (originally called Owen Falls Dam), located at the city of Jinja (source of the Nile) on the shores of the largest Lake in Africa, in Uganda, was the first (1959) major hydroelectric plant to be constructed in the region. The Bujagali dam is expected to be commissioned in 2011. The Murchison Falls dam in Uganda and several other dams in Sudan & Egypt are under construction or in the planning phase. The temporal variability of the level of Lake Victoria is primarily determined by the rainfall variability over the basin. The leading regional mode of climate variability is associated with the El Niño-Southern Oscillation (ENSO) climate teleconnections originating from the Pacific Ocean, followed by the Eastern Africa dipole mode dominated by decadal variability. Other factors including, evaporation, lake area fluctuations, ground water & bottom sedimentation play some but less important roles in determining the variability of the water balance.

We hypothesize that ENSO, the dipole mode and natural hydrologic adjustment of the lake primarily determine the levels of Lake Victoria but we are uncertain how they rank in their contribution to the variability of the lake level. The relationship between ENSO and dipole mode with Lake Victoria levels is nonlinear & complicated. The first objective of this study is to determine the relative contributions of these factors in modulating Lake Victoria levels. One of the hydrological indices commonly used for decision-making in regulating hydroelectric power production over the White Nile is 'low' and 'high' Lake Victoria hydrology. Low hydrology corresponds to the accumulative level of the lake's depth at the end of each year, satisfying the condition, 10.64 meters < lake level < 12.14 meters (mean water release target of 687 m3/s), while high hydrology corresponds to lake level >12.14 meters (mean water release target of 1247 m3/s). The second objective of this study is to determine if climate change is likely to cause sustained shifts between the two hydrological regimes, and to develop a framework for incorporating this information into the existing long-term strategic plans for the regional energy industry.

Regarding our first objective, for the contemporary climate, the results show that the sudden increase in lake levels from 1961 to 1964 was mainly caused by consistently above normal precipitation during those years due to large SST anomalies over the western Indian Ocean basin, while the decline from 1965-2005 was due to the lake's hydrologic adjustment to original rainfall climatology. The first Empirical Orthogonal Function (EOF) mode for the annual regional rainfall variability (associated with ENSO) accounts for the highest impact on the annual variability of Lake Victoria levels. The second annual rainfall EOF (associated with the dipole mode) accounts for approximately 10% of the Eastern Africa variability; however its affect on the variability of lake levels is nearly negligible because the loadings over the lake where the EOF dipole mode loading pattern changes sign are near zero. Regarding our second objective, climate change projections based on the downscaling of the IPCC global products indicate an increase of 2 meters in the lake's level above the current state. Therefore, all things being equal, the Eastern Africa countries could benefit from higher potential of hydroelectric power as a result of climate change. Further analysis, based on GIS, indicates that climate change could make the road network infrastructure near the coastline prone to flooding. This and other potential impacts, such as, the effects on real estate must be taken into account in planning for future social-economic development for this part of Eastern Africa.