



Projecting future water availability in Lake Malawi and the Shire River basin

Malawi's development is strongly tied to water availability

Malawi is highly dependent on water from Lake Malawi and the Shire River basin (Figure 1). Over 90% of Malawi's electricity depends on outflows from the lake into the Shire River which feed three existing hydropower plants – Tedzani, Nkula and Kapichira – with expansion anticipated at the latter two, and plans for additional hydropower stations. Most of the country's irrigated agriculture is dependent on the river. Regular flows of water are also essential to maintain a wetland system (the Elephant Marsh) and the ecosystem services that it provides.

Pressure on water resources is likely to increase as a result of a growing population, and competing demands for water for energy, agriculture, industrial and domestic purposes. Understanding the scale of potential future changes in water availability under climate change is thus essential to inform socio-economic development planning in Malawi. In this brief we use computer-based water resources models to project future water availability reflecting demand and the effects of water management strategies.

Lake Malawi and the Shire River basin: a dynamic system

Water levels in Lake Malawi fluctuate throughout the year reflecting the contribution of lake tributaries, rainfall and evaporation over the lake, and outflows to the Shire River. The highest outflows usually occur at the end of the rainy season, and the lowest outflows at the end of the dry season.

Water levels also show change over time, reflecting a combination of natural factors and management decisions (Figure 2). In the early 20th century

rainfall variability led to low lake levels which resulted in no outflows to the Shire River (1910-24). Construction of the Kamuzu Barrage in 1965 enabled control of outflows from the lake into the Shire River. The highest recorded outflows occurred in 1979-80. However, since then droughts have significantly reduced water availability on several occasions, including in 1992-3 and 2015-16 with the El Niño events.

Decisions to change land use in the basin – from forestry to agriculture – also play a role in affecting the speed with which water drains into the lake from the catchment. While climate change is expected to be an important driver of changes in rainfall, and therefore water availability, decisions regarding the management of lake levels will

also affect the ability of Lake Malawi and the Shire River to supply water to different sectors.

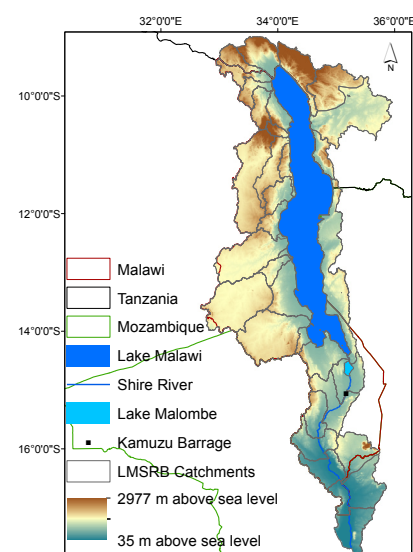
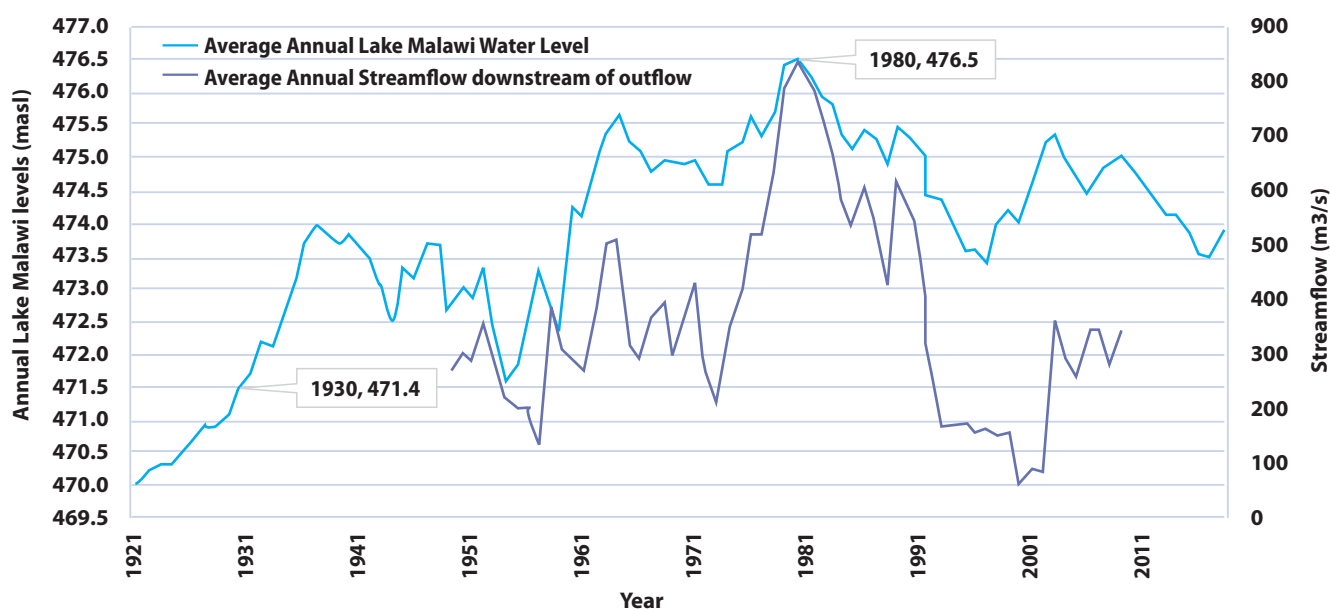


Figure 1: Location, elevation and catchments of the Lake Malawi Shire River Basin

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Future Climate for Africa (FCFA) aims to generate fundamentally new climate science focused on Africa, and to ensure that this science has an impact on human development across the continent.

Figure 2: Past water levels in Lake Malawi (1921-2018) and Shire River streamflow at the Kamuzu Barrage at Liwonde (1948-2009)



Pre 1965

Significantly lower in the past with fluctuations and outflow threshold of 471.5 metres above sea level (masl) crossed in the early 20th century

1965-1993

Kamuzu Barrage constructed in 1965 allowed management of lake outflows; historic high (477m) reached in 1979-80

Post 1993

After a drought from 1992-5 the barrage restricted outflows to maintain lake levels

Determining water availability – using the Water Evaluation And Planning system (WEAP) model

WEAP (Water Evaluation And Planning, www.weap21.org) is a software tool for integrated water resources planning developed by the Stockholm Environment Institute. WEAP is easily accessible without payment of a software licence for users from developing

countries. It includes analysis of water demand (water use patterns and allocation) and supply (streamflow, groundwater, reservoirs and transfers). Once established, WEAP can be used as a decision support tool for assessing water availability and supply requirements for key sectors. Scenarios can also be explored to evaluate the implications of different water development and management options on water availability and demand.

Customising the modelling and analysis to the local context of hydrology and management decisions is crucial to generating stakeholder-relevant information.

The UMFULA research team of the Future Climate for Africa (FCFA) Programme developed a WEAP model for the Lake Malawi Shire River basin using a four step process of stakeholder engagement over a three year period (Figure 3). This is part of UMFULA's work that aims to

support long-term decisions in central and southern Africa around resource use, infrastructure investment and cross-sectoral growth priorities.

Stakeholders that were consulted for the development of the WEAP model include:

- Ministry of Agriculture, Irrigation and Water Development (Departments of Irrigation, Surface Water, and Agriculture Extension Services)
- Department of National Parks and Wildlife

- Electricity Supply Corporation of Malawi Ltd (ESCOM) (ESCOM has recently been split into ESCOM and Electricity Generation Company Ltd. (EGENCO))
- Shire River Basin Management Programme (SRBMP)
- Operators of the Kamuzu Barrage.

Stakeholders informed our understanding of historical and current water resource management practices, planned infrastructure (new barrages,

offtakes and irrigation), and priority features of the basin to model (Figure 4). An iterative development process produced a model that addresses stakeholder questions and priorities. The model is transferable and, with further development, could be used by Malawi's planners and decision makers for scenario analysis, to examine different combinations of future water, energy and food production in the country. Further details are available in the submitted journal article by Bhave *et al.*

Figure 3: The iterative WEAP model development process between UMFULA researchers and local stakeholders

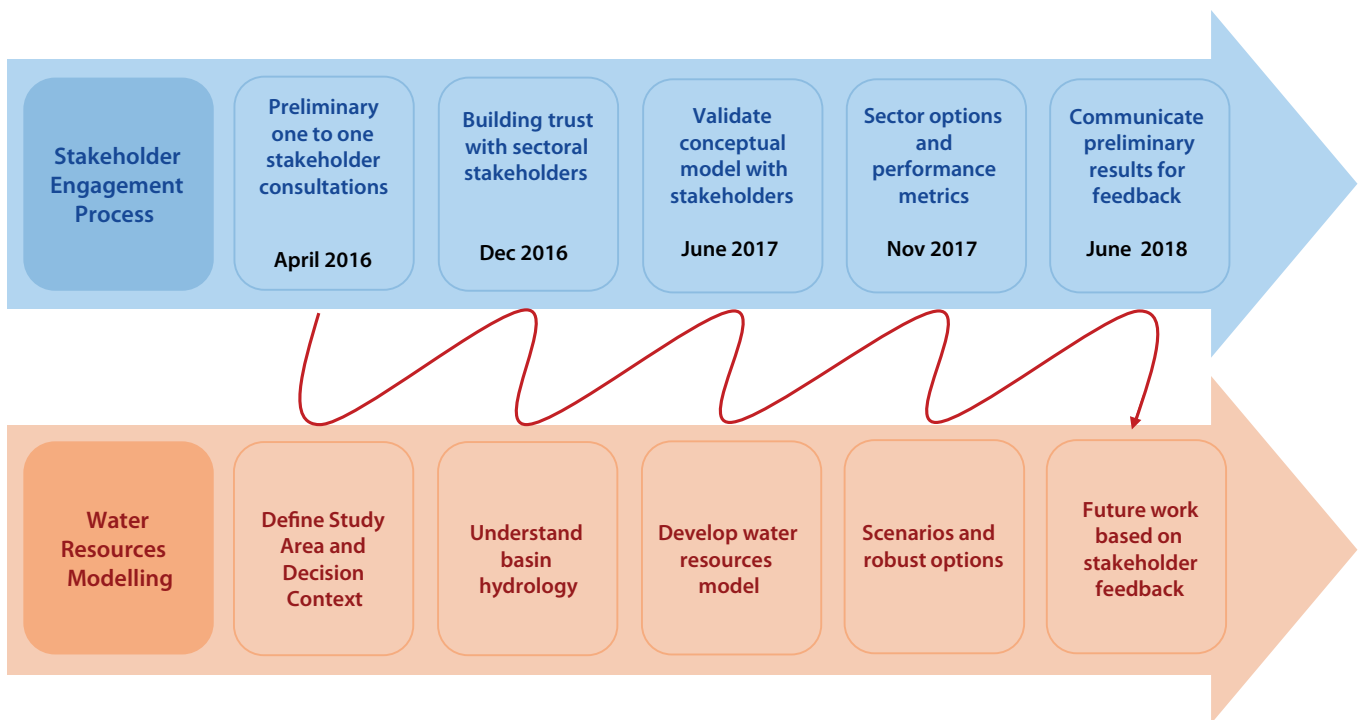
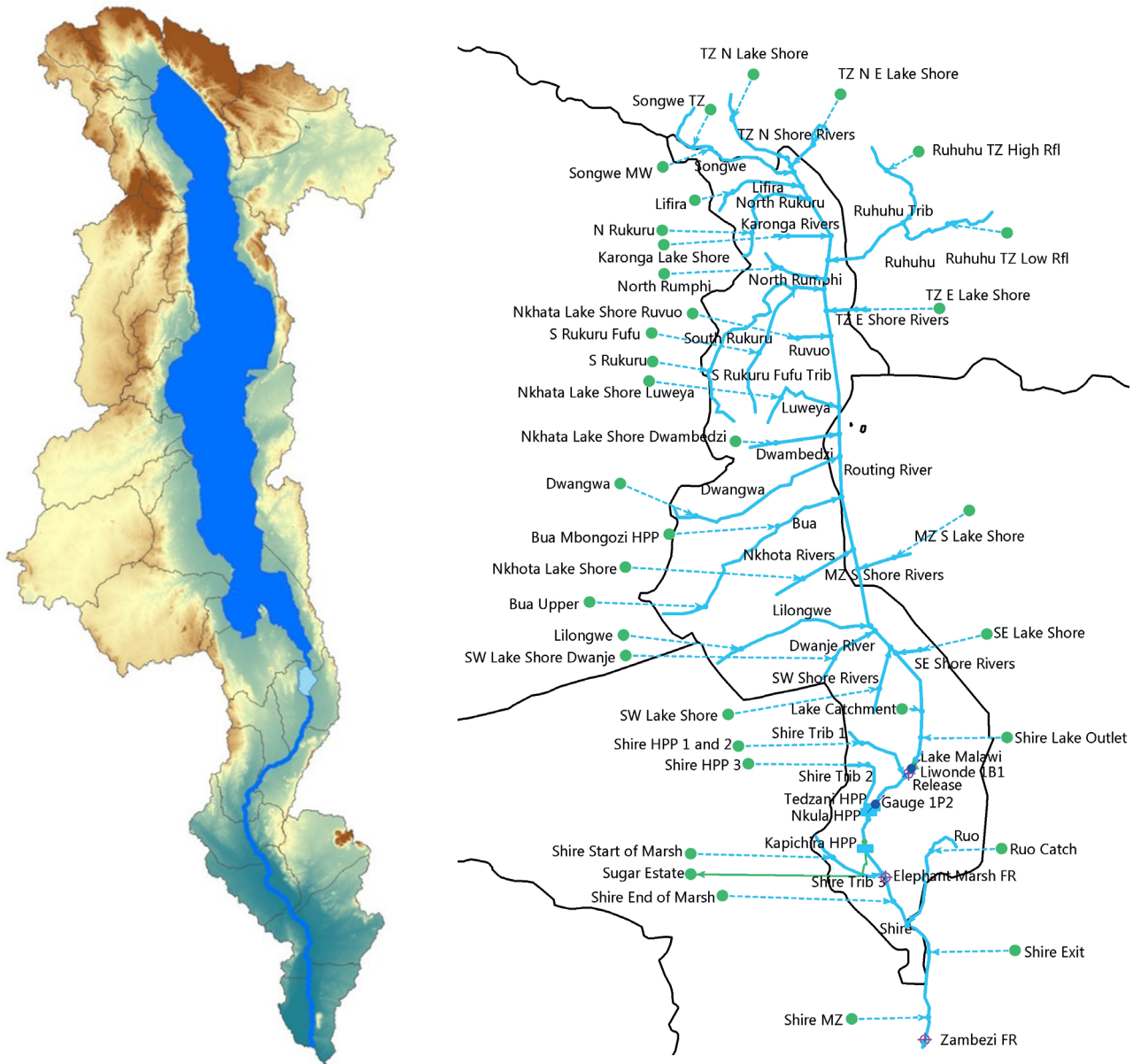


Figure 4: WEAP model schematic for the Lake Malawi Shire River Basin representing the catchments delineated in the map showing elevation (left). This transboundary basin covers parts of Malawi, Tanzania and Mozambique. The WEAP model structure includes lake catchments, Lake Malawi reservoir, flow requirement downstream of the barrage (termed Release) and three existing hydropower stations. Lake Malawi catchments inflow into the 'Routing River' which flows to the Lake Malawi reservoir.



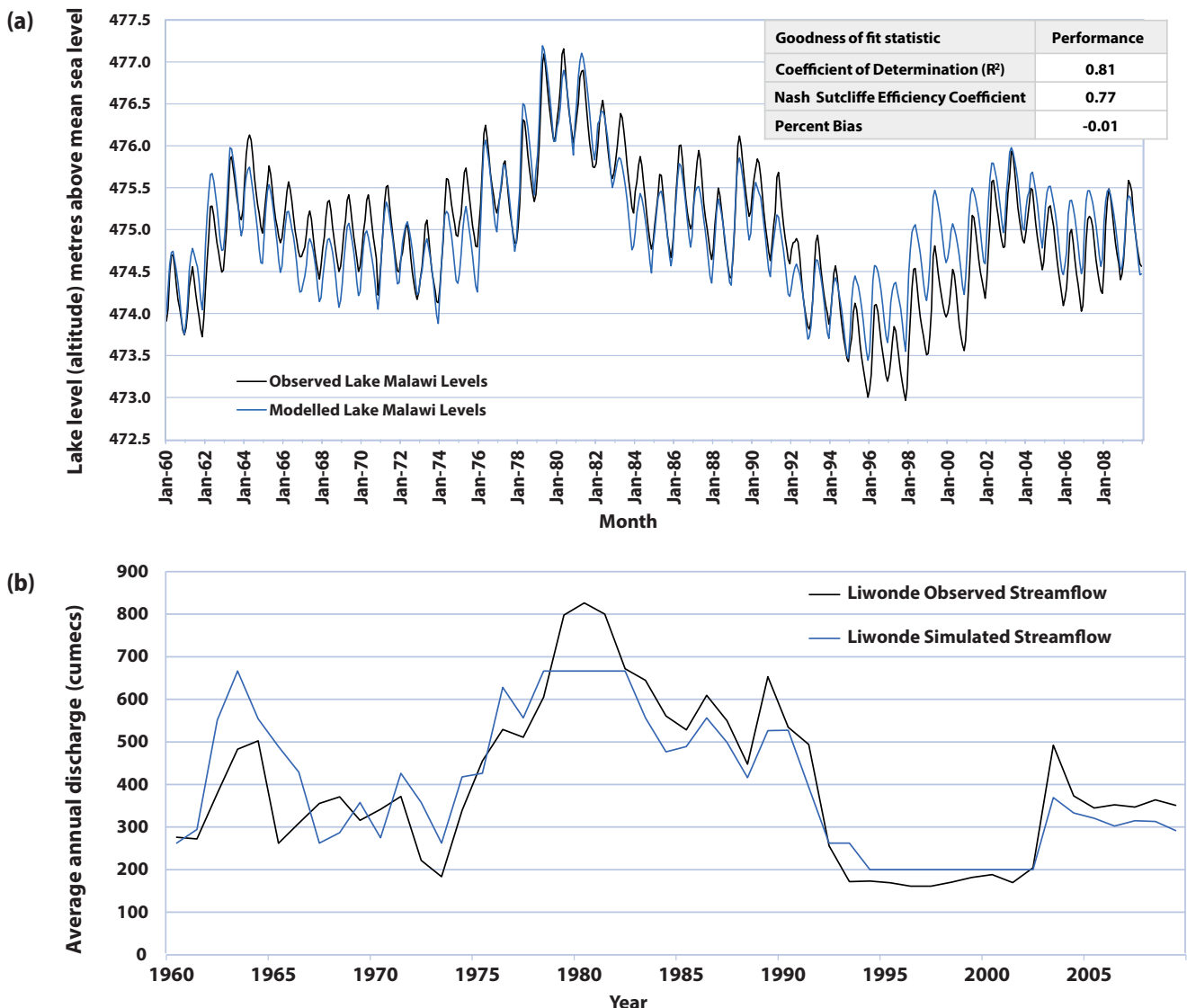
How accurate is the WEAP model in simulating variability in Lake Malawi and the Shire River basin?

It is important to assess the extent to which the model is able to capture the hydrological and water management characteristics of the basin before it is

used to analyse future scenarios. Model performance is assessed by comparing observational data with simulated data. The WEAP model shows reasonable ability to simulate lake levels, capturing seasonal variation, and showing sensitivity to changes in rainfall and barrage operation, which is an important

indicator of the utility of the model for representing future lake level changes (Figure 5). The model has less ability to capture monthly flows downstream of Lake Malawi. Model performance is strongly affected by limited data availability and intermittent records of management decisions at the Kamuzu Barrage.

Figure 5: (a) Observed and simulated monthly Lake Malawi levels for the period 1960-2009 along with inset of table with goodness-of-fit statistics for the entire period. (b) shows observed and simulated average annual streamflow at Liwonde (Kamuzu Barrage) (Bhave *et al.* submitted).



How will climate change affect future outflows from Lake Malawi?

The WEAP model was then run under future climate projections from 29 bias-corrected state-of-the-art Global Climate Models based on the RCP 8.5 scenario. The future climate projections represent the period 2021-2050. For the intermediate period of 11 years (from 2010 – 2020), we use observations from the 1960-1970 period to run the model. The impacts show a wide range of rainfall-driven changes in lake levels that can be grouped into three main categories (Figure 6):

(i) high lake levels leading to high Shire River outflows

Five models show that lake levels rise

to the maximum level that can be simulated (480 metres above sea level), after which unrestricted downstream flows occur (effectively reservoir overtopping) which would likely lead to downstream flooding. Moreover, for nine models monthly outflows exceed 1000 m³/s for substantial periods. Such outflows during the 1979-1981 period caused extremely high river flows in the Lower Shire.

(ii) lake level behaviour similar to the recent range

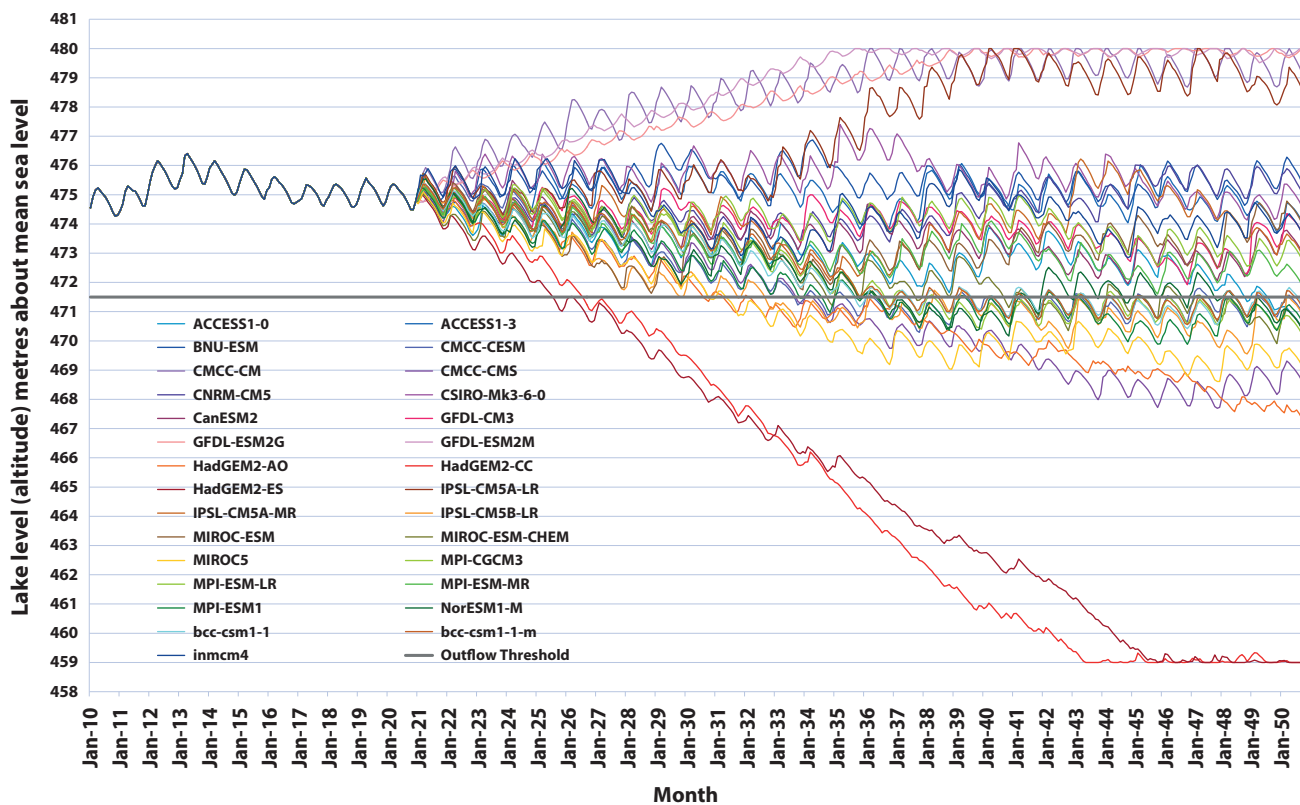
Some climate projections lead to lake levels staying moderately high, meaning that barrage operation could provide consistent flows for downstream requirements. However, for other projections, lake levels remain only just high enough to allow outflows into the

Shire River as they show a consistent reduction over time. Under such conditions, downstream releases would likely need to be constrained, leading to the risk of insufficient water downstream to maintain hydropower production and supply for irrigated agriculture and the environment.

(iii) lake levels falling below the outflow threshold

Reduced rainfall in the Lake Malawi catchment leads to much lower lake levels. Projections from 11 models lead to a breaching of the threshold (471.5 metres above sea level) below which no water outflows would occur from Lake Malawi into the Shire River. In such cases the Shire River would effectively change from a perennial to a seasonal river.

Figure 6: Climate change impacts on the Lake Malawi levels based on 29 Global Climate Model projections



What other factors affect future water supply?

Inflows

Since the catchment area of Lake Malawi covers parts of Malawi, Tanzania and Mozambique, changes in water availability from neighbouring countries can affect inflow to the lake. The model shows that, over the long term, land-based catchments in Malawi have contributed 55%, Tanzania 41% and Mozambique 4% to the total Lake Malawi inflow.

Tanzania's contribution of water to Lake Malawi is substantial, and therefore lake levels will be sensitive to future management decisions in Tanzania that affect water availability. Historically much of Tanzania's contribution has come from the Ruhuhu basin, which has relatively high rainfall but a low population density and limited water use for irrigation. However, this catchment is included in irrigation expansion plans under the Southern Agricultural Growth Corridor of Tanzania (SAGCOT). Malawi also has plans to expand irrigation along the lake coast through its Green Belt Initiative and other irrigation schemes which will reduce water inflows to the lake or lead to direct

water extraction from Lake Malawi. Both countries are also cooperating to share water resources of the Songwe River, which forms their border, to expand irrigated agriculture.

Outflows

Water management decisions, especially how the outflows are regulated by the Kamuzu Barrage, have major implications for existing and planned downstream infrastructure. New hydropower plants are planned to increase electricity generation to meet rising demand, while plans for canal-based irrigation in the Lower Shire have been identified to promote food security and socio-economic development.

Implications and recommendations

The model performance is highly constrained by data availability and knowledge of past operating decisions, but demonstrates good ability to simulate Lake Malawi levels. The results show a wide range of impacts due to large differences in climate model projections in this region of Africa. The impacts presented here assume no change in lake evaporation in the

future or the operation of infrastructure like the Kamuzu Barrage that would critically affect future lake level and outflow behaviour.

Sustainability of future investments will require more effective and extensive data collection and use. Lake Malawi/Shire River development plans need to address uncertainty in future water availability and demand changes, including how multi-year shifts in lake levels would affect water trade-offs between hydropower, irrigation and the environment. The wide range of potential future lake level changes and impacts on outflow suggest a need for decision making under uncertainty approaches. Such approaches can help identify management decisions (particularly for the Kamuzu Barrage) that work effectively across a range of future climates (dry and wet conditions) and basin development scenarios. The WEAP model is intended to be a useful tool to assess such options, and allow stakeholders to explore scenarios and thereby support robust decision making. The UMFULA research team is working with stakeholders to do exactly this, and a subsequent brief will be published later this year.





Reference

Bhave, A.G., Bulcock, L., Dessai, S., Conway, D., Jewitt, G., Dougill, A.J., Kolusu, S.R. and Mkwambisi, D. Lake Malawi's threshold behaviour: A stakeholder-informed model to simulate sensitivity to climate change, Submitted to Journal of Hydrology.

About Future Climate for Africa

Future Climate for Africa (FCFA) aims to generate fundamentally new climate science focused on Africa, and to ensure that this science has an impact on human development across the continent. This brief was written by members of the UMFULA research team: Ajay Bhave (a.g.bhave@leeds.ac.uk), Katharine Vincent (katharine@kulima.com) and David Mkwambisi (dmkwambisi@must.ac.mw). It is based on the journal article by Bhave *et al.*, as referenced above. The authors are immensely grateful to the stakeholders who took out time from their busy schedule to attend meetings to engage in discussions, help develop the model, and provide valuable feedback. This includes representatives of the Ministry of Agriculture, Irrigation and Water Development (Departments of Irrigation, Surface Water, and Agriculture Extension Services), Department of National Parks and Wildlife, Electricity Supply Corporation of Malawi Ltd (ESCOM), Electricity Generation Company Ltd. (EGENCO), Shire River Basin Management Programme (SRBMP) and operators of the Kamuzu Barrage.



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