FEATURE

Planning under Pressure: New Strategies for Resilient Water Utilities in Sub-Saharan Africa

Guillermo Mendoza, Marc Tkach, and John Kucharski

TO CALL WATER RISK MANAGEMENT IN SUB-SAHARAN Africa difficult is an understatement. And the difficulty has concrete consequences for economic well-being and public health. A 2018 World Bank assessment of Zimbabwe's irrigation sector showed that annual gross domestic product (GDP) is highly correlated with annual rainfall. Even under normal conditions, the correlation of economic productivity with rainfall makes development spotty and unreliable in poorer sub-Saharan countries.

When disaster strikes, matters are worse. Countries like Zimbabwe have fewer resources to support the collection of high-resolution, longer-term datasets and have limited technical and institutional capacity to help them respond to water-related disasters. What is more, poorer countries are disproportionately impacted by such disasters. If an essential purpose of water resources management is to translate variable hydrology into reliable benefits for a community, then water management in many sub-Saharan African countries has failed.

Climate change adds a new dimension of complexity to the problem. The challenge is not to develop better climate science tools. Plenty of effective tools are available. It is, rather, to incorporate climate change into the planning process in a pragmatic, transparent, and justifiable way.

Part of the difficulty lies in the haziness of current predictions. As Johan Grijsen noted in a report for the World Bank, climate change runoff projections vary wildly—from 20% increases to 20% decreases. This presents a challenge for planners and decision makers. How can we make informed decisions about a future that is so uncertain? Water resource managers working to develop resilient water utilities in sub-Saharan Africa are planning under additional pressures as well: they face an uncertain future, weak available data, a narrow time frame, and severe budgetary constraints.

The Iolanda Water Treatment Plant (IWTP) serves nearly 1 million residents in and around Lusaka, Zambia. Although the Millennium Challenge Corporation has helped address the plant's chronic performance failures, future impacts of climate change will require further investment. Source: Photo by Chipili Chikamba, MCA-Zambia.

But there are ways forward. By piloting a bottom-up, community-oriented approach to planning for water infrastructure resilience, the Millennium Challenge Corporation (MCC) is taking this challenge head on.

Building Resilience from the Bottom Up

The MCC is a U.S. foreign assistance agency that provides grants to impoverished countries to build infrastructure and reduce poverty. For countries in Africa, where 490 million people live in extreme poverty, grants from organizations like the MCC are crucial for addressing the challenge of water management. The Iolanda Water Treatment Plant (IWTP) for the city of Lusaka, Zambia, is a prime example of MCC investments in action (Figure 1). The plant serves almost 1 million residents. But over the years it has faced chronic performance failures driven by droughts and the condition of local water resources infrastructure.

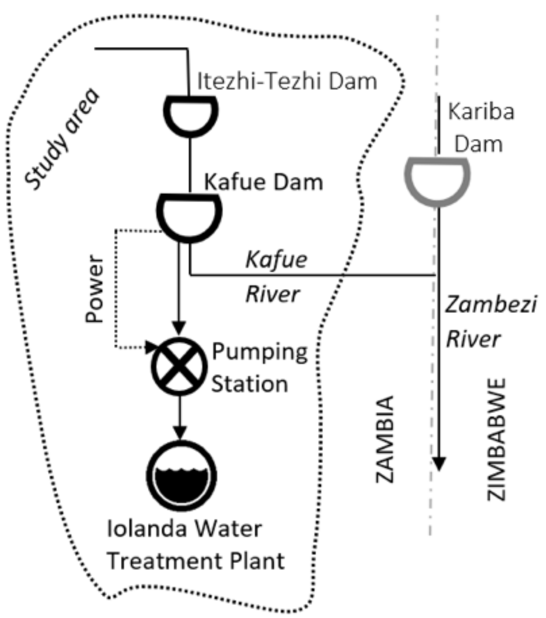

Figure 1. A conceptual schematic of the Iolanda Water Treatment Plant system. Source: Authors.

This has led to uneven service reliability, which dips to between 60 and 70% when the dry season ends between October and December. This, in turn, drives up the incidence of waterborne diseases because as water is rationed, communities turn to untreated alternative sources of water or they store water at the household level, where it is at higher risk of getting contaminated.

To address these infrastructural and public health issues, the MCC was asked to step in. The MCC's project to rehabilitate IWTP pipelines, intakes, and facilities cost around $57.9 million. Early returns on this baseline investment were clear: the MCC's efforts increased reliability to 90% and higher in critical months.

But in addition to the challenges of today, the MCC began planning for an uncertain tomorrow. In particular, the MCC was interested in investments that would enhance the IWTP's resilience to future drought impacts resulting from climate change. It would need to conduct a resilience study in only a few months, on a limited budget, with thin data. To do so, the MCC piloted the use of Climate Risk Informed Decision Analysis (CRIDA), a planning guide endorsed by the Intergovernmental Hydrology Programme (IHP) that brings together scientific modeling and the input of local communities to develop more resilient water systems in the face of climate change.

One the chief advantages of planning with CRIDA is its bottom-up approach. When beginning from a set of climate change projections, planners can quickly find themselves overwhelmed by cascading uncertainties. CRIDA allows planners to sidestep this difficulty by beginning with the water-related issues that keep planners awake at night. Doing so, planners maximize the strategic value of less-than-certain climate change projections rather than being paralyzed by them.

Planning for Resilience, Step by Step

The MCC took full advantage of the CRIDA approach in support of the IWTP. The five steps it undertook to enhance the resiliency of the plant and related infrastructure were as follows:

- **Step 1—Decision context:** The MCC worked with relevant stakeholders and decision makers to agree on performance thresholds that were then used to determine what issues should be targeted through investment. Together, the MCC and local community members determined that, for the IWTP, reliability of less than 90% represented an unacceptable failure.
- **Step 2—Bottom-up vulnerability assessment:** Existing system models were used to evaluate performance under a broad range of plausible future stressors, include climate change. The models were stress tested with graduated combinations of incrementally more stressful inputs to identify combinations of stressors and shocks that would lead to failure. Inputs that caused failures were further investigated. The MCC's stress tests revealed what is likely to be the primary source of performance failures under future conditions: the system's capacity to deliver enough power to transport and treat water.

  In addition to isolating the most likely cause of system failure, the stress tests allow planners to make a level-of-concern (LOC) analysis of the future state of the system and the risk of chronic failure. They can then determine if a baseline investment is sufficient or whether additional, incremental investments will be necessary. For the IWTP, the LOC analysis resulted in a high risk rating due to the plant's long history of catastrophic performance failures and the strong link between aridity (higher temperature or lower precipitation) and system failure. But the analysis was far from certain. Data were poor in quality (only four years of streamflow and meteorology data were available to calibrate systems models), unrepresentative (there were only two gauges for 60,000 square miles outside the basin), and simplistic (only a monthly empirical water balance was given for a region with high hydrologic variability). As a result, the MCC favored an incremental and adaptable strategy for providing resilient, reliable power to support plant operations.

- **Step 3—Plan formulation:** To formulate plans for incremental investment, the MCC created "plan bins" (Figure 2). Each bin was associated with a unique narrative about plan plausibility and an implied level of risk tolerance. Plan bins combined uncertain sources of future stress such as demographic shifts and climate change scenarios. The plausibility assigned to each bin was based on the risk assessment in the LOC analysis and on discussions among experts and local stakeholders and decision makers.

  In accordance with the acceptable reliability threshold, the bins for the IWTP included a cost-effective plan to ensure water supply reliability of 90%. Since every bin represents an incrementally more stressful future, the plan of action for each bin is correspondingly more robust or adaptable. For the IWTP, three plans were considered: (1) creation of a dedicated power source from the Kafue hydropower station; (2) installation of additional water storage through enhancement of existing reservoir capacity and construction of additional storage tanks in Lusaka; and (3) provision of power generation capacity to supplement losses in hydropower during periods of extreme drought. For the IWTP, the most cost-effective and practical option was the installation of a power generator to supplement shortfalls from the Kafue hydropower station.
- **Step 4—Plan selection:** While we know the planet is growing hotter, it is not possible to confidently assign probabilities to the precise climatic conditions that will result from climate change. As a result, it is difficult to clearly establish the benefits and costs of any single risk mitigation effort. To cope with this limitation, the MCC used a semi-quantitative incremental cost and benefit assessment (ICA) for plan selection decisions. The use of ICA allows all parties to examine the added costs associated with each incrementally more stressful planning bin (see Figure 2). This provides a pragmatic risk-informed framework to evaluate the incremental costs of added robustness.

  Using this method, the MCC's study determined that a 1,400 kW generator would be a cost-effective investment to enhance the resilience of the power supply to the IWTP. The study also considered a 2,100 kW generator. But while the larger generator would produce more power for the plant, the increase in avoided losses of water service would not ultimately offset the generator's higher cost.

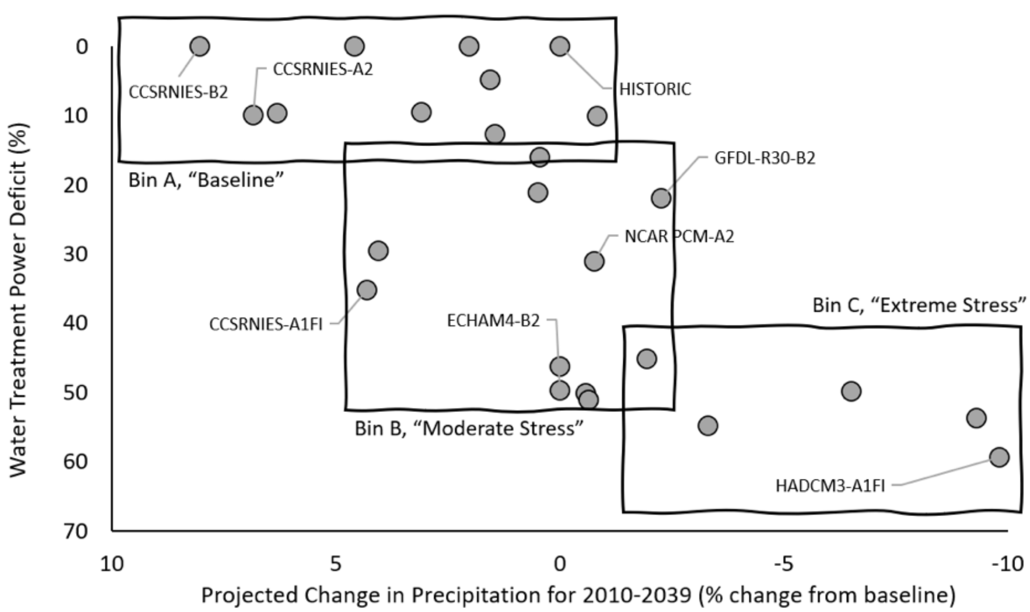

Figure 2. Average power deficits for water treatment as a percentage reduction relative to the baseline versus projected annual precipitation reduction. Power deficits are based on meeting water demand during critical dry months with a 90% reliability. The loss in performance is simulated by changing the historical input hydrology to more stressful conditions. A hydrology system model (in Excel) is stressed by changing the streamflow time series into the Itezhi-Tezhi and Kafue reservoirs. Reductions in seasonal rainfall totals, increases in temperature, or higher rainfall variability lead to lower streamflow (or longer drought periods), lower potential for hydropower generation, and deficits in the energy required for water treatment. Each of the 24 dots represents a synthetic 50-year streamflow time series that is developed by reorganizing and modifying existing hydrology data ("bootstrap" method) based on the seasonal temperature and precipitation shifts of IPCC GCM projections with the CO2 emission scenarios they represent (a select few are labeled). The most cost-effective and feasible plan is formulated for each of the "planning bins": A (baseline), B (moderate), and C (extreme). Each plan must ensure that the design performance is achieved despite the increased stress in their bin. The number of planning bins results from a collaborative process with decision makers and can contain different combinations of stressors—both climatic (such as rainfall variability or drought persistence) and nonclimatic (such as maintenance and labor force disruptions)—that lead to chronic failed performance.

- **Step 5—Institutionalizing the resilience plan:** Decisions are usually dominated by political, social, and institutional considerations. In this case, owing to other financial priorities, full funding could not immediately be identified, and options for future adaptation had to be available in the short term because of poor institutional capacity to adapt. In the case of the IWTP, it was not possible to immediately finance a 1,400 kW generator. It was, however, possible in the near term to justify a generator housing at an added cost of $20,000 to provide adaptive capacity for a 1,400 KW generator. The ICA approach also provides a framework to institutionalize finance. Each increment for robustness can be financed by a different source.

Low-income countries need support to develop more resilient water management systems in the face of climate change. Even where the will to solve these problems exists, however, thorny strategic challenges remain. Planners are often short on time, low on cash, and working with weak data. Additionally, the staggering range of possible scenarios makes evaluating the fitness of a given plan extremely difficult. The MCC used the CRIDA approach to clear away the fog of uncertainty, assess the relevant risks, and develop an effective resiliency plan for the IWTP—all despite poor data and a short time frame. ■

Acknowledgments: The authors of this paper would like to acknowledge the broader team working on the MCC's project: Jennifer M. Olszewski (USACE-ERDC), Chipili Chikamba (MPCA-Zambia), and Jessica Lawson (independent consultant).

Guillermo Mendoza (Guillermo.F.Mendoza@usace.army.mil) is international program manager for the U.S. Army Corps of Engineers Institute for Water Resources. He is the lead author of the book *Climate Risk Informed Decision Analysis: Collaborative Water Resources Planning for an Uncertain Future*, published by IHP.

John Kucharski (John.R.Kucharski@usace.army.mil) is an economist and senior researcher at the U.S. Army Corps of Engineers' Engineer Research and Development Center's Environmental Laboratory. His work focuses on system dynamics and decision support under uncertainty.

Marc Tkach (tkachm@mcc.gov) is a director of infrastructure and integrated program management at the Millennium Challenge Corporation. He received his master's degree from the University of Cambridge for research on how practitioners make sense of sustainability during upstream infrastructure planning.