Technical Annex

Tanzania Mara River Basin: Scenarios of the future

November 2019

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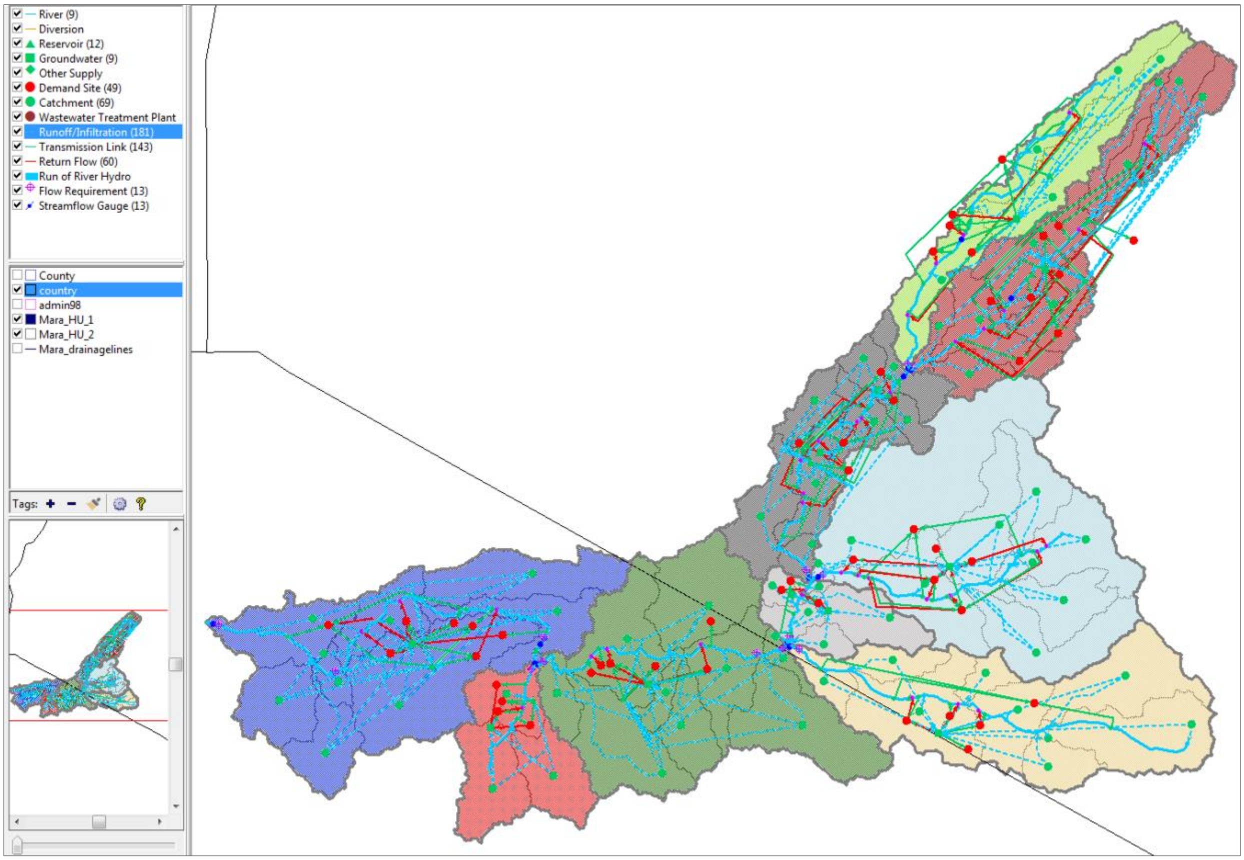


1. INTRODUCTION

Effective water planning requires an understanding of current water demands and supplies, as well as a recognition of the uncertainties around both in the future. For example, on the supply side, climate change can affect both the wet and dry seasons, the frequency and duration of extreme events, and the water requirements with higher temperatures. On the demand side, there can be demographic, economic and political shifts that can be quite unpredictable. The challenge is to find the best path forward with the current knowledge at hand, obtain data that are crucial to know better going forward, and take actions – both in the form of policy and infrastructure development – that ensure the highest level of water security that is equitable and sustainable.

1.1. THEORY AND DEVELOPMENT OF RDS WORKSHOPS

Together with its partners at SWP, the Stockholm Environment Institute facilitated several robust decision support (RDS) workshops with stakeholders. The key components of the RDS problem formulation are based on the RAND Corporation's robust decision making (RDM) framework. RDM is based on the recognition that conditions of deep uncertainty often confront decision-makers, with one particularly salient example being the uncertainty related to future climate change. When the ability to confidently define the prior probabilities of future conditions breaks down, the utility of traditional risk-assessment techniques erodes. In some respects, RDM is a variant of traditional scenario analysis, where a set of narrative futures are articulated in order to bracket possible outcomes. The difference is that RDM scenarios are not constructed to define the limits of future outcomes. Rather, they are constructed to populate a full representation of the future outcome space, and to explore the implications of specific decisions across this full spectrum of possible future conditions. Actions that perform well with respect to this full spectrum are deemed to be robust.

The search for robust decisions is initiated through the application of the XLRM problem formulation framework. XLRM divides a problem into three distinct components: X, the plausible exogenous factors, or uncertainties, which exist outside the control of decision-makers, yet have the potential to impact outcomes; L, the levers, or management actions, that can be taken in the attempt to improve outcomes; and M, the metrics of performance used to evaluate outcomes from specific actions in the face of plausible futures across a diverse set of management objectives. The final component of the tool, R, corresponds to models developed to define the relationships between uncertainties and actions in order to generate estimates for important metrics. Application of the XLRM framework yields an experimental design whereby model runs, R, cover the full combination of future conditions defined by X for each member of the management action list, L, to produce values, M, for the key performance metrics: X, L, R M.

1.2. USAID MAY 2019 "VULNERABILITY AND ADAPTATION IN THE MARA RIVER BASIN" TECHNICAL REPORT

In May 2019, USAID published its technical report, "Vulnerability and Adaptation in the Mara River Basin." The report analyzed vulnerability in the Mara River Basin within three separate categories:

1. Exposure, indicated by trends in rainfall and temperature and extreme events across the basin.
2. Sensitivity, indicated by population density, livestock and wildlife dynamics, and land-use changes.
3. Future risk, indicated by projected temperature rise and projected change in rainfall by 2030 and 2050.

The report found that temperature had risen 1-1.5°C from 1960 to 2014 and predicted that average temperature would increase by 0.7-1.97°C by 2030 and by 1.5-2.71°C by 2050. It also predicted that the duration of heat waves would increase significantly during this period. Average annual rainfall had not changed significantly since 1960, but the intensity of rains had increased and their frequency had become less predictable. The report predicted that in the future, the basin would experience increased rainfall variability and a further increase in the intensity of heavy rainfall events. In addition to temperature and rainfall changes, the report noted that the Mara River Basin faced additional pressures that made it more sensitive to climate change. Among these, population dynamics, land-use change, deforestation, the conversion of shrublands and woodlands for grazing, increasing swampland, and increases in land allocated for settlements were all significant challenges for the basin.

To address these issues, the report made three key recommendations:

1. Strengthen governance and institutions.
2. Improve access to information.
3. Pilot interventions.

The SWP activity in the Mara is actively implementing the three key recommendations, which are incorporated to the extent possible in the scenarios described below.

2. RDS WORKSHOPS IN THE MARA RIVER BASIN

SEI has held RDS workshops in Tanzania in an effort to understand the goals for the basin in terms of water management, the uncertainties water managers and stakeholders face (X), the actions they take to mitigate that uncertainty and meet their goals (L), and the ways in which they measure whether or not they are achieving their goals (M). Additionally, the workshops aimed to familiarize attendees with WEAP, the software used to develop the MRB model, and the model itself. By having water managers participate in hands-on WEAP trainings with the MRB model, they both gain a better understanding of how the model can be useful to them, and also provide feedback for how the model can best represent their basin and water use within it. In August 2018, key stakeholders met in Mwanza, Tanzania to define the scope of the analysis towards integrated solutions for sustainable water resources planning on the Tanzanian side of the Mara River Basin in Tanzania. This workshop provided great insight into the demands, opportunities, and constraints of the water system in the basin.

As part of the RDS process, the main goal of the August 2018 workshop was to solicit input from key actor groups – experts, resource managers, policy-makers, and stakeholders involved in the governance of the MRB – to define the scope of the analysis towards integrated solutions for sustainable water resources planning in the MRB in Tanzania. The stakeholders' feedback provided guidance to experts from SEI for refining the hydrological model of the Tanzanian side of the MRB to better reflect the policies and uncertainties most relevant to those in the region.

In July 2019, SWP members met with stakeholders in Mwanza again, this time to present updates and outputs from the re-formulated MRB WEAP model, which has been revised since the previous workshop in 2018 to reflect key stakeholder concerns. SWP members built on the capacity development started in the previous workshop, so that stakeholders continued to gain understanding of the model and changes that had been implemented since the previous workshop. They then reviewed model outputs that demonstrated the current and future levels of water security in the basin on the Tanzania side, given the key uncertainties identified in the problem formulation workshop held in 2018. The main goal of this workshop was to obtain a shared understanding of the function of the WEAP model and why it is useful to evaluate future scenarios. Participants also sought to refine the analysis so that it addresses the issues the stakeholders face in achieving water security in the Mara on the Tanzanian side.

2.1. INITIAL XLRM

During the August 2018 RDS workshop in Mwanza, stakeholders developed an XLRM framework for the Tanzanian side of the Mara River Basin. This process began by identifying a shared vision of goals for the basin and indicators by which to measure progress towards them. Next, workshop participants considered the critical uncertainties facing the basin. Finally, stakeholders agreed upon strategies that could be used to increase resilience in the MRB.

2.1.1. GOALS FOR THE MARA RIVER BASIN AND ASSOCIATED METRICS (M)

To begin the process of developing an XLRM for the Tanzanian side of the MRB, the workshop participants were divided into three groups. These groups represented (1) the Lake Victoria Basin Water Board, (2) local and national government organizations, and (3) institutional partners, development agencies, scientific research agencies, and non-government organizations. Within these groups, participants were asked two questions:

1. What signifies success for you (as a stakeholder or agency) in terms of water and related uses? e.g. meeting urban, agricultural, energy, or ecological demands.
2. What additional definitions of success would you like to see added? e.g. effective stakeholder engagement, access to water and sanitation.

After considering these questions and proposing possible answers within groups, stakeholders were then asked to identify indicators or metrics for measuring the success or failure of achieving the goals. The three groups presented their goals and metrics to the room and together decided upon a joint vision to use moving forward. Below is a list of the four key goals agreed upon by stakeholders, along with each goal's respective indicators. For each group's complete list, refer to Appendix A: Raw inputs from the visioning process: goals and indicators.

   a. Water quality.
   b. Water quantity.
   c. Biodiversity.
   d. Wetland extent.
   e. Forest area.

2. Equitable water use across the basin
   a. Functioning MRB secretariat and harmonization of WAPs.

3. Achieve water-related development potential
   a. Sustainable livelihoods.

b. Increased incomes and alternative livelihoods.
c. Reduced negative impacts on water quantity and quality.
d. Safe drinking water and sanitation.
e. Limited unmet demands.

4. Resilience to climate change and variability (floods and droughts)
    a. Reduction in flood- and drought-related damage.

2.1.1. CRITICAL UNCERTAINTIES FOR THE MARA RIVER BASIN (X)

After developing their shared vision of goals for the MRB, the stakeholders were divided into three new groups, this time to consider the critical uncertainties facing the basin. Within these groups, participants were asked the question:

- What are key uncertainties that are outside of your control, that can affect your ability to meet your goals and/or mandate?

Each group proposed possible answers to this question and then was asked to assign these answers into three quadrants of an impact-uncertainty matrix, as shown in Figure 1 below. To see each group's list of impacts and uncertainties, refer to Appendix B: Raw Input on critical uncertainties.

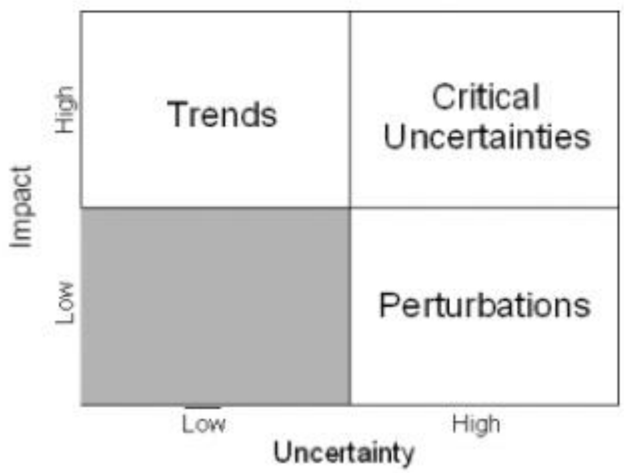


Figure 1. Impact-uncertainty matrix.

After completing this task, the workshop participants discussed together which of the suggested uncertainties they wanted to prioritize. They knew that their choices would be included in the quantitative models that the SWP team would develop for the basin. The group selected three critical uncertainties to carry forward in the quantitative scenarios:

- Climate change.
- Land-use change.
- Ecological change.
- Upstream development.

2.1.1. STRATEGIES TO INCREASE RESILIENCE IN THE MARA RIVER BASIN (L) AND THE XLRM MATRIX

For their final break-out sessions, stakeholders remained in their groups and were asked to respond to the question:

- What are the projects/strategies or infrastructure that you or your agency could implement to improve water-related goals the group defined given the critical uncertainties?

Each group created a list of five to eight strategies per goal, which was then shared with the larger group. The participants were then assigned to four new groups. Each group was asked to summarize the strategies proposed for the goal that it was assigned. For each group's complete list of uncertainties, refer to Appendix C: Raw Input on strategies/levers.

The final result of the workshop is a formal XLRM matrix, as noted below.

X: Uncertainties	**L: Management strategies (levers)**
• Climate change and variability • Land-use change • Ecological change • Upstream development	• Climate smart agriculture • Integrated land-use plans • Promotion of alternative water sources (rainfed, reuse & GW) • Promote communications, education, participation and awareness on adaptation and WASH • Introduce alternative livelihoods • Implementation of CIP • Improve water efficiency • Implement joint TZ-KE projects and monitoring • Ecosystem flows and restoration • Establish MRB Secretariat, with financing capacity • Basin wide WAP in place • Establish early warning systems for floods and droughts
R: Relationships (models)	**M: Performance metrics**
• WEAP for the Mara	• Heathy ecosystems • Equitable water use across the basin • Achieve water-related development potential • Resilience to climate change

3. SCENARIO DEVELOPMENT

During the initial workshops in Tanzania, stakeholders identified uncertainties that may hinder their ability to achieve their water management goals, and strategies they may use to meet those goals. These uncertainties and strategies were combined and included in the model to develop three scenarios. These scenarios were then tested against the performance metrics outlined by participants to determine how well the strategies performed under the various uncertainties. The representation of each uncertainty and each strategy in the model is described below, as well as the data and assumptions used to develop their representation.

3.1. UNCERTAINTIES/TRENDS

Uncertainties, as described in section 2.1.1, are occurrences and issues that water managers cannot control, but that may heavily impact their ability to meet their water management goals. In previous workshops participants discussed the uncertainties they face as water managers, and their representation in the model and scenarios is described below. As described in section 2.1.1, not all future occurrences that affect water managers are highly uncertain, but they still can have major impacts on water management. These we call trends. The one trend considered in the scenarios is also described in detail below.

3.1.1. CLIMATE CHANGE

Climate change is an uncertainty faced globally. Exactly how weather patterns and seasons will change is largely unknown, but global climate models can provide information to help plan for a wide range of plausible patterns. The WEAP Mara model includes 20 climate change projections derived from the IPCC fifth assessment report (AR5), which considered various representative concentration pathways (RCPs) for greenhouse gas emissions. The WEAP model uses climate projections downscaled from ten global climate models (GCMs). These GCMs were run for RCP 4.5, which assumes greenhouse gas emissions peak around 2040 and then decline, and for RCP 8.5, which assumes emissions continue to rise throughout the 21st century. In the downscaling process, time series of temperature and precipitation from global climate models are scaled to local historical temperature and precipitation data to develop projected time series that are locally relevant to the Mara River Basin.

Figure 2 shows the average precipitation and temperature for the 20 climate projections, based on RCP 4.5 and RCP 8.5, out to 2028 and 2038. When compared with historical, it is evident that, on average, all projections indicate warmer temperatures, but there is a range of wetter and drier futures. The projections range in terms of seasonality. Many indicate a wetter long wet period, while others indicate the opposite out to 2028 (Figure 3). Out to 2038, however, most projections show a wetter peak in April. Still, there is a range in the dry periods whether they will be wetter or drier in the future (Figure 3).

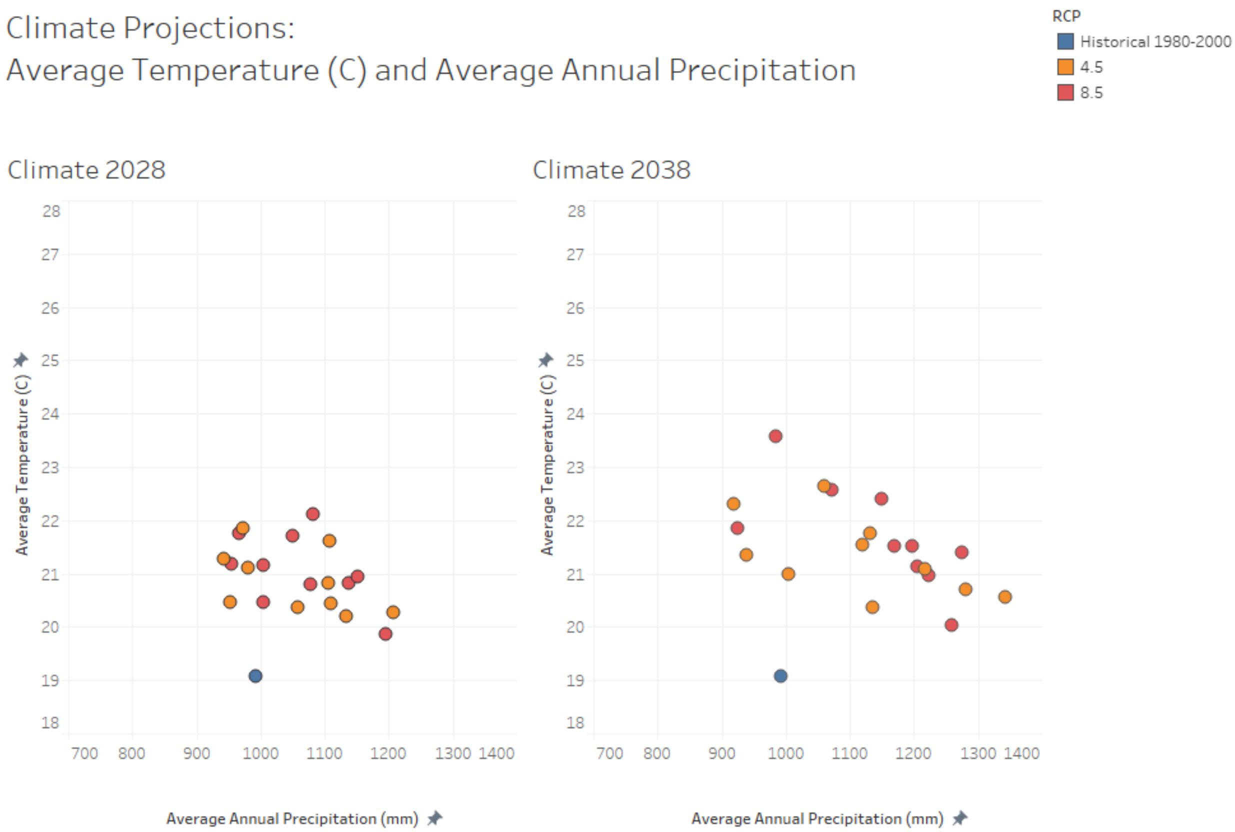


Figure 2. Average temperature and precipitation for climate projections used in this analysis. The left graph shows one point per climate projection, average temperature and precipitation to 2028. The graph to the right shows the same in 2038. Both compare with historical average climate (blue point).

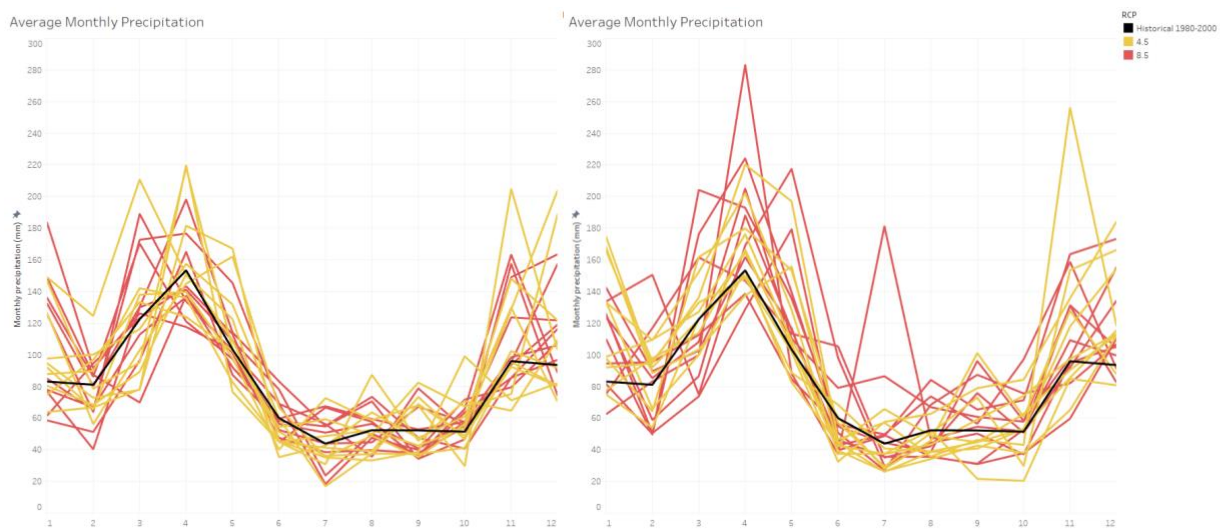


Figure 3. Average Monthly Precipitation across all climate projections used in this analysis. The left graph shows average monthly precipitation out to 2028 and the right shows out to 2038.

3.1.1. UPSTREAM DEVELOPMENT IN KENYA

As Tanzania is the downstream user in a transboundary watershed, upstream development and water use in Kenya is something that is out of the control of Tanzania, but does impact water availability. Although agricultural development and inter-basin transfers in Kenya may not be built in the future, these hypothetical situations are included in the model so that Tanzania can assess what the effects of upstream development might be on their water supply, to allow them to better plan. Agricultural expansion in Kenya in the model includes 1,600 hectares of agriculture (average demand of 850 m^3/ha) taking water from the Nyangores River. It also includes 2,170 ha of agriculture (average demand of 6,258 m^3/ha) and an inter-basin transfer of 2.6 m^3/s, both taking water from the Amala River. It is assumed that with new upstream development in Kenya, Kenya will also enforce the reserve so that demands will not abstract water from the river when it is in the reserve.

3.1.1. SOCIO-ECONOMIC GROWTH

Increases in population and water demand are trends that, while somewhat uncertain, are more predictable based on historical information than, for example, climate change or upstream development. However predictable, socio-economic growth is a consideration that water managers do need to plan for. Socio-economic growth is included in the model by applying a growth rate to demands into the future. Growth rates were defined by the previous work of MaMaSe through a Demand Assessment of the Tanzania side of the MRB. The rates are shown in Table 1 below. [1]

Table 1. Growth rates for each demand category used to represent socio-economic growth in future scenarios. Data are sourced from the Demand Assessment for Tanzania conducted under the MaMaSe Project, with the exception of "Other", which had no growth rate included in the assessment. A base rate of 1.1 was instead assumed for "Other."

Demand category	Growth Rate
Domestic	Mara HU: 2.6 Somoche HU: 3.1 Serengeti HU: 3.1
Agriculture	Mara HU: 2.6 Somoche HU: 3.1 Serengeti HU: 3.1
Livestock	2.0
Wildlife	Assumed population stays constant
Mining	For Mara mine: no projected growth For artisanal mines: 12.3
Tourism	3.2
Other	1.1

[1] More information about the incorporation of previously developed reports and information into model development can be found within the Mara River Basin Model Documentation.

3.2. STRATEGIES

While uncertainties are a major concern for water managers, they have the ability to implement strategies to mitigate those uncertainties to help meet their goals. Two key strategies that were suggested in the RDS workshops are described below: enforcing the reserve and new irrigation development. The description includes how they are implemented in the model.

3.2.1. ENFORCE RESTRICTIONS ON LIMITING WATER EXTRACTION WHEN IN THE RESERVE

The reserve has two components: water for river functioning (aquatic habitat, river health, geomorphic processes such as erosion and deposition, etc.), and water for basic human needs (25L/person/day). Water for other uses should not be withdrawn from the river when it is in the reserve. However, this can be quite challenging to implement and enforce. On the Tanzania side of the basin, an environmental flow assessment was conducted to develop a detailed understanding of the streamflow requirements for aquatic habitat and geomorphologic functions of the river. These requirements are included in the model on the Mara River at Kogatende, just downstream of the Kenya/Tanzania border; at the Mara Mines; and downstream at Bisarwi. The requirements are also included on the Somoche River where it flows into the Mara (Figure 4). In the model, this requirement is set to the monthly streamflow value associated with the maintenance flow values in the environmental flow assessment. These requirements are not entirely the reserve. They do not include 25L/person/day, because this requirement is included separately in the domestic demand nodes in the model. This, however, is a good representation of the water needed, particularly during low flow periods, to ensure river health. Basic human needs are very small compared to this value. This will be referred to as the reserve threshold, or the flow at which the river changes from normal flows to being in the reserve. In the historical and baseline situations, it is assumed that the reserve is not enforced as is true currently, so even when the river is in the reserve at these locations (flows in the river are at or below the threshold), demands can still take all the water they need from the rivers. However, when this enforcement strategy is implemented, only domestic and wildlife demands can take water from the river when the river is in the reserve.

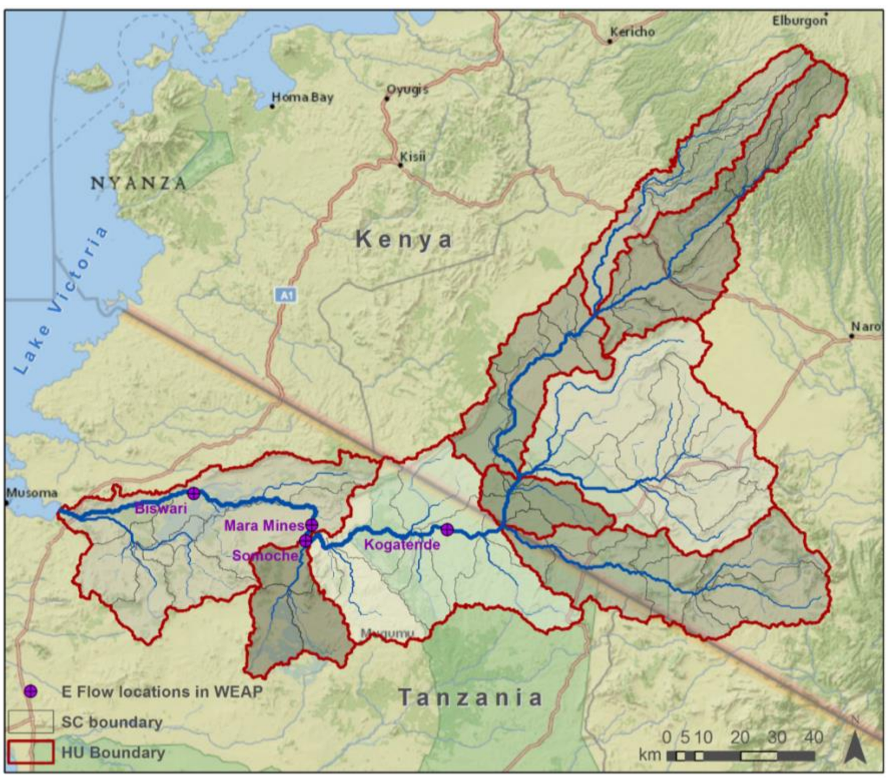


Figure 4. Map of flow requirement locations in Tanzania.

3.2.2 EXPANDED IRRIGATION IN TANZANIA

Two potential irrigation projects are included in the model as strategies in Tanzania: the Mara Valley Project and Nyamitita Irrigation Scheme. Details for these two projects were collected from the Tanzania Water Demand Assessment and are shown in Table 2. It is assumed that Command Area 1 of the Mara Valley Project is developed by 2028, and the rest by 2038. It is assumed the entire Nyamitita Irrigation scheme is developed by 2023. In the WEAP model, the Nyamitita Irrigation Scheme takes water from the Somoche River. The Mara Valley Project takes water from the Mara River.

Month	Mara Valley Project			Nyamitita Irrigation Scheme (92.9 ha)	
	Command Area 1 Demands (1,314 ha) (m^3/day)	All Command Areas Demand (6,903 ha) (m^3/day)	Total Demand (m^3)	Demand (m^3/day)	Total Demand (m^3)
January	127,063	667,008	20,677,248	8,977	278,287
February	91,824	482,026	13,496,728	6,487	181,636
March	54,101	283,997	8,803,907	3,822	118,482
April	20,442	107,309	3,219,270	1,444	43,320
May	72,732	381,802	11,835,862	5,138	159,278
June	88,352	463,795	13,913,850	6,242	187,260
July	81,719	428,976	13,298,256	5,773	178,963
August	161,791	849,312	26,328,672	11,430	354,330
September	104,794	550,109	16,503,270	7,403	222,090
October	115,377	605,664	18,775,584	8,151	252,681
November	91,133	478,397	14,351,910	6,438	193,140
December	126,997	666,662	20,666,522	8,972	278,132

Table 2. Mara Valley Project and Nyamitita Irrigation Scheme projected demands. Sourced from the Tanzania Water Demand Assessment.

3.3. SCENARIOS

The various trends, uncertainties, and strategies were combined to develop three scenarios, which were simulated under the 20 climate projections. A comparison of these three scenarios is shown in Table 3. Because the three scenarios are simulated with 20 climate projections, there are a total of 60 unique sets of results. There are 20 per scenario, incorporating each of the climate projections. All scenarios were simulated from 2020 to 2050.

Baseline	**Reserve Enforced**	**Upstream Devel**
Socio economic growth + Expanded irrigation in TZ	Baseline + Reserve Enforced in TZ	Baseline + Expanded Agriculture in KE + Reserve Enforced in KE + Reserve Enforced in TZ
20 Climate Projections		

Table 3. Table depicting the scenarios assessed in this analysis. Names of each scenario are listed at the top in bold.

4. PERFORMANCE METRICS

Participants identified four performance metric categories that represent their water management goals: heathy ecosystems, equitable water use across the basin, water-related development potential, and resilience to climate change. Specific results in WEAP have been assessed to determine whether the strategies are achieving these intended outcomes in the future scenarios. These results are largely divided between assessing the reserve, and meeting the demands. These are listed below.

Assessment of the reserve

- Annual and monthly average streamflows at the border and at Musoma.
- Monthly streamflows at three key locations: Kogatende, Mara Mines, and Biswari; compared to the requirement at the respective locations.
- Duration of months the river at each key location is in the reserve.

Note that an assessment of the reserve for Somoche is not included, as there are no data to calibrate the stream flows. This is a critical point, as the water allocation plan will attempt to set reserves for all three tributaries within Tanzania. Without data to calibrate against, however, the modeled flows are not sufficiently robust to use in assessing the reserve.

Assessment of demands

- Annual water demands
- Annual deliveries to demands
- Annual coverage of demands (percent of the demand satisfied)
- Annual unmet demands
- Annual groundwater overdraft

5. MODEL RESULTS

The Mara River WEAP model was run for the three scenarios summarized in the previous section. Every scenario was assessed based on the performance metrics described above. Selected examples of the visualization of scenario performance based on these metrics are presented below for individual model runs. These metrics are also presented as vulnerability maps. The maps present results from all 60 scenarios together. They indicate the extent to which streamflow and water delivery targets were met for defined periods, such as 2020-2025, 2026-2030, 2031-2040, and 2041-2050.

5.1. ASSESSMENT OF THE RESERVE

Annual and monthly average flows in the Mara River at the border are presented for the three scenarios for the historical climate (1970-2005) in Figure 5. These results indicate the extent to which flows at the border could be expected to decrease as a result of upstream developments in Kenya. For this particular example, the average decrease in flow is roughly 50 million cubic meters per year, which equates to about a ten percent reduction of flows as compared to scenarios without any additional upstream development. Figure 5 shows the results for one climate sequence, but a reduction in flows is seen across all climate projections in scenarios with upstream development in Kenya. Monthly average flow decreases are notable, particularly after April.

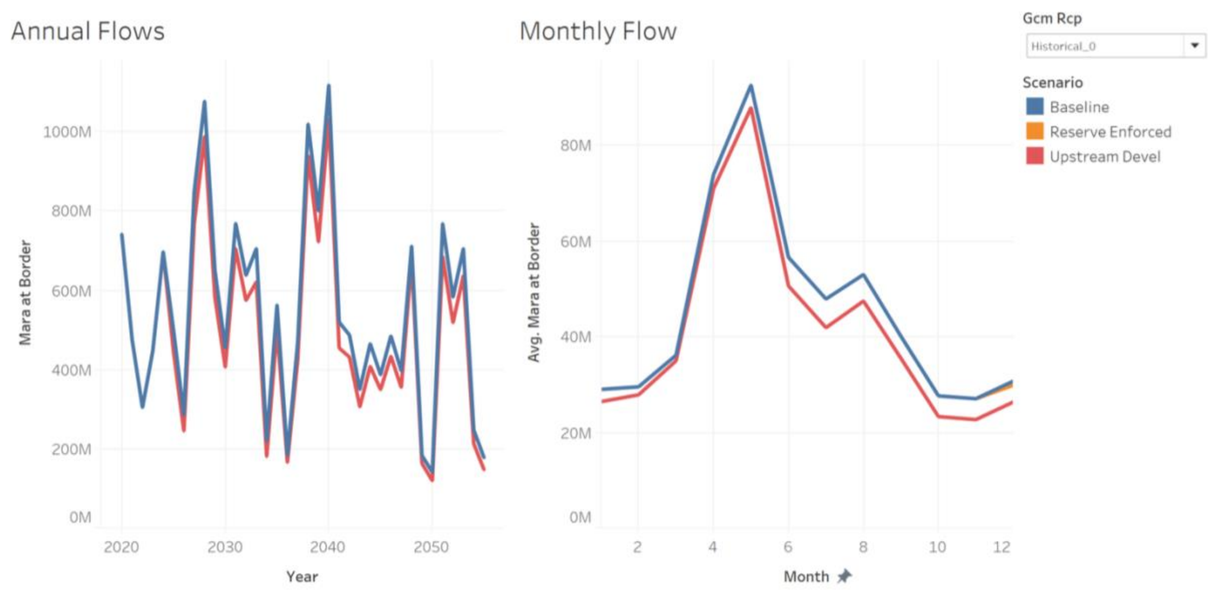
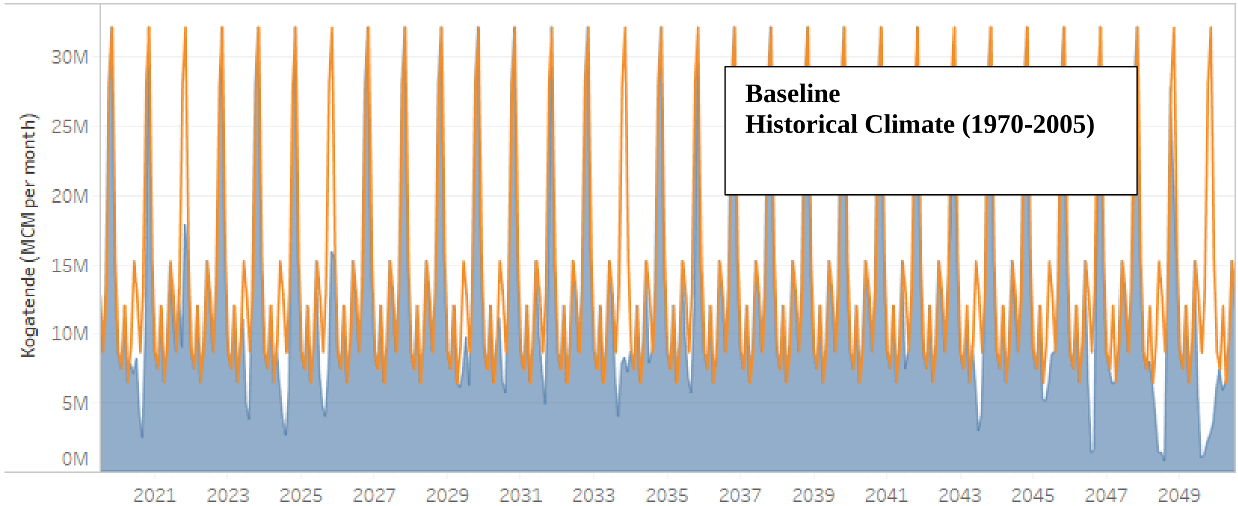


Figure 5. Mara River flows at the Border of Kenya and Tanzania.

Modeled flows and the reserve threshold in the Mara River at Kogatende are presented for the baseline scenario with and without upstream development in Figure 9. The orange line is the reserve threshold, and the blue solid area is the modeled flow in the river. Where there are white spaces between the two, the river is in the reserve. This graph shows how the reduction in inflows from Kenya may affect the number of months and the degree to which the river is in the reserve. In general, the results suggest that the overall decrease in total flow at the border (Figure 5) does not lead to increased incidence of months where the river is in the reserve. In fact, if the upstream developments are accompanied by a prioritization of reserve flows in Kenya, as they were in these scenarios, it may help to alleviate the frequency and prominence of the gaps between the reserve threshold and actual flows. It will be important to determine at what point the extent the river is in the reserve is such that the river cannot recover.



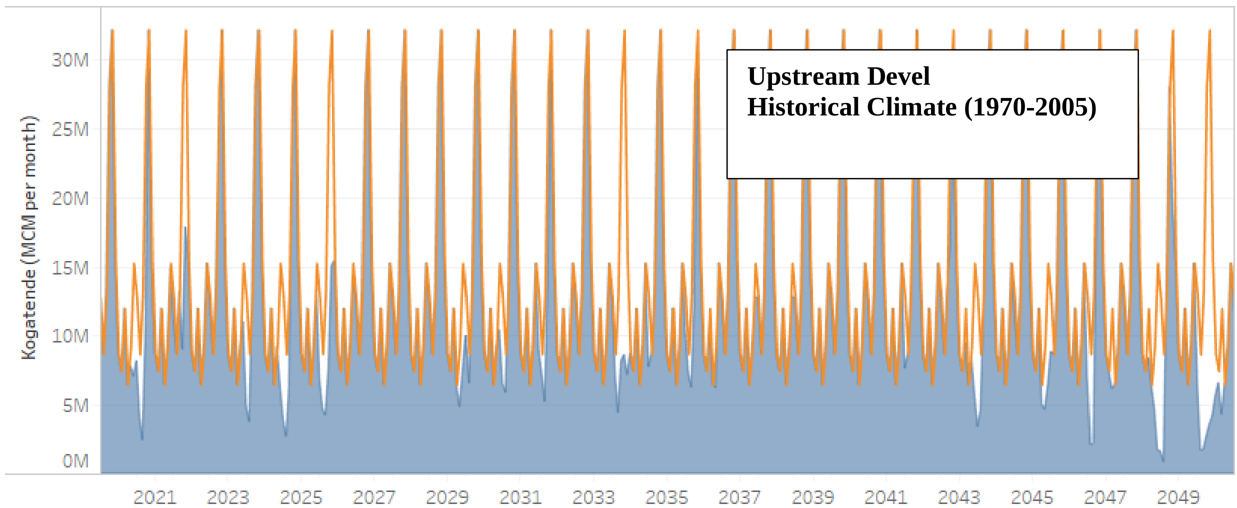


Figure 6. Reserve threshold and modeled flows at Kogatende (2020-2050).

To investigate this further, the duration of time the river is in the reserve can be a useful metric. Figure 7 shows the number of consecutive months the Mara River is in the reserve at the three key locations. Only very minor changes are seen when comparing the Baseline scenario (left set of graphs) and the scenario that includes upstream development in Kenya (right set of graphs). This is because it was assumed in this scenario that with new development in Kenya, the reserve in Kenya will also be enforced.

Figure 7. Number of consecutive months that the river is in the reserve, at each of the three key locations. The set of graphs on the left shows results for the Baseline scenario. The graphic on the right show for Upstream Development in Kenya. Both are run with the historical climate (1970 – 2005).

It can be challenging to digest and compare information from 20 climate scenarios, because the results thus far have only been presented for the historical climate. Figure 10 presents a vulnerability map for the reserve that compares the percentage of years in which the river is in the reserve for three consecutive months or more. The map makes this comparison across all scenarios at the three key locations on the Mara River (Kogatende, Mara Mines, and Bisarwi) and across all climate projections. Each column represents one scenario for each of the three key locations, and each row represents one projection.

The greater the percentage of years that the river is in the reserve, the more red the cell is. The map on the top shows the percentage of years between 2020-2030 in which the river is in the reserve at those three locations for three consecutive months or more. The bottom map shows this percentage for the period of 2041-2050. Considerable variability across climate projections is evident in each map (range of results within one column, across all rows). Comparing the maps from top to bottom, almost all climate scenarios indicate an increase in the percentage of years with at least three consecutive months in the reserve. This is to say that it is likely the river will spend more time in the reserve over time due to climate change and increasing demands on water resources.

Upstream development in Kenya would further increase the likelihood of long periods where the river is in the reserve. On the other hand, enforcing the reserve does not have a noticeable effect on decreasing periods where the river is in the reserve, nor does pursuing the expansion of irrigation. Enforcing the reserve does not generally affect the ability to meet demands due to the fact that, during these times, the demands are quite small relative to the volume of water required to keep the river out of the reserve.

Num.Fail Months: 3

Time Segments: ☑ 2020-2025 ☑ 2026-2030 ☐ 2031-2040 ☐ 2041-2050

0.000 – 1.000

	Kogatende			Mara Mines			Bisarwi		
	Baseline	Reserve Enforced	Upstream Devel	Baseline	Reserve Enforced	Upstream Devel	Baseline	Reserve Enforced	Upstream Devel
BCC-CSM1-1_4.5	9%	9%	18%	18%	18%	27%	9%	9%	18%
BCC-CSM1-1_8.5	9%	9%	18%	18%	18%	18%	9%	9%	18%
CanESM2_4.5	27%	27%	27%	27%	27%	27%	18%	18%	27%
CanESM2_8.5	9%	9%	9%	9%	9%	18%	9%	9%	9%
CNRM-CM5_4.5	45%	45%	45%	73%	64%	73%	36%	36%	45%
CNRM-CM5_8.5	27%	27%	27%	27%	27%	27%	27%	27%	27%
CSIRO-MK3-6-0_4.5	36%	36%	45%	45%	45%	45%	45%	45%	45%
CSIRO-MK3-6-0_8.5	27%	27%	27%	45%	45%	55%	36%	27%	36%
GISS-E2-H_4.5	45%	45%	55%	55%	55%	64%	45%	45%	55%
GISS-E2-H_8.5	64%	64%	73%	82%	82%	91%	55%	55%	64%
HadGEM2-ES_4.5	55%	55%	55%	73%	73%	82%	64%	55%	64%
HadGEM2-ES_8.5	27%	27%	36%	45%	45%	45%	27%	27%	36%
Historical_0	45%	45%	36%	45%	45%	45%	27%	27%	27%
MIROC-ESM_4.5	0%	0%	0%	0%	0%	9%	0%	0%	0%
MPI-ESM-LR_4.5	9%	9%	9%	9%	9%	9%	0%	0%	0%
MPI-ESM-LR_8.5	27%	27%	27%	27%	27%	27%	18%	18%	27%
MRI-CGCM3_4.5	36%	36%	36%	36%	36%	36%	36%	36%	36%
MRI-CGCM3_8.5	36%	36%	45%	55%	55%	55%	45%	45%	45%
NorESM1-M_4.5	45%	45%	45%	45%	45%	64%	45%	45%	45%
NorESM1-M_8.5	27%	27%	45%	64%	64%	73%	27%	27%	45%

Num.Fail Months: 3

Time Segments: ☐ 2020-2025 ☐ 2026-2030 ☐ 2031-2040 ☑ 2041-2050

0.000 – 1.000

	Kogatende			Mara Mines			Bisarwi		
	Baseline	Reserve Enforced	Upstream Devel	Baseline	Reserve Enforced	Upstream Devel	Baseline	Reserve Enforced	Upstream Devel
BCC-CSM1-1_4.5	44%	44%	50%	69%	69%	69%	38%	31%	44%
BCC-CSM1-1_8.5	50%	50%	50%	56%	50%	56%	50%	44%	56%
CanESM2_4.5	6%	6%	19%	19%	19%	19%	6%	6%	6%
CanESM2_8.5	6%	6%	6%	6%	6%	6%	6%	6%	6%
CNRM-CM5_4.5	6%	6%	6%	13%	13%	13%	13%	6%	13%
CNRM-CM5_8.5	44%	44%	44%	44%	44%	50%	38%	38%	38%
CSIRO-MK3-6-0_4.5	31%	31%	50%	63%	63%	75%	19%	19%	31%
CSIRO-MK3-6-0_8.5	38%	38%	50%	50%	50%	63%	31%	31%	38%
GISS-E2-H_4.5	81%	81%	81%	81%	81%	94%	63%	63%	69%
GISS-E2-H_8.5	75%	75%	75%	75%	75%	81%	75%	75%	75%
HadGEM2-ES_4.5	69%	69%	69%	75%	75%	75%	38%	38%	50%
HadGEM2-ES_8.5	44%	44%	50%	63%	56%	63%	38%	38%	38%
Historical_0	38%	38%	38%	50%	50%	56%	31%	31%	38%
MIROC-ESM_4.5	0%	0%	6%	6%	6%	19%	0%	0%	0%
MPI-ESM-LR_4.5	6%	6%	6%	6%	6%	6%	0%	0%	0%
MPI-ESM-LR_8.5	13%	13%	19%	19%	19%	31%	13%	6%	13%
MRI-CGCM3_4.5	31%	31%	31%	44%	44%	50%	25%	25%	25%
MRI-CGCM3_8.5	31%	31%	31%	31%	31%	38%	19%	19%	19%
NorESM1-M_4.5	56%	56%	56%	56%	56%	63%	38%	38%	44%
NorESM1-M_8.5	44%	44%	44%	56%	56%	63%	50%	50%	50%

Figure 8. Vulnerability of reserve flows in 2020-2030 (top) and 2040-2050 (bottom). Percentages indicate the percentage of years that will have a period of three or more months that the Mara River is in the reserve. The top label indicates the three key locations assessed along the river, with one column per scenario. Each row represents one climate projection. Assessment of demands

Annual water demands for the six water use types in Tanzania are presented in Figure 9 and

Table 4.

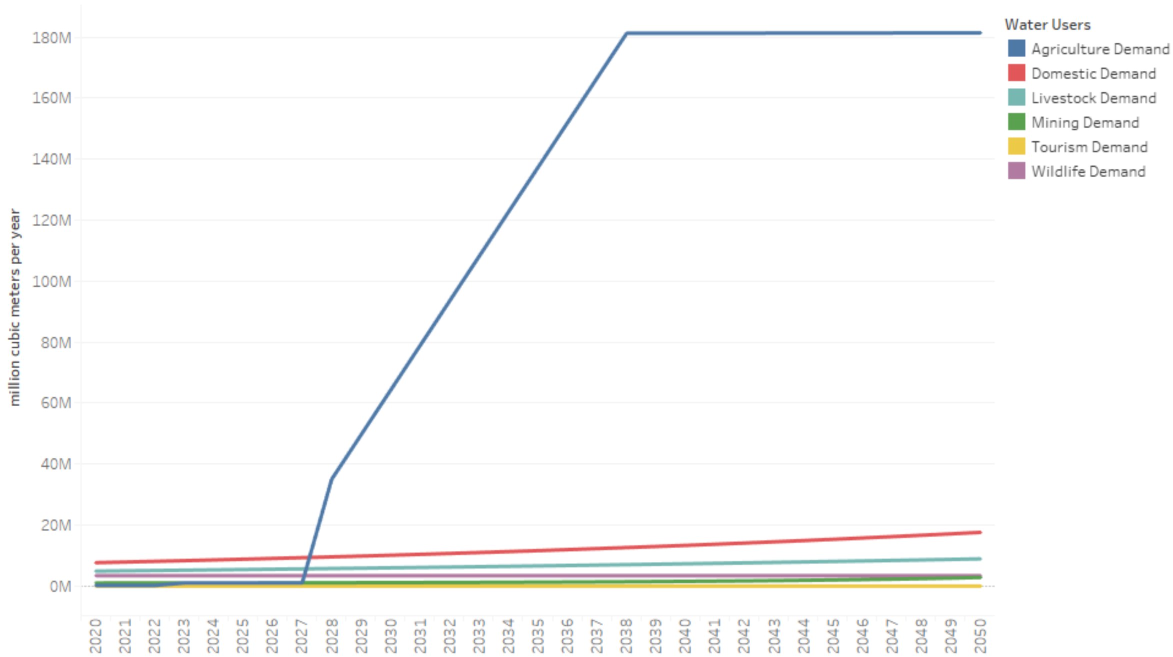


Figure 9. Annual water demands (2020-2050) – All demand types

	Annual Demand (MCM/year)		Percent Increase
	2020	2050	
Agriculture	0.239	181.443	75680%
Domestic	7.714	20.277	163%
Livestock	4.948	9.895	100%
Mining	1.065	4.344	308%
Tourism	0.024	0.073	201%
Wildlife	3.438	3.438	0%

Table 4. Annual demands in Tanzania in 2020 and 2050, as well as the percent increase in demands across those years.

Annual water demands and total deliveries were reviewed first for the historic climate to give perspective on the potential impacts of climate change.

For domestic demands, no significant variation in supply delivered is seen across scenarios. This is because domestic demands take water from multiple sources, including groundwater, which is largely unlimited as currently represented in the model. Deliveries to domestic demands also did not vary across climate projections, indicating that between the various water sources, there is sufficient water for domestic demands.

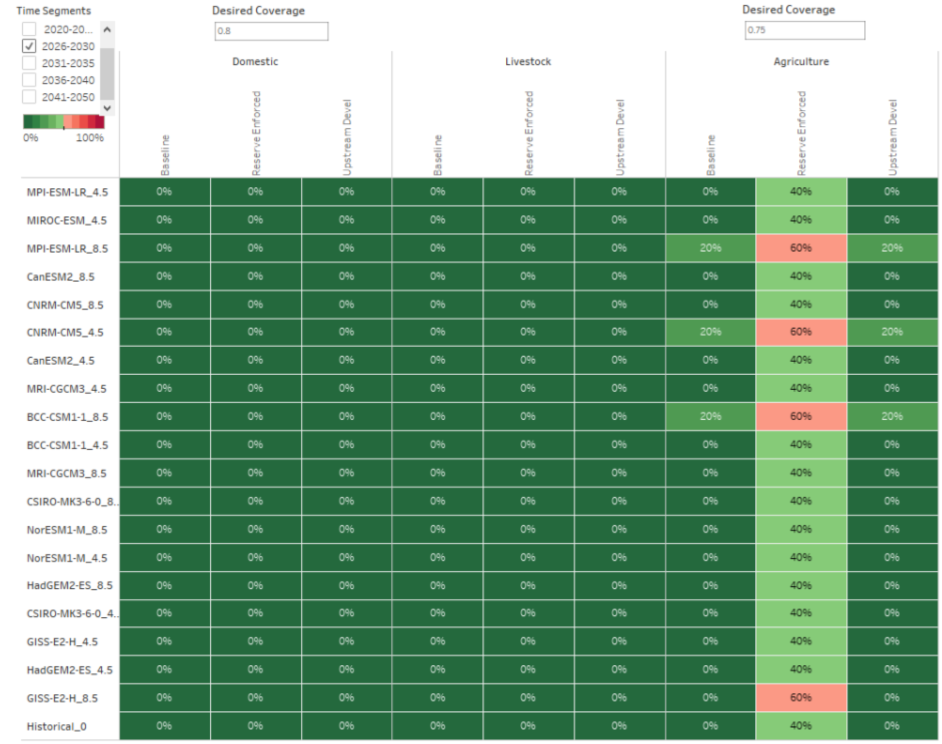
For livestock, demands are also largely met.

It is assumed that regardless of strategies, wildlife will always take water from the river and other available sources as needed. Because of this assumption, wildlife does not see significant shortages across scenarios.

Tourism and mining demands are also met across scenarios. This is because these demands draw water almost entirely from groundwater in the model, which is not limited at this time. Due to limited information on groundwater availability, demands that use groundwater are able to take as much water as needed. This assumption replicates users developing new wells as additional water is needed.

In scenarios where agriculture demands in Tanzania are increased due to expanded agriculture and irrigation, shortages are seen particularly in later years, where the water delivered does not meet the demands across many years. Seasonally, shortages are more evident from December to April.

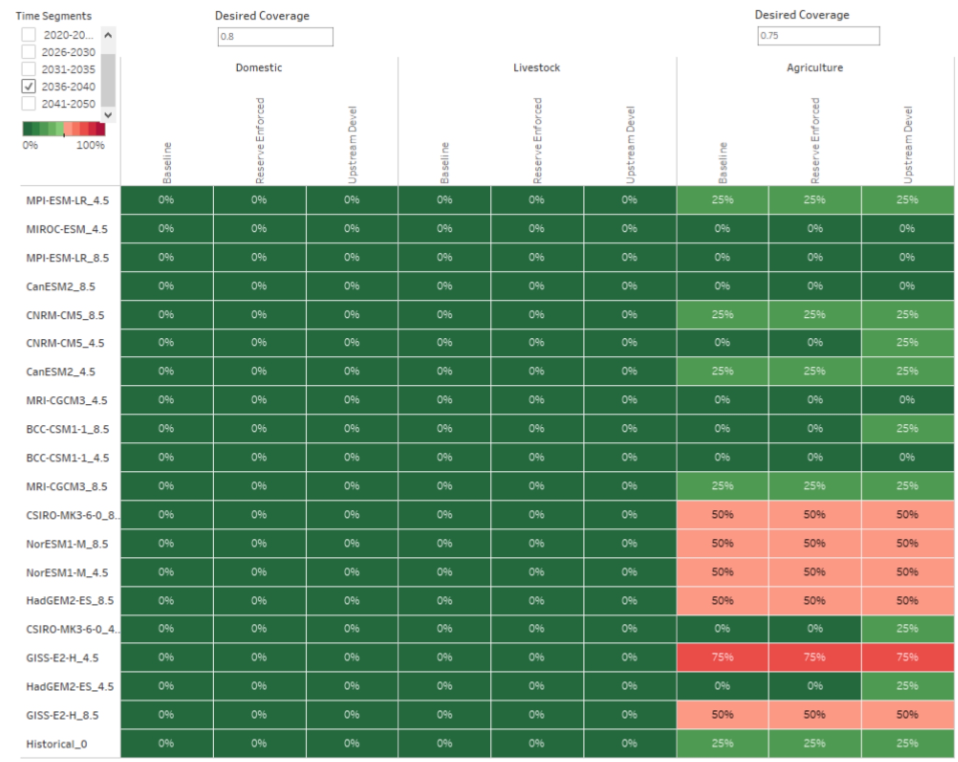
Figure 10 shows a vulnerability map comparing the extent to which each demand is able to meet its water requirements across all demand types, scenarios, and climate projections. The top map shows the period 2026-2030, and the bottom shows 2036-2040. These results reflect for the full suite of runs. Water shortages for agriculture become more common under scenarios in which irrigation is expanded, because the magnitude of the water required increases from 500 thousand cubic meters per year to more than 180 million cubic meters per year. Water shortages are amplified in scenarios with upstream development in Kenya. Lastly, these shortages increase over time across most climate projections, as the time horizon considered increases from ten (top left) to 30 years (bottom left). This means shortages are slightly more likely to occur over time due to climate change and increasing demands.



Time Segments
2020-20...
2026-2030 (selected)
2031-2035
2036-2040
2041-2050
0% 100%

Desired Coverage 0.8 (Domestic); Desired Coverage 0.75 (Agriculture)

	Domestic			Livestock			Agriculture		
	Baseline	Reserve Enforced	Upstream Devel	Baseline	Reserve Enforced	Upstream Devel	Baseline	Reserve Enforced	Upstream Devel
MPI-ESM-LR_4.5	0%	0%	0%	0%	0%	0%	0%	40%	0%
MIROC-ESM_4.5	0%	0%	0%	0%	0%	0%	0%	40%	0%
MPI-ESM-LR_8.5	0%	0%	0%	0%	0%	0%	20%	60%	20%
CanESM2_8.5	0%	0%	0%	0%	0%	0%	0%	40%	0%
CNRM-CM5_8.5	0%	0%	0%	0%	0%	0%	0%	40%	0%
CNRM-CM5_4.5	0%	0%	0%	0%	0%	0%	20%	60%	20%
CanESM2_4.5	0%	0%	0%	0%	0%	0%	0%	40%	0%
MRI-CGCM3_4.5	0%	0%	0%	0%	0%	0%	0%	40%	0%
BCC-CSM1-1_8.5	0%	0%	0%	0%	0%	0%	20%	60%	20%
BCC-CSM1-1_4.5	0%	0%	0%	0%	0%	0%	0%	40%	0%
MRI-CGCM3_8.5	0%	0%	0%	0%	0%	0%	0%	40%	0%
CSIRO-MK3-6-0_8..	0%	0%	0%	0%	0%	0%	0%	40%	0%
NorESM1-M_8.5	0%	0%	0%	0%	0%	0%	0%	40%	0%
NorESM1-M_4.5	0%	0%	0%	0%	0%	0%	0%	40%	0%
HadGEM2-ES_8.5	0%	0%	0%	0%	0%	0%	0%	40%	0%
CSIRO-MK3-6-0_4..	0%	0%	0%	0%	0%	0%	0%	40%	0%
GISS-E2-H_4.5	0%	0%	0%	0%	0%	0%	0%	40%	0%
HadGEM2-ES_4.5	0%	0%	0%	0%	0%	0%	0%	40%	0%
GISS-E2-H_8.5	0%	0%	0%	0%	0%	0%	0%	60%	0%
Historical_0	0%	0%	0%	0%	0%	0%	0%	40%	0%



Time Segments
2020-20...
2026-2030
2031-2035
2036-2040 (selected)
2041-2050
0% 100%

Desired Coverage 0.8 (Domestic); Desired Coverage 0.75 (Agriculture)

	Domestic			Livestock			Agriculture		
	Baseline	Reserve Enforced	Upstream Devel	Baseline	Reserve Enforced	Upstream Devel	Baseline	Reserve Enforced	Upstream Devel
MPI-ESM-LR_4.5	0%	0%	0%	0%	0%	0%	25%	25%	25%
MIROC-ESM_4.5	0%	0%	0%	0%	0%	0%	0%	0%	0%
MPI-ESM-LR_8.5	0%	0%	0%	0%	0%	0%	0%	0%	0%
CanESM2_8.5	0%	0%	0%	0%	0%	0%	0%	0%	0%
CNRM-CM5_8.5	0%	0%	0%	0%	0%	0%	25%	25%	25%
CNRM-CM5_4.5	0%	0%	0%	0%	0%	0%	0%	0%	25%
CanESM2_4.5	0%	0%	0%	0%	0%	0%	25%	25%	25%
MRI-CGCM3_4.5	0%	0%	0%	0%	0%	0%	0%	0%	0%
BCC-CSM1-1_8.5	0%	0%	0%	0%	0%	0%	0%	0%	25%
BCC-CSM1-1_4.5	0%	0%	0%	0%	0%	0%	0%	0%	0%
MRI-CGCM3_8.5	0%	0%	0%	0%	0%	0%	25%	25%	25%
CSIRO-MK3-6-0_8..	0%	0%	0%	0%	0%	0%	50%	50%	50%
NorESM1-M_8.5	0%	0%	0%	0%	0%	0%	50%	50%	50%
NorESM1-M_4.5	0%	0%	0%	0%	0%	0%	50%	50%	50%
HadGEM2-ES_8.5	0%	0%	0%	0%	0%	0%	50%	50%	50%
CSIRO-MK3-6-0_4..	0%	0%	0%	0%	0%	0%	0%	0%	25%
GISS-E2-H_4.5	0%	0%	0%	0%	0%	0%	75%	75%	75%
HadGEM2-ES_4.5	0%	0%	0%	0%	0%	0%	0%	0%	25%
GISS-E2-H_8.5	0%	0%	0%	0%	0%	0%	50%	50%	50%
Historical_0	0%	0%	0%	0%	0%	0%	25%	25%	25%

Figure 10. Vulnerability of demands in 2026-2030 (top) and 2036-2040 (bottom). Percentages indicate the percentage of years that demand coverage will fall below the threshold indicated above each demand category. The top column label indicates each demand type with one column per scenario. Each row shows results for one climate projection.

As was observed from the Abstraction Survey, many water users have multiple sources available to them, such as river diversions, water pans, and groundwater. It is plausible that water users will continue to develop supplemental sources if their primary source becomes limited in the future. As such, the WEAP model was constructed so as to allow possible mining of these sources. Domestic and tourism water demands in particular are able to turn to groundwater to meet shortages. This delivery reliability is reflected in reductions in groundwater storage. Figure 18 shows groundwater overdraft — where positive values indicate decreased storage — for the Baseline scenario under each of the 20 climate projections. These box and whisker plots show the range of overdraft occurring across the 20 climate scenarios. Fifty percent of values (25th to 75th percentiles) fall within the boxed area, and the whiskers capture the expected maximum and minimum values (with statistical outliers appearing beyond the whiskers). These results show groundwater storage decline in the majority of climate projections.

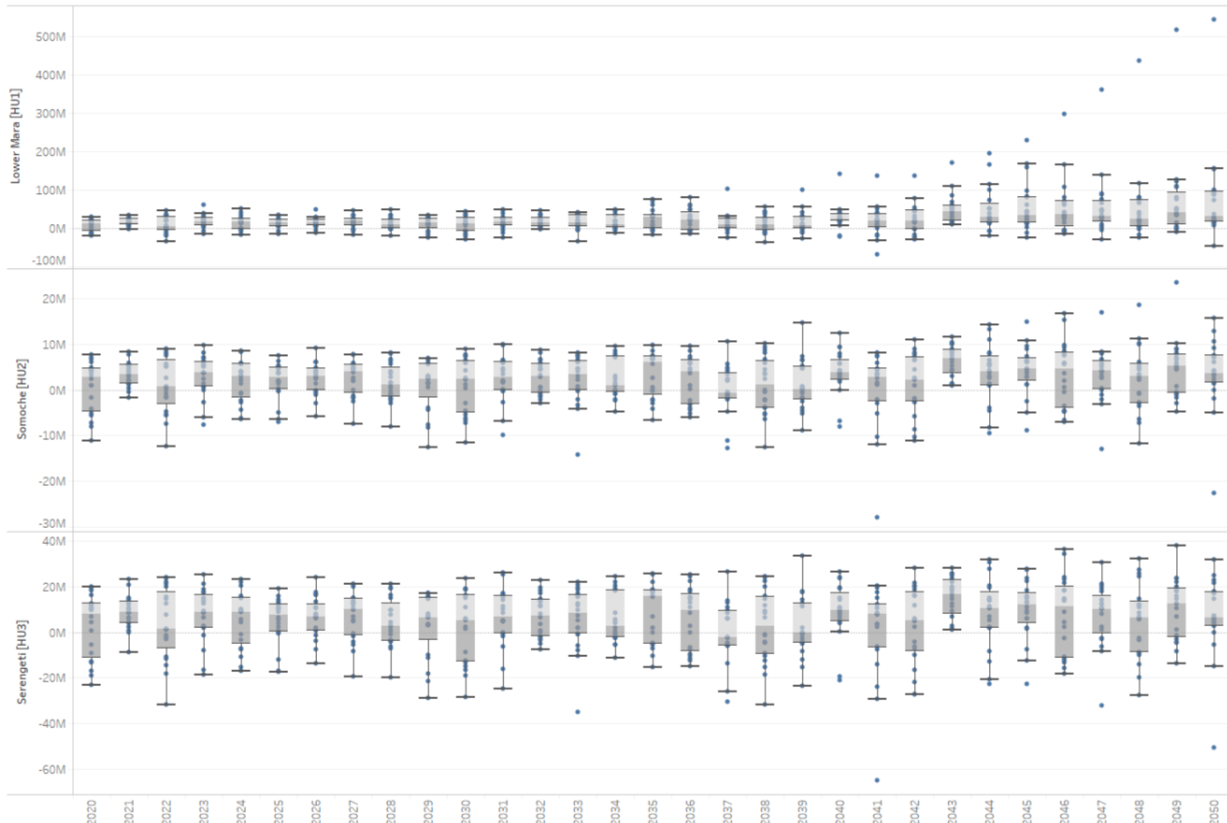


Figure 11. Groundwater overdraft for Lower Mara, Somoche, and Serengeti hydrological units.

6. DISCUSSION AND CONCLUSIONS

Tanzania faces two distinct forms of uncertainty in planning for the Mara that are critical to address, but also to distinguish. The first form of uncertainty is a lack of data, which is something within the ability of the Tanzanian government to address. The second form of uncertainty (deep uncertainty) concerns factors Tanzania has little to virtually no control over, such as climate change, sudden political or ecological shifts, and decisions about upstream developments, diversions, or dams.

Regarding data, perhaps the most critically missing point of reference is any stream gage data in the three tributaries. Without these data it is not feasible to plausibly model the tributaries with any degree of confidence. Given that most of the water withdrawals in the basin are currently from within these tributaries, it is likely the scenarios analysis may be underestimating shortfalls. But it is impossible to know without better data.

With respect to deep uncertainty, as modeled in WEAP around upstream developments and climate change, there are strategies that Tanzania can take to become more water secure. There are two fundamental actions – one regarding policy and one concerning infrastructure. On the policy side, establishing and enforcing the reserve is critical for ecosystems and humans. For infrastructure, storage is key, as long as the withdrawals are taken when the Mara River is not in the reserve.

A key conclusion, based on the available data, is that if there are upstream developments that go hand-in-hand with upstream enforcement of the reserve, Tanzania can meet its reserve, at least on the mainstem of the Mara. This will not impact meeting the reserve on the tributaries, which have not been represented in WEAP due to a lack of gage data.

APPENDICES

Appendix A: Raw inputs from the visioning process: goals and indicators

Lake Victoria Basin Water Board

1. Sufficient flows for water-related development
    a. Unmet demands for different sectors
2. Water allocated equitably for competing demands
    a. No conflicts
    b. Meeting demands
    c. No complaints
3. Sufficient water flow for sustainable food security
    a. Reduced malnutrition
    b. Increased productivity
    c. Increased incomes
4. Adequate flow to meet ecological and environmental demands
    a. Minimum flows met
    b. Species intact
    c. Species richness
    d. Wetland extent
5. Unpolluted river free of sediments
    a. Sediment loads reduced
    b. Water quality parameters (DO, pH, EC, P and N)
    c. Species richness

National and Local Government Agencies

1. Adequate water quantity and quality for ecosystems
    a. Flow at location x at quantity y
    b. Measures of water quality such as turbidity, salinity, mercury, DO
2. Increased water security
    a. Unmet demand
    b. Agricultural productivity
    c. Per capita water-related income
3. Increased resilience to climate change
    a. Afforestation rates
    b. Number/size of multi-purpose reservoirs
    c. Frequency of floods and droughts
4. Sustainable water allocation plans and management
    a. Number of water use conflicts
    b. Unmet demands
5. Increased community livelihoods
    a. Access to social services
    b. Per capita water-related income
    c. Morbidity rates
6. Improved ecological status
    a. River health
    b. Water quality measures such as TSS, DO, BOD, chemicals
    c. River flows

Research and non-government organizations

1. Equitable use of the water resources especially competing users
    a. Degree of harmonization between the Tanzanian and Kenyan WAP, with mechanisms for implementation

2. Improved water quality
    a. Level of contamination reduced to acceptable standards
    b. Restoration of catchments, including forest cover and river bank protection
3. Strong and functional institutions with capacity and mandates
    a. Functional MRB Secretariat
    b. Availability of plans, strategies, and budget
4. Alternative livelihoods
    a. Change of livelihood activities
    b. Adoption of new practices
    c. Increase in water-related incomes
    d. Improved lifestyle

Appendix B: Raw Input on critical uncertainties

Group 1
Critical Uncertainties

- Climate change
- Population growth
- Poverty
- Land-use change
- Ecological change

Trends

- Cultural practices
- Increase in wildlife
- Change in government structure

Perturbations

- Technological change
- Food security
- Political statements

Group 2
Critical Uncertainties

- Climate change and variability
- Change in demands and priorities
- Natural calamities and epidemics

Trends

- Population growth
- Conflicts over resource use
- Uncontrolled livestock movements
- Political interference

Perturbations

- Wildlife migration
- Changes in policies and regulations

Group 3
Critical Uncertainties

- Climate change and variability
- Land-use change
- Political interference and regime change

Trends

- Population growth and urbanization
- Lifestyle change (which could be a critical uncertainty)

Perturbations

- Legislation change
- Unintended introduction of invasive species
- Disease outbreaks (livestock/wildlife) and/or disasters

Appendix C: Raw Input on strategies/levers

Group 1: Healthy ecosystem projects and strategies

1) Economic valuation of ecosystem services in the MRB

2) Public education and awareness campaigns on healthy ecosystem (wetland, biodiversity, forests, and water)
3) Harmonization of policies and laws through legal enforcement
4) Establishment of joint water resources monitoring systems
5) Integrated environmental restoration projects
6) Wetland-friendly investments or catchment conservation
7) Conjunctive water use/alternative water sources (groundwater, rainwater harvest, reefs, reuse)
8) Ecosystem flow requirements

Group 2: Equitable water projects and strategies

1) Development and operationalization of WAP in the basin
2) Harmonization and enforcement of transboundary framework
3) Development and implementation of alternative water sources
4) Joint development projects within countries of MRB
5) Promote communication, education, participation, and awareness (CEPA)
6) Support efficient water use projects
7) Establishment of research and development unit within secretariat of the basin (financing and investment arm of MRB)

Group 3:Water Related Development Projects and Strategies

1) Introducing alternative income-generating activities (e.g. beekeeping, handcrafts)
2) Public awareness campaigns on safe water and sanitation and hygiene
3) Development of alternative sources of water (e.g. ground water, rainwater harvesting, and storage)
4) Implementation of conservation investment plan (CIPs)
5) Joint development projects and development between countries
6) Alternative to develop high value crops (resilient to climate) and livestock breeds
7) Efficient water use projects to be introduced

Group 4: Resilience to climate change projects and strategies

1) To support integrated land-use plans
2) River flow regulation and identification of flood hotspots (early warning)
3) Behavior change and adaptation
4) Implementation of conservation (wetland-oriented, friendly) investment plans (CIPs)
5) Joint water-related projects
6) Enhancing coping strategies on climate-smart agriculture and biodiversity through analysis of projected impacts of climate change
7) Awareness campaign on adaptation of climate change
8) To promote alternative use of energy sources, e.g. biogas, solar, energy, electricity, and wind