

CUMULATIVE IMPACT ASSESSMENT (CIA) OF THE MPATAMANGA HPP ON THE SHIRE RIVER BASIN

2nd Draft CIA Report

October 2024



Proposed location of the Mpatamanga dam wall, taken from upstream within reservoir footprint, March 9th 2023 (Photo: Elizabeth Molloy, C₁₂)

Multiconsult



Deltares



Cumulative Impact Assessment (CIA) of the Mpatamanga HPP on the Shire River Basin

2nd Draft Final CIA Report

October, 2024

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LIST OF ACRONYMS AND ABBREVIATIONS

ASTAE	Asia Sustainable and Alternative Energy Program
BAP	Biodiversity Action Plan
BOOT	Build-Own-Operate-Transfer
CC	Climate Change
CHIRPS	Climate Hazard Group InfraRed Precipitation
CIA	Cumulative Impact Assessment
DEM	Digital Elevation Model
DRIFT	Downstream Response to Imposed Flow Transformations
EDF	Electricite de France
ESF	Environmental and Social Framework
ESIA	Environmental and Social Impact Assessment
ESM	Eco-Social Model
GBV	Gender Based Violence
GIS	Geographical Information System
GCM	Global Climate Model
GoM	Government of Malawi
GRDC	Global Runoff Data Center
IBA	Important Bird Areas
IFC	International Finance Corporation
IPCC	International Panel on Climate Change
ISIMIP	Inter-Sectoral Impact Model Intercomparison Project
JICA	Japan International Cooperation Agency
KABOM	Kamuzu Barrage Operation Model
LAI	Leaf Area Index
MASAF	Malawi Social Action Fund
MHPL	Mpatamanga Hydropower Limited
MHPP	Mpatamanga Hydropower Project
MODIS	Moderate Resolution Imaging Spectroradiometer
MOMA	Mozambique-Malawi 400-kV Interconnection Project
MW	Megawatt
MWASIP	Malawi Watershed Services Improvement Project
NFLRA	National Forest Landscape Restoration Assessment
NP	National Park
NRT	Near Real Time
NWRA	National Water Resources Authority
PM	Project Manager
PWS	Public Water Supply
RUSLE	Revised Universal Soil Loss Equation
SRBMP	Shire River Basin Management Program
SVTP	Shire Valley Transformation Program
ToR	Terms of Reference
TSS	Total Stressor Score
TVS	Total VEC Score

VECs Valued Environmental and Social Components
WR Wildlife Reserve

PREFACE

This is the 2nd Draft CIA Report (Main Report – Volume 1) for the *Cumulative Impact Assessment of the Mpatamanga HPP on the Shire River*. It follows the delivery of the 1st Draft CIA Report on 12th August 2024.

The Mpatamanga Hydropower Project (MHPP) is being co-developed by the Government of Malawi with the International Financial Corporation (IFC), SCATEC and EDF through an agreement signed under Malawi's Public-Private Partnership (PPP) framework. The Project lead developer is a consortium comprised of EDF and SCATEC. The Project Company, Mpatamanga Hydro Power Limited (MHPL), whose shareholders are affiliates of EDF and SCATEC, is THE CLIENT for this study. MHPL has hired Multiconsult (Norway), Southern Waters (Republic of South Africa), Deltares (the Netherlands) and C₁₂ (Malawi) to carry out the assessment.

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Baseline surveys during July 2023: Data collection activities were a source of great entertainment for local youngsters.

EXECUTIVE SUMMARY

This is the Executive Summary of the 2nd Draft CIA Report” for the **Cumulative Impact Assessment of the Mpatamanga HPP on the Shire River** study.

Objectives of the CIA

The objectives of this assignment are to:

- Assess the cumulative environmental and social impacts of the Mpatamanga Hydropower Project and other developments across the Shire Basin.
- Prepare mitigation measures for these cumulative impacts, to be implemented by Mpatamanga Hydropower Project, by other developments, and at a basin level.
- Prepare the CIA for the Mpatamanga Hydropower Project, meeting CIA requirements set out in the World Bank Environmental and Social Framework (ESF; World Bank 2017), IFC Performance Standards (IFC 2012), and the guidance set out in the IFC Good Practice Handbook on Cumulative Impact Assessment and Management (IFC 2013).

The CIA is also undertaken in accordance with relevant national and international standards.

The CIA was conducted for the Shire River Basin downstream of Lake Malawi to the confluence with Zambezi, with focus areas from Kamuzu Barrage to the border with Mozambique. Some drivers and impacts on Valued Environmental and Social Components (VECs) extend beyond these boundaries, e.g., Lake Malawi long-term water level fluctuations. These are also to be taken into consideration in the assessment, although not as diligently modelled and assessed as the selected driver/causes and stressors within the CIA catchment focus area (e.g., infrastructure development, deforestation due to charcoal and firewood production, demographic change and influx/migration).

HPP on the Shire River

There are currently three operational hydropower stations in the Middle Shire River: Nkula, Tedzani and Kapichira, generating a combined ~339 MW. The earliest, Nkula Falls A (16 MW), was constructed in conjunction with Kamuzu Barrage and completed in 1966, and an 8-MW unit was added in 1967. The Tedzani 1 and 2 projects were developed in the mid-1970s and have a combined installed capacity of 40 MW. Nkula B was constructed between 1980 and 1992 and has an installed capacity of 100 MW. Tedzani 3 (52 MW) was completed in 1995, followed by Kapichira Phase I (65 MW) in 2000. The installed capacity at Kapichira was increased to 130 MW in 2012 and Tedzani to 62 MW in 2018. In January 2022, Kapichira HPP was badly damaged by Tropical Storm Ana, resulting in its closure. It was back to full operation after rehabilitation in May 2023¹.

The proposed MHPP is located on the Mpatamanga Falls between the Tedzani HPP and Kapichira HPP just upstream of the Majete Wildlife Reserve and ~40 km west of Blantyre (see also Figure next page).

¹ <https://www.egenco.mw/egenco-restores-kapichira/>

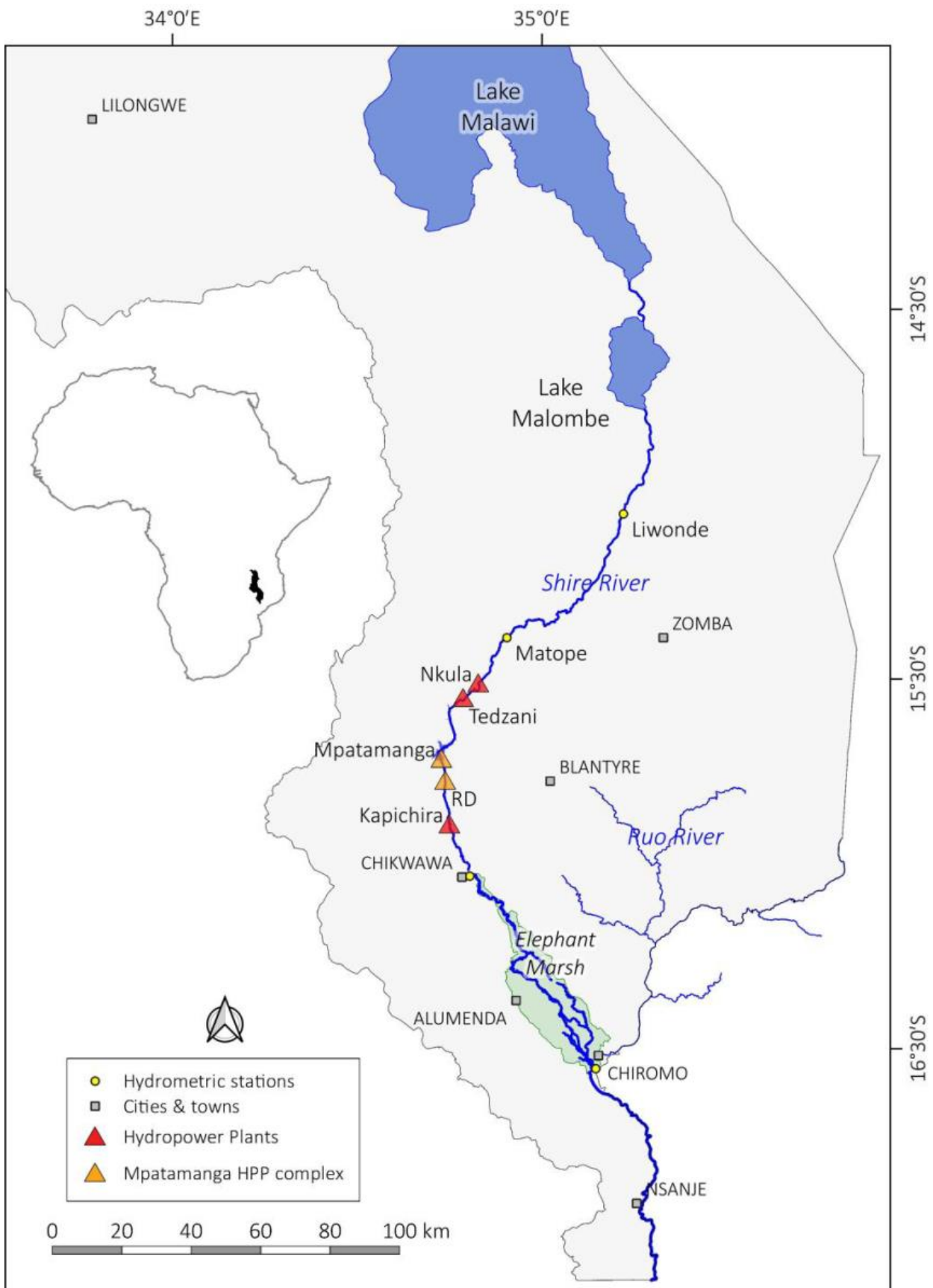


Figure ES-0-1 The Shire River showing the proposed MHPP complex (orange triangles), existing HPPs, hydrometric stations, main villages and the Elephant Marsh. River flows are from north to south. RD: Regulating Dam (Source: Brown *et al.* 2022).

The hydropower potential at Mpatamanga was first studied in detail in the Power Development Study Phase 1 undertaken by TAMS Hydro in 1985. The project was further considered in the Malawi Power System Development and Operation Study (Lahmeyer International and Knight Piésold 1998). In 2015 Fichtner GmbH was appointed by the Ministry of Natural Resources, Energy and Mining to undertake Prefeasibility and Feasibility studies for the Chingonda and Mpatamanga hydropower projects. These studies were funded by the World Bank. The final Feasibility Study Report for the Mpatamanga Project was issued in 2017 (Fichtner 2017). This has been followed by various other technical, environmental and social studies between 2018-2022 mentioned in the ToR (Section 8, pages 27-28), including the Mpatamanga Technical and Additional Studies (Multiconsult 2019) and the Rapid Cumulative Impact Assessment (Brown *et al.* 2022).

CIA Process

The process used for the CIA is that recommended by the IFC Good Practise Handbook for Cumulative Impact Assessments (IFC 2013), with the tasks aligned accordingly.

The tasks are arranged in three Phases, as follows:

- Phase I: Inception;
- Phase II: Scoping, which encompasses Steps 1, 2 and 3 of the CIA process and the required stakeholder engagements, data collection and analyses;
- Phase III: Analysis and Monitoring Design, which encompasses Step 4, 5 and 6 of the CIA process.

The tasks in this assignment are also aligned according to the main steps of the CIA process (IFC 2013).

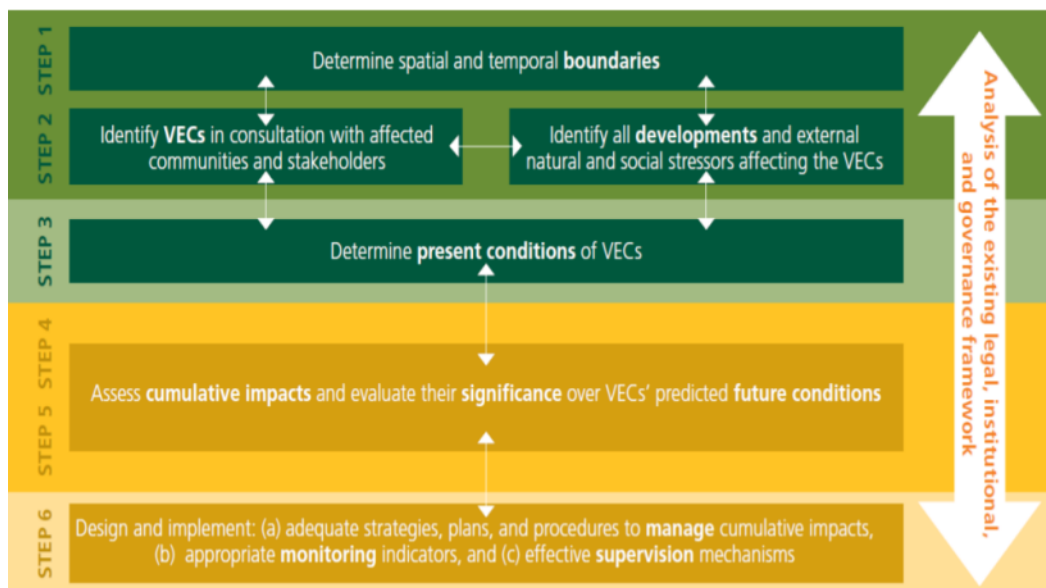


Figure ES-0-2 The six steps of a Cumulative Impact Assessment (IFC 2013).

The cumulative impacts of activities and developments in the basin are assessed by means of scenarios, using two main approaches:

- Impact Pathway Network Analysis method (World Bank/ASTAE 2014)² (this Volume 1)

² ASTAE (Asia Sustainable and Alternative Energy Program). 2014. *Cumulative Impacts and Joint Operation of Small-Scale Hydropower Cascades*. South Asia Energy Studies. Washington, DC: World Bank.

- DRIFT Eco-Social Modelling (DRIFT ESM) and analysis (see Volume 2 for the detailed assessment).

VEC approach for the CIA assessment

The Valued Environmental and Social Components (VECs) are the core attributes to be assessed in this CIA. Candidate VECs considered important in assessing risks include the following (adapted from IFC, 2021):

- Physical features, habitats, and wildlife populations (for example, biodiversity)
- Ecosystem services
- Natural processes (for example, water and nutrient cycles and provisions)
- Social conditions (for example, health, livelihoods and economics)
- Cultural activities (for example, traditional spiritual ceremonies, historical and sacred places)

The difference between a CIA and an environmental and social impact assessment (ESIA) is illustrated in the Figure below.

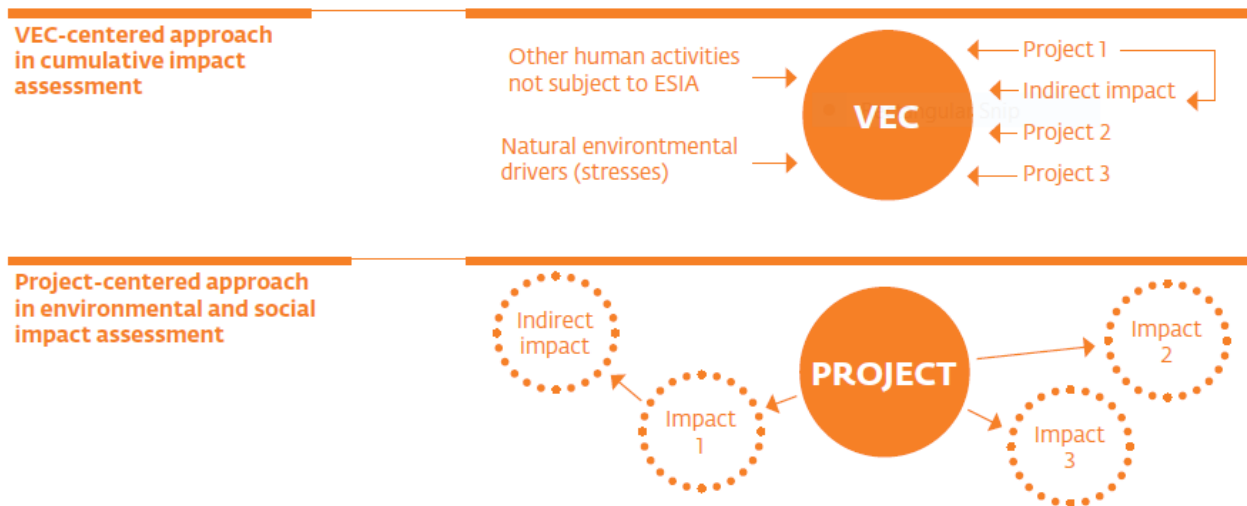


Figure ES-0-3 Comparison of Cumulative Impact Assessment and Environmental and Social Impact Assessment (Source: IFC, 2013).

The VECs assessment is supported by the physical, chemical, biological and social indicators assessment in the DRIFT ESM analysis (Volume 2), and an interlinkage between those indicators and the VECs embedded in the analysis.

Summary of Causes and Drivers of Change and Selection of Stressors and VECs for the Mpatamanga CIA

Identification of causes and drivers as well as stressors and VECs was undertaken through consultation with stakeholders during the July 2023 Scoping Mission. Thereafter they were prioritised by the Consultant together with the Client and WB/IFC through a rigorous analysis. The consultations were undertaken without having any pre-defined list of stressors and VECs in order for the stakeholder to be free to choose what they perceived was of highest importance. Basically, two distinct groups of stakeholders were consulted, namely:

- National and regional level stakeholders; e.g. government agencies, private sector, parastatals and NGOs.
- Community level stakeholders; e.g. community representatives from villages close to or in the vicinity of the DRIFT ESM sites.

Causes and Drivers of Change

The main drivers and causes of change in the Shire River Basin, based on the stakeholder inputs along with research, can be summarised as shown below. These have been included in the overall CIA analysis (Impact Pathway Network Analysis) discussed in Section 7.1 of this report.

Anthropogenic (human-induced) causes/drivers:

- Charcoal and firewood production and encroachment into forested areas (most widespread throughout the basin)
- Agricultural and industrial development
- HPP and dams' development and operation (Nkula, Tedzani, Kapichira, Mpatamanga HPPs plus Kamuzu Barrage)
- Irrigation and water supply development (SVTP, Illovo, Agricane, etc., plus Blantyre Water Board and Southern Region Water Board developments)
- Transmission lines and roads development (Mpatamanga, MOMA, etc.)

Natural system causes/drivers:

- Climate change (besides charcoal production etc. the most profound driver of change at basin scale)

Summary of stressors/primary impacts

The causes/drivers of change discussed above have led to identification of a group of main stressors/primary impacts. These are as follows:

- Extreme weather events, e.g. floods and droughts. Primarily caused by climate change but exacerbated also by deforestation due to charcoal/firewood production and encroachment into forested areas.
- Deforestation and land use change. Main cause is charcoal/firewood production and encroachment into forested areas, but also affected by infrastructure and agricultural development.
- Environmental degradation other than deforestation (pollution, etc.). Impacted by multiple causes/drivers but most profoundly by agricultural and industrial practises.
- Changes to flow regime. Impacted by multiple causes/drivers, but most profoundly by HPP development and operation.
- Influx of people. Impacted by HPP, irrigation and transmission line and roads development.

These again have multiple secondary impacts which are discussed in the Summary of Baseline Conditions for the Prioritised VECs section to this Executive Summary.

Summary of prioritised VECs

The VECs prioritised and discussed in detail in Table 3-4 and 3-5 in Section 3.2 of this report have been pooled for the Impact Pathway Network Analysis, and the final list of prioritised VECs is as follows:

- Reliable water availability and quality.

- Biodiversity and habitats for wildlife, birds and aquatic life (VEC species and habitats).
- Ecosystem services for livelihoods.
- Productive land/soil for agriculture.
- Historical, cultural and religious sites.
- Tourism and social services.

Modelling Suite

For the scenario assessment to be undertaken in Phase III, a modelling suite was built up in Phase II, which is illustrated below. Details of the model suite set up are given in Section 2.9 of this report.

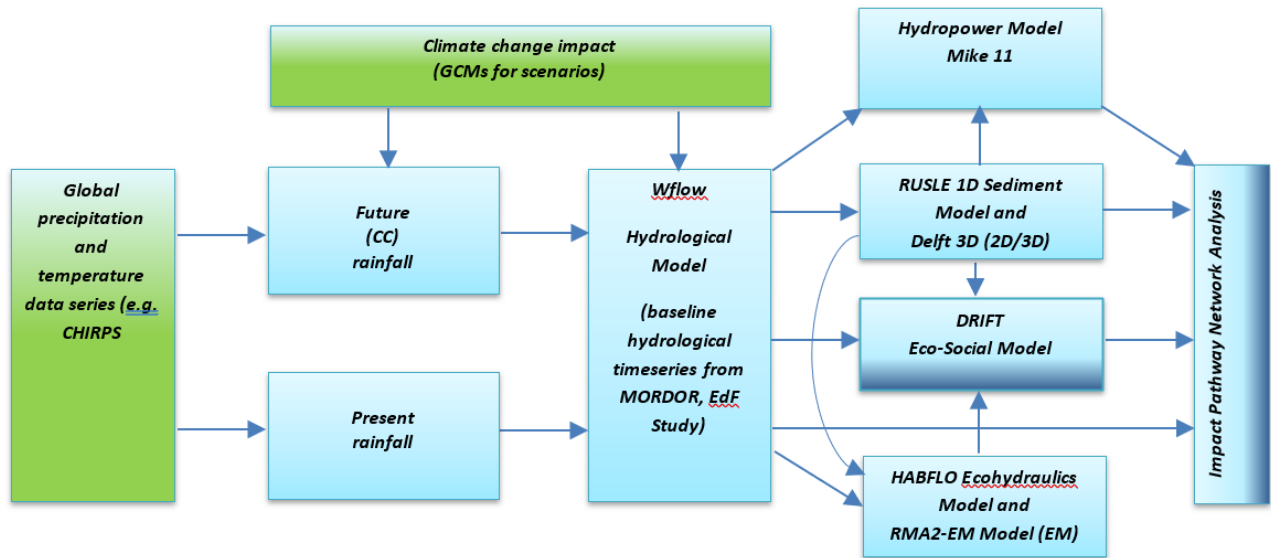


Figure ES-0-4 Illustration of the modelling suite of the Mpatamanga CIA, with the DRIFT Eco-Social Model and the Impact Pathway Network Tool as the main receptor models/tools for the scenarios cumulative impact assessment.

Spatial Boundaries

The spatial boundaries for the CIA are the Shire River Basin downstream of Lake Malawi to the confluence with the Zambezi River. However, the main focus area of the study is the catchment of the Shire River from the Kamuzu Barrage to the Mozambican border, including its significant tributaries (see Figure on next page).

The Impact Pathway Network Analysis assessed the status and changes within the whole catchment of the main focus area whereas the DRIFT ESM investigated the status and changes to the aquatic and riparian systems at the ESM sites and their associated zones/river reaches.

The temporal and spatial boundaries of the study were discussed and agreed with the Client, WB/IFC and stakeholders during the Scoping Phase.

Selection of scenarios for the CIA

The scenarios with their temporal boundaries were selected through an interactive process with the Client, IFC/WB, the ESIA consultant and a few other stakeholders. Ten main scenarios have been selected and can be grouped into four main scenario groups, namely:

- Near Natural and Historical (trended past) scenarios;
- Baseline scenarios (current and 2030);
- Near Future scenarios (2035); and
- Distant Future scenarios (2070).

The details of each scenario (or sub-scenario) are outlined in Table ES-1 below. All the hydrological conditions of the scenarios, including the baseline conditions, have been based on the CIA Wflow hydrological modelling (with a hydrological reference period between 1992-2023), but comparison/adjustments have been undertaken with the EDF baseline time-series for 1992-2022, where found necessary.

Table ES-1 provides a more detailed description of the main input characteristics/parameters for each scenario (with each of the four main scenario groups highlighted in white/ grey background colour).

Table ES-0-1 Description of the main scenarios for the CIA analysis, including main input characteristics/parameters.

#	Code	Scenario	Temporal boundary	Description with regard to HPP Development	Description with regard to other infrastructure developments	Time/Period Basin Land Cover	Forest Cover relative to baseline 1 Closed BDF (Estimated Forest Cover)	Estimated Basin Population ³
1	Natural	Near Natural Scenario	Early 1900	Historical conditions without large dams in the basin	Historical conditions without other large infrastructure in the basin and low levels of deforestation, and inputs by; <ul style="list-style-type: none"> - 1900 water resource and other infrastructure developments 	1900	+37% (Closed BDF = 35.21%, Total = 53.38%)	< 250 000
2	HS Trend	Historical Scenario	From 1992 to 2022	This trended scenario will track the changes in the hydrology, Kapichira coming online, changes in frequency of flooding, etc. Will also be used to calibrate DRIFT, and inputs by: <ul style="list-style-type: none"> - Pre-1992: Kamuzu Barrage, Tedzani 1, Nkula 1, 2 and 3 - 1992-2002: + Tedzani 2 and Kapichira Phase 1 - 2012-2022: + Kapichira Phase 2 + Tedzani III 	Actual water resources development that came online between 1992-2022. Irrigation developments, water supply developments <p><u>Irrigation</u></p> <ul style="list-style-type: none"> - Illovo - Agricane + others <p><u>Water Supply</u></p> <ul style="list-style-type: none"> - BWB + SRWB 	Pre-1992 1992-2002 2002 – 2023	Pre-1992: +30% (Closed BDF = 33.41%) 1992-2002: +15% (Closed BDF = 29.56%) 2002-2023: 0% (Closed BDF = 25.7%)	1992: 2 200 000 2002: 2 600 000 2012: 3 400 000 2022: 4 500 000

³ Based on that Shire Basin comprises 16 % of the land area of Malawi, but 22 % of its population (Coulibaly, Y.J., Mbow, C., Sileshi, G.W., Beedy, T., Kundhlande, G. and Musau, J. (2015) Mapping Vulnerability to Climate Change in Malawi: Spatial and Social Differentiation in the Shire River Basin. *American Journal of Climate Change*, 4, 282-294. <http://dx.doi.org/10.4236/ajcc.2015.43023>). Estimates for all scenarios except “near natural” derived from this source of total Malawi population projections <https://worldpopulationreview.com/countries/malawi-population>.

#	Code	Scenario	Temporal boundary	Description with regard to HPP Development	Description with regard to other infrastructure developments	Time/Period Basin Land Cover	Forest Cover relative to baseline 1 Closed BDF (Estimated Forest Cover)	Estimated Basin Population ³
3	Base 2022/3	Baseline Scenario 1 (Reference Scenario)	Current conditions – 2023	Current situation and HPP development within the spatial boundary and institutions <ul style="list-style-type: none"> - Kamuzu Barrage (KABOM operation rules) - Nkula (peaking) - Tedzani (peaking) - Kapichira (peaking) 	Current development status and land use of the spatial boundary area. <p><u>Irrigation</u></p> <ul style="list-style-type: none"> - Illovo - Agricane + others <p><u>Water Supply</u></p> <ul style="list-style-type: none"> - BWB + SRWB Current transmission lines and roads	2023 (same as HS 2023 forest cover)	⁴ Closed BDF = 25.7% Open BDF = 16.59% Mosaic cropland = 1.15% Closed to open BE = 0.43% ⁵ Total = 43.87%	4 600 000
4.1	2030BAU	Baseline Scenario 2 –with/without Mpatamanga Operational	Near Future 2030	Sub-scenario BS 2.1: Conditions 2030 without Mpatamanga <ul style="list-style-type: none"> - Kamuzu Barrage (KABOM projections) - Nkula (peaking) - Tedzani (peaking) - Kapichira (peaking) 	Development status 2030. SVTP (Illovo and Agricane connected); MWASIP, water supply and transmission lines/roads included (including MOMA).	2030 (same as BS1 2023 forest cover)	<1% (Closed BDF = 25.4%)	5 500 000
4.2	2030MPTBAU			Sub-scenario BS 2.2: Conditions when Mpatamanga becomes operational				

⁴ Considering all landcover classes relevant to forests the current forest cover within our model domain is up to 44%, with a breakdown from the unmodified ESA Globcover product in the present-day baseline (<https://www.esa-landcover-cci.org/>). When modifying landcover we increased the proportion of closed canopy broadleaved deciduous forest (Closed BDF), but not at the expense of 3 other forest-relevant classes (Open BDF, Mosaic cropland and Closed to open BE; see footnote 3)

⁵ Closed BDF = Closed (>40%) broadleaved deciduous forest (>5m); Open BDF = Open (15-40%) broadleaved deciduous forest (>5m); Mosaic Cropland = Mosaic cropland (50-70%) / vegetation (grassland, shrubland, forest) (20-50%); Closed to open BEF = Closed to open (>15%) broadleaved evergreen and/or semi-deciduous forest (>5m)

#	Code	Scenario	Temporal boundary	Description with regard to HPP Development	Description with regard to other infrastructure developments	Time/Period Basin Land Cover	Forest Cover relative to baseline 1 Closed BDF (Estimated Forest Cover)	Estimated Basin Population ³
				<ul style="list-style-type: none"> - Kamuzu Barrage (Kabom projections) - Nkula (peaking) - Tedzani (peaking) - Mpatamanga (peaking) - Kapichira (<u>not peaking</u>) 				
5	NF1BAU	Near Future Scenario 1 – Business as Usual Pathway	Future conditions – as planned for 2035	Planned HPP infrastructure development and operations <ul style="list-style-type: none"> - Kamuzu Barrage - Nkula (peaking) - Tedzani (peaking) - Mpatamanga (peaking) - Kapichira (not peaking) 	Future infrastructure development scenario as of 2035 with SVTP, MWASIP, Irrigation as of Master Plan up to 2035, water supply and transmission lines (including MOMA).	2035 BAU (Business as usual catchment management and sectors development; Same as BS1 2023 forest cover)	<1% (Closed BDF 25.4%) (1.8% increase in agricultural land)	6 200 000
6	NF2BAU	Near Future Scenario 2 – Business as Usual + Joint Dams Operation	Future conditions as planned for 2035	Planned HPP infrastructure development and operations as of Near Future Scenario 1 plus joint operation of Kamuzu Barrage, Nkula, Tedzani, Mpatamanga and Kapichira <ul style="list-style-type: none"> - Kamuzu Barrage (KABOM projections) - Nkula (peaking) - Tedzani (peaking) - Mpatamanga (peaking) 	As of Near Future Scenario 1	2035 BAU + JDO	As NF1	6 200 000

#	Code	Scenario	Temporal boundary	Description with regard to HPP Development	Description with regard to other infrastructure developments	Time/Period Basin Land Cover	Forest Cover relative to baseline 1 Closed BDF (Estimated Forest Cover)	Estimated Basin Population ³
				- Kapichira (not peaking)				
7	NF3BAUCC	Near Future Scenario 3 – Business as Usual Pathway + Joint Operation + Climate Change	Future conditions as planned for 2035	Planned HPP infrastructure development and operations as of Near Future Scenario 2 plus climate change superimposed	As of Near Future Scenario 2 plus climate change superimposed	2035 BAU + JDO + CC	As NF1	6 200 000
8	NF4SPCC	Near Future Scenario 4 – Sustainable Pathway (including energy transition and catchment mitigation) + Joint Operation + Climate Change	Future conditions as planned for 2035	Planned HPP infrastructure development and operations as of Near Future Scenario 3	<p>Projected future infrastructure development scenario as of 2035 with SVTP, MWASIP, Irrigation as of Master Plan up to 2035, water supply and transmission lines (including MOMA).</p> <p>Energy source transition as of National Energy Policy up to 2035 and National Charcoal Strategy.</p>	<p>2035 JDO + CC + SP (30% increase in forest cover viz SRBM Plan 2017)</p> <p>Stepwise build in (i) catchment rehabilitation⁶, (ii) tourism and protected areas management⁷ and (iii) Sustainable land use enhancement and energy source transition⁸ in the basin. Introduce (i) to (iii) sequentially.</p>	<p>2040-50: +10% (Closed BDF = 28.27%)</p> <p>2050-60: +20% (Closed BDF = 30.84%)</p> <p>2060-70: +30% (Closed BDF = 33.41, Total = 51.58%)</p>	6 200 000

⁶ **Catchment rehabilitation that includes rehabilitation/reforestation of targeted erosion hotspot areas** in tributaries with highest sediment yield to Shire, e.g. erosion hotspots in Ruo, Lisungwe, Nkulumadzi, Lirangwe, Likabula and maybe Rivi Rivi and Mwanza tributaries + MWASIP pilot areas in Lisungwe, Nkulumadzi, Lirangwe/Likabula (as of HR Wallingfords sediment study: Baseline Report and Erosion Hotspot Maps + projected reduction of sediment transport for 2035 and 2070 conditions).

⁷ **Enhancing tourism and protected areas management of protected areas** in the basin, and then especially the selected Flagship VECs for the CIA, e.g. Liwonde NP, Majete WR, Lengwe NP and Elephant Marsh (incl. restricted access into, and cultivation in, the Elephant Marsh). The two first are quite well protected by African Parks running them but some encroachment, etc. still occurs (include also Northern Corridor suggestion, close to Majete, of BAP study). Lengwe NP is under high pressure viz encroachment/ poaching and especially the New Lengwe part. The CIA suggests full restoration of New Lengwe or at least major parts of it. Tourism development should go hand in hand with strengthening of protected areas management.

⁸ **Sustainable land use enhancement and energy source transition** that follows the goals and targets in the Renewable Energy Strategy (2017), National Charcoal Strategy (2017) and National Forest Landscape Restoration Strategy (2017) implemented for the Shire Basin, e.g. transition from biomass (woodfuel/charcoal) to more renewable (or sustainable sources) as the energy source, e.g. biofuels/biogas, LPG and electricity as well as sustainable charcoal production (plantation trees in targeted areas).

#	Code	Scenario	Temporal boundary	Description with regard to HPP Development	Description with regard to other infrastructure developments	Time/Period Basin Land Cover	Forest Cover relative to baseline 1 Closed BDF (Estimated Forest Cover)	Estimated Basin Population ³
9	DF1BAUCC	Distant Future Scenario 1 – Business as Usual plus Climate Change	Future conditions as projected for 2070	As for Near Future Scenario 1 but with Climate Change 2070 conditions	As for Near Future Scenario 1 but with Climate Change 2070 conditions	2070 BAU (BS1 Forest Cover) + CC	As NF1 (Closed BDF= 25.4%)	10 600 000
10	DF2SPCC	Distant Future Scenario 2 – Sustainable Pathway + Joint Operation + Climate Change	Future conditions – as projected for 2070	As for Near Future 4 but with 2070 conditions	As for Near Future Scenario 4 but with 2070 conditions	2070 + CC + SP (50% increase in forest cover)	2070 50% (Closed BDF = 38.55, Total = 56.72)	10 600 000

General Description for Mpatamanga CIA Impact Pathway Network Analysis

A cumulative impact assessment (CIA) is a process of analysing potential impacts on and risks to VECs resulting from existing and proposed projects in the context of human activities and natural environmental and social external drivers over time (IFC, 2021)⁹. The complex relationships and interactions among Drivers/Causes, Stressors/Primary Impacts, and Secondary Impacts that lead to cumulative impacts on the prioritised VECs in the Shire Basin, as illustrated in Figure ES-6, have been assessed for all the 10 scenarios in Table ES-1.

The stressor/primary impact score is the sum of the impact from the drivers/causes, each with a magnitude (vector weight) ranging from 0 (no impact) to 4 (very high impact) as follows:

- 0 = no/negligible impact
- 1 = low impact
- 2 = moderate impact
- 3 = high impact
- 4 = severe impact

Then the following steps are undertaken; (1) Determination of which drivers/causes affect which stressors/primary impacts, and assigning them a 1-4 score for each link; (2) Summarising these scores for each stressor/primary impact; (3) Then determine which stressors/primary impacts affect which secondary impacts and assign a 1-4 score to each link; (4) For each link, the score is multiplied by the primary impact score and then summarised for all links to provide a final score for the secondary impact; and lastly (5) Determine which secondary impacts affect which VECs, and summarise the secondary impact scores for each VEC¹⁰.

A summary of the assessment for each main CIA scenario is provided in the subsequent sections of this Executive Summary. A more detailed description of the assessment and results for each scenario is provided in Section 8 of the CIA Report. For the results of the DRIFT ESM assessment, reference is made to Volume 2 and 3 to this report.

Summary of Baseline Scenario 2023 (Current Conditions and Reference Scenario)

From the Impact Pathway Network Analysis Diagram in Figure ES-6 the two most prominent drivers/causes to change in the basin, with its subsequent impacts on stressors/primary impacts and secondary impacts towards the VECs, are (i) climate change and (ii) charcoal and firewood production as well as encroachment into forested areas. The magnitude of impact of these two drivers/causes is also given the score 3 (high impact) in one of their pathways towards primary impacts/stressors for the current situation, e.g. (i) climate change: leading to *extreme weather events* and subsequently the amount of tropical storms (7) over the past decade, and (ii) charcoal and firewood production/encroachment into forested areas: the basin-wide impact of this driver/cause over the past decades leading to large scale *deforestation and land use change*. This driver/cause also exacerbates the impact of extreme weather events, as deforestation and land degradation

⁹ IFC. 2021. *Cumulative Impact Assessment and Management of Renewable Energy Development in the Sekong Basin, Lao People's Democratic Republic*. International Finance Corporation, Washington, D.C.

¹⁰ For example, the 5 impact pathways towards the Reliable water availability and quality gives the total impact score of 138 on this VEC.

lead to a less climate resilient basin that is more prone to floods and drought shocks. Hence, the impact pathway is given the score of 2 (moderate impact).

In comparison, the anthropogenic impacts from the drivers/causes (i) agricultural and industrial practices, (ii) HPP development and operation, (iii) irrigation and water supply development and (iv) transmission lines and roads, are assessed for current situation to have more moderate impacts than that of climate change and charcoal/firewood production and encroachment, including their subsequent effects on stressors/primary impacts and secondary impacts and then finally the VECs. One major reason for this more moderate (or lower) impact score is that most of these drivers/causes are more confined to specific areas in the basin (for example large scale irrigation to the Lower Shire), and hence their impacts are not seen basin-wide to the same extent. Agricultural and industrial practices is, however, assessed to have moderate impact (score 2) on pollution¹¹, and HPP development and operation is also given the same score viz its impact pathways towards changes to flow regime and influx of people (Kapichira, Tedzani, Nkula for current situation). The different pathways from irrigation/water supply development and transmission lines/roads development towards the stressors/primary impacts is by comparison, for the current situation, given an impact score of 1 (low impact). This will of course change for future conditions when SVTP and the Mptatamanga/MOMA transmission lines are finalised or constructed.

The two stressors/primary impacts with *highest assessed magnitude of impacts* on the secondary impacts are: (i) extreme weather events and its impact on flood and low flow magnitude, frequency and duration (score 3 = high impact) and its exacerbated effect on erosion and sedimentation (score 2 = moderate impact)¹² (both seen basin-wide) and; (ii) deforestation and land use change with its subsequent impact on erosion and sedimentation, habitat degradation and fragmentation and biodiversity loss (all three pathways with a magnitude score of 3 = high impact, also because it can be seen basin-wide). Deforestation and land use change also exacerbates flood and low flow magnitude, frequency, and duration (magnitude score 2 = moderate impact) and catchment ecosystem regulatory¹³ and provisioning¹⁴ services (magnitude score 2 = moderate impacts). The stressors/primary impacts (i) environmental degradation other than deforestation; (ii) changes to flow regime; and (iii) influx of people are assessed to have a lower magnitude of impacts in its different pathways towards the secondary impacts, for the current situation¹⁵. They are generally also less basin-wide than the two most prominent stressors/primary impacts mentioned above.

The VEC groups that are most impacted through the pathways from the secondary impacts, for the current situation, are (i) biodiversity and habitats for wildlife, birds, and aquatic life (flagship VEC species and habitats); (ii) ecosystem services for livelihood (both with an aggregated score in the high impact range); and (iii) reliable water availability and quality (aggregated score between 140-200). More moderately impacted high impact range (aggregated score between 80-140) are: (iv) productive land/soil for agriculture (especially at community level) and (v) tourism and social services. The last VEC group, (vi) historical, cultural, and religious sites, is less affected (aggregated score in the low impact range between 10-80).

¹¹ *Environmental degradation other than deforestation.*

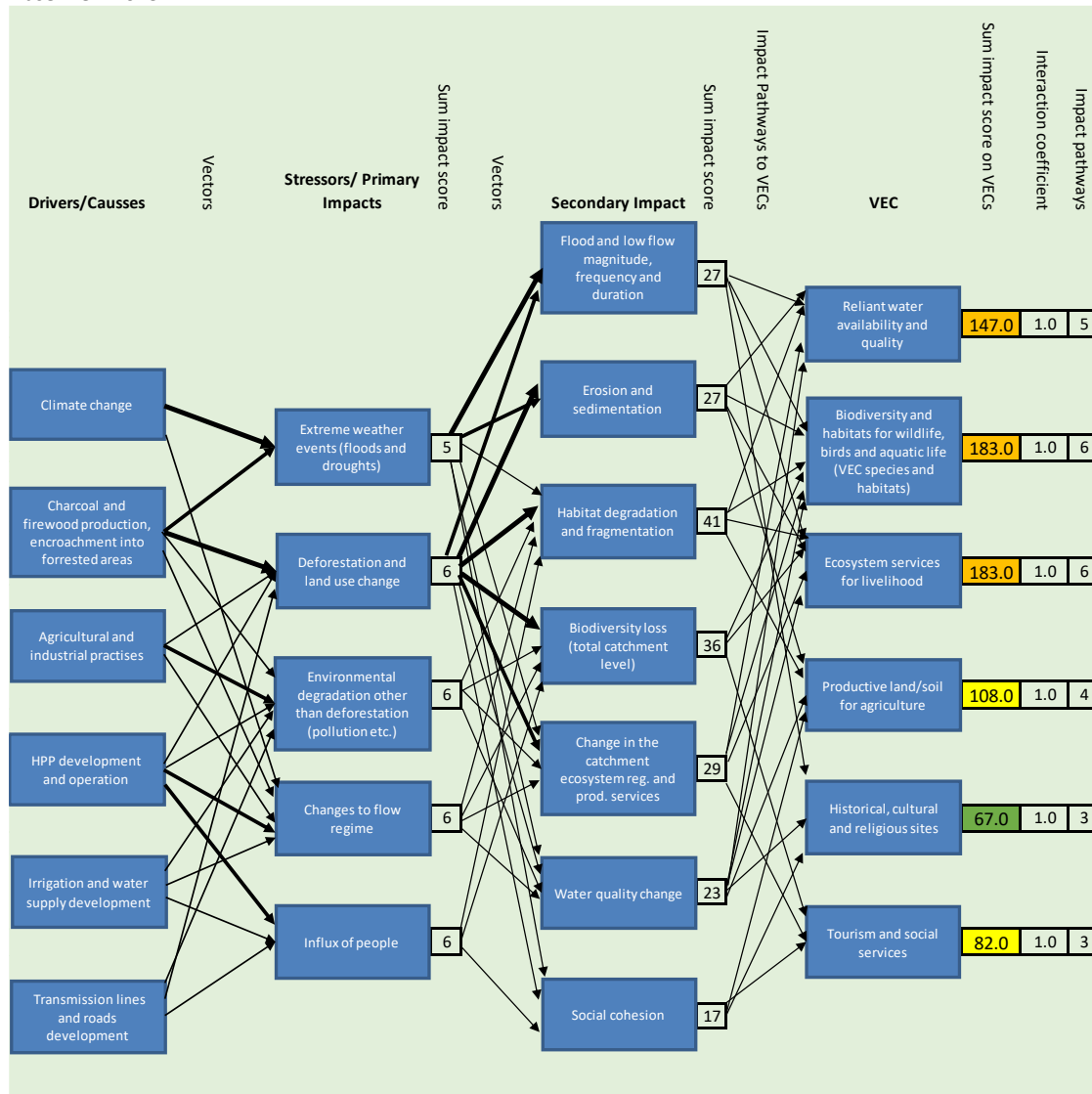
¹² *Three other impact pathways are given a score of 1 (low impact).*

¹³ *For example, water purification, erosion and flood control (soil stabilization), and carbon storage and climate regulation*

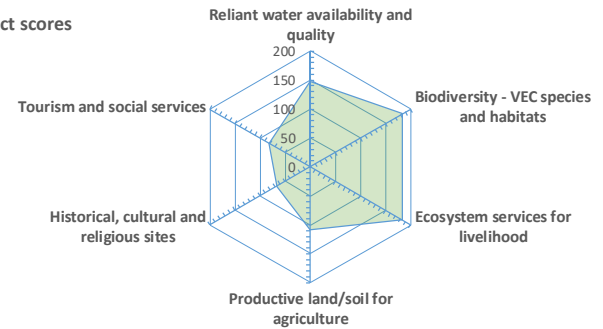
¹⁴ *Like plants and animals (including fish) for livelihoods, important for example in the Elephant Marsh.*

¹⁵ *All their impact pathways are for the current situation assessed to have an impact score of 1 (low impact)*

Baseline 1 2023



Sum, Impact scores

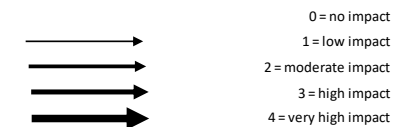


VECs

VECs	Sum	IC*	Impact Pathways
Reliant water availability and quality	147.00	1.00	5.00
Biodiversity - VEC species and habitats	183.00	1.00	6.00
Ecosystem services for livelihood	183.00	1.00	6.00
Productive land/soil for agriculture	108.00	1.00	4.00
Historical, cultural and religious sites	67.00	1.00	3.00
Tourism and social services	82.00	1.00	3.00

*IC= Interaction Coefficient

Vectors toward primary and secondary impacts



Ranges for sum impact score on VECs

Severe Impact	> 200
High Impact	140 - 200
Moderate Impact	80 - 140
Low Impact	10 - 80
Negligible Impact	0-10

Figure ES-0-6 The CIA Impact Pathway Network Analysis of Baseline Scenario 1, i.e. current situation (2023).

Summary of Near Natural Scenario (Early 1900)

Conditions in the basin in early 1900 is anticipated to have been characterised by a largely pristine and unmodified Shire River Basin with largely intact forest, terrestrial and riverine ecosystems (see also Multiconsult et. al, 2023, Scoping Report Vol 1 Chapter 5 for details). The Chiromo Bridge and railway embankment was, however, constructed in 1907 with some impacts on the extent of lakes in the southern portion of the Elephant Marsh. Basin population has been estimated to be low (see Table ES-1). The drivers/causes have been anticipated to have either no or low impact on the stressors/primary impacts and subsequently also on the secondary impacts and finally on the VECs. The total impact score on the four VEC groups (i) reliable water availability and quality; (ii) biodiversity and habitats for wildlife, birds and aquatic life; (iii) ecosystem services for livelihood; and (iv) productive land/soil for agriculture has been estimated to be in the lower portion of the low impact score range (10-80), whilst both (v) historical, cultural and religious sites and (vi) tourism and social services has been estimated to have been negligibly impacted.

Near Natural Scenario (1900)

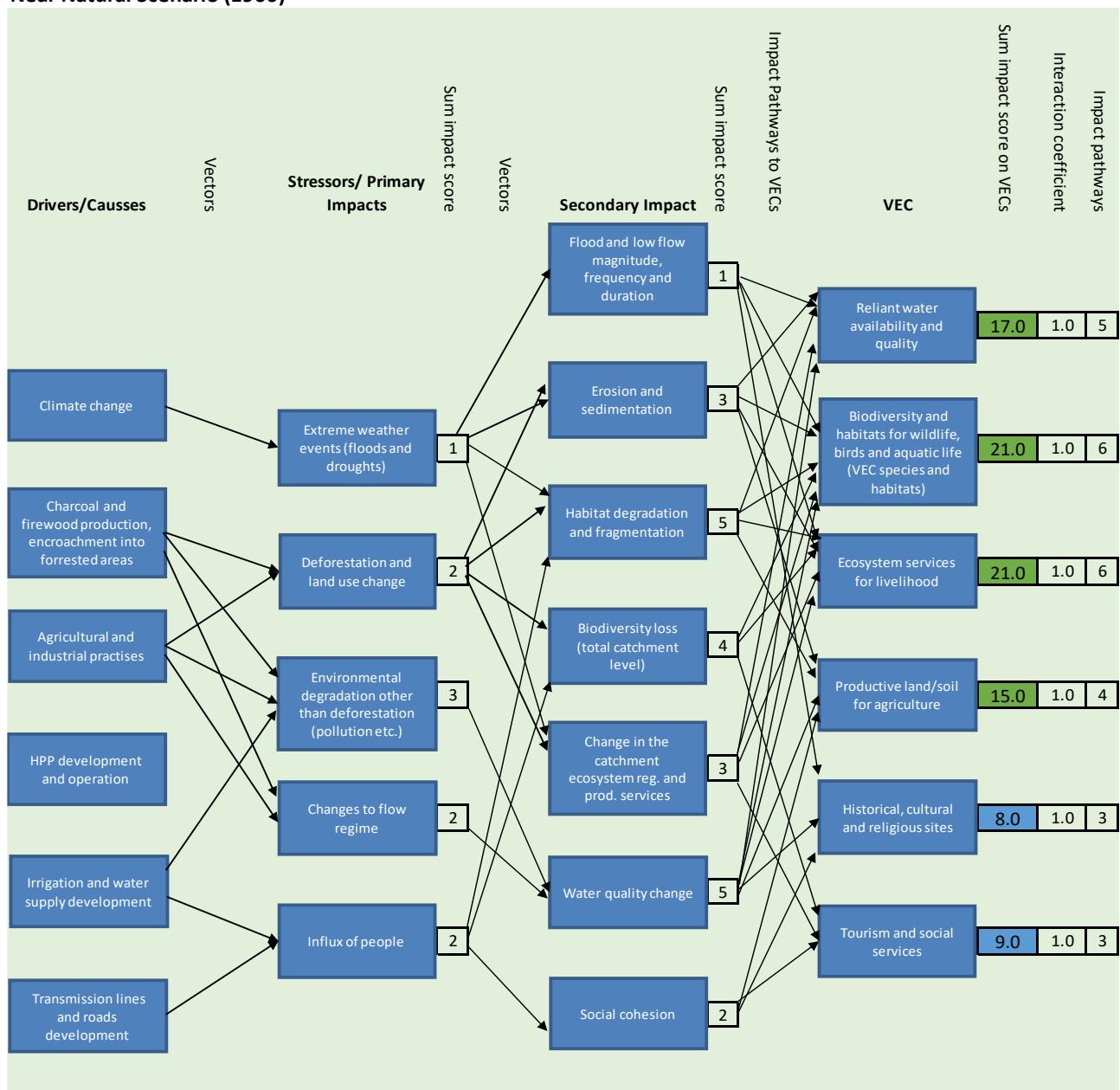


Figure ES-0-7 CIA analysis results of the Near Natural Scenario (early 1900).

Summary of Historical (Trended) Scenario

The trended scenario set has been divided into three distinct periods, i.e. pre-1992, 1992 to 2002 and lastly 2002 to 2022. The basin development between 2002 and 2022 is captured in Baseline Scenario 1 (2023).

Pre-1992

Between 1900 and 1992 we see a stark population increase in the basin, and the estimated population in the basin in 1992 was at 2 200 000 (see Table ES-1), putting more pressure on the basin. Between 1900 and 1992 several major historical events have also affected the aquatic and terrestrial ecosystems of the Shire, many of them directly related to the interplay between human pressures (deforestation, over-fishing, transformation of wetlands). In this period, we also see the development of the first major in-channel infrastructure such as Kamuzu Barrage, the first stages of the Tedzani and Nkula hydropower plants, bridges, and embankments, as well as transmission lines and roads etc. affecting the terrestrial environment. With regards to hydrology Lake Malawi levels (that dictate/affect the baseflows of Shire) are characterised by a period of low levels between 1900-1940, whilst between 1940-1992 there is a period of medium lake levels (see Table ES-2). Some deforestation is occurring, but this becomes more prominent during the next periods (see Table ES-3). Loss of megafauna due to hunting and poaching also occurs in this period.

Table ES-0-2 Key historical events affecting the ecological integrity of the Shire Basin Pre-1992.

Date	Event	Consequences for the aquatic ecosystems	References
1900 onwards	Loss of megafauna	Movements of hippopotamus (<i>Hippopotamus amphibius</i>) and elephant (<i>Loxodonta africana</i>) create incised, vegetation-free pathways on the floodplain and in the Marsh through which water can flow during flooding, diverting water and sediment into adjacent areas. These are valuable fish habitats.	Mosopele <i>et al.</i> (2009)
Hydrology			
1900-1940	Lake Malawi levels low	Lake Malawi levels dictate the baseflows in the Shire River, particularly prior to the construction of the Kamuzu Barrage. Higher baseflows translate into greater flooded areas, such as wetlands and lakes in the Lower Shire River.	Birkhead <i>et al.</i> (2022); Bhave <i>et al.</i> (2020)
1941-1970	Lake Malawi levels medium		
1971-1990	Lake Malawi levels medium		
In-channel infrastructure			
1907	Chiromo Bridge and railway embankment constructed	Changes in the extent of lakes in the southern portion of the Marsh linked to construction, and subsequent breaches and repairs, of the railway embankment	Birkhead <i>et al.</i> (2022)
1948	Chiromo Bridge and railway embankment washed away		
1949	New Chiromo Bridge and railway embankment constructed		
1956	Bund constructed across the Shire River to prevent outflow from Lake Malawi	Probably no long-term impacts but would have reduced dry season flows in the Shire for a short time.	Birkhead <i>et al.</i> 2022

Date	Event	Consequences for the aquatic ecosystems	References
1965	Kamuzu Barrage constructed	The Kamuzu Barrage at Liwonde, constructed in 1965, is the main regulating facility on Shire River. It is intended to facilitate development and operation of hydropower plants in Middle Shire, and to support irrigation in the Lower Shire. The barrage dampens the seasonal pattern of flows in the downstream river.	Birkhead <i>et al.</i> (2022)
1973	Tedzani I operationalised	Operated also as a hydropeaking plant when demand requires. Hydropeaking fundamentally changes conditions in the downstream river. Damage to ecosystems and people is well-documented. In the case of the Shire, hydropeaking affects the river for 100s of kilometres downstream of turbines.	
1980	Nkula 1 operationalised	Operated also as a hydropeaking plant when demand requires.	
1986	Nkula 2 operationalised		
1992	Nkula 3 operationalised		
Major cyclones and tropical storms			
1946	Cyclone “Edith”	Major flooding. Changes in the extent of lakes in the southern portion of the Marsh linked to construction, and subsequent breaches (during floods) and repairs, of the railway embankment	Ngongondo <i>et al.</i> (2011)

All drivers/causes impacting the basin health comes into play during this period, albeit they are anticipated to have low impact compared to current conditions (2023) on the stressors/primary impacts. However, the combined effect of (i) charcoal/firewood production and encroachment into forested areas (ii) expansion of agricultural and industrial practises (iii) HPP development/operation and (iv) transmission lines and roads development on deforestation and land use change (stressor/primary impact) leads to a combined moderate impact on (i) habitat degradation and fragmentation and (ii) biodiversity loss at catchment level (both secondary impacts). The total impact score on the two VEC groups (i) biodiversity and habitats for wildlife, birds and aquatic life, and (ii) ecosystem services for livelihood is estimated to be moderately impacted, whilst the four other VECs are assessed to be in the range of low impact.

Trended Pre 1992

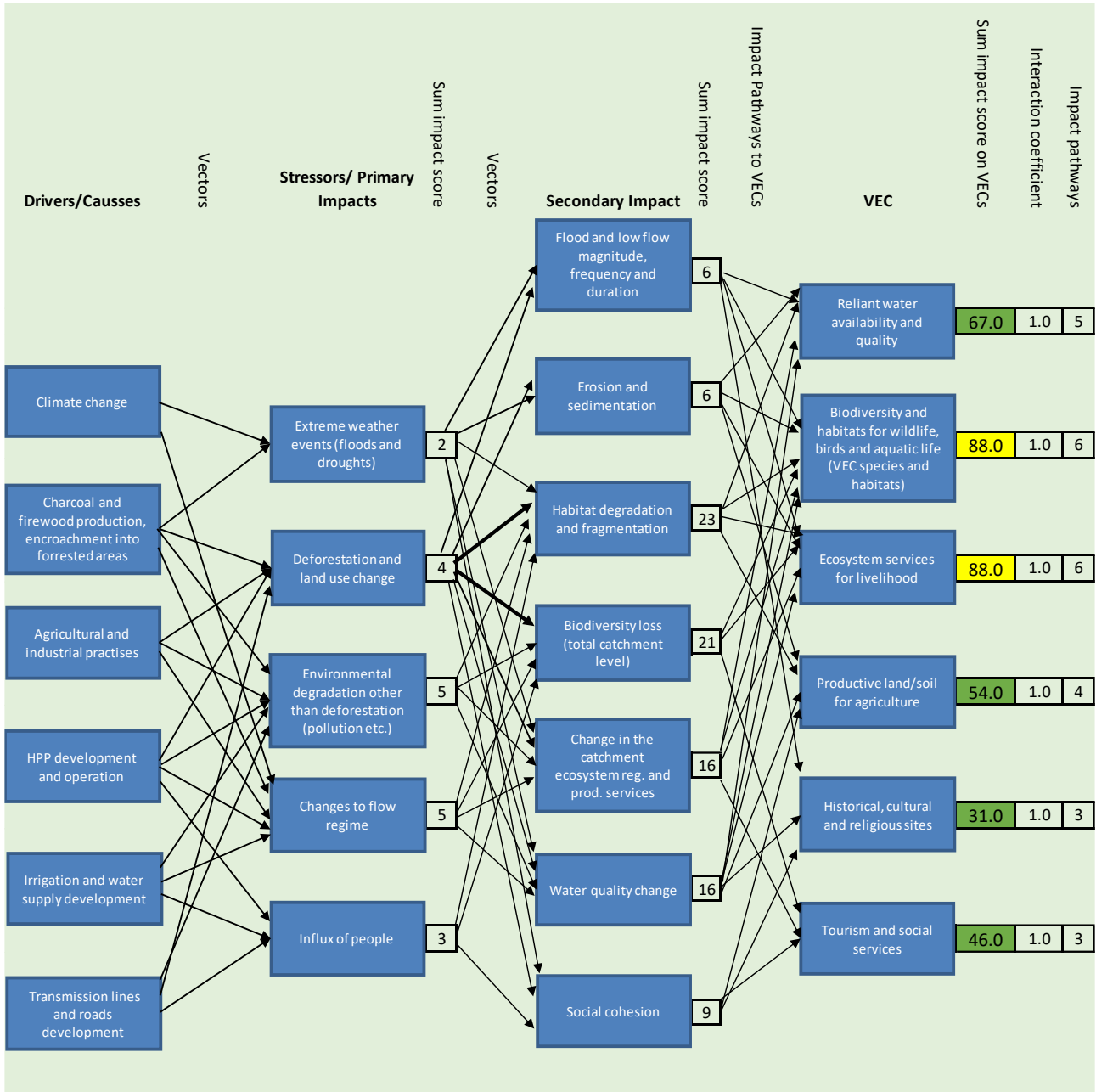


Figure ES-0-8 CIA analysis results of the Trended Scenario Pre-1992.

1992-2002 Period

Between 1992 and 2022 the population in the basin is estimated to have increased from 2 200 000 to 2 600 000. Further infrastructure comes online including Tedzani II (1996), Kapichira Phase I (2000), and transmission lines and roads development continues. Deforestation rates also increase in this period with charcoal/firewood production and encroachment into forested areas as the main driver/cause.

Table ES-0-3 Key historical events affecting the ecological integrity of the Shire Basin 1992-2002.

Date	Event	Consequences for the aquatic ecosystems	References
1996	Tedzani II operationalised	Operated also as a hydropeaking plant when demand requires.	Birkhead <i>et al.</i> (2022)
2000	Kapichira Phase 1 operationalised	Partially operated as a hydropeaking plant, with severe consequences for downstream river. In addition, sediment management (sediment flushing and sediment dumping) has been damaging to both the upstream and downstream river.	Southern Waters (2022)
Deforestation and sedimentation			
1990-2023	Impacts of deforestation become increasingly evident in landcover	Sediment supply to the Shire River increased significantly with deforestation of the upper catchment. Sedimentation in the Elephant Marsh increased from ~10 mm/yr in the early part of the 20 th century to ~34 mm/yr) in the early part of the 21 st century.	Mzuza <i>et al.</i> (2019)

Some of the drivers/causes impose bigger pressure during this period than the previous one (Pre-1992) on the basin health and on the stressors/primary impacts, with (i) climate change, (ii) expansion of agricultural and industrial practises, and (iii) HPP development/operation set to have moderate impact on various stressors/primary impact, whilst charcoal/firewood production and encroachment into forested areas is estimated to have high/very high impact on deforestation and land use change. Habitat degradation and biodiversity loss continues (secondary impact) but there is also an increase in impact on (i) flood and low flow magnitude, frequency and duration and (ii) erosion and sedimentation. The total impact score on the two VEC groups (i) biodiversity and habitats for wildlife, birds and aquatic life, and (ii) ecosystem services for livelihood is estimated have to been highly impacted, whilst (iii) reliable water availability and (iv) productive land/soil for agriculture is estimated at moderate impact. The two last VEC groups, (i) historical, cultural and religious sites and (ii) tourism and social services, is estimated to still be in the low impact range.

Trended 1992-2002

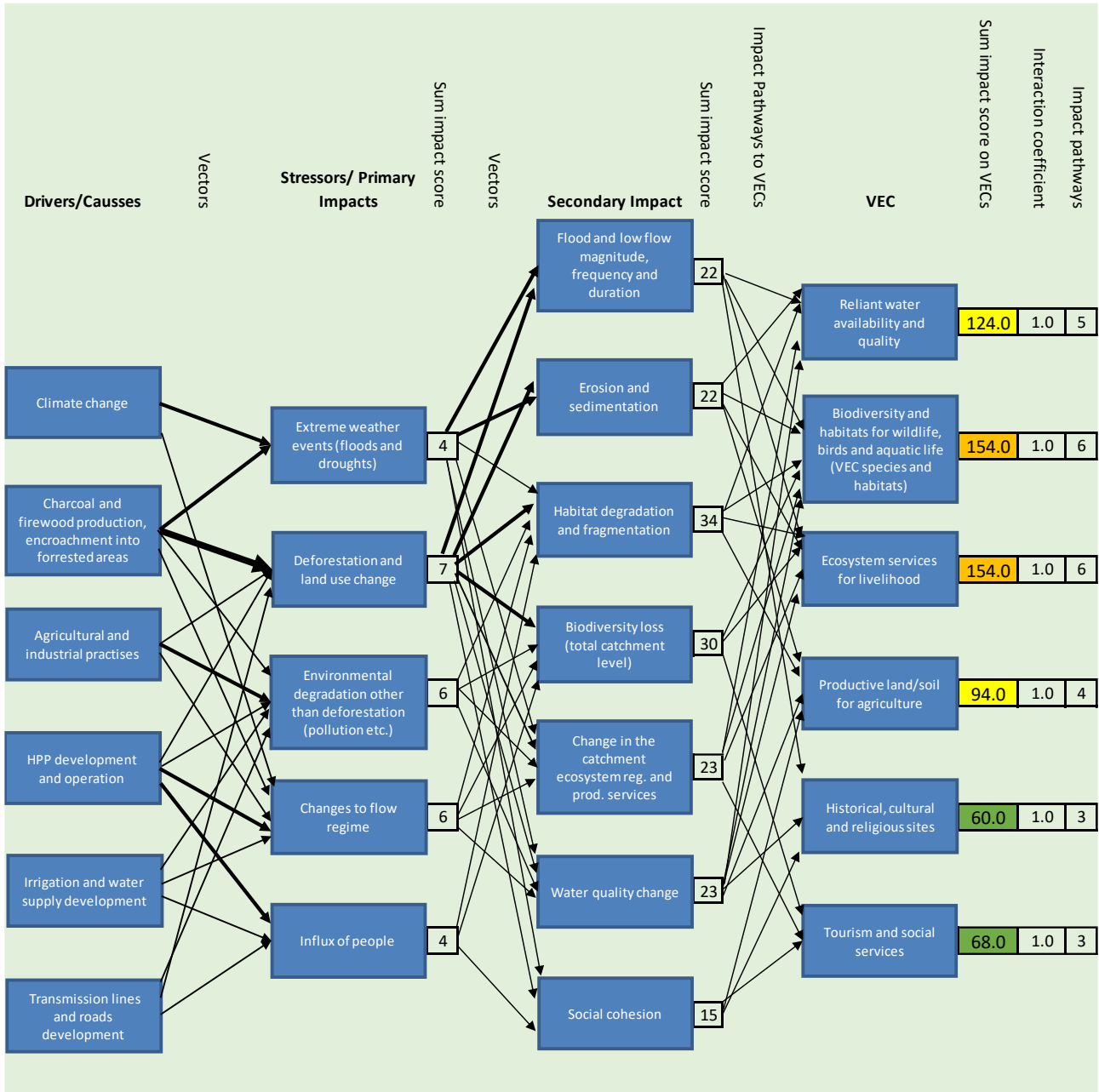


Figure ES-0-9 CIA analysis results of the Trended Scenario 1992-2002.

2002-2022 Period

Obviously, the impact on the basin over this period is very similar to that of the current situation (Baseline 1 2023) and its impact pathways, so reference is made to the impact pathway diagram ES-6 with regards to impact scores on VECs and elsewhere in the pathway. Compared to the previous period, forest degradation continues at the same rate for the first 10 years but seems somehow to stabilise around 2012-2015. Basin population increases to an estimated 4 500 000 in 2022. Further infrastructure developments come into place or are under construction including Kapichira Phase 2 (2014), Tedzani III (2017), Upgrading of Kamuzu Barrage (2018) and SVTP canal, amongst others. There is also a stark increase in the frequency of major cyclones and tropical storms over this period, especially in the last 10 years (see Table ES-4).

Table ES-0-4 Key historical events affecting the ecological integrity of the Shire Basin 2002-2022.

Date	Event	Consequences for the aquatic ecosystems	References
2014	Kapichira Phase 2 operationalised	Partially operated as a hydropeaking plant, with severe consequences for downstream river. In addition, sediment management (sediment flushing and sediment dumping) has been damaging to both the upstream and downstream river.	Southern Waters (2022)
2017	Tedzani III operationalised	Operated as a hydropeaking plant when demand requires.	Bhave <i>et al.</i> (2022)
2018	Upgrading of Kamuzu Barrage	No major impact, but greater control of Shire River flow regime.	
2021	Construction starts on the Shire Valley Transformation Program (SVTP)s	Once constructed, the off take for the canal will affect dry season low flows in the Lower Shire. While this is a move back towards a more natural seasonal distribution of flow, it will also facilitate greater intrusion of cultivated fields into wetland areas.	http://stvp.gov.mw
2022	Cyclone Ana causes a break in the Kapichira dam wall at the point at which STVP canal joins		
2022	Repair works to Kapichira dam wall		
Deforestation and sedimentation			
1990-2023	Impacts of deforestation become increasingly evident in landcover	Sediment supply to the Shire River increased significantly with deforestation of the upper catchment. Sedimentation in the Elephant Marsh increased from ~10 mm/yr in the early part of the 20 th century to ~34 mm/yr in the early part of the 21 st century.	Mzuza <i>et al.</i> (2019)
Major cyclones and tropical storms			
2015	Tropical Storm Chedza	Major flooding. Realignment of Ruo River into the Southern Elephant Marsh as a direct result of increased sedimentation at the Shire/Ruo confluence.	Birkhead <i>et al.</i> 2022
2019	Cyclone Desmond	Major flooding	https://www.worlddata.info/africa/malawi/cyclones.php
2003	Tropical Storm Delfina		
2021	Cyclone Eloise		
2021	Cyclone Guambe		
2022	Cyclone Ana	Major flooding. Kapichira Dam bursts	
2022	Cyclone Gombe	Major flooding	
2023	Cyclone Freddy		

Summary of Baseline Scenario 2 (2030)

This scenario constitutes two sub-scenarios, i.e. with and without Mpatamanga HPP, respectively (see Table ES 1), as well as other dams/HPPs in the basin. In the sub-scenario with Mpatamanga in place (2.2) this leads to Kapichira turning into non-peaking mode compared to peaking without Mpatamanga in place. SVTP is also in place (with Illovo and Agricane connected) as well as transmission lines (including MOMA). Forest cover is anticipated to be similar to 2023, and basin population is estimated to have risen to 5 500 000.

The drivers/causes imposing the biggest pressure on the basin health and on the stressors/primary impacts are for sub-scenario 2.1 (without Mpatamanga) still charcoal/firewood production and encroachment into forested areas (very high impact on deforestation) and climate change (high impacts on extreme weather events). For sub-scenario 2.2 Mpatamanga HPP is anticipated to increase the impact on changes to flow regime and influx of people (both set at high impact). The other stressors/primary impacts are anticipated to be negligibly affected by Mpatamanga at basin scale level, albeit some more local impacts are anticipated with regards to land use change and environmental degradation (reservoir and dam area of main dam and regulating dam). Habitat degradation, biodiversity loss and changes to the basin ecosystem services increase compared to Baseline 1, but at basin scale Mpatamanga is estimated to cause minor changes because deforestation is still largely driven by charcoal/firewood production and encroachment into forested areas. The influx of people due to Mpatamanga and other infrastructure like SVTP and MOMA is also increasing the impact on social cohesion. Erosion and sedimentation also increase due to deforestation and extreme weather events. The latter also increases the impacts on flood and low flow magnitude, frequency and duration. The total impact score on the two VEC groups (i) biodiversity and habitats for wildlife, birds and aquatic life, and (ii) ecosystem services for livelihood is estimated to be severely impacted in both sub-scenarios, with only a slight increase with Mpatamanga in place (which is also the case for the overall VEC outcomes in the DRIFT ESM assessment in Volume 3). The continued basin degradation and extreme weather events continue to impact the reliable water availability and quality in both sub scenarios, and there are little differences with and without Mpatamanga, with both impacts scored as high. Impacts on productive land/soil for agriculture and tourism and social services are estimated at moderate for both sub-scenarios, whilst historical, cultural and religious sites rise from low impact without to moderate impacts with Mpatamanga (mainly due to the construction of the dam complex and influx of people).

Baseline 2 (2030) without Mpatamanga

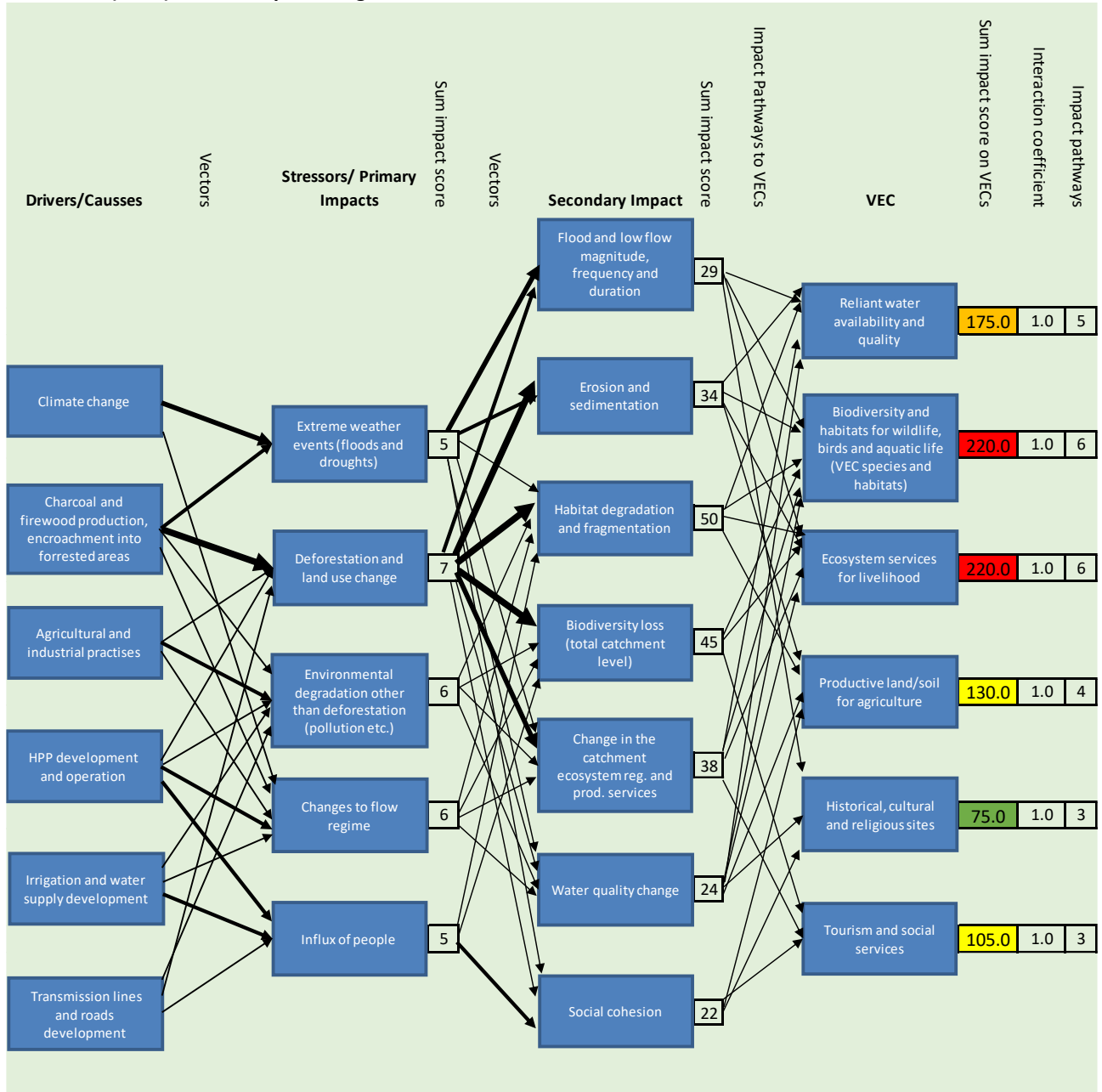


Figure ES-0-10 CIA analysis results of Baseline Scenario 2.1, without Mpatamanga.

Baseline 2 (2030) with Mpatamanga

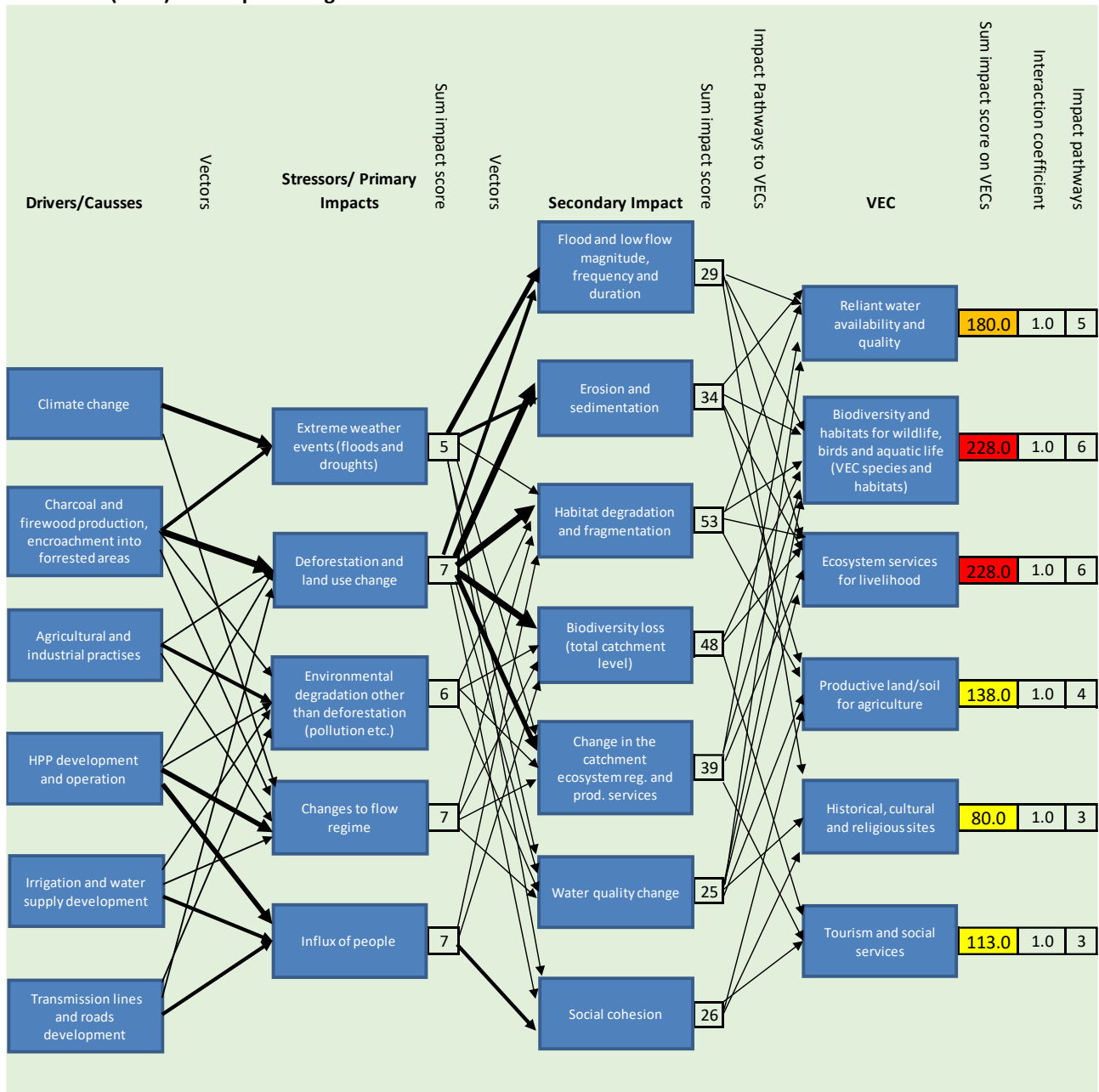


Figure ES-0-11 CIA analysis results of Baseline Scenario 2.1, with Mpatamanga.

Near Future Scenarios 1, 2 and 3 (2035)

This set constitutes the business as usual (BAU) scenario (Near Future 1), BAU with joint dams’ operation (BAU + JDO) scenario (Near Future 2) and BAU + JDO with climate change (CC) scenario (Near Future 3). Basin degradation continues and the impact profile in the impact pathway towards the VECs is quite similar, especially between Near Future 1 and 2 (only a slight decrease on VECs due to JDO, but with an increase again when adding climate change). The latter leads to increases in extreme weather events, with its subsequent increases in impacts on (i) flood and low flow magnitude, frequency and duration, and (ii) sedimentation and erosion (see also Annex 1, 2 and 3). Near Future 1 impact scores are exemplified in the figure overleaf. Impacts on the three VEC groups (i) reliable water availability and quality; (ii) biodiversity and habitats for wildlife, birds and aquatic life; and (iii) ecosystem services for livelihood are estimated to be

severe, while (iv) productive land soil for agriculture is high, and the two last are moderate. For Near Future Scenarios 2 and 3 reference is made to the main report, Section 7.

Near Future 1 (2035) - BAU

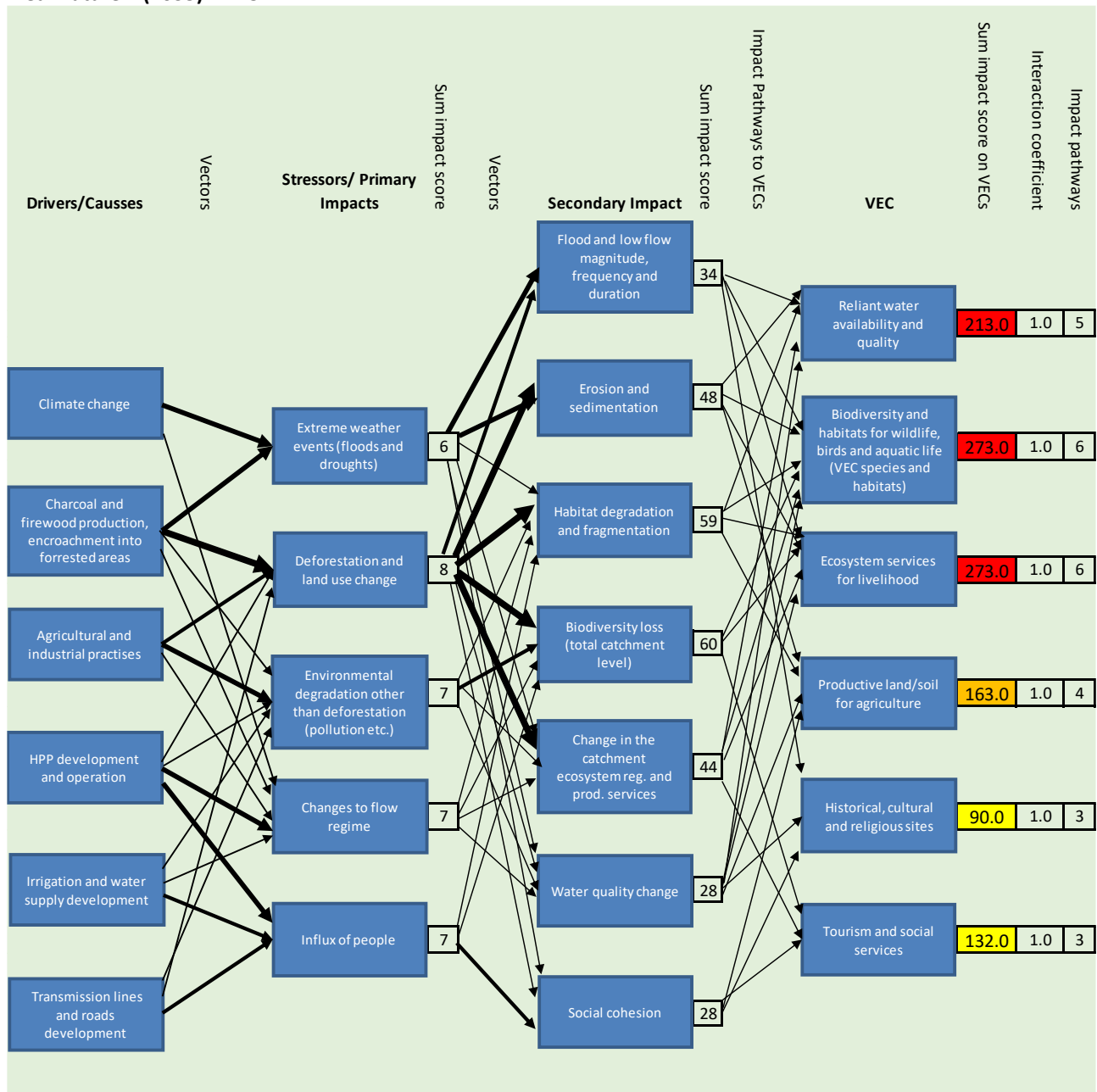


Figure ES-0-12 CIA analysis results of Near Future Scenario 1 (2035).

Near Future Scenario 4

This scenario is the sustainable pathway scenario where we sequentially include catchment restoration, reforestation and mitigation measures via: *Stepwise build in (1) catchment rehabilitation, (2) tourism and protected areas management, and (3) Sustainable land use enhancement and energy source transition in the basin.* Reference is also made to Table ES 1 for more details. In the diagram shown overleaf we have included all three steps. Impacts of each of the three steps are described in the main report, Chapter 7. As can be seen in Figure ES-13, the reduction in magnitude of the impacts from especially (i) charcoal/firewood production

and encroachment into forested areas and (ii) agricultural and industrial practices have knock on effects on many of the stressors/primary impact and secondary impacts, leading to reduction of impacts on all VEC groups compared to Near Future 1, 2 and 3 Scenarios. Impacts are lowered to moderate (4 VEC groups) or low (2 VEC groups).

Near Future (2035) - Sustainable Pathway (Step 1+2+3)

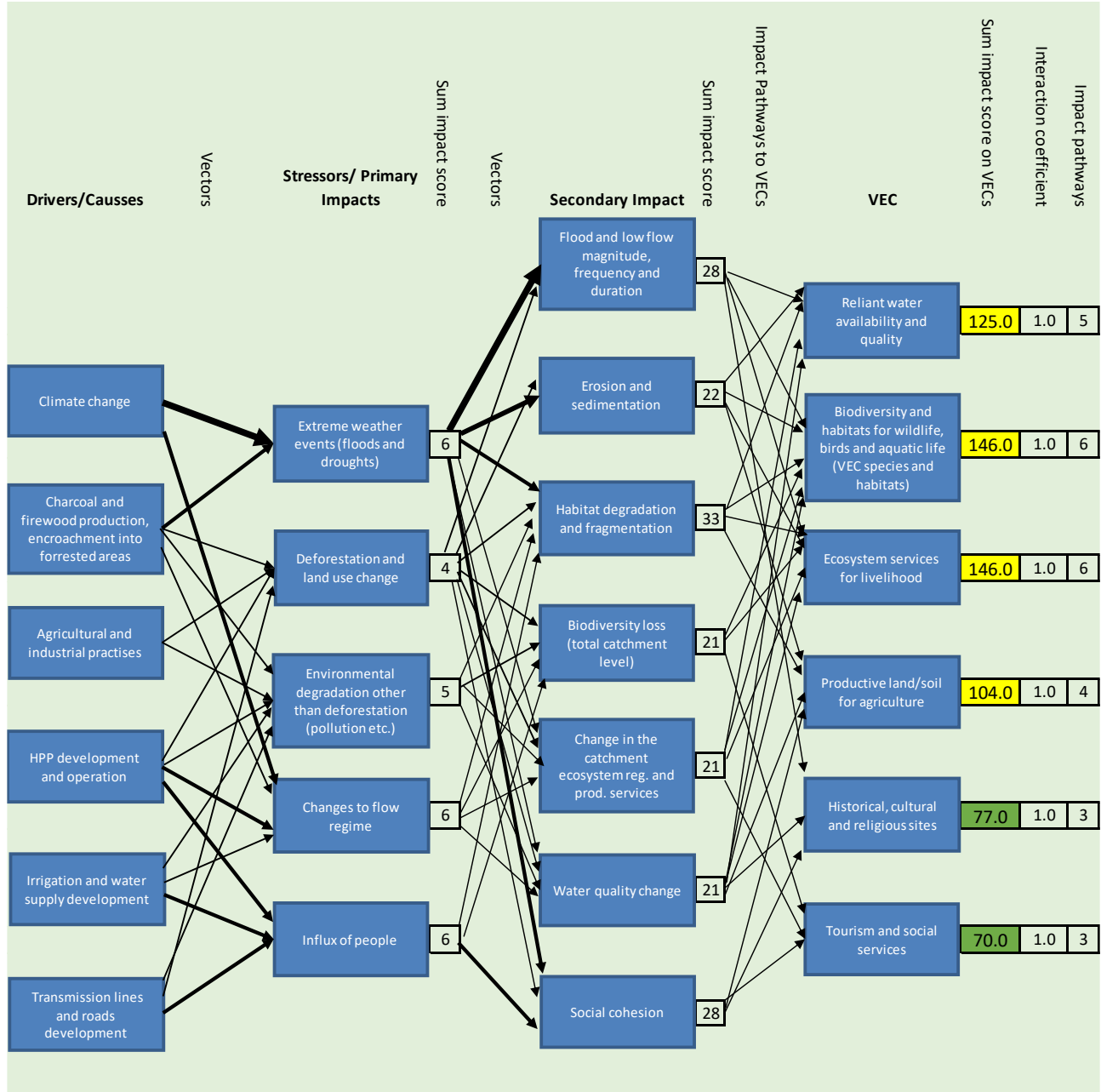


Figure ES-0-13 CIA analysis results of Near Future Scenario 4 (2035).

Distant Future Scenario 1 and 2 (2070)

This scenario set constitutes the BAU for 2070 (Distant Future 1), which is similar to Near Future 1 (2035) but with further basin degradation and more extreme weather events due to climate change, and the Sustainable Pathway Scenario for 2070 (Distant Future 2) with continued basin restoration and reforestation as of Near Future 4 scenario. As can be seen from Figure ES 14, in the BAU case (Near Future 1), the magnitude of almost all impact pathways becomes more prominent eventually leading to severe impact scores on all VEC groups.

Hence, we are probably witnessing a possible major change in the state of the basin ecosystems with its subsequent impacts on livelihoods, etc., if no large-scale restoration, reforestation and other mitigation measures are implemented.

Distant Future (2070) - BAU + CC

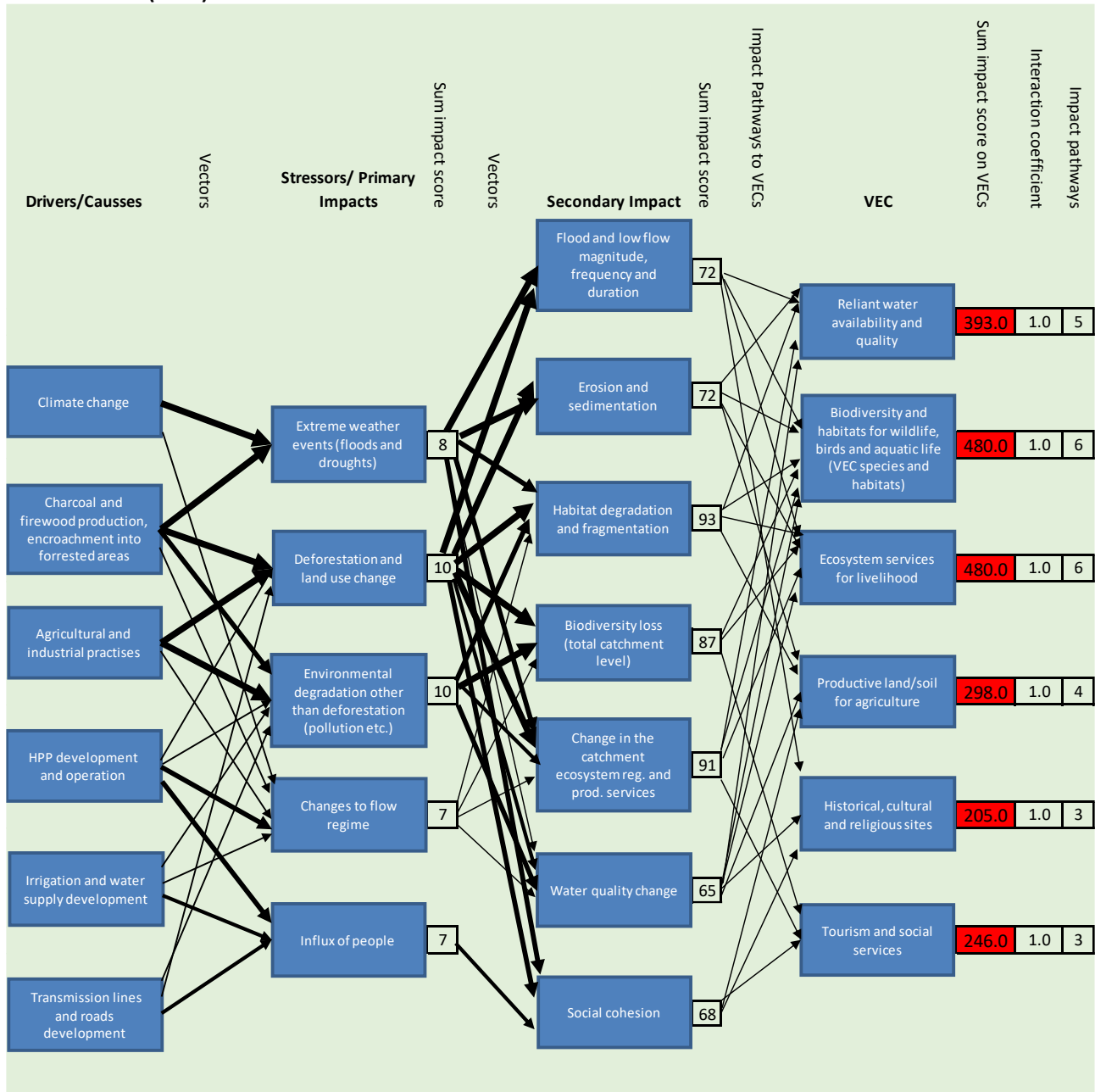


Figure ES-0-14 CIA analysis results of the Distant Future Scenario 1 (2070).

On the other hand, if the steps in the sustainable pathways continue to be implemented up to 2070, the basin health and impacts on the VECs are significantly reduced as shown in Figure ES-15. Only continued climate change remains somehow prominent. Impacts on all VEC groups are considerably lowered and are even lower than for Near Future 4, due to the continued restoration, reforestation and other mitigation measures. Three of the VEC groups are in the moderate impact range and the remaining three are in the low impact range.

Distant Future (2070) - Sustainable Pathway (Step 1+2+3)

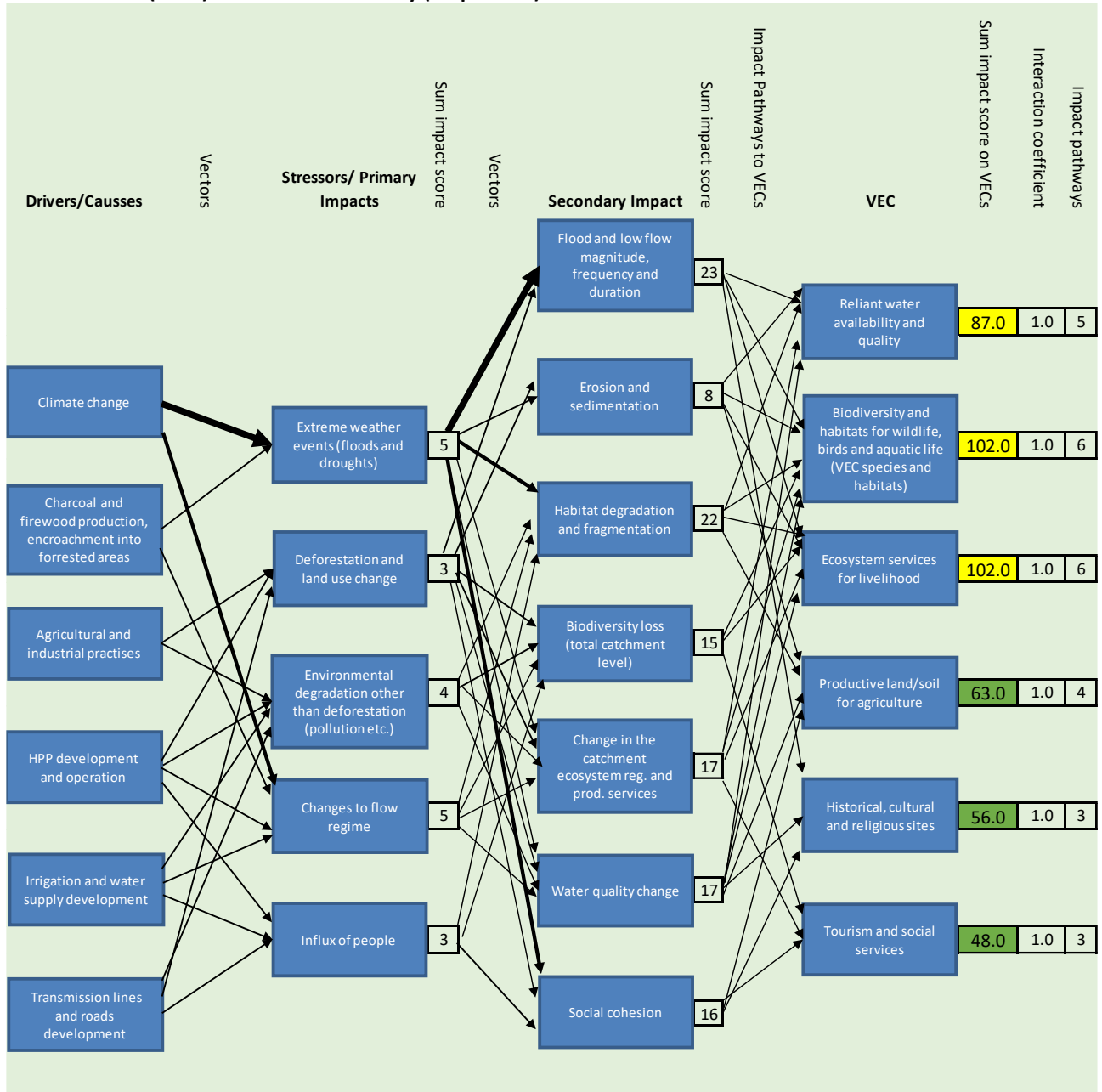


Figure ES-0-15 CIA analysis results of the Distant Future Scenario 2 (2070).

A summary table of impacts on VECs for all scenarios is given in Table ES 0-5 overleaf.

Table ES 0-5 Summary VEC impact table for all scenarios.

VEC	Without Mpatamanga HPP							With Mpatamanga HPP						
	Near natural and historical scenarios				Baseline scenarios			Near Future				Distant Future		
	Early 1900s	Pre-1992	1922-2002	2002-2022	2023	2030	2030	2035				2070		
								BAU	BAU+JDO	BAU+JDO+CC	SP+JDO+CC	BAU	SP+JDO+CC	
Reliable water availability and quality	Low Impact	Low Impact	Moderate Impact	High Impact	High Impact	High Impact	High Impact	Severe Impact	Severe Impact	Severe Impact	Moderate Impact	Severe Impact	Moderate Impact	
Biodiversity and habitats	Low Impact	Moderate Impact	High Impact	High Impact	High Impact	Severe Impact	Severe Impact	Severe Impact	Severe Impact	Severe Impact	Moderate Impact	Severe Impact	Moderate Impact	
Ecosystem services for livelihoods	Low Impact	Moderate Impact	High Impact	High Impact	High Impact	Severe Impact	Severe Impact	Severe Impact	Severe Impact	Severe Impact	Moderate Impact	Severe Impact	Moderate Impact	
Productive land/soil for agriculture	Low Impact	Low Impact	Moderate Impact	Moderate Impact	Moderate Impact	Moderate Impact	Moderate Impact	High Impact	High Impact	High Impact	Moderate Impact	Severe Impact	Low Impact	
Historical, cultural and religious sites	Insignificant Impact	Low Impact	Low Impact	Low Impact	Low Impact	Low Impact	Moderate Impact	Moderate Impact	Moderate Impact	Moderate Impact	Low Impact	Severe Impact	Low Impact	
Tourism and social services	Insignificant Impact	Low Impact	Low Impact	Moderate Impact	Moderate Impact	Moderate Impact	Moderate Impact	Moderate Impact	Moderate Impact	Moderate Impact	Low Impact	Severe Impact	Low Impact	

Cumulative Impacts Management Measures and Monitoring

Measures to mitigate impacts of hydropower and other infrastructure and basin developments can include a combination of measures that may be classified into four main categories of action: **avoid, minimise, restore, and offset**—known as the mitigation hierarchy (IFC, 2021). The mitigation hierarchy is a widely used tool that guides users towards limiting as far as possible the negative impacts on environment and human well-being from development projects. It emphasises best-practice of avoiding and minimising any negative impacts, and then restoring sites no longer used by a project, before finally considering offsetting residual impacts (adapted from IFC 2021 and TBC 2015¹⁶, but tailored to the CIA of Mpatamanga HPP on the Shire River Basin).

- **Avoidance** through choices about project selection, location/site selection, engineering designs, and operating practices. Avoidance is often the easiest, cheapest and most effective way of reducing potential negative impacts, but it requires environmental and social impacts to be considered in the very early stages of a project or a portfolio of projects.
- **Minimisation** through measures taken to reduce the duration, intensity and/or extent of impacts that cannot be completely avoided. Effective minimisation can eliminate some negative impacts, such as measures to reduce noise and pollution, designing powerlines to reduce the likelihood of bird collisions/electrocutions, or building wildlife crossings on roads. Minimisation can also include provision of environmental flows (EFlows), fish passages (not relevant for Mpatamanga), and sediment flushing facilities.
- **Restoration/rehabilitation** through improving degraded or lost ecosystems or habitats following exposure to impacts that cannot be completely avoided or minimised in the basin/sub-basins and by restoring livelihoods and incomes of affected and resettled communities.

Collectively, avoidance, minimisation and rehabilitation/restoration serve to reduce, as far as possible, the residual impacts that a project (or as for this CIA a portfolio of projects and developments) has on the environment, livelihoods, incomes, etc.

- **Offset or compensate:** Offsetting aims to compensate for any residual adverse impacts after full implementation of the previous three steps of the mitigation hierarchy and is most often linked to biodiversity. Biodiversity offsets are of two main types: ‘restoration offsets’ which aim to rehabilitate or restore degraded habitat, and ‘averted loss offsets’ which aim to reduce or stop biodiversity loss in areas where this is predicted. Offsets are often complex and expensive, so attention to earlier steps in the mitigation hierarchy is usually preferable. In the case of social impacts this refers to compensation for loss of livelihoods or resettlement.

In the following a set of identified catchment scale mitigation measures are listed as relevant for the sustainable development of the Shire River Basin, and most of them go beyond that of the Mpatamanga HPP. For more project scale mitigation measures, reference is made Chapter 11 in this CIA and to the ESIA and BAP main reports (both 2024) for the Mpatamanga HPP.

¹⁶ TBC. 2015. *A cross-sector guide for implementing the Mitigation Hierarchy*.

Table ES-5 Identified catchment scale mitigation measures for the Shire River Basin.

No	Mitigation Measure	Key Risks and Impacts	Expected Outcomes	Parties Responsible for Implementation	Relevant Regulatory Framework	Preliminary costing of measure (Responsible Unit)	Reference source if relevant
Catchment Scale Cumulative Mitigation Measures (Shire Basin and/or Sub-Basins therein)							
1	<p>Joint operation of Shire River Dams: Kamuzu Barrage, Nkula, Tedzani, Mpatamanga and Kapichira (and Kholombidzo if realized). The details on joint operation of the dams for optimization of power generation and flood management needs to be studied more in detail in a specialist study</p>	<ul style="list-style-type: none"> - Flood and drought risks - Sub-optimal power generation outputs - EFlows requirements in important (triggering) periods are not met - Geomorphological changes affecting livelihoods and riverine ecology 	<ul style="list-style-type: none"> - Coordinated flood monitoring and warnings - Optimization of power production across HPPs in the basin - Synchronization of EFlows for water uses, livelihoods and riverine ecology 	EGENCO, NWRA, MHPL	Environment Management Act (2017) and National Environmental Policy (2004), Water Resources Regulations (2018), Water Resources Act (2013) and Water Resources Policy (2005)	<ul style="list-style-type: none"> - Cost of EFlows release and flood management for each project (part of dams operation). For Mpatamanga (MHPL) this EFlows release and flood management is directly integrated as a constraint and commitment in the Implementation Agreement and accounted for in the estimates of power production. Kapichira, Nkula, Tedzani are the responsibility of EGENCO. Kamuzu Barrage is the responsibility of NWRA. - Mpatamanga EFlows monitoring cost is part of the ESIA/ESMP mitigation budget 	ESIAs/ESMPs for each HPP project

No	Mitigation Measure	Key Risks and Impacts	Expected Outcomes	Parties Responsible for Implementation	Relevant Regulatory Framework	Preliminary costing of measure (Responsible Unit)	Reference source if relevant
2	Institutional Strengthening of NWRA including a Stakeholder Co-Management Platform for Shire: MHPL should participate in such a Co-Management Platform together with EGENCO, NWRA, and other major water users such as SVTP, Agricane, Illovo etc.	<ul style="list-style-type: none"> - Sub-optimal water management of the Shire River 	<ul style="list-style-type: none"> - Better coordination of water management on the Shire, due to closer cooperation between main stakeholders, benefiting the water users and other relevant stakeholders 	NWRA, EGENCO, MHPL, SVTP etc.	Water Resources Regulations (2018), Water Resources Act (2013) and Water Resources Policy (2005)	<ul style="list-style-type: none"> - NWRA's own budget for strengthening its organisation - Stakeholder Co-Management Platform cost for MHPL. Less than 100 000 USD per year up to 2040. Preliminary period. Start in 2029 and end in 2040. Total cost at maximum = 1.1 Million USD 	NORPLAN. 2015. Consultancy Services Related to Financial and Institutional Aspects of the Kamuzu Barrage Management. SRBMP Phase 1.
3	Catchment rehabilitation that includes rehabilitation / reforestation of targeted erosion hotspot areas in tributaries with highest sediment yield to Shire, e.g. erosion hotspots in Ruo, Lisungwe, Nkulumadzi, Lirangwe, Likabula and maybe Rivi Rivi and Mwanza tribs) + MWASIP pilot areas in Lisungwe, Nkulumadzi, Lirangwe/Likabula.	<ul style="list-style-type: none"> - Deforestation due to charcoal extraction and agricultural encroachment - Sedimentation of the riverine ecosystem and degradation of it - Subsequent impact on livelihoods along the Shire 	<ul style="list-style-type: none"> - Reduced erosion rates and sediment transport with its positive impact on the riverine environment and ecology (biodiversity and habitats) 	<p>Department of Forestry, MWASIP/Ministry of Water and Sanitation, Department of Environmental Affairs</p> <p>Will require also public action to manage the impact of / deliver benefits for private activities</p>	Environment Management Act (2017) and National Environmental Policy (2004), Water Resources Regulations (2018), Water Resources Act (2013) and Water Resources Policy (2005), Forest Act (2017) and Forestry Amendment Act (2019)	<ul style="list-style-type: none"> - MWASIP total cost USD 110 Million (GoM, 2023). This includes also irrigation schemes development (WB funded). (WB 107 Million; GoM 3 Million USD) - Reforestation / rehabilitation of targeted erosion hotspot areas estimate at 20 Million USD (rough estimate). Some of this might be drawn from the total MWASIP cost above, but erosion hotspots include also areas outside MWASIP Pilot Catchments. Responsibility: Ministry of Natural Resources and Climate Change (Possible financing institutions) 	HR Wallingford (2023). Mpatamanga HPP Sediment Study: Baseline Report

No	Mitigation Measure	Key Risks and Impacts	Expected Outcomes	Parties Responsible for Implementation	Relevant Regulatory Framework	Preliminary costing of measure (Responsible Unit)	Reference source if relevant
						WB, EfDB, USAID, NORAD)	
4	<p>Enhancing tourism and protected areas management of protected areas in the basin, and then especially the selected Flagship VECs for the CIA, e.g. Liwonde NP, Majete WR, Lengwe NP and Elephant Marsh (incl. restricted access into, and cultivation in, the Elephant Marsh). The two first are quite well protected by African Parks running them but some encroachment etc. still occurs. Lengwe NP is under high pressure viz encroachment/ poaching and especially the New Lengwe part. The CIA suggests full restoration of New Lengwe or at least major parts of it. Tourism development should go hand in hand with strengthening of protected areas management.</p>	<ul style="list-style-type: none"> - Mpatamanga and Kapichira HPP construction and operation; SVTP construction; TL/Roads construction are drivers leading to: - Influx of workers and hence increased risk of deforestation (also due to additional charcoal/woodfuel extraction) - Biodiversity loss due to increased encroachment and poaching 	<ul style="list-style-type: none"> - Enhancement of protected areas; especially management of Elephant Marsh and restoration and management of Lengwe NP; Majete Community Buffer Protection Area (as of BAP study) - Enhanced protection of wildlife species (including Flagship VEC species) - Enhanced quality of Wildlife Tourism - Enhanced livelihood opportunities for local communities 	<p>Department Tourism, Department of National Parks and Wildlife, African Parks, Robin Pope</p> <p>MHPL could also have a role due to its support to the Biodiversity Offset between the reg dam and the main dam.</p>	<p>National Parks and Wildlife Act (1994), Environment Management Act (2017) and National Environmental Policy (2004), Fisheries and Aquaculture Policy (2016) and Fisheries Conservation and Management Act (1998)</p>	<ul style="list-style-type: none"> - Majete WR and Liwonde NP: African Parks' Annual Report on cost of running the parks and plans for future. BAP study has estimated cost of MHPL to support management and protection of Majete and suggested Private Conservancy between Reg and Main Dams. Improved management of both parks can potentially increase tourism revenues. - Lengwe National Park: SVTP mitigation budget + 3 million USD (SVTP 2023) plus rehabilitation / management of New Lengwe with a rough estimate of 20 million USD + for rehabilitation (annual cost as of Elephant Marsh (> 2 million USD) or higher for management). Responsible DNPW - Elephant Marsh: Annual cost as of SRBMP (2018) at > 2 	<p>Malawi National Tourism Investment Masterplan (2022), SVTP Updated ESIA (2023), SRBMP Business Plan for Elephant Marsh (2018)</p>

No	Mitigation Measure	Key Risks and Impacts	Expected Outcomes	Parties Responsible for Implementation	Relevant Regulatory Framework	Preliminary costing of measure (Responsible Unit)	Reference source if relevant
						million USD. Responsible DNPW	
5	<p>Sustainable land use enhancement and energy source transition that follows the goals and targets in the Renewable Energy Strategy (2017), National Charcoal Strategy (2017) and National Forest Landscape Restoration Strategy (2017) implemented for the Shire Basin, e.g. transition from biomass (woodfuel/charcoal) to more renewable (or sustainable sources) as the energy source. E.g., LPG, electricity and fuel-efficient charcoal/woodfuel cookstoves as well as sustainable charcoal production (plantation trees in targeted areas) where appropriate.</p>	<ul style="list-style-type: none"> - Widespread deforestation and degradation of natural habitats due to charcoal/woodfuel extraction - Deforestation again leads to increased erosion and sedimentation to Shire - Biodiversity loss 	<ul style="list-style-type: none"> - Enhancement of natural and semi-natural habitats - Better protection of protected areas and their bordering buffer zones <p><u>Cleaner cookstove transition:</u></p> <ul style="list-style-type: none"> - <u>LPG:</u> Increased adoption of LPG reduces pressure on forests and deforestation, reduces air pollution, diseases, and carbon emissions and enhances energy services, based on adequate incentives for early take-off, but this is initially targeted for middle to high income urban dwellers, institutions and the food/hospitality industry. - <u>Electricity:</u> Potential impacts include cleaner, more efficient, healthier, and superior energy services that reduce drudgery and deforestation. Longer implementation period than LPG. Most 	Department of Environmental Affairs, Ministry of Energy, Malawi Energy Regulation Authority, Department of Forestry	Land Act (2016), The Electricity Act (2004) and Electricity Amendment Act (2016), Liquid Fuels and Gas Act (2004), Public Health Act (1992), Malawi National Energy Policy (2018)	As of Malawi Integrated Energy Plan (2022) probably 10 million USD + each year up to 2030 for the population in the whole basin. Responsible Ministry of Energy	Renewable Energy Strategy (2017), National Charcoal Strategy (2017) and National Forest Landscape Restoration Strategy (2017), SEE4All. Malawi Integrated Energy Plan (2022)

No	Mitigation Measure	Key Risks and Impacts	Expected Outcomes	Parties Responsible for Implementation	Relevant Regulatory Framework	Preliminary costing of measure (Responsible Unit)	Reference source if relevant
			<p>relevant to urban and semi-urban centres</p> <ul style="list-style-type: none"> - <u>Fuel efficient charcoal/woodfuel cookstoves</u>: Increasing adoption of fuel-efficient charcoal and firewood cookstoves presents the most immediate option to slow deforestation and forest degradation across Shire River Basin; Reduction in air pollution resulting in improved health of women and children; labour savings, particularly for rural women and children; household income savings. 				
6	<p>Conservation agriculture, farmer-managed natural regeneration and agro forestry: (i) Increase tree cover on degraded low-yielding cropland and pastures in agricultural landscapes through farmer-managed and assisted natural regeneration, direct seeding, and planting of agroforestry trees and shrubs. (ii) Implement climate smart</p>	<ul style="list-style-type: none"> - Reduction in soil productivity and soil erosion - Resilience to extreme weather events - Pollutants runoff 	<p>Increased crop yields with reduced dependence on inorganic inputs, reduced soil/nutrient loss, increased resilience to drought and other climate shocks affecting the following:</p> <ul style="list-style-type: none"> - Improved food security - Improved climate resilience - Poverty alleviation - Improved gender equity and equality 	<p>Department of Agricultural Extension Services, Department of Agricultural Research Services</p>	<p>Land Act (2016), Environmental Management Act (2017), National Agricultural Policy (2016)</p>	<p>As of National Forest and Landscape Restoration Strategy some 25 + Million USD in total cost roughly estimated for the whole basin. Responsible Ministry of Agriculture</p>	<p>National Forest Landscape Restoration Strategy (2017)</p>

No	Mitigation Measure	Key Risks and Impacts	Expected Outcomes	Parties Responsible for Implementation	Relevant Regulatory Framework	Preliminary costing of measure (Responsible Unit)	Reference source if relevant
	agricultural techniques (including FMNR), continuous cover crops, crop rotation etc.						
7	Payment for Ecosystem Services (PES) Lisungwe Catchment: Reforestation of erosion hotspots in Upper Lisungwe catchment to reduce erosion and subsequent sediment transport into Mpatamanga reservoir	<ul style="list-style-type: none"> - High sedimentation rates into Mpatamanga reservoir - Environmental degradation. Livelihoods prone to droughts and floods 	<ul style="list-style-type: none"> - Decrease in sediment yield into Mpatamanga reservoir - Livelihoods enhancement - Protection of biodiversity/wildlife - Catchment less prone to floods/droughts 	Department of Forestry, NWRA, MHPL	Environmental Management Act (2017)	Possible PES Benefit Sharing Mechanism from MHPL to cover part of the reforestation. Possibly in the range of 1 Million USD For MHPL, piggybacked on potential funds from, say 2-3 Mill USD from MWASIP (WB) and GoM. Period for MHPL budget support suggested to be 2030-2035, with 300 000 USD the first two years and 150 000 per year the last three years. Responsible MHPL and MWASIP.	Lillehammer et al. Benefit Sharing and Hydropower: Enhancing Development Benefits of Hydropower Investments Through and Operational Framework (2011).
8	Implementation of sustainable fisheries management plans from Chikwawa to Chiromo, i.e., the extent of the Elephant Marsh modelled in the CIA. The development and implementation of a fisheries management plan is considered imperative for the health of the river and the local communities	At present there is no apparent coherent fisheries plan for the Lower Shire fishery, and fisheries are largely overlooked in the SVTP documents, although the SRBMP targets “Participatory fisheries management plans in place for all designated fisheries areas by 2022”.	Regulation of the fisheries in the Lower Shire is a necessary first step in ensuring the sustainability of the fisheries.	Department of Fisheries; Beach Village Committees (BVCs)	Environment Management Act (2017) and National Environmental Policy (2004), Fisheries and Aquaculture Policy (2016) and Fisheries Conservation and Management Act (1998)	The World-Bank funded Shire River Basin Management Program (Phase-I) Project (P117617) has an approved budgeted for a management plan for the Elephant Marsh, which extends from Chikwawa to Chiromo. Rough estimate 300 000 to 500 000 USD yearly. Responsible: Department of Fisheries	Bayliss, J. 2018. The Elephant Marsh: General Adaptive Management Plan. Shire River Basin Management Programme, Government of Malawi. 104 pp.
9	Control of hyacinth and mimosa in the Elephant Marsh.	There are early indications that mimosa and hyacinth could	Preventing the spread of mimosa and hyacinth, while their numbers are still	Shire Valley Transformation Project (SVTP),	None	Unknown, but not high if implemented immediately. Rough estimate 50 000 –	

No	Mitigation Measure	Key Risks and Impacts	Expected Outcomes	Parties Responsible for Implementation	Relevant Regulatory Framework	Preliminary costing of measure (Responsible Unit)	Reference source if relevant
	Mimosa: Once a year cut adult plants, stack dry and burn; return to cleared areas two months later and spot treat re-sprouting cut stumps and seedlings; release biocontrol agents for Mimosa twice a year; revegetate cleared areas with a seed mix of indigenous floodplain grass seeds. Hyacinth: Physical removal, biocontrol agents for hyacinth in September and December.	become problem invaders in the Elephant Marsh as their abundance increased markedly between 2015 and 2023 (Supporting Specialists Report). If left uncontrolled both of these can have devastating effects on biodiversity and community access and use of the Marsh.	manageable would benefit biodiversity and local communities. It would also be considerably more possible and more cost effective that delaying these actions. Mimosa in particular has become an intractable problem on several floodplains in Southern Africa, e.g., Kafue Flats, Zambia.	supported by Government Departments.		100 000 USD every 3-5 years. Responsible DEA and DNPW	
10	Implementation of Community Conservation Areas (CCAs) in the Elephant Marsh. Target = 50% CCA.	The difficulty and time-consuming nature of establishing CCAs in the Elephant Marsh is a major constraint. SVTP is supporting the establishment of CCAs in the Elephant Marsh as it plays an important role in maintaining the Valley's hydrological regime through flood control, water storage and supply of nutrient-rich sediment. Chikwawa and Nsanje District Councils have endorsed the need to establish the CCAs for the sustainable	Restricting access to one or more area of the Marsh would improve ecosystem condition, and consequently its sustainability. Key aspects that should be mitigated are cultivation in the floodplain/marsh, over-fishing and poor gear choice, overharvesting of reeds, burning and bush-meat hunting of small mammals, reptiles and birds. It is unlikely that Communities will support a total ban on access, even although that would give the best results in terms of ecological condition. A	Shire Valley Transformation Project (SVTP), supported by Government Departments.	RAMSAR agreement	The World-Bank funded Shire River Basin Management Program (Phase-I) Project (P117617) has an approved budgeted for a management plan for the Elephant Marsh that incorporates CCAs. Estimate 2-3 million USD in total	https://documents1.worldbank.org/curated/en/584761569595531675/pdf/Malawi-Shire-River-Basin-Management-Program-Project.pdf https://svtp.gov.mw/2022/08/22/first-cca-established-in-the-elephant-marsh/ BROWN, C.A., JOUBERT, A., TURPIE, J. REINECKE, M.K. BIRKHEAD, A. FORSYTHE, K., DAVIES, T. MGOOLA, W., NYIRENDA, J. and ARTHUR, R. 2022. The Elephant Marsh, Malawi

No	Mitigation Measure	Key Risks and Impacts	Expected Outcomes	Parties Responsible for Implementation	Relevant Regulatory Framework	Preliminary costing of measure (Responsible Unit)	Reference source if relevant
		management of the Elephant Marsh. Two Committees have been established, one at Mbenje and another at Ntchenyera to support interventions in the CCA. Elephant Marsh covers an area of ~61,556 ha. To date, however, communities under Mbenje CCA have contributed 2,164 ha of land for conservation, i.e., ~3.5% of the area.	more pragmatic option is the CCAs supported by SVTP.				– Part 3: The application of an eco-social model to assess options for managing ecological status. African Journal of Aquatic Science, 47:3, 405-420, DOI: 10.2989/16085914.2022.2044750.
Transboundary Mitigation Measures							
11	Harmonization of basin/catchment management measures towards (including also dams operation and water resources) ZAMCOM	As of ZAMCOM Strategic Plan: <ul style="list-style-type: none"> - Environmental degradation and disaster risk (most relevant for this CIA. - The strategic plan also lists persistent poverty, competing uses and infrastructure deficit as key risks 	<ul style="list-style-type: none"> - Transboundary harmonization of catchment management practises - Joint operation of dams, including synchronized flood releases for Zambezi 	NWRA and ZAMCOM	ZAMCOM Agreement and ZAMCOM Strategic Plan 2018-2040	<ul style="list-style-type: none"> - Malawi GOV administrative budget for ORASECOM membership etc. - Potential cost of synchronized flood releases (should be in the implementation / operation agreement for each HPP, including Mpatamanga) 	ZAMCOM Strategic Plan 2018-2040
12	Transboundary monitoring of EFlows releases	Uneven conditions for EFlows releases affecting water users and riverine ecology	EFlows agreements are met to possible counteract risks and impacts	GoM/NWRA and ZAMCOM	ZAMCOM Agreement, Water Resources Regulations (2018), Water Resources Act (2013)	Cost for monitoring by possible levy on projects (as of ZAMCOM Strategic Plan). MHPL responsible for potential levy on Mpatamanga. Cost is currently unknown, but should not be high	ZAMCOM Strategic Plan 2018-2040

1 BACKGROUND AND INTRODUCTION

1.1 Project Overview

1.1.1 Context of CIA

Some of the key constraints to further developing Malawi's economy are access to energy, potable water, and irrigation infrastructure. To foster sustained economic growth, the IFC and the World Bank are currently engaged in several existing and potential operations in the Shire River Basin (SRB), namely: Mpatamanga Hydropower Project, Malawi Emergency Power Restoration Project (following cyclone-induced damage to Kapichira HPP), Shire River Valley Transformation Program (SVTP), and the Malawi Watershed Services Improvement Project (MWASIP). The World Bank previously supported the Shire River Basin Management Program (SRBMP). The IFC is a minority equity partner, with the Government of Malawi (GoM) and SCATEC / EDF in the Mpatamanga HPP.

The Shire River (SR) is an important tributary of the Zambezi River, an international waterway shared with Mozambique, and the only outlet for Lake Malawi. The Shire River Basin (SRB) is a strategic resource for Malawi. The vast majority of the country's energy is generated in this watershed, but it also supports significant economic and social activities such as irrigation/agriculture, and water supply for industrial and human use. The Mpatamanga Hydropower Project will help the country meet peak demand and will be the fourth hydropower scheme located in the SRB between upstream and downstream hydropower plants (in addition to future plants planned elsewhere in SRB). Blantyre draws its water supply from the watershed, and the IFC is currently advising the Government of Malawi (GoM) to structure a PPP to improve Lilongwe's water supply. Furthermore, extraction for irrigation in the SRB is expected to continue increasing, with a number of large-scale schemes planned and under execution downstream of Mpatamanga, including the World Bank supported Shire River Valley Transformation Program (SVTP).

Since all these operations are located within the SRB, they are likely to have cumulative environmental and social (E&S) risks and impacts and face similar E&S challenges viz; the management of sediment inflow and erosion, catchment management, disruption of ecosystems services due to altered downstream flows, impeded riparian habitat connectivity, and allocation of waters between competing generation, irrigation, water supply and ecosystem objectives. Cumulative impacts could potentially involve economic displacement, impacts on nutrition and health, reduced community and women's access to water, decline in important wetlands (Elephant Marsh, Majete Wildlife Reserve), and reduced tourism income.

Climate change will induce further stress on the Shire River Basin. Floods and droughts are less predictable, more frequent, and extreme – as seen in recent years with Tropical Storm Ana and Cyclone Gombé. These climate-related uncertainties, together with the degradation of the Shire River catchment due to human activities (e.g., deforestation, riverbank encroachment), present a very challenging context to further develop the Shire River Basin in a sustainable manner. If the above risks are not assessed and managed appropriately, poverty will remain persistent and social vulnerabilities will likely increase.

The World Bank-supported SRBMP (2012-2019) developed the SRB planning framework, as well as investing in land and water management. This included: a Shire River Basin Plan, prepared and adopted by GoM in June 2017; the Shire River Basin Atlas; State of the Shire Basin Report; spatial analysis products and 16 sector and thematic studies; revamping of 75 meteorological and 25 hydrological stations in SRB; and the creation of a National Water Resource Authority (NWRA) following the passing of the Water Resources Act in 2013. In addition, a National Forest Landscape Restoration Assessment (NFLRA) provides the best science and

knowledge on landscape restoration at the national scale in Malawi, and proven approaches are set out in the National Catchment Management Guidelines and Manual.

IFC has published a Good Practice Handbook (IFC, 2013 - Cumulative Impact Assessment and Management: Guidance for the Private Sector in Emerging Markets) which includes a summary (pages 15-17) of the requirements of IFC Performance Standard 1 and Guidance Note 1 relating to CIA. IFC believes that when a private sector project sponsor faces cumulative environmental and social impacts, it should have mechanisms for identifying the magnitude and significance of its contribution to those risks and impacts, and should include appropriate mitigation measures as an integral component of the project's environmental and social management system (ESMS). For private sector management of cumulative impacts, IFC considers good practice to be two-pronged:

- Effective application of and adherence to the mitigation hierarchy in environmental and social management of the specific contributions by the Project to the expected cumulative impacts; and
- Best efforts to engage in, enhance, and/or contribute to a multi-stakeholder, collaborative approach to implementing management actions that are beyond the capacity of an individual project proponent.

Specifically, Performance Standard 1 Guidance Note 1 (GN1), in paragraph GN38, states, "in situations where multiple projects occur in, or are planned for, the same geographic area...it may also be appropriate for the client to conduct a CIA as part of the risks and impacts identification process." Paragraph GN41 recommends that this assessment should be commensurate with the incremental contribution, source, extent, and severity of the cumulative impacts anticipated, and should determine whether the project is incrementally responsible for impacts beyond an acceptable predetermined threshold.

As co-developer of Mpatamanga HPP, IFC has supported a Rapid CIA (Southern Waters, 2022), which delivered a qualitative assessment of a range of scenarios, incorporating existing developments and trends, Mpatamanga Hydropower Project, SVTP, and, to a limited extent, climate change. The VECs (Valued Environmental and Social Components) addressed were: (social) ecosystem services support for livelihoods; access to clean, safe and sustainable energy; safety; community infrastructure; (environmental) aquatic ecosystem integrity; river morphology; water quality; riparian vegetation; fish; river-related mammals; river-related birds; (economic) bulk energy production; and tourism. The RCIA identified several knowledge gaps related to the VECs, on sediments and river morphology, water quality, fish and fisheries, and climate change.

1.1.2 Objectives of CIA

The objectives of this assignment are to:

- Assess the cumulative environmental and social impacts of the Mpatamanga Hydropower Project and other developments across the Shire Basin.
- Prepare mitigation measures for these cumulative impacts, to be implemented by Mpatamanga Hydropower Project, by other developments, and at a basin level.
- Prepare the CIA for the Mpatamanga Hydropower Project, meeting CIA requirements set out in the World Bank Environmental and Social Framework (ESF; World Bank 2017), IFC Performance Standards (IFC 2012), and the guidance set out in the IFC Good Practice Handbook on Cumulative Impact Assessment and Management (IFC 2013).

The CIA is also undertaken in accordance with relevant national and international standards.

The CIA is conducted for the Shire River Basin downstream of Lake Malawi to the confluence with Zambezi, with focus areas from Kamuzu Barrage to the border with Mozambique. Some drivers and impacts on Valued Environmental and Social Components (VECs) extend beyond these boundaries, e.g., Lake Malawi long-term water level fluctuations. These are also to be taken into consideration in the assessment, although not as diligently modelled and assessed as the selected driver/causes and stressors within the CIA catchment focus area (e.g., infrastructure development, deforestation due to charcoal and firewood production, demographic change and influx/migration).

1.1.3 Phasing of the CIA

It was agreed with the Client at a briefing meeting on 30th November 2022 that the CIA should aim to be high quality and high resolution, and that it would include provisions for a detailed Eco-Social Modelling (ESM) component using the DRIFT model. The CIA relies heavily on input and modelling results from the parallel/allied studies, in particular, the *ESIA, BAP, sediment, hydrology and Topo/Bathy studies*. With this in mind, the CIA was divided into phases and the duration was extended beyond that originally envisaged in the Terms of Reference (ToR), such that better use could be made of the results from the parallel studies. The CIA study is phased as follows:

- Phase I – Inception and Review Phase (March to June 2023).
- Phase II – Scoping Phase (July to November 2023), including baseline surveys.
- Phase III – CIA Analysis Phase (November 2023 to September 2024). This constitutes the major Phase for the scenario modelling and CIA analysis.

1.1.4 Overview of the Mpatamanga HPP

The proposed MHPP (the Project; Figure 1-1) is being developed by MHPL. The project (including the transmission power lines) will be located in the Neno, Blantyre and Balaka districts, and in the Kunthembwe, Miauli, Symon and Nsamala Traditional Authorities (ToR). A main dam (50 m high) on the Shire River will create a 19-km² reservoir at full supply level, with a total storage volume of 261 million m³. Water from the main reservoir will drop ~66 m to a 309-MW powerhouse located 1 km downstream of the main dam. The water discharged from the main powerhouse into the Shire River (installed capacity of 550 m³/s) will then flow into a 1-km² regulating reservoir (at full supply level) created by a 27-m high regulating dam located on the Shire River 6 km downstream of the main dam. Water from the regulating reservoir will be discharged into the Shire River through a 41-MW powerhouse located at the foot of the dam (installed capacity 360 m³/s). From the upper part of the main reservoir to the regulating dam, the Project footprint will extend >29 km of river length. No fish passes are planned on either dam (SLR 2023).

The Project will have a total generation capacity of 350 MW (IFC 2022) and is expected to contribute significantly towards enhanced energy security in Malawi. The 309-MW main plant is designed to provide much needed energy during peak demand hours and should improve overall grid stability with its ability to ramp up or down production to meet actual demand. The targeted average annual energy production is 1,510 GWh (MHPL 2023).

The electricity generated by the Project will be delivered to the grid through two transmission lines: a 62-km long 400 kV transmission line from the main powerhouse to the existing Phombeya sub-station; and an 11-

km long 132 kV transmission line that will connect the regulation dam powerhouse to the existing Tedzani-Kapichira Transmission Line (Loop-In-Loop-Out).

Part of the S137 road that links Blantyre to Mwanza will be flooded by the future MHPP main reservoir. A new bypass S137 road will be built by the Project. The future Chileka-Mwanza/M6 S137 road will be ~50 km long and out of these, 7 km will be newly constructed by the Project to bypass the main dam and the reservoir, and 26 km road to Blantyre will be upgraded. A 120-m long new road bridge will be built over the Shire River downstream of the main powerhouse.

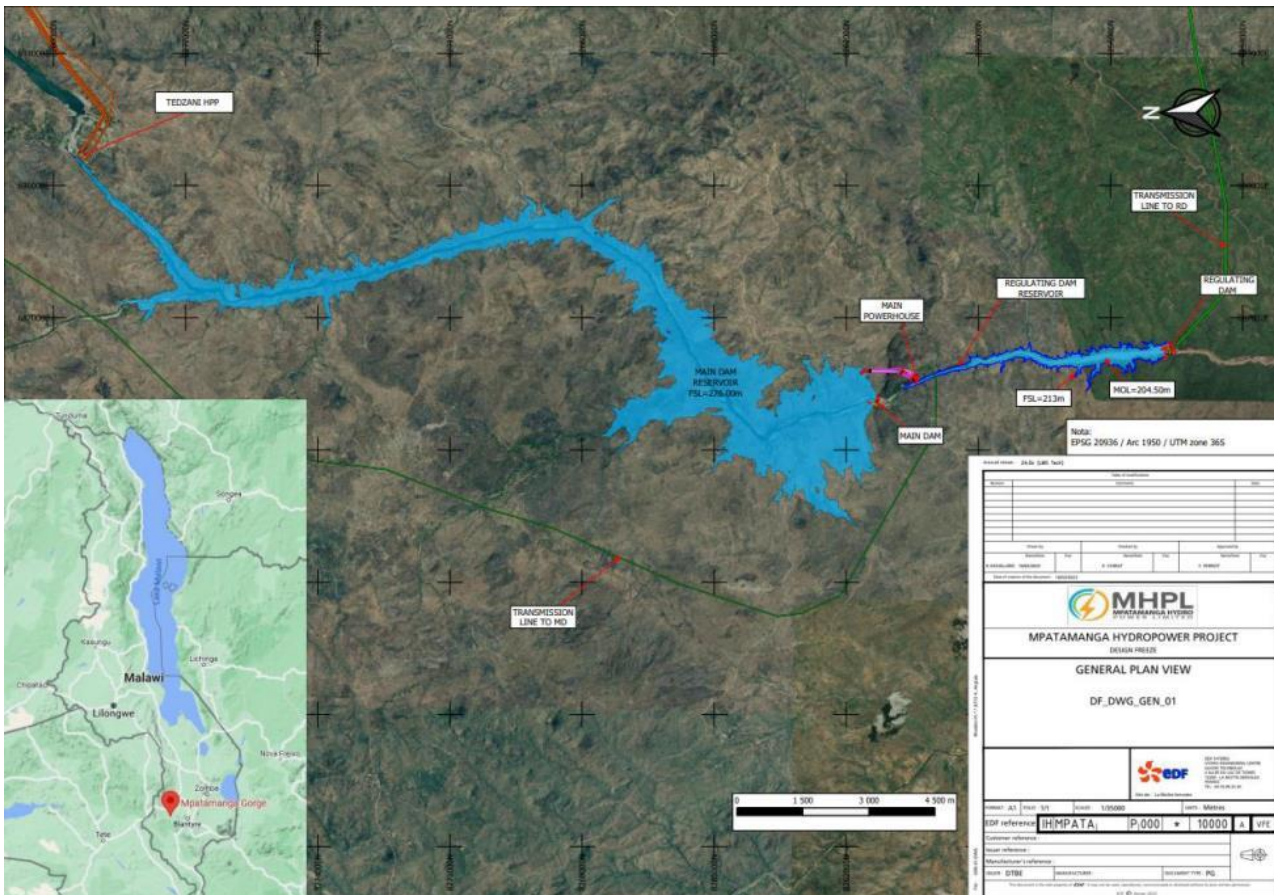


Figure 1-1 MHPP: General plan view: Main Dam, Regulating Dam and Transmission Lines (Source: MHPL, 2023).

The workforce will be accommodated in one construction camp during the construction period. A 4-year construction schedule has been estimated for the Project, starting in 2026, with commissioning of the project in 2030. Non-physical works such as geotechnical investigations are ongoing, and construction of the camps, laydown areas and access roads are planned to be started in 2025.

A permanent operators' village will be built close to the main powerhouse to accommodate the operators of the two dams. A new 6-km long service road will be built by the Project from the main powerhouse to the regulating dam.

The Project is to be developed on a Build-Own-Operate-Transfer (BOOT) basis by MHPL and the GoM. MHPL will be responsible for constructing and operating the Project for 30 years, after which it will be transferred to GoM. An Implementation Agreement, which stipulates the responsibilities of MHPL and GOM, will support

the BOOT agreement. The BOOT approach is designed to protect the GoM from construction costs and operating risk, while at the same time allowing it to benefit from a 30% share in the Project through the Electricity Generation Company (Malawi) Limited (EGENCO). The remaining 70% of MHPL is or will be owned by EDF (27.5%), SCATEC (14%) and its joint venture partners British International Investment (6.75%) and Norfund (6.75%), and the IFC (15%).

Downstream flow rules

There will be a dedicated deliverable for the O&M rules at Basic Design stage from the technical consultant. Details of this are not known to the CIA consultant yet, as per submission of this 2nd Draft CIA Report.

However, the discharged flow downstream the regulating dam shall comply at any time with the following rule

With $x = 10\%$

$$(1-x) * Q_{\text{reg dam}}(d-1) < Q_{\text{reg dam}}(t) < (1+x) * Q_{\text{reg dam}}(d-1)$$

This means that the discharged flow at the regulating dam shall be +/- 10% of the previous day incoming flow (daily mean incoming flow in the main reservoir). This rule aims at avoiding significant water level and flow variation downstream of Mpatamanga scheme, while simulating as much as possible the “natural” flow pattern of the Shire River.

1.2 Definition of Cumulative Impacts

Cumulative impacts are those resulting “from the successive, incremental, and/or combined effects of an action, project, or activity when added to other existing, planned, and/or reasonably anticipated future ones” (IFC 2013). Successive and incremental environmental and social impacts from multiple developments over time can result in significant cumulative impacts that would not be identified through even the most thorough project-specific environmental and social impact assessment. Henceforth, a CIA is a systematic process of identifying and analysing potential environmental and social risks and impacts resulting from past, current, and anticipated developments (IFC, 2021). This is accomplished through a screening process that identifies environmental and social attributes that actions, projects, and activities within the scope of the CIA are likely to affect significantly. These attributes are termed *valued environmental and social components* (VECs). For definition of VECs, see next Section 1.3.

Assessing cumulative impacts might require more than just adding up all impacts from individual projects or developments. Although the combined impacts of several projects may be larger than the sum of individual impacts because interactions may amplify their collective impacts, one project added to another can also lead to fewer severe cumulative impacts than the sum of the impacts of both projects. Cumulative impacts can occur through different *interactive pathways* (Bain, Irving, and Olsen 1986). Three basic interactions can be discerned:

- Strictly additive – The sum of the individual impacts from the project(s) and other actions equals the total impact.
- Synergistic – Total impact is more than the sum of each individual impact of a project.
- Antagonistic – Total impact is less than the sum of each individual impact of a project.

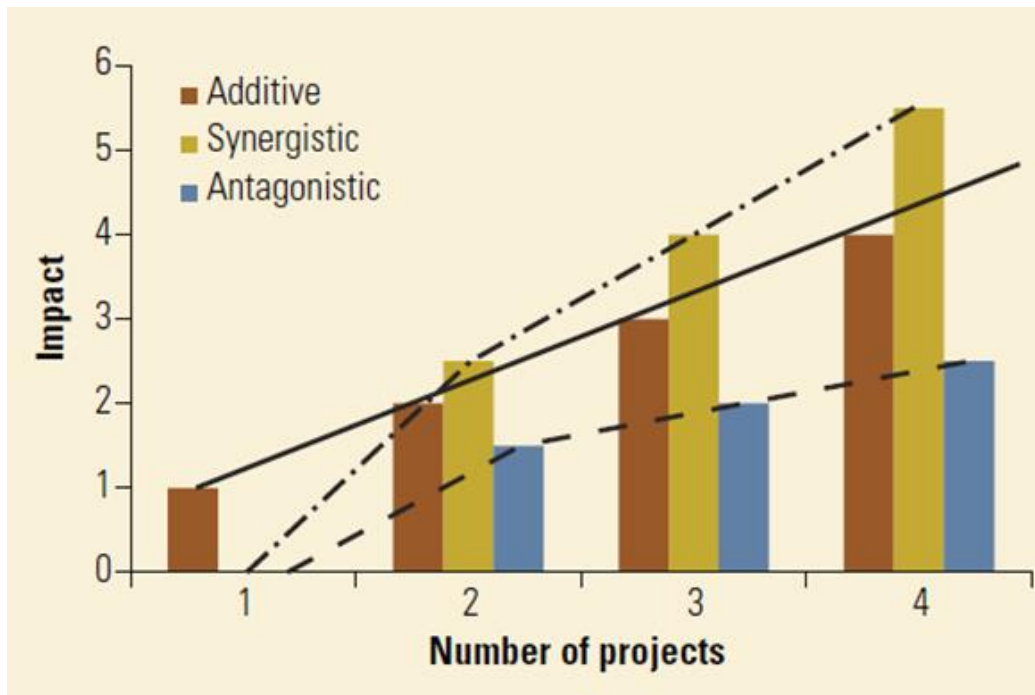


Figure 1-2 CIA Interactive Pathways (Source: WB, 2014).

Cumulative impacts can also be related to passing certain threshold levels. For instance, some habitat loss may not have a large impact on wildlife. However, when a certain threshold is passed, an entire population can be wiped out because the habitat becomes too fragmented (also through loss of connectivity).

Further, in some cases, the impact of multiple small-scale projects may be greater than the impact of a single large-scale project. For example, when total impacts due to a cascade of small hydropower plants exceed those that would have occurred with a single larger dam with the same power generating capacity.

1.3 Definition of Valued Environmental and Social Components (VECs)

VECs are parts/components of the environmental and social fabric of Shire River Basin that the proponent, stakeholders, the community, environmental and social scientists/experts and government representatives involved in the assessment process consider important. Attributes of a VEC can be biological, cultural, ecological, physical, social or economic; and also include changes in the livelihoods of affected people, resettlement, plus any other attributes of concern identified as relevant during a CIA. In some studies, VECs are defined with a narrow focus on elements of the biophysical environment (Szuster and Flaherty 2002; Bérubé 2007; Noble 2010) but are more broadly also understood to encompass social and economic aspects (for example, Shoemaker 1994; Olangunju 2012, Lieblig-Andersen and Lillehammer 2020). In this study, the broader definition of VECs is used.

VECs considered important for assessing risks may then be the following (adapted from IFC, 2021):

- Physical features, habitats, and wildlife populations (for example, biodiversity)
- Ecosystem services
- Natural processes (for example, water and nutrient cycles and provisions)
- Social conditions (for example, health, livelihoods and economics)
- Cultural activities (for example, traditional spiritual ceremonies, historical and sacred places)

These VECs are the focus of the CIA process. The difference between a CIA and an environmental and social impact assessment (ESIA) is illustrated in Figure 1-3.

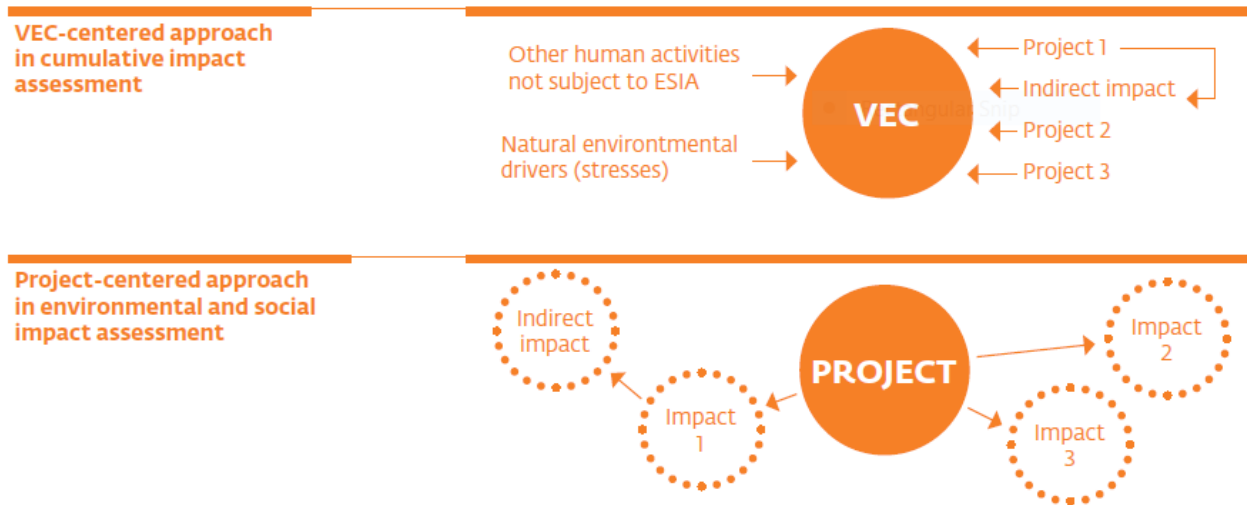


Figure 1-3 Comparison of Cumulative Impact Assessment and Environmental and Social Impact Assessment (Source: IFC, 2013).

1.4 Summary of Shire Basin Profile

The Shire River is the only outlet of Lake Malawi and is an important tributary of the Zambezi River, an international waterway shared with Mozambique. The Shire River Basin is a strategic resource for Malawi since the vast majority of the country's energy is generated in this watershed; but it also supports other significant economic and social activities such as irrigation/agriculture, and water supply for industrial and human use. The flow regime of the Shire River has been highly regulated since 1965 when the Kamuzu Barrage at Liwonde was constructed.

The Shire River is divided into three distinct zones based on hydrology and geomorphology (see also Figure 1-4):

1. Upper Shire: From Lake Malawi to the Kamuzu Barrage where the river has a very low gradient and flows through marshy areas, including Lake Malombe.
2. Middle Shire: Where the river drops 360 m over ~70 km through a series of rapids and waterfalls, including Mpatamanga and Kapichira Falls.
3. Lower Shire: Downstream of Kapichira Falls where the river flows across a wide floodplain and opens out into the Elephant Marsh and numerous other marshes before joining the Zambezi River upstream of Caia in Mozambique.

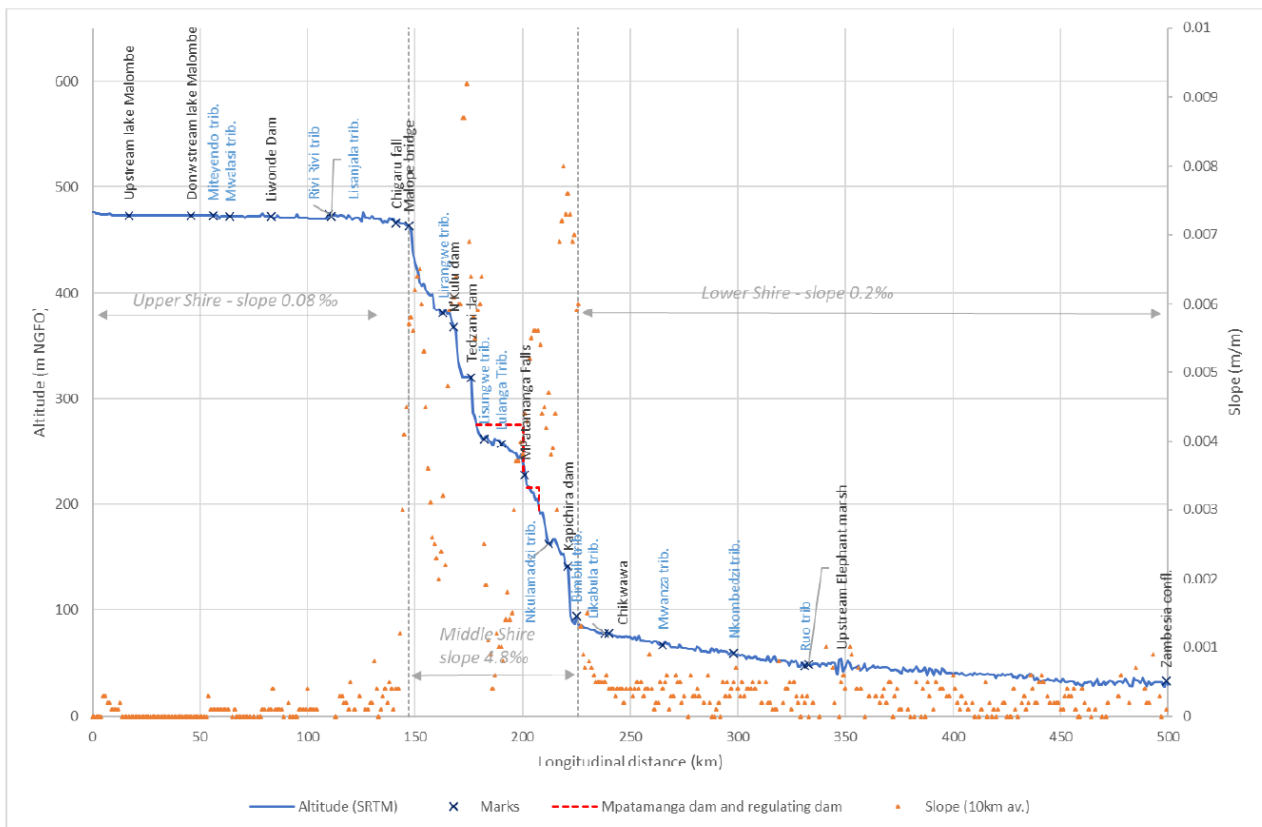


Figure 1-4 Longitudinal profile of Shire River (from ToR of the Sediment Study 2022).

There are currently three operational hydropower stations in the Middle Shire River: Nkula, Tedzani and Kapichira, generating a combined ~339 MW. The earliest, Nkula Falls A (16 MW), was constructed in conjunction with Kamuzu Barrage and completed in 1966, and an 8-MW unit was added in 1967. The Tedzani 1 and 2 projects were developed in the mid-1970s and have a combined installed capacity of 40 MW. Nkula B was constructed between 1980 and 1992 and has an installed capacity of 100 MW. Tedzani 3 (52 MW) was completed in 1995, followed by Kapichira Phase I (65 MW) in 2000. The installed capacity at Kapichira was increased to 130 MW in 2012 and Tedzani to 62 MW in 2018. In January 2022, Kapichira HPP was badly damaged by Tropical Storm Ana, resulting in its closure. It was back to full operation after rehabilitation in May 2023¹⁷.

The proposed MHPP is located on the Mpatamanga Falls between the Tedzani HPP and Kapichira HPP just upstream of the Majete Wildlife Reserve and ~40 km west of Blantyre (see also Figure 1-5).

¹⁷ <https://www.eqenco.mw/eqenco-restores-kapichira/>

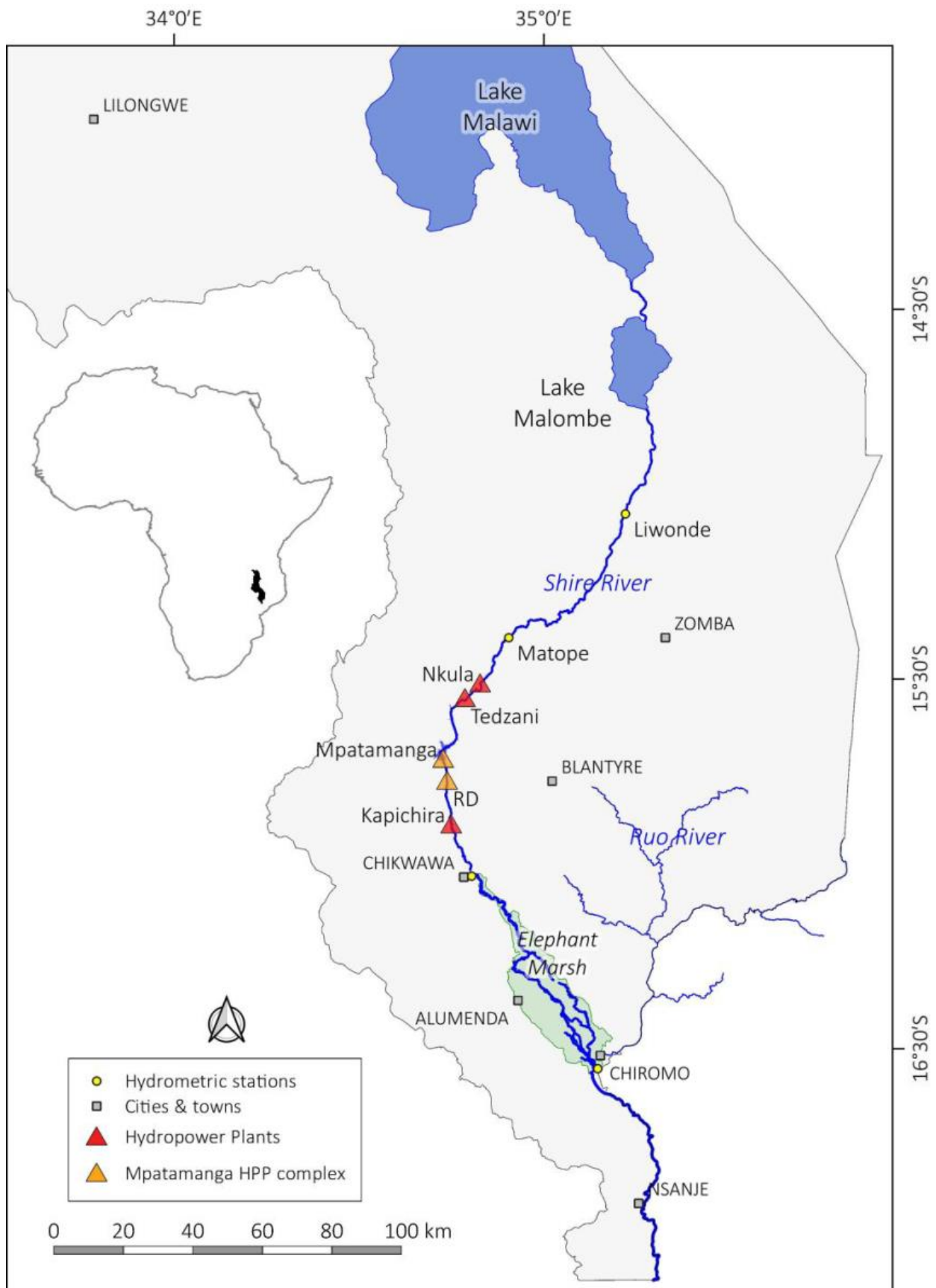


Figure 1-5 The Shire River showing the proposed MHPP complex (orange triangles), existing HPPs, hydrometric stations, main villages and the Elephant Marsh. RD: Regulating Dam (Source: Brown *et al.* 2022).

The hydropower potential at Mpatamanga was first studied in detail in the Power Development Study Phase 1 undertaken by TAMS Hydro in 1985. The project was further considered in the Malawi Power System Development and Operation Study (Lahmeyer International and Knight Piésold 1998). In 2015 Fichtner GmbH was appointed by the Ministry of Natural Resources, Energy and Mining to undertake Prefeasibility and Feasibility studies for the Chimgonda and Mpatamanga hydropower projects. These studies were funded by the World Bank. The final Feasibility Study Report for the Mpatamanga Project was issued in 2017 (Fichtner 2017). This has been followed by various other technical, environmental and social studies between 2018-2022 mentioned in the ToR (Section 8, pages 27-28), including the Mpatamanga Technical and Additional Studies (Multiconsult 2019) and the Rapid Cumulative Impact Assessment (Brown *et al.* 2022).

An additional HPP development, Kholombidzo HPP, has been identified on the Shire River albeit construction of it is still unknown. The Kholombidzo Falls are located in the Middle Shire River, upstream of Nkula Falls, and are the first waterfalls downstream of Liwonde. Kholombidzo Hydropower Plant will rely on water from the Shire River. The site offers, as a run-of-river development, an identified potential electricity generation capacity ranging from 60 MW to 200 MW. The project will involve, amongst others, construction of a dam/intake to provide the needed water storage under a head of 50-65 m for the expected range of electricity generation (COBA 2015).

The Shire River Basin has been the focus of several basin planning and watershed management initiatives, relevant to this CIA. These initiatives reflect its size and importance to energy, water and food security, and the basin's hotspot status for natural resources degradation and soil erosion in Malawi and beyond. The Shire River Basin Management Plan (SRBMP Phase 1, 2012-18, ~US\$ 122 million) was conceived as pilot for implementing a suite of measures aimed at strengthening land and water management in a fast-degrading basin to support the GoM's long-term, multi-sectoral vision for the basin, laying the foundations for further work in the Shire and other river basins. The SRBMP was followed by the Malawi Watershed Services Improvement Project (MWASIP), which adopts a 'Series of Projects' approach over 11 years (2020–2031), with an estimated budget envelope of US\$ 350-600 million. The aim of MWSIP is to "*increase the adoption of sustainable landscape management practices and improve watershed services in targeted watersheds*" (Callow 2021). The Government of Malawi (GoM), through the Ministry of Agriculture, Irrigation and Water Development, with support from the World Bank, the African Development Bank and the Global Environment Facility (GEF), is also implementing the Shire Valley Transformation Programme (SVTP), which is a 14-year program (2018-2031) that will be implemented in three partially overlapping phases. The SVTP will irrigate 43,370 hectares of land by abstracting water from the Shire River at Kapichira and conveying it by gravity to an area in Chikwawa and Nsanje districts through canals.

The Shire River plays a crucial role in terms of supporting livelihoods and providing ecosystem services. In addition to being of crucial importance to the people of Malawi, the Middle Shire River between Matope and Kapichira hosts populations of ~30 species of fish, not including 15-20 straggler species from the Upper Shire that are occasionally swept downstream but do not have viable Middle Shire populations (Tweddle *et al.* 1979). Four of these stragglers, *Labeo mesops*, *Bagrus meridionalis*, *Serranochromis robustus* and *Oreochromis karongae* (or *O. squamipinnis*) are listed as Critically Endangered but there is no viable habitat for any of them in the Middle Shire and hence their occasional presence has no relevance. Upstream from the start of the rapids section of the river at Matope, the river hosts a depauperate Lake Malawi fauna with 34 species (not including the Lake Malawi endemic cichlid species flock with a similar species composition to

those occasionally recorded downstream of Matope) recorded in the river in Liwonde National Park and downstream to Kamuzu Barrage (Tweddle, 2018). The Middle Shire River also supports a diverse and complex ecosystem of riverine and riparian organisms ranging from benthic algae to African elephants. Downstream from Kapichira Falls, 66 fish species, mainly of Lower Zambezi origin, have been recorded in the Lower Shire River and tributaries (Tweddle and Willoughby 1979; Tweddle 2008; 2015).

The Majete Wildlife Reserve, which is situated ~7 km downstream of the planned MHPP was established in 1955, and experienced severe problems with poaching and other adverse human activities in the 1970s and 1980s. However, the situation has since been resolved and the park is now one of the country's best run parks and most popular tourist attractions.

The Lengwe National Park was established in 1970 and is situated south of the Majete Wildlife Reserve and 40 km south-west of the Mpatamanga HPP. It is a mix of thicket vegetation and deciduous woodland and includes a number of fauna species, including some rare birds, Nyala, Greater Kudu and African Buffalo (Malawi Tourism 2019a). The park has some areas of intact natural habitat (in particular in the old section of the park) but also degraded natural habitat more in the extension area, with some patches of modified habitat where encroachment from local communities has occurred. The park is known to support the two vulture species White-backed Vultures and White-headed Vultures (TBC, 2023).

Approximately 50 km downstream of the planned MHPP, the Shire River spreads out into the Elephant Marsh, a >600 km² Ramsar wetland that supports a wide array of waterbirds, herpetofauna, hippopotami and hundreds of species of aquatic invertebrates. The marsh plays a crucial role in regulating the hydrological and sediment regimes of the Lower Shire Valley, as demonstrated by the impact of a sudden excessive closure of Kamuzu Barrage in 1978 (Tweddle 2015).

The Shire River downstream of Chiromo to its confluence with the Zambezi River is characterised by a wide floodplain (up to ~9km wide) that incorporates the Ndindi Marsh.

1.5 Limitations to the CIA

Predicting the effect of flow, sediment, connectivity and demographic changes on rivers is inherently difficult because the actual trajectory and magnitude of the change is dependent on so many other variables, such as climate, politics, human use of the system and regulations. Thus, several assumptions and limitations apply to this CIA, including those highlighted below.

A major assumption is that the modelled reference time-series of flow and other drivers of ecosystem condition approximate the actual conditions in the river over the period of record and for the development levels selected. Should this not be the case, then the baseline for the scenarios would be different to that used and so the scenario predictions could also change.

The main limitation is in being able to capture the complexity of the system, which is confounded by the paucity of data. This is a universal problem, as by their nature human interactions with ecosystems are complex; complete certainty of the present and possible future characteristics of the ecosystems is not realistic. Instead, it is essential to proceed cautiously, and aid decision-making using best available information. The alternative is that development and management decisions are made without consideration

of the consequences for the supporting ecosystems, eventually making management of sustainability impossible. Data paucity has been addressed in the DRIFT-Shire-ESM (Vol 2) by accessing as much available knowledge as possible within the constraints of the ToR using general scientific understanding; international scientific literature; local wisdom and insights from people who have lived and worked in the Shire Basin for many years; traditional knowledge; and specific data from the river under consideration (or from similar ones).

Another limitation is that predictions are based on a 30-year horizon (1992-2022), which may be insufficient time to capture the full extent of some changes.

These limitations and uncertainties mean that attention should be directed toward trends in the sequence of scenarios, rather than towards absolute values.

1.6 Administrative and Regulatory Framework

This Section is largely derived from the works undertaken by Southern Waters for the Rapid Cumulative Impact Assessment (Southern Waters, 2022), with some additions and updates relevant for the CIA. Institutions, and their roles, are discussed in Section 3.1 – Stakeholder Mapping and Analysis.

1.6.1 Relevant Acts

1.6.1.1 The Malawi Constitution (1995)

The Malawi Constitution of 1995 lays the foundation for policy and legal reform in social and environmental governance. Section 13 of the constitution states the *Principles of national policy*, reproduced below:

"The State shall actively promote the welfare and development of the people of Malawi by progressively adopting and implementing policies and legislation aimed at achieving the following goals:

a. Gender Equality

To obtain gender equality through:

- i. full participation of women in all spheres of Malawian society on the basis of equal opportunities with men;*
- ii. the implementation of the principles of non-discrimination and such other measures as may be required; and*
- iii. the implementation of policies to address social issues such as domestic violence, security of the person, lack of maternity benefits, economic exploitation and rights to property.*

b. Nutrition

To achieve adequate nutrition for all to promote good health and self-sufficiency.

c. Health

To provide adequate health care, commensurate with the health needs of Malawian society and international standard of health care.

d. The Environment

To manage the environment responsibly in order to:

- i. prevent the degradation;*
- ii. provide healthy living and working environments;*

- iii. *recognize the rights of future generations by means of environmental protection and the sustainable development of natural resources; and*
- iv. *conserve and enhance the biological diversity”.*

1.6.1.2 Energy Act (2004) and subsequent By-Laws

The legal and regulatory framework for the generation, transmission and distribution of energy in Malawi is governed by the Energy Regulation Act (2004) and by-laws as well as the Electricity Act (2007), Electricity Amendment Act (2016), and the Independent Power Producer (IPP) Framework (2017), and the Rural Electrification Act (2004). Malawi Energy Regulation Authority (MERA) is mandated under the Energy Regulation Act 2004, together with the Energy Regulation By Laws to regulate the energy sector as well as approve energy tariffs etc. Further, the Electricity Act 2004 and the Electricity Amendment Act 2016 provide a requirement for a licence from MERA for generation, transmission, distribution, importation, exportation, system and market operation, single buyer, and distribution licence.

1.6.1.3 Water Resources Act (2013)

Under the Water Resources Act, the priority for allocation of water to various uses is not defined, although the implication is that basic human needs should receive the highest priority. Water for protection of the environment and ecosystems may be reserved under this Act. The Act also aims to strengthen institutions for water resources management and provides for the establishment of a National Water Resources Authority. Henceforth, NWRA was established in 2013 with the mandate to provide for the management, conservation, use and control of water resources and for the acquisition and regulation of rights to use water.

1.6.1.4 Irrigation Act (2001)

The Irrigation Act makes provision for the sustainable development and management of irrigation, protection of the environment from irrigation-related degradations, and for the establishment of the National Irrigation Board. It aims to increase irrigation-related investments to enhance household food security and increase irrigation water use efficiency.

1.6.1.5 Water Works Act (No 17 of 1995)

The Water Works Act provides for the establishment of water-areas managed by Water Boards. Relevant for the Mpatamanga CIA is the Blantyre Water Board and the Southern Region Water Board with its role and responsibilities.

1.6.1.6 Environmental Management Act (2017)

The Environmental Management Act (EMA) recognizes the right of every person to a clean and healthy environment and the responsibility of every person to protect and manage the environment, to conserve natural resources and to promote sustainable utilization of natural resources. The EMA also provides for the establishment of a Malawi Environmental Protection Agency (MEPA) with broad and substantial powers to strengthen environmental planning and risk management at national and local levels. Only recently gazetted, the EMA is yet to be fully implemented.

1.6.1.7 Forestry Act (1997)

The Forestry Act promotes participatory forestry, forest management, research and education, forest industries, protection and rehabilitation of environmentally fragile areas and international co-operation in forestry. It also supports the sustainable management of forests in water catchment areas.

1.6.1.8 Local Government Act (1998)

The goals of the Local Government Act are to promote infrastructural and economic development through the formulation, approval and execution of district development plans (including agricultural water), and to mobilise resources within the local government area for governance and development.

1.6.1.9 Fisheries Conservation and Management Act (1997)

This Act provides rules relative to the conservation and management of the fisheries of Malawi such as the conservation of fish stocks; the assessment of fish stocks and the collection of statistics; the development and management of fisheries; the monitoring, control and surveillance of fishing operations; and the regulation and control of fishing operations including aquaculture.

1.6.1.10 Gender Equality Act (2014)

The Gender Equality Act seeks to: promote gender equality, equal integration, influence, empowerment, dignity and opportunities for men and women in all functions of society; prohibit and provide redress for sex discrimination, harmful practices and sexual harassment; and provide for public awareness on the promotion of gender equality. The Act also urges GoM to take active measures to ensure that employers have developed and are implementing appropriate policies and procedures aimed at eliminating sexual harassment in the workplace.

1.6.1.11 Monuments and Relics Act (1990)

The Monuments and Relics Act (1990) provides statutory protection against all kinds of threats on all cultural resources as defined in it. One such threat is development that might alter the use of a landscape. The Mpatamanga Hydropower Project development has likelihood of impacting some cultural resources in both Blantyre and Neno areas.

1.6.1.12 ZAMCOM Agreement

The eight Zambezi Basin riparian states that participate in ZAMCOM are Angola, Botswana, Malawi, Mozambique, Namibia, Tanzania, Zambia and Zimbabwe. ZAMCOM operations are in line with the revised SADC Protocol on Shared Watercourses (SADC, 2004). Seven of the riparian states signed the ZAMCOM Agreement on 13 July 2004 at Kasane in Botswana (except Zambia), and came into force in 2011. The Commission is headquartered in Harare, Zimbabwe. The purpose of ZAMCOM is "to promote the equitable and reasonable utilization of the water resources of the Zambezi Watercourse as well as the efficient management and sustainable development thereof" (ZAMCOM, 2011).

1.6.2 Relevant Vision, Policies and Strategies

1.6.2.1 Malawi 2063 Vision

Malawi 2063 (MW2063) aims to transform Malawi into a wealthy and self-Reliable industrialized upper-middle-income country by the year 2063. Its goals are for Malawi to be/have:

- An inclusively wealthy and self-Reliable industrialized upper middle-income country
- A vibrant knowledge-based economy with a strong and competitive manufacturing industry that is driven by a productive and commercially vibrant agriculture and mining sector
- World-class urban centres and tourism hubs across the country with requisite socioeconomic amenities for a high-quality life
- A united, peaceful, patriotic and proud people that believe in their own abilities and are active participants in building their nation
- Effective governance systems and institutions with strict adherence to the rule of law
- A high-performing and professional public service
- A dynamic and vibrant private sector
- Globally competitive economic infrastructure
- A globally competitive and highly motivated human resource
- An environmentally sustainable economy.

1.6.2.2 National Environmental Policy (2004)

Creates an enabling policy and legal framework for cross-sector coordination, participation of non-state sectors, strengthening the enforcement machinery and decentralising natural resources and environmental management and governance.

Aims to promote a secured environment that supports health and wellbeing; sustainable utilization and management of the country's natural resources; self-sufficiency in food, fuel wood and other energy requirements; cooperation with other Governments and relevant regional and international organisations in the management and conservation of the environment.

1.6.2.3 National Biodiversity Strategy and Action Plan II (2015)

The National Biodiversity Strategy and Action Plan (2015-2025) was prepared in response to the Malawi Growth and Development Strategy II (MGDS II 2011- 2016) which prioritises biodiversity management programs among other socioeconomic and environmental issues. In addition, this Strategy and Action Plan demonstrates Malawi's commitment to the implementation of Decision X/2 of the Tenth Conference of Parties (COP10) of the Convention on Biological Diversity (CBD), which requested parties to revise their strategies in line with the Global Strategic Plan for Biodiversity 2011-2020. This Strategy and Action Plan was preceded by the National Biodiversity Strategy and Action Plan of 2006.

1.6.2.4 National Water Policy (2005)

Recognises the dependence of the economy on water resources and aims to ensure sustainable management and utilization of water resources, to provide basic water and sanitation services to all Malawians, and to enhance the country's natural ecosystems.

1.6.2.5 National Sanitation Policy (2006)

Aims to empower the people of Malawi to achieve universal access to improved sanitation by 2020. Identifies untreated sewage discharge into rivers as a key issue.

1.6.2.6 National Irrigation Policy (2000)

Outlines irrigation development objectives, specifically: to contribute to poverty alleviation by targeting resource-poor smallholders for irrigation development and crop diversification.

1.6.2.7 National Agriculture Policy (2016)

Promotes the commercialization of agriculture to meet the country's requirements for food, foreign exchange, and rural incomes. Priority measures include sustainable irrigation development, mechanization of agriculture, market development, agro-processing, and value addition.

1.6.2.8 National Forest Policy (2016)

Aims to conserve, establish, protect and manage trees and forests for sustainable development. The goal of the National Forest Policy is to improve provision of forest goods and services to contribute towards sustainable development of Malawi through protection and conservation of forest resources. The policy aspires to control deforestation and forest degradation. The policy takes a holistic approach to sustainable forest management. It adequately addresses issues of forests and water; climate change; food security; HIV and AIDS; gender and equity; wealth creation; biodiversity and Payments for Ecosystem Services (PES); Reduced Emissions from Deforestation and Forest Degradation (REDD+) and Clean Development Mechanisms (CDM).

1.6.2.9 National Forest Landscape Restoration Strategy (2018)

The National Forest Landscape Restoration Strategy established the foundation point for the process of regaining ecological functionality and enhancing human well-being across deforested or degraded forest landscapes. The Strategy outlines priority opportunities and interventions that can translate the potential of restoration into multiple benefits such as improved food security, increased biodiversity, improved water supply, job creation, income, carbon sequestration and enhanced resilience to climate change.

1.6.2.10 National Energy Policy (2018)

Framework for increased access to affordable, reliable, sustainable, efficient and modern energy for all sectors and every person in the country. It emphasizes private sector participation as well as the development of sustainable, clean and accessible energy.

1.6.2.11 Malawi Renewable Energy Strategy (2017)

The Malawi Renewable Energy Strategy (MRES) follows the directions set out in the National Energy Policy (NEP) and suggest strategic priorities to reach the vision of "Universal access to renewable electricity and a

sustainable bioenergy sector”. For GoM, the MRES will be used to set the immediate agenda for action to promote renewables and improve the regulatory, fiscal and legal framework for the sector.

1.6.2.12 National Biomass Energy Strategy (2008)

Biomass contributed to 93% of Malawi’s total energy consumption in 2000, 88.5% in 2008, and 80.5% in 2015. Biomass fuels have been linked to environmental degradation and at times those involved in their production have become criminalized, especially in the case of charcoal production. Although earlier policy aimed to shift Malawi away from biomass and towards electricity, the current energy policy adopts a more balanced approach and recognises the importance of biomass to the economy and people, and promotes *sustainable* charcoal and woodfuel production with other cleaner energy sources like Liquefied Petroleum Gas (LPG), biogas etc. alongside electricity.

1.6.2.13 National Charcoal Strategy (2017)

Promotes adoption of alternative cooking and heating fuels (LPG, biofuels etc.), and the adoption of fuel-efficient charcoal and firewood cook stoves. Aims to increase sustainable wood production, through promoting formalised charcoal production, encouraging producers to grow and manage their own forests and limiting illegal production.

1.6.2.14 National Disaster Risk Management Policy (2015)

The vision of this Policy is 'a nation resilient to disasters. The long-term goal for disaster risk management in Malawi is to sustainably reduce disaster losses in lives and in the social, economic and environmental assets of individuals, communities and the nation. The policy is aimed at ensuring that disaster risk management (DRM) is mainstreamed in development planning and the policies of all sectors in order to reduce the impact of disasters and ensure sustainable development in the country.

1.6.2.15 National Climate Change Management Policy (2016)

The National Climate Change Management Policy (NCCMP) seeks to guide programming of interventions for reduction of greenhouse gas emissions in the atmosphere, as well as adapting to the adverse effects of climate change and climate variability. The NCCMP has been developed to assist the country achieve its long-term goal for climate change management which is to reduce the socioeconomic impacts of adverse effects of climatic change. The medium-term outcome is improved community resilience to climate change through the development of sustainable livelihoods and reduced emissions of GHGs. The Policy guides implementation of critical climate change issues and strategies, including capacity building; education, training and public awareness; the Clean Development Mechanism (CDM); Reducing Emissions from Deforestation and Forest Degradation (REDD+); adaptation and mitigation in Agriculture, Energy, Industrial processes, Waste management, Forestry, Water resources, and Wildlife sectors. In particular, the Policy will build on the National Environmental Policy (NEP) that deals with issues of air quality, reduction of greenhouse gas emissions and supplement several guiding principles.

1.6.2.16 National Employment and Labor Policy (2017)

The National Employment & Labor Policy of 2017 offers a framework for a holistic and focused approach in addressing the challenge of unemployment, underemployment and low productivity as part of the national strategy to fight widespread poverty among the population. The policy seeks to promote productive and decent employment in the economy and increase compliance with labor standards by employers, investors and workers. It also aims at unleashing the potential for Malawi to move into a development path that is more inclusive, pro-poor and job rich thereby strengthening the link between economic growth and job creation on one hand and poverty reduction on the other hand.

1.6.2.17 National Gender Policy (2015)

The National Gender Policy of 2015 seeks to support the implementation of the Gender Equality Act of 2014 by strengthening gender mainstreaming and women empowerment at all levels. The policy specifically deals with challenges and problems confronted by women such as: persistent unequal power relations between men and women, boys and girls due to strong patriarchal attitudes; increasing cases of gender based violence; high HIV and AIDS infection rates especially among women and girls; limited male involvement in reproductive health, HIV and AIDS programmes, continued high dropout rates for girls from schools; high poverty levels particularly amongst women; limited participation and representation of women in decision-making processes at all levels; and huge disparities in access and control over resources by the majority of women

1.6.2.18 Malawi Growth and Development Strategy (2017)

The third and current Malawi Growth and Development Strategy (MGDS III) was planned for implementation from 2017 to 2022. It is the fourth medium-term national development strategy (after the Poverty Reduction Strategy Paper and the Malawi Growth and Development Strategy I and II) aligned to the country's long-term national development aspirations, which are articulated in Vision 2020.

1.6.2.19 National Land Policy (2002)

The goal of the National Land Policy in Malawi is to ensure tenure security and equitable access to land, to facilitate the attainment of social harmony and broad based social and economic development through optimum and ecologically balanced use of land and land-based resources.

1.6.2.20 Livestock Policy (2006)

Aims to contribute towards improved household, national food security and poverty reduction through sustainable private sector and farmer demand-driven livestock services.

1.6.2.21 National Livestock Development Plan and Strategy (2003)

Aims to promote livestock productivity, improve livestock-based incomes and sustainable use of natural resources in partnership with other stakeholders while protecting the public against zoonotic diseases.

1.6.2.22 National Fisheries and Aquaculture Policy (2016)

Replaces the 2001 policy and shifts the focus from natural resource conservation and management to promoting production of fish for food security and income generation through capture fisheries, aquaculture and improved fish quality and value addition for export.

1.6.2.23 National Transport Policy (2019)

Builds on the National Transport Master Plan 2017 – 2037. Aims to ensure the development of a coordinated and efficient transport system, including on rivers and lakes.

1.6.2.24 Mines and Minerals Policy (2013)

Aims to enhance the contribution of mineral resources to the economy of the country so as to move from an agro-based to a mineral-based economy.

1.6.2.25 National Export Strategy (2013)

Provides a road map for expanding Malawi's productive base to generate sufficient exports to match the upward pressure from imports.

1.6.2.26 National Industry Policy (2014)

Complementary to the National Export Strategy and aims to promote the industrialization of the economy.

1.6.2.27 National Cultural Policy (2014)

The goal of this policy is to have, preserve and protect the vibrant Malawian culture for national identity, unity in diversity and sustainable socioeconomic development. Its mission is to; to uphold and promote the Malawian cultural identity and unity in diversity through youth empowerment, recreational activities, study, conservation and preservation of tangible and intangible national cultural heritage for education, recreation, posterity and poverty reduction.

1.6.2.28 Strategic Plan for the Zambezi Watercourse 2018-2040

The ZAMCOM Agreement provides the legal mandate for the preparation and implementation, in close collaboration with the Member States, of the Strategic Plan for the Zambezi Watercourse. Article 14.9 states that *“Member States shall conduct their management and development plans, projects and programmes relating to the resources of the Zambezi Watercourse in accordance with the Strategic Plan”*. The Strategic Plan for the Zambezi Watercourse is the primary plan in terms of the ZAMCOM Agreement, under which all activities of ZAMCOM and the ZAMCOM Secretariat (ZAMSEC) fall and which incorporates all other programmes and activities of the Commission. The strategic plan focuses on the shared future of all the people of the Zambezi Watercourse, and for the preservation of the wealth of the natural resources of the Watercourse, to ensure that development is undertaken in a planned and mutually agreed fashion. For this to be achieved, this strategic flexible plan was required which equitably reflects the needs and aspirations of all the Member States and to which all parties consent.

1.6.3 Relevant Plans, Programmes, and Initiatives

The Shire River Basin Management Project (SRBMP), the Malawi Watershed Services Improvement Project (MWASIP) and the Shire Valley Transformation Programme (SVTP) have been discussed in Sections 1.1.1 and 1.1.4 already. The following additional plans, programs and initiatives are also relevant for the CIA.

1.6.3.1 Strategic Action Plan for the Shire River-Aquifer System (2019)

The Strategic Action Plan (SAP) for the Shire River Basin-Aquifer System is a negotiated policy document for transboundary water management between the Republic of Malawi and the Republic of Mozambique, prepared in 2019. The aim of the SAP is to initiate and guide joint development and management of the Shire River Basin and the associated critical shared groundwater aquifers according to agreed-upon priorities and actions.

1.6.3.2 National Climate Change Investment Plan (2013-2018)

Identifies four priority areas to promote climate change management: adaptation; mitigation; climate change research; technology development and transfer, and capacity building. It details a regulatory framework, financing opportunities and eleven programmes to enable its implementation.

1.6.3.3 National Adaption Programmes for Adaption (2006)

The National Adaptation Programmes of Action (NAPA 2006) evaluated the possible impacts of adverse climatic conditions in eight important sectors of Malawi's economy (namely agriculture, water, health, energy, fisheries, wildlife, forestry and gender). The plan presented 15 priority needs for adaptation across these sectors such as sustaining livelihoods of vulnerable communities, improving crop productivity, developing community-based seed and food storage, improving electricity access, and developing technologies to mitigate climate change such as small dams, drought management strategies and flood zoning works. These 15 general actions were summarised into five actionable projects.

1.6.3.4 Malawi Rural Electrification Programme

The Malawi Rural Electrification Programme (MAREP) was launched in 1980 and presently operates under the Rural Electrification Act of 2004, which also established the Rural Electrification Fund. The goals of the programme are to increase rural electrification through various off-grid and on-grid options such as micro, mini and small hydropower stations and solar photovoltaic (PV) installations.

1.6.3.5 Malawi National Tourism Investment Masterplan (2022)

The Master Plan aims to assist the Ministry, as well as other institutions, to target national and foreign investors for the development of the tourism sector in support of the national development vision as set out in Malawi 2063 (MW 2063). The tourism vision of developing inclusive tourism to make Malawi a preferred tourist destination with well-conserved wildlife resources and unique cultural heritage provides a framework consistent with the aspirations for the sector. The Master Plan seeks to build and upscale the implementation of tourism programmes through a focused and prioritised approach that is designed to deliver a more competitive, sustainable and inclusive tourism sector.

1.6.3.6 National Greenbelt Initiative (2009)

This initiative seeks to increase production and productivity of agricultural crops, livestock and fish farming, including along the Lower Shire River, and the development of irrigation schemes.

1.6.4 International Commitments

Management of the Shire System lies within the jurisdiction of the Member States of Malawi and Mozambique, but the shared watercourse also falls under several other international agreements and action plans that affect the governing principles, shared protocols and planned measures in the Shire Basin. These include those at the international level, the Southern African Development Community (SADC) level, and the Zambezi Watercourse Commission (ZAMCOM) level. Examples are, not necessarily all ratified by Malawi, as follows:

- Convention on Biological Diversity
- Stockholm Convention on Persistent Organic Pollutants
- United Nations Framework Convention of Climate Change
- Montreal Protocol on Ozone Depleting Substances
- Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade
- Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal
- RAMSAR Convention on Wetlands of International Importance
- Convention on International Trade in Endangered Species (CITES) of Wild Fauna and Flora
- Convention on the World Heritage Sites
- The United Nations Convention to Combat Desertification and Drought
- International Treaty on Plant Genetic Resources for Food and Agriculture
- Convention on International Plant Protection
- UN Convention on the Law of the Sea
- Protocol on Shared Watercourse
- Systems and Revised Protocol on Shared Watercourses
- Protocol on Wildlife Conservation and Law Enforcement
- SADC Policy and Strategy for Environment and Sustainable Development.
- The Convention on the Elimination of All Forms of Discrimination Against Women (1987)
 - • The Beijing Declaration and Platform for Action (1995)
 - • The Protocol to the African Charter on People and Human Rights on the Rights of Women in Africa (2005) (Maputo Protocol)
 - • SADC Protocol on Gender and Development (2000)

1.7 This Report

1.7.1 Purpose

The purpose of this 2nd Draft CIA Report is closely related to its objectives, i.e. to:

- Assess the cumulative impacts for past, present and future scenarios on a select set of Valued Ecosystem and Social Components based on developments in the Shire Basin

- Prepare catchment scale mitigation measures to reduce overall basin impacts due to developments.
- Prepare the CIA for the Mpatamanga Hydropower Project, meeting CIA requirements set out in the World Bank Environmental and Social Framework (ESF; World Bank 2017), IFC Performance Standards (IFC 2012), and the guidance set out in the IFC Good Practice Handbook on Cumulative Impact Assessment and Management (IFC 2013).

1.7.2 Structure

This CIA Report is structured as follows:

Chapter 1	Background and Introduction: Describes the study context objectives and phasing as well as gives an overview of Shire River Basin and the MHPP:
Chapter 2	CIA Process, Overall Approach, Methodology and Boundaries: Describes the CIA process, overall approach, modelling and assessment tools, spatial and temporal boundaries, and definition of scenarios.
Chapter 3	Stakeholder Engagement: Describes the stakeholder mapping and analysis as well as the stakeholder engagement process and stakeholders consulted.
Chapter 4	Prioritisation and Selection of Valued Environmental and Social Components, Stressors and Boundaries: Identifies, reviews, and prioritises the VECs through consultation with stakeholders and own research, defines the drivers of change (causes), stressors and primary impacts, and secondary impacts – through cause-and-effect chains (Impact Pathway Network Analysis) affecting the VECs.
Chapter 5	Definition and Selection of Scenarios and Pathways: Describes the scenarios and pathways and what they constitute in detail.
Chapter 6	Set up of Models for Scenario Assessment: Describes the set-up of models for the scenario assessment including that of climate change, hydrology and water resources, sediments, DRIFT ESM and hydropower modelling.
Chapter 7	Overall Assessment Results of the Mpatamanga CIA Impact Pathway Network Analysis: Describes the physical, environmental, and social/socioeconomic, as well as VECs impacts for all scenarios.
Chapter 8	Cumulative Impact Assessment of VECs (all Scenarios): Describes the impact of each VEC group with its indicators more in detail.
Chapter 9	CIA Transboundary Impact Assessment: Outlines possible transboundary impacts.
Chapter 10	Cumulative Impact Management Measures and Plans: Describes the proposed mitigation measures in detail.

Annexes

2 CIA PROCESS AND PHASING OF THE STUDY, OVERALL APPROACH AND BOUNDARIES

2.1 CIA Process and Phasing of the Study

The process used for the CIA is that recommended by the IFC Good Practise Handbook for Cumulative Impact Assessments (IFC 2013), with the tasks aligned accordingly.

The tasks are arranged in the three Phases outlined in Section 1.1.3, as follows, with its subsequent alignment to the steps in the IFC Good Practice Handbook:

- Phase I: Inception and Review
- Phase II: Scoping, which encompasses Steps 1, 2 and 3 of the CIA process and the required stakeholder engagements, data collection, baseline surveys and analyses
- Phase III: CIA Analysis and Monitoring Design, which encompasses Step 4, 5 and 6 of the CIA process.

The tasks in this assignment are also aligned according to the main steps of the CIA process (IFC 2013).

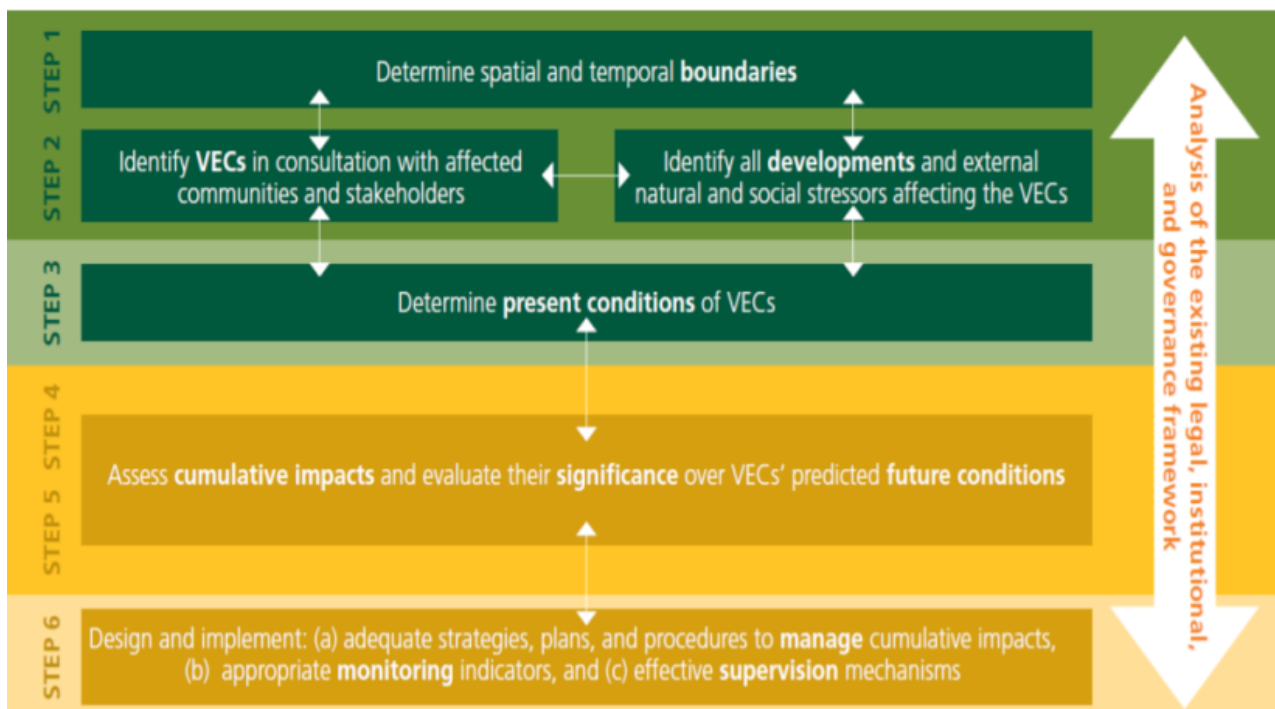


Figure 2-1 The six steps of a Cumulative Impact Assessment (IFC 2013).

2.2 Overall Approach

The cumulative impacts of activities and developments in the basin are assessed by means of scenarios, using two main approaches:

- Impact Pathway Network Analysis method (World Bank/ASTAE 2014)¹⁸
- DRIFT Eco-social assessment.

Reservoir operation, outflows and water levels in the main dam and the regulating dam have been modelled using Mike Plus for each of the CIA scenarios. As part of this, power production has been computed outside using a Python script. For low-head hydropower plants with river-like reservoirs, such as those in the Shire River, a hydraulic model gives more realistic results than, for example, water balance models. Water availability for power production was prioritised as a VEC (see Section 4.1), henceforth, hydropower modelling was used as part of the CIA Impact Pathway Network Analysis (see Sections 2.3).

2.3 Impact Pathway Network Analysis Method

Within the CIA Framework, the Impact Network Pathway Analysis developed for the Red River Vietnam (World Bank/ASTAE 2014) was used in this Mpatamanga CIA to assess cumulative impacts of activities and developments on VECs. The cumulative impact analysis uses a systematic procedure for identifying and evaluating the significance of effects from multiple activities that stem from the MHPP itself, as well as other past, present and future developments. The analysis is based on a network methodology that identifies causes, impact pathways, and consequences, i.e. cause and effect chains from originating drivers/stressors to ultimate receptors of impact (VECs) (in accordance with Bain *et al.*, 1986 and World Bank/ASTAE, 2014)

An example of a network for hydropower cascades is depicted in Figure 2-2 from the study on small hydropower cascades on tributaries of Red River Vietnam (World Bank/ASTAE, 2014). The main components of an impact pathway network analysis are explained as follows:

- **Causes** – Stressors or drivers that impact on the environment at large. These are likely to be the hydropower cascade development on Shire River; water abstraction for irrigation and water supply; related power transmission lines and roads; forest extraction/degradation; wetland encroachment; and climate change, etc.
- **Primary Impacts** – Direct impact of the development, often physical in nature.
- **Secondary impacts** – Effects of the primary impact. Secondary impacts in turn impose effects on the receptor/VECs.
- **Receptors** – These are the VEC's.

The method was improved into a numerical and semi-quantitative (spreadsheet) model for the World Bank funded SESIA (incl. CIA) for the Lake Victoria Transport Programme (Lieblig-Andersen and Lillehammer 2020)

¹⁸ ASTAE (Asia Sustainable and Alternative Energy Program). 2014. *Cumulative Impacts and Joint Operation of Small-Scale Hydropower Cascades*. South Asia Energy Studies. Washington, DC: World Bank.

and is now an in-house Multiconsult model/tool. The tool was also used in the IFC funded Sekong CIA, between 2018-2019 (IFC, 2021)¹⁹.

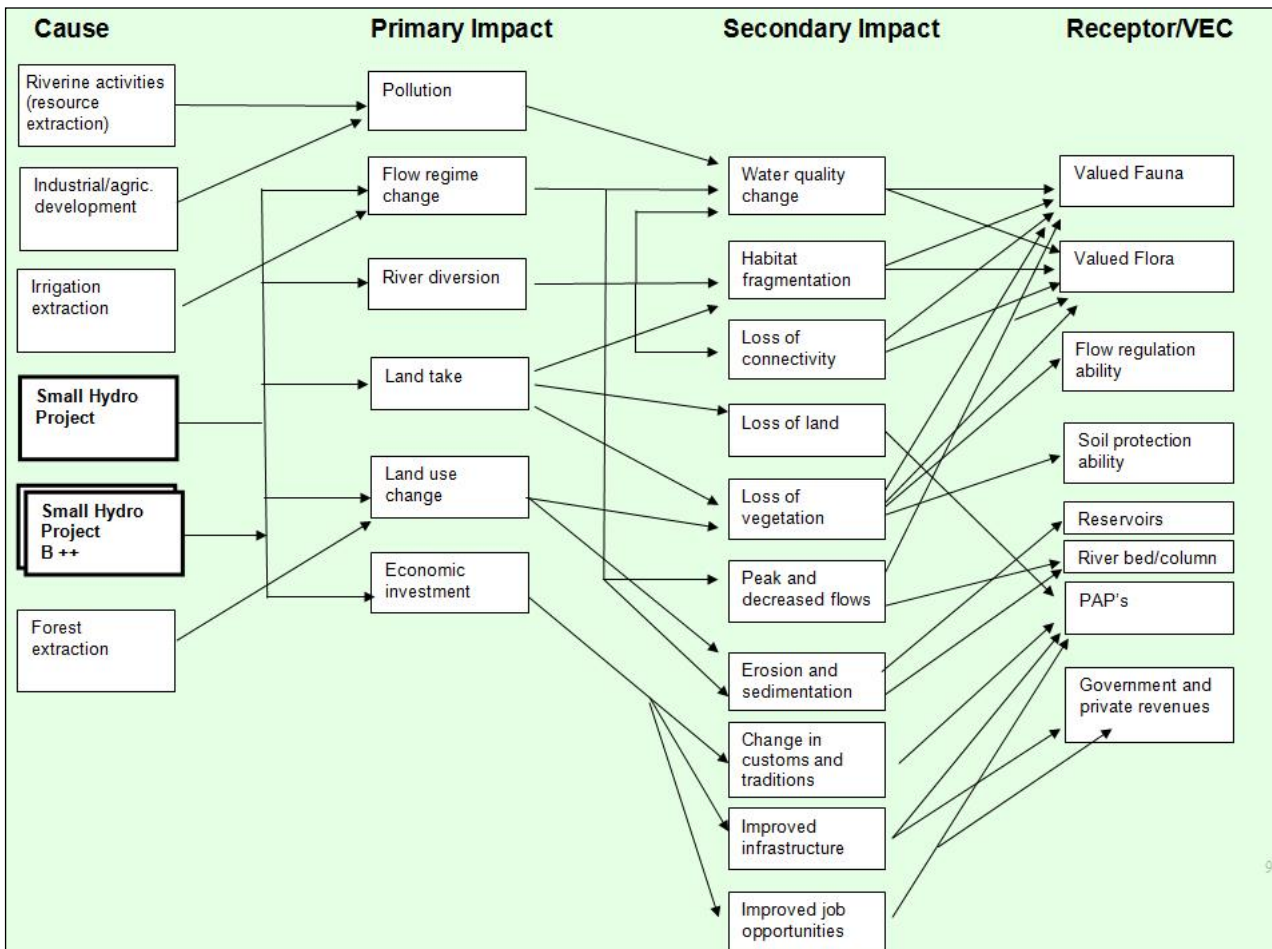


Figure 2-2 Example of a cause-effect network for hydropower cascades (Source: World Bank/ASTAE 2014, Marchand *et al.* 2014).

For the tailored Impact Pathway Network Analysis for the CIA of the Mpatamanga HPP on the Shire River, see Section 7.

2.4 The DRIFT Eco-Social Model

In DRIFT-Shire-ESM (Volume 2 and 3 to this report), the eco-social aspects of the aquatic ecosystems are represented by nine disciplines:

- Geomorphology
- Riparian and instream vegetation
- Macroinvertebrates
- Benthic algae
- Fish

¹⁹ IFC. 2021. *Cumulative Impact Assessment and Management of Renewable Energy Development in the Sekong River Basin, Lao People's Democratic Republic*. International Finance Corporation, Washington, D.C. Undertaken by Multiconsult and Deltares for IFC.

- Herpetofauna
- Waterbirds
- River-related mammals
- Social use.

The main input data to DRIFT-Shire-ESM are 30-year daily timeseries of hydrological, hydrodynamic and hydraulic and sediment, and simulations of how these are expected to change with infrastructure and its operation, abstractions, social use and climate change. Other input data include:

- Landuse
- Human population
- Hunting, cropping and harvesting levels
- Fishing regulations for gear and off-seasons
- Ambient temperature
- Protected areas
- Effluent quality.

DRIFT-Shire-ESM has been set up for 18 sites/zones in the Shire River Basin; five sites on the Shire River and six sites on tributaries, two floodplain lakes and five zones in the Elephant Marsh.

DRIFT-Shire Eco-social sites in the study area:

ES site	River name
1	Shire
2	
3	
4	
5	
2a	Lisungwe
4a	Nkulamadzi
4b	
5a	Lukhubula
5b	Mwanza
7	Ruo
5c1	Northern Lake
5c2	Southern Lake
6a	Elephant Marsh: Northern
6b	Elephant Marsh: Western
6c	Elephant Marsh: Eastern
6d	Elephant Marsh: Central
6e	Elephant Marsh: Southern

For further details of the DRIFT ESM methodology, modelling and assessment, reference is made to Volume 2 and 3 of the CIA.

2.5 Modelling Suite and Digital Platform

2.5.1 Modelling Suite

The overall modelling suite/chain for impact assessment of the scenarios for this study is illustrated in Figure 2-4 overleaf. As part of the climate assessment these have been prepared for both the historical, current, baseline, near future and distant future scenarios climate data from the ensemble of Global Climate Model (GCM) projections belonging to the IPCC 6th assessment report. The historical meteorological data have been sourced from the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS), which is a 30+ year quasi-global rainfall dataset. For the climate simulations, we aligned as much as possible with the climate change resilience assessment of Edf and the high-resolution climate dataset from FocusAfrica (planned to be used by Edf) or ISIMIP3 (a globally established dataset). The CHIRPS and climate model datasets were re-gridded to the higher resolution grid of the hydrological wflow_sbm model using linear interpolation. The temperature and variables needed to calculate the potential evapotranspiration were extracted from ERA5. Both the temperature and the pressure were corrected for using an elevation lapse rate. The wflow_sbm hydrological model is a fully distributed and open-source hydrological model (Wflow) with which the water availability for any location within the basin can be calculated whilst making optimal use of the available global and local data. The wflow_sbm utilises the baseline hydrological time-series (1992-2022). The hydrological simulation results were then subsequently feed into/be used in the sediment model (Delft 3D), the hydropower model (MIKE 11), the hydrodynamic/ecohydraulics models (HABFLO and RMA2-EM), the DRIFT Eco-Social Model, and the Impact Pathway Network Analysis tool. With regard to sediment modelling, we utilised both results from the sediment study (HR Wallingford), that uses the Revised Universal Soil Loss Equation (RUSLE) and their 1D model for larger scale impacts, and Delft3D viz the many of the DRIFT ES sites. The Delft3D was run in quasi-3D, so actually 2D depth average with parametrisation of 3D processes in bends and at sand bars. The Delft3D modelling was then closely connected to the DRIFT Eco-Social Model, but also partly to the two hydrodynamic/ecohydraulics models. The ecohydraulics computational model HABLFO (Habitat Flow simulation model; Birkhead, 2010) was used to develop hydraulic text tables for the DRIFT ES cross-section locations, exempt at Elephant Marsh where the RMA2-EM model was applied instead. Outputs from both of these models were then utilised in the DRIFT Eco-Social Model. The hydropower operation model (MIKE Plus) modelled the effect of different operation of the dams and reservoirs in the Shire River, including the Kamuzu Barrage. It then fed into the Impact Pathway Network Analysis, but also the DRIFT ESM viz routing of the flow. The Impact Pathway Network Analysis Tool and the DRIFT Eco-Social Model are described earlier in Section 2.4.

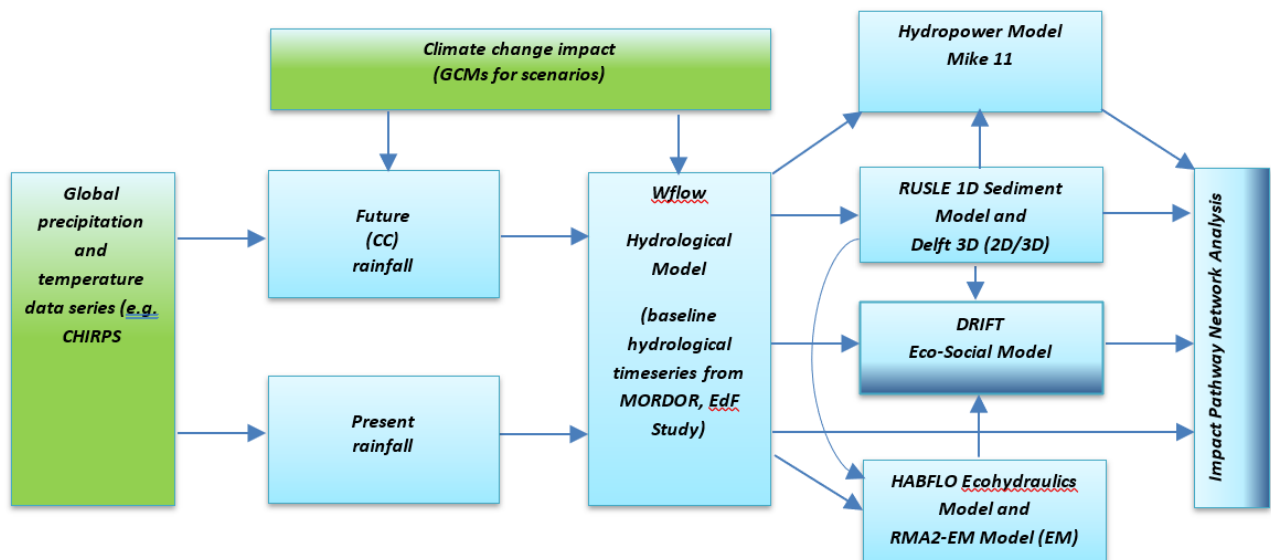


Figure 2-3 Illustration of the modelling suite of the Mpatamanga CIA, with the DRIFT Eco-Social Model and the Impact Pathway Network Tool as the main receptor models/tools for the scenarios cumulative impact assessment.

2.5.2 Digital Platform

A webmap is a geographic information systems (GIS) tool that hosts an interactive online map. It provides a dynamic platform for visualising and analysing spatial data. In the Mpatamanga CIA, we developed a webmap using ArcGIS, a leading GIS software, to facilitate the sharing of critical spatial data among the project team. The Mpatamanga CIA webmap serves as a centralised repository for various layers of spatial information pivotal to development projects in the Shire. Basin. This webmap is accessible (by invitation) at:

<https://cloudgis.multiconsult.no/portal/apps/instant/interactivelegend/index.html?appid=6211c7236d90441882ae931d96dafc44>

The layers in this webmap encompass a range of important aspects of these development projects. This includes detailed infrastructure components, which provide insights into the physical framework of the projects, such as roads, buildings, and utilities. Additionally, it captures land-take zones, highlighting areas designated for development and their respective boundaries. Environmental resources are also a key component of this map, offering valuable data on natural features and ecosystems that might be impacted by the development activities. Moreover, the webmap integrates population and socioeconomic data, giving a comprehensive view of the demographic distribution and economic conditions within the Shire basin. This integration of diverse data layers not only aids in effective project planning and management but also ensures that all team members have access to consistent and up-to-date information, fostering informed decision-making and efficient collaboration.

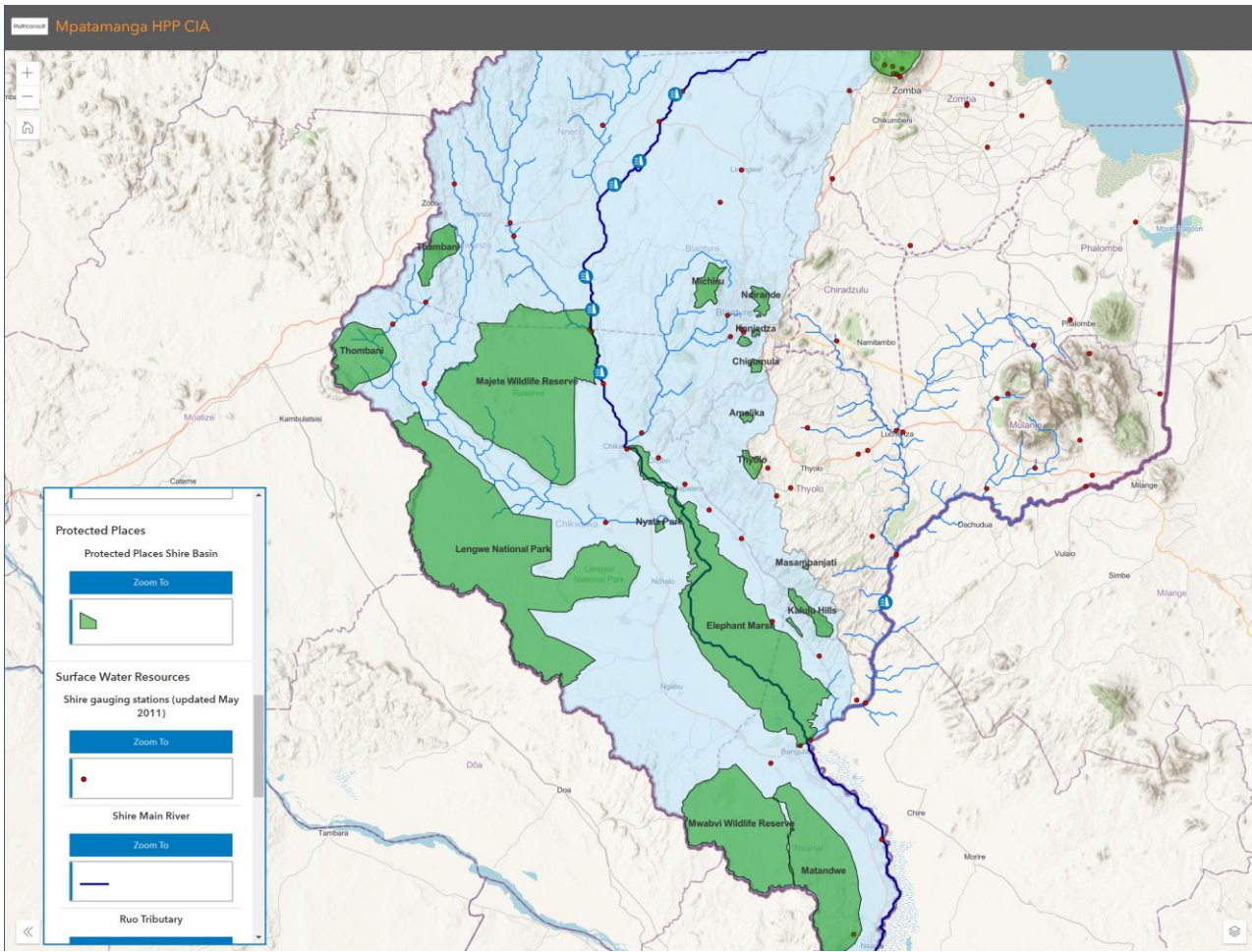


Figure 2-4 Screenshot of Mpatamanga CIA webmap.

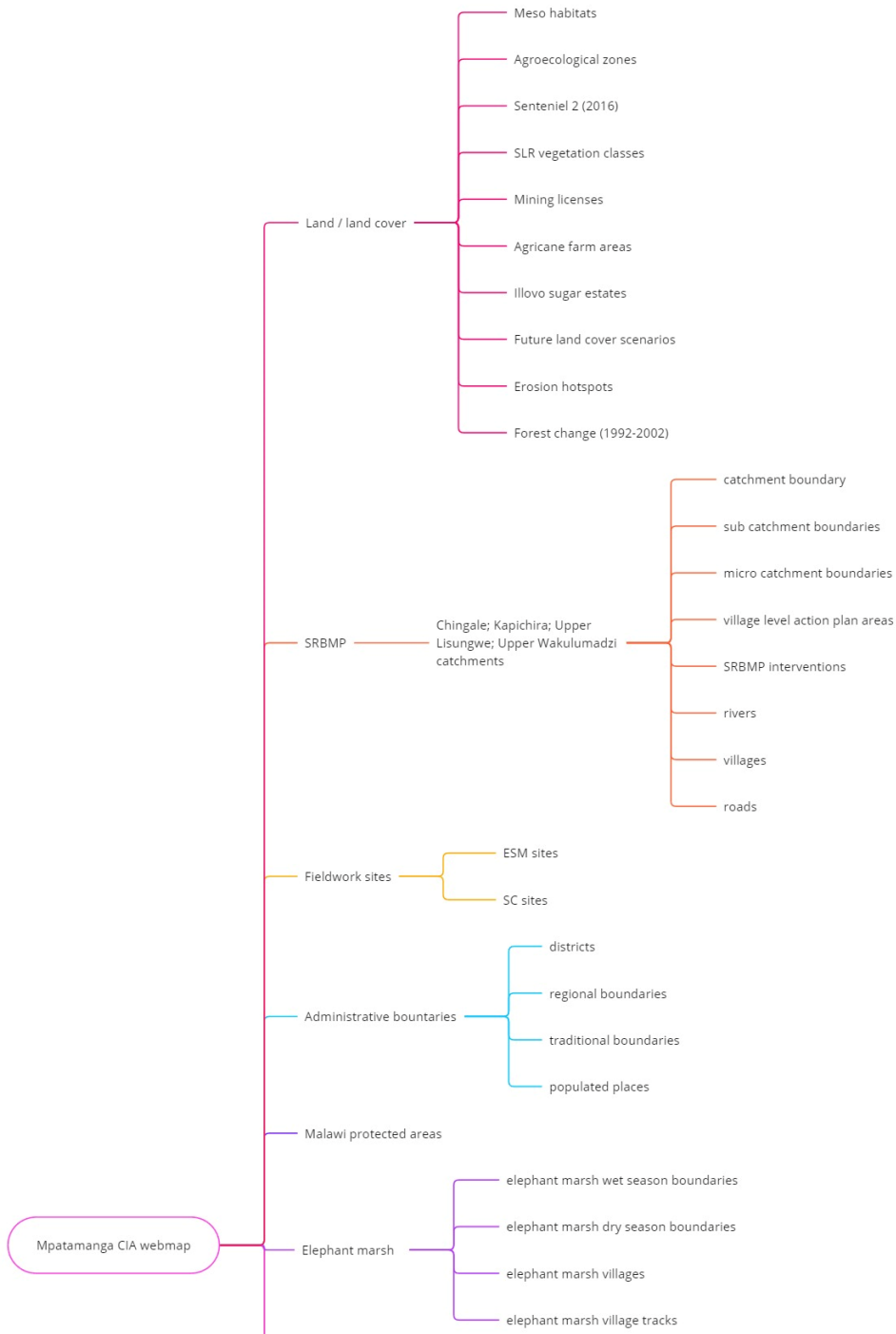


Figure 2-5 Framework of the Mpatamanga CIA webmap platform part 1.

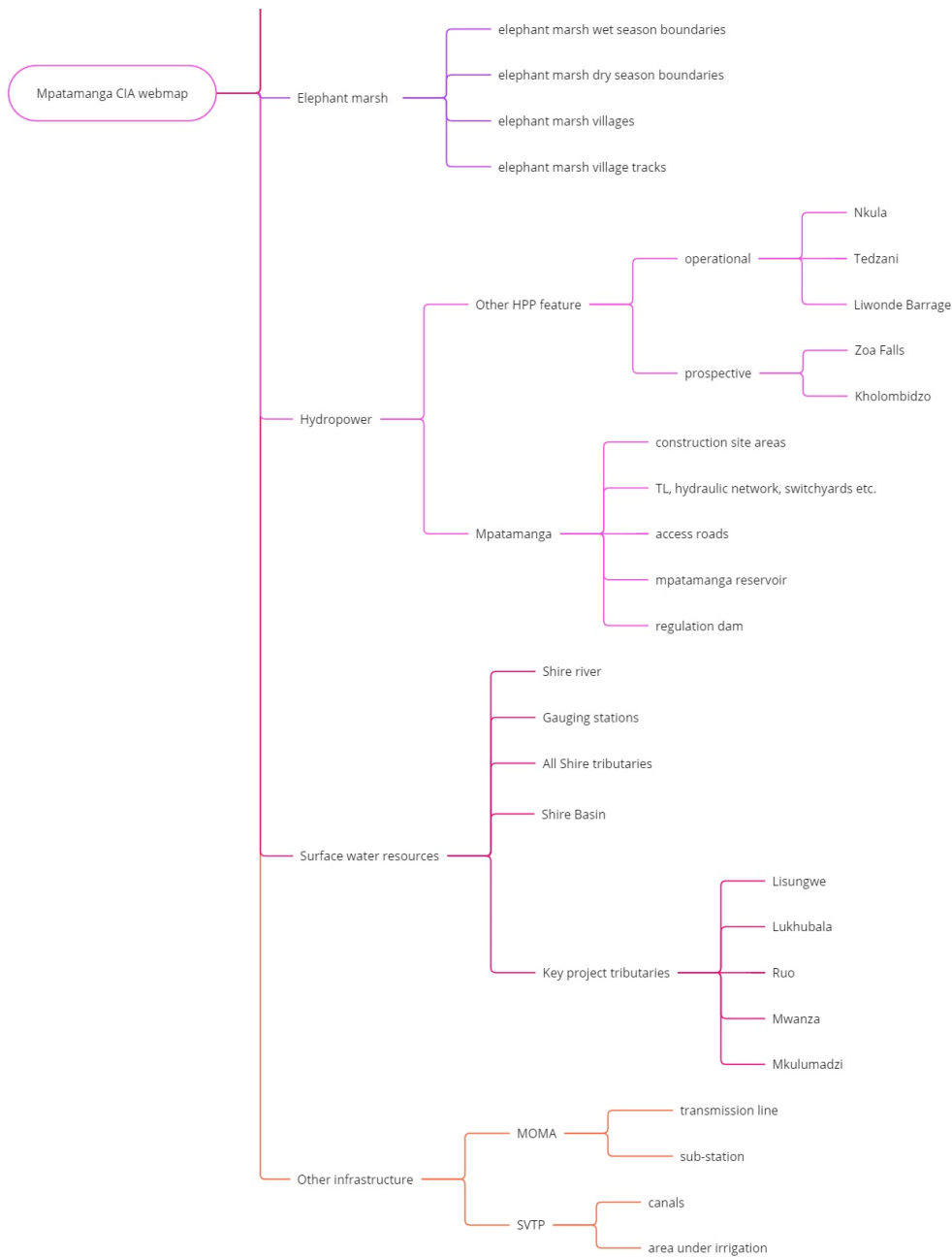


Figure 2-6 Framework of the Mpatamanga CIA webmap platform part 2.

3 STAKEHOLDER ENGAGEMENT

3.1 Stakeholder Mapping and Analysis

The identification and mapping of stakeholders undertaken for the CIA followed the approach taken to Stakeholder Engagement Mapping developed by TBC in the Project's BAP, as suggested by MHPL.

Key stakeholders for the project's Cumulative Impact Assessment were identified based on the following:

- Awareness of the large scale of the CIA's area of interest, and the need to focus on stakeholders at the national and district level, rather than the community level.
- Review of The Biodiversity Consultancy's SEP for the Mpatamanga project's Biodiversity Action Plan, which drew on relevant existing Project documentation, i.e., SEP (Mott McDonald 2020), Updated Stakeholder List (MHPL 2023), MHPL Stakeholder Meeting Attendance Lists (MHPL 2022).
- Interviews with stakeholders performed by C₁₂ and Multiconsult during the following visits in 2023: Inception Visit (March), Sedimentation visit (April), Terrestrial ecology visit (May) and the full Scoping and Baseline Survey mission (July). Some additional stakeholders were identified during the early autumn 2023 as a result of the July mission, especially relation to deforestation and transition to clean cooking technologies. Some of these were consulted in September 2024.
- C₁₂, MHPL's and Multiconsult's previous experience in Malawi.

Stakeholders identified broadly fell into four stakeholder types.

- *Decision making power:* Stakeholders who have influence or power over the Project in some way. This group broadly relates to national level and district level government ministries, departments, and agencies.
- *Interest in CIA issues:* Stakeholders based in Malawi who have either a broad interest in, or engage in, issues relating to the Shire or tributaries, including watershed management and environmental issues. Broadly, this grouping includes national advocacy organisations and donors.
- *Natural resources use:* National or district level stakeholders who use the natural resources that will be impacted by the Project for livelihoods or income. This stakeholder group includes local community members and PAPs, and private sector organisations (as well as African Parks, which is an NGO) close to the Project site who rely on water, local biodiversity, or other natural resources for income through fishing, tourism, charcoal burning, agriculture, hunting, etc. These stakeholders are likely to be directly impacted by the Project, with a high level of interest, but frequently with low levels of power or influence over Project outcomes.
- *Specialist knowledge:* Stakeholders who hold specialist knowledge which may be of use in the development of the CIA. These stakeholders tend to not be directly impacted by the knowledge, with varying levels of interest in the project, and low control or influence over project outcomes, beyond the influence they may have on aspects of the CIA if consulted on specific issues.

For each identified stakeholder, the following parameters were assessed and categorised as either High or Low:

- Stakeholder's **interest in Project-related issues**. This is the extent to which a stakeholder may have concerns about the way the Project impacts the Shire River, its tributaries, or watersheds. For an organisation or institution, it may relate to jurisdictional relevance, or stake in the outcomes of the cumulative impact assessment.

- Stakeholder’s **power over Project-related issues**. This is the extent to which a stakeholder may influence the outcomes of the CIA, including for political, economic and/or legal reasons.

Both parameter values were then combined to obtain the four **stakeholder priority categories**, as shown in Figure 3-1.

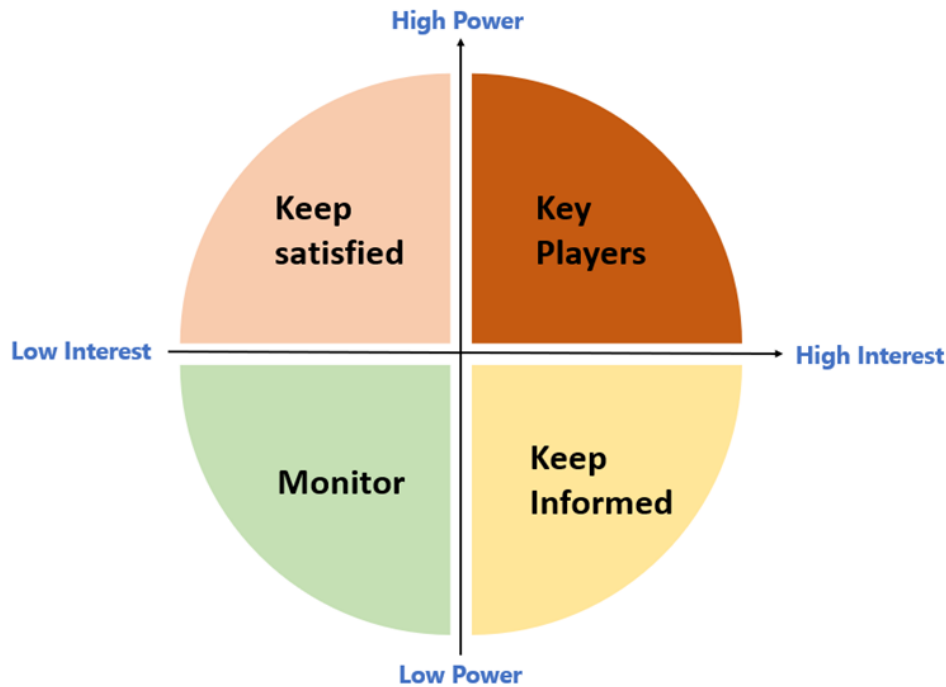


Figure 3-1 Stakeholder categories based on interest and power towards the CIA.

The parameter values (High / Low) and the related stakeholder priority categorisation were preliminary estimates based on an understanding of the Project, and the way stakeholders are believed to be linked to risk and opportunities at the time of preparation of the present document. It is worth noting that the mapping of stakeholder parameter values and the specific categorisation of stakeholders may change over time depending on Project management of issues relating to the Shire and its catchment, as well as on external factors (e.g. social, economic, political, amongst others), which may influence stakeholders’ position towards the project. Stakeholder mapping is an interactive process that should be frequently reviewed to track any changes in stakeholder context.

The four stakeholder priority categories can be understood as follows:

1. **Key CIA Players:** Stakeholders who have both a **high** level of interest in the project and a **high** level of influence and power over project outcomes. These stakeholders will be the stakeholders with whom the CIA team have the highest level of engagement. They will be consulted individually by the CIA team.
2. **Keep Informed:** This category of stakeholder has a **high** level of interest in the project but has a **lower** level of influence or power to control project outcomes. These stakeholders will be kept informed of CIA progress through regular MHPL stakeholder engagement meetings (where relevant), and project newsletters.
3. **Keep Satisfied:** This category of stakeholder is perceived to have a **lower** level of interest in the project, but a **high** level of influence or power over project outcomes. This includes indirect funding

organisations such as British Investment International (BII) and Norfund. It is expected that engagement of this group will be managed directly by MHPL. The CIA team will not directly engage them unless a request is made by MHPL or the stakeholder. The CIA aims to ensure that the requirements of ‘Keep Satisfied’ stakeholders are met, and that they are kept informed of project progress through MHPL’s Project Development Committee (PDC).

4. **Monitor:** These stakeholders are perceived to especially have a **lower** level of interest in the CIA. The CIA team will continue to monitor these stakeholders to see if their level of interest or influence increases and/or a greater level of engagement is required. These stakeholders will be kept informed of project progress through MHPL’s project newsletter.

A full list of identified and mapped stakeholders can be found in the Stakeholder Engagement Plan to the CIA (Multiconsult et al. 2023a).

3.2 Stakeholder Engagement Conducted

The stakeholder engagement conducted (including minutes from the meetings) in March, April and May 2023 is reported in Appendix A (Mobilisation trip), Appendix B (Sediment trip) and Appendix (Terrestrial Ecology trip) of the Inception and Review Report (Multiconsult et al. 2023c), whilst the stakeholder engagement conducted in July 2023, including consultation transcripts is reported the Scoping Mission and Baseline Surveys Field Trip Report (Multiconsult et al. 2023b). In the following, they are listed, and reference is made to the Inception and Review Report and the Scoping Mission and Baseline Surveys Field Trip Report with regard to details from the meetings.

Mobilisation Trip (March 2023)

Stakeholder organisation	Stakeholder type	Stake in the project	Overall CIA priority
EGENCO (consulted 2 times, in Blantyre and at Kapichira)	Large Parastatal or WB Infrastructure Projects	Decision making power	Key CIA player
Agricane/Kaombe Estate	Private Sector	Natural resource user	Key CIA player
African Parks	NGOs, CBOs and Advocacy Groups	Natural resources user	Key CIA player
Robin Pope Safaris	Private Sector	Natural resource user	Key CIA player

Sediment Trip (April 2023)

Stakeholder organisation	Stakeholder type	Stake in the project	Overall CIA priority
EGENCO (consulted 3 times at Kapichira, Tedzani and Nkula)	National Level Government MDAs	Decision making power	Key CIA player
Agricane/Kaombe Estate	Private Sector	Natural resource user	Key CIA player
Robin Pope Safaris	Private Sector	Natural resource user	Key CIA player

Terrestrial Ecology Trip (May 2023)

Stakeholder organisation	Stakeholder type	Stake in the project	Overall CIA priority
MWASIP – Blantyre District	Specialist Knowledge	Watershed management improvement and catchment restoration in the Shire tributaries	Key CIA player
MWASIP – Neno District	Specialist Knowledge	Watershed management improvement and catchment restoration in the Shire tributaries	Key CIA player

Scoping Mission and Baseline Surveys Field Trip (July 2023)

Stakeholder organisation	Stakeholder type	Stake in the project	Overall CIA priority
EGENCO (4 times, at Kamuzu Barrage, Nkula, Tedzani and Kapichira)	National Level Government MDAs	Decision making power	Key CIA player
Agricane/Kaombe Estate (by Teams)	Private Sector	Natural resource user	Key CIA player
Illovo Estate	Private Sector	Natural resource user	Key CIA player
Blantyre Water Board	Large Parastatal or WB Infrastructure Projects	Natural resource user	Key CIA player
SVTP	Large Parastatal or WB Infrastructure Projects	Natural resource user (and infrastructure development)	Key CIA player
ESCOM (incl. MOMA)	National Level Government MDAs	Natural resource user (and infrastructure development)	Keep Informed
NWRA	National Level Government MDAs	Decision making power (and possible long term “owner” of the CIA)	Key CIA player
DWRM	National Level Government MDAs	Decision making power	Key CIA player
Fisheries Department (by phone)	National Level Government MDAs	Decision making power	Key CIA player
Department of Forestry	National Level Government MDAs	Decision making power	Key CIA player
Department of Irrigation (by Teams)	National Level Government MDAs	Decision making power	Key CIA player
DNPW (2 times, Blantyre and in Lengwe National Park)	National Level Government MDAs	Decision making power	Key CIA player
Malawi Human Rights Commission	NGOs, CBOs and Advocacy Groups	Interest in CIA focus	Keep informed
Department of Museums and Monuments	National Level Government MDAs	Decision making power	Keep informed
Department of Environmental Affairs	National Level Government MDAs	Decision making power	Key CIA player

Stakeholder organisation	Stakeholder type	Stake in the project	Overall CIA priority
World Bank (Malawi and Washington DC) and IFC	Lenders	Decision Making Power	Key CIA players (owners)
Mkoko village, Neno	Village Development Committees	Natural resource use	Keep satisfied
Symon village, Neno	Village Development Committees	Natural resource use	Keep satisfied
Ntingale village, Blantyre	Village Development Committees	Natural resource use	Keep satisfied
Felemu and Kambalane villages, Blantyre	Village Development Committees	Natural resource use	Keep satisfied
Lukhubula village, Chicwawa	Village Development Committees	Natural resource use	Keep satisfied
Mwanza village, Chicwawa	Village Development Committees	Natural resource use	Keep satisfied
Nyenere village, Elephant Marsh	Community Conservation Area Members	Natural resource use	Keep satisfied
Fishermen in Elephant Marsh, Lishulu Gumbwa Lagoons and Nkulumadzi tributary	Single local stakeholders	Natural resource use	Keep satisfied

The following additional consultations were conducted in September 2024 prior to the CIA workshop:

Consultations in September 2024 prior to the CIA Workshop 25th September.

Stakeholder organisation	Stakeholder type	Stake in the project	Overall CIA priority
Irish Aid	Lenders	Clean cooking programs and initiatives	Keep informed
NWRA	National Level Government MDAs	Decision making power (and possible long term “owner” of the CIA)	Key CIA player
Modern Cooking for Healthy Forests	Private Sector/NGOs	Clean cooking programs and initiatives	Keep informed
US Aid	Lenders	Clean cooking programs and initiatives	Keep informed

3.3 Stakeholders Identification of VECs and Stressors

3.3.1 Development of Approach to VEC Identification

Identification of stressors and VECs was undertaken through consultation with stakeholders during the July 2023 Scoping Mission. The consultations were undertaken without having any pre-defined list of stressors and VECs so that the stakeholders were free to choose what they perceived was of highest importance. Basically, two distinct groups of stakeholders were consulted, namely:

- National and regional level stakeholders; e.g. government agencies, private sector, parastatals and NGOs.
- Community level stakeholders; e.g. community representatives from villages close to or in the vicinity of the DRIFT ESM sites.

At national and regional level 17 different stakeholders were consulted and asked to prioritise up to 4 of the most important stressors and VECs, with stressor/VEC 1 having the highest/most important priority followed subsequently by stressor/VEC 2, 3, and 4 by importance. Meeting minutes from these consultations are attached to the Scoping Report Volume 1 (Multiconsult et al. 2024a).

At community level, 7 villages were consulted, and a similar exercise with prioritising stressors and VECs was undertaken. The social team organised the consultation meetings through the Village Development Committee. By doing so, community engagements became focus group discussions, comprising not only villages but also key members of the village and community-level governance level.

Engagements with communities and focus group discussions generally began with semi-structured interviews and open-ended discussions. During the initial communication, fieldwork specialists facilitated communities to identify important livelihood communities.

During the local consultations, livelihood components not directly linked to VECs (e.g. employment schemes, schools, etc.) were not disregarded. This maintained a steady flow of information, perceptions and ideas from the communities and interview participants. Thereafter, the group split into two different groups (male and female) to rank the identified livelihood components and the associated stressors/challenges. What communities identified as livelihood components has been studied and was subsequently converted into the analysis of the VECs in the Shire Basin. This also includes the interlinkages of VECs and livelihood components that are indirectly associated with VECs. Summary notes from the community level consultations are attached to the Scoping Report Volume 1 (Multiconsult et al. 2024a).

3.3.2 Stakeholder Perception and Feedback on VECs

The next step was to extract the stakeholder perception and feedback on VECs (prioritisation of stressors and VECs) from the meeting minutes (national and regional level) and summary notes (community level) and summarise them in a raw data table (see Table 3-1, next page), before undertaking scoring of them across all stakeholders (scoring at the two stakeholder levels were held separate at this point).

Table 3-1 Raw data table with the stakeholders prioritising stressors and VECs (PP= Power Production; CC= Climate Change; WQ=water quality).

Stakeholder	Stressor 1	Stressor 2	Stressor 3	Stressor 4	VEC 1	VEC 2	VEC 3	VEC 4
National and Regional Level Stakeholders								
EGENCO (Kamuzu Barrage)	Deforestation	Environmental degradation	Climate change	Over reliance on Shire for PP	Water availability for power generation	Access to drinking water	Tourism along river (incl. fish supply for facilities)	Catchment health
EGENCO (Nkula HPP)	Deforestation– Sedimentation affecting dam and power plant	Environmental degradation - Sedimentation affecting dam and power plant	Environmental degradation – Floating debris	Droughts (CC) affecting production	Water availability for power generation	Availability of water in river channel for local community use	Availability of water for staff use on site	-
EGENCO (Tedzani HPP)	Droughts (lack of water for PP – CC)	Environmental degradation – debris runoff affecting power plant	Deforestation – silt and sediment	-	Water availability for power generation	Water quality for power gen	Catchment health	-
EGENCO (Kapichira HPP)	Droughts (lack of water for PP – CC)	Environmental degradation – debris runoff affecting power plant	Deforestation and catchment degradation– silt and sediment	-	Water availability for power generation and irrigation (SVTP canal)	Water quality for power gen and irrigation (SVTP canal)	-	-
Agricane	Deforestation – sediments and silt	Catchment degradation – silts, sediments, and water quality	Extreme weather events (floods and droughts) - CC	-	Water availability for irrigation	Eco-tourism in relation to a healthy Elephant Marsh	-	-
Ilovo	Extreme weather events (floods and droughts) - CC	Catchment degradation/ deforestation – siltation - WQ	(Increased water salinity in Lower Shire) – Cause?	-	Water availability for irrigation	Water quality for irrigation	A healthy Elephant Marsh	-
Blantyre Water Board	Extreme weather events (floods and droughts) - CC	Degradation of catchment and deforestation – siltation and runoff of chemicals	-	-	Availability of water (quantity and quality)	A healthy catchment	-	-
SVTP	Catchment degradation/ deforestation – erosion, sedimentation, siltation (underlying cause)	More extreme weather (droughts, floods) – CC (build more resilient features, structures)	-	-	Availability of water (steady regular flow)	Quality of water	Elephant Marsh and Lengwe National Park	-

Stakeholder	Stressor 1	Stressor 2	Stressor 3	Stressor 4	VEC 1	VEC 2	VEC 3	VEC 4
	population growth and associated sprawl)							
ESCOM	Extreme weather events (floods)	Lack of infrastructure to supply consumers	-	-	-	-	-	-
NWRA	Droughts and floods (CC)- Water availability (quantity and quality)	Catchment degradation/ deforestation – sedimentation, siltation	-	-	Healthy catchment	Availability and quality of water	-	-
DWRM	Droughts and floods (CC)- Water availability (quantity and quality). Cause (land degradation + CC)	Catchment degradation/ deforestation – sedimentation, siltation	Aquatic weeds in waterways – Cause – Fertilizers/ nutrient runoff	-	Availability of water for water supply	Availability of water for irrigation	Availability of water for hydropower generation	
DEA	Extreme weather events (droughts and floods - CC)	Catchment degradation/ deforestation – sedimentation and nutrient/chemical runoff	-	-	Community livelihoods dependent on river	Elephant Marsh	Riverine aquatic life	-
Fisheries Dept	Land and catchment degradation – Cause charcoal and firewood production	Gold mining affecting water quality (Mwanza and Bua tribs)	Poverty. Few income generating opportunities in parts of the basin. -> charcoal - firewood	-	Water availability for power production	Water (quantity and quality) for fish production	Water for aquaculture farms	-
Forestry Dept	Deforestation due to charcoal production	Encroachment into forested/protected areas (charcoal and cultivation)	-	-	Biodiversity (aquatic and terrestrial)	Community livelihoods (linked to biodiversity)	-	-
Irrigation Dept	Extreme weather events (CC)	Catchment degradation (with CC affecting water availability) – Cause: charcoal and encroachment	Excessive livestock grazing (leads to overgrazing and soil erosion)	Use of pesticides in agriculture (runoff non-point source pollution)	Reliable water availability for irrigation	-	-	-

Stakeholder	Stressor 1	Stressor 2	Stressor 3	Stressor 4	VEC 1	VEC 2	VEC 3	VEC 4
			affecting quality of water)					
DNPW	Extreme weather events (flooding)	Deforestation due to charcoal production (also exacerbating flooding and sedimentation silting of aquatic habitats. Also increased poaching during floods)	Encroachment on land near pristine or protected areas (due to population growth and poverty)	-	Habitats for wildlife and birds	Majete WR, Lengwe NP, Liwonde NP, Elephant Marsh	Flagship VEC species: Hippos, crocs, rhinos, nyala antelope, pangolin and migratory birds in Elephant Mars	-
Malawi Human Rights Commission	Deforestation	-	-	-	Community livelihoods	Reliable water availability for irrigation	-	-
DMM	Construction of infrastructure (irrigation, roads, HPP, etc.)	Extreme weather events due to CC			Livingstone trail	Sacred forest, trees, tributaries Cultural sites	Historical, Pre-historical and palaeontological sites	
Community Level Stakeholder								
Simon Village (SC2)	Loss of community livelihoods. Especially through the stoppage of the rural works program (Malawi Social Action Fund - MASAF)	Extreme weather events	Access roads (linked to increased transportation costs and value-chain isolation)	Declining soil productivity	Agricultural fields	Rangelands	Social services: healthcare	River and groundwater
Mkoko village (SC1)	Declining soil productivity	Extreme weather events	Growing population and resource pressures	Loss of land and influx of migrant workers due to Nkula HPP	Productive land and soil for agriculture	Social services: schools and healthcare	Biodiverse forests and woodlands	River resources
Ntingala village (SC3)	Extreme weather events	Lack of employment opportunities	Accessibility during wet season	Declining fish stocks	Productive land and soil for agriculture	Social services: schools and healthcare	Rangelands and livestock	CBO-village savings and loans scheme
Felemu and Kambalane Villages (SC4)	Access roads	Poor education levels among youth (prompted by bridge collapse which cut-off access to schools)	Extreme weather events	Charcoal harvesting	Productive land and soil for agriculture (incl. cattle ranches)	River resources	Social services: schools and healthcare	Biodiverse forests and woodlands

Stakeholder	Stressor 1	Stressor 2	Stressor 3	Stressor 4	VEC 1	VEC 2	VEC 3	VEC 4
Kanjala village (SC5)	Extreme weather events. Especially floodings	Sedimentation	Access roads	Lack of electricity	Productive land and soil for agriculture (especially flood recession agriculture in the flood plain lake)	Biodiverse forests and woodlands	River/floodplain lake	Rangeland and livestock
Chambuluka village (SC7)	Access roads	Declining fish stocks	Sedimentation	Exotic livestock breeds	Productive land and soil for agriculture	Biodiverse forests and woodlands	River resources	Social services: schools and healthcare
Ntchenyera village (SC9)	Lack of employment opportunities	Extreme climatic events, especially periods of high rainfall (slowly receding water levels delay the dry season cropping window)	Access roads	Land tenure agreements with sugar cane estates	Productive land and soil for agriculture (including flood recession agriculture in the Elephant Marsh)	Elephant Marsh	River Resources	Rangelands and livestock

*SC= Social Consultation site

3.3.3 Key Findings

Most of the national level stakeholders were concerned about the continuing degradation of the basin due to the land use change and deforestation and climate change and its impacts on water and natural resources, protected areas and wildlife with some difference in focus. Typically, Department of Forestry and DWNP have focus on catchment degradation as a whole and also on biodiversity, wildlife and protected areas. NWRA and DEA have focus on this as well but also on water resources (quantity and quality), whilst the water users like EGENCO, SVTP, Illovo and Agricane as well as Department of Irrigation have more focus on impacts on the availability and quality of water (albeit environmental “programs” are part of their portfolio as well). The consulted stakeholders’ VEC focus/prioritisation (during the July 2023 trip) is reported in Section 4.1.2.

The local level stakeholders are, understandably, more focused on impacts at local level (very much due to local level developments) and on social impacts, including natural resources upon which they base their livelihoods.

4 PRIORITISATION AND SELECTION OF VALUED ENVIRONMENTAL AND SOCIAL COMPONENTS, STRESSORS AND BOUNDARIES

4.1 *Prioritisation and Selection of VECs and Stressors*

Scoring of the stressors and VECs across all stakeholders was undertaken to rank the importance of the stressors and VECs as perceived by the stakeholders. Some stressors from the raw data table were also pooled or renamed for harmonization and simplification purposes. A total stressor sum was then calculated as follows: $S1=4$, $S2=3$, $S3=2$ and $S4=1$ multiplied by number of stakeholders (NS) prioritising them; then total stressor sum (TSS) is $S1 \times NS + S2 \times NS + S3 \times NS + S4 \times NS$. Similarly, the total VECs Sum (TVS) was calculated from the TSS. The stressors and VECs were grouped in prioritised and non-prioritised groups based on their total score, and sound judgement was allowed for if scoring was lower while the CIA consultant thought it was important that these stressors and VECs should be part of the prioritised groups. The consultant also identified a few new stressors (influx of people) and VECs (tourism), not prioritised by the stakeholders, perceived as important in the Shire Basin.

It is important to note that stressors identified by the stakeholders are actually primary impacts from Drivers/Causes, so in the Impact Pathway Network Diagram, Drivers/Causes have been identified and the primary impact column has been termed Stressors/Primary impacts.

In the following, the results from the scoring exercise described above are provided, with comments on the drivers/causes included.

National and Regional Level Stakeholders

Total Stressor Sum (TSS) (Prioritised and Non-Prioritised)

Prioritised

1. Deforestation = **55** (Drivers are population growth with associated sprawl into pristine areas, poverty, charcoal and firewood production, cultivation)
2. Extreme weather events = **51** (Drivers are climate change, but both drought and floods events are also exacerbated by degradation of the catchment including deforestation)
3. Environmental degradation other than deforestation (pollution etc) = **23** (Drivers are use of pesticides, fertilizers etc in agriculture and industrial activities)
4. Influx of people (added by Client/Consultant) = Not scored by stakeholders (Drivers are infrastructure development (HPPs, SVTP and other irrigation dev., water supply development, transmission line dev.) and population growth).

Non-prioritised

5. Encroachment into pristine or protected areas = **5** (Drivers are population growth, poverty, and lack of livelihood opportunities)
6. Infrastructure development (including HPPs) = **4** (Drivers are population and economic growth)
7. Excessive livestock grazing = **2** (Drivers are poorly managed agricultural applications due to environmental knowledge and poverty)

8. Increased water salinity in Lower Shire = **2** (May be increasingly exacerbated by the impacts of irrigated agriculture as a driver (Foster et al., 2018))
9. Over reliance of Shire for power production = **1**

Total VECs Sum (TVS) (as of TSS) (Prioritised and Non-Prioritised)

Prioritised

1. Reliable water availability and quality = **84**
 - For power generation, irrigation, water supply and livelihoods
2. Biodiversity and habitats for flora, wildlife, birds and aquatic life = **25**
 - Flagship VEC species
 - i. Hippos
 - ii. Crocodiles
 - iii. Rhinos (especially Black Rhino as of BAP study)
 - iv. Nyala antelope
 - v. Pangolin
 - vi. Migratory birds (Elephant Marsh) and Vultures (as of BAP study)
 - Flagship VEC Habitats
 - i. Majete WR
 - ii. Lengwe NP
 - iii. Liwonde NP
 - iv. Elephant Marsh
3. Catchment health = **12** (not really a VEC, but a stressor and response to it a mitigation strategy instead. Hence, taken out in Summary Stressor Table)
 - Helps also regulating Reliable water availability and quality and supports biodiversity
4. Historical sites = **6**
 - Livingstone trail, other historical sites, archaeological sites, paleoanthropological and paleontological sites etc.
5. Cultural and religious sites = **3** (*pooled together with historical sites in Summary VEC Table*).
 - Sacred forest, sacred tree's (baobab etc.), sacred tributaries etc.
6. Tourism (Not scored by stakeholders. Added by Client/Consultant)

Non-prioritised

7. Resilient community livelihoods = **3**

Community Level Stakeholders

Total Stressor Sum

Prioritised

1. Extreme Weather Events = **21**
2. Loss of livelihoods/Lack of Employment Opportunities = **15**
3. Influx of people (added by Client/Consultant) = Scored low by stakeholders (Drivers are infrastructure development (HPPs, SVTP and other irrigation dev., water supply development, transmission line dev.) and population growth).

4. Lack of infrastructure development or Infrastructure collapse = **12** (Infrastructure collapse due to cyclones/floods; e.g. drivers are either economic development or extreme weather events)

Non-prioritised

5. Declining agricultural and soil productivity = **5** (due to non-sustainable management/practises, and is a primary impact of deforestation and environmental degradation)
6. Increased sedimentation/siltation = **5** (this is actually a primary impact of deforestation and extreme weather events)
7. Declining fish stocks = **4** (secondary impact of sedimentation/siltation, pollution, and overfishing)
8. Population growth/Influx of people = **3**
9. Charcoal production = **1** (Driver to the stressor deforestation and subsequent effects)
10. Sugarcane Estate expansion = **1** (Part of influx of people)
11. Introduction of exotic livestock = **1**

Total VECs Sum

Prioritised

1. Productive land/soil for agriculture = **28**
2. Biodiversity and habitats for flora, wildlife, birds and aquatic life = **21** (*Changed to Ecosystem Services for Livelihood in VEC summary Table*)
 - a. Forest and woodlands biodiversity and resources
 - b. Riverine and wetlands biodiversity and resources
 - c. Flagship VEC habitats (Elephant Marsh, floodplain lake near Lukhubula tributary, etc.)
3. Social Services (education and health facilities and community loans etc.) = **12**

Non-prioritised

4. Productive rangelands for livestock = **7** (*part of productive land/soil for agricultures*)

A further assessment/detailing of the drivers/causes behind the stressors and the indicators of the stressors quantifiability is given in Tables 4-1 (national and regional level stakeholders) and 4-2 (community level stakeholders).

Table 4-1 Summary prioritised stressor table for Impact Pathway Network Analysis (national and regional level stakeholders).

Rank	Stressor	Drivers to Stressor	Total Stressor Score (TSS)	Average Score (TSS/17)	Quantifiable indicators
1	Deforestation	Charcoal and firewood production and encroachment into forested area (with ultimate cause associated with poverty and population growth)	55	3.06	Yes: Percentage or total amount of deforested area over time (land cover change analysis)
2	Extreme weather events (floods and droughts)	Climate change (the stressor is also exacerbated by deforestation)	51	2.83	Yes: Climate change results with subsequent impacts on basin hydrology

Rank	Stressor	Drivers to Stressor	Total Stressor Score (TSS)	Average Score (TSS/17)	Quantifiable indicators
					/ precipitation anomaly data (magnitude and frequency)
3	Environmental degradation other than deforestation (pollution etc.)	Agricultural practises (pesticides, fertilizers) and industrial activities	23	1.28	Yes: Estimated non-point or point source pollution and/or changes in water quality
4	Influx of people ²⁰	Infrastructure development (HPPs, Irrigation, Water Supply, Roads, Transmission Lines)	Non-scored by stakeholders. Added by Client/Consultant	Non-scored by stakeholders. Added by Client/Consultant	Yes: Estimated amount of influx due to various development activities

Table 4-2 Summary prioritised stressor table for Impact Pathway Network Analysis (community level stakeholders).

Rank	Stressor	Drivers to Stressor	Total Stressor Score (TSS)	Average Score (TSS/7)	Quantifiable indicators
1	Extreme weather events	Climate change (the stressor is also exacerbated by deforestation)	21	3	Yes: Climate change results with subsequent impacts on basin hydrology; precipitation anomaly climate data (magnitude and frequency)
2	Loss of livelihood/Lack of employment opportunities	(i) Infrastructure development, (ii) extreme weather events, (iii) lack of economic development/poverty	15	2.14	(i) Yes (Loss of land), (ii) Yes (amount and increase in events), (iii) Yes (estimates of employment rates/poverty rates)
3	Influx of people	Infrastructure development (HPPs, Irrigation, Water Supply, Roads, Transmission Lines)	Non-scored by stakeholders. Added by Client/Consultant	Non-scored by stakeholders. Added by Client/Consultant	Yes: Estimated amount of influx due to various development activities
4	(i) Lack of infrastructure development or (ii) infrastructure collapse	(i) Lack of economic development and (ii) extreme weather events	12	1.71	Yes: Estimated needs for infrastructures dev. and probability for infrastructure collapse

²⁰ Workforce plus additional opportunistic influx.

Similarly, as with the stressors, a further assessment/detailing of the VECs with their indicators and the indicators quantifiability is given in Table 4-3 (national and regional level stakeholders) and Table 4-4 (community level stakeholders).

Table 4-3 Summary prioritised VEC table for Impact Pathway Network Analysis (national and regional level stakeholders).

Rank	VEC group	VEC details/indicators	Total VEC Score (TVS)	Average Score (TVS/17)	Quantifiable indicators
1	Reliable water availability and quality	For: Power generation Irrigation schemes Water supply Ecosystem Services (floodplain agriculture etc.)	84	4.67	Yes: Available water volumes and data on water quality.
2	Biodiversity and habitats for wildlife, birds and aquatic life	<u>Flagship VEC species:</u> Elephants, Hippos, Crocodiles, Black Rhinoceros (BAP Study), Nyala antelope, Pangolin, Migratory Birds (especially in Elephant Marsh) and White-backed and White-headed Vultures (BAP Study) <u>Flagship VEC habitats:</u> Majete WR, Lengwe NP, Liwonde NP and Elephant Marsh DRIFT ESM assessment of river zones with regard to ecosystem health	25	1.39	Yes: To some extent viz number of animals per VEC species / IUCN Red List classification category. VEC habitats, to some extent with regard to area of non-degraded protected areas. Yes: With regard to the DRIFT ESM assessment
4	Historical, cultural and religious sites	Livingstone trail and other historical sites, including sites such as 'Thornton's grave' downstream of Kapichira, archaeological sites, paleoanthropological and paleontological sites, including recently discovered paleontological site close to Kapichira dam. Cultural and religious sites like sacred forests patches, sacred tree's (baobab), and sacred tributaries, including the Mbona Rain Shrines at Khulubvi close to the Shire in Nsanje district, which are on the UNESCO World Heritage tentative list as of 2011.	9	0.5	Yes: Number of sites affected and for larger sites also area

5	Tourism (added by Client/Consultant)	Eco- and wildlife tourism. Lodges	Non-scored by stakeholders	Non-scored by stakeholders	Yes: Number of tourists/overnight stays; statistics on employment in the travel and tourism industry
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Table 4-4 Summary prioritised VEC table for Impact Pathway Network Analysis (community level stakeholders).

Rank	VEC group	VEC details/indicators	Total VEC Score (TVS)	Average Score (TVS/7)	Quantifiable indicators
1	Productive land/soil for agriculture	Aggregated amount/size of productive land/soil for agriculture Productive rangeland for livestock	28 (35 with productive rangeland for livestock)	4 (5)	Yes: To some extent this can be quantified by the amount of land under cultivation and by national agriculture production census data such as: National crop production and hectare estimates for rainfed and irrigated agriculture; Agriculture Development and Marketing Corporation (ADMARC) domestic commodity purchases; etc.
2	Ecosystem Services for Livelihood	Forest and woodlands biodiversity and resources Riverine and wetlands biodiversity and resources Flagship VEC habitats (esp. Elephant Marsh)	21	3	Yes: Possibly to some extent with regard to available sustainable outtake of resources for livelihoods. This can also be quantified by calculating the total land use/changes in land cover for woodland
3	Social services (also affected by influx of people and extreme weather events as stressors)	Education and health facilities and community loans Social cohesion	12	1.71	Yes: Access to these services. Census data that could inform the quantification of social services include; early childhood development statistics; energy and sanitation statistics; etc.

4.2 Summary of Causes and Drivers of Change

The main drivers and causes of change in the Shire River Basin, based on the stakeholder inputs discussed in Section 3.2 and 3.3 along with research, can be summarised as follows. These have been included in the preliminary overall CIA analysis (Impact Pathway Network Analysis) discussed in Section 7.1.

Anthropogenic (human-induced) causes/drivers

- Charcoal and firewood production and encroachment into forested areas (most widespread throughout the basin).
- Agricultural and industrial development (practises).
- HPP and dams development and operation (Nkula, Tedzani, Kapichira, Mpatamanga HPPs plus Kamuzu Barrage).
- Irrigation and water supply development (SVTP, Illovo, Agrigane etc., plus Blantyre Water Board Southern Region Water Board developments).
- Transmission lines and roads development (MOMA etc.).

Natural system causes/drivers

- Climate change (besides charcoal production etc. the most profound driver of change at basin scale)

4.3 Summary Stressors/Primary Impacts

The causes/drivers of change discussed above have led to identification of a group of main stressors/primary impacts as a result of the causes/drivers of changes. These are as follows:

- Extreme weather events, e.g. floods and droughts. Primarily caused by climate change but exacerbated also by deforestation due to charcoal/firewood production and encroachment into forested areas.
- Deforestation and land use change. Main cause is charcoal/firewood production and encroachment into forested areas, but also affected by infrastructure and agricultural development.
- Environmental degradation other than deforestation (pollution etc.). Impacted by multiple causes/drivers but most profoundly by agricultural and industrial practises.
- Changes to flow regime. Impacted by multiple causes/drivers, but most profoundly by HPP development and operation.
- Influx of people. Impacted by HPP, irrigation and transmission line and roads development.

These again have multiple secondary impacts which are discussed in Section 8 of this report.

4.4 Summary Prioritised VECs

The VECs prioritised and discussed in detail in Table 4-3 and 4-4 have been pooled for the Impact Pathway Network Analysis, and the final list of prioritised VECs is as follows:

- Reliable water availability and quality.
- Biodiversity and habitats for wildlife, birds and aquatic life (VEC species and habitats).
- Ecosystem services for livelihoods.
- Productive land/soil for agriculture.
- Historical, cultural and religious sites.
- Tourism and social services.

4.5 Spatial Boundaries

The spatial boundaries for the CIA are the Shire River Basin downstream of Lake Malawi to the confluence with the Zambezi River. However, the main focus area of the study is the catchment of the Shire River from the Kamuzu Barrage to the Mozambican border, including its significant tributaries (see Figure 4-1).

The Impact Pathway Network Analysis assessed the status and changes within the whole catchment of the main focus area whereas the DRIFT ESM investigated the status and changes to the aquatic and riparian systems at the ESM sites and their associated zones/river reaches.

The temporal and spatial boundaries of the study have been discussed and agreed with the Client, WB/IFC and stakeholders during the Scoping Phase.



Figure 4-1 Spatial scope of the CIA.

5 DEFINITION AND SELECTION OF SCENARIOS AND PATHWAYS

5.1 General

The scenarios with their *temporal boundaries* have been selected through an interactive process with the Client, IFC/WB, the ESIA consultant and a few other stakeholders. Ten main scenarios have been selected and can be grouped into four main scenario groups, namely:

- Near Natural and Historical (trended past) scenarios;
- Baseline scenarios (current and 2030);
- Near Future scenarios (2035); and
- Distant Future scenarios (2070).

5.2 Summary of Selected Scenarios with Pathway Developments

A summary description of all the selected past, present, and future scenarios for the modelling and analysis of the Mpatamanga CIA is given in Table 5-1 overleaf, where the details, with main input characteristics/ parameters are outlined. Each of the four main scenario groups are highlighted in white/ grey background colour.

The hydrological conditions of the scenarios have been based on the CIA Wflow hydrological modelling (with a hydrological reference period between 1992-2023; however, comparison/ adjustments have been undertaken with the EDF baseline time-series for 1992-2022, where found necessary).

Table 5-1 Description of the main scenarios for the CIA analysis. Including main input characteristics/parameters.

#	Code	Scenario	Temporal boundary	Description with regard to HPP Development	Description with regard to other infrastructure developments	Time/Period Basin Land Cover	Forest Cover relative to baseline 1 Closed BDF (Estimated Forest Cover)	Estimated Basin Population ²¹
1	Natural	Near Natural Scenario	Early 1900	Historical conditions without large dams in the basin	Historical conditions without other large infrastructure in the basin and low levels of deforestation, and inputs by; <ul style="list-style-type: none"> - 1900 water resource and other infrastructure developments 	1900	+37% (Closed BDF = 35.21%, Total = 53.38%)	< 250 000
2	HS Trend	Historical Scenario	From 1992 to 2022	This trended scenario will track the changes in the hydrology, Kapichira coming online, changes in frequency of flooding, etc. Will also be used to calibrate DRIFT, and inputs by: <ul style="list-style-type: none"> - Pre-1992: Kamuzu Barrage, Tedzani 1, Nkula 1, 2 and 3 - 1992-2002: + Tedzani 2 and Kapichira Phase 1 - 2012-2022: + Kapichira Phase 2 + Tedzani III 	Actual water resources development that came online between 1992-2022 Irrigation developments, water supply developments <p><u>Irrigation</u></p> <ul style="list-style-type: none"> - Illovo - Agricane + others <p><u>Water Supply</u></p> <ul style="list-style-type: none"> - BWB + SRWB 	Pre-1992 1992-2002 2002 – 2023	Pre-1992: +30% (Closed BDF = 33.41%) 1992-2002: +15% (Closed BDF = 29.56%) 2002-2023: 0% (Closed BDF = 25.7%)	1992: 2 200 000 2002: 2 600 000 2012: 3 400 000 2022: 4 500 000

²¹ Based on that Shire Basin comprises 16 % of the land area of Malawi, but 22 % of its population (Coulibaly, Y.J., Mbow, C., Sileshi, G.W., Beedy, T., Kundhlande, G. and Musau, J. (2015) Mapping Vulnerability to Climate Change in Malawi: Spatial and Social Differentiation in the Shire River Basin. *American Journal of Climate Change*, 4, 282-294. <http://dx.doi.org/10.4236/ajcc.2015.43023>). Estimates for all scenarios except near natural derived from this source of total Malawi population projections <https://worldpopulationreview.com/countries/malawi-population/>.

#	Code	Scenario	Temporal boundary	Description with regard to HPP Development	Description with regard to other infrastructure developments	Time/Period Basin Land Cover	Forest Cover relative to baseline 1 Closed BDF (Estimated Forest Cover)	Estimated Basin Population ²¹
3	Base 2022/3	Baseline Scenario 1 (Reference Scenario)	Current conditions – 2023	Current situation and HPP development within the spatial boundary and institutions <ul style="list-style-type: none"> - Kamuzu Barrage (KABOM operation rules) - Nkula (peaking) - Tedzani (peaking) - Kapichira (peaking) 	Current development status and land use of the spatial boundary area. <p><u>Irrigation</u></p> <ul style="list-style-type: none"> - Illovo - Agricane + others <p><u>Water Supply</u></p> <ul style="list-style-type: none"> - BWB + SRWB Current transmission lines and roads	2023 (same as HS 2023 forest cover)	²² Closed BDF = 25.7% Open BDF = 16.59% Mosaic cropland = 1.15% Closed to open BE = 0.43% ²³ Total = 43.87%	4 600 000
4.1	2030BAU	Baseline Scenario 2 –with/without Mpatamanga Operational	Near Future 2030	Sub-scenario BS 2.1: Conditions 2030 without Mpatamanga <ul style="list-style-type: none"> - Kamuzu Barrage (KABOM projections) - Nkula (peaking) - Tedzani (peaking) - Kapichira (peaking) 	Development status 2030. SVTP (Illovo and Agricane connected); MWASIP, water supply and transmission lines/roads included (including MOMA).	2030 (same as BS1 2023 forest cover)	<1% (Closed BDF = 25.4%)	5 500 000
4.2	2030MPTBAU			Sub-scenario BS 2.2: Conditions when Mpatamanga becomes operational				

²² Considering all landcover classes relevant to forests the current forest cover within our model domain is up to 44%, with a breakdown from the unmodified ESA Globcover product in the present-day baseline (<https://www.esa-landcover-cci.org/>). When modifying landcover we increased the proportion of closed canopy broadleaved deciduous forest (Closed BDF), but not at the expense of 3 other forest-relevant classes (Open BDF, Mosaic cropland and Closed to open BE; see footnote 3)

²³ Closed BDF = Closed (>40%) broadleaved deciduous forest (>5m); Open BDF = Open (15-40%) broadleaved deciduous forest (>5m); Mosaic Cropland = Mosaic cropland (50-70%) / vegetation (grassland, shrubland, forest) (20-50%); Closed to open BEF = Closed to open (>15%) broadleaved evergreen and/or semi-deciduous forest (>5m)

#	Code	Scenario	Temporal boundary	Description with regard to HPP Development	Description with regard to other infrastructure developments	Time/Period Basin Land Cover	Forest Cover relative to baseline 1 Closed BDF (Estimated Forest Cover)	Estimated Basin Population ²¹
				<ul style="list-style-type: none"> - Kamuzu Barrage (Kabom projections) - Nkula (peaking) - Tedzani (peaking) - Mpatamanga (peaking) - Kapichira (<u>not peaking</u>) 				
5	NF1BAU	Near Future Scenario 1 – Business as Usual Pathway	Future conditions – as planned for 2035	Planned HPP infrastructure development and operations <ul style="list-style-type: none"> - Kamuzu Barrage - Nkula (peaking) - Tedzani (peaking) - Mpatamanga (peaking) - Kapichira (not peaking) 	Future infrastructure development scenario as of 2035 with SVTP, MWASIP, Irrigation as of Master Plan up to 2035, water supply and transmission lines (including MOMA).	2035 BAU (Business as usual catchment management and sectors development; Same as BS1 2023 forest cover)	<1% (Closed BDF 25.4%) (1.8% increase in agricultural land)	6 200 000
6	NF2BAU	Near Future Scenario 2 – Business as Usual + Joint Dams Operation	Future conditions as planned for 2035	Planned HPP infrastructure development and operations as of Near Future Scenario 1 plus joint operation of Kamuzu Barrage, Nkula, Tedzani, Mpatamanga and Kapichira <ul style="list-style-type: none"> - Kamuzu Barrage (KABOM projections) - Nkula (peaking) - Tedzani (peaking) - Mpatamanga (peaking) 	As of Near Future Scenario 1	2035 BAU + JDO	As NF1	6 200 000

#	Code	Scenario	Temporal boundary	Description with regard to HPP Development	Description with regard to other infrastructure developments	Time/Period Basin Land Cover	Forest Cover relative to baseline 1 Closed BDF (Estimated Forest Cover)	Estimated Basin Population ²¹
				- Kapichira (not peaking)				
7	NF3BAUCC	Near Future Scenario 3 – Business as Usual Pathway + Joint Operation + Climate Change	Future conditions as planned for 2035	Planned HPP infrastructure development and operations as of Near Future Scenario 2 plus climate change superimposed	As of Near Future Scenario 2 plus climate change superimposed	2035 BAU + JDO + CC	As NF1	6 200 000
8	NF4SPCC	Near Future Scenario 4 – Sustainable Pathway (including energy transition and catchment mitigation) + Joint Operation + Climate Change	Future conditions as planned for 2035	Planned HPP infrastructure development and operations as of Near Future Scenario 3	<p>Projected future infrastructure development scenario as of 2035 with SVTP, MWASIP, Irrigation as of Master Plan up to 2035, water supply and transmission lines (including MOMA).</p> <p>Energy source transition as of National Energy Policy up to 2035 and National Charcoal Strategy.</p>	<p>2035 JDO + CC + SP (30% increase in forest cover viz SRBM Plan 2017)</p> <p>Stepwise build in (i) catchment rehabilitation²⁴, (ii) tourism and protected areas management²⁵ and (iii) Sustainable land use enhancement and energy source transition²⁶ in the basin. Introduce (i) to (iii) sequentially.</p>	<p>2040-50: +10% (Closed BDF = 28.27%)</p> <p>2050-60: +20% (Closed BDF = 30.84%)</p> <p>2060-70: +30% (Closed BDF = 33.41, Total = 51.58%)</p>	6 200 000

²⁴ *Catchment rehabilitation that includes rehabilitation/reforestation of targeted erosion hotspot areas in tributaries with highest sediment yield to Shire, e.g. erosion hotspots in Ruo, Lisungwe, Nkulumadzi, Lirangwe, Likabula and maybe Rivi Rivi and Mwanza tribs) + MWASIP pilot areas in Lisungwe, Nkulumadzi, Lirangwe/Likabula (as of HR Wallingfords sediment study: Baseline Report and Erosion Hotspot Maps + projected reduction of sediment transport for 2035 and 2070 conditions).*

²⁵ *Enhancing tourism and protected areas management of protected areas in the basin, and then especially the selected Flagship VECs for the CIA, e.g. Liwonde NP, Majete WR, Lengwe NP and Elephant Marsh (incl. restricted access into, and cultivation in, the Elephant Marsh). The two first are quite well protected by African Parks running them but some encroachment etc. still occurs (include also Northern Corridor suggestion, close to Majete, of BAP study). Lengwe NP is under high pressure viz encroachment/ poaching and especially the New Lengwe part. The CIA suggests full restoration of New Lengwe or at least major parts of it. Tourism development should go hand in hand with strengthening of protected areas management.*

²⁶ *Sustainable land use enhancement and energy source transition that follows the goals and targets in the Renewable Energy Strategy (2017), National Charcoal Strategy (2017) and National Forest Landscape Restoration Strategy (2017) implemented for the Shire Basin, e.g. transition from biomass (woodfuel/charcoal) to more renewable (or sustainable sources) as the energy source. E.g. biofuels/biogas, LPG and electricity as well as sustainable charcoal production (plantation trees in targeted areas).*

#	Code	Scenario	Temporal boundary	Description with regard to HPP Development	Description with regard to other infrastructure developments	Time/Period Basin Land Cover	Forest Cover relative to baseline 1 Closed BDF (Estimated Forest Cover)	Estimated Basin Population ²¹
9	DF1BAUCC	Distant Future Scenario 1 – Business as Usual plus Climate Change	Future conditions as projected for 2070	As for Near Future Scenario 1 but with Climate Change 2070 conditions	As for Near Future Scenario 1 but with Climate Change 2070 conditions	2070 BAU (BS1 Forest Cover) + CC	As NF1 (Closed BDF= 25.4%)	10 600 000
10	DF2SPCC	Distant Future Scenario 2 – Sustainable Pathway + Joint Operation + Climate Change	Future conditions – as projected for 2070	As for Near Future 4 but with 2070 conditions	As for Near Future Scenario 4 but with 2070 conditions	2070 + CC + SP (50% increase in forest cover)	2070 50% (Closed BDF = 38.55, Total = 56.72)	10 600 000

6 SET UP OF MODELS FOR SCENARIO ASSESSMENT

6.1 *Climate, Hydrological and Water Resources Modelling*

6.1.1 Climate Change Modelling

As a starting point the climate changes analysis of the current study was aligned as much as possible with the Climate Change Resilience Assessment conducted by the consortium of EDF. Most of the data used by both EDF and the current project are prepared by DCCMS. The climate model datasets are developed as part of the European FOCUS Africa project²⁷ that aimed at the development of sustainable climate services in the Southern African Development Community (SADC) region for different sectors. The dataset consists of a set of global climate models (GCMs) that were part of the IPCC 6th assessment report. The climate datasets were dynamically down-scaled and statistically bias-corrected to improve the datasets performance and reach a higher spatial resolution.

Similar to EDF we decided to focus on the following SSPs: *SSP2-4.5* as a middle of the road scenario and *SSP3-7.0* as a relatively pessimistic scenario. *SSP1-2.6* is based on hypotheses that have already been surpassed, so it is rather optimistic, whereas *SSP5-8.5* is overly pessimistic in assuming that nothing is done at all over a very long time period.

We processed 30-years of climate model data around the near- and distant-future temporal boundaries (starting 2040 and 2070, respectively). These 30-year periods are considered to be sufficiently long to capture natural climate variability, while they do not contain a climate trend yet. Both for the current and future climate conditions we calculated the change in long-term average annual precipitation and the annual average temperature. The scatter plot attached (Figure 6-1) illustrates the model selection process resulting in three choices that represent a dry wet and mean case that considers all models from the middle-of-the-road to the pessimistic. These three chosen models are used as forcing over the Wflow modelling domain in the Near Future 3, Near Future 4 and both Distant Future scenarios.

The selection process of the representative cases is done by computing the 30-year mean for the present (1992-2022) period and deriving the relative change to the end of the century for both precipitation and discharge. We do not consider the *SSP1-2.6*, for reasons discussed above, and are left with a sample of 33 potential series. Removing (or “clipping”) the most extreme changes we can select the wet and dry case as the most positive and most negative combined change, respectively. The mean case is decided as the minimum Euclidian distance from the mean change of the in both variables for the whole sample.

²⁷ [Focus-AFRICA – Full-value chain Optimised Climate User-centric Services for Southern Africa \(focus-africaproject.eu\)](https://focus-africa.eu/).

n=33, n clipped=1, clipped by=Mean Precipitation

Change in Mean Precipitation and Outflow from 1992-2022 to 2070-2100

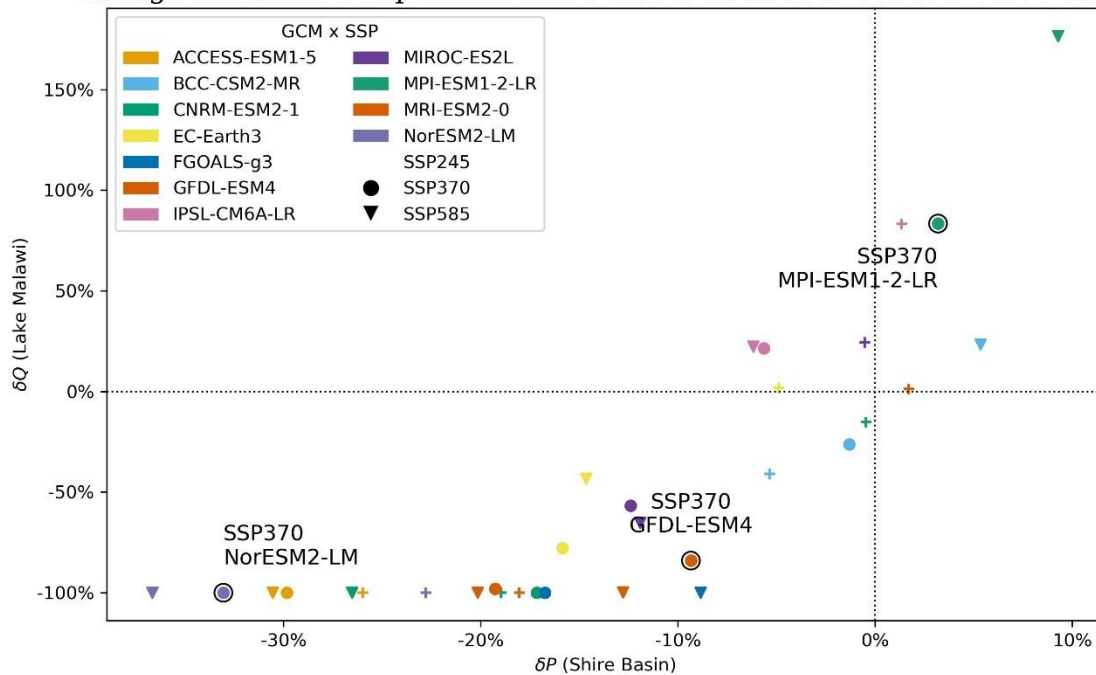


Figure 6-1 The selected climate data representing the three chosen cases are displayed in the scatter plot circled in black and annotated with their respective SSP and GCM. The scatter plots change in lake outflow (Q) and basin average precipitation (P) relative to the present period. Three models under SSP3.70 are representative cases: MPI-ESM1-2-LR (wet), GFDL-ESM4 (mean), NorESM2-LM (dry).

6.1.2 Hydrological Modelling

The hydrological modelling for this CIA is undertaken by Deltares in 2024 using Wflow adapting the scenarios defined in the CIA and summarised in table 5-1. The baseline model setup, calibration and historical (now 'near natural') scenario are described in the CIA Scoping Report (Multiconsult et al. 2024a), as such only key changes and new developments are highlighted here. The primary changes to note are the widening of the temporal boundaries for the baseline scenarios up to 2023-05-01 to include and observe the consequences of the tropical cyclone 'Freddy' and the necessary bias correction to the CHIRPS precipitation to ensure a fair representation of those extremes. The wflow_sbm hydrological model is a fully distributed and open-source hydrological model (Wflow) with which the water availability for any location within the basin can be calculated whilst making optimal use of the available global and local data.

6.1.2.1 Forcing and CHIRPS Gauge Adjustment

Primarily forcing is calculated from ECMWF ERA5 gridded daily reanalysis data (Hersbach H. et al. 2020), reprojected and resampled to the model resolution using Hydromt, the Deltares core model building platform. The temperature and variables needed to calculate the potential evapotranspiration are extracted from ERA5. Both the temperature and the pressure are corrected for using an elevation lapse rate.

Precipitation data are provided as a gridded daily forcing and sourced from the *Climate Hazards Group InfraRed Precipitation with Station* (CHIRPS) 2.0 Africa open data source (Funk, C. et al. 2015). CHIRPS is primarily a remotely sensed product that assimilates gauge data where available to perform bias correction. A noticeable lack of peaks in river discharge in the preliminary modelling stages highlighted that CHIRPS was not capturing the extremes over the Shire Basin sufficiently. It was confirmed that over time that direct, dense ground observations within the Shire Basin have not been made available and assimilated overlapping with the present period and is the primary reason for underestimation. The CIA assessment with access to up-to-date local rainfall series (Figure 6-2), allows assimilation more data to perform precipitation bias corrections over the basin resulting in an adjusted CHIRPS dataset.

Gauged rainfall timeseries are provided to Deltares for 12 locations within or near the boundary of the Shire Basin. At each daily timestep the bias is assessed between the grid cell and the most relevant gauge, determined by snapping the coordinates of the gauge to the CHIRPS grid cells. This additive and multiplicative bias is then interpolated using inverse distance weighting (IDW) to apply the appropriate offset in a manner that is sensitive to the spacing of the observations. Bias is almost entirely eliminated at each respective site, with RMSE reduced from 36mm to 1.7mm assessed over 120 timesteps. The behaviour of the IDW is the primary uncertainty, whereby the any extension of the footprint of the rainfall is uncertain and may have undesirable exaggeration of storm footprints. We hope that this uncertainty is reduced significantly by the existing remotely sensed observations between the gauge locations. This adjusted dataset forms the primary precipitation forcing for all scenarios that do not have climate change superimposed.

The newly adjusted CHIRPS data is considered to be our best available distributed ‘ground truth’, being a hybrid of local gauges and satellite observation, and so represents the reference case utilised in bias correcting climate models for the Near Future and Distant Future scenarios.

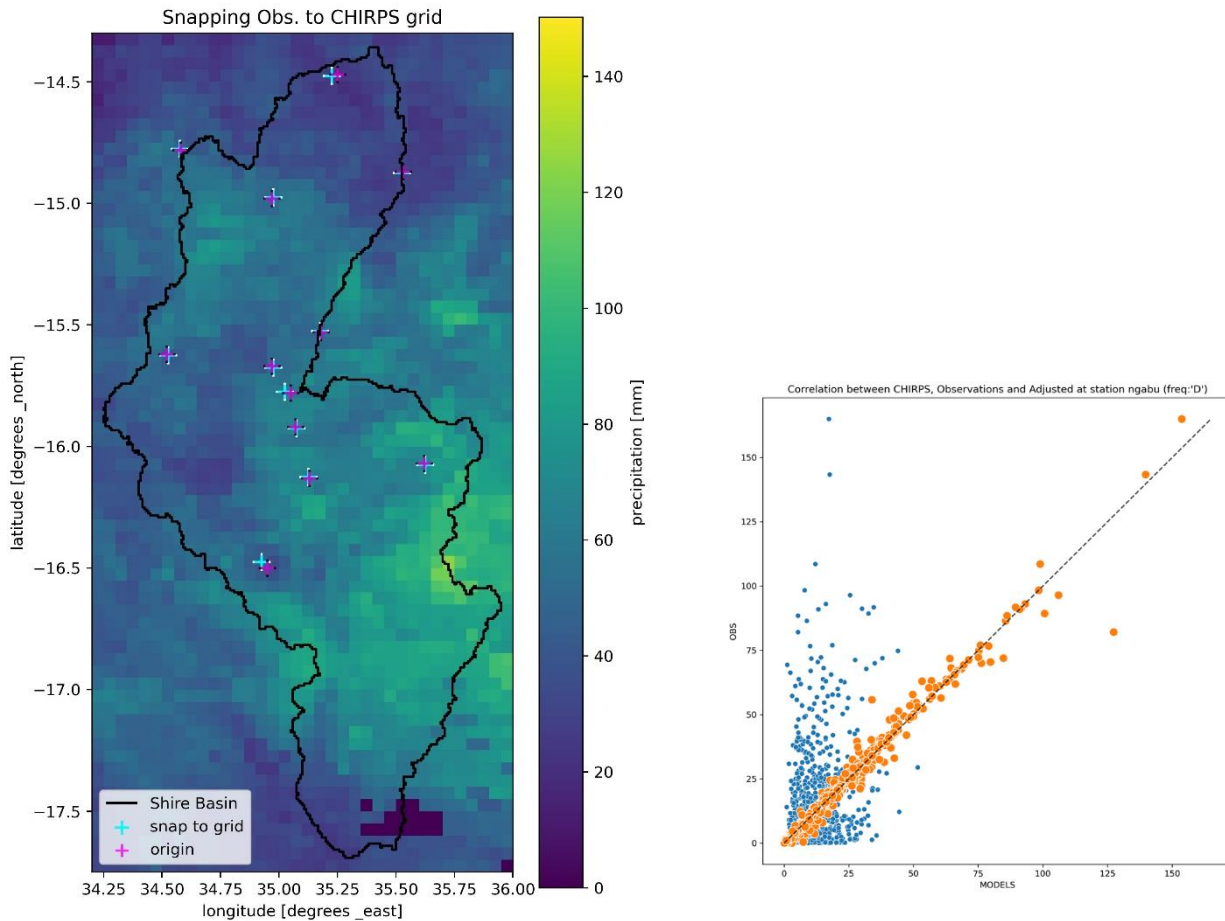


Figure 6-2 (left) 12 locations (magenta) provide the rainfall bias adjustment to the CHIRPS data, those locations are snapped to the grid of the CHIRPS data (cyan). (right) The correlation example between the observations at Ngabu meteorological station from 1992-2023 (blue) and after bias correction we see that the systematic underestimation and number of dry days are better reflected in the corrected product (orange).

6.1.3 Hydrological Scenarios

Three temporal boundaries groups distinguish the hydrological scenarios simulations in this CIA, the present (1992-2023), near-future (2040-2070) and distant future (2070-2100). For each scenario a Wflow model is set up with the appropriate changes to the meteorological forcing, land use, inflows and abstractions as described in table 5-1. The daily Wflow model utilised in this scenario analysis was calibrated over the 10-year period from 1981-1992 and described in detail in the scoping report.

6.1.3.1 Present - Baseline Scenario 1

This first baseline is described in the calibration and scoping phase (Multiconsult 2024a), we use Globcover global landcover unmodified from the source to represent the present day landcover. The scenario is forced with the same precipitation and forcing as with the baseline scenario (i.e. from 1992-2023) with a natural inflow provided by Multiconsult resulting from a KABOM simulation with no infrastructure.

GlobCover Landcover Classes by Percentage of Basin Area	
Mosaic vegetation (grassland/shrubland/forest) (50-70%) / cropland (20-50%)	37.11%
Closed (>40%) broadleaved deciduous forest (>5m)	25.71%
Open (15-40%) broadleaved deciduous forest/woodland (>5m)	16.56%
Closed to open (>15%) (broadleaved or needleleaved evergreen or deciduous) shrubland (<5m)	12.83%
Closed to open (>15%) herbaceous vegetation (grassland savannas or lichens/mosses)	2.32%
Rainfed croplands	1.59%
Mosaic cropland (50-70%) / vegetation (grassland/shrubland/forest) (20-50%)	1.13%
Water bodies	1.11%
Mosaic forest or shrubland (50-70%) / grassland (20-50%)	0.42%
Closed to open (>15%) broadleaved evergreen or semi-deciduous forest (>5m)	0.41%
Open (15-40%) needleleaved deciduous or evergreen forest (>5m)	0.27%
Artificial surfaces and associated areas (Urban areas >50%)	0.27%
Mosaic grassland (50-70%) / forest or shrubland (20-50%)	0.26%
Closed to open (>15%) grassland or woody vegetation on regularly flooded or waterlogged soil - Fresh brackish or saline water	0.01%

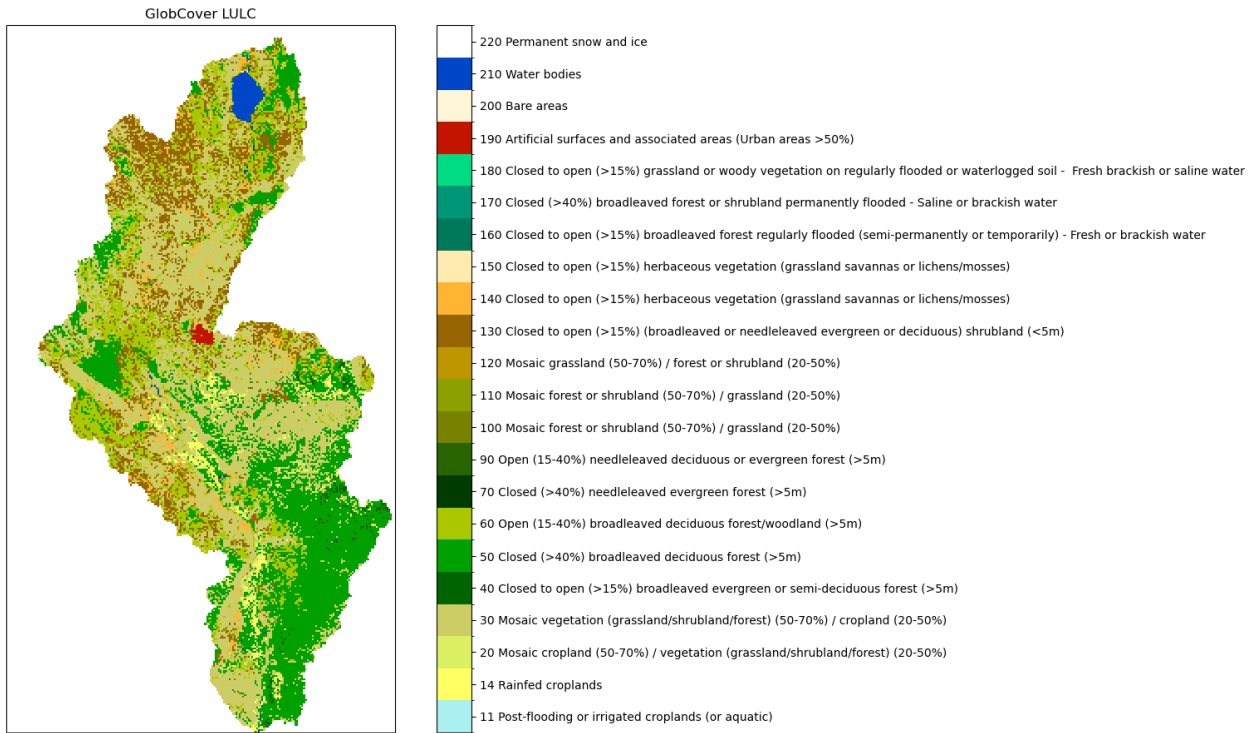


Figure 6-3 GlobCover Land Use Land Cover Map, the spatial extent matches the spatial extent of the hydrological model (source: ESA 2010 and UCLouvain - http://due.esrin.esa.int/page_globcover.php)

6.1.3.2 Near Natural Scenario (early 1900)

To achieve a near natural scenario, intended to mimic hydrological response of The Shire Basin with a less intensive land use modifications are applied to the static parameters before model initialisation. The land use classes correspond to urban areas and different types of croplands. To return to the conditions at the beginning of the 20th century, we assume there was more forest present at that time, which has been cut in the past decades, either for charcoal or to intensify agricultural production. (see also Table 5-1) Therefore, the original vegetation classes have been remapped to forest. This means that the original classes were as follows:

- 20: Mosaic cropland (50-70%) / vegetation (grassland/shrubland/forest)
- 30: Mosaic vegetation (grassland/shrubland/forest) (50-70%) / cropland (20-50%)
- 190: Artificial surfaces and associated areas (Urban areas > 50 %)

These are now remapped entirely to forest, represented by the following land class:

- 50: Closed (>40%) broadleaved deciduous forest (>5m)

Hydromt and Wflow use land cover class lookup tables to derive maps of physical static parameters per grid cell. In practice, increasing forest landcover in the Wflow changes specific physical parameters at affected grid cell, where the magnitude of change will depend on the class of change. Two parameter classes are affected, cyclical and static. The annually cyclical parameters derived from leaf area index (*LAI*) are changed at locations coincident with afforestation. The Wflow SBM concept can derive cyclical interception parameters affecting actual evapotranspiration from the soil as a result of the now larger, interception storage capacity.

Static parameter changes associated with afforestation can either be related to the surface or subsurface. Land surface roughness (*N*) is generally higher slowing the overland flow, specific leaf storage (*SI*) is moderately decreased, woody vegetation storage (*swood*) is significantly increased. Subsurface parameters affected include an increase in K_{ext} , the extinction coefficient used in determining the canopy gap fraction (van Dijk and Bruijnzeel 2001) and a significant increase in the rooting (approximately 30mm).

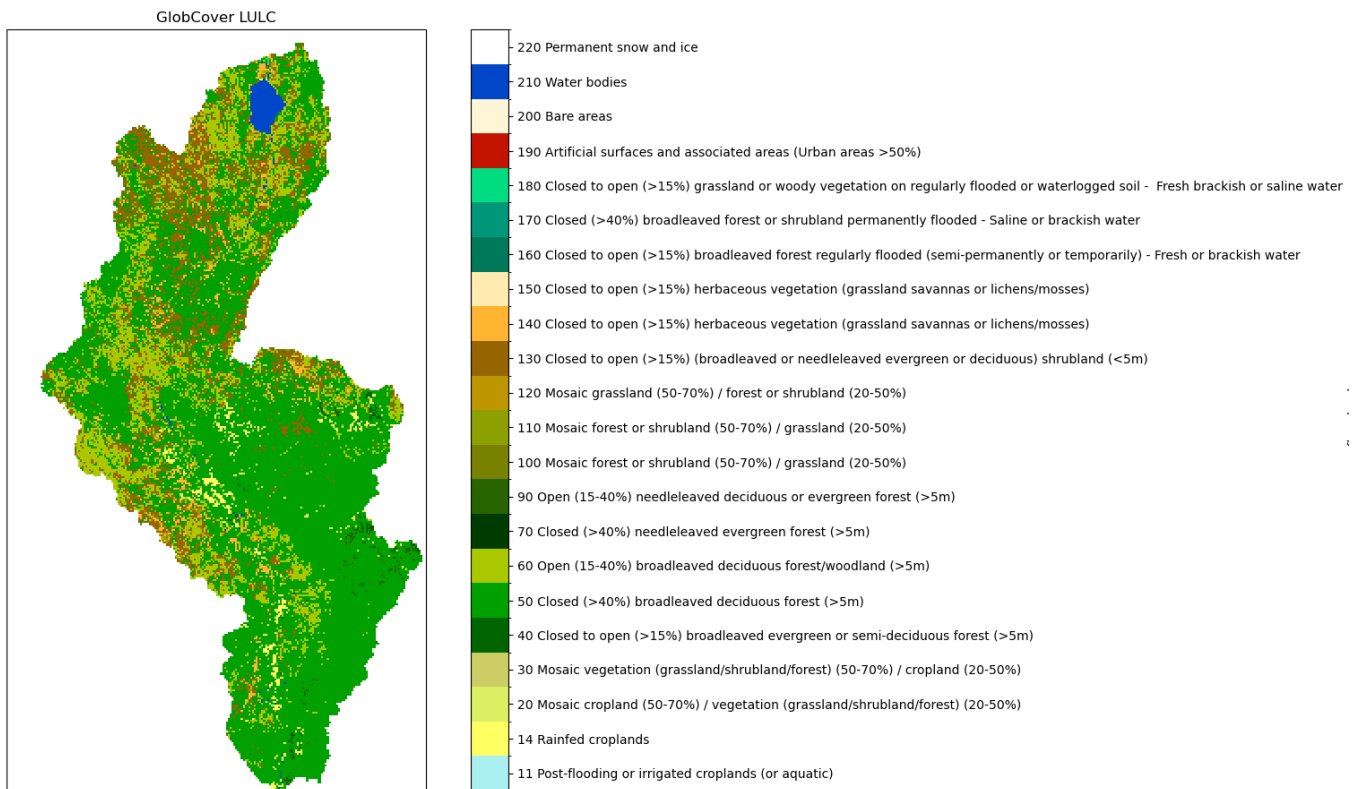


Figure 6-4 Modified GlobCover Land Use Land Cover Map prepared by Deltares representing conditions at the beginning of the 20th Century.

6.1.3.3 Present – Trended Past Scenario (1992-2023)

This scenario is intended to simulate a changing landcover within the temporal bounds of the present situation. The forcing is the same as baseline 1 with the observations at Liwonde forming the upper boundary condition and adjusted CHIRPS forming the primary meteorological forcing. Within an active Wflow simulation it is not possible to implement a gradual change in landcover, since LAI is a cyclic property that is determining interception on an annual basis, following an estimated annual vegetation growth cycle. Our approach compromises to simulate gradual landcover change by setting up models that simulate discrete periods with differing landcover. The preceding model state at the final timestep can be used as a warm start to the latter model, and the resulting timeseries can be stitched.

To achieve this, we research the master plan, satellite observations and existing landcover datasets from 1992 to 2023. The prevailing consensus is that forest cover has changed in this time to decrease by approximately 10-15%, primarily resulting in an increase in the basin proportion of grass and croplands, resulting in the current proportions of present day landcover (Figure 6-4). Two simulation periods are identified, whereby the pre 2002 simulation will have a 15% larger broadleaf forest cover relative to present day at the expense of grassland. The landcover change results in surface and subsurface property changes.

6.1.3.4 Baseline Scenario 2 (2030)

The near future scenario that constitutes baseline 2 is practically the same as baseline 1, with some near future Shire Basin development schemes implemented. Wflow is not capable of

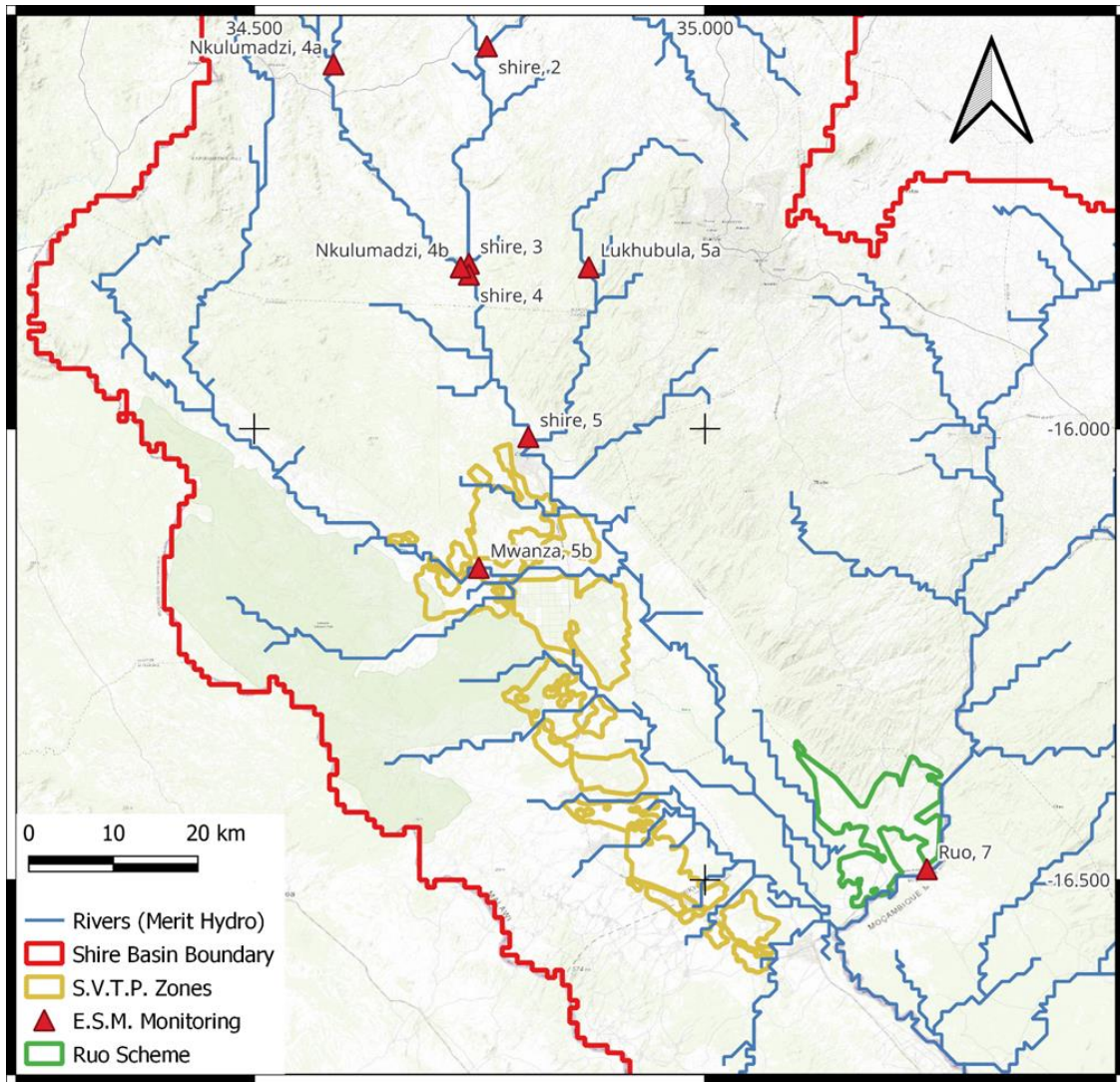


Figure 6-5 The Shire Valley Transformation Project is actively converting land within the SVTP zones (yellow, above) into active irrigated crop and pasture lands amounting to approximately 43k targeted hectares in.

simulating complex hydropower operational changes, like when Mpatamanga HPP becomes operational (this is however undertaken in the hydropower modelling as described in Section 6.3), so the hydrological simulations focus on the changes in water balance and landcover. The Shire Valley Transformation Project (SVTP) promises to expand and intensify the agricultural usage of land in the SW portion of the basin, south of Chikwawa, to a maximum of 43K Ha. For this intensification new irrigation canals are being built to convey a maximum of $50\text{m}^3\text{s}^{-1}$ to the area from the reservoir at Kapichira. This is the only abstraction that is significant to the hydrology ($>1\text{m}^3\text{s}^{-1}$) within this period, returns to the main channel are not significant within the tributaries that flow to the Shire (Multiconsult 2024a, Scoping Report, Volume 1). Return flows are reportedly less than a few percent, and thus negligible to include in the modelling.

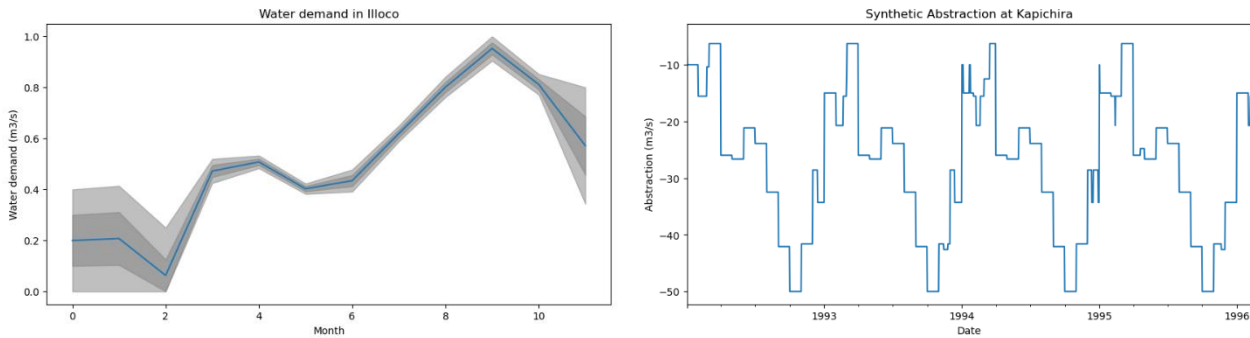


Figure 6-6 (left) Water demand from Illovo reported in the scoping phase of the CIA yields a pattern of seasonal demand for agriculture in the region. (right) A simple model for water demand per week conveyed by the SVTP irrigation canal from Kapichira.

We derive a simple cyclical model based on the 4-week precipitation mean, compared to the 30-year monthly average, combined with the estimated annual demand reported by a primary agricultural stakeholder, Illovo, a sugarcane company operating in this region. Both phases of the SVTP are intended to be complete by 2035 and thus we apply a landcover change within the planned regions from both phases, converting any unprotected land within the designated SVTP zones to agricultural (Globcover class 20: Mosaic cropland).

6.1.3.5 Near Future 1 and 2 Scenarios (2035)

The Near Future 1 and 2 Scenarios²⁸, intended to represent the 2035-2070 hydrological conditions, implements further landcover intensification and further abstraction within the Shire around the Ruo in line with the Ruo irrigation scheme, adding to the agricultural coverage already implemented in baseline 2. More abstractions are incorporated to reflect the aspirations of the irrigation master plan 2035 (REF) in addition to the irrigation canal at Kapichira. We apply additional abstractions at Walkers Ferry ($3.73\text{m}^3\text{s}^{-1}$), Lisungwe ($3.17\text{m}^3\text{s}^{-1}$), RiviRivi ($1.24\text{m}^3\text{s}^{-1}$) and the Ruo ($1.14\text{m}^3\text{s}^{-1}$). These abstractions are not notably cyclical and are thus considered constant losses to the system, representing the only abstractions implemented within Wflow that directly affect the tributaries to the Shire, and may have a small impact during low flow periods.

6.1.3.6 Near Future 3 Scenario (with climate change superimposed by 2035)

Static landcover adopted from Near Future 1 Scenario remains unchanged in the third near future scenario. This model differs in that it is forced with the adapted climate data from DCCMS for our three chosen cases. Under SSP 3.70 the three G.C. models (GCMs) chosen are GFDL-ESM4 (mean), MPI-ESM1-2-LR (wet), NorESM2-LM (dry). Similarly to the underestimation previously discussed in the original CHIRPS dataset, extremes are not well captured in the reference (1992-2023) period for the precipitation data provided. The lake outflow data for the climate scenarios are also positively biased, with inverted seasonality.

It was necessary to apply bias-correction of the simulated discharges using a quantile mapping approach (Cannon et al., 2015). Empirical quantile mapping is essentially transferring the probability distribution

²⁸ Hydrological conditions

function (pdf) of simulated timeseries to the pdf of an observed timeseries for a given station by defining a transfer function.

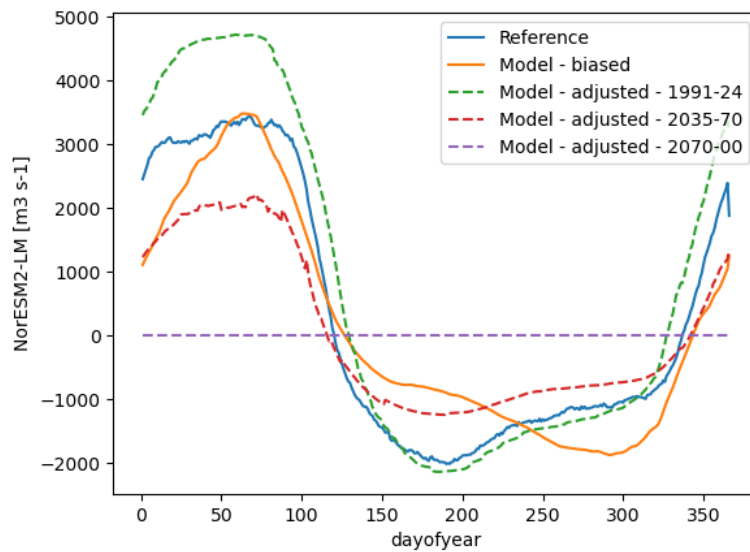


Figure 6-7 Plots of yearly freewater for the reference (blue), biased model (orange) and the corrected models for the NorESM2-LM dry case lake outflow.

The bias corrected model in the provided example and in the other relevant corrected models successfully corrects for the inverted seasonality of the lake outflows. The transfer function is saved and applied to the climate data beyond the reference period, into the future.

Precipitation has a similar seasonality problem, with a significant underestimation in intensity. Empirical quantile mapping over the basin is similarly employed as with the lake outflow, this time using a 2-dimensional grid, training a transfer function at every pixel. In the comparative example given below we see an example of the pre- and post-correction comparison for basin average precipitation over the Ruo subbasin basin. The reference model seasonality is inverse to the given model which is not successfully corrected. The magnitude of the extremes in precipitation is, however, well corrected with multiple peaks over 50mmd^{-1} in the adjusted product, that reflect better the magnitude of the reference. Across the reference period a cumulative bias of -680mm is evident (or -0.22mmd^{-1}) within the provided data, the bias is reduced in the corrected model to $+189\text{mm}$ (or 0.06mmd^{-1}).

Seasonality discrepancies are not well addressed in the precipitation bias correction, when compared with the successful seasonal inversion of the lake outflow. This can be explained by the prominence of zero values in the uncorrected dry season precipitation data, since quantile maps are built by grouping monthly data to train a set of multiplicative factors. Ideally, bias correction of the precipitation forcing for this seasonal data would be applied in an earlier phase. It was decided however to proceed with the simulations with reduced overall precipitation bias, preferring events that are truer to reference for the resulting flow magnitudes.

Scenarios are simulated with a precipitation and boundary inflow from all three GCMs (now corrected) representing the probable range of wet, mean and dry futures.

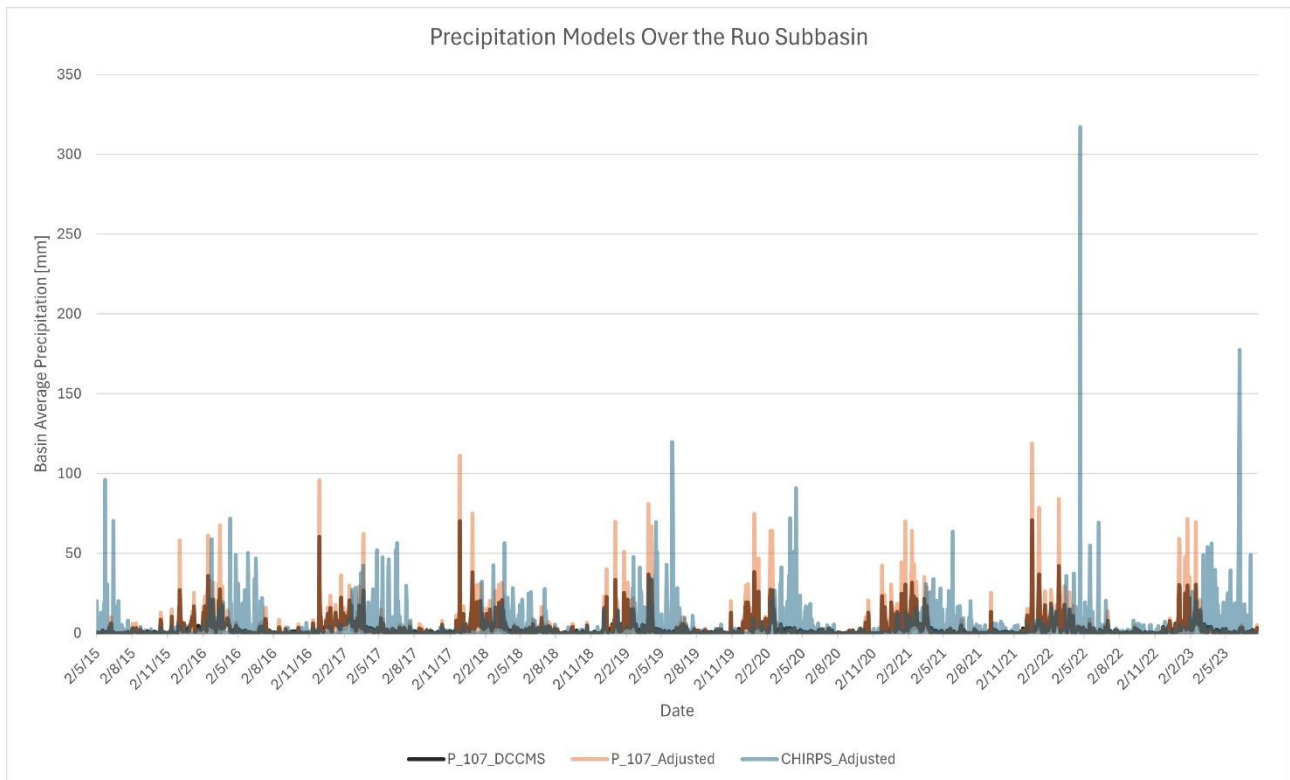


Figure 6-8 A comparative plot covering the reference period used for quantile mapping of the precipitation data provided by DCCMS (black).

6.1.3.7 Near Future 4 Scenario (2035)

This trended scenario attempts to mimic catchment restoration of erosion hotspots areas identified in the sediment study (HR Wallingford 2023) and goals of MWASIP, the latter a WB funded watershed improvement project that refers to significant catchment regeneration intended to reduce sedimentation by targeting hotspots in the basin. We have been supplied with sedimentation hotspots over the Shire Basin by HR Wallingford, delineating areas with varying rates of soil loss. We then resampled the sedimentation hotspots to the model resolution and assumed that these will form ranked targets based on the erosional intensity. Similar to the trended past scenario, where we created two separate models to simulate landcover changes over the desired simulation period. We created multiple models that are built to represent decadal changes in forest cover.

Afforestation within the Wflow landcover maps prioritised the areas of most severe sediment losses within the erosion hotspot areas of HR Wallingford and the MWASIP regeneration target areas. Once all the target areas within the MWASIP areas are reforested, severe erosion hotspot areas outside of MWASIP²⁹ are mapped to forest until the target of 30% reforestation within the basin is achieved. We decided that it is unlikely that urbanised areas would be reforested, or areas that have been part of the SVTP or Ruo agricultural initiatives. This trended scenario is forced with climate data from the identified wet, dry and mean cases, including lake outflow, applied as a boundary condition at Liwonde, replacing the observation series implemented previously.

²⁹ The HR Wallingford hotspots areas from the sediment study.

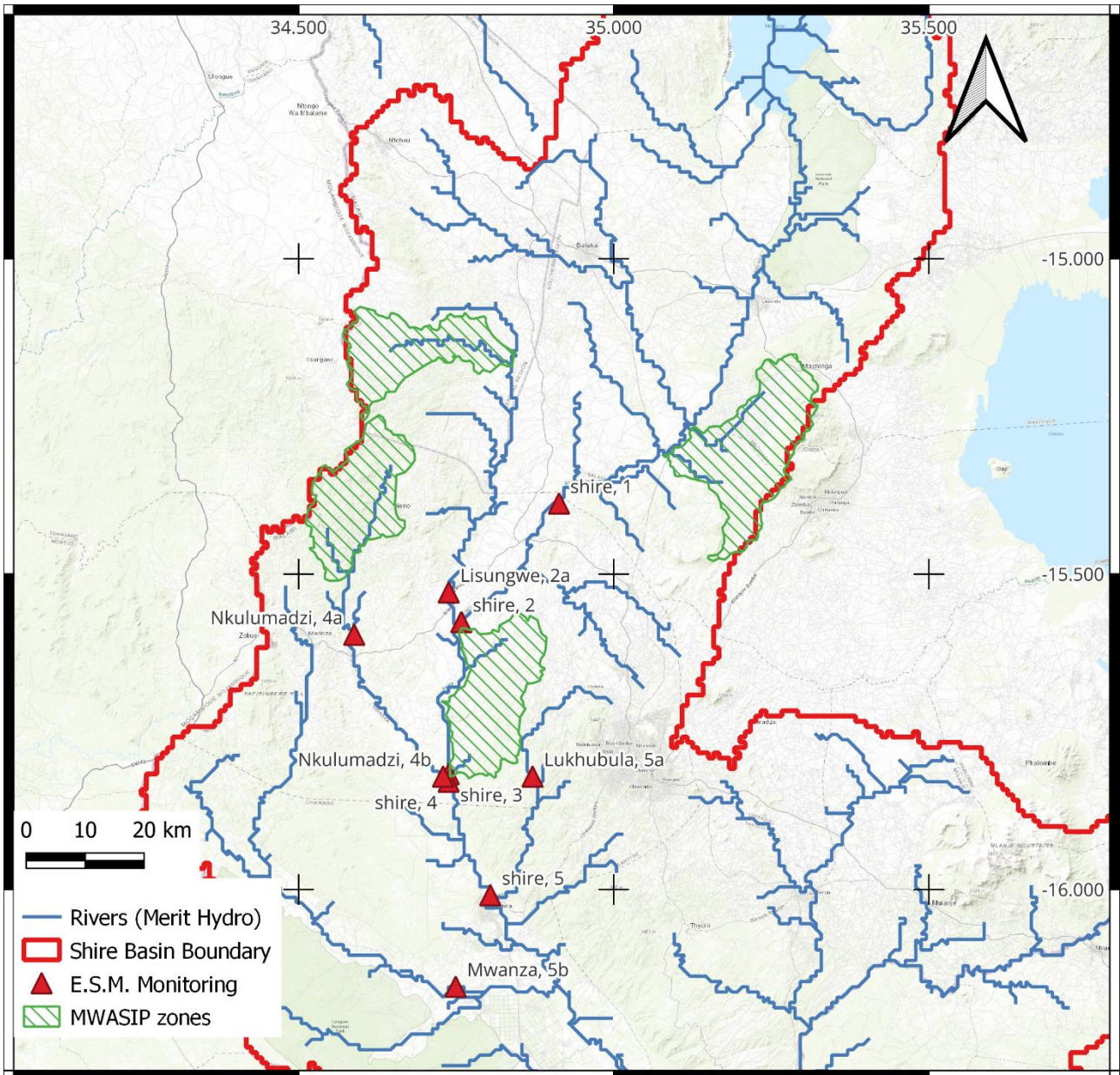


Figure 6-9 The prioritised zones for the MWASIP program, the first areas in our simulation to receive afforestation.

Within this NF3 scenario, the 2035-50 period incorporates +10% forest cover, 2050-60 is +20% and the 2060-70 is +30% relative to Near Future 1 Scenario forest cover.

6.1.3.8 Distant Future 1 Scenario (2070)

Distant Future 1 maintains the same forest cover as the baseline 1, the abstractions and developments of the near-future scenario but is simulated with the three climate models for the period 2070-2100. The scenario is run for each of the wet, mean and dry cases.

6.1.3.9 Distant Future 2

Distant future 2 differs from DF1 by incorporating a significant afforestation target relative to present day. Regenerative practices within the basin are targeted within areas presenting severe erosion, firstly in MWASIP identified zones and severe areas outside of MWASIP in order to reach a 50% afforestation target.

6.1.4 Water Resources Assessment

For the water resources situation, no modelling is required as most of the water abstractions are isolated occurrences without priority settings or conflicting interests that would warrant a modelling effort. In the Scoping report, an overview is provided of the various water demand sectors, both for the present situation and for the future situations, with an emphasis on the SVTP irrigation development. For detailed information on the water demand situation, reference is made to the Baseline status summary in the CIA Scoping Report, Volume 1 (Multiconsult et al. 2024a). In Chapter 7, a summary is provided of the most salient points on water demands in the Shire basin.

6.2 Sediment Modelling

With the modelling we aimed to simulate the hydraulic conditions and sediment conditions in the reaches around the selected ES sites (with selected VECs). The baseline (or historic and present) sediment loads are already derived and presented in the study of HR Wallingford (2023). These are annual loads at specific sites, but do not yet provide a time series with daily discharges and sediment loads at the ES sites. This relevant information is needed for more detailed assessment of the geomorphology in the Shire and its tributaries for the DRIFT ESM assessment (Vol 2 and 3 to this report).

For the sediment modelling of the scenarios, we used computer models that simulate flows and sediment transport in reaches of the river and predict the changes in bed level as function of space and time (morphodynamics). We separated the large-scale long-term channel-shape development from more rapid small-scale changes in the riverbed. Large-scale is tenths of kilometres and several decades, while small scale is channel width or less than a kilometre and periods up to a year or less. Note that large-scale changes in bed level, covering processes such as overall bed-degradation along tenths of kilometres, will be simulated in a separate modelling effort in the “Sediment Study” by HR Wallingford using their one-dimensional (1D) modelling approach. It was expected that this 1D model effort would be able to provide the required 30-year time series of sediment discharges at the DRIFT ESM sites in the main branch of the Shire River.

Ecological relevant elements that are not covered by the 1D modelling effort of the “Sediment Study” are sand bars, bank erosion and bank accretion, and floodplain (lake) deposition. These features can be considered as variations in cross-sections and are not captured in a 1D cross-section average approach. For this purpose, we introduce several local two-dimensional (2D) models (depth-average) which calculate bed levels with much more details along the reaches and in cross-sections. Because these models are more computationally intensive (i.e., with long run times and high data demand), we apply them only to reaches that cover the relevant ES sites. In the 2D modelling approach we did not aim to run long-term simulations covering the full length of the river. The approach focuses on the local small-scale morpho dynamics, such as sand bars and bank erosion risks which are short-term responses (mostly seasonal variations and flood events). Combining the large-scale changes over long periods of time from the 1D model (Sediment Study)

and these detailed short-term 2D results, we could still simulate the long-term effects that we will assess for the scenario analyses. Nevertheless, it is possible to run some of the smaller 2D models for periods of 30-years.

Requirements on the modelling approach are based on the observed geomorphological and sediment condition of the Shire River and its tributaries in 2023 sediment missions. For the different river reaches/zones we have chosen the following approaches:

- The steep reaches of major tributaries and the Shire River up- and downstream of the Mpatamanga dam, upstream of Kapichira: abundant sand bars on banks along an otherwise rocky channel caused by a large input of sand from catchment erosion. The 2D model will mimic these sand bars and sand waves migrating downstream, mostly along the banks, over a non-erodible substrate. The present volume of sand stored in sand bars in these sections is not known, but assumption will be made on the thickness of these sand volumes.
- The Shire River downstream of Kapichira dam, downstream reaches of tributaries: these reaches are fully alluvial, with sandy riverbed. During normal flows, these reaches have a large width to depth ration, which causes development of migrating low-flow channels with sand bars and eroding banks. These variations in cross-section can be reproduced when careful choice of parameters that reproduce processes in river bends and curved channels.
- The Elephant Marsh receives much of the fine sediment during high flows, whereas it spreads over inundated wetland sections. The concentrations of fines can be derived from the 1D models and sediment yields as calculated by HR Wallingford in their “Sediment Study”.
- The riverbed has shown to have been altered severely during the recent tropical cyclones, with transitions in channel width, major bank shifts, and changes in sand-bar deposits. Generally, floods are the main driver of these morphodynamical changes in this basin, as they come along with large sediment yields. A separation between average conditions and pulses by (extreme) events is relevant. The 2D models will simulate full unsteady conditions, which allows running it with time-varying flood discharges.
- It is uncertain how resilient the system is to large gradual changes in conditions (for instance by dams, or by climate change) and to extreme pulses (for instance, can river channel return to a dynamic equilibrium after it was highly perturbed by an extreme event?). With the interpretation of the model runs we will consider these questions in relation to VECs.

For the reaches in the main Shire River, we defined a number of separate 2D models, where some of the ES sites can be covered in 1 model, where others will have individual sub models. In tributaries the ES sites can be defined as individual models. Not for all the ES sections in the Shire upstream of Mpatamanga dam we will develop 2D models. Notably the section at Lisungwe confluence because that is already covered in the reservoir sedimentation study of HRW. For the Lisungwe we anticipate a single 2D model at the selected ES site.

Each of the 2D models will have a length of several kilometres to tenths of kilometres (e.g., main river downstream of Kapichira). The 2D models consists of a curvi-linear grid, with initial bed-level and bed composition for each grid cell. For each grid cell we compute flow conditions (depth, velocity), sediment load, and bed level as function of time. To illustrate the resolution of this model, i.e. how many grid cells are

available in a cross-section and along the channel, we show an example of the model grid of the Shire River near Chikwawa in Figure 6-10 shows an example of the model grid of the Shire River near Chikwawa (downstream Kapichira dam). This grid also covers the flood plain and the lake with ES 5c DIFT site (see Vol 2 to this report).

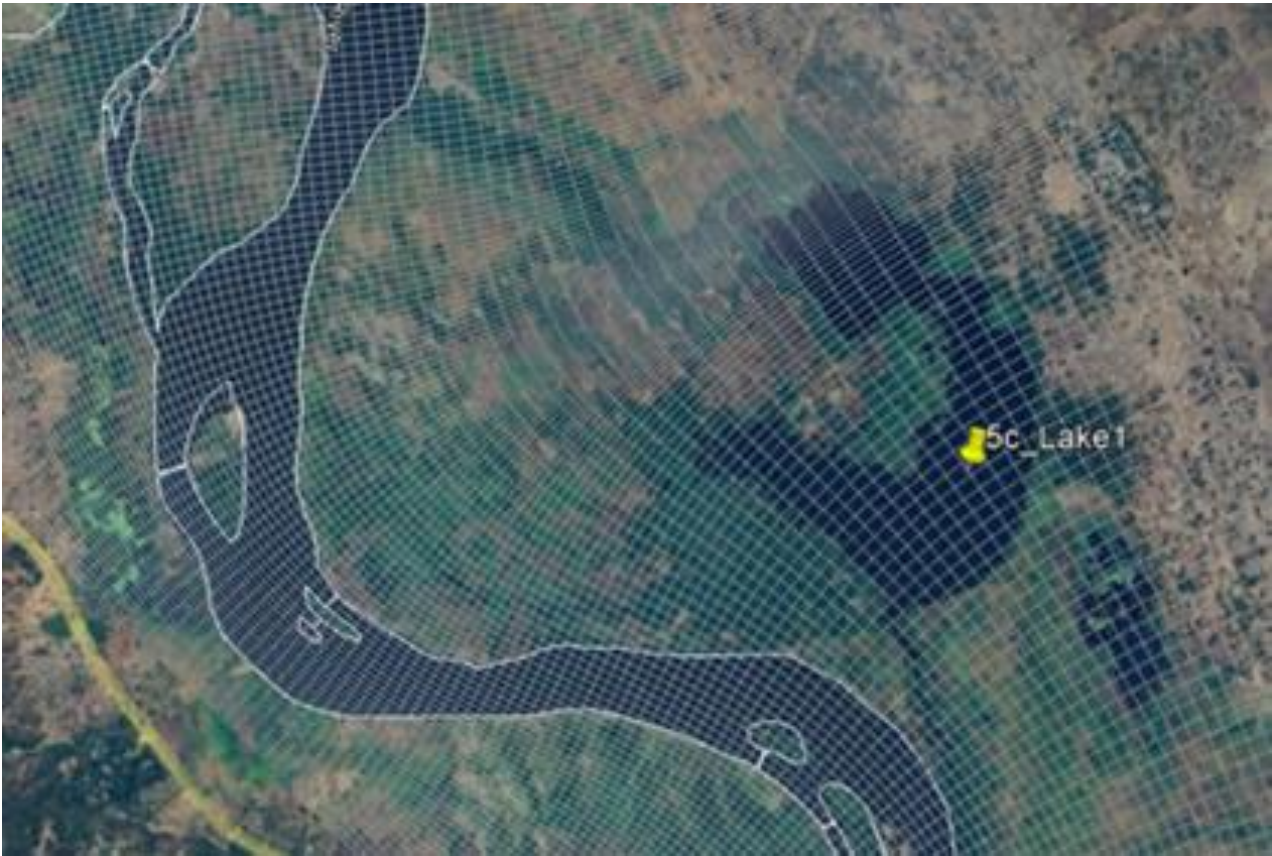


Figure 6-10 Curvi-linear grid covering the main channel and flood plain (including the lake) of the Shire River downstream of Kapichira dam. Mesh size is in the order of 20 to 50 m.

Another example is shown in Figure 6-11, illustrating the projection of LIDAR bed topography on the curvi-linear grid near the confluence of the Nkulumadzi River and the Shire River. For this purpose, we average the ascii-raster data from the LIDAR per grid cell. The LIDAR ascii raster has a much higher resolution than the intended grid size of the models. As the LIDAR does not penetrate through the water surface, the wet parts of the LIDAR are adjusted (removed and redefined) using the measured cross-sections.

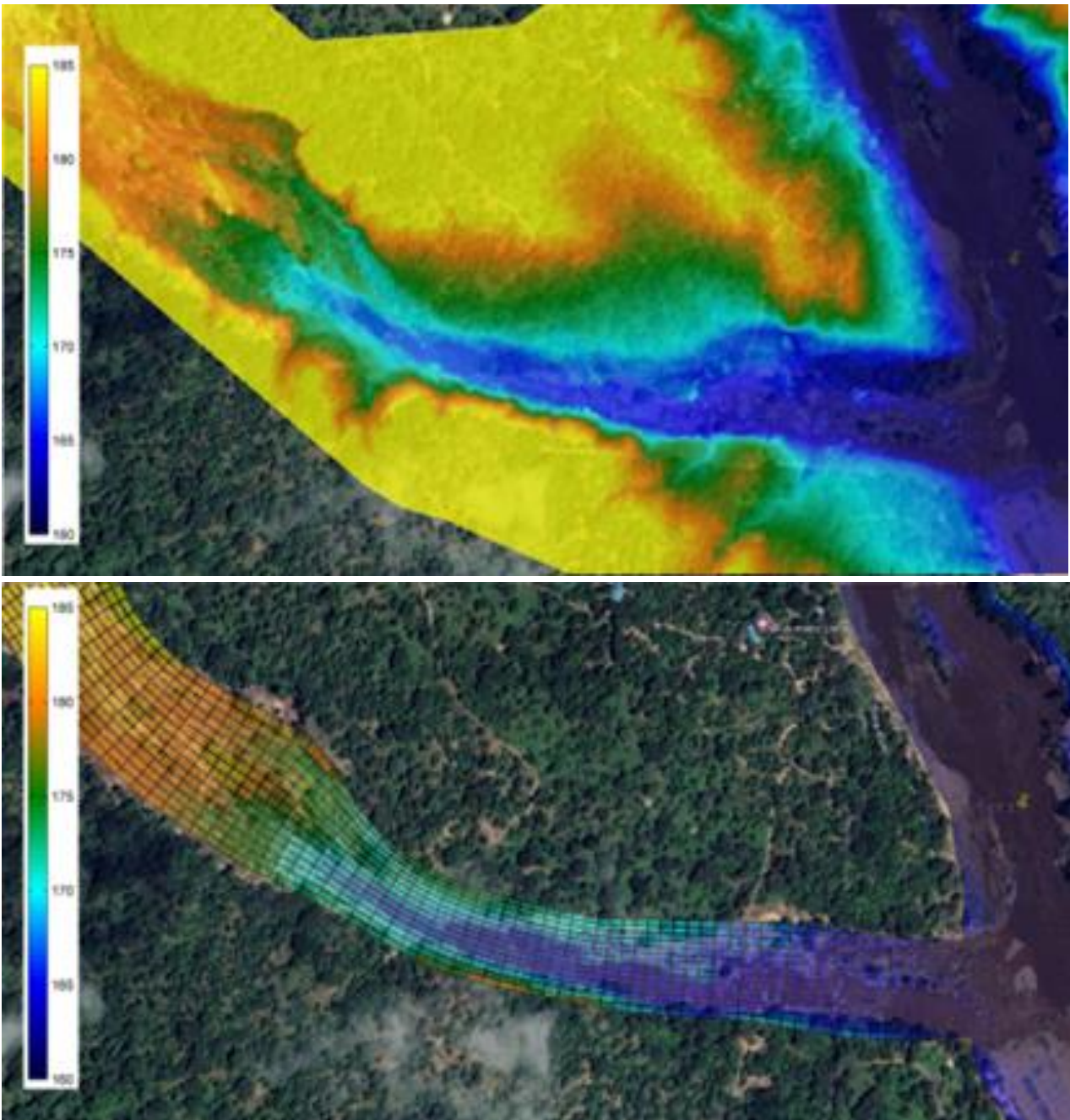


Figure 6-11 Lidar topography (upper figure) and its projection on the curvi-linear grid at the Lower reach of the Nkulumadzi tributary and Shire confluence (lower figure).

For the scenarios, the 2D models will be executed for at least a period of 1 year to cover the full annual hydrograph (low flows and high flows) and the fluctuations in bed level that can be associated to these flow variations. By superposing the long-term bed-level changes from the 1D simulations (of the Sediment Study) we can make prognoses of bed-level changes for the full 30-year period. A separate model run for an extreme event (cyclone) is used to judge the effect of the flood pulses.

6.3 Hydropower Modelling

Hydropower modelling is performed using a one-dimensional hydrodynamic simulation model, with regulating (flow controlling) features, equipped with a complex combination of power production schemes. The core of the model is a combination of different, previously developed models, applied for the same river in other projects. After merging these models, the result still had to be heavily modified to adapt to the modelling concept of the present study.

The resulting model features cover 500 cross-sections, dam profiles, 6 river regulating structures, each with several control conditions, and over 30 point-source inflows from tributaries, while the main inflow is to Lake Malawi. Separate model variations have been developed for each hydrological and climatic scenario, and regulation strategy.

6.3.1 Hydraulic model

The software used for developing the model was Mike+ 2024 Update 1, developed by DHI. We employed the “River network” feature with “Hydrodynamic (HD)” module and “Control rules”. All input data, such as source inflows to the river, and other time-series-type model parameters, like time-dependent control rules, were converted to DHI’s own time series file-types marked “dfs0”.

6.3.1.1 Model geometry

The model geometry has been constructed as a combination of previously surveyed cross sections from different time periods, as well as the openly available SRTM DEM. This has been extended with interpolated cross sections to improve the numerical stability of the simulations. All model variations share the same model geometry, which means that dam-crest elevations are not necessarily represented with correct elevations in the cross sections, but instead the total discharge at dams are controlled by the model independently from the profile capacity in the model. This way both the existence and absence of any of the dams can be simulated using the same model geometry data.

River cross sections had to be manually extended in cases where surveyed data did not cover the entire flood zone. In these cases, SRTM DEM and neighbouring cross sections gave guidance on estimating topography. This procedure introduces some uncertainty to the total capacity of sections of the river.

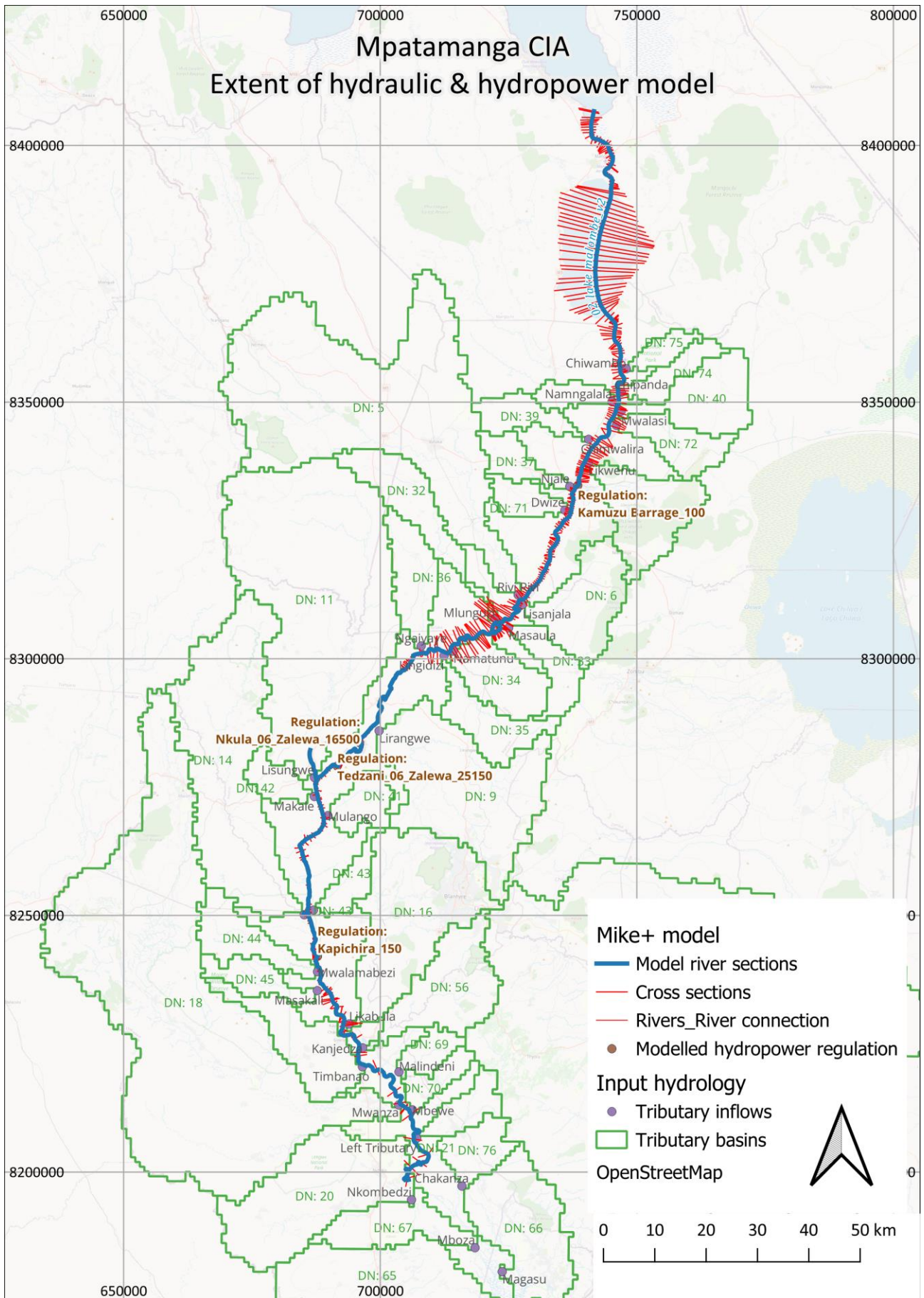


Figure 6-12 Hydraulic & hydropower model layout.

6.3.1.2 Regulating structures

Kamuzu Barrage, Nkula, Tedzani, Mpatamanga and Kapichira dams are represented by discharge controlling features in the model. These features control this charge at certain points based on calculated or observed conditions somewhere else. These conditions typically are water levels upstream from the control section (For instance highest regulated level and so forth), and dates or seasons. In order to be able to simulate river regulation in this fashion, regulating rules had to be simplified in such a way that single rating curves (functional relations between discharge and water level) are used for each regulation condition. Consequently, separate discharge components such as flow through single gates, turbines, floodway's, etc. are combined into single values at each time step. The advantage of this modelling approach is that complex structures can easily be turned on and off as single elements for the sake of different simulation scenarios. The table below show the main regulating levels of the considered dams:

Table 6-1 Main regulating levels of the considered dams.

Regulating structure	Reservoir HRWL (m)	Reservoir LRWL (m)
Kamuzu Barrage	475.72	473.5
Nkula	376	374.5
Tedzani	318.53	315.75
Mpatamanga	276	273
Mpatamanga regulating	213	206
Kapichira	147	144

Overflow rating curves (discharge-reservoir level relations) have been estimated using dam geometry and available plans. Operation of hydropower dams is modelled by sequentially evaluating a set of conditions in an objective and logical order, and therefore may differ from what in practice is performed. At each regulating structure, parameters from the preceding timestep (typically water levels in the actual reservoir) are compared with conditions of the predefined set of rules, in priority order. To improve stability of the model, each rule is applied for a minimum amount time, referred to as “Block time”. As an example, the set of rules for Nkula is shown below:

Table 6-2 The set of rules for Nkula HPP.

Rule priority	Condition	Action to apply	Block time [min]	Description
1	[Nkula_WL] > 376	Nkula overflow	50	If water level in the reservoir is over HRW
2	[Nkula_WL] <= 374.5	Minimum flow	50	If water level in the reservoir is under LRW
3	[Nkula_WL] <=372.231	Block flow	10	If water level is below the highest bed elevation inside the reservoir
4	[Nkula_WL] <= 376	Nkula optimum for the date	10	Otherwise

An additional rule applies for Mpatamanga regulating dam (in the scenarios where relevant). The flow downstream from the dams should be similar to the daily mean from the preceding day upstream from the Mpatamanga main dam, unless extremes apply. For the scenarios that includes Mpatamanga and has joint operation, we have also implemented a similar rule for Kapichira dam.

Kamuzu Barrage is regulated differently. Here the actual level of Lake Malawi is considered, which are compared to seasonally varying limits of ranges. The varying limits are provided as timeseries as input to the model, so that regulating levels are related to dates during simulations. In addition to that, flood capacity is increased in case when water levels exceed HRWL by at least 0.2m to mimic manoeuvring capabilities compensating for extreme high lake levels at the barrage.

6.3.1.3 Reservoir volumes

Storage volumes at Nkula, Tedzani and Kapichira dams had not been surveyed in the present study. The available information gives a very blended picture on the actual storage available for regulation today. Attempts have been made to find the most realistic and still reasonable volumes, but this parameter bears high uncertainty. Technically, volume values in the model are linked to single cross sections, where simulated water levels are linked to dam operations as flow control at the structure. These cross sections are referred to as “Sensors” in the model. Only active volume is included, simplified as tanks with vertical walls, divided by elevation-levels defined with fine-resolution. The following table shows the volumes considered in the model, in millions of m³:

Table 6-3 The volumes of the HPPs considered in the model

Nkula	Tedzani	Mpatamanga	Kapichira
1.125	0.6	59	1.35

6.3.1.4 Boundary conditions

The main inflow to the model is not coming from the hydrological simulations. Instead, historical inflow, also known as “Freewater” to lake Malawi is calculated based on observed water levels and discharges at Kamuzu BarrageLiwonde. This is the upper boundary condition in the model. Since the main purpose of the model is to simulate flow to generate hydropower, it is necessary to mimic all regulating elements operated for this purpose. The first of these elements is Kamuzu Barrage, where operation determines Lake Malawi (regulated) outflows. The historical (observed) flows at the Barrage do not always correspond to what is ideal for regulation, which principle our model needs to follow on the other hand, and therefore model simulations may give results deviating from observations at certain times.

Furthermore, inflow to the model is divided into 30 additional point-sources along the entire reach, as shown in Figure 6-12. The values at these locations are taken directly from the hydrological simulations, since river regulation don’t affect them.

Hydraulic roughness along the river reaches, has been reused from the previous studies, completed in 2012/13 and in 2018. At interpolated cross sections, roughness has also been interpolated. The river channel is typically divided into 3 zones using different roughness values. Adjustments have been made in the vicinity of dams, to improve simulation stability.

6.3.1.5 Initial conditions

Initial conditions, especially water levels at Lake Malawi highly influence the model results in the entire simulation period. Preliminary model runs are performed to achieve stable conditions in the entire stretch from Lake Malawi to Elephant Marsh, as well as reaching a correct lake level at the starting point of the simulation. The preliminary runs are then used as starting points for the complete simulation of the actual scenario. From the preliminary runs, a situation is selected when Lake Malawi level is at 474.70 m, as observed on 2 Jan 1992, starting date of Scenarios 1-6 (see table below). For simplicity, the same starting elevation is selected also for the climate change scenarios 7-10.

6.3.1.6 Model variations

Separate model versions had to be prepared for the different scenarios. Different hydrological conditions including but not limited to actual climatic and runoff features changing both in space and time, seasonal and sub-daily variations of the demand for hydropower and the different grades of development of various other power sources, all need to be combined into a single set of boundary conditions for each variant of the hydraulic model. This resulted in the following set of simulations.

Table 6-4 Model variations for the main scenarios.

Scenario	Mike model file	from	to	Input TS file	Turbine flow
Near Natural Scenario (1)	Sc1-NIN	2.1.1992	31.1.2022	historic_full_results	None (Mike: all HPP turned off in Direct discharges & all control turned off in Control rules)
Historical trended Scenario (2)	Sc2-HT	2.1.1992	1.5.2023	historic_trended	Series_Turbine_flow_1992-2023-Sc2
Baseline Scenario 1 (3)	Sc3-B1	2.1.1992	1.5.2023	baseline_1_full_results	Series_Turbine_flow_1992-2023-Sc3
Baseline Scenario 2 without Mpatamanga Operational (4.1)	Sc41-B2- NoMpatata	2.1.1992	1.5.2023	baseline_2_full_results	Series_Turbine_flow_1992-2023-Sc41
Baseline Scenario 2 –with Mpatamanga Operational (4.2)	Sc42-B2- OpMpatata	2.1.1992	1.5.2023	baseline_2_full_results	Series_Turbine_flow_2030-Sc4.2-6
Near Future Scenario 1 – Business as Usual Pathway (5)	Sc5-NF1	2.1.1992	1.5.2023	NearFuture_1_full_results	Series_Turbine_flow_2030-Sc5

Scenario	Mike model file	from	to	Input TS file	Turbine flow
Near Future Scenario 2 – Business as Usual + Joint Dams Operation (6)	Sc6-NF2	2.1.1992	1.5.2023	NearFuture_1_full_results	Series_Turbine_flow_2030-Sc4.2-6
Near Future Scenario 3 – Business as Usual Pathway + Joint Operation + Climate Change (7)	Sc7-NF3.1 Sc7-NF3.2 Sc7-NF3.3	2.5.2040	1.5.2070	1: NearFuture_31_GFDL-ESM4 2: NearFuture_32_MPI-ESM1-2-LR 3: NearFuture_33_NorESM2	Series_Turbine_flow_2030-Sc7-8
Near Future Scenario 4 – Sustainable Pathway (including energy transition and catchment mitigation) + Joint Operation + Climate Change (8)	Sc8-NF4.1 Sc8-NF4.2 Sc8-NF4.3	2.5.2040	1.5.2070	1: NearFuture_41_GFDL-ESM4 2: NearFuture_42_MPI-ESM1-2-LR 3: NearFuture_43_NorESM2-LM	Series_Turbine_flow_2030-Sc7-8
Distant Future Scenario 1 – Business as Usual plus Climate Change (9)	Sc9-DF1.1 Sc9-DF1.2 Sc9-DF1.3	2.1.2060	31.12.2100	1: DistantFuture_11_GFDL-ESM4 2: DistantFuture_12_MPI-ESM1 3: DistantFuture_13_NorESM2-LM	Series_Turbine_flow_2030-Sc9-10
Distant Future Scenario 2 – Sustainable Pathway + Joint Operation + Climate Change (10)	Sc10-DF2.1 Sc10-DF2.2 Sc10-DF2.3	2.1.2060	31.12.2100	1: DistantFuture_21_GFDL-ESM4 2: DistantFuture_22_MPI-ESM1 3: DistantFuture_23_NorESM2-LM	Series_Turbine_flow_2030-Sc9-10

6.3.2 Operation of Kamuzu Barrage

6.3.2.1 Purpose of the barrage

Kamuzu Barrage controls the release of water from Lake Malawi and regulates the lake with about 2 meters. The effect of the barrage is mainly to move flow from the wet season to the dry season, which is illustrated in Figure 6-13.

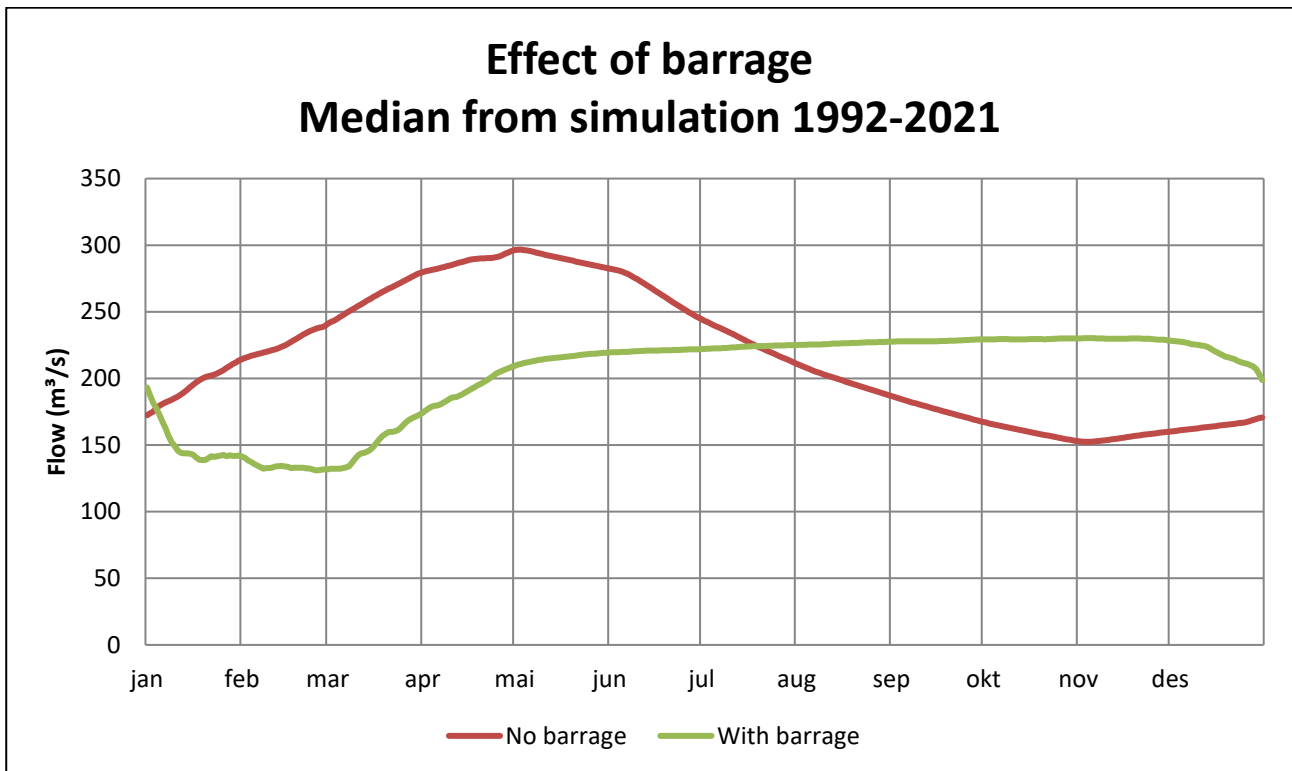


Figure 6-13 Effect of the barrage on Shire River flows.

6.3.2.2 Release strategies

Release from Kamuzu Barrage is decided based on a tool called KABOM, Kamuzu Barrage Operation Model. This model forecasts the water level in the next year based on a stochastic model, and suggest a release of water so that the lake water level will not go above the highest regulated water level or the lowest regulated water level in the next 12 months.

We have not implemented KABOM in the hydropower operation model, but chosen a simplified strategy for the release of water depending on the water level and the time of the year. This is illustrated in Figure 6-14.

The release strategies are as follows:

- A. Very low water level. Gates are set in an open position
- B. Save water. Release 130 m³/s
- C. Release to satisfy the demand of downstream water users
- D. Flood control. Release 450 m³/s
- E. Very high water level. Gates are set in an open position

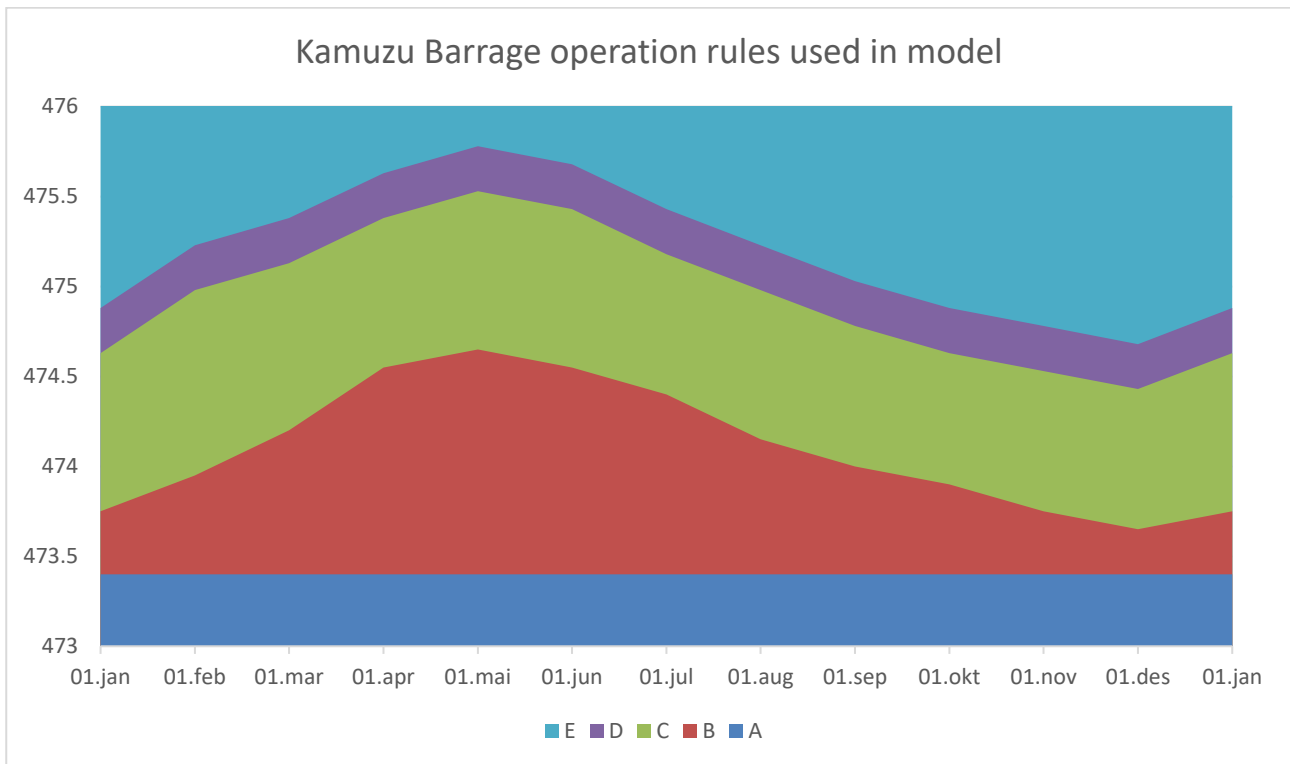


Figure 6-14 Operation rules A-E used in the MIKE+ model to control the release from the barrage.

6.3.2.3 Release goal

In strategy C, we need to know the demand of the downstream water users. This includes hydropower, irrigation and water supply. The required river flow for hydropower generation has been calculated for the different scenarios based on the electricity demand.

We have used two different time series for water demand for irrigation, one for scenarios 2 and 3 (historical and baseline) and one for the future scenarios. Assumed water demand each month can be seen in Figure 6-15. Water demand in scenario 2-3 is based on the demand of the Illovo estate, while water demand for the future scenarios is based on the feasibility report of the Shire Valley Transformation Project (Korea Rural Community Corporation, 2017).

Other water demands, including Blantyre drinking water, environmental flow and leakages from the dams, is set to 20 m³/s for all scenarios. The required flow per month of the year for 2023, 2030 with Mpatamanga and 2030 without Mpatamanga can be seen in Figure 6-16. For the historical scenarios, the required flow varies with -50 m³/s to +10 m³/s compared to 2023. The lowest required flow was just after Kapichira was set in operation (2001-2004), while the highest required flow was in 2014-2016 when there was a jump in the electricity demand.

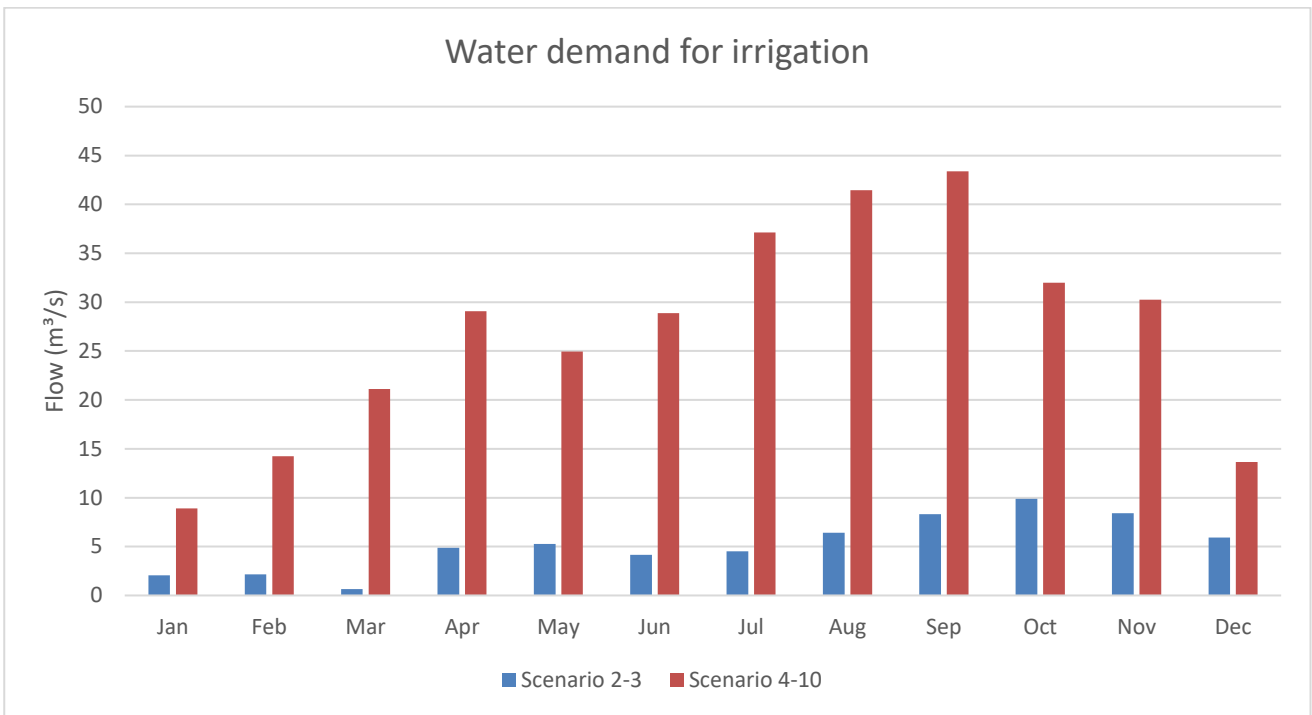


Figure 6-15 Water demand for irrigation.

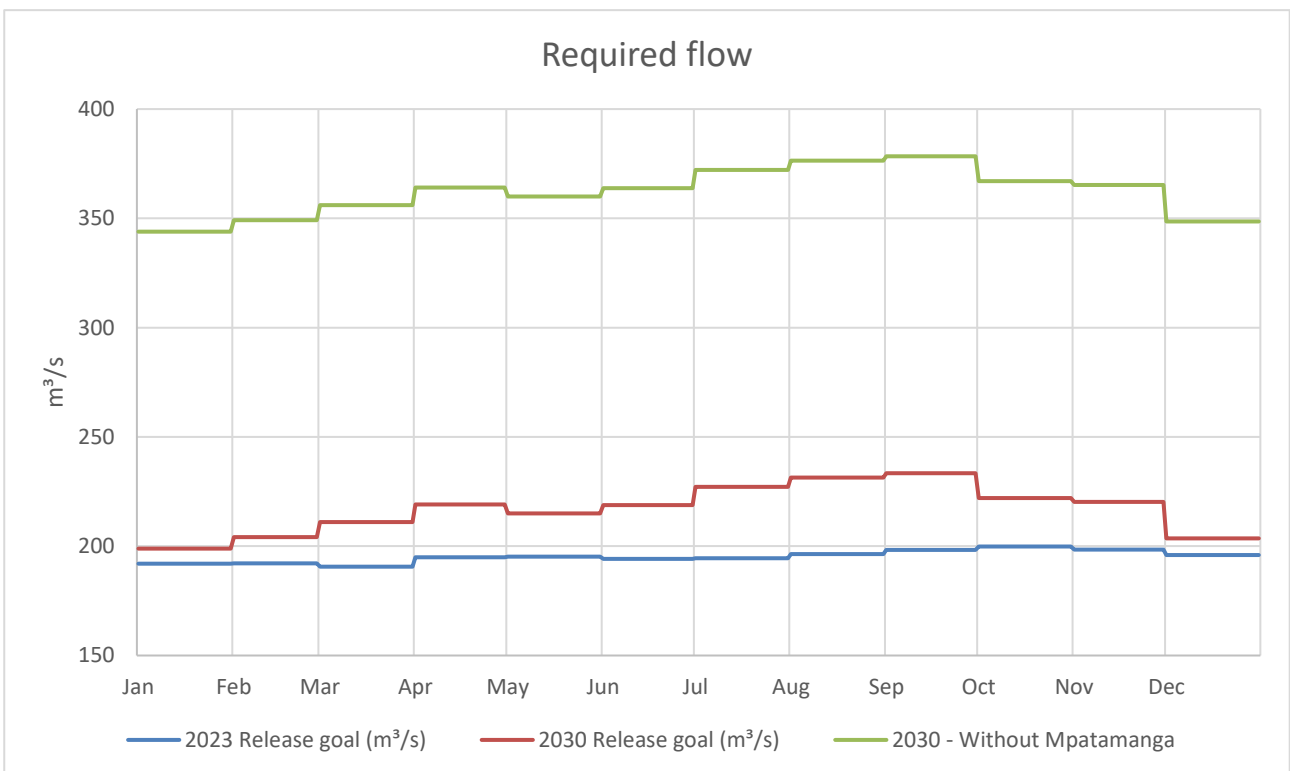


Figure 6-16 Required flow at Nkula for some scenarios (Baseline 1 (blue) and Baseline 2 with (red) and without (green) Mpatamanga.

Figure 6-16 shows the required flow at Nkula dam. The required release from Kamuzu Barrage in order to have this flow at Nkula will normally be smaller, as there are several tributaries flowing into the river between the barrage and Nkula. To find the release goal, we have subtracted the tributary flow from the required flow

in Figure 6-16. If the resulting release is less than 130 m³/s, we have set the release to 130 m³/s. Otherwise we have used the calculated flow.

Note that KABOM also reduces release based on the recorded flow in the tributaries.

6.3.3 Mpatamanga HPP

The peaking capability of Mpatamanga HPP will be essential for the Malawi power system. Without Mpatamanga there will be large load shedding during the peak hours in the morning and in the evening, as there is not enough capacity in the system. Even in the wet season, in 2030 there is about 200 MW missing in order to be able to meet the demand. The missing capacity could possibly be imported from Zambia or Mozambique when and if the planned transmission lines are working at full capacity, but given the delays in the construction of MOMA, it is likely that the construction of the transmission lines will not be able to keep up with the increase in electricity demand.

6.3.4 Joint Operation of Dams and HPPs on Shire River

6.3.4.1 Optimization of Power Production

All the hydropower plants on Shire River uses the same water, and joint operation is essential to be able to utilise the water as efficient as possible. Without joint operation, the required release from Kamuzu Barrage would be equal to the peak turbine flow. The difference in flow requirement can be seen in Figure 6-16. The dotted line shows the observed flow at Liwonde. If the available flow is less than what is required, the hydropower plants are not able to meet the electricity demand, and there will be load shedding, with large consequences for industry, businesses and households. As can be seen from Figure 6-17, a scenario without joint operation would have much more load shedding than a scenario with joint operation. Note the calculation of joint operation assumes that the active storage in Nkula, Tedzani and Kapichira are at least 0.75, 0.40 and 0.90 million m³. If the available reservoir volumes are smaller, the effect of joint operation decreases.

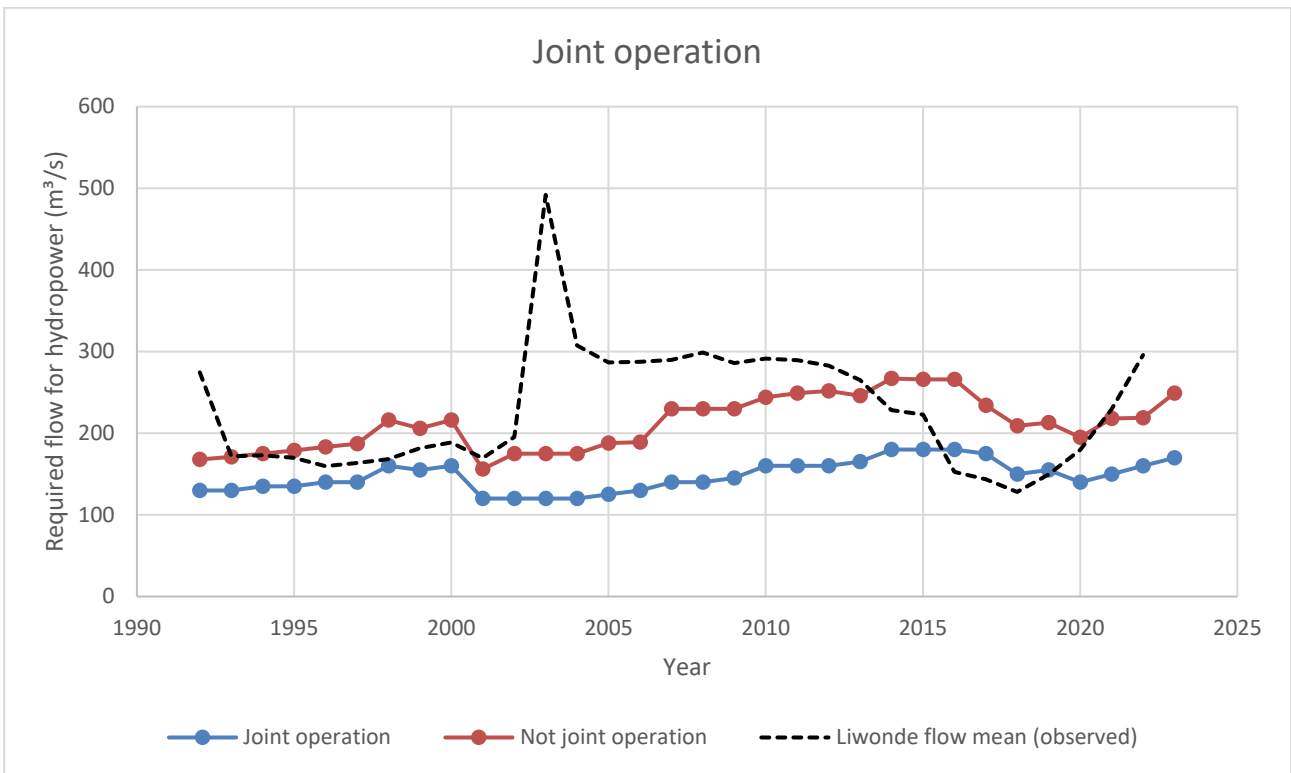


Figure 6-17 Required flow with and without joint operation.

7 OVERALL ASSESSMENT RESULTS OF THE MPATAMANGA CIA IMPACT PATHWAY NETWORK ANALYSIS

This section constitutes the overall assessment of the Mpatamanga CIA Impact Pathway Network Analysis. It includes also an assessment of the main drivers of change, stressors, primary and secondary impacts towards the selected main VEC groups for each scenario. Details on impact for selected indicators for each VEC group are outlined in Section 8.

7.1 Historical Events Affecting the Shire Basin

In any river basin, an understanding of past major events and their effect on the river and catchment ecosystems and the people that depend on it is vital to contextualise the present and potential future changes in that ecosystem and on those people.

Prior to 1900, the Shire Basin was described as “well-wooded” (Morris 2016). Certainly, when European explorers first ventured into the Shire Highlands, they were struck by the abundance of streams and rivers featuring crystal-clear water, even during the dry season. Equally impressive were the lush fringes of evergreen forests that typically bordered these watercourses, particularly at 760 to 1200 masl, where these riparian forests thrived. Within the forests, one could find towering evergreen trees, some ~50 m high. Many of these trees, including *Khaya anthotheca* (mbawa), *Adina microcephala* (chonya), and *Bridelia micrantha* (mpasa) were valuable timber sources used for furniture and other household items (Chapman and White 1970; White *et al.* 2001; Morris 2009 – all in: Morris 2016). Since then, Shire River Basin has become much more densely populated (see also Table 5-1 in Section 5), putting pressure on the basin ecosystems. Several major historical events have also affected the aquatic and terrestrial ecosystems of the Shire, many of them directly related to the interplay between human pressures (deforestation, over-fishing, transformation of wetlands), in-channel infrastructure (barrages, hydropower plants, bridges, and embankments) and also over the past decade extreme weather events (tropical storms and cyclones). This section provides an overview of the main such events (Table 7-1), drawn from the available literature. It does not claim, nor is it intended, to be exhaustive.

Additional detail in terms of discipline-specific impacts and knock-on effects linked with some of these are discussed further in the sections that follow. A timeline for events specifically affecting the Elephant Marsh (Birkhead *et al.* 2022) is shown in Figure 7-2.

Table 7-1 Key historical events affecting the ecological integrity of the rivers in the Shire Basin.

Date	Event	Consequences for the basin ecosystems	References
1900 onwards	Loss of megafauna	Movements of hippopotamus (<i>Hippopotamus amphibius</i>) and elephant (<i>Loxodonta africana</i>) create incised, vegetation-free pathways on the floodplain and in the Marsh through which water can flow during flooding, diverting water and sediment into adjacent areas. These are valuable fish habitats.	Mosopele <i>et al.</i> (2009)

Date	Event	Consequences for the basin ecosystems	References
Hydrology			
1900-1940	Lake Malawi levels low	Lake Malawi levels dictate the baseflows in the Shire River, particularly prior to the construction of the Kamuzu Barrage. Higher baseflows translate into greater flooded areas, such as wetlands and lakes in the Lower Shire River.	Birkhead <i>et al.</i> (2022); Bhawe <i>et al.</i> (2020)
1941-1970	Lake Malawi levels medium		
1971-1990	Lake Malawi levels medium		
In-channel infrastructure			
1907	Chiromo Bridge and railway embankment constructed	Changes in the extent of lakes in the southern portion of the Marsh linked to construction, and subsequent breaches and repairs, of the railway embankment	Birkhead <i>et al.</i> (2022)
1948	Chiromo Bridge and railway embankment washed away		
1949	New Chiromo Bridge and railway embankment constructed		
1956	Bund constructed across the Shire River to prevent outflow from Lake Malawi	Probably no long-term impacts but would have reduced dry season flows in the Shire for a short time.	Birkhead <i>et al.</i> 2022
1965	Kamuzu Barrage constructed	The Kamuzu Barrage at Liwonde, constructed in 1965, is the main regulating facility on Shire River. It is intended to facilitate development and operation of hydropower plants in Middle Shire, and to support irrigation in the Lower Shire. The barrage dampens the seasonal distribution of flows in the downstream river.	Birkhead <i>et al.</i> (2022)
1973	Tedzani I operationalised	Operated also as a hydropeaking plant when demand requires. Hydropeaking fundamentally changes conditions in the downstream river. Damage to ecosystems and people is well-documented. In the case of the Shire, hydropeaking affects the river for 100s of kilometres downstream of turbines.	
1980	Nkula 1 operationalised	Operated also as a hydropeaking plant when demand requires.	
1986	Nkula 2 operationalised		
1992	Nkula 3 operationalised		
1996	Tedzani II operationalised	Operated also as a hydropeaking plant when demand requires.	
2000	Kapichira Phase 1 operationalised	Partially operated as a hydropeaking plant, with severe consequences for downstream river. In addition, sediment management (sediment flushing and sediment dumping) has been damaging to both the upstream and downstream river.	Southern Waters (2022)
2014	Kapichira Phase 2 operationalised		

Date	Event	Consequences for the basin ecosystems	References
2017	Tedzani III operationalised	Operated as a hydropeaking plant when demand requires.	Bhave <i>et al.</i> (2022)
2018	Upgrading of Kamuzu Barrage	No major impact, but greater control of Shire River flow regime.	
2021	Construction starts on the Shire Valley Transformation Program (SVTP)s	Once constructed, the off take for the canal will affect dry season low flows in the Lower Shire. While this is a move back towards a more natural seasonal distribution of flow, it will also facilitate greater intrusion of cultivated fields into wetland areas.	http://stvp.gov.mw
2022	Cyclone Ana causes a break in the Kapichira dam wall at the point at which STVP canal joins		
2023	Repair works to Kapichira dam wall		
Deforestation and sedimentation			
1990-2023	Impacts of deforestation become increasingly evident in landcover	Sediment supply to the Shire River increased significantly with deforestation of the upper catchment. Sedimentation in the Elephant Marsh increased from ~10 mm/yr in the early part of the 20 th century to ~34 mm/yr in the early part of the 21 st century.	Mzuza <i>et al.</i> (2019)
Major cyclones and tropical storms			
1946	Cyclone “Edith”	Major flooding. Changes in the extent of lakes in the southern portion of the Marsh linked to construction, and subsequent breaches (during floods) and repairs, of the railway embankment	Ngongondo <i>et al.</i> (2011)
2015	Tropical Storm Chedza	Major flooding. Realignment of Ruo River into the Southern Elephant Marsh as a direct result of increased sedimentation at the Shire/Ruo confluence.	Birkhead <i>et al.</i> 2022
2019	Cyclone Desmond	Major flooding	https://www.worlddata.info/africa/malawi/cyclones.php
2003	Tropical Storm Delfina		
2021	Cyclone Eloise		
2021	Cyclone Guambe		
2022	Cyclone Ana	Major flooding. Kapichira Dam bursts	
2022	Cyclone Gombe	Major flooding	
2023	Cyclone Freddy		

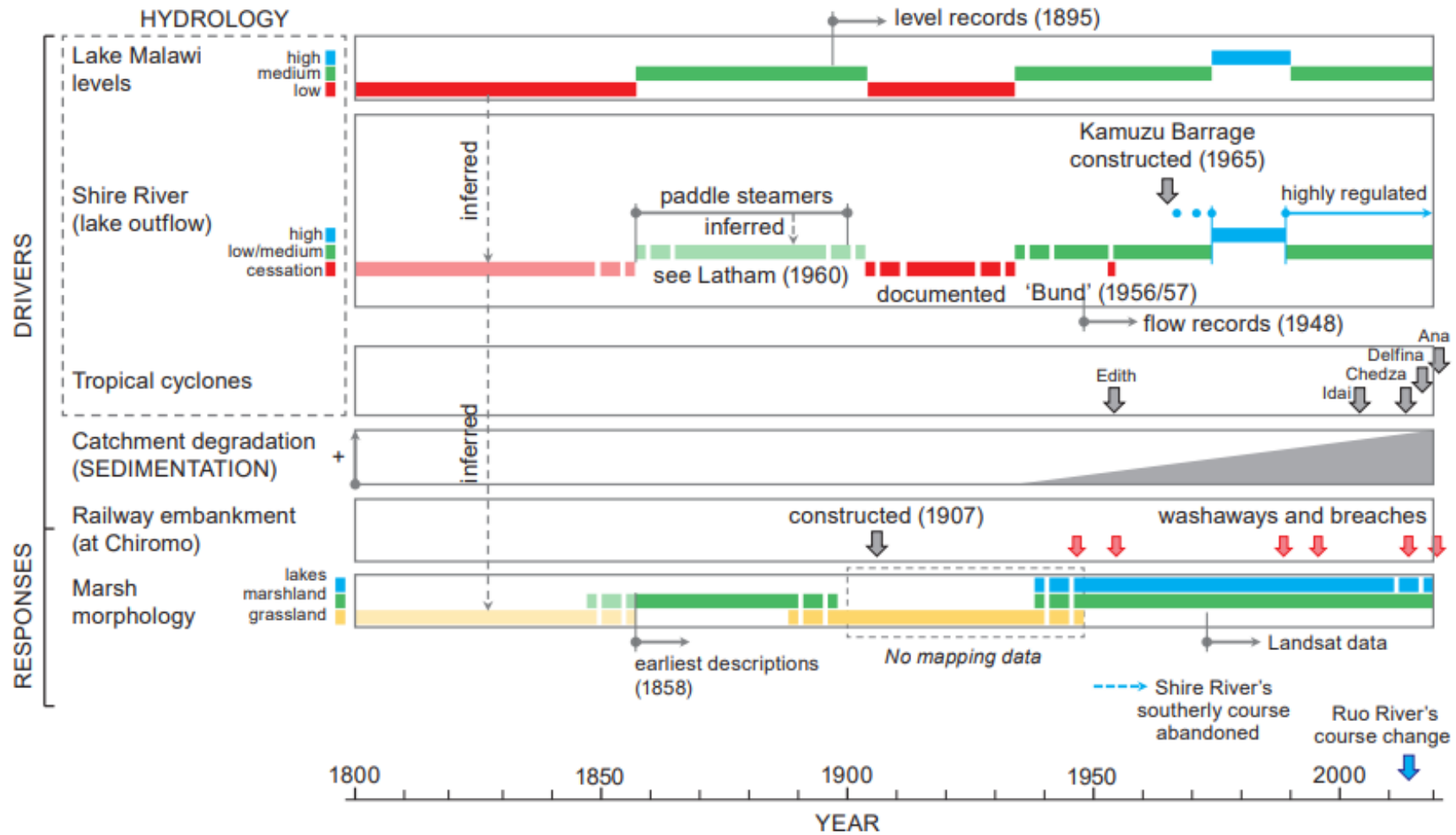


Figure 7-1 Timeline (c. 1800 to 2020) of drivers and events, both natural and anthropogenic, and the responses of the Elephant Marsh morphology, based on multiple sources of evidence (Source: Birkhead *et al.* 2022).

7.2 Scenario Assessment of Main Drivers of Change, Stressors, Primary and Secondary Impacts for Main VEC Groups

7.2.1 General Description for Mpatamanga CIA Impact Pathway Network Analysis

A cumulative impact assessment (CIA) is a process of analysing potential impacts on and risks to VECs resulting from existing and proposed projects in the context of human activities and natural environmental and social external drivers over time (IFC, 2021)³⁰. The complex relationships and interactions among Drivers/Causes, Stressors/Primary Impacts, and Secondary Impacts that lead to cumulative impacts on the prioritised VECs in the Shire Basin, as illustrated in Figure ES-6, have been assessed for all the 10 scenarios in Table ES-1.

The stressor/primary impact score is the sum of the impact from the drivers/causes, each with a magnitude (vector weight) ranging from 0 (no impact) to 4 (very high impact) as follows:

- 5 = no/negligible impact
- 6 = low impact
- 7 = moderate impact
- 8 = high impact
- 9 = severe impact

Then the following steps are undertaken; (1) Determination of which drivers/causes affect which stressors/primary impacts, and assigning them a 1-4 score for each link; (2) Summarising these scores for each stressor/primary impact; (3) Then determine which stressors/primary impacts affect which secondary impacts and assign a 1-4 score to each link; (4) For each link, the score is multiplied by the primary impact score and then summarised for all links to provide a final score for the secondary impact; and lastly (5) Determine which secondary impacts affect which VECs, and summarise the secondary impact scores for each VEC³¹.

A summary of the assessment for each main CIA scenario is provided in the subsequent sections of this Chapter 7. A more detailed description of the assessment and results for each scenario impact on VECs is provided in the Section 8 of the CIA Report. For the results of the DRIFT ESM assessment, reference is made to Volume 2 and 3 to this report.

7.2.2 Summary of Baseline Scenario 2023 (Current Conditions and Reference Scenario)

From the Impact Pathway Network Analysis Diagram in Figure 7-2, the two most prominent drivers/causes to change in the basin, with its subsequent impacts on stressors/primary impacts and secondary impacts towards the VECs, are (i) climate change and (ii) charcoal and firewood production as well as encroachment into forested areas. The magnitude of impact of these two drivers/causes is also given the score 3 (high impact) in one of their pathways towards primary impacts/stressors for the current situation, e.g. (i) climate change: leading to *extreme weather events* and subsequently the amount of tropical storms (7) over the past decade, and (ii) charcoal and firewood production/encroachment into forested areas: the basin-wide impact

³⁰ IFC. 2021. *Cumulative Impact Assessment and Management of Renewable Energy Development in the Sekong Basin, Lao People's Democratic Republic*. International Finance Corporation, Washington, D.C.

³¹ For example the 5 impact pathways towards the Reliable water availability and quality gives the total impact score of 138 on this VEC.

of this driver/cause over the past decades leading to large scale *deforestation and land use change*. This driver/cause also exacerbates the impact of extreme weather events, as deforestation and land degradation lead to a less climate resilient basin that is more prone to flood and drought shocks. Hence, impact pathway is given the score of 2 (moderate impact).

In comparison the anthropogenic impacts from the drivers/causes (i) agricultural and industrial practices, (ii) HPP development and operation, (iii) irrigation and water supply development, and (iv) transmission lines and roads are assessed for current situation to have more moderate impacts than that of climate change and charcoal/firewood production and encroachment, including subsequent effects on stressors/primary impacts and secondary impacts and then the VECs. One major reason for this more moderate (or lower) impact score is that most of these drivers/causes are more confined to specific areas in the basin (for example large scale irrigation to the Lower Shire), and hence their impacts are not seen basin-wide to the same extent. Agricultural and industrial practices is however assessed to have moderate impact (score 2) on pollution³², and HPP development and operation is also given the same score viz its impact pathways towards changes to flow regime and influx of people (Kapichira, Tedzani, Nkula for current situation). The different pathways from irrigation/water supply development and transmission lines/roads development towards the stressors/primary impacts are by comparison, for the current situation, given an impact score of 1 (low impact). This will of course change for future conditions when SVTP and the Mpatamanga/MOMA transmission lines are finalised or constructed.

The two stressors/primary impacts with *highest assessed magnitude of impacts* on the secondary impacts are (i) extreme weather events and its impact on flood and low flow magnitude, frequency and duration (score 3 = high impact) and its exacerbated effect on erosion and sedimentation (score 2 = moderate impact)³³ (both seen basin-wide), and (ii) deforestation and land use change with its subsequent impact on erosion and sedimentation, habitat degradation and fragmentation and biodiversity loss (all three pathways with a magnitude score of 3 = high impact, also because it can be seen basin-wide). Deforestation and land use change also exacerbate flood and low flow magnitude, frequency, and duration (magnitude score 2 = moderate impact) and catchment ecosystem regulatory³⁴ and provisioning³⁵ services (magnitude score 2 = moderate impacts). The stressors/primary impacts (i) environmental degradation other than deforestation; (ii) changes to flow regime; and (iii) influx of people are assessed to have a lower magnitude of impacts in their different pathways towards the secondary impacts, for the current situation³⁶. They are generally also less basin-wide than the two most prominent stressors/primary impacts mentioned above.

The VEC groups that are most impacted through the pathways from the secondary impacts, for the current situation, are (i) biodiversity and habitats for wildlife, birds, and aquatic life (flagship VEC species and habitats); (ii) ecosystem services for livelihood (both with an aggregated score in the high impact range); and (iii) reliable water availability and quality (aggregated score between 140-200). More moderately impacted high impact range (aggregated score between 80-140) are: (iv) productive land/soil for agriculture (especially at community level) and (v) tourism and social services. The last VEC group, (vi) historical, cultural, and religious sites, is less affected (aggregated score in the low impact range between 10-80).

³² *Environmental degradation other than deforestation.*

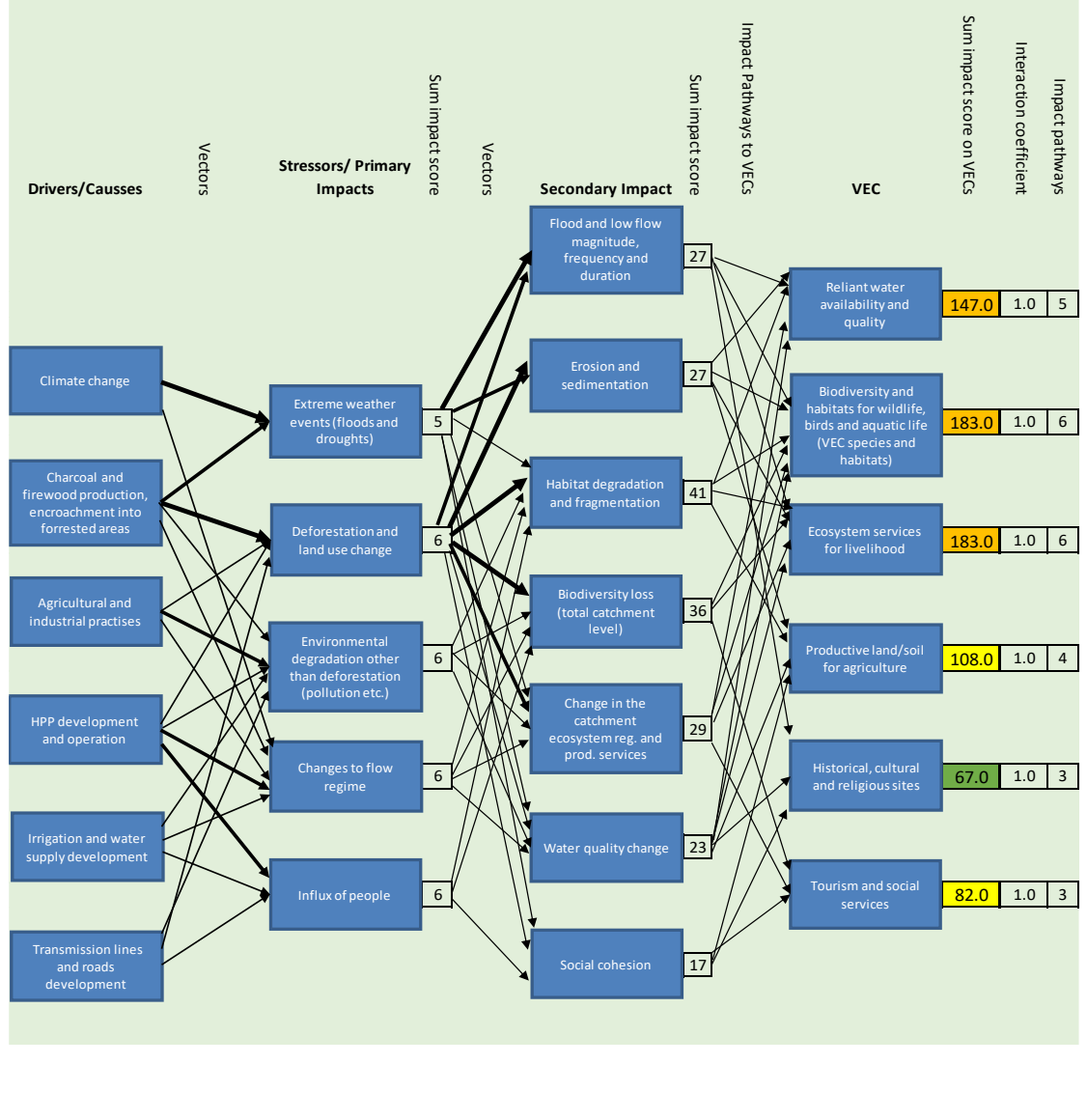
³³ *Three other impact pathways are given a score of 1 (low impact).*

³⁴ *For example, water purification, erosion and flood control (soil stabilization), and carbon storage and climate regulation*

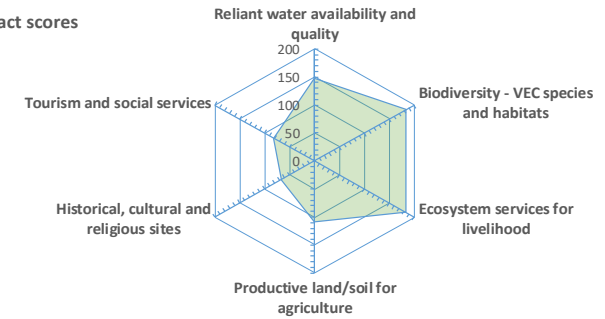
³⁵ *Like plants and animals (including fish) for livelihoods, important for example in the Elephant Marsh.*

³⁶ *All their impact pathways are for the current situation assessed to have an impact score of 1 (low impact)*

Baseline 1 2023

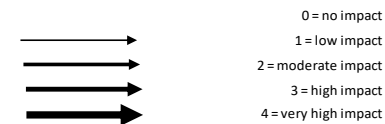


Sum, Impact scores



VECs	Sum	IC*	Impact Pathways
Reliant water availability and quality	147.00	1.00	5.00
Biodiversity - VEC species and habitats	183.00	1.00	6.00
Ecosystem services for livelihood	183.00	1.00	6.00
Productive land/soil for agriculture	108.00	1.00	4.00
Historical, cultural and religious sites	67.00	1.00	3.00
Tourism and social services	82.00	1.00	3.00

Vectors toward primary and secondary impacts



Ranges for sum impact score on VECs

Severe Impact	> 200
High Impact	140 - 200
Moderate Impact	80 - 140
Low Impact	10 - 80
Negligible Impact	0-10

Figure 7-2 The CIA Impact Pathway Network Analysis of Baseline Scenario 1, i.e. current situation (2023).

7.2.3 Summary of Near Natural Scenario (Early 1900)

Conditions in the basin in early 1900 is anticipated to have been characterised by a largely pristine and unmodified Shire River Basin with largely intact forest, terrestrial and riverine ecosystems (see also Section 7.1). The Chiromo Bridge and railway embankment was however constructed in 1907 with some impacts on the extent of lakes in the southern portion of the Elephant Marsh. Basin population has been estimated to be low (see Table 5-1). The drivers/causes have been anticipated to have either no or low impact on the stressors/primary impacts and subsequently also on the secondary impacts and finally on the VECs. The total impact score on the four VEC groups (i) reliable water availability and quality; (ii) biodiversity and habitats for wildlife, birds and aquatic life; (iii) ecosystem services for livelihood; and (iv) productive land/soil for agriculture has been estimated to be in the lower part of the low impact score range (10-80), whilst both (v) historical, cultural and religious sites; and (vi) tourism and social services have been estimated to have been negligibly impacted.

Near Natural Scenario (1900)

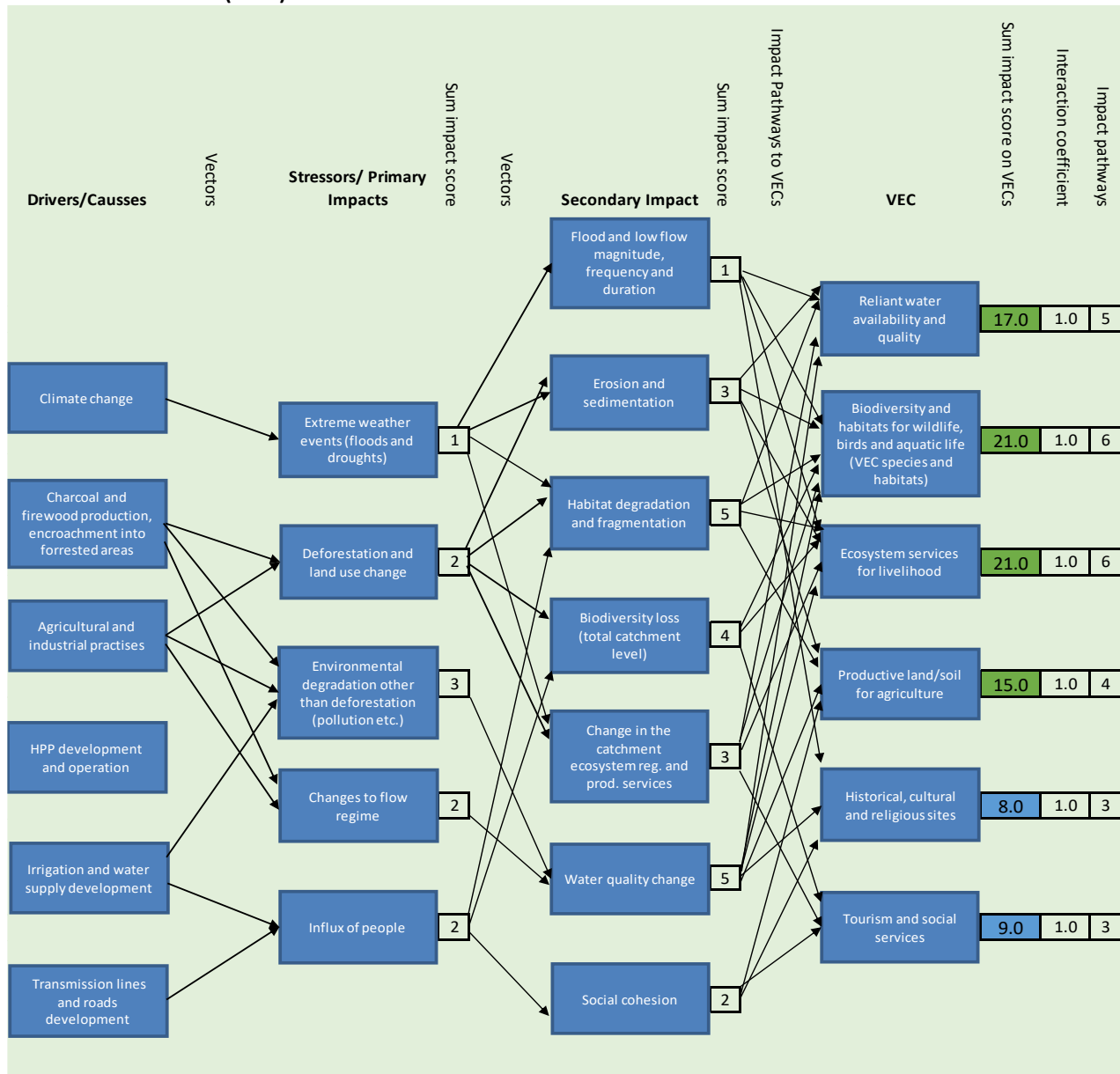


Figure 7-3 CIA analysis results of the Near Natural Scenario (early 1900).

7.2.4 Summary of Historical (Trended) Scenario

The trended scenario set has been divided into three distinct periods, i.e. pre-1992, 1992 to 2002 and lastly 2002 to 2012. The basin development between 2012 and 2022 is captured in Baseline Scenario 1 (2023).

Pre-1992

Between 1900 and 1992 we see a stark population increase in the basin, and the estimated population in the basin in 1992 was at 2 200 000 (see Table 5-1), putting more pressure on the basin and its resources. Between 1900 and 1992 several major historical events have also affected the aquatic and terrestrial ecosystems of the Shire, many of them directly related to the interplay between human pressures (deforestation, over-fishing, transformation of wetlands). In this period, we also see the development of the first major in-channel infrastructure such as Kamuzu Barrage, the first stages of the Tedzani and Nkula hydropower plants, bridges, and embankments, as well as transmission lines and roads, etc. affecting the terrestrial environment. With regards to hydrology Lake Malawi levels (that dictate/affect the baseflows of Shire) are characterised by a period of low levels between 1900-1940, whilst between 1940-1992 there is a period of medium lake levels (see Table 7-1). Some deforestation is occurring, but this becomes more prominent during the next periods (see Table 5-1). Loss of megafauna due to hunting and poaching also occurs in this period.

All drivers/causes impacting the basin health come into play during this period, albeit they are anticipated to have low impact on the stressors/primary impacts, compared to current conditions (2023). However, the combined effect of (i) charcoal/firewood production and encroachment into forested areas; (ii) expansion of agricultural and industrial practises; (iii) HPP development/operation; and (iv) transmission lines and roads development on deforestation and land use change (stressor/primary impact) leads to a combined moderate impact on (i) habitat degradation and fragmentation; and (ii) biodiversity loss at catchment level (both secondary impacts). The total impact score on the two VEC groups (i) biodiversity and habitats for wildlife, birds and aquatic life; and (ii) ecosystem services for livelihood is estimated to be moderately impacted, whilst the four others VECs are assessed to be in the range of low impact.

Trended Pre 1992

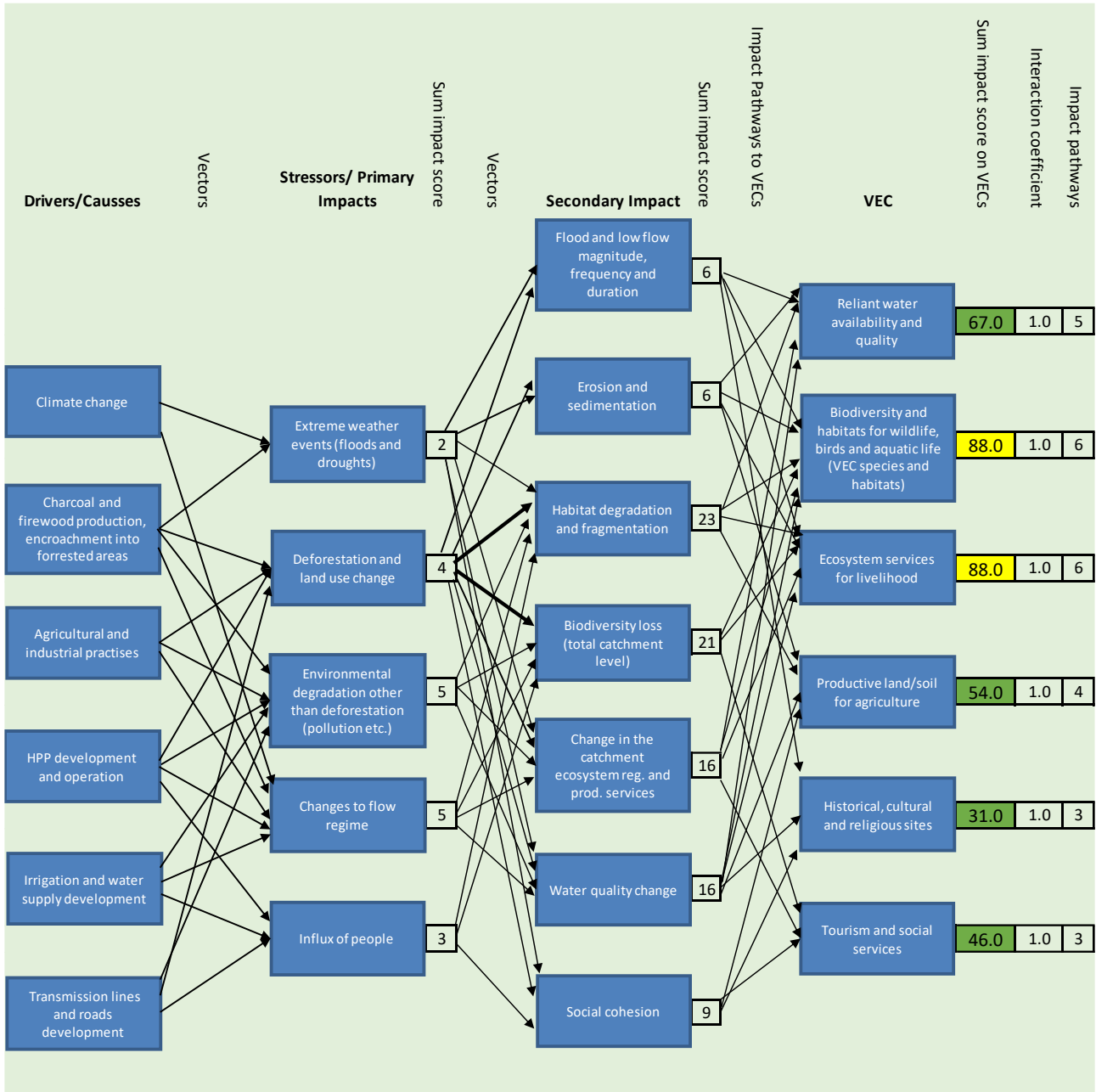


Figure 7-4 CIA analysis results of the Trended Scenario Pre-1992.

1992-2002 Period

Between 1992 and 2022 the population in the basin is estimated to have increased from 2 200 000 to 2 600 000. Further infrastructure comes online including Tedzani II (1996), Kapichira Phase I (2000), and transmission lines and roads development continues. Deforestation rates also increase in this period with charcoal/firewood production and encroachment into forested areas as the main driver/cause (see also Table 7-1).

Some of the drivers/causes impose bigger pressure during this period than the previous one (Pre-1992) on the basin health, with (i) climate change, (ii) expansion of agricultural and industrial practises, and (iii) HPP development/operation set to have moderate impact on various stressors/primary impact, whilst (iv) charcoal/firewood production and encroachment into forested areas is estimated to have high/very high

impact on deforestation and land use change. Habitat degradation and biodiversity loss continues (secondary impact) but there is also an increase in impact on (i) flood and low flow magnitude, frequency and duration and (ii) erosion and sedimentation. The total impact score on the two VEC groups (i) biodiversity and habitats for wildlife, birds and aquatic life; and (ii) ecosystem services for livelihood is estimated to have been highly impacted, whilst (iii) reliable water availability and (iv) productive land/soil for agriculture are estimated to have moderately impacted. The two last VEC groups (i) historical, cultural and religious sites and (ii) tourism and social services are estimated to still be in the low impact range.

Trended 1992-2002

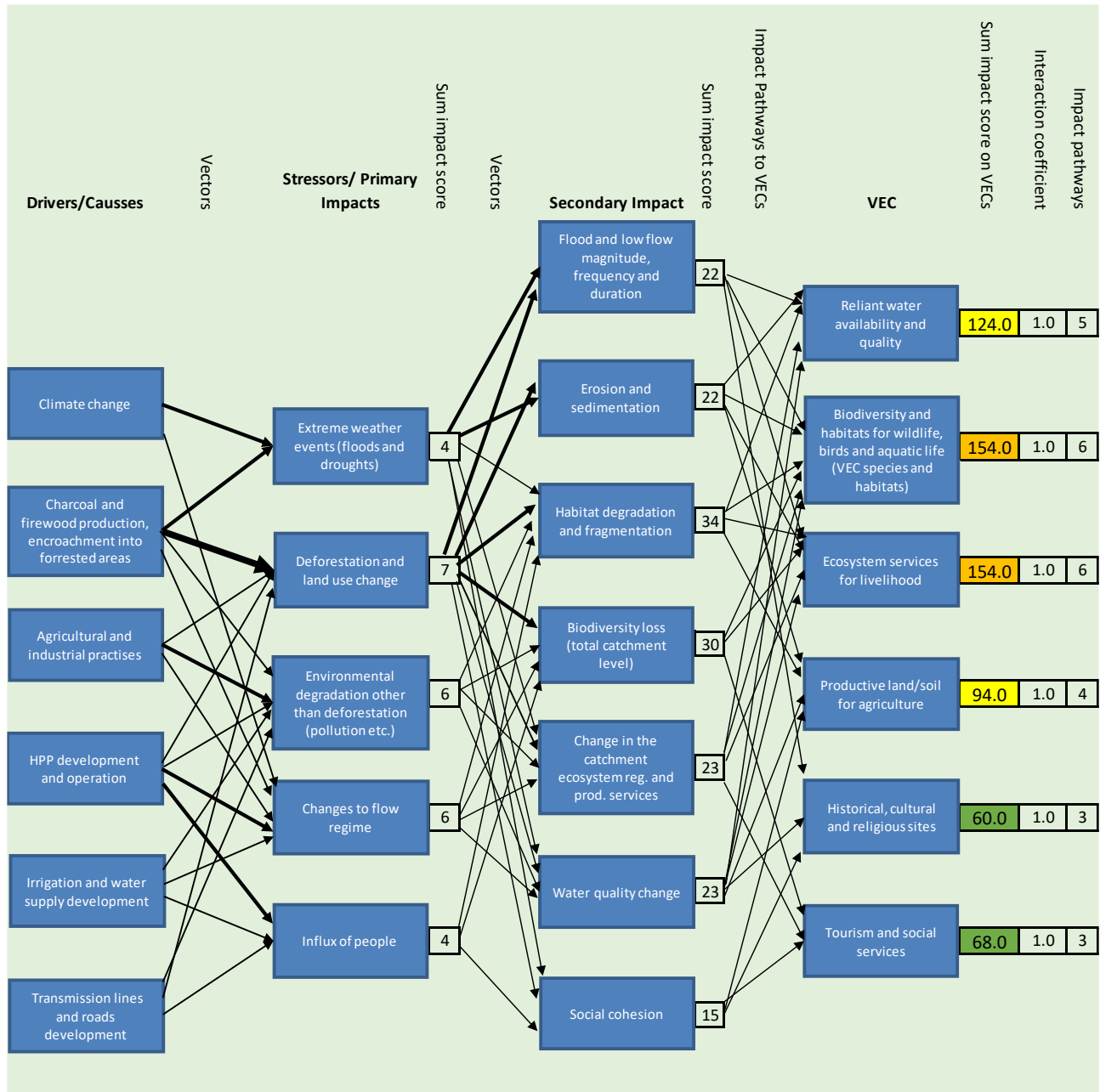


Figure 7-5 CIA analysis results of the Trended Scenario 1992-2002.

2002-2022 Period

Obviously, the impact on the basin over this period is very similar to that of the current situation (Baseline 1 2023) and its impact pathways, so reference is made to the impact pathway in Figure 7-2 with regards to

impact scores on VECs and elsewhere in the pathway. Compared to the previous period, forest degradation continues at the same rate in the first 10 years but seems somehow to stabilise around 2012-2015. Basin population increases to an estimated 4 500 000 in 2022. Further infrastructure developments come into place, or are under construction, including Kapichira Phase 2 (2014), Tedzani III (2017), Upgrading of Kamuzu Barrage (2018) and SVTP canal, amongst others. There is also a stark increase in the frequency of major cyclones and tropical storms over this period, especially in the last 10 years (see Table 7-1).

7.2.5 Summary of Baseline Scenario 2 (2030)

This scenario constitutes two sub-scenarios, i.e. with and without Mpatamanga HPP, respectively (see Table 5-1), together with the other dams/HPPs in the basin. In the sub-scenario with Mpatamanga in place (2.2) Kapichira turns into non-peaking mode compared to peaking without Mpatamanga in place (see also Annex 4). SVTP is also in place (with Illovo and Agricane connected) as well as additional transmission lines (including MOMA and Mpatamanga). Forest cover is anticipated to be similar to 2023 (see Table 5-1), and basin population is estimated to have risen to 5 500 000.

The drivers/causes imposing the biggest pressure on the basin health and on the stressors/primary impacts, is for sub-scenario 2.1 (without Mpatamanga) still (i) charcoal/firewood production and encroachment into forested areas (very high impact on deforestation) and (ii) climate change (high impacts on extreme weather events). For sub-scenario 2.2 Mpatamanga HPP is anticipated to increase the impact on changes to flow regime and influx of people (both set at high impact). The other stressors/primary impacts are anticipated to be negligibly affected by Mpatamanga at basin scale level, albeit some more local impacts are anticipated with regard to land use change and environmental degradation (reservoir and dam area of main dam and regulating dam). Habitat degradation, biodiversity loss and changes to the basin ecosystem services increases compared to Baseline 1, but at basin scale there is estimated to be minor changes due to Mpatamanga as deforestation is still largely driven by charcoal/firewood production and encroachment into forested areas. The influx of people due to Mpatamanga and other infrastructure like SVTP and MOMA is also increasing the impact on social cohesion. Erosion and sedimentation also increase due to deforestation and extreme weather events. The latter also increases the impacts on flood and low flow magnitude, frequency and duration. Sum impact score on the two VEC groups (i) biodiversity and habitats for wildlife, birds and aquatic life; (ii) ecosystem services for livelihood is estimated to be severely impacted in both sub-scenarios, with only a slight increase with Mpatamanga in place (which is also the case of the overall VEC outcomes in the DRIFT ESM assessment in Volume 3). The continued basin degradation and extreme weather events continues to impact the reliable water availability and quality in both sub scenarios, and there are little differences with and without Mpatamanga, with both impact score as high. Impacts on productive land/soil for agriculture and tourism and social services is estimated at moderate impact for both sub-scenarios, whilst historical, cultural and religious sites rise from low impact without to moderate impacts with Mpatamanga (mainly due to construction of the dam complex and influx of people).

Baseline 2 (2030) without Mpatamanga

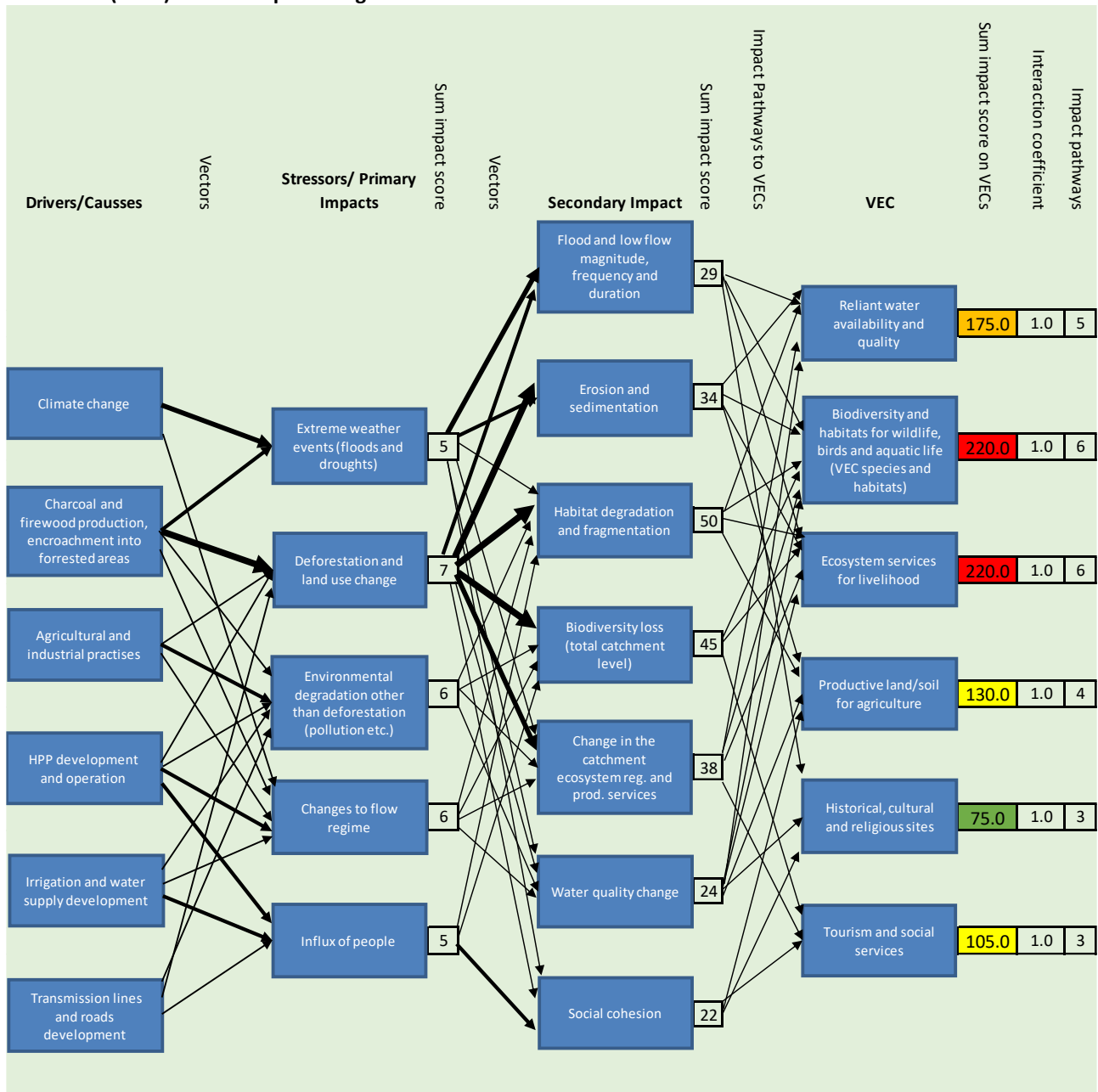


Figure 7-6 CIA analysis results of Baseline Scenario 2.1, without Mpatamanga.

Baseline 2 (2030) with Mpatamanga

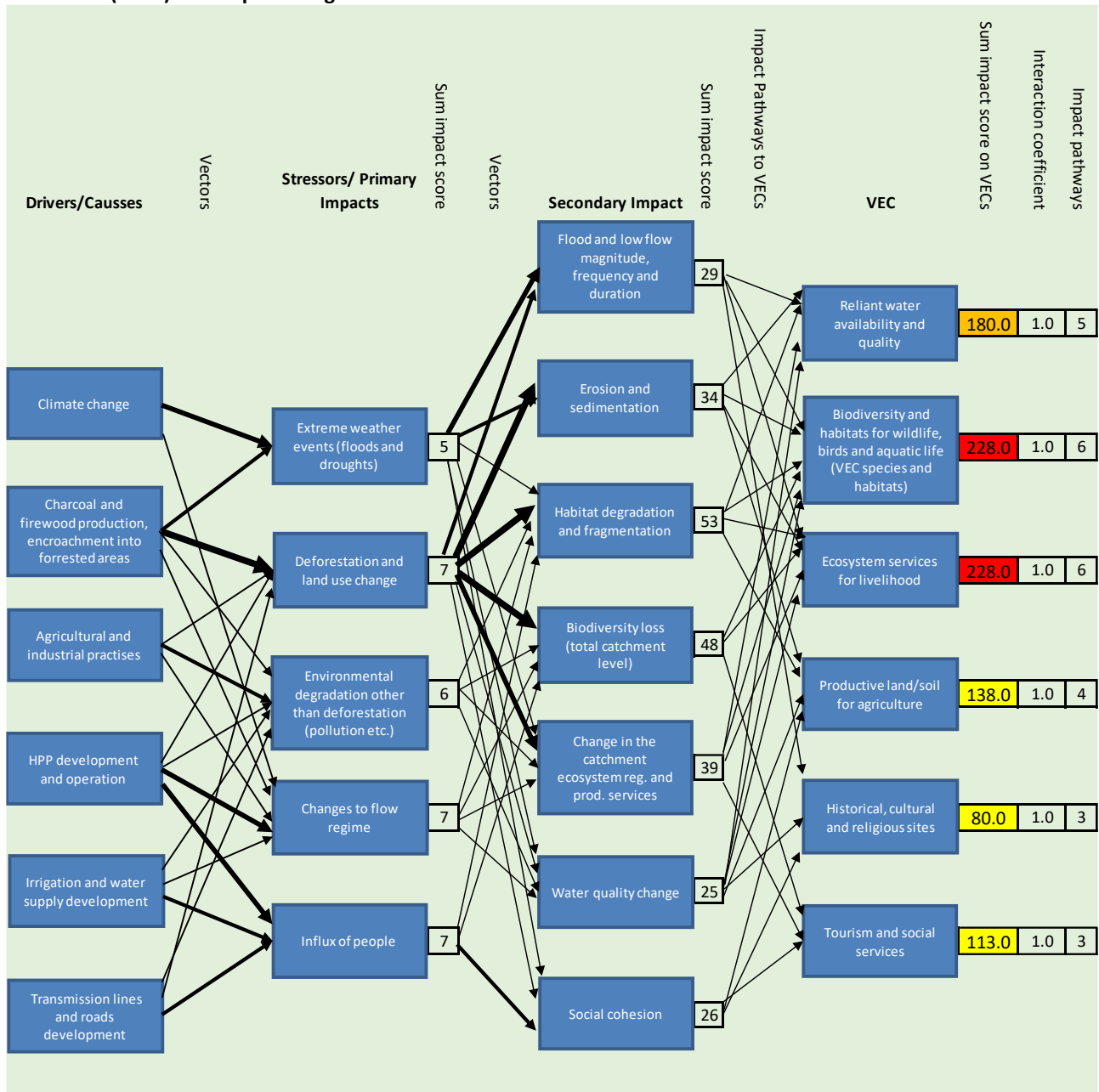


Figure 7-7 CIA analysis results of Baseline Scenario 2.1, with Mpatamanga.

7.2.6 Near Future Scenarios 1, 2 and 3 (2035)

This set of scenarios constitutes the business as usual (BAU) scenario (Near Future 1), BAU with joint dams’ operation (BAU + JDO) scenario (Near Future 2) and BAU + JDO with climate change (CC) scenario (Near Future 3). Basin degradation continues and the impact profile in the impact pathway towards the VECs is quite similar, especially between Near Future 1 and 2 (only a slight decrease in impact on VECs due to JDO³⁷, but with an increase again when adding climate change, Near Future 3). The latter leads to increases in extreme weather events, with its subsequent increases in impact on (i) flood and low flow magnitudes,

³⁷ Modelled JDO impact on flows and hydropower generation compared to BAU (Scenario 6 compared to Scenario 5) is reported in detail in Sections A.4.3 and A.4.4 of Annex 4 and shows only slight differences. Hence this only this slight decrease on impacts on VECs has been assessed.

frequency and duration; and (ii) sedimentation and erosion (see also Annex 3). Near Future 1, 2 and 3 impact scores are exemplified in Figure 7-8 - 7-10. Impacts on the three VEC groups (i) reliable water availability and quality; (ii) biodiversity and habitats for wildlife, birds and aquatic life; and (iii) ecosystem services for livelihood are estimated to be severe, while (iv) productive land soil for agriculture is high. The two last VECs are estimated to be moderately impacted.

Near Future 1 (2035) - BAU

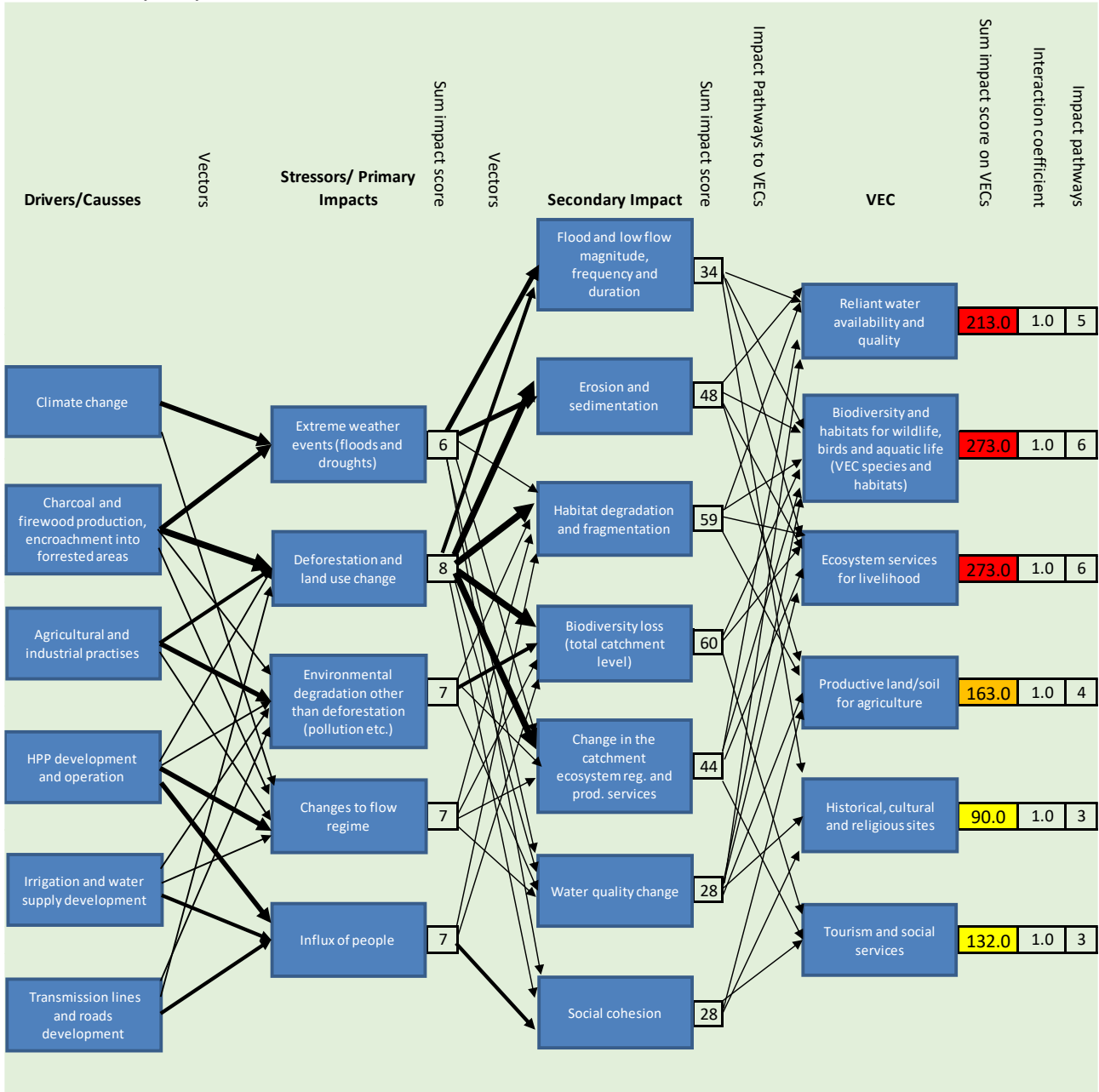


Figure 7-8 CIA analysis results of Near Future Scenario 1 (2035).

Near Future 2 (2035) - BAU+JDO

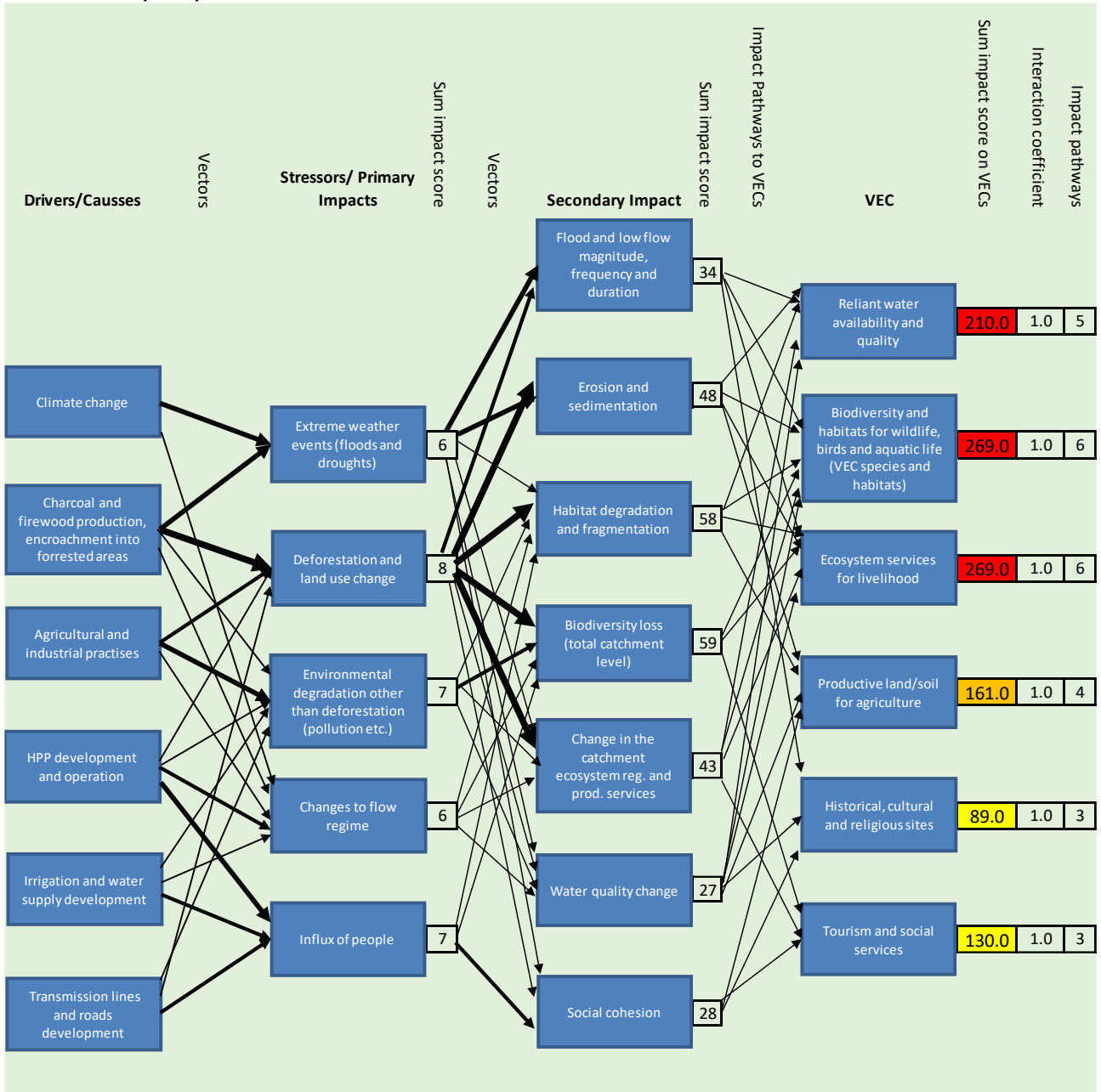


Figure 7-9 CIA analysis results of Near Future Scenario 2 (2035).

Near Future 3 (2035) - BAU+JDO+CC

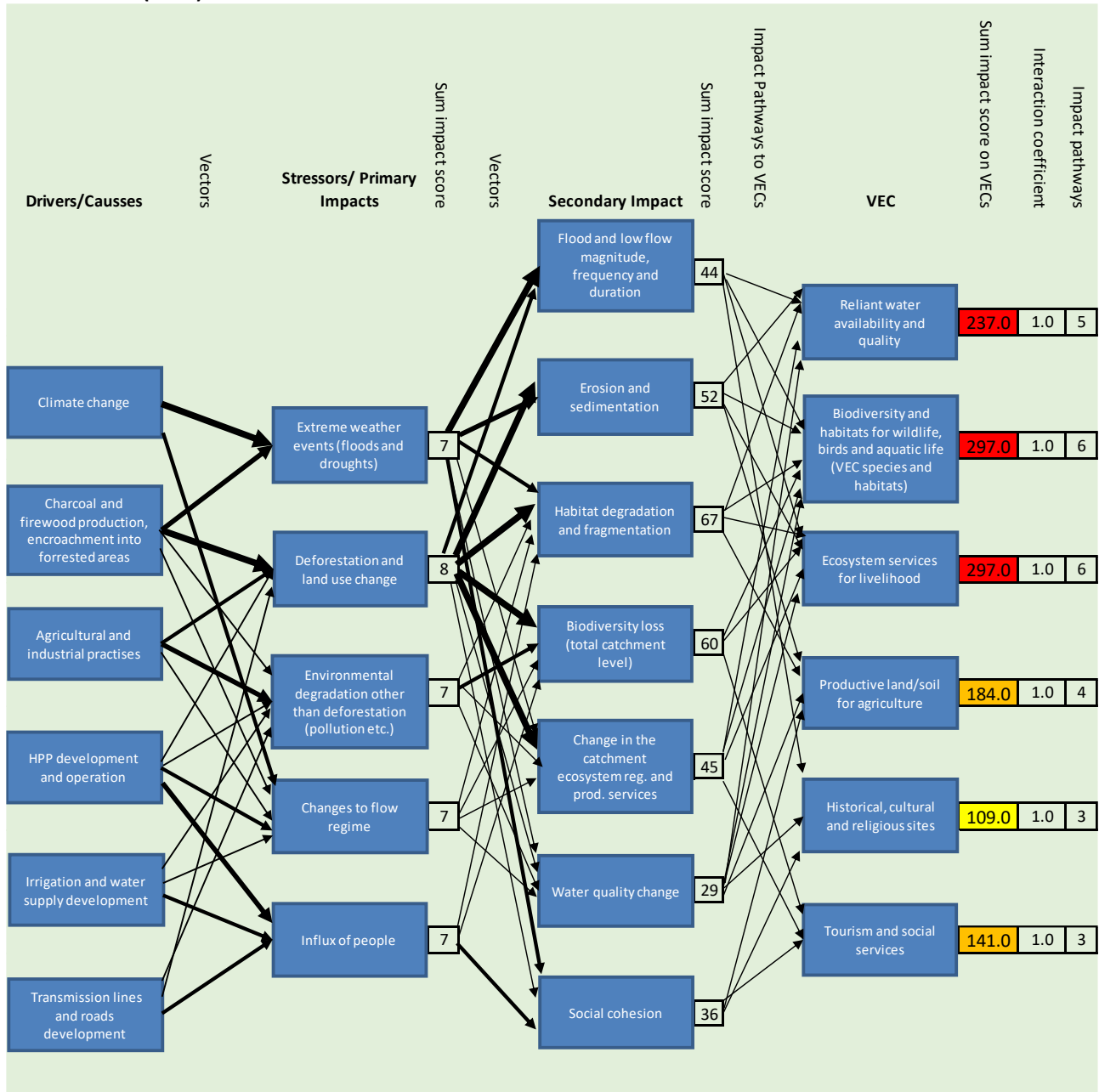


Figure 7-10 CIA analysis results of Near Future Scenario 3 (2035).

7.2.7 Near Future Scenario 4

This scenario is the sustainable pathway scenario where we sequentially include catchment restoration, reforestation and mitigation measures via: *Stepwise build in (1) catchment rehabilitation, (2) tourism and protected areas management and (3) Sustainable land use enhancement and energy source transition in the basin.* Reference is also made to Table 5-1 for more details. As can be seen in Figure 7-11 to 7-13, the reduction in magnitude of the impacts decreases for each step, especially for (i) charcoal/firewood production and encroachment into forested areas, and (ii) agricultural and industrial practices. This has knock-on effects on many of the stressors/primary impact and secondary impacts, leading to reduction of impacts on all VEC groups compared to Near Future 1, 2 and 3 Scenarios. Impacts are lowered to moderate (4 VEC groups) or low (2 VEC groups) when all these catchment scale measures are put in place (Figure 7-13).

Near Future 4 (2035) - Sustainable Pathway (Step 1)

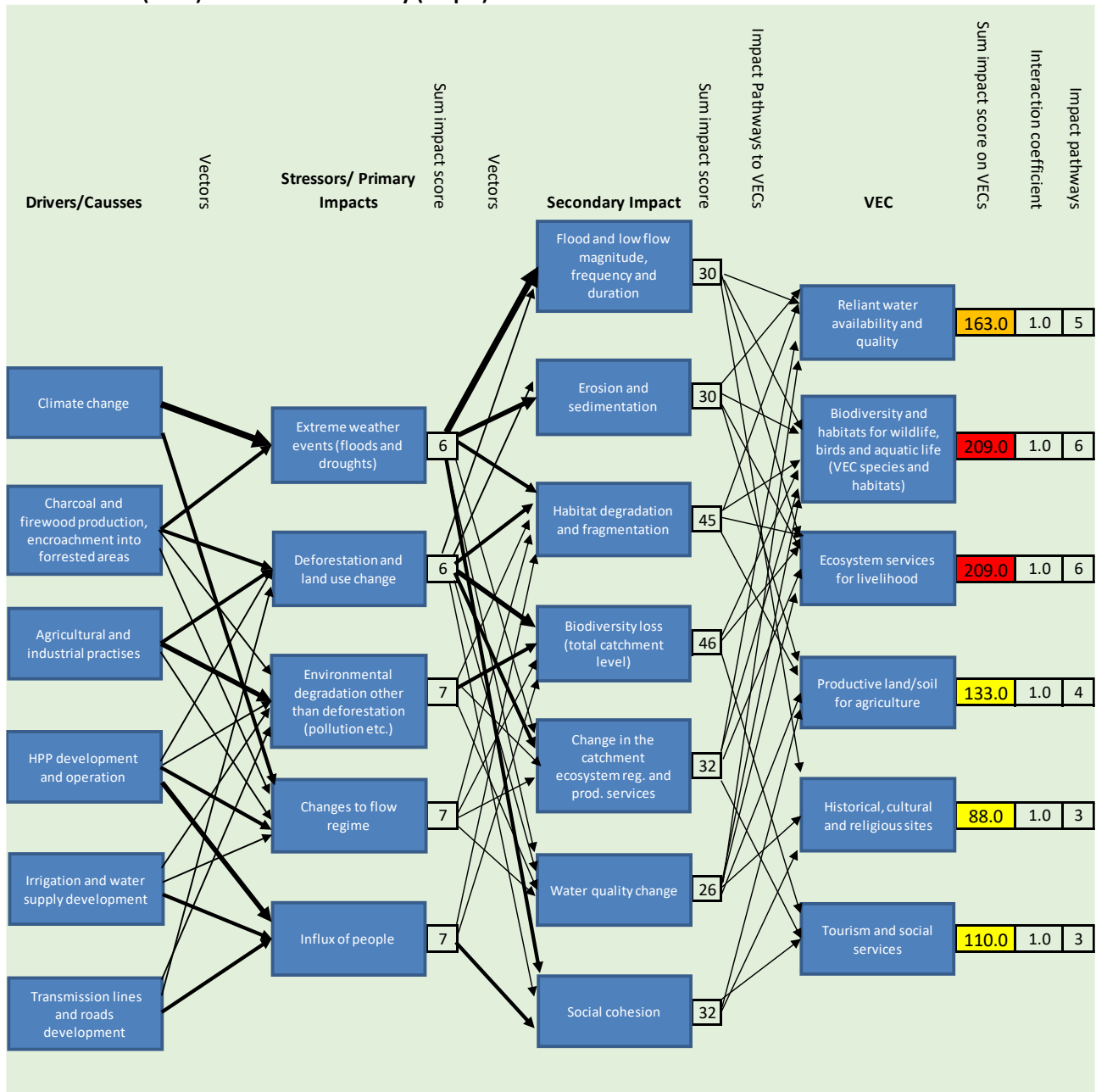


Figure 7-11 CIA analysis results of Near Future Scenario 4 (2035) – Step 1 (catchment rehabilitation).

Near Future (2035) - Sustainable Pathway (Step 1+2)

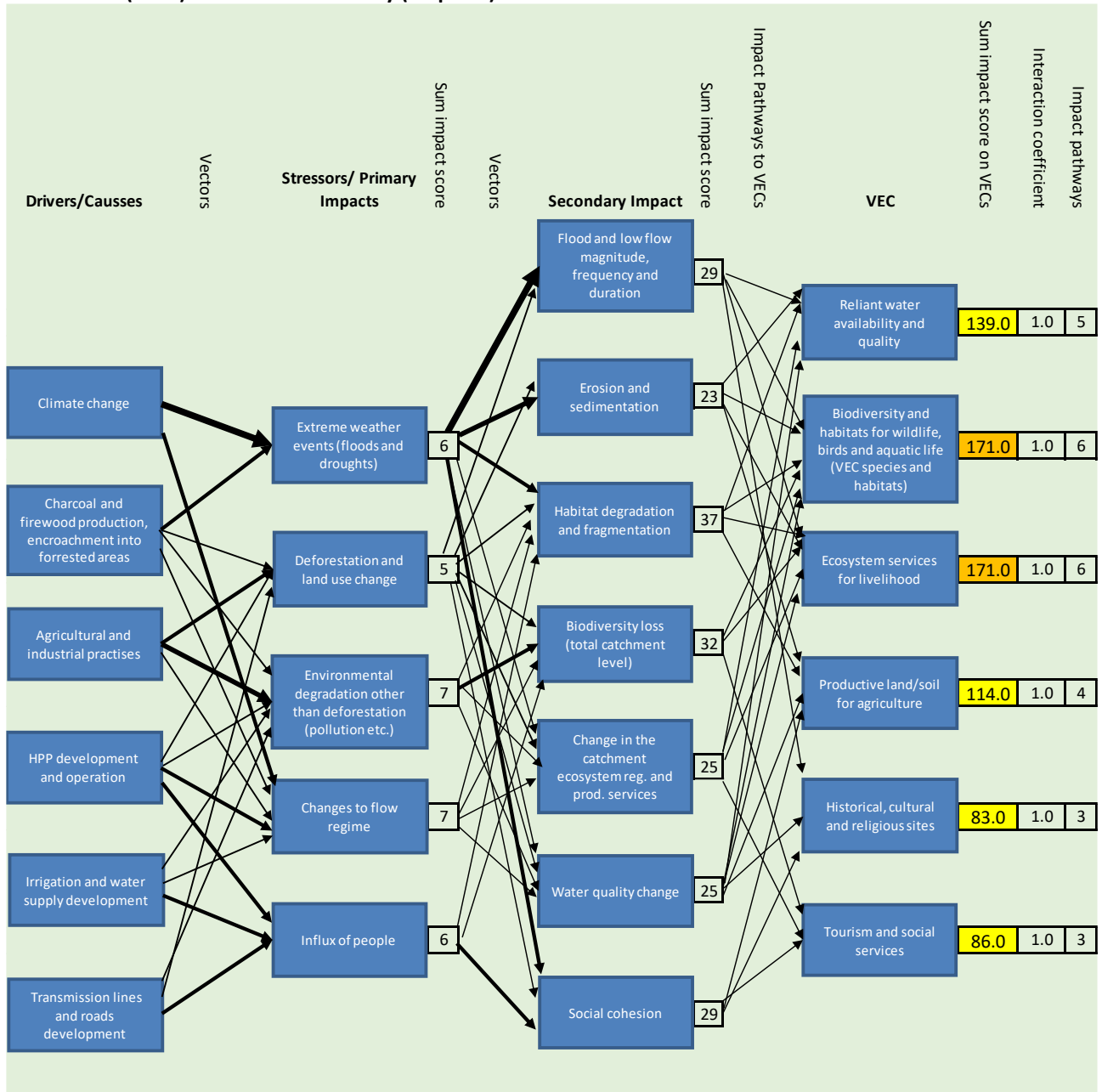


Figure 7-12 CIA analysis results of Near Future Scenario 4 (2035) – Step 1 +2 (catchment rehabilitation + tourism and protected areas management).

Near Future (2035) - Sustainable Pathway (Step 1+2+3)

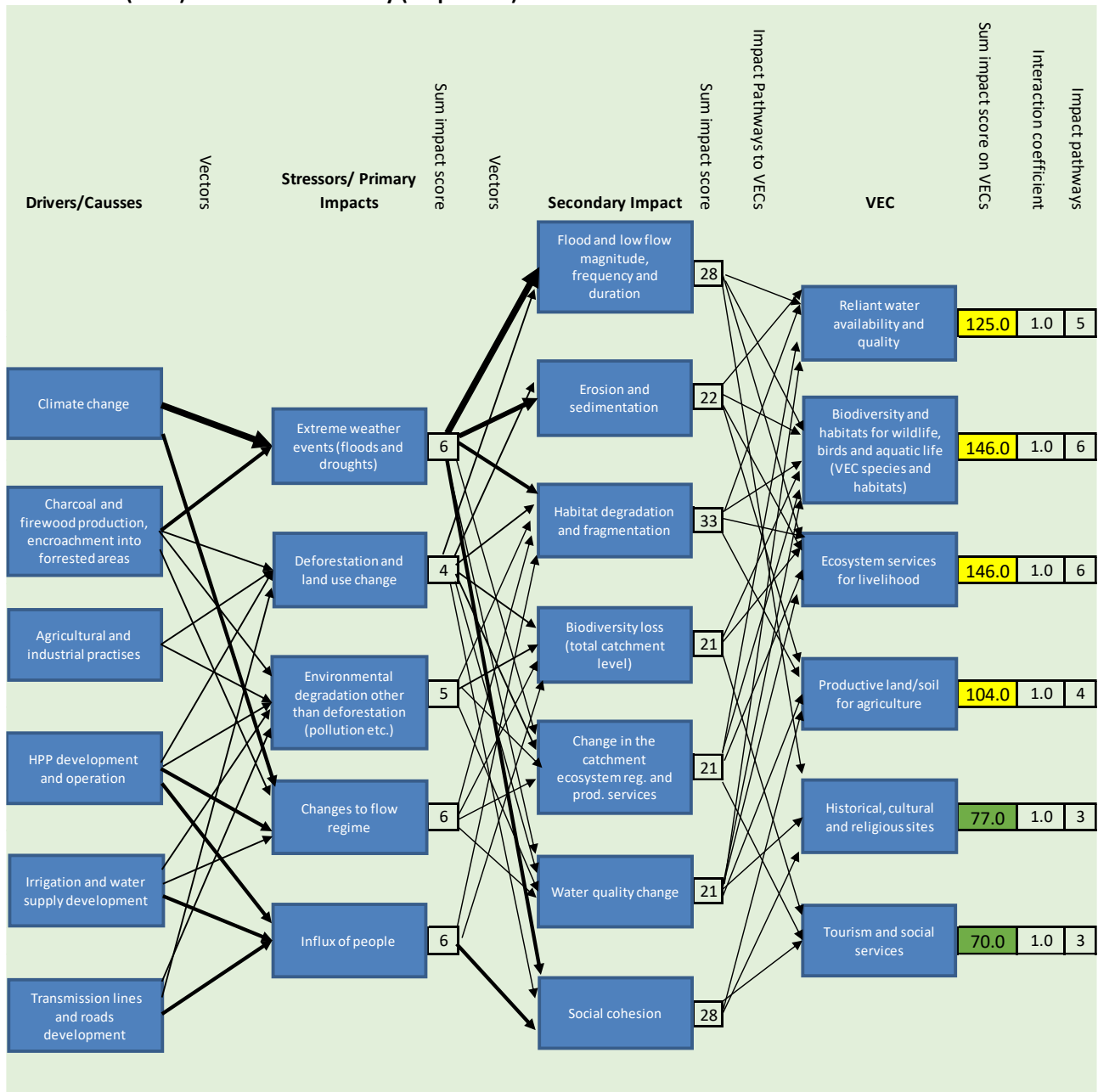


Figure 7-13 CIA analysis results of Near Future Scenario 4 (2035) – Step 1 + 2 + 3 (catchment rehabilitation + tourism and protected areas management + Sustainable land use enhancement and energy source transition).

7.2.8 Distant Future Scenario 1 and 2 (2070)

This scenario set constitutes the BAU for 2070 (Distant Future 1), which is similar to Near Future 1 (2035) but with further basin degradation and more extreme weather events due to climate change; and the Sustainable Pathway Scenario for 2070 (Distant Future 2) with continued basin restoration and reforestation as of Near Future 4 scenario. As can be seen from Figure 7-14, in the BAU case (Near Future 1), the magnitude of almost all impact pathways becomes more prominent eventually leading to severe impact scores on all VEC groups. Hence, we are probably witnessing a possible major change in the state of the basin ecosystems with its

subsequent impacts on livelihoods etc., if no large-scale restoration, reforestation and other mitigation measures are implemented.

Distant Future (2070) - BAU + CC

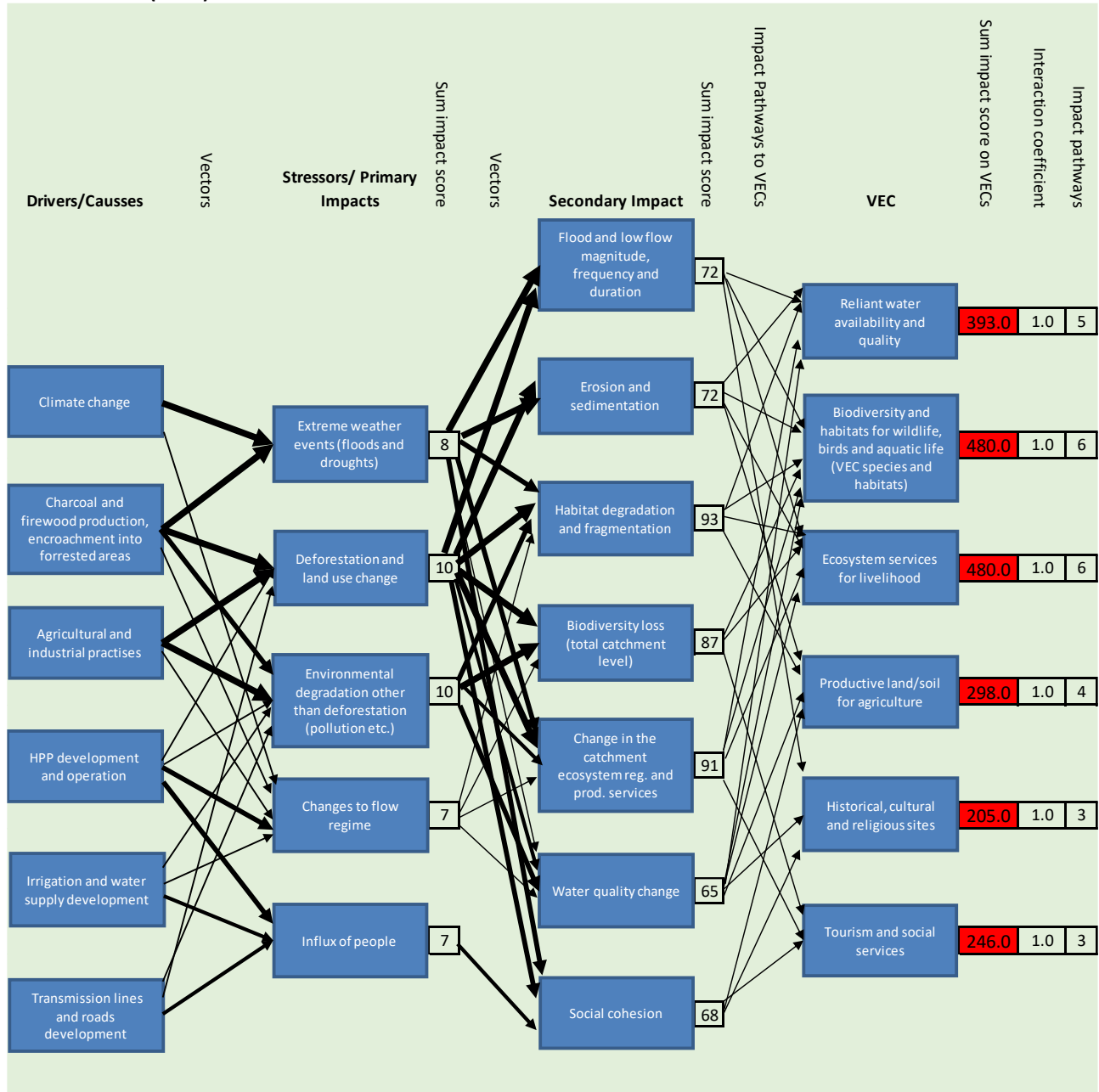


Figure 7-14 CIA analysis results of the Distant Future Scenario 1 (2070) - BAU.

On the other hand, if the steps in the sustainable pathways continue to be implemented up to 2070, including reforestation of erosion hotspot areas (see Table 5-1 and Annex 1 for details), the basin health and impacts on the VECs are considerably reduced as shown in Figure 7-15. Only continued climate change remains somehow prominent³⁸. Impacts on all VEC groups are considerably lowered and are even lower than for Near Future 4, due to the continued restoration, reforestation and other mitigation measures. Three of the VEC groups are in the moderate impact range and the remaining three in the low impact range.

³⁸ Basin population is however expected to increase beyond 10 million, and can impose additional pressure. Volume 3 has looked into effects with and without this population increase. Figure 7-15 is without this magnitude in increase.

Distant Future (2070) - Sustainable Pathway (Step 1+2+3)

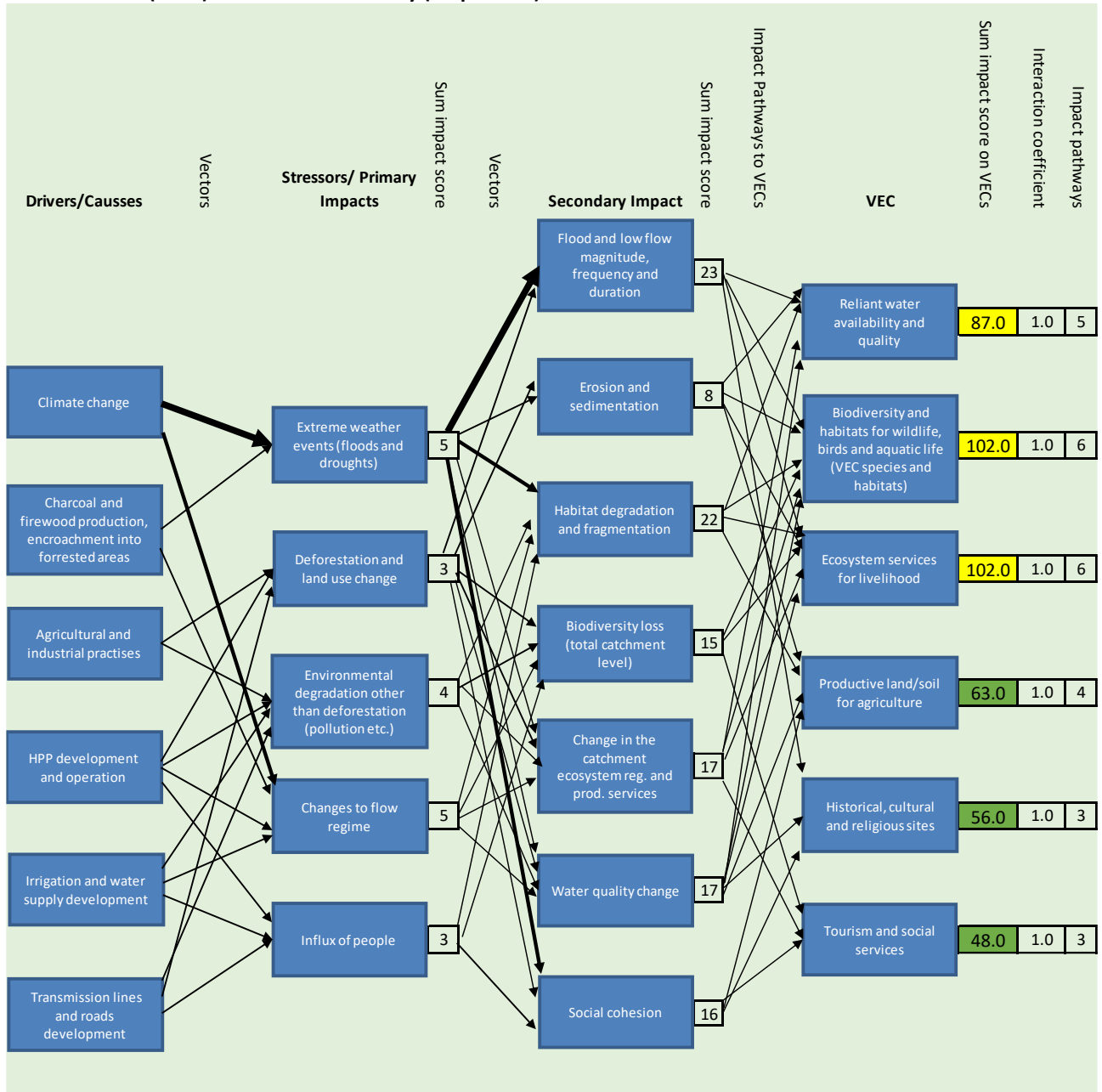


Figure 7-15 CIA analysis results of the Distant Future Scenario 2 (2070) – Sustainable Pathway Steps 1+2+3.

8 CUMULATIVE IMPACT ASSESSMENT OF VECs (ALL SCENARIOS)

This chapter outlines the impact of each scenario of the CIA assessment on each VEC group and its selected indicator. In a few of the VEC groups the indicators have been pooled to avoid repetition since the impacts are quite similar. For relevant mitigation options for the VECs, reference is made to Section 11.3 (Summary of Mitigation Measures) in Tables 11-1 and 11-2, to avoid repetition in this Chapter.

8.1 VEC 1 – Reliable Water Availability and Quality

8.1.1 Hydropower Production

Table 8-1 Summary of impacts of each scenario on hydropower production (see also Annex 4 for details with regard to power production).

No	Scenario	VEC Impact score ³⁹	Comments
1	Near Natural	No Impact	Hydropower absent
2.1	Trended Pre-1992	Low Impact	Kamuzu Barrage, Tedzani I 1, Nkula 1+2+3 comes online (prone to Lake Malawi and Shire flow variations)
2.2	Trended 1992-2002	Moderate Impact	Tedzani II and Kapichira Phase 1 operationalised (prone to Lake Malawi and Shire flow variations and increasing erosion/sediment transport).
2.3	Trended 2002-2012	High Impact	Increasing erosion/sediment transport due to deforestation. Filling of reservoirs
3	Baseline 1 (2023)	High Impact	Increasing erosion/sediment transport due to deforestation. Filling of reservoirs
4.1	Baseline 2.1 (2030) – without Mpatamanga	High Impact	Increasing erosion/sediment transport due to deforestation. Filling of reservoirs
4.2	Baseline 2.2 (2030) – with Mpatamanga	High Impact	Increasing erosion/sediment transport due to deforestation. Filling of reservoirs (Kapichira less prone to reservoir filling due to Mpatamanga)
5	Near Future 1 (2035) – BAU	Severe Impact	Increasing erosion/sediment transport due to deforestation. Filling of reservoirs (Kapichira less prone to reservoir filling due to Mpatamanga). Lake Malawi levels, due to CC, starts to add additional impacts,
6	Near Future 2 (2035) – BAU + JDO	Severe Impact (slightly less than Near Future 1 though)	Increasing erosion/sediment transport due to deforestation. Filling of reservoirs (Kapichira less prone to reservoir filling due to Mpatamanga). Lake Malawi levels, due to CC, starts to add additional impacts,
7	Near Future 3 (2035) – BAU + JDO + CC	Severe Impact (higher than both Near Future 1 and 2 due to CC)	Increasing erosion/sediment transport due to deforestation. Filling of reservoirs (Kapichira less prone to reservoir filling due to Mpatamanga). Lake Malawi levels, due to CC, starts to add additional impacts,

³⁹ Derived/extracted from the impact scores in the diagram in Chapter 7, in this and the following tables in Chapter 8.

No	Scenario	VEC Impact score ³⁹	Comments
8	Near Future 4 (2035) – SP Step 1+2+3	Moderate Impact	Decreasing erosion and sediment transport/supply due to sustainable pathway (SP) mitigation measures. Slightly less prone to high and low flows due to SP mitigation measures
9	Distant Future (2070) – BAU	Severe Impact	Almost doubling of impact score compared to Near Future 1. Major reason is CC and drop in Lake Malawi levels
10	Distant Future (2070) – SP Step 1+2+3	Moderate Impact	Continued (compared to Near Future 4) decreasing erosion and sediment transport/supply due to sustainable pathway (SP) mitigation measures. Slightly less prone to high and low flows due to SP mitigation measures

8.1.2 Irrigation and Water Supply

Table 8-2 Summary of impacts of each scenario water availability and quality for irrigation and water supply.

No	Scenario	VEC Impact score	Comments
1	Near Natural	No Impact	Mostly undeveloped
2.1	Trended Pre-1992	Low Impact	Kamuzu Barrage comes online also to regulate water release for irrigation and water supply. Increasing impact on quantity and quality of water due to population increase and basin infrastructure development
2.2	Trended 1992-2002	Moderate Impact	Increasing impact on quantity and quality of water for irrigation and water supply due to population increase and basin infrastructure development continues. Large scale deforestation starts and exacerbates this impact.
2.3	Trended 2002-2012	High Impact	Increasing impact on quantity and quality of water for irrigation and water supply due to population increase and basin infrastructure development continues. Continued large scale deforestation from previous period and exacerbates this impact even further.
3	Baseline 1 (2023)	High Impact	Increasing impact on quantity and quality of water for irrigation and water supply due to population increase and basin infrastructure development continues. Continued large scale deforestation from previous period and exacerbates this impact even further.

No	Scenario	VEC Impact score	Comments
			Frequency and magnitude of extreme weather events adds on to this.
4.1	Baseline 2.1 (2030) – without Mpatamanga	High Impact	Increasing impact on quantity and quality of water for irrigation and water supply due to population increase and basin infrastructure development continues. Continued large scale deforestation from previous period and exacerbates this impact even further. Frequency and magnitude of extreme weather events adds on to this
4.2	Baseline 2.2 (2030) – with Mpatamanga	High Impact	Upstream Mpatamanga: Increasing impact on quantity and quality of water for irrigation and water supply due to population increase and basin infrastructure development continues. Continued large scale deforestation from previous period and exacerbates this impact even further. Frequency and magnitude of extreme weather events add to this. Mpatamanga potentially serves as an extreme weather events regulator to downstream water users and reduces sediment supply and siltation
5	Near Future 1 (2035) – BAU	Severe Impact	Upstream Mpatamanga: Increasing impact on quantity and quality of water for irrigation and water supply due to population increase and basin infrastructure development continues. Continued large scale deforestation from previous period and exacerbates this impact even further. Frequency and magnitude of extreme weather events add to this. Mpatamanga potentially serves as an extreme weather events regulator to downstream water users and reduces sediment supply and siltation
6	Near Future 2 (2035) – BAU + JDO	Severe Impact (slightly less than Near Future 1 though)	Same as Near Future 2
7	Near Future 3 (2035) – BAU + JDO + CC	Severe Impact (higher than both Near Future 1 and 2 due to CC)	More extreme weather events increase the same impact as outlined in Near Future 2
8	Near Future 4 (2035) – SP Step 1+2+3	Moderate Impact	Decreasing erosion and sediment transport/supply due to sustainable pathway (SP) mitigation measures. Slightly less prone to high and low flows due to SP mitigation measures. Mpatamanga potentially serves as an extreme weather events regulator to

No	Scenario	VEC Impact score	Comments
			downstream water users and reduces sediment supply and siltation
9	Distant Future (2070) – BAU	Severe Impact	Possible basin collapse and almost doubling of impact score compared to Near Future 1
10	Distant Future (2070) – SP Step 1+2+3	Moderate Impact	Continued (compared to Near Future 4) decreasing erosion and sediment transport/supply due to sustainable pathway (SP) mitigation measures. Less prone to high and low flows due to SP mitigation measures. Mpatamanga potentially serves as an extreme weather events regulator to downstream water users and reduces sediment supply and siltation

8.1.3 Livelihoods

Table 8-3 Summary of impacts of each scenario water availability and quality for livelihoods

No	Scenario	VEC Impact score	Comments
1	Near Natural	Low Impact	Basin population low, but prone to natural weather variations
2.1	Trended Pre-1992	Low Impact	Kamuzu Barrage comes online also to regulate water release for livelihoods. Increasing impact on quantity and quality of water due to population increase and basin infrastructure development
2.2	Trended 1992-2002	Moderate Impact	Increasing impact on quantity and quality of water for livelihoods due to population increase and basin infrastructure development continues. Large scale deforestation starts and exacerbates this impact.
2.3	Trended 2002-2012	High Impact	Increasing impact on quantity and quality of water for livelihoods due to population increase and basin infrastructure development continues. Continued large scale deforestation from previous period and exacerbates this impact even further.
3	Baseline 1 (2023)	High Impact	Increasing impact on quantity and quality of water for livelihoods due to population increase and basin infrastructure development continues. Continued large scale deforestation from previous period and exacerbates this impact even further. Frequency and magnitude of extreme weather events adds on to this.
4.1	Baseline 2.1 (2030) – without Mpatamanga	High Impact	Increasing impact on quantity and quality of water for livelihoods due to population

No	Scenario	VEC Impact score	Comments
			increase and basin infrastructure development continues. Continued large scale deforestation from previous period and exacerbates this impact even further. Frequency and magnitude of extreme weather events adds on to this
4.2	Baseline 2.2 (2030) – with Mpatamanga	High Impact	Upstream Mpatamanga: Increasing impact on quantity and quality of water for livelihoods due to population increase and basin infrastructure development continues. Continued large scale deforestation from previous period and exacerbates this impact even further. Frequency and magnitude of extreme weather events add to this. Mpatamanga potentially serves as an extreme weather events regulator to downstream water users and reduces sediment supply and siltation
5	Near Future 1 (2035) – BAU	Severe Impact	Upstream Mpatamanga: Increasing impact on quantity and quality of water for livelihoods due to population increase and basin infrastructure development continues. Continued large scale deforestation from previous period and exacerbates this impact even further. Frequency and magnitude of extreme weather events add to this. Mpatamanga potentially serves as an extreme weather events regulator to downstream water users and reduces sediment supply and siltation
6	Near Future 2 (2035) – BAU + JDO	Severe Impact (slightly less than Near Future 1 though)	Same as Near Future 2
7	Near Future 3 (2035) – BAU + JDO + CC	Severe Impact (higher than both Near Future 1 and 2 due to CC)	More extreme weather events increase the same impact as outlined in Near Future 2
8	Near Future 4 (2035) – SP Step 1+2+3	Moderate Impact	Decreasing erosion and sediment transport/supply due to sustainable pathway (SP) mitigation measures. Slightly less prone to high and low flows due to SP mitigation measures. Mpatamanga potentially serves as an extreme weather events regulator to downstream water users and reduces sediment supply and siltation
9	Distant Future (2070) – BAU	Severe Impact	Possible basin collapse and almost doubling of impact score compared to Near Future 1

No	Scenario	VEC Impact score	Comments
10	Distant Future (2070) – SP Step 1+2+3	Moderate Impact	Continued (compared to Near Future 4) decreasing erosion and sediment transport/supply due to sustainable pathway (SP) mitigation measures. Less prone to high and low flows due to SP mitigation measures. Mpatamanga potentially serves as an extreme weather events regulator to downstream water users and reduces sediment supply and siltation

8.2 VEC 2 – Biodiversity and Habitats for Wildlife, Birds and Aquatic Life

8.2.1 Flagship VEC Species

Table 8-4 Summary of impacts of each scenario on Flagship VEC Species.

No	Scenario	VEC Impact score	Comments
1	Near Natural	Low Impact	Little pressure on Flagship VEC species due to low basin population, albeit some hunting and poaching possibly occurring
2.1	Trended Pre-1992	Moderate Impact	Loss of megafauna in this period due to poaching and hunting. Some agricultural extension increases the impacts on Flagship VEC species
2.2	Trended 1992-2002	High Impact	Increasing impact on Flagship VEC species due to population increase and that basin infrastructure development continues. Large scale deforestation starts and exacerbates this impact.
2.3	Trended 2002-2012	High Impact	Increasing impact on Flagship VEC species due to population increase and basin infrastructure development continues. Continued large scale deforestation from previous period and exacerbates this impact even further.
3	Baseline 1 (2023)	High Impact	Increasing impact on Flagship VEC species due to population increase and basin infrastructure development continues. Continued large scale deforestation from previous period exacerbates this impact even further. Frequency and magnitude of extreme weather events adds on to this.
4.1	Baseline 2.1 (2030) – without Mpatamanga	Severe Impact	Increasing impact on Flagship VEC species due to population increase and basin infrastructure development continues. Continued large scale deforestation from previous period and exacerbates this impact

No	Scenario	VEC Impact score	Comments
			even further. Frequency and magnitude of extreme weather events adds on to this
4.2	Baseline 2.2 (2030) – with Mpatamanga	Severe Impact	Upstream Mpatamanga: Increasing impact Flagship VEC species due to population increase and basin infrastructure development continues. Continued large scale deforestation from previous period and exacerbates this impact even further. Frequency and magnitude of extreme weather events add to this. Mpatamanga imposes some extra impacts on Flagship VEC species in parts of the basin (around Majete WR especially), but mitigation of this is proposed in ESIA and BAP studies
5	Near Future 1 (2035) – BAU	Severe Impact	Upstream Mpatamanga: Increasing impact Flagship VEC species due to population increase and basin infrastructure development continues. Continued large scale deforestation from previous period and exacerbates this impact even further. Frequency and magnitude of extreme weather events add to this. Mpatamanga imposes some extra impacts on Flagship VEC species in parts of the basin (around Majete WR especially), but mitigation of this is proposed in ESIA and BAP studies)
6	Near Future 2 (2035) – BAU + JDO	Severe Impact (slightly less than Near Future 1 though)	Same as Near Future 2
7	Near Future 3 (2035) – BAU + JDO + CC	Severe Impact (higher than both Near Future 1 and 2 due to CC)	More extreme weather events increase the same impact as outlined in Near Future 2
8.1	Near Future 4 (2035) – SP Step 1	Still severe Impact (but quite lower than the other Near Future scenarios without catchment restoration)	Decreasing impacts of Flagship VEC species outside protected areas (including) Pangolins and Vultures) due to catchment restoration. Reduced erosion and sediment transport/supply due to sustainable pathway (SP) mitigation measures, specifically affecting important fish and bird species positively (including Elephant Marsh). Wetland species slightly less prone to high and low flows due to large scale catchment restoration. Mpatamanga potentially serves as an extreme weather events regulator to downstream Flagship VEC species and reduces sediment supply and siltation affecting these

No	Scenario	VEC Impact score	Comments
8.2	Near Future 4 (2035) – SP Step 1+2	High Impact	Same as SP step 1 but enhancing protected areas management, including in Lengwe NP, reduces impacts on Flagship VEC species (for example on large mammals like the Nyala Antelope)
8.3	Near Future 4 (2035) – SP Step 1+2+3	Moderate Impact	Same as SP step 1+2 but sustainable land use management and energy source transition, reduces impacts natural forests (including in and around protected areas and henceforth Flagship VEC species)
9	Distant Future (2070) – BAU	Severe Impact	Possible basin collapse and almost doubling of impact score on Flagship VEC species compared to Near Future 1
10	Distant Future (2070) – SP Step 1+2+3	Moderate Impact (albeit lower than Near Future 4 scenario)	Continued (compared to Near Future 4 Step 1+2+3) decreasing impacts on Flagship VEC species in and outside protected areas throughout the basin. Mpatamanga potentially serves as an extreme weather events regulator to downstream Flagship VEC species and reduces sediment supply and siltation affecting these

8.2.2 Flagship VEC Habitats

Table 8-5 Summary of impacts of each scenario on Flagship VEC Habitats.

No	Scenario	VEC Impact score	Comments
1	Near Natural	Low Impact	Little pressure on Flagship VEC habitats due to low basin population, albeit some hunting and poaching possibly occurring
2.1	Trended Pre-1992	Moderate Impact	Loss of megafauna in this period due to poaching and hunting. Some agricultural extension increases the impacts on Flagship VEC habitats
2.2	Trended 1992-2002	High Impact	Increasing impact on Flagship VEC habitats due to population increase and that basin infrastructure development continues. Large scale deforestation starts and exacerbates this impact.
2.3	Trended 2002-2012	High Impact	Increasing impact on Flagship VEC habitats due to population increase and basin infrastructure development continues. Continued large scale deforestation from previous period and exacerbates this impact even further.
3	Baseline 1 (2023)	High Impact	Increasing impact on Flagship VEC habitats due to population increase and basin infrastructure development continues.

No	Scenario	VEC Impact score	Comments
			Continued large scale deforestation from previous period exacerbates this impact even further. Frequency and magnitude of extreme weather events adds on to this.
4.1	Baseline 2.1 (2030) – without Mpatamanga	Severe Impact	Increasing impact on Flagship VEC habitats due to population increase and basin infrastructure development continues. Continued large scale deforestation from previous period and exacerbates this impact even further. Frequency and magnitude of extreme weather events adds on to this
4.2	Baseline 2.2 (2030) – with Mpatamanga	Severe Impact	Upstream Mpatamanga: Increasing impact Flagship VEC habitats due to population increase and basin infrastructure development continues. Continued large scale deforestation from previous period and exacerbates this impact even further. Frequency and magnitude of extreme weather events add to this. Mpatamanga and SVTP imposes some extra impacts on Flagship VEC habitats in parts of the basin (around Majete WR and Lengwe NP especially, but mitigation of this is proposed in ESIA and BAP studies
5	Near Future 1 (2035) – BAU	Severe Impact	Upstream Mpatamanga: Increasing impact Flagship VEC species due to population increase and basin infrastructure development continues. Continued large scale deforestation from previous period and exacerbates this impact even further. Frequency and magnitude of extreme weather events add to this. Mpatamanga and SVTP imposes some extra impacts on Flagship VEC species in parts of the basin (around Majete WR and Lengwe especially, but mitigation of this is proposed in ESIA and BAP studies)
6	Near Future 2 (2035) – BAU + JDO	Severe Impact (slightly less than Near Future 1 though)	Same as Near Future 2
7	Near Future 3 (2035) – BAU + JDO + CC	Severe Impact (higher than both Near Future 1 and 2 due to CC)	More extreme weather events increase the same impact as outlined in Near Future 2
8.1	Near Future 4 (2035) – SP Step 1	Still severe Impact (but quite lower than the other Near Future	Decreasing impacts of Flagship VEC habitats outside national protected areas, like the Elephant Marsh. Reduced erosion and sediment transport/ supply due to

No	Scenario	VEC Impact score	Comments
		scenarios without catchment restoration)	sustainable pathway (SP) mitigation measures, specifically affecting habitats of important fish and bird species positively (including Elephant Marsh). Elephant Marsh slightly less prone to high and low flows due to large scale catchment restoration. Mpatamanga potentially serves as an extreme weather events regulator to for the downstream Elephant Marsh and reduces sediment supply and siltation affecting it.
8.2	Near Future 4 (2035) – SP Step 1+2	High Impact	Same as SP step 1 but enhancing protected areas management, including in Lengwe NP, reduces impacts on all the four Flagship VEC (but especially Lengwe NP and Elephant Marsh that are less protected than Majete WR and Lilongwe NP)
8.3	Near Future 4 (2035) – SP Step 1+2+3	Moderate Impact	Same as SP step 1+2 but sustainable land use management and energy source transition, reduces impacts natural forests (including in and around Flagship VEC habitats
9	Distant Future (2070) – BAU	Severe Impact	Possible basin collapse and almost doubling of impact score on Flagship VEC habitats compared to Near Future 1
10	Distant Future (2070) – SP Step 1+2+3	Moderate Impact (albeit lower than Near Future 4 scenario)	Continued (compared to Near Future 4 Step 1+2+3) decreasing impacts on Flagship VEC species in and outside protected areas throughout the basin. Mpatamanga potentially serves as an extreme weather events regulator to downstream Flagship VEC species and reduces sediment supply and siltation affecting these

8.3 VEC 3 – Ecosystem Services for Livelihoods

8.3.1 Forest, Woodlands, Riverine, Wetlands and VEC habitats Biodiversity and Resources

Table 8-6 Summary of impacts of each scenario on Forest, Woodlands, Riverine, Wetlands and VEC habitats Biodiversity and Resources (indicators pooled into one group).

No	Scenario	VEC Impact score	Comments
1	Near Natural	Low Impact	Little pressure on these Ecosystem Services for Livelihoods due to low basin population
2.1	Trended Pre-1992	Moderate Impact	Loss of megafauna in this period due to poaching and hunting. Large increase in basin population and agricultural extension increases the impacts on these Ecosystem Services for Livelihood
2.2	Trended 1992-2002	High Impact	Increasing impact on these Ecosystem Services for Livelihoods due to population increase and that basin infrastructure development continues. Large scale deforestation starts and exacerbates this impact.
2.3	Trended 2002-2012	High Impact	Increasing impact on these Ecosystem Services for Livelihoods due to population increase and basin infrastructure development continues. Continued large scale deforestation from previous period and exacerbates this impact even further.
3	Baseline 1 (2023)	High Impact	Increasing impact on these Ecosystem Services for Livelihoods due to population increase and basin infrastructure development continues. Continued large scale deforestation from previous period exacerbates this impact even further. Frequency and magnitude of extreme weather events adds on to this.
4.1	Baseline 2.1 (2030) – without Mpatamanga	Severe Impact	Increasing impact on these Ecosystem Services for Livelihoods due to population increase and basin infrastructure development continues. Continued large scale deforestation from previous period and exacerbates this impact even further. Frequency and magnitude of extreme weather events adds on to this
4.2	Baseline 2.2 (2030) – with Mpatamanga	Severe Impact	Upstream Mpatamanga: Increasing impact these Ecosystem Services for Livelihoods due to population increase and basin infrastructure development continues. Continued large scale deforestation from previous period exacerbates this impact even

No	Scenario	VEC Impact score	Comments
			further. Frequency and magnitude of extreme weather events add to this. Mpatamanga and SVTP imposes some extra impacts on these Ecosystem Services for Livelihoods in parts of the basin, e.g. around Majete WR (Mpatamanga), in and around Lengwe NP (SVTP) and Elephant Marsh (SVTP), but mitigation of this is proposed in their ESIA, BAP and RAP studies.
5	Near Future 1 (2035) – BAU	Severe Impact	Upstream Mpatamanga: Increasing impact these Ecosystem Services for Livelihoods due to population increase and basin infrastructure development continues. Continued large scale deforestation from previous period and exacerbates this impact even further. Frequency and magnitude of extreme weather events add to this. Mpatamanga imposes some extra impacts on these Ecosystem Services for Livelihoods in parts of the basin (around Majete WR especially, but mitigation of this is proposed in ESIA and BAP studies)
6	Near Future 2 (2035) – BAU + JDO	Severe Impact (slightly less than Near Future 1 though)	Same as Near Future 2
7	Near Future 3 (2035) – BAU + JDO + CC	Severe Impact (higher than both Near Future 1 and 2 due to CC)	More extreme weather events increase the same impact as outlined in Near Future 2
8.1	Near Future 4 (2035) – SP Step 1	Still severe Impact (but quite lower than the other Near Future scenarios without catchment restoration)	Decreasing impacts of these Ecosystem Services for Livelihoods outside protected areas. Reduced erosion and sediment transport/ supply due to sustainable pathway (SP) mitigation measures, specifically affecting important fish and bird species, harvested for livelihoods, positively (including in Elephant Marsh). Wetland species, utilised for livelihoods, slightly less prone to high and low flows due to large scale catchment restoration.
8.2	Near Future 4 (2035) – SP Step 1+2	High Impact	Same as SP step 1
8.3	Near Future 4 (2035) – SP Step 1+2+3	Moderate Impact	Same as SP step 1+2 but sustainable land use management and energy source transition, reduces impacts natural forests (including in and around protected areas and henceforth and henceforth these resources used for livelihoods

No	Scenario	VEC Impact score	Comments
9	Distant Future (2070) – BAU	Severe Impact	Possible basin collapse and almost doubling of impact score on these Ecosystem Services for Livelihoods compared to Near Future 1
10	Distant Future (2070) – SP Step 1+2+3	Moderate Impact (albeit lower than Near Future 4 scenario)	Continued (compared to Near Future 4 Step 1+2+3) decreasing impacts on these Ecosystem Services for Livelihoods in and outside protected areas throughout the basin.

8.4 VEC 4 – Productive Land/Soil for Agriculture

8.4.1 Agricultural Land for Crops

Table 8-7 Summary of impacts of each scenario on Agricultural Land for Crops

No	Scenario	VEC Impact score	Comments
1	Near Natural	Low Impact	Little pressure on Agricultural Land for Crops due to low basin population.
2.1	Trended Pre-1992	Low Impact	Large increase in basin population, urbanization and infrastructure development increases the impacts on Agricultural Land for Crops. However, impacts still remains in the low range.
2.2	Trended 1992-2002	Moderate Impact	Increasing impact on these Agricultural Land for Crops due to population increase and that basin infrastructure development continues. Large scale deforestation starts and exacerbates this impact.
2.3	Trended 2002-2012	Moderate Impact	Increasing impact on these Agricultural Land for Crops due to population increase and basin infrastructure development continues. Continued large scale deforestation from previous period and exacerbates this impact even further, but still remains in the moderate range.
3	Baseline 1 (2023)	Moderate Impact	Increasing impact on these Agricultural Land for Crops due to population increase and basin infrastructure development continues. Continued large scale deforestation from previous period exacerbates this impact even further. Frequency and magnitude of extreme weather events adds on to this.
4.1	Baseline 2.1 (2030) – without Mpatamanga	High Impact	Increasing impact on these Agricultural Land for Crops due to population increase and basin infrastructure development continues. Continued large scale deforestation from previous period and exacerbates this impact

No	Scenario	VEC Impact score	Comments
			even further. Frequency and magnitude of extreme weather events adds on to this.
4.2	Baseline 2.2 (2030) – with Mpatamanga	High Impact	Increasing impact on Agricultural Land for Crops due to population increase and basin infrastructure development continues. Continued large scale deforestation from previous period exacerbates this impact even further. Frequency and magnitude of extreme weather events add to this. Mpatamanga imposes some extra impacts on Agricultural Land for Crops in parts of the basin around the dam/reservoir and ancillary infrastructure especially, but mitigation of this is proposed in ESIA and RAP studies. Influx of people due to Mpatamanga, SVTP, MOMA adds on to this.
5	Near Future 1 (2035) – BAU	High Impact	Increasing impact on Agricultural Land for Crops due to population increase and basin infrastructure development continues. Continued large scale deforestation from previous period and exacerbates this impact even further. Frequency and magnitude of extreme weather events add to this. Mpatamanga imposes some extra impacts on Agricultural Land for Crops in parts of the basin around the dam/reservoir and ancillary infrastructure especially, but mitigation of this is proposed in ESIA and RAP studies
6	Near Future 2 (2035) – BAU + JDO	High Impact (slightly less than Near Future 1 though)	Same as Near Future 2
7	Near Future 3 (2035) – BAU + JDO + CC	High Impact (higher than both Near Future 1 and 2 due to CC)	More extreme weather events increase the same impact as outlined in Near Future 2
8.1	Near Future 4 (2035) – SP Step 1	Moderate Impact	Decreasing impacts of Agricultural Land for Crops, due to catchment restoration measures. Agricultural Land for Crops also slightly less prone to high and low flows.
8.2	Near Future 4 (2035) – SP Step 1+2	Moderate Impact	Same as SP step 1
8.3	Near Future 4 (2035) – SP Step 1+2+3	Moderate Impact	Same as SP step 1+2 but sustainable land use management and energy source transition measures, reduces impacts even further.
9	Distant Future (2070) – BAU	Severe Impact	Possible basin collapse and almost doubling of impact score on these Agricultural Land for Crops compared to Near Future 1

No	Scenario	VEC Impact score	Comments
10	Distant Future (2070) – SP Step 1+2+3	Low Impact (albeit lower than Near Future 4 scenario)	Continued (compared to Near Future 4 Step 1+2+3) decreasing impacts on Agricultural Land for Crops throughout the basin.

8.4.2 Rangeland for Livestock

Table 8-8 Summary of impacts of each scenario on Rangeland for Livestock

No	Scenario	VEC Impact score	Comments
1	Near Natural	Low Impact	Little pressure on Rangeland for Livestock due to low basin population.
2.1	Trended Pre-1992	Low Impact	Large increase in basin population, urbanization and infrastructure development increases the impacts on Rangeland for Livestock. However, impacts still remains in the low range.
2.2	Trended 1992-2002	Moderate Impact	Increasing impact on Rangeland for Livestock due to population increase and that basin infrastructure development continues. Large scale deforestation starts and exacerbates this impact.
2.3	Trended 2002-2012	Moderate Impact	Increasing impact on Rangeland for Livestock due to population increase and basin infrastructure development continues. Continued large scale deforestation from previous period and exacerbates this impact even further, but still remains in the moderate range.
3	Baseline 1 (2023)	Moderate Impact	Increasing impact on Rangeland for Livestock due to population increase and basin infrastructure development continues. Continued large scale deforestation from previous period exacerbates this impact even further. Frequency and magnitude of extreme weather events adds on to this.
4.1	Baseline 2.1 (2030) – without Mpatamanga	High Impact	Increasing impact on Rangeland for Livestock due to population increase and basin infrastructure development continues. Continued large scale deforestation from previous period and exacerbates this impact even further. Frequency and magnitude of extreme weather events adds on to this.
4.2	Baseline 2.2 (2030) – with Mpatamanga	High Impact	Increasing impact on Rangeland for Livestock due to population increase and basin infrastructure development continues. Continued large scale deforestation from previous period exacerbates this impact even further. Frequency and magnitude of extreme

No	Scenario	VEC Impact score	Comments
			weather events add to this. Mpatamanga imposes some extra impacts on Rangeland for Livestock in parts of the basin around the dam/reservoir and ancillary infrastructure especially, but mitigation of this is proposed in ESIA and RAP studies. Influx of people due to Mpatamanga, SVTP, MOMA adds on to this.
5	Near Future 1 (2035) – BAU	High Impact	Increasing impact on Rangeland for Livestock due to population increase and basin infrastructure development continues. Continued large scale deforestation from previous period and exacerbates this impact even further. Frequency and magnitude of extreme weather events add to this. Mpatamanga imposes some extra impacts on Rangeland for Livestock in parts of the basin around the dam/reservoir and ancillary infrastructure especially, but mitigation of this is proposed in ESIA and RAP studies
6	Near Future 2 (2035) – BAU + JDO	High Impact (slightly less than Near Future 1 though)	Same as Near Future 2
7	Near Future 3 (2035) – BAU + JDO + CC	High Impact (higher than both Near Future 1 and 2 due to CC)	More extreme weather events increase the same impact as outlined in Near Future 2
8.1	Near Future 4 (2035) – SP Step 1	Moderate Impact	Decreasing impacts on Rangeland for Livestock, due to catchment restoration measures. Rangeland for Livestock also slightly less prone to high and low flows.
8.2	Near Future 4 (2035) – SP Step 1+2	Moderate Impact	Same as SP step 1
8.3	Near Future 4 (2035) – SP Step 1+2+3	Moderate Impact	Same as SP step 1+2 but sustainable land use management and energy source transition measures, reduces impacts even further.
9	Distant Future (2070) – BAU	Severe Impact	Possible basin collapse and almost doubling of impact score on these Rangeland for Livestock compared to Near Future 1
10	Distant Future (2070) – SP Step 1+2+3	Low Impact (albeit lower than Near Future 4 scenario)	Continued (compared to Near Future 4 Step 1+2+3) decreasing impacts on Rangeland for Livestock throughout the basin.

8.5 VEC 5 – Historical, Cultural and Religious Sites

8.5.1 Historical and Pre-Historical Sites

Table 8-9 Summary of impacts of each scenario Historical and Pre-Historical Sites.

No	Scenario	VEC Impact score	Comments
1	Near Natural	Negligible Impact	Little pressure on Historical and Pre-Historical Sites due to low basin population.
2.1	Trended Pre-1992	Low Impact	Large increase in basin population, urbanization and infrastructure development increases the impacts on Historical and Pre-Historical Sites. Impacts moves from negligible to the low range.
2.2	Trended 1992-2002	Low Impact	Increasing impact on Historical and Pre-Historical Sites due to population increase and that basin infrastructure development continues. Large scale deforestation starts and exacerbates this impact.
2.3	Trended 2002-2012	Low Impact	Increasing impact on Historical and Pre-Historical Sites due to population increase and basin infrastructure development continues.
3	Baseline 1 (2023)	Low Impact	Increasing impact on Historical and Pre-Historical Sites due to population increase and basin infrastructure development continues. Frequency and magnitude of extreme weather events adds on to this.
4.1	Baseline 2.1 (2030) – without Mpatamanga	Low Impact	Increasing impact on Historical and Pre-Historical Sites due to population increase and basin infrastructure development continues. Frequency and magnitude of extreme weather events adds on to this.
4.2	Baseline 2.2 (2030) – with Mpatamanga	Moderate Impact	Increasing impact on Historical and Pre-Historical Sites to population increase and basin infrastructure development continues. Frequency and magnitude of extreme weather events add to this. Mpatamanga imposes some extra impacts on Historical and Pre-Historical Sites in parts of the basin around the dam/reservoir and ancillary infrastructure especially, but mitigation of this is proposed in ESIA and RAP studies. Influx of people due to Mpatamanga, SVTP, MOMA adds on to this.
5	Near Future 1 (2035) – BAU	Moderate Impact	Increasing impact on Historical and Pre-Historical Sites due to population increase and basin infrastructure development continues. Frequency and magnitude of extreme weather events add to this.

No	Scenario	VEC Impact score	Comments
			Mpatamanga imposes some extra impacts on Historical and Pre-Historical Sites in parts of the basin around the dam/reservoir and ancillary infrastructure especially, but mitigation of this is proposed in ESIA and RAP studies
6	Near Future 2 (2035) – BAU + JDO	Moderate Impact	Same as Near Future 2
7	Near Future 3 (2035) – BAU + JDO + CC	Moderate Impact (higher than both Near Future 1 and 2 due to CC)	More extreme weather events increase the same impact as outlined in Near Future 2
8.1	Near Future 4 (2035) – SP Step 1	Moderate Impact	Decreasing impacts Historical and Pre-Historical Sites, due to catchment restoration measures.
8.2	Near Future 4 (2035) – SP Step 1+2	Moderate Impact	Same as SP step 1
8.3	Near Future 4 (2035) – SP Step 1+2+3	Low Impact	Same as SP step 1+2 but sustainable land use management and energy source transition measures, reduces impacts even further.
9	Distant Future (2070) – BAU	Severe Impact	Possible basin collapse and almost doubling of impact score on these Historical and Pre-Historical Sites compared to Near Future 1
10	Distant Future (2070) – SP Step 1+2+3	Low Impact (albeit lower than Near Future 4 scenario)	Continued (compared to Near Future 4 Step 1+2+3) decreasing impacts on Historical and Pre-Historical Sites throughout the basin.

8.5.2 Cultural and Religious Sites

Table 8-10 Summary of impacts of each scenario on Cultural and Religious Sites.

No	Scenario	VEC Impact score	Comments
1	Near Natural	Negligible Impact	Little pressure on Cultural and Religious Sites due to low basin population.
2.1	Trended Pre-1992	Low Impact	Large increase in basin population, urbanization and infrastructure development increases the impacts on Cultural and Religious Sites. Impacts moves from negligible to the low range.
2.2	Trended 1992-2002	Low Impact	Increasing impact on Cultural and Religious Sites due to population increase and that basin infrastructure development continues. Large scale deforestation starts and exacerbates this impact.
2.3	Trended 2002-2012	Low Impact	Increasing impact on Cultural and Religious Sites due to population increase and basin infrastructure development continues.

No	Scenario	VEC Impact score	Comments
3	Baseline 1 (2023)	Low Impact	Increasing impact on Cultural and Religious Sites due to population increase and basin infrastructure development continues. Frequency and magnitude of extreme weather events adds on to this.
4.1	Baseline 2.1 (2030) – without Mpatamanga	Low Impact	Increasing impact on Cultural and Religious Sites due to population increase and basin infrastructure development continues. Frequency and magnitude of extreme weather events adds on to this.
4.2	Baseline 2.2 (2030) – with Mpatamanga	Moderate Impact	Increasing impact on Cultural and Religious Sites to population increase and basin infrastructure development continues. Frequency and magnitude of extreme weather events add to this. Mpatamanga imposes some extra impacts on Historical and Pre-Historical Sites in parts of the basin around the dam/reservoir and ancillary infrastructure especially, but mitigation of this is proposed in ESIA and RAP studies. Influx of people due to Mpatamanga, SVTP, MOMA adds on to this.
5	Near Future 1 (2035) – BAU	Moderate Impact	Increasing impact on Cultural and Religious Sites due to population increase and basin infrastructure development continues. Frequency and magnitude of extreme weather events add to this. Mpatamanga imposes some extra impacts on Historical and Pre-Historical Sites in parts of the basin around the dam/reservoir and ancillary infrastructure especially, but mitigation of this is proposed in ESIA and RAP studies
6	Near Future 2 (2035) – BAU + JDO	Moderate Impact	Same as Near Future 2
7	Near Future 3 (2035) – BAU + JDO + CC	Moderate Impact (higher than both Near Future 1 and 2 due to CC)	More extreme weather events increase the same impact as outlined in Near Future 2
8.1	Near Future 4 (2035) – SP Step 1	Moderate Impact	Decreasing impacts Cultural and Religious Sites, due to catchment restoration measures.
8.2	Near Future 4 (2035) – SP Step 1+2	Moderate Impact	Same as SP step 1
8.3	Near Future 4 (2035) – SP Step 1+2+3	Low Impact	Same as SP step 1+2 but sustainable land use management and energy source transition measures, reduces impacts even further.

No	Scenario	VEC Impact score	Comments
9	Distant Future (2070) – BAU	Severe Impact	Possible basin collapse and almost doubling of impact score on these Cultural and Religious Sites compared to Near Future 1
10	Distant Future (2070) – SP Step 1+2+3	Low Impact (albeit lower than Near Future 4 scenario)	Continued (compared to Near Future 4 Step 1+2+3) decreasing impacts on Historical and Pre-Historical Sites throughout the basin.

8.6 VEC 6 – Tourism and Social Services

8.6.1 Eco- and Wildlife Tourism

Table 8-11 Summary of impacts of each scenario Tourism and Social Services.

No	Scenario	VEC Impact score	Comments
1	Near Natural	Negligible Impact	Eco- and Wildlife Tourism rarely developed.
2.1	Trended Pre-1992	Moderate Impact	Loss of megafauna in this period due to poaching and hunting. Eco- and Wildlife Tourism takes form but still not very well developed. In the 1980 Majete WR suffered from severe poaching and deforestation though ⁴⁰
2.2	Trended 1992-2002	Moderate Impact	Increasing impact on Eco- and Wildlife Tourism due to basin infrastructure development. Large scale basin deforestation starts and impacts the quality Eco- and Wildlife Tourism.
2.3	Trended 2002-2012	Moderate Impact	Increasing impact on Eco- and Wildlife Tourism due to basin infrastructure development. Majete WR and Liwonde National Parks under better protection, but increased pressure on and further degradation of Lengwe NP and Elephant Marsh.
3	Baseline 1 (2023)	Moderate Impact	Increasing impact on Eco- and Wildlife Tourism due to and basin infrastructure development continues (SVTP canal impacts Majete WR). Continued large scale deforestation from previous period affects quality of Eco- and Wildlife Tourism (for example the deforestation of Lengwe NP). Frequency and magnitude of extreme weather events adds on to this.
4.1	Baseline 2.1 (2030) – without Mpatamanga	Moderate Impact	Increasing impact on Eco- and Wildlife Tourism due to population increase and basin infrastructure development continues. Continued large scale deforestation from

⁴⁰ <https://worldnationalparks.com/national-parks-of-malawi/>

No	Scenario	VEC Impact score	Comments
			previous period affects quality of Eco- and Wildlife Tourism (for example the deforestation of Lengwe NP). Frequency and magnitude of extreme weather events adds on to this.
4.2	Baseline 2.2 (2030) – with Mpatamanga	Moderate Impact	Increasing impact on Eco- and Wildlife Tourism due to population increase and basin infrastructure development continues. Continued large scale deforestation from previous period affects quality of Eco- and Wildlife Tourism (for example the deforestation of Lengwe NP). Frequency and magnitude of extreme weather events adds on to this. Mpatamanga (together with Kapichira and SVTP) imposes some extra impacts on Eco- and Wildlife Tourism around Majete WR especially, but mitigation of this is proposed in ESIA and BAP studies.
5	Near Future 1 (2035) – BAU	Moderate Impact	Increasing impact on Eco- and Wildlife Tourism due to population increase and basin infrastructure development. Continued large scale deforestation from previous period affects quality of Eco- and Wildlife Tourism (for example the deforestation of Lengwe NP). Frequency and magnitude of extreme weather events adds on to this. Mpatamanga (together with Kapichira and SVTP) imposes some extra impacts on Eco- and Wildlife Tourism around Majete WR especially, but mitigation of this is proposed in ESIA and BAP studies.
6	Near Future 2 (2035) – BAU + JDO	Moderate Impact (slightly less than Near Future 1 though)	Same as Near Future 2
7	Near Future 3 (2035) – BAU + JDO + CC	High Impact (higher than both Near Future 1 and 2 due to CC)	More extreme weather events increase the same impact as outlined in Near Future 2
8.1	Near Future 4 (2035) – SP Step 1	Moderate Impact (but quite lower than the other Near Future scenarios without catchment restoration)	Decreasing impacts on Eco- and Wildlife Tourism, due to catchment restoration measures (for example the catchments of Lengwe NP)
8.2	Near Future 4 (2035) – SP Step 1+2	Moderate Impact	Quite marked decrease in impact due to implementation of measures for Tourism and Protected Areas management (almost down to the low range).

No	Scenario	VEC Impact score	Comments
8.3	Near Future 4 (2035) – SP Step 1+2+3	Low Impact	Same as SP step 1+2 but sustainable land use management and energy source transition, reduces impacts natural forests, including in and around protected areas like Majete and Lengwe as well as on wetland ecosystems like Elephant Marsh. Henceforth, this positively affects Eco- and Wildlife Tourism.
9	Distant Future (2070) – BAU	Severe Impact	Possible basin collapse and almost doubling of impact score on Eco- and Wildlife Tourism compared to Near Future 1
10	Distant Future (2070) – SP Step 1+2+3	Low Impact (albeit lower than Near Future 4 scenario)	Continued (compared to Near Future 4 Step 1+2+3) decreasing impacts on Eco- and Wildlife Tourism in and outside protected areas throughout the basin.

8.6.2 Historical and Cultural Tourism

Table 8-12 Summary of impacts of each scenario

No	Scenario	VEC Impact score	Comments
1	Near Natural	Negligible Impact	Historical and Cultural Tourism sparsely developed, exempt some early explorers.
2.1	Trended Pre-1992	Low Impact	Increasing impact on Historical and Cultural Tourism due to basin infrastructure development
2.2	Trended 1992-2002	Low Impact	Increasing impact on Historical and Cultural Tourism due to basin infrastructure development.
2.3	Trended 2002-2012	Moderate Impact	Continued increased impact on Historical and Cultural Tourism due to basin infrastructure development.
3	Baseline 1 (2023)	Moderate Impact	Continued increased impact on Historical and Cultural Tourism due to basin infrastructure development.
4.1	Baseline 2.1 (2030) – without Mpatamanga	Moderate Impact	Continued increased impact on Historical and Cultural Tourism due to basin infrastructure development.
4.2	Baseline 2.2 (2030) – with Mpatamanga	Moderate Impact	Increasing impact on Historical and Cultural Tourism due to population increase and basin infrastructure development continues. Frequency and magnitude of extreme weather events adds on to this. Mpatamanga (together with Kapichira and SVTP) imposes some extra impacts on Historical and Cultural Tourism sites in vicinity of these structures.
5	Near Future 1 (2035) – BAU	Moderate Impact	Increasing impact on Historical and Cultural Tourism due to population increase and basin infrastructure development. Frequency and

No	Scenario	VEC Impact score	Comments
			magnitude of extreme weather events adds on to this. Mpatamanga (together with Kapichira and SVTP) imposes some extra impacts on Historical and Cultural Tourism sites in vicinity of these structures.
6	Near Future 2 (2035) – BAU + JDO	Moderate Impact (slightly less than Near Future 1 though)	Same as Near Future 2
7	Near Future 3 (2035) – BAU + JDO + CC	High Impact (higher than both Near Future 1 and 2 due to CC)	More extreme weather events increase the same impact as outlined in Near Future 2
8.1	Near Future 4 (2035) – SP Step 1	Moderate Impact (but quite lower than the other Near Future scenarios without catchment restoration)	Decreasing impacts Historical and Cultural Tourism, due to catchment restoration measures
8.2	Near Future 4 (2035) – SP Step 1+2	Moderate Impact	Tourism and protected areas measures also positively affects some historical and cultural sites.
8.3	Near Future 4 (2035) – SP Step 1+2+3	Low Impact	Same as SP step 1+2 but sustainable land use management and energy source transition, reduces impacts on historical and cultural sites connected to natural forests areas, including in and around protected areas like Majete WR and Lengwe NP. Henceforth, this positively affects Historical and Cultural Tourism.
9	Distant Future (2070) – BAU	Severe Impact	Possible basin collapse and almost doubling of impact score on Historical and Cultural Tourism compared to Near Future 1
10	Distant Future (2070) – SP Step 1+2+3	Low Impact (albeit lower than Near Future 4 scenario)	Continued (compared to Near Future 4 Step 1+2+3) decreasing impacts on Historical and Cultural Tourism in and outside protected areas throughout the basin.

8.6.3 Education and Health Services and Infrastructure

Table 8-13 Summary of impacts of each scenario on Education and Health Services and Infrastructure.

No	Scenario	VEC Impact score	Comments
1	Near Natural	Negligible Impact	Meagre education and health services in the basin.
2.1	Trended Pre-1992	Low Impact	Quality and amount of education and health services increases over the century. Infrastructure development positively contributes to this.
2.2	Trended 1992-2002	Low Impact	Same as previous period.
2.3	Trended 2002-2012	Low Impact	Same as previous period.

No	Scenario	VEC Impact score	Comments
3	Baseline 1 (2023)	Moderate Impact	Same as previous period, but the frequency and magnitude of extreme weather events (cyclone and flooding) increases impacts on education and health services (including its infrastructure).
4.1	Baseline 2.1 (2030) – without Mpatamanga	Moderate Impact	Continued increased impact on Education and Health Services frequency and magnitude of extreme weather events.
4.2	Baseline 2.2 (2030) – with Mpatamanga	Moderate Impact	Continued increased impact on Education and health services frequency and magnitude of extreme weather events. Mpatamanga contributes positively though through its implementation of education and health measures ⁴¹ .
5	Near Future 1 (2035) – BAU	Moderate Impact	Continued increased impact on Education and Health Services frequency and magnitude of extreme weather events. Mpatamanga contributes positively though through its implementation of education and health measures.
6	Near Future 2 (2035) – BAU + JDO	Moderate Impact (slightly less than Near Future 1 though)	Same as Near Future 2
7	Near Future 3 (2035) – BAU + JDO + CC	High Impact (higher than both Near Future 1 and 2 due to CC)	Even more extreme weather events increase the same impact as outlined in Near Future 2
8.1	Near Future 4 (2035) – SP Step 1	Moderate Impact (but quite lower than the other Near Future scenarios without catchment restoration)	Catchment restoration measure possibly reduce magnitude and frequency of flash floods and henceforth can have a positive impact on Education and Health Services and its infrastructure.
8.2	Near Future 4 (2035) – SP Step 1+2	Moderate Impact	Tourism and protected areas measures also can positively affects some Education and Health Services (especially education related to the protected areas, like for example in Majete WR).
8.3	Near Future 4 (2035) – SP Step 1+2+3	Low Impact	Same as SP step 1 and sustainable land use management and energy source transition, brings catchment restoration and reforestation even further, henceforth reduces the magnitude and frequency of flash floods even further and thus have a positive

⁴¹ This might depend on the level of influx and the capacity of Mpatamanga education and health measures to handle the additional demand. If the capacity of the latter is of low the positive measures may not evidently be realized in general. While Mpatamanga plans to include these measure, other development projects will also need to include similar measures to cumulatively mitigate the possible impacts.

No	Scenario	VEC Impact score	Comments
			impact on Education and Health Services and its infrastructure.
9	Distant Future (2070) – BAU	Severe Impact	Possible basin collapse and almost doubling of impact score on Education and Health Services compared to Near Future 1
10	Distant Future (2070) – SP Step 1+2+3	Low Impact (albeit lower than Near Future 4 scenario)	Continued (compared to Near Future 4 Step 1+2+3) decreasing impacts on Education and Health Services.

8.7 Summary of Impacts and Mitigation Options of All Scenarios

A summary of main scenario results with regards to impacts on VECs is outlined below. The prioritised VECs studied for all scenarios, through a cause-and-effect impact pathway, from drivers/causes via stressors/primary impacts and secondary impacts, include the following main VEC groups (each supported by a prioritised set of VEC indicators):

- Reliable water availability and quality (WAQ)
- Biodiversity and habitats for wildlife, birds and aquatic life (VEC species and habitats, VEC-SH)
- Ecosystem services for livelihoods (ESL)
- Productive land/soil for agriculture (PLA)
- Historical, cultural and religious sites (HCR)
- Tourism and social services (TSS)

Near natural (Early 1900): Characterised by a largely pristine and unmodified Shire River Basin with largely intact forest, terrestrial and riverine ecosystems. Impacts on VECs are minor or absent.

Trended past: Pre-1992: Stark population increase in this period and infrastructure development in the basin including HPPs/dams. Agricultural expansion. Deforestation starts to take place, especially in second half of the period. Impact on VECs increases to moderate impacts on (i) biodiversity and habitats for wildlife, birds and aquatic life and (ii) ecosystem services for livelihood, whilst the four other VECs is considered to be in the low impact range. Between 1992-2002 and 2002-2022 population increases considerably. There is widespread deforestation and land use change in the basin, the main cause being charcoal/woodfuel extraction and agricultural expansion. More extreme weather events occur in the second half of 2002-2022 period, due to climate change. More infrastructure comes online including HPPs, transmission lines, roads etc. Bigger pressure and is imposed. The cumulative impact on the VECs rises considerably over both periods, and we see high impacts on WAQ, VEC-SH, ESL and moderate impacts on PLA and TSS in 2022.

Baseline 1 (2023): Same as end of 2002-2023 period.

Baseline 2 (with and without Mpatamanga HPP, 2030): Population growth and agricultural expansion/deforestation continue. Deforestation and extreme weather events remain the most prominent stressors to the basin. Adding Mpatamanga has more local than basin wide effects on the VECs with its resulting influx of people assessed to be the most prominent resulting basin related stressor. Both with and

without Mpatamanga, the impacts on the VECs rise to severe for VEC-SH and ESL and WAQ to high. There is just a slight increase in impact on all VECs at basin scale with Mpatamanga in place.

Near Future Scenarios 1, 2 and 3 (2035): This set constitutes the BAU, BAU + JDO and BAU + JDO + CC. Basin degradation continues and the impact profile in the impact pathway towards the VECs is quite similar, especially between Near Future 1 and 2 (only a slight decrease on VEC impacts due to JDO, but with an increase again when adding climate change. Impacts on the three VEC groups WAQ, VEC-SH and are estimated to become severe, while PLA high and the two last to be moderate.

Near Future 4 – Sustainable Pathway (2035): This is the recommended basin development scenario and what it constitutes of measures is shortly summarised in footnote 2. With these catchment scale measures in place we estimate a reduction in magnitude of the impacts from especially (i) charcoal/firewood production and encroachment into forested areas and (ii) agricultural and industrial practices has a knock-on effect on many of the stressors/primary impact and secondary impacts, leading to reduction of impacts on all VEC groups compared to Near Future 1, 2 and 3 Scenarios. Impacts are lowered to moderate (4 of the VEC groups) or low (2 of the VEC groups).

Distant Future (2070): This scenario set constitutes the BAU for 2070 (Distant Future 1), which is similar to Near Future 1 (2035) but with further basin degradation and more extreme weather events due to climate change, and the Sustainable Pathway Scenario for 2070 (Distant Future 2) with continued basin restoration and reforestation as of Near Future 4 scenario. For the Near Future 1 scenario, the magnitude of almost all impact pathways becomes more prominent eventually leading to severe impact scores on all VEC groups. Hence, we are probably witnessing a basin collapse or transition into a completely different state of the basin, if no large-scale restoration, reforestation and other mitigation measures is not implemented. On the other hand, if the steps in the sustainable pathways continue to be implemented up to 2070, the basin health and impacts on the VECs is considerably reduced. Only continued climate change remains somehow prominent. Impacts on all VEC groups are considerably lowered and is even lower than for Near Future 4, due to the continued restoration, reforestation and other mitigation measures. Three of the VEC groups are in the moderate impact range and the remaining three in the low impact range.

An overall summary diagram on impact on each VEC group, for each scenario, is given in Table 8-14 overleaf.

Table 8-14 Summary VEC impact table for all scenarios.

VEC	Without Mpatamanga HPP							With Mpatamanga HPP						
	Near natural and historical scenarios				Baseline scenarios			Near Future				Distant Future		
	Early 1900s	Pre-1992	1922-2002	2002-2022	2023	2030	2030	2035				2070		
								BAU	BAU+JDO	BAU+JDO+CC	SP+JDO+CC	BAU	SP+JDO+CC	
Reliable water availability and quality	Low Impact	Low Impact	Moderate Impact	High Impact	High Impact	High Impact	High Impact	Severe Impact	Severe Impact	Severe Impact	Moderate Impact	Severe Impact	Moderate Impact	
Biodiversity and habitats	Low Impact	Moderate Impact	High Impact	High Impact	High Impact	Severe Impact	Severe Impact	Severe Impact	Severe Impact	Severe Impact	Moderate Impact	Severe Impact	Moderate Impact	
Ecosystem services for livelihoods	Low Impact	Moderate Impact	High Impact	High Impact	High Impact	Severe Impact	Severe Impact	Severe Impact	Severe Impact	Severe Impact	Moderate Impact	Severe Impact	Moderate Impact	
Productive land/soil for agriculture	Low Impact	Low Impact	Moderate Impact	Moderate Impact	Moderate Impact	Moderate Impact	Moderate Impact	High Impact	High Impact	High Impact	Moderate Impact	Severe Impact	Low Impact	
Historical, cultural and religious sites	Insignificant Impact	Low Impact	Low Impact	Low Impact	Low Impact	Low Impact	Moderate Impact	Moderate Impact	Moderate Impact	Moderate Impact	Low Impact	Severe Impact	Low Impact	
Tourism and social services	Insignificant Impact	Low Impact	Low Impact	Moderate Impact	Moderate Impact	Moderate Impact	Moderate Impact	Moderate Impact	Moderate Impact	Moderate Impact	Low Impact	Severe Impact	Low Impact	

Main recommendations for cumulative mitigation measures

The recommendations from the CIA for further basin development and management of the Shire Basin are largely embedded in the sustainable pathway scenarios and the measures embedded in those. A set of catchment scale mitigation measures has been developed (see Chapter 10.2.2 for more details). Most of these go beyond the responsibility of MHPL and is rather the main responsibility of GoM, e.g. (i) catchment rehabilitation that includes rehabilitation/reforestation of targeted erosion hotspot areas, (ii) enhancing tourism and protected areas management of protected areas, and (iii) sustainable land use enhancement and energy source transition.

The recommended measures specifically relevant for Mpatamanga HPP/MHPL are (i) implement/enhance joint operation of Shire River dams (ii) implement a Co-Management Platform for Shire (especially for the water users), and (iii) payment for ecosystem services (PES) for the rehabilitation/reforestation of erosion hotspots in the Lisungwe catchment (that drains into the main reservoir).

9 CIA TRANSBOUNDARY IMPACT ASSESSMENT

9.1 Introduction

The Shire River is a tributary to the Zambezi River, and thus part of the Zambezi River Basin which is shared by eight countries: Angola, Namibia, Botswana, Zambia, Zimbabwe, Tanzania, Malawi, and Mozambique.

The main strategic issues faced in the Zambezi River Basin are similar to that of Shire, e.g. achieving the balance between economic growth (inclusive of ensuring environmental sustainability) and the risk of ever-increasing droughts and floods posed by a historical variable climate, a risk that over the recent decade has increased and is predicted to be further exacerbated in the near and distant future. As for Shire, poverty and poverty-induced degradation of Zambezi River Basin is the biggest treats to livelihoods, the ecosystems and future development and management of the basin. An important cause/driver to this degradation is charcoal/firewood production and encroachment into forested area. As for Shire River Basin, this degradation is likely to intensify unless a concerted effort to improve the livelihoods of a major part of the Zambezi River Basin population. Poverty induced degradation has resulted in 51% of land in the basin becoming moderately degraded and 14% highly degraded (ZAMCOM 2019). Sustainable pathway development as recommended for Shire River Basin in the CIA for Mpatamanga HPP is therefore also needed for the whole Zambezi through joint effort of basin governments and henceforth this will be spearheaded by the Zambezi Watercourse Commission (ZAMCOM).

Over the past 60 years, a number of large dams have been constructed in the basin, including the Kariba and Cahora Bassa dams. Although Mpatamanga HPP is not in the range of these giant dams and power stations it can also be considered relatively large. There are plans for coordinated operation of the dams in the whole basin, e.g. dam synchronisation for flood releases and storage in drought period. Kamuzu Barrage which regulates Lake Malawi levels and Mpatamanga HPP as the major storage/regulating facility on the Shire are important infrastructures in this sense, also since the Lake Malawi/Shire system is the lowermost major tributary to join Zambezi before it reaches the Zambezi Delta. The Shire River Basin also contributes to approximately 12% of the mean annual discharge to Zambezi at the delta (SADC 2011).

9.2 Transboundary Impact Assessment

Upstream of MHSP, Tanzania and Mozambique, together with Malawi, have tributaries joining Lake Malawi, which outflow create the Shire River. The Shire River enters into Mozambique and joins the Zambezi, downstream of the Cahora Bassa Dam, and close to the Zambezi delta before it reaches the Indian Ocean. The construction and operation of Mpatamanga HPP is anticipated to have negligible impact on neighbouring countries and the Zambezi River. One of the pre-requisites for design of the Mpatamanga Project has been that downstream flows should not be altered due to protection of the Majete Wildlife Reserve, and henceforth, there are minimal impacts on flows where Shire enters Mozambique and further down to the Zambezi confluence. However, through the reservoir created by the main dam (19 km²) there is theoretically an impact of evaporation creating a net loss and a hindrance of sediment transport. The loss of evaporation is estimated at approximately 1.1 m³/s, which is 0.03% of the outflow in Zambezi delta of 4,134 m³/s. Sediment outflow from Shire River to Mozambique and Zambezi is mainly governed by the function of the Elephant and Ndindi Marshes⁴², which are downstream of Mpatamanga, and therefore also construction and

⁴² Ndindi Marsh is situated downstream of Elephant Marsh close to the border of Mozambique. It has a size of 80 000 hectares, whilst the Elephant Marsh is 60 000 hectares. It is reported to be less modified and more intact (SADC 2011).

operation of the Mpatamanga HPP is anticipated to have negligible impact of sediment transport at basin scale and to the Zambezi and subsequently the Zambezi Delta.

These conditions are anticipated to prevail for the Near Future (2035), especially if further Shire Basin developments follow the recommended Sustainable Pathway scenario (Near Future 4) of the CIA. However, if further basin degradation continues⁴³, i.e. not following the sustainable pathway, the regulating ability⁴⁴ of these marshes will decrease and it is uncertain when it reaches a tipping point and eventually collapse (with its knock-on effects on biodiversity, fisheries and livelihoods etc.), which may also have transboundary implications. This will especially be the case if not following the sustainable pathway for Distant Future (Distant Future 1), where the CIA predicts a possible Shire Basin collapse. In the case of following the sustainable pathway for the Distant Future (Distant Future 2), this will however be prevented.

Climate change, with extreme weather events, will prevail and be on the increase for the near and especially distant future, but Mpatamanga HPP with its storage and regulating ability can help build in climate change resilience in the system of dams of the Zambezi watercourse. There is also a ZAMCOM-led collaboration for synchronisation of operational activities of these dams also with the goal to reduce impacts of climate change and extreme weather events. Long-term sustainable pathway planning with regards to this will henceforth be needed to adapt to the actual changes of the climate. There are also some climate change predictions for the distant future, from the FocusAfrica study, with an anticipated drop in Lake Malawi levels, with transboundary impacts on the riparian countries around the lake. Kamuzu Barrage can to some extent help to mitigate this, but not if the lake level drops below its regulating range.

9.3 Mpatamanga/ZAMCOM Arrangements

The level of collaboration between Malawi and Mozambique on water issues is currently limited. At a broader Zambezi Basin level, Malawi and Mozambique cooperate within the framework of the Southern African Development Community (SADC) Water Resources Technical Committee. Some cooperation is also achieved through the Zambezi Watercourse Commission (ZAMCOM), of which Angola, Botswana, Mozambique, Namibia, Tanzania, Zambia and Zimbabwe are member states. Malawi has not yet ratified this agreement, but nonetheless participates as an observer (IWMI 2015).

Following the procedures for ZAMCOM, Malawi sent a preliminary notification to ZAMCOM on June 30, 2023, including an overview of the Mpatamanga Project. In June 2024, no responses had been received from any of the riparian countries through ZAMCOM based on this notification. The Technical Notification to ZAMCOM, including the technical design and the 2024 ESIA, will be submitted to ZAMCOM in September 2024 as per procedures. In addition, GoM has agreed to send bi-lateral notifications to the seven riparian countries to meet the World Bank OP7.50 requirements before negotiations. Notifications are planned to be sent out in mid-2024 with a 30-days response time for the riparian countries to respond with any objections. A legal covenant will ensure that the ZAMCOM procedure is fulfilled, should there be any responses on the Technical Notification, before start of main works planned for November 2025.

⁴³ With charcoal/firewood extraction and encroachment into forested areas (including the marshes) as the main cause/driver

⁴⁴ Flow-, sediment transport- and nutrient cycling regulation etc.

10 CUMULATIVE IMPACTS MANAGEMENT MEASURES AND PLANS

10.1 Mitigation Hierarchy Approach

Measures to mitigate impacts of hydropower and other infrastructure and basin developments, as elaborated in Chapter 8 and 9, can include a combination of measures that may be classified into four main categories of action: **avoid, minimise, restore, and offset**—known as the mitigation hierarchy (IFC, 2021). The mitigation hierarchy is a widely used tool that guides users towards limiting as far as possible the negative impacts on environment and human well-being from development projects. It emphasises best-practice of avoiding and minimising any negative impacts, and then restoring sites no longer used by a project, before finally considering offsetting residual impacts (adapted from IFC 2021 and TBC 2015⁴⁵, but tailored to the CIA of Mpatamanga HPP on the Shire River Basin).

- **Avoidance** through choices about project selection, location/site selection, engineering designs, and operating practices. Avoidance is often the easiest, cheapest and most effective way of reducing potential negative impacts, but it requires environmental and societal impacts to be considered in the very early stages of a project or a portfolio of projects.
- **Minimisation** through measures taken to reduce the duration, intensity and/or extent of impacts that cannot be completely avoided. Effective minimisation can eliminate some negative impacts, such as measures to reduce noise and pollution, designing powerlines to reduce the likelihood of bird electrocutions, or building wildlife crossings on roads. Minimisation can also include provision of environmental flows (EFlows), fish passages (not relevant for Mpatamanga), and sediment flushing facilities.
- **Restoration/rehabilitation** through the aim of improving degraded or removed ecosystems or habitats following exposure to impacts that cannot be completely avoided or minimised in the basin/sub-basins and by restoring livelihoods and incomes of affected and resettled communities.

Collectively, avoidance, minimisation and rehabilitation/restoration serve to reduce, as far as possible, the residual impacts that a project (or as for this CIA a portfolio of projects and developments) has on the environment, livelihoods, incomes, etc.

- **Offset or compensate:** Offsetting aims to compensate for any residual, adverse impacts after full implementation of the previous three steps of the mitigation hierarchy and is most often linked to biodiversity. Biodiversity offsets are of two main types: ‘restoration offsets’ which aim to rehabilitate or restore degraded habitat, and ‘averted loss offsets’ which aim to reduce or stop biodiversity loss in areas where this is predicted. Offsets are often complex and expensive, so attention to earlier steps in the mitigation hierarchy is usually preferable. In the case of social impacts this refers to compensation for loss of livelihoods or resettlement.

A guiding principle of impact mitigation is that avoidance and minimisation are preferred over restoration and offsetting, as opportunities to mitigate impacts and enhance benefits of hydropower are greater at earlier stages of project development. For example, impacts can be avoided during the creation of a basin, regional, or national master plan when decisions about prioritisation and siting of which infrastructure

⁴⁵ TBC. 2015. *A cross-sector guide for implementing the Mitigation Hierarchy*.

projects (HPPs, irrigation etc.) are made. During project feasibility studies, impacts can also be avoided and minimised by adjusting location, dam height, reservoir size, and other design parameters. During subsequent phases (detailed design, construction, and operation), mitigation options are largely restricted to compensatory measures (restoration and offsetting). Opportunities to mitigate environmental and social impacts in projects already built or under construction are limited. The main physical features of the project (dam, reservoir, powerhouse, and transmission lines, canal lining) cannot be modified much. However, for hydropower projects, operating rules (including those of EFlows) can be changed to reduce environmental and social impacts, but often these rules tend to be rigidly defined in power purchase agreements. Therefore, addressing cumulative hydropower risks and impacts on the Shire River Basin (together with other developments in the basin) requires applying the mitigation hierarchy throughout the hydropower development cycle, with a particular focus on planning at the basin and sub-basin scale (as core to this CIA).



Figure 10-1 The mitigation hierarchy: Avoid, minimise, restore, offset (from TBC, 2015).

10.2 Identified CIA Mitigation Measures including Institutional Roles and Preliminary Costing

10.2.1 Project Level CIA Relevant Mitigation Measures Extracted from other Studies

10.2.1.1 Mpatamanga HPP

The mitigation measures and the monitoring plans for Mpatamanga HPP have been extensively studied and reported in the Mpatamanga ESIA (SLR 2024a), the RAP (SLR 2024b) and the BAP and are not repeated here. Reference is made to those studies in this regard. We have assumed, in doing the CIA, that the ESIA/RAP/BAP measures will be implemented. And in some cases, a few of these are embedded within the CIA measures. Catchment scale mitigation measures have also been provided to the ESIA, from this CIA report.

10.2.1.2 Other HPPs and Infrastructure Development

Project level mitigation measures that are CIA VEC relevant have been assessed for the Kamuzu Barrage, Nkula-Tedzani-Kapichira HPPs, SVTP and MOMA. The assessment also includes benefits assessment of the proposed measures, role of institutions and relevant regulations. A summary of this is given in Table 11-1

Table 10-1 Project Level – CIA/VEC relevant measures solely.

No	Mitigation Measure ⁴⁶	Key Risks and Impacts ⁴⁷	Expected Outcomes	Parties Responsible for Implementation	Relevant Regulatory Framework	Preliminary costing of measure (Responsible unit)	Reference source if relevant
Project Level – CIA/VEC relevant measures solely							
Kamuzu Barrage							
1	Joint Operation of Shire River Dams (see also CIA catchment scale mitigation measure 1 in Table 11-2): Optimize releases from Kamuzu Barrage to the HPPs and Water Users. Update of the KABOM tool for this usage. Also update the rating curve for Kamuzu Barrage	<ul style="list-style-type: none"> - Flood and drought risks - Sub-optimal power generation outputs 	<ul style="list-style-type: none"> - Coordinated flood monitoring and warnings - Optimization of power generation across HPPs in the basin - Irrigation and Water Supply demands met 	NWRA	Water Resources Regulations (2018), Water Resources Act (2013)	Part of the release strategy (ies) of Kamuzu Barrage (Responsible NWRA). Connected to mitigation measure 1 on joint operation.	NORPLAN. 2015. Consultancy Services Related to Financial and Institutional Aspects of the Kamuzu Barrage Management. SRBMP Phase 1.
Nkula and Tedzani HPP							
2	Coordinated operation with other dams for power optimization and flood releases	<ul style="list-style-type: none"> - Flood and drought risks - Sub-optimal power generation outputs 	<ul style="list-style-type: none"> - Coordinated flood monitoring and warnings - Optimization of power generation across HPPs in the basin 	EGENCO	Water Resources Regulations (2018), Water Resources Act (2013)	Part of the dams operation (Responsible EGENCO)	
3	Coordinated EFlows releases with other dams	<ul style="list-style-type: none"> - EFlows requirements in important (triggering) periods are not met. 	<ul style="list-style-type: none"> - Synchronization of EFlows for water uses, livelihoods and riverine ecology 	EGENCO	Water Resources Regulations (2018), Water Resources Act (2013)	Part of the dams operation (Responsible EGENCO)	
Kapichira HPP							

⁴⁶ These project level measures respond to risks and impacts also identified at catchment level, and can for the various development projects collectively mitigate cumulative impacts.

⁴⁷ The risks and impacts here is taken from other studies, and do not necessarily correspond fully to the primary and secondary impacts in the CIA study,

No	Mitigation Measure ⁴⁶	Key Risks and Impacts ⁴⁷	Expected Outcomes	Parties Responsible for Implementation	Relevant Regulatory Framework	Preliminary costing of measure (Responsible unit)	Reference source if relevant
4	Coordinated operation with other dams for power optimization and flood releases	<ul style="list-style-type: none"> - Flood and drought risks - Sub-optimal power generation outputs 	<ul style="list-style-type: none"> - Coordinated flood monitoring and warnings - Optimization of power generation across HPPs in the basin 	EGENCO	Water Resources Regulations (2018), Water Resources Act (2013)	Part of the dams operation (Responsible EGENCO)	
5	Coordinated EFlows releases with other dams. Securing EFlows releases meet riverine ecology and livelihoods requirements to Shire downstream areas, including Elephant Marsh	<ul style="list-style-type: none"> - EFlows requirements in important (triggering) periods are not met 	<ul style="list-style-type: none"> - Synchronization of EFlows for water uses, livelihoods and riverine ecology, including Elephant Marsh 	EGENCO	Water Resources Regulations (2018), Water Resources Act (2013)	Part of the dams operation (Responsible EGENCO)	Rapid CIA 2022 by Southern Waters
6	General disturbance to wildlife mitigation: (i) Prohibit establishment of workers' camps within Majete Wildlife Reserve (parts already taken and fenced for the Kapichira Rehabilitation) (ii) Prohibit contractor and workers so as not to hunt, kill, capture or trap any wildlife or bird at the project sites and vicinity; (iii) Ensure regular and proper servicing of machinery and vehicles to reduce the impact of noise; (iv) Ensure that no construction takes place at night in the protected areas; and (v)	<ul style="list-style-type: none"> - Civil works have potential to disturb wildlife especially within Majete Wildlife Reserve. 	<ul style="list-style-type: none"> - Reduction of potential impacts on wildlife in and close to Majete Wildlife Reserve 	EGENCO, DNPW and African Parks	National Parks and Wildlife Act (1994), Environment Management Act (2017) and National Environmental Policy (2004)	Unknown (Responsible EGENCO)	

No	Mitigation Measure ⁴⁶	Key Risks and Impacts ⁴⁷	Expected Outcomes	Parties Responsible for Implementation	Relevant Regulatory Framework	Preliminary costing of measure (Responsible unit)	Reference source if relevant
	Ensure that blasting does not take place outside the times agreed with African Parks.						
7	Social cohesion mitigation: (i) Workers education programs and code of conduct; Collaborate with district and local health offices; (iii) Sensitive communities (including those from opportunistic influx); (iv) Labor influx and management procedures will need to be put in place	Labor influx related risks including the spread of infectious and sexually transmitted diseases such as HIV, COVID 19 and other communicable diseases; exacerbation of Gender-Based Violence/Sexual Exploitation and Abuse and Sexual Harassments (GBV/SEA/SH)	Reduction in health and unwanted social impacts	EGENCO (also collaborate with district and local health offices)	Public Health Act (2014)	Unknown (Responsible EGENCO)	WB (2022) - Appraisal Environmental and Social Review Summary
SVTP (Relevant measures from SVTP Updated ESIA from 2023)							
Lengwe 8	Improved attraction infrastructure to Lengwe National Park (LNP): (i) Establish eco-bridges that will be additional attractive feature to the park for education and tourism and (ii) Establish resource center important for tourism and education	Impacts on wildlife and their migration within Lengwe	Enhancement measures, so positive impact on park conservation and tourism	SVTP and DNPW	National Tourism Policy (2006)	Included in construction and SE contracts (Responsible SVTP)	SVTP (2023)

No	Mitigation Measure ⁴⁶	Key Risks and Impacts ⁴⁷	Expected Outcomes	Parties Responsible for Implementation	Relevant Regulatory Framework	Preliminary costing of measure (Responsible unit)	Reference source if relevant
Lengwe 9	Enhanced access to water by wildlife in New Lengwe: (i) Provide water holes in the western side of the park; (ii) Provide water troughs fed by water from the canal and driven by gravity in the eastern side of the park and (iii) Provide enough security for water holes	Deprivation of wildlife access to water	Better and more secure accessibility to water in LNP	SVTP and DNPW	National Parks and Wildlife Act (1994), Environment Management Act (2017) and National Environmental Policy (2004)	Included in construction and SE contracts (Responsible SVTP)	SVTP (2023)
Lengwe 10	Improved facilities such as rangers' houses, camp sites and roads in LNP	Limitations to ranges protection and management of wildlife in Lengwe	Enhancement measures, so positive impact on park conservation	SVTP and DNPW	National Parks and Wildlife Act (1994), Environment Management Act (2017) and National Environmental Policy (2004)	2.9 Million USD (Responsible SVTP)	SVTP (2023)
Lengwe 11	Construct eco-bridges to enable game movement between the Old and New Lengwe and provide for under passes (see also 15).	Limitations on wildlife movement between the eastern and western parts of the park due to canal construction	Improvement of wildlife movement in LNP	SVTP and DNPW	National Parks and Wildlife Act (1994), Environment Management Act (2017) and National Environmental Policy (2004)	Included in construction and SE contracts (Responsible SVTP)	SVTP (2023)
Lengwe 12	Enhance enforcement capacity of park authority + additional logistic/physical support measures	Increased cases of illegality in the park including poaching, cutting of trees for wood fuel and charcoal and encroachment due to increased influx of workers etc.	Better protection of wildlife and avoidance of tree cutting and encroachment	SVTP and DNPW	National Parks and Wildlife Act (1994), Environment Management Act (2017) and National Environmental Policy (2004)	Part of measure 17 (Responsible SVTP)	SVTP (2023)
Majete 13	(i) Include loss of revenue in the	Loss of revenue from tourism as most visitors	Compensation of impact on tourism to Majete WR	SVTP and African Parks	National Tourism Policy (2006)	Unknown (Responsible SVTP)	SVTP (2023)

No	Mitigation Measure ⁴⁶	Key Risks and Impacts ⁴⁷	Expected Outcomes	Parties Responsible for Implementation	Relevant Regulatory Framework	Preliminary costing of measure (Responsible unit)	Reference source if relevant
	<p>compensation for Majete;</p> <p>(ii) Construct alternate access routes for tourists coming to Majete; and (iii) Support improvements and construction of new tourism facilities in Majete and (iv) Develop bridge to provide access to Kapichira falls</p>	may not be comfortable with construction works					
Majete 14	<p>(i) Support African Parks Majete in the development and implementation of the Biodiversity Management Plan;</p> <p>(ii) Develop and implement a restoration plan covering the Intake and the First 6 km including the borrow pit.</p>	Loss of vegetation emanating from clearance of vegetation - The construction works under SVTP will, in certain areas including protected areas, necessitate clearing of vegetation.	Compensation of impacts on vegetation in protected areas	SVTP, DNPW	National Parks and Wildlife Act (1994), Environment Management Act (2017) and National Environmental Policy (2004)	Unknown (Responsible SVTP)	SVTP (2023)
15	General disturbance to wildlife mitigation: (i) Prohibit establishment of workers' camps within the wildlife reserve and National Park (ii) Prohibit	Civil works have potential to disturb wildlife especially within Majete Wildlife Reserve, Lengwe National Park, Shire	Reduction of potential impacts on wildlife in protected areas and Shire ecosystems	SVTP, DNPW and African Parks	National Parks and Wildlife Act (1994), Environment Management Act (2017) and National Environmental Policy (2004)	Unknown (Responsible SVTP)	SVTP (2023)

No	Mitigation Measure ⁴⁶	Key Risks and Impacts ⁴⁷	Expected Outcomes	Parties Responsible for Implementation	Relevant Regulatory Framework	Preliminary costing of measure (Responsible unit)	Reference source if relevant
	contractor and workers so as not to hunt, kill, capture or trap any wildlife or bird at the project sites and vicinity; (iii) Ensure regular and proper servicing of machinery and vehicles to reduce the impact of noise; (iv) Ensure that no construction takes place at night in the protected areas; and (v) Ensure that blasting does not take place outside the times agreed with DNPW or APM.	River and the Elephant Marsh.					
16	Social cohesion mitigation: (i) Workers education programs and code of conduct; Collaborate with district and local health offices; (ii) Sensitive communities (including those from opportunistic influx); (iv) Labor influx and management procedures will need to be put in place.	Surge in GBV and STI causes due to influx of workers etc.	Reduction in health and unwanted social impacts	SVTP (also collaborate with district and local health offices)	Public Health Act 2014	Part (i) and (iii) included in construction and SE contracts; Part (ii) 100 000 USD (Responsible SVTP)	SVTP (2023)
	MOMA						
17	Undertake ROW vegetation cutting with the supervision of a botanist in order to	Terrestrial habitat fragmentation and degradation along the MOMA line	Reduced impact on ecosystem connectivity	ESCOM, Department of Forestry through	National Parks and Wildlife Act (1994), Environment Management Act	10 000 USD (Responsible ESCOM)	MOMA ESIA (2019)

No	Mitigation Measure ⁴⁶	Key Risks and Impacts ⁴⁷	Expected Outcomes	Parties Responsible for Implementation	Relevant Regulatory Framework	Preliminary costing of measure (Responsible unit)	Reference source if relevant
	identify and relocate if possible, species of conservation concern as well as protect vegetation that does not represent a risk for the powerline. Any species of conservation concern that need to be cut will be located and its habitat will be fully described. This information will be integrated in the planning of a reforestation program. If possible, collect seeds from species of conservation concern for propagation.			the District Forestry Offices	(2017) and National Environmental Policy (2004)		
18	Includes (i) Promote the selection of areas with less of a need for tree cutting for construction of temporary worker's campsites and storage facilities and (ii) Implement a biodiversity protection awareness program with workers. Prohibit workers from owning firearms and other hunting gear and raise awareness about the prohibition to engage in any kind of poaching.	Construction works, and associated influx of people can put pressure/risk on Thambani Forest reserve	Less pressure/ risk on forest reserve and associated wildlife	ESCOM and DNPW	National Parks and Wildlife Act (1994), Environment Management Act (2017) and National Environmental Policy (2004)	Included in construction and SE contracts (Responsible ESCOM)	MOMA ESIA (2019)

No	Mitigation Measure ⁴⁶	Key Risks and Impacts ⁴⁷	Expected Outcomes	Parties Responsible for Implementation	Relevant Regulatory Framework	Preliminary costing of measure (Responsible unit)	Reference source if relevant
19	Social cohesion mitigation: (i) Workers education programs and code of conduct; Collaborate with district and local health offices; (ii) Sensitive communities (including those from opportunistic influx); (iv) Labor influx and management procedures will need to be put in place.	Surge in GBV and STI causes due to influx of workers etc.	Reduction in health and unwanted social impacts	ESCOM and District Councils (District Health Offices, District labour offices etc).	Public Health Act 2014	Unknown (Responsible ESCOM)	MOMA ESIA (2019)
Mpatamanga HPP mitigation measures outlined in BAP and ESIA studies							

10.2.2 Catchment Scale Mitigation Measures

The most prominent catchment scale mitigation measures assessed for the CIA for further basin development and management of the Shire Basin are largely embedded in the in the ***sustainable pathway scenarios*** and the measures proposed for them. A set of catchment scale mitigation measures has been developed. Most of these go beyond the responsibility of MHPL and are rather the main responsibility of GoM, for example (i) catchment rehabilitation that includes rehabilitation/reforestation of targeted erosion hotspot areas, (ii) enhancing tourism and protected areas management of protected areas, and (iii) sustainable land use enhancement and energy source transition.

The recommended measures specifically relevant for Mpatamanga HPP/MHPL are (i) implement/enhance joint operation of Shire River dams (II) implement a Co-Management Platform for Shire (especially for the water users) and (iii) payment for ecosystem services (PES) for the rehabilitation/reforestation of erosion hotspots in the Lisungwe catchment (that drains into the main reservoir).

Table 10-2 Identified catchment scale mitigation measures for the Shire River Basin.

No	Mitigation Measure	Key Risks and Impacts	Expected Outcomes	Parties Responsible for Implementation	Relevant Regulatory Framework	Preliminary costing of measure (Responsible Unit)	Reference source if relevant
Catchment Scale Cumulative Mitigation Measures (Shire Basin and/or Sub-Basins therein)							
1	<p>Joint operation of Shire River Dams: Kamuzu Barrage, Nkula, Tedzani, Mpatamanga and Kapichira (and Kholombidzo if realized). The details on joint operation of the dams for optimization of power generation and flood management needs to be studied more in detail in a specialist study</p>	<ul style="list-style-type: none"> - Flood and drought risks - Sub-optimal power generation outputs - EFlows requirements in important (triggering) periods are not met - Geomorphological changes affecting livelihoods and riverine ecology 	<ul style="list-style-type: none"> - Coordinated flood monitoring and warnings - Optimization of power production across HPPs in the basin - Synchronization of EFlows for water uses, livelihoods and riverine ecology 	EGENCO, NWRA, MHPL	Environment Management Act (2017) and National Environmental Policy (2004), Water Resources Regulations (2018), Water Resources Act (2013) and Water Resources Policy (2005)	<ul style="list-style-type: none"> - Cost of EFlows release and flood management for each project (part of dams operation). For Mpatamanga (MHPL) this EFlows release and flood management is directly integrated as a constraint and commitment in the Implementation Agreement and accounted for in the estimates of power production. Kapichira, Nkula, Tedzani is the responsibility of EGENCO. Kamuzu Barrage is the responsibility of NWRA. - Mpatamanga EFlows monitoring cost is part of the ESIA/ESMP mitigation budget 	ESIAs/ESMPs for each HPP project

No	Mitigation Measure	Key Risks and Impacts	Expected Outcomes	Parties Responsible for Implementation	Relevant Regulatory Framework	Preliminary costing of measure (Responsible Unit)	Reference source if relevant
2	Institutional Strengthening of NWRA including a Stakeholder Co-Management Platform for Shire: MHPL should participate in such a Co-Management Platform together with EGENCO, NWRA, and other major water users such as SVTP, Agricane, Illovo etc.	<ul style="list-style-type: none"> - Sub-optimal water management of the Shire River 	<ul style="list-style-type: none"> - Better coordination of water management on the Shire, due to closer cooperation between main stakeholders, benefiting the water users and other relevant stakeholders 	NWRA, EGENCO, MHPL, SVTP etc.	Water Resources Regulations (2018), Water Resources Act (2013) and Water Resources Policy (2005)	<ul style="list-style-type: none"> - NWRA's own budget for strengthening its organisation - Stakeholder Co-Management Platform cost for MHPL. Less than 100 000 USD per year up to 2040. Preliminary period. Start in 2029 and end in 2040. Total cost at maximum = 1.1 Million USD 	NORPLAN. 2015. Consultancy Services Related to Financial and Institutional Aspects of the Kamuzu Barrage Management. SRBMP Phase 1.
3	Catchment rehabilitation that includes rehabilitation/reforestation of targeted erosion hotspot areas in tributaries with highest sediment yield to Shire, e.g. erosion hotspots in Ruo, Lisungwe, Nkulumadzi, Lirangwe, Likabula and maybe Rivi Rivi and Mwanza tribs) + MWASIP pilot areas in Lisungwe, Nkulumadzi, Lirangwe/Likabula.	<ul style="list-style-type: none"> - Deforestation due to charcoal extraction and agricultural encroachment - Sedimentation of the riverine ecosystem and degradation of it - Subsequent impact on livelihoods along the Shire 	<ul style="list-style-type: none"> - Reduced erosion rates and sediment transport with its positive impact on the riverine environment and ecology (biodiversity and habitats) 	<p>Department of Forestry, MWASIP/Ministry of Water and Sanitation, Department of Environmental Affairs</p> <p>Will require also public action to manage the impact of / deliver benefits for private activities</p>	Environment Management Act (2017) and National Environmental Policy (2004), Water Resources Regulations (2018), Water Resources Act (2013) and Water Resources Policy (2005), Forest Act (2017) and Forestry Amendment Act (2019)	<ul style="list-style-type: none"> - MWASIP total cost USD 110 Million (GoM, 2023). This includes also irrigation schemes development (WB funded). (WB 107 Million; GoM 3 Million USD) - Reforestation / rehabilitation of targeted erosion hotspot areas estimate at 20 Million USD (rough estimate). Some of this might be drawn from the total MWASIP cost above, but erosion hotspots include also areas outside MWASIP Pilot Catchments. Responsibility: Ministry of Natural Resources and Climate Change (Possible financing institutions) 	HR Wallingford (2023). Mpatamanga HPP Sediment Study: Baseline Report

No	Mitigation Measure	Key Risks and Impacts	Expected Outcomes	Parties Responsible for Implementation	Relevant Regulatory Framework	Preliminary costing of measure (Responsible Unit)	Reference source if relevant
						WB, EfDB, USAID, NORAD)	
4	<p>Enhancing tourism and protected areas management of protected areas in the basin, and then especially the selected Flagship VECs for the CIA, e.g. Liwonde NP, Majete WR, Lengwe NP and Elephant Marsh (incl. restricted access into, and cultivation in, the Elephant Marsh). The two first are quite well protected by African Parks running them but some encroachment etc. still occurs. Lengwe NP is under high pressure viz encroachment/ poaching and especially the New Lengwe part. The CIA suggests full restoration of New Lengwe or at least major parts of it. Tourism development should go hand in hand with strengthening of protected areas management.</p>	<ul style="list-style-type: none"> - Mpatamanga and Kapichira HPP construction and operation; SVTP construction; TL/Roads construction are drivers leading to: - Influx of workers and hence increased risk of deforestation (also due to additional charcoal/woodfuel extraction) - Biodiversity loss due to increased encroachment and poaching 	<ul style="list-style-type: none"> - Enhancement of protected areas; especially management of Elephant Marsh and restoration and management of Lengwe NP; Majete Community Buffer Protection Area (as of BAP study) - Enhanced protection of wildlife species (including Flagship VEC species) - Enhanced quality of Wildlife Tourism - Enhanced livelihood opportunities for local communities 	<p>Department Tourism, Department of National Parks and Wildlife, African Parks, Robin Pope</p> <p>MHPL could also have a role due to its support to the Biodiversity Offset between the reg dam and the main dam.</p>	<p>National Parks and Wildlife Act (1994), Environment Management Act (2017) and National Environmental Policy (2004), Fisheries and Aquaculture Policy (2016) and Fisheries Conservation and Management Act (1998)</p>	<ul style="list-style-type: none"> - Majete WR and Liwonde NP: African Parks' Annual Report on cost of running the parks and plans for future. BAP study has estimated cost of MHPL to support management and protection of Majete and suggested Private Conservancy between Reg and Main Dams. Improved management of both parks can potentially increase tourism revenues. - Lengwe National Park: SVTP mitigation budget + 3 million USD (SVTP 2023) plus rehabilitation / management of New Lengwe with a rough estimate of 20 million USD + for rehabilitation (annual cost as of Elephant Marsh (> 2 million USD) or higher for management). Responsible DNPW - Elephant Marsh: Annual cost as of SRBMP (2018) at > 2 	<p>Malawi National Tourism Investment Masterplan (2022), SVTP Updated ESIA (2023), SRBMP Business Plan for Elephant Marsh (2018)</p>

No	Mitigation Measure	Key Risks and Impacts	Expected Outcomes	Parties Responsible for Implementation	Relevant Regulatory Framework	Preliminary costing of measure (Responsible Unit)	Reference source if relevant
						million USD. Responsible DNPW	
5	Sustainable land use enhancement and energy source transition that follows the goals and targets in the Renewable Energy Strategy (2017), National Charcoal Strategy (2017) and National Forest Landscape Restoration Strategy (2017) implemented for the Shire Basin, e.g. transition from biomass (woodfuel/charcoal) to more renewable (or sustainable sources) as the energy source. E.g., LPG, electricity and fuel-efficient charcoal/woodfuel cookstoves as well as sustainable charcoal production (plantation trees in targeted areas) where appropriate.	<ul style="list-style-type: none"> - Widespread deforestation and degradation of natural habitats due to charcoal/woodfuel extraction - Deforestation again leads to increased erosion and sedimentation to Shire - Biodiversity loss 	<ul style="list-style-type: none"> - Enhancement of natural and semi-natural habitats - Better protection of protected areas and their bordering buffer zones <p><u>Cleaner cookstove transition</u></p> <ul style="list-style-type: none"> - <u>LPG</u>: Increased adoption of LPG reduces pressure on forests and deforestation, reduces air pollution, diseases, and carbon emissions and enhances energy services, based on adequate incentives for early take-off, but this is initially targeted for middle to high income urban dwellers, institutions and the food/hospitality industry. - <u>Electricity</u>: Potential impacts include cleaner, more efficient, healthier, and superior energy services that reduce drudgery and deforestation. Longer implementation period than LPG. Most 	Department of Environmental Affairs, Ministry of Energy, Malawi Energy Regulation Authority, Department of Forestry	Land Act (2016), The Electricity Act (2004) and Electricity Amendment Act (2016), Liquid Fuels and Gas Act (2004), Public Health Act (1992), Malawi National Energy Policy (2018)	As of Malawi Integrated Energy Plan (2022) probably 10 million USD + each year up to 2030 for the population in the whole basin. Responsible Ministry of Energy	Renewable Energy Strategy (2017), National Charcoal Strategy (2017) and National Forest Landscape Restoration Strategy (2017), SEE4All. Malawi Integrated Energy Plan (2022)

No	Mitigation Measure	Key Risks and Impacts	Expected Outcomes	Parties Responsible for Implementation	Relevant Regulatory Framework	Preliminary costing of measure (Responsible Unit)	Reference source if relevant
			<p>relevant to urban and semi-urban centres</p> <ul style="list-style-type: none"> - <u>Fuel efficient charcoal/woodfuel cookstoves</u>: Increasing adoption of fuel-efficient charcoal and firewood cookstoves presents the most immediate option to slow deforestation and forest degradation across Shire River Basin; Reduction in air pollution resulting in improved health of women and children; labour savings, particularly for rural women and children; household income savings. 				
6	<p>Conservation agriculture, farmer-managed natural regeneration and agro forestry: (i) Increase tree cover on degraded low-yielding cropland and pastures in agricultural landscapes through farmer-managed and assisted natural regeneration, direct seeding, and planting of agroforestry trees and shrubs. (ii) Implement climate smart</p>	<ul style="list-style-type: none"> - Reduction in soil productivity and soil erosion - Resilience to extreme weather events - Pollutants runoff 	<p>Increased crop yields with reduced dependence on inorganic inputs, reduced soil/nutrient loss, increased resilience to drought and other climate shocks affecting the following:</p> <ul style="list-style-type: none"> - Improved food security - Improved climate resilience - Poverty alleviation - Improved gender equity and equality 	<p>Department of Agricultural Extension Services, Department of Agricultural Research Services</p>	<p>Land Act (2016), Environmental Management Act (2017), National Agricultural Policy (2016)</p>	<p>As of National Forest and Landscape Restoration Strategy some 25 + Million USD in total cost roughly estimated for the whole basin. Responsible Ministry of Agriculture</p>	<p>National Forest Landscape Restoration Strategy (2017)</p>

No	Mitigation Measure	Key Risks and Impacts	Expected Outcomes	Parties Responsible for Implementation	Relevant Regulatory Framework	Preliminary costing of measure (Responsible Unit)	Reference source if relevant
	agricultural techniques (including FMNR), continuous cover crops, crop rotation etc.						
7	Payment for Ecosystem Services (PES) Lisungwe Catchment: Reforestation of erosion hotspots in Upper Lisungwe catchment to reduce erosion and subsequent sediment transport into Mpatamanga reservoir	<ul style="list-style-type: none"> - High sedimentation rates into Mpatamanga reservoir - Environmental degradation. Livelihoods prone to droughts and floods 	<ul style="list-style-type: none"> - Decrease in sediment yield into Mpatamanga reservoir - Livelihoods enhancement - Protection of biodiversity/wildlife - Catchment less prone to floods/droughts 	Department of Forestry, NWRA, MHPL	Environmental Management Act (2017)	Possible PES Benefit Sharing Mechanism from MHPL to cover part of the reforestation. Possibly in the range of 1 Million USD For MHPL, piggybacked on potential funds from, say 2-3 Mill USD from MWASIP (WB) and GoM. Period for MHPL budget support suggested to be 2030-2035, with 300 000 USD the first two years and 150 000 per year the last three years. Responsible MHPL and MWASIP.	Lillehammer et al. Benefit Sharing and Hydropower: Enhancing Development Benefits of Hydropower Investments Through and Operational Framework (2011).
8	Implementation of sustainable fisheries management plans from Chikwawa to Chiromo, i.e., the extent of the Elephant Marsh modelled in the CIA. The development and implementation of a fisheries management plan is considered imperative for the health of the river and the local communities	At present there is no apparent coherent fisheries plan for the Lower Shire fishery, and fisheries are largely overlooked in the SVTP documents, although the SRBMP targets “Participatory fisheries management plans in place for all designated fisheries areas by 2022”.	Regulation of the fisheries in the Lower Shire is a necessary first step in ensuring the sustainability of the fisheries.	Department of Fisheries; Beach Village Committees (BVCs)	Environment Management Act (2017) and National Environmental Policy (2004), Fisheries and Aquaculture Policy (2016) and Fisheries Conservation and Management Act (1998)	The World-Bank funded Shire River Basin Management Program (Phase-I) Project (P117617) has an approved budgeted for a management plan for the Elephant Marsh, which extends from Chikwawa to Chiromo. Rough estimate 300 000 to 500 000 USD yearly. Responsible Department of Fisheries	Bayliss, J. 2018. The Elephant Marsh: General Adaptive Management Plan. Shire River Basin Management Programme, Government of Malawi. 104 pp.
9	Control of hyacinth and mimosa in the Elephant Marsh.	There are early indications that mimosa and hyacinth could	Preventing the spread of mimosa and hyacinth, while their numbers are still	Shire Valley Transformation Project (SVTP),	None	Unknown, but not high if implemented immediately. Rough estimate 50 000 –	

No	Mitigation Measure	Key Risks and Impacts	Expected Outcomes	Parties Responsible for Implementation	Relevant Regulatory Framework	Preliminary costing of measure (Responsible Unit)	Reference source if relevant
	Mimosa: Once a year cut adult plants, stack dry and burn; return to cleared areas two months later and spot treat re-sprouting cut stumps and seedlings; release biocontrol agents for Mimosa twice a year; revegetate cleared areas with a seed mix of indigenous floodplain grass seeds. Hyacinth: Physical removal, biocontrol agents for hyacinth in September and December.	become problem invaders in the Elephant Marsh as their abundance increased markedly between 2015 and 2023 (Supporting Specialists Report). If left uncontrolled both of these can have devastating effects on biodiversity and community access and use of the Marsh.	manageable would benefit biodiversity and local communities. It would also be considerably more possible and more cost effective that delaying these actions. Mimosa in particular has become an intractable problem on several floodplains in Southern Africa, e.g., Kafue Flats, Zambia.	supported by Government Departments.		100 000 USD every 3-5 years. Responsible DEA and DNPW	
10	Implementation of Community Conservation Areas (CCAs) in the Elephant Marsh. Target = 50% CCA.	The difficulty and time-consuming nature of establishing CCAs in the Elephant Marsh is a major constraint. SVTP is supporting the establishment of CCAs in the Elephant Marsh as it plays an important role in maintaining the Valley's hydrological regime through flood control, water storage and supply of nutrient-rich sediment. Chikwawa and Nsanje District Councils have endorsed the need to establish the CCAs for the sustainable	Restricting access to one or more area of the Marsh would improve ecosystem condition, and consequently its sustainability. Key aspects that should be mitigated are cultivation in the floodplain/marsh, over-fishing and poor gear choice, overharvesting of reeds, burning and bush-meat hunting of small mammals, reptiles and birds. It is unlikely that Communities will support a total ban on access, even although that would give the best results in terms of ecological condition. A	Shire Valley Transformation Project (SVTP), supported by Government Departments.	RAMSAR agreement	The World-Bank funded Shire River Basin Management Program (Phase-I) Project (P117617) has an approved budgeted for a management plan for the Elephant Marsh that incorporates CCAs. Estimate 2-3 million USD in total	https://documents1.worldbank.org/curated/en/584761569595531675/pdf/Malawi-Shire-River-Basin-Management-Program-Project.pdf https://svtp.gov.mw/2022/08/22/first-cca-established-in-the-elephant-marsh/ BROWN, C.A., JOUBERT, A., TURPIE, J. REINECKE, M.K. BIRKHEAD, A. FORSYTHE, K., DAVIES, T. MGOOLA, W., NYIRENDA, J. and ARTHUR, R. 2022. The Elephant Marsh, Malawi

No	Mitigation Measure	Key Risks and Impacts	Expected Outcomes	Parties Responsible for Implementation	Relevant Regulatory Framework	Preliminary costing of measure (Responsible Unit)	Reference source if relevant
		management of the Elephant Marsh. Two Committees have been established, one at Mbenje and another at Ntchenyera to support interventions in the CCA. Elephant Marsh covers an area of ~61,556 ha. To date, however, communities under Mbenje CCA have contributed 2,164 ha of land for conservation, i.e., ~3.5% of the area.	more pragmatic option is the CCAs supported by SVTP.				– Part 3: The application of an eco-social model to assess options for managing ecological status. African Journal of Aquatic Science, 47:3, 405-420, DOI: 10.2989/16085914.2022.2044750.
Transboundary Mitigation Measures							
11	Harmonization of basin/catchment management measures towards (including also dams operation and water resources) ZAMCOM	As of ZAMCOM Strategic Plan: <ul style="list-style-type: none"> - Environmental degradation and disaster risk (most relevant for this CIA. - The strategic plan also lists persistent poverty, competing uses and infrastructure deficit as key risks 	<ul style="list-style-type: none"> - Transboundary harmonization of catchment management practises - Joint operation of dams, including synchronized flood releases for Zambezi 	NWRA and ZAMCOM	ZAMCOM Agreement and ZAMCOM Strategic Plan 2018-2040	<ul style="list-style-type: none"> - Malawi GOV administrative budget for ORASECOM membership etc. - Potential cost of synchronized flood releases (should be in the implementation / operation agreement for each HPP, including Mpatamanga) 	ZAMCOM Strategic Plan 2018-2040
12	Transboundary monitoring of EFlows releases	Uneven conditions for EFlows releases affecting water users and riverine ecology	EFlows agreements are met to possible counteract risks and impacts	GoM/NWRA and ZAMCOM	ZAMCOM Agreement, Water Resources Regulations (2018), Water Resources Act (2013)	Cost for monitoring by possible levy on projects (as of ZAMCOM Strategic Plan). MHPL responsible for potential levy on Mpatamanga. Cost is currently unknown, but should not be high	ZAMCOM Strategic Plan 2018-2040

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APPENDIXES – SUPPORTING SPECIALIST STUDIES

A.1. SUPPORTING HYDROLOGICAL AND WATER RESOURCES SCENARIO ASSESSMENT

Scenario implementation within Wflow has been extensive, modelling land use, climate and water demand changes within the Shire Basin. Analysing the effect of the scenarios on flow regimes permits insight into changes to magnitude and frequency of high flows that may affect the potential risk to populations or reshaping ecosystems. Low flow periods, varying in magnitude and duration, may also change with land use and climate drivers affecting water availability and quality. This section attempts to summarise the effects of the by presenting the most relevant changes. Wflow is not currently capable of modelling the complex interaction between multiple hydropower plants, and so our summary remains fixed upon the simulated effects on the tributary sites focussed on by the DRIFT ESM (table below) process occasionally referring to the overall basin effects where necessary, with the acknowledgement that the hydropower influence is not accounted for.

Name	Location	Longitude	Latitude	ESM_id
Shire	Main	34.913	-15.388	1
Shire	Main	34.758	-15.576	2
Shire	Main	34.738	-15.817	3
Shire	Main	34.738	-15.829	4
Shire	Main	34.804	-16.009	5
Lisungwe	Tributary	34.738	-15.529	2a
Nkulumadzi	Tributary	34.588	-15.596	4a
Nkulumadzi	Tributary	34.729	-15.821	4b
Lukhubula	Tributary	34.871	-15.821	5a
Mwanza	Tributary	34.749	-16.154	5b
Ruo	Tributary	35.246	-16.488	7

TABLE A1-1: Locations of interest from DRIFT ESM.

Baseline scenarios show little effect on the high flows within the Ruo. It is evident that only the baseline historic scenario from the present day and baseline scenarios results in some notable effect. We can compare

the effect on high flow probability for the various scenarios by comparing individual scenarios effect on the T10 flow magnitude at select stations. This T10 magnitude can be understood as the discharge magnitude that has a 10% chance of exceedance per given year in the simulated series.

	Return Period	Baseline 1	Near Natural	Historical	Baseline 2
Ruo	T10	5094.833	4973.76	5074.647	5094.833
Lisungwe	T10	443.6456	428.847	443.6385	443.6456
Nkulumadzi (a)	T10	307.198	314.2708	307.198	307.198
Lukhubula	T10	211.87	201.8606	211.27	211.87
Nkulumadzi (b)	T10	391.4173	395.6446	391.6673	391.4173
Mwanza	T10	607.3116	610.2697	606.3762	607.348

TABLE A1-2 The T10 discharge simulations at each of the DRIFT ESM tributaries.

We acknowledge that flow magnitude comparisons are delivered with the inherent uncertainty presented by the climate model data in this study. Though this data has been bias corrected, as described in section 6.1.2, some biases in timing and magnitude will remain.

Reforestation accounts for the modelled changes between the Near Natural and the other present scenarios. The tributary locations display only moderate change in T10 flows in response to reforestation changes and are otherwise relatively unaffected. The average reduction in the T10 flow for the Near Natural scenario tributaries is -0.08% compared to the baseline runs while the largest relative change is evident in the sub catchment with the lowest discharge, Lukhubula (-4.7%). Lukhubula is a small catchment that contains a significant proportion of the city of Blantyre, a reduction in the proportion of impervious surfaces could account for the reduction in discharge severity. Eliminating the urban fraction, reforestation has a slight positive but negligible effect the extremes in streamflow for this period.

Scenarios relevant to the near future and beyond are show generally expected trends with some surprising magnitude, the per sub catchment comparison relative to baseline 1 is included as an appendix item (table A1-1). The Near Future 1 (business as usual) scenario with increased land intensification around the Ruo presents a negligible negative difference to the T10 discharge NF1 presents less than 0.5% increase on average relative to baseline across the tributaries with Nkulumadzi being the most affected with a potential 2.7% increase to 395 m³s⁻¹.

Near Future 3 (business as usual with climate change, NF3BAUCC) represents an elaboration on NF1BAU by imposing representative climate change forcing to NF1BAU. The mean case suggests that all tributaries may experience an average -8% reduction in T10 peak magnitude with pronounced reductions at Lukhubula (-34%) and even an increase in magnitude in the Ruo (+5%). These differences can be attributed to the change in forcing, where a negative bias in precipitation intensity may account for the reduction in T10 between these two scenarios and the spatial discrepancy in forcing may account for the contrast in tributaries.

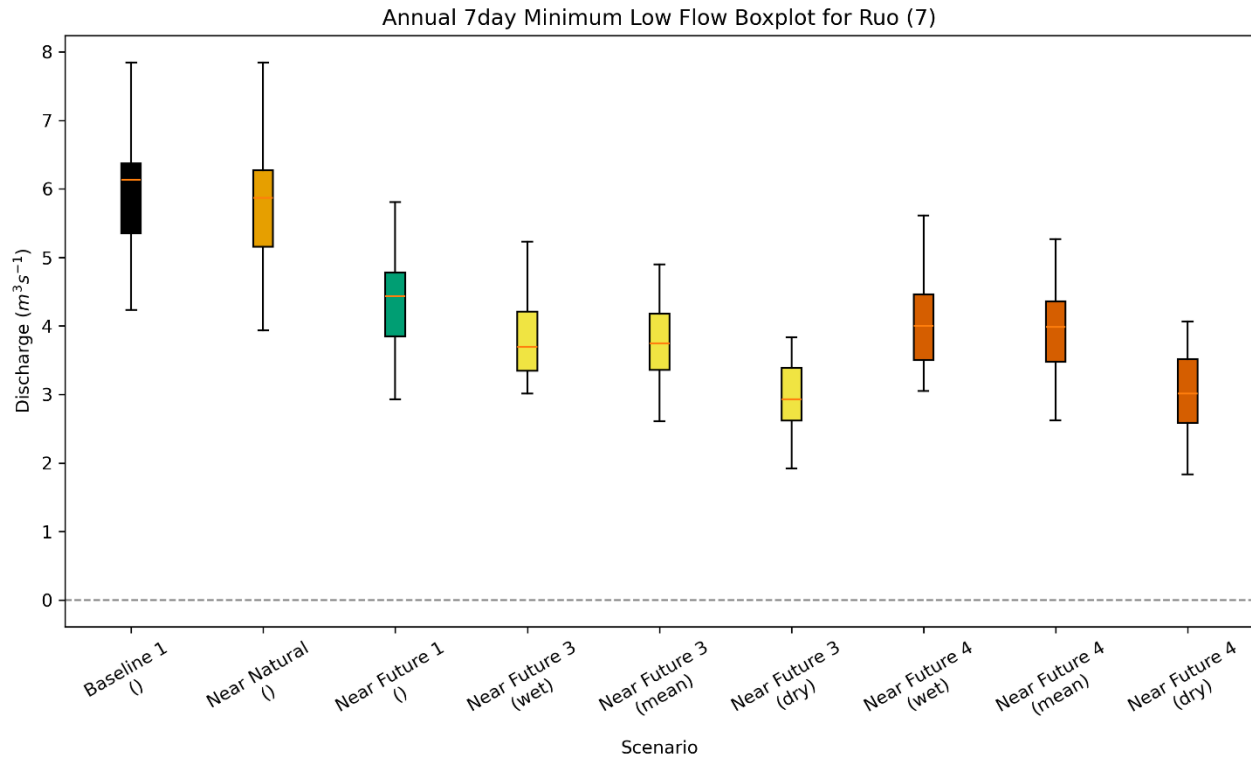


Figure A1-1 Boxplots show the median (middle line) inter-quartile range (box) and 1.5*IQR (whiskers) for the sample of minimum annual 7-day average flow as a measure of base flow variation. The plot shows selected present scenarios and the near future scenarios for the Ruo tributary.

Near Future 4 (sustainable pathway) mean case reinforces the case for only minor impact of reforestation on the peak flow magnitude. An increase in 30% forest cover over the basin impacts the tributaries by increasing landscape storages, slowing flows by increasing roughness and increasing atmospheric losses via interception and transpiration. The mean T10 peak magnitude is -8.63% relative to baseline, but only a -0.6% reduction in T10 relative to the less forested previous scenario, on average for all tributaries (NF3BAUCC). The hazard of higher discharge in the wet case of this scenario is on average, the same as the previous scenario and the dry scenario suggests discharge reductions because of afforestation are more pronounced as the overall water supply decreases (average reduction -2.24% dry NF4SPCC).

The late-century Distant future 1 and 2 (2040-2070) scenarios differ by the underlying forest cover, whereby DF2 simulates a gradual +50% increase in forest cover throughout the simulation. The mean case suggests a +22% increase for the BAU pathway in contrast to a +17% increase in T10, relative to NF3BAUCC, for the sustainable pathway. DF2SPCC suggests that a reforestation target of 50% may impact T10 flows by a relative with an average reduction of -6% and as much as -12%. Unlike the previous near future comparison, it can be observed that the reduction in T10 for the dry case and wet case respond to afforestation approximately the same. DF cases do represent significant increase in T10 flows overall with a 22%, 14% and 1% increase in T10 relative to NF3BAUCC mean, wet and dry respectively.

Low flows are simultaneously affected as the land cover and climate that underpin the model configuration change. In order to compare the effects of these changes we determine the annual 7-day lowest discharge for each series and by comparison to the baseline 1 continue with our commentary. Supplementary material is provided in the appendix for the associated data, in table A2. We include the gauge Shire (5) to illustrate the effect of the potential lake outflow trajectory, which could have significant impact as early as mid-century. The significance is already implied in figure 6-1 whereby the end of the century approximately half of the climate models result in no lake outflow to the Shire Basin from lake Malawi.

The present-day forcing scenario statistics for the annual minimum 7-day average discharge are reported in the table below. Notable differences in the main channel of the Shire reiterate the key differences between the scenarios simulated. The Near Natural scenario differs from the B1 in that the inflow applied at the model boundary is a simulation of a natural lake outflow without the influence of Kamuzu Barrage, secondly it differs in the prominence of trees within the model domain. A 23% reduction in annual baseflow is partially due to the inflow applied, while a significant proportion will be a mean low flow reduction due to increased interception and evaporation upland of each gauge. The average reduction in this measure for the near natural scenario for tributaries is a reduction of -6.39%.

Main channel flows in Baseline 2 are notably affected where the application of abstraction is applied and is the only functional difference between Baseline 1 and Baseline 2. The reduction in water availability, without accounting for reservoir operation, as a result of the SVTP is approximately -18% relative to the present baseline.

	Baseline 1		Near Natural		Baseline 2		Historic	
	Q [m ³ s ⁻¹]	σ	Q [m ³ s ⁻¹]	σ	Q [m ³ s ⁻¹]	σ	Q [m ³ s ⁻¹]	σ
Shire (5)	218.87	63.24	168.30	63.70	178.86	72.48	218.47	63.51
Ruo	7.15	7.16	6.96	7.01	7.15	7.16	7.13	7.16
Lisungwe	3.99	2.33	3.74	2.21	3.99	2.33	3.94	2.34
Nkulumadzi (a)	1.33	0.53	1.32	0.53	1.33	0.53	1.33	0.53
Lukhubula	0.72	0.40	0.68	0.39	0.72	0.40	0.71	0.40
Nkulumadzi (b)	2.74	0.80	2.71	0.80	2.74	0.80	2.73	0.80
Mwanza	3.84	1.23	3.66	1.14	3.83	1.23	3.81	1.23

TABLE A1-3 The annual minimum 7-day average discharge simulations at each of the DRIFT ESM tributaries.

Almost all scenarios across all tributary gauges show null or negative change in this measure of low flows relative to the present baseline. With the most severe reductions in these base discharges occurring in the latter half of the century. The most severely affected tributary is Lisungwe (2a) with an average of -84.6% and -87.11% reduction in base flows for the near-future and distant-future scenarios, respectively. This is the result of planned abstractions upstream, detailed in the master plan and the scenario description. The Ruo tributary, the largest along the Shire, is the second worst affected by mid-century with an estimated -42% reduction relative to baseline. These dramatic reductions are driven primarily by the planned abstractions upstream of the monitoring stations, while the other tributaries with no planned water supply upgrades average a reduction in baseflows of -13% and -30.3% for the near and distant futures respectively.

Comparing the distant future 1 and 2, where the land area proportion of forest cover is increased by 50%, the resulting additional losses of baseflow are -3.18%, -2.71% and -1.23% for the mean, wet and dry cases, respectively.

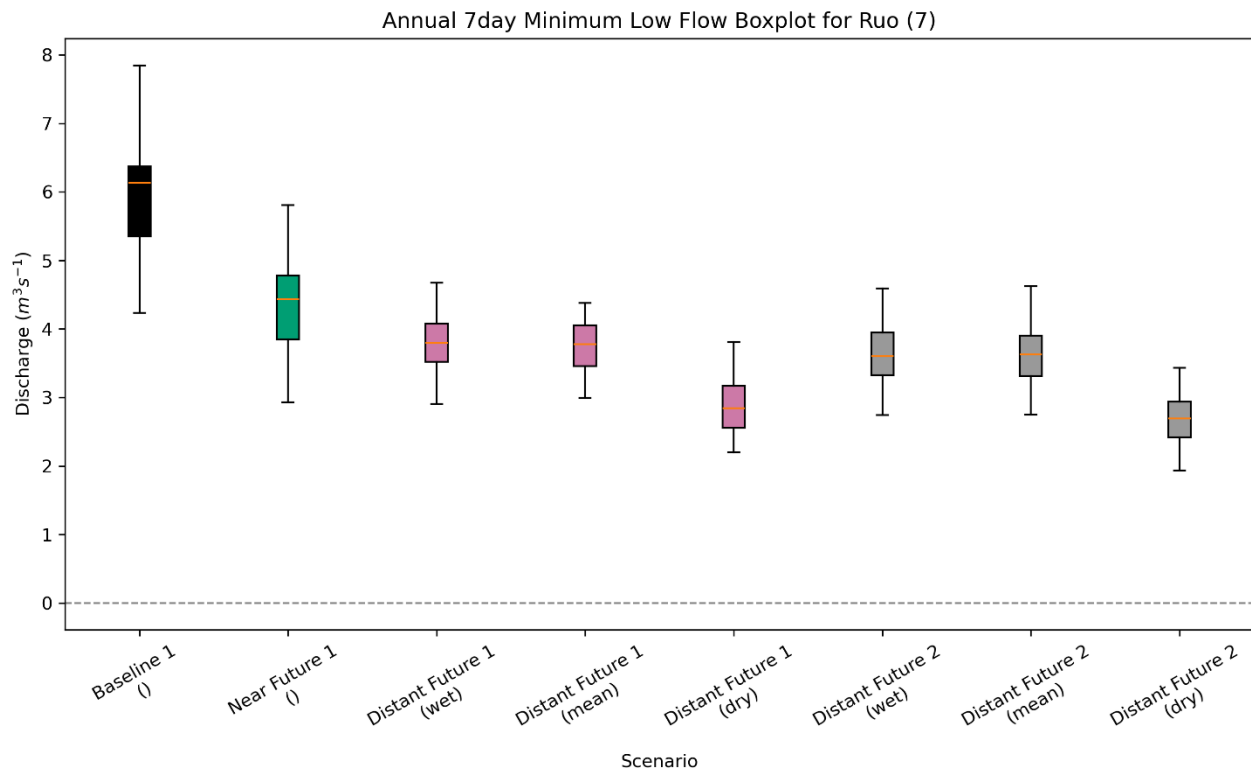


Figure A1-2 The plot shows selected baseline, near future and distant future scenarios for the Ruo tributary.

Our analysis focuses on a single Shared Socioeconomic Pathway (SSP 3.70) with three representative cases. These cases provide inconclusive results regarding whether T10 flows may significantly increase or decrease by mid-century. However, it is likely that these extremes will increase by the end of the century.

Sustainable land management practices, such as afforestation, may mitigate the severity of peak discharges and associated risks. In the coming decades, afforestation targets may reduce baseflows while potentially decreasing flood risk. Increased tree cover has a marginal impact on low flow magnitudes; more severe impacts to water supplies may be attributable to water abstractions in the tributaries.

Modelling indicates that land cover changes play a minor role in the current situation compared with the potential climatic changes. A primary, emerging concern is the non-zero probability of Lake Malawi outflows being dry by mid-century. The most uncertainty surrounds the future of the hydrological cycle in the Shire basin, primarily due to climatic factors, which can have a far greater impact on the basin or sub-basin scale than land cover changes.

A.2. SUPPORTING CLIMATE CHANGE MODELLING AND ASSESSMENT

The climate change analysis of the current study was aligned as much as possible with the Climate Change resilience Assessment conducted by the consortium of EDF. Most of the data is prepared and provided by DCCMS. The climate model datasets are developed as part of the European FOCUS-AFRICA project⁴⁸.

A.2.1. FOCUS-AFRICA

FOCUS-AFRICA aimed to provide a climate service for the SADC region. The team conducted a historical trend analysis and assessed future changes for the SADC region. Their analysis⁴⁹ revealed that temperatures have increased substantially and that there is a general drying trend in the SADC region. In addition, there is a signal of increasing intense rainfall events in the eastern part of Southern Africa, especially for Mozambique. This is a result of changing cyclone frequencies and intensities (Ranasinghe et al., 2021)⁵⁰. Looking into the future, these changes will likely be amplified. Temperatures will further increase, and the drying trend will continue. Most models indicate that more precipitation will fall as extreme events and thus even when a model projects that annual average precipitation may increase, dry periods will still become drier according to those models. In the North of Malawi precipitation amounts may increase slightly due to an expansion of the tropical belt (Lee et al., 2021⁵¹) – see also Figure A2-1. Temperatures will increase throughout Southern Africa (see Figure A2-2). The FOCUS AFRICA team also calculated a drought index, the Keetch and Byram drought index. Values range from 0 to 10, where a value of 10 indicates completely dried out soil and vegetation. Increases of the Keetch and Byram drought index up to 4 are projected for Southern Africa (see Figure A2-3). For Malawi increase of ~2 is projected indicating that in the future drought conditions will likely become more severe.

⁴⁸ [Focus-AFRICA – Full-value chain Optimised Climate User-centric Services for Southern Africa \(focus-africaproject.eu\)](https://focus-africa.eu/).

⁴⁹ Engelbrecht, et al. (2023) FOCUS-Africa Research and Innovation Action (RIA) - Report describing regional climate extremes.

⁵⁰ Ranasinghe, R. et al., 2021: *Climate Change Information for Regional Impact and for Risk Assessment*. In *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte et al. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1767–1926, doi:10.1017/9781009157896.014.

⁵¹ Lee J.Y. et al. (2021). *Future Global Climate: Scenario-Based Projections and Near-Term Information*. In: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte et al. (eds.)]. Cambridge University Press. Retrieved February 8, 2023

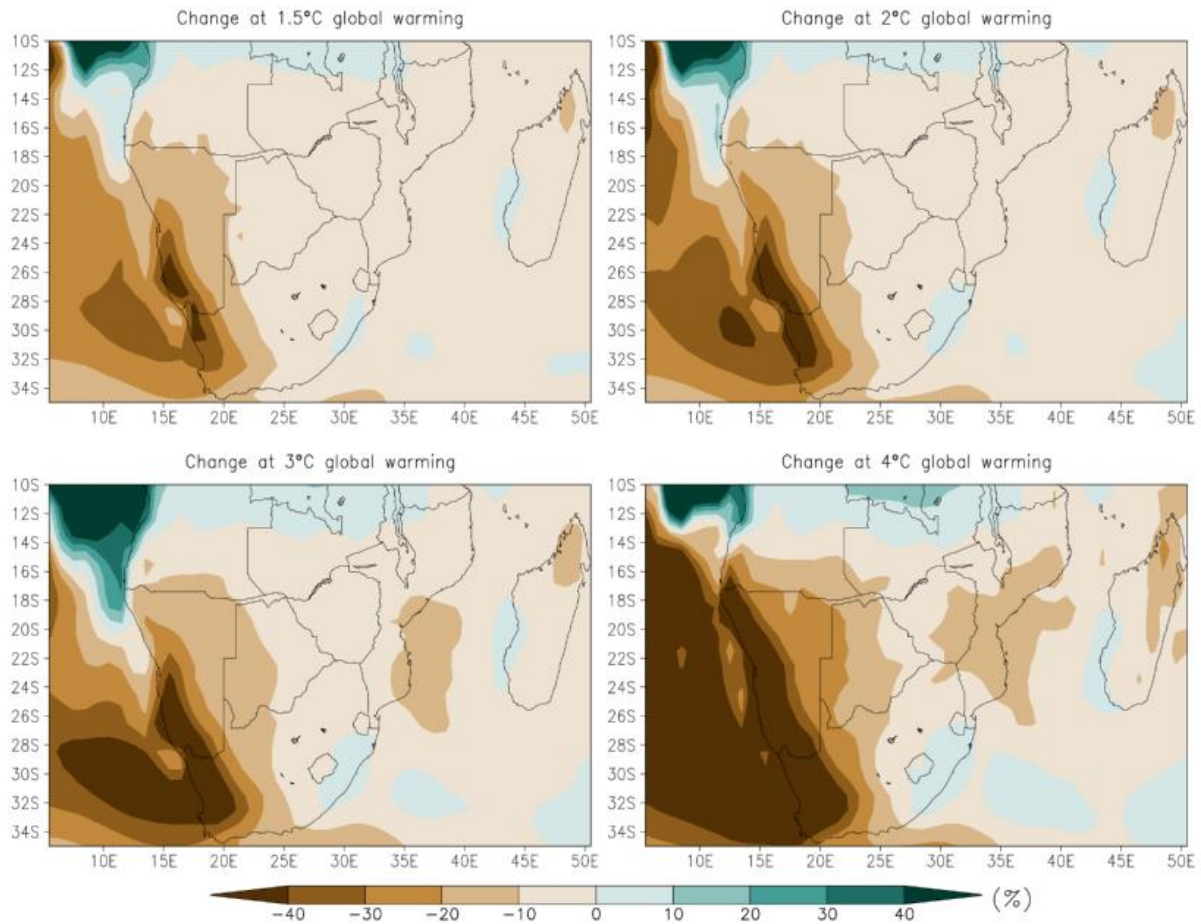


Figure A2-1: Changes in annual rainfall totals (% change) over southern Africa projected by the CMIP6 SSP5-8.5 ensemble-average, across various levels of global warming reached with respect to the 1850-1900 baseline period, with the upper two panels directly representing the end members of the global mitigation goal expressed in the Paris Agreement [source: Engelbrecht et al., 2023].

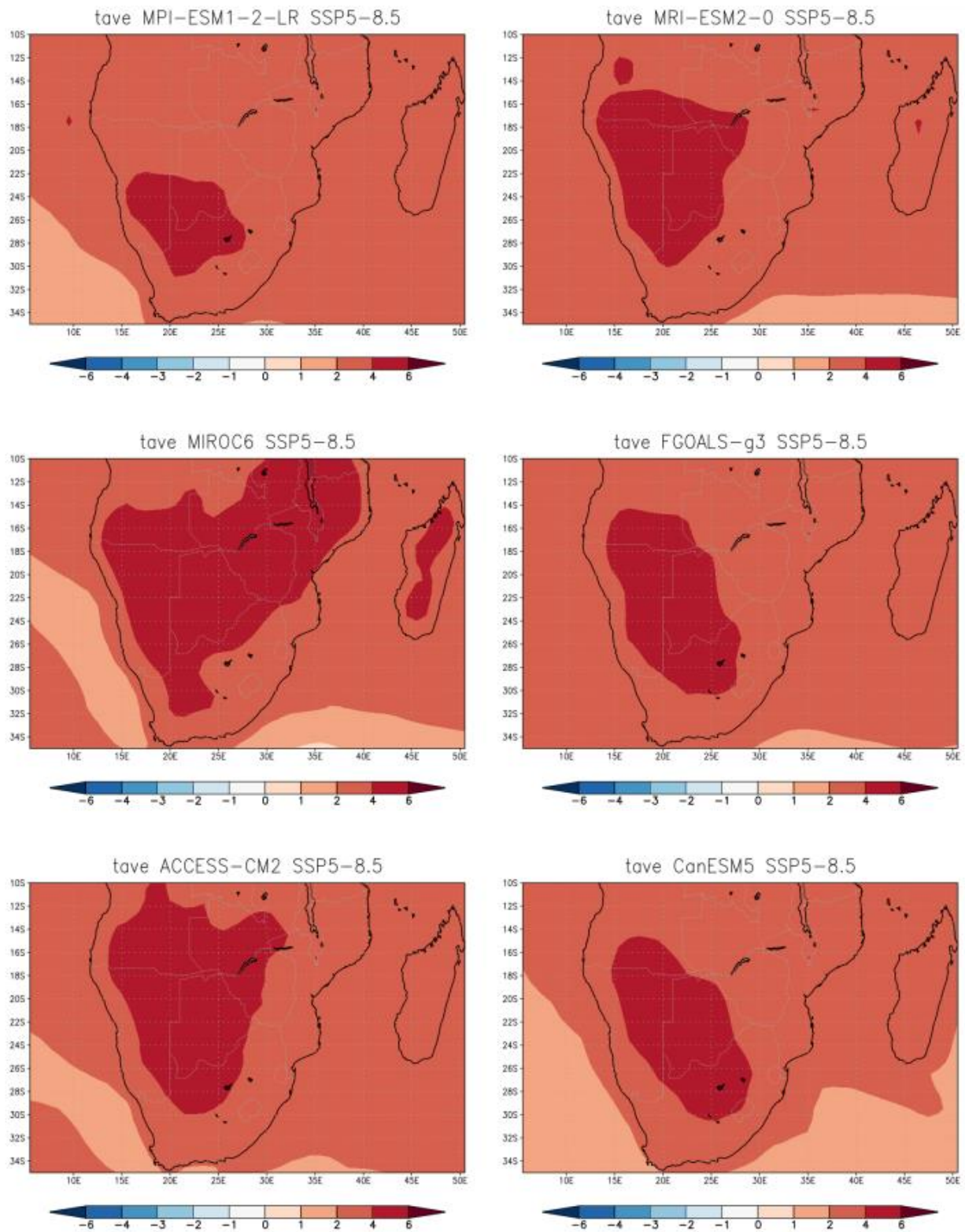


Figure A2-2 Projected changes in annual average temperature (°C) over southern Africa under 3 °C of global warming relative to pre-industrial climate, as per an ensemble of six CMIP6 GCMs [source: Engelbrecht et al., 2023].

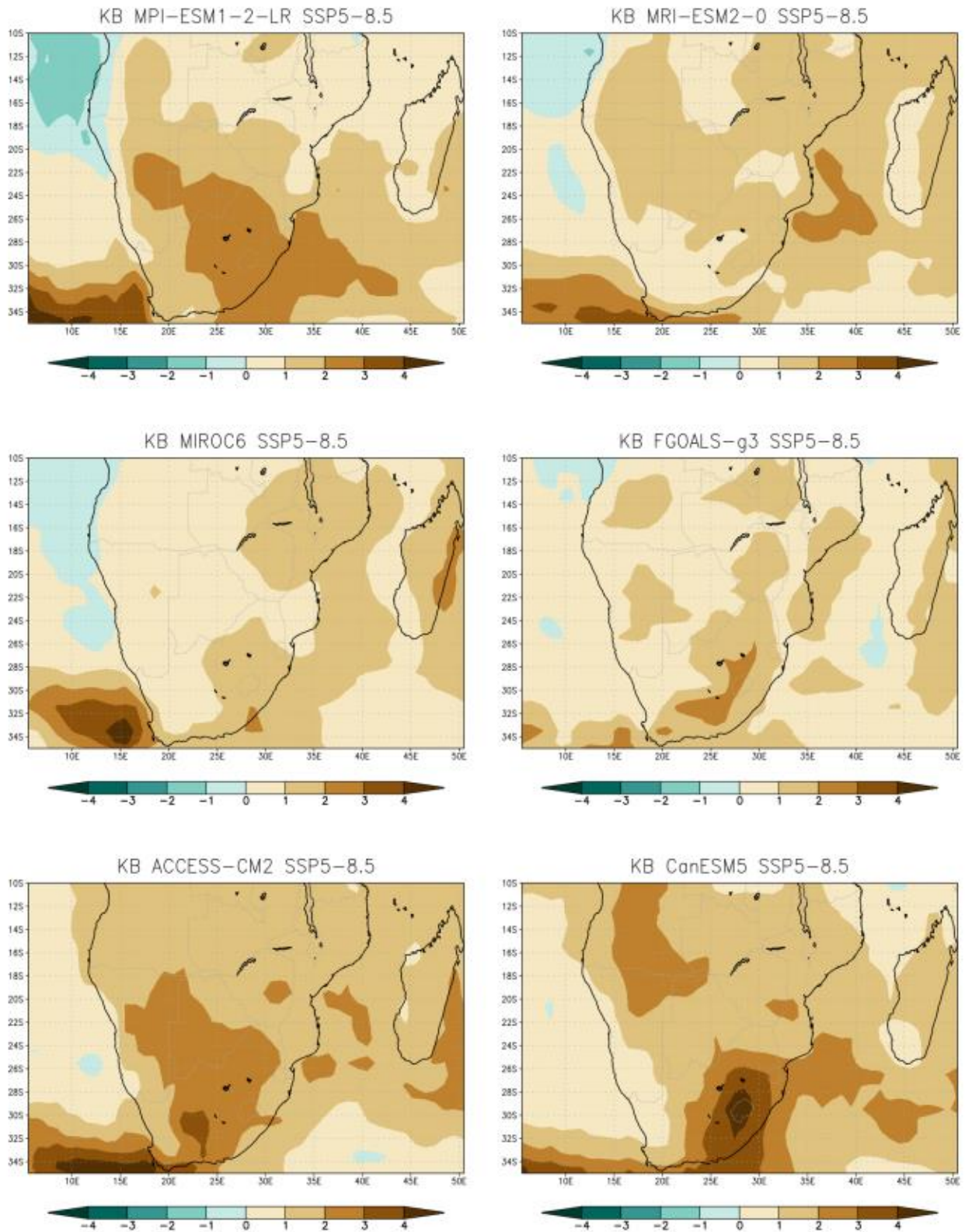


Figure A2-3: Projected changes in the Keetch-Byram drought index over southern Africa under 3 °C of global warming relative to pre-industrial climate, as per an ensemble of six CMIP6 GCMs

A.2.2. FOCUS AFRICA selection and processing

The FOCUS AFRICA datasets consist of a set of global climate models (GCMs) that were part of the IPCC 6th assessment report that was released in 2021. These climate datasets were dynamically down-scaled and statistically bias-corrected to improve the datasets performance and to reach a higher spatial resolution. The quality of the data from the FOCUS Africa project was further improved by Deltares with a bias-correction with the CHIRPS precipitation dataset that was also used for the historical simulations. The dataset consists of multiple SSPs. Similar to EDF, we focus on the SSP3-7.0 scenario a relatively pessimistic scenario with high socioeconomic challenges and regional fragmentation (Figure A2-4).

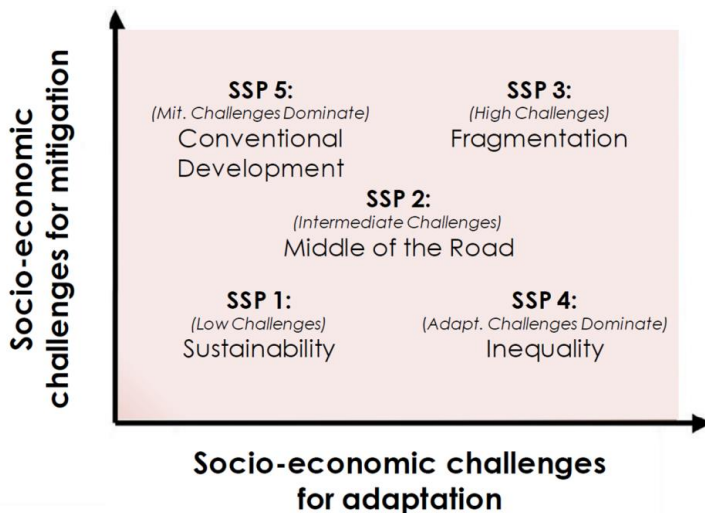


Figure A2-4 Shared Socioeconomic Pathways mapped in the challenges to mitigation/adaptation space [source: O'Neill et al., 2017⁵²]

A.2.3. Statistical analysis

We processed 30-years of climate model data around the near- and distant-future temporal boundaries (starting 2040 and 2070, respectively). These 30-year periods are considered to be sufficiently long to capture natural climate variability, while they do not contain a climate trend yet. We calculated the change in long-term average annual precipitation and the annual average temperature relative to the reference period 1992-2022 for which the CHIRPS historical meteorological precipitation data was available. The result is a sample of 33 potential series (see the scatter plot in Figure A2-5). We first remove (or “clipping”) the most extreme changes, after that we can select the wet and dry case as the most positive and most negative combined change, respectively. The mean case is decided as the minimum Euclidian distance from the mean change for the whole sample. The three selected climate models have been circled in the scatter plot:

- MPI-ESM1-2-LR (wet; left)
- GFDL-ESM4 (average; middle)
- NorESM2-LM (dry; right).

⁵² O'Neill et al. (2017) *The roads ahead: Narratives for shared socioeconomic pathways describing world futures in the 21st century*, *Global Environmental Change*, <https://doi.org/10.1016/j.gloenvcha.2015.01.004>.

n=33, n clipped=1, clipped by=Mean Precipitation

Change in Mean Precipitation and Outflow from 1992-2022 to 2070-2100

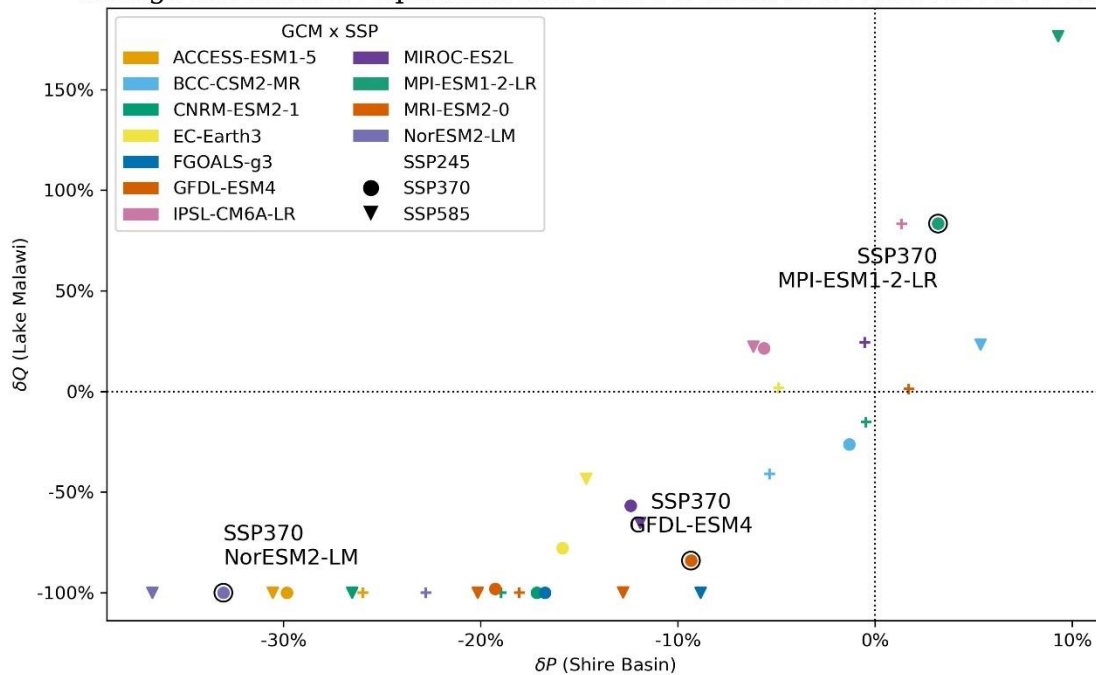


Figure A2-5 The selected climate data representing the three chosen cases are displayed in the scatter plot circled in black and annotated with their respective SSP and GCM. The scatter plots change in lake outflow (Q) and basin average precipitation (P) relative to the present period. Three models under SSP3.70 are representative cases: MPI-ESM1-2-LR (wet), GFDL-ESM4 (mean), NorESM2-LM (dry).

A.2.4. Projections of future changes in basin average precipitation and potential evapotranspiration

Figure A2-6 shows the projected change in precipitation for the Near Future 3 (equal to Near Future 4 from a precipitation point of view) and Distant Future 1 (precipitation is equal to Distant Future 2) scenario for the wet, average and dry variant. All scenarios can be considered equally likely. The wet scenario stands out. It is clear that already in the near future rainfall could increase and will then remain higher over the remainder of the century. Once analysing the discharge results, we may see that this is partly compensated by temperature increases causing increases in evaporation. According to the mean scenario there is a small reduction in annual average rainfall. The dry scenario projects a gradual and large decrease of annual average precipitation over time. A decrease in the median from ~3.5 mm/day to 1.5 mm/day.

Figure A2-7 displays the long-term average daily potential evapotranspiration for the historical period and all future climate scenarios. It is clear that for all scenarios the potential evapotranspiration will increase. This will clearly lead to a decrease in water availability in the area. For the wettest scenario increases in potential evapotranspiration are smallest.

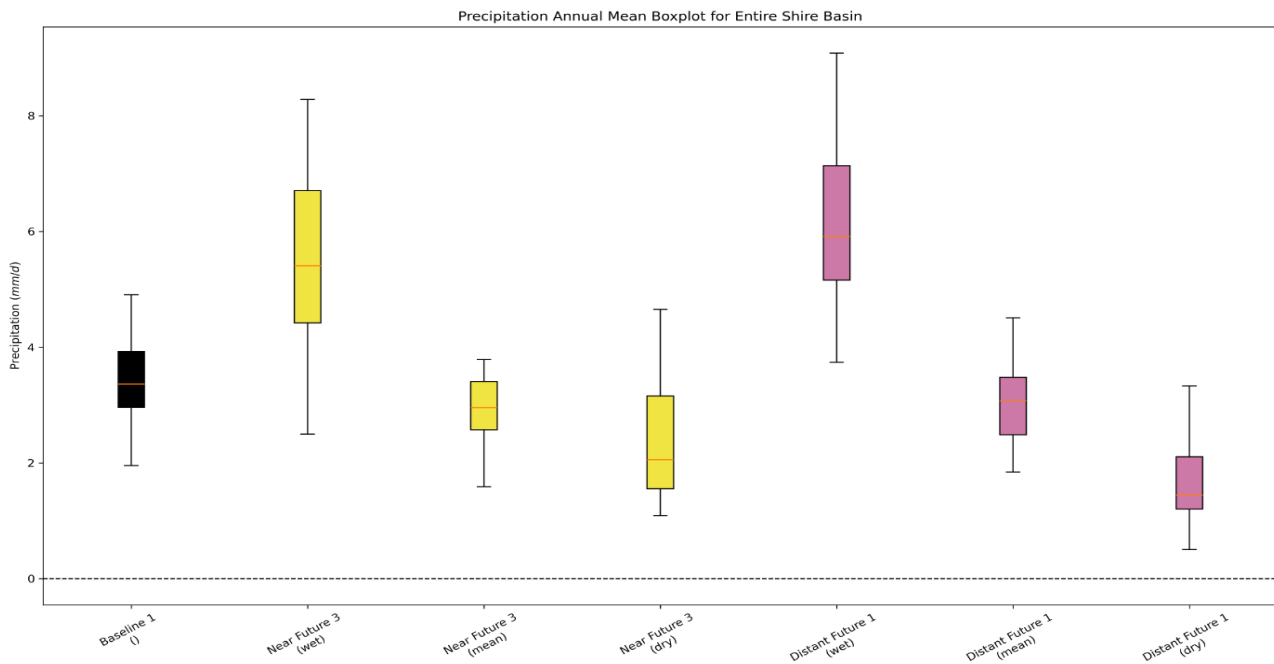


Figure A2-6 Boxplots show the median (middle line) inter-quartile range (box) and 1.5*IQR (whiskers) for the annual average daily basin mean precipitation. The plot shows data for all future time-horizons. Precipitation for Near Future 4 equals Near Future 3, and Distant Future 2 equals Distant Future 1, these have for visibility not been included in the graph.

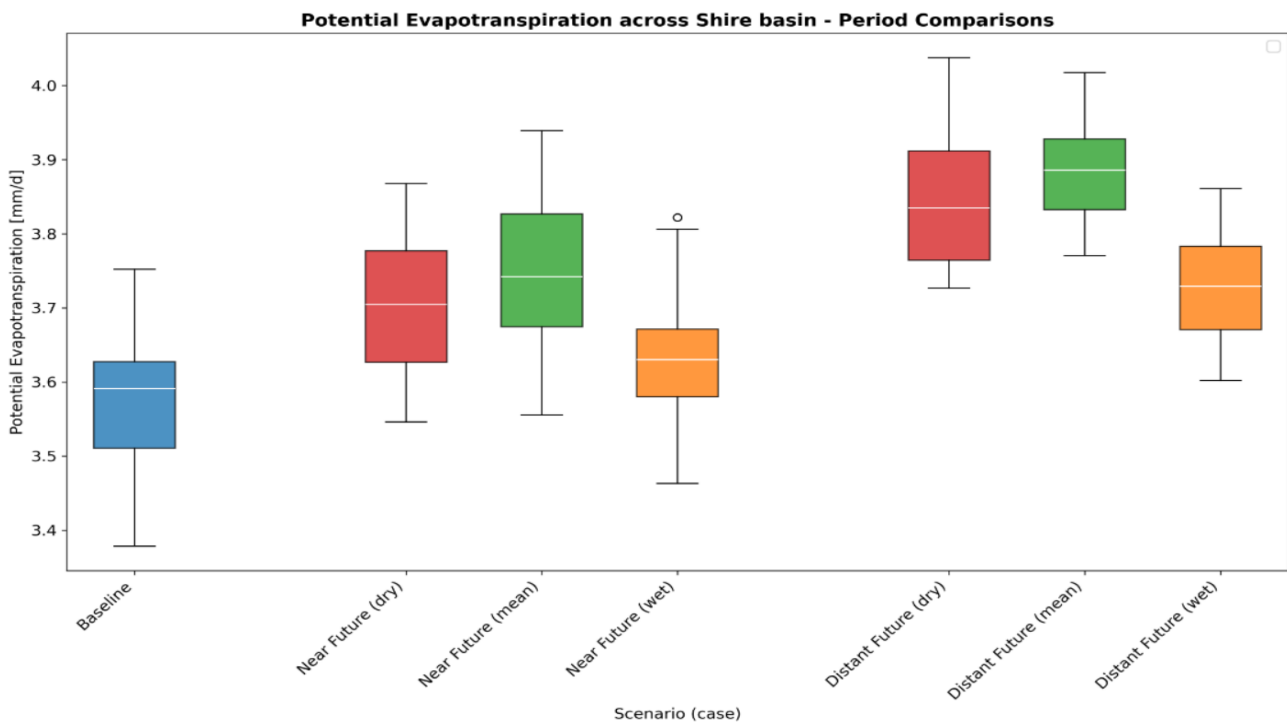


Figure A2-7 Boxplots show the median (middle line) inter-quartile range (box) and 1.5*IQR (whiskers) for the annual average daily potential evapotranspiration. The plot shows data for all future time-horizons. Potential evapotranspiration for Near Future 4 equals Near Future 3, and Distant Future 2 equals Distant Future 1, these have for visibility not been included in the graph.

Finally, we calculated the monthly average daily precipitation for the Baseline climate and the different scenarios for the near and distant future to get an impression of the changes in the wet and dry season. The

dry season projects a clear decrease in precipitation for the months November and December (Figure A2-8). In the distant future decreases are also projected by the dry scenario for the rainy season from January to April. The mean scenario is rather similar to the baseline climate. The wet scenario projects strong increases in rainfall for the wet season for the period January to April. This could potentially lead to increases in water availability and streamflow during the wet season, but it is to be investigated with the hydrological model what is more important. The increases in evaporation or the increases in precipitation.

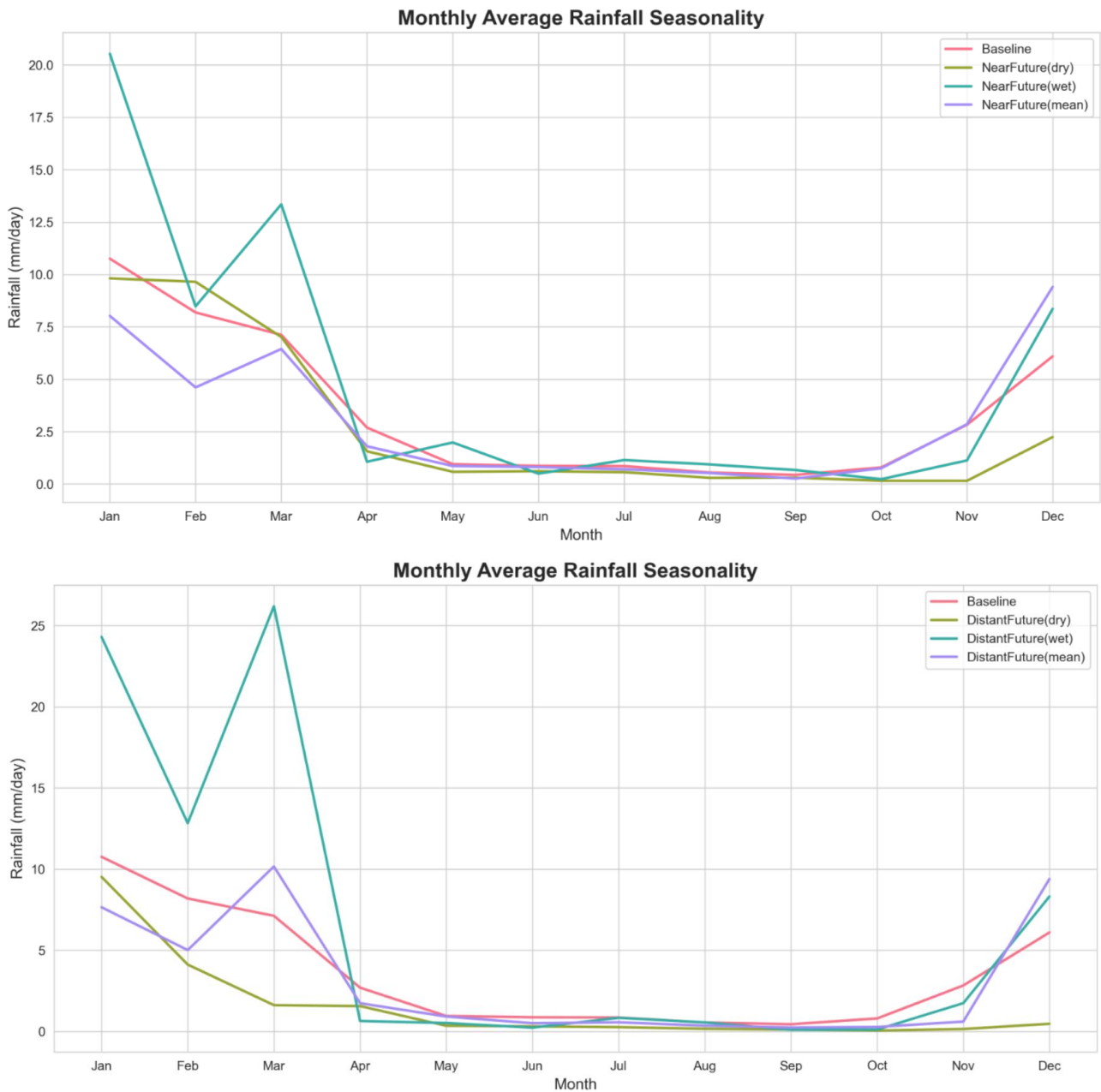


Figure A2-8 Monthly average precipitation (mm/day) for the baseline climate and the dry, wet and mean scenario variants for the near future (top) and distant future (bottom).

A.3. SUPPORTING SEDIMENT MODELLING AND ASSESSMENT

A.3.1. Introduction

In this annex we present the results of modelling and assessment of sediment transport and morphology. The analysis builds on the sediment study carried out by HR Wallingford. The results in this annex support the expert rules and response curves in the DRIFT module (see Volume 2 and 3).

A.3.2. Time series sediment loads (processing HRW results)

- We derived regression relations for sediment loads as function of discharge from the time series calculated by HR Wallingford sediment study.
- The regression relations can serve to translate alternative time series to the corresponding sediment-transport capacities at each ES site.

HR Wallingford (2023) simulated a 30-year time series of daily discharges, and their representative fluxes of sand and fines for the Shire and for all the ES sites. The data covers the “Baseline” condition and a “natural” condition. In the Baseline for 2020, the modelled average soil erosion rate is 780 ton/km²/yr, but varying for sub catchments from 107 ton/km²/yr (Nkombezi catchment) to 1,500 ton/km²/yr (in the steep Lirangwe catchment). Locally, some of the highest soil erosion rates occur in the Upper Lisungwe, alongside with the Upper Lirangwe, the hills around Blantyre and in the Mulanje Massif of the Ruo catchment. HRW also reported that hotspots (areas with extreme erosion rates of above 10,000 ton/km²/yr) contribute 25% of total soil erosion while covering only 1% of the Shire catchment. About 75% of hotspots are located on cropland. From the amount of soil erosion actually reaching the river (sediment delivery) HRW calculated annual loads of 0.01 Mt to 1.9 Mt. The overall balance for the Baseline, for annual loads, is presented in the table below.

Tabel A3-1 Overview of tributary sediment loads for the Baseline as calculated by HRW.

Name	Tributary loads (Baseline)		Cumulative at confluence [Numbers between brackets indicate Shire in-channel sedimentation]	
	Fines	Sand	Fines	Sand
Rivi Rivi & Lisanjala	0.34 Mt/yr	0.28 Mt/yr	0.34 Mt/yr	0.28 Mt/yr
Lirangwe	0.25 Mt/yr	0.21 Mt/yr	0.59 [- 0.01] Mt/yr	0.49 [- 0.02] Mt/yr
• <i>Nkula & Tedzani</i>				
Lisungwe	0.53 Mt/yr	0.43 Mt/yr	1.11 Mt/yr	0.9 Mt/yr
• <i>Mpatamanga</i>				
Nkulumadzi	0.24 Mt/yr	0.2 Mt/yr	1.35 Mt/yr	1.1 Mt/yr
Lukhubula	0.29 Mt/yr	0.23 Mt/yr	1.64 [- 0.01] Mt/yr	1.33 [- 0.02] Mt/yr
Mwanza	0.42 Mt/yr	0.18 Mt/yr	2.05 [- 0.65] Mt/yr	1.49 [- 0.97] Mt/yr
Ruo	1.1 Mt/yr	0.8 Mt/yr	2.5 Mt/yr	1.32 Mt/yr

From the time series of data a more detailed overview of the loads can be derived, which has been used as the basis for further analysis and derivation of boundary conditions for the models. The following two tables present the calculated sediment loads per ES site, to be used for modelling the Baseline condition.

Tabel A3- 2 Overview of annual loads at key station along the Shire, derived from HRW series (Baseline).

ES Site	Name	Type	Total annual 30-years	Total annual last 5 years	Total annual 30-years (excl pores)	Total annual last 5 years (excl pores)
			[ton/yr]	[ton/yr]	m ³ /yr	m ³ /yr
2	Shire down Tedzani	Fines	579,999	615,501	218,868	232,264
2		Sand	470,001	498,773	177,359	188,216
3	Shire down Mpatamanga	Fines	1,122,734	1,221,371	423,673	460,895
3		Sand	900,210	1,003,680	339,702	378,747
4	Shire down Nkulumadzi	Fines	1,362,734	1,772,141	514,239	668,732
4		Sand	1,100,210	1,462,659	415,174	551,947
5	Shire up Lukhubula conf	Fines	1,362,734	1,772,141	514,239	668,732
5		Sand	1,261,188	1,044,943	475,920	394,318

Tabel A3- 3 Overview of annual sediment loads at ES sites, as derived from HRW series (Baseline).

ES Site	Name	Type	Total annual 30-years	Total annual last 5 years	Total annual 30-years (excl pores)	Total annual last 5 years (excl pores)
			[ton/yr]	[ton/yr]	m ³ /yr	m ³ /yr
1	Shire Matope gauge	Fines	330,042	249,528	124,544	94,162
1		Sand	260,001	195,547	98,114	73,791
2a	Lisungwe	Fines	530,008	765,289	200,003	288,788
2a		Sand	430,009	620,897	162,268	234,301
4a	Nkulumadzi up	Fines	172,838	368,738	65,222	139,147
4a		Sand	144,030	307,281	54,351	115,955
4b	Nkulumadzi down	Fines	239,999	550,766	90,566	207,836
4b		Sand	199,998	458,972	75,471	173,197
5a	Lukhubula upstr	Fines	98,797	240,829	37,282	90,879
5a		Sand	80,833	197,039	30,503	74,354
5b	Mwanza	Fines	420,010	962,257	158,494	363,116
5b		Sand	180,013	412,404	67,929	155,624
7	Ruo	Fines	1,087,069	794,948	410,215	299,981
7		Sand	805,239	588,855	303,864	222,209

To be able to translate adjusted discharge series for the CIA scenarios to time series of sediment loads, we first derived regression relations that relate sediment load (and sediment concentrations) of the HRW Baseline time series to the discharges of that series. The regression was applied to sand and fines separately, and for each of the ES sites. Because the data from HRW follows from a blend of catchment modelling and numerical modelling, some of the relationships show larger scatter (notably the Shire, derived through the 1D model), while others show a well determined curve (more directly connected to the catchment models). This is illustrated in Figure A3-1.

While most stations are well represented with a linear relation, some are better fitted using a power function. Although we calculated the regression coefficient for the full 30-year series, we finally used the regression coefficients that followed from the most recent 5 years of the time series, as these approached the present

condition the best. There were significant trend changes for some stations during the 30-year period that may be associated to some extent to the model spin-up. The chosen regression coefficients appear to work also reasonably well to approximate the “naturalised” time series of sediment loads from HRW at the ES stations.

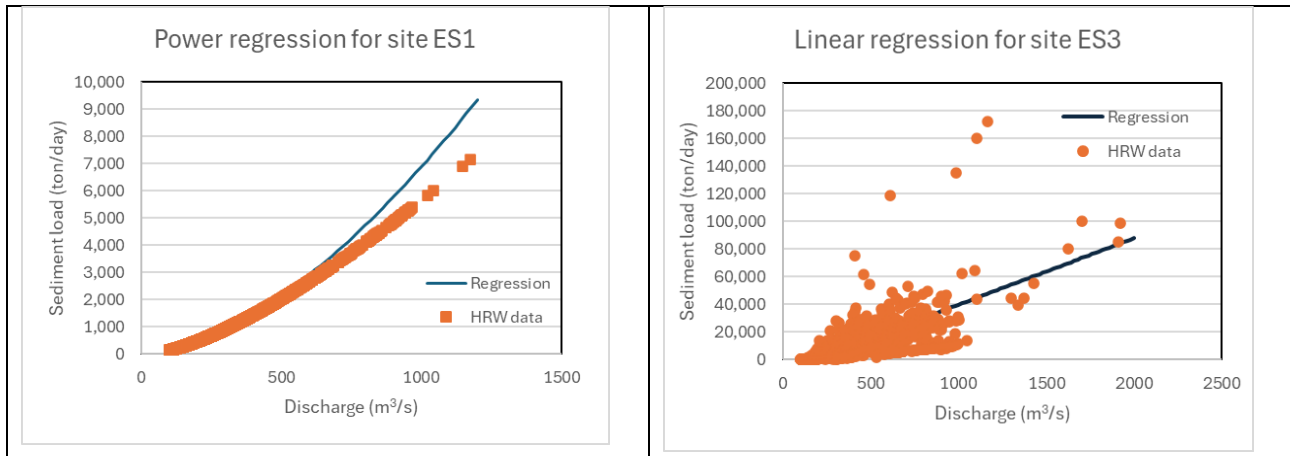


Figure A3- 1 Example of regression curves on HRW data for relating sediment load to discharge.

As indicated by HRW, the numbers should be considered with care as they are highly uncertain since they depend on the highly variable rainfall and land-use, their prognoses are even more uncertain. When applying the regression curves on the Q-series of EDF for the period 1992-2020, and average per year, we can see that at some stations these relations overestimate the annual load that was proposed by HRW. For the Shire stations this overestimation is about 20 to 30% of the total load, which is well within the uncertainty ranges that we can expect for this type of modelling. When applying these curves for the time-series generated with WFLOW in our CIA study, we found that the annual loads were even higher. For that reason, we calculated reduction factors for each ES site, to guarantee that annual loads based on the WFLOW Q-series (periode 1992-2020 Baseline) are the same as those reported by HRW (in Table A3-2 and Table A3-3).

Sand transport

For further analysis of responses of sediment loads for the scenarios, we have restricted ourselves to the regression relations for sand-transport only. As transport of sand is governed by local in-channel processes, it is more likely that the regression equations for sand respond stronger to local changes in discharge, than the load of fines that is dependent mainly on supply from catchment erosion. Although the latter also responds to precipitation changes, like discharge, it is also land use (e.g. reforestation) that makes the fines responds differently for the different scenarios. The regression relations are derived from the Baseline condition, and therefore represent conditions with the annual sediment supply per ES station as provided by HRW (Table A3-2) and sand coverage of the bed in Baseline (present) situations. For now, we consider this a representation of the sand-transport ‘capacity’, i.e. the ability of the river to carry this amount of sand with a certain discharge series, assuming an equal sand-coverage and geometry (and slope) of the river bed as in the Baseline (present).

In Table A3-4, Table A3-5, and Table A3-6 the calculated average discharge and sand-transport load per scenario and station is presented respectively. For sand transport we applied the regression relations from the HRW Baseline (Tabel A3- 5) as well as the regression relations from the Delft3D simulations for the

baseline (Table A3-6). The Delft3D model is discussed in the next section. We restricted the tables to two scenarios for Near Future and two scenarios for Distant Future. At the end of this section also other (hydrological) scenarios are presented. The colors in the tables indicate the magnitude of difference to the Baseline 1. Scenario Near Future 3 with mean climate shows a rather strong reduction of average discharge and sand transport capacity. For the Distance Future scenario, the mean climate shows again a bit of increase of discharge and sand load, but still below the Baseline. The wet-climate scenarios show a strong increase in discharge and sediment load. The results are consistent for the regression equations of HRW results and of Delft3D results.

Tabel A3- 4 Average discharge [m³/s] for scenarios per ES site (Dark red = equal or more than 100% increase relative to Baseline 1, Dark blue= equal or more than 100% decrease relative to Baseline 1).

Qavg	Baseline 1	Historic trended past	Near future 3 mean	Near future 3 wet	Distant future mean	Distant future wet
ES1	304	303	17	625	167	1043
ES2	314	313	22	634	172	1055
ES2a	17	17	6	20	10	26
ES3	336	335	30	661	186	1089
ES4	351	350	35	681	197	1113
ES4a	9	9	3	12	7	15
ES4b	14	14	5	18	11	22
ES5	358	357	37	661	173	1095
ES5a	3	3	1	4	2	4
ES5b	18	18	4	27	13	35
ES7	102	102	31	122	86	126

Tabel A3- 5 Regression relations HRW: annual sand load [tons] only sand fraction (Dark red = equal or more than 100% increase relative to Baseline 1, Dark blue= equal or more than 100% decrease relative to Baseline 1).

30 yr	Baseline 1	Historic trended past	Near future 3 mean	Near future 3 wet	Distant future mean	Distant future wet
ES1	1,261,188	1,255,854	20,344	4,290,509	653,111	9,946,855
ES2	470,001	466,872	2,112	1,446,463	178,936	2,725,189
ES2a	430,009	425,626	79,914	560,059	238,793	743,652
ES3	900,210	893,699	6,792	2,658,732	353,277	4,968,981
ES4	1,100,210	1,092,549	10,008	3,279,165	450,458	6,128,989
ES4a	144,030	144,782	15,512	224,750	107,486	285,988
ES4b	199,998	200,517	21,481	389,239	154,765	525,276
ES5	1,100,210	1,092,723	11,243	3,039,808	394,875	5,784,463
ES5a	80,833	79,547	9,060	124,997	58,506	157,723
ES5b	180,013	179,753	2,566	317,494	101,455	448,580
ES7	805,239	801,915	189,783	1,000,014	683,164	1,035,627

Tabel A3- 6 Regression relations Delft3D simulations, annual load [tons] only sand fraction (Dark red = equal or more than 100% increase relative to Baseline 1, Dark blue= equal or more than 100% decrease relative to Baseline 1). For ES2a and ES5a the results of the Delft3D runs were not available.

Sand	Baseline 1	Historic trended past	Near future 3 mean	Near future 3 wet	Distant future mean	Distant future wet
ES1	1,261,188	1,255,428	142,464	4,912,816	789,107	12,954,382
ES2	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
ES2a	430,035	426,043	27,240	856,882	288,460	1,255,490
ES3	900,210	898,947	7,155	2,631,229	355,788	4,898,505
ES4	1,105,682	1,098,401	11,912	3,098,796	451,895	5,706,106
ES4a	144,030	145,171	7,866	349,131	144,908	463,994
ES4b	200,213	200,858	13,287	502,285	167,676	708,544
ES5	1,100,210	1,096,690	187,088	1,962,264	574,986	3,197,824
ES5a	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
ES5b	180,013	176,952	47,985	242,813	103,164	345,232
ES7	805,239	801,933	54,422	1,220,269	657,644	1,218,318

Flood season

For the analysis of the contribution of high flows (wet season) we have looked at the 20-day exceedance discharges for each scenario. An overview per location and per scenario is presented in Table A3-7. For the full 30-years we calculate the discharge that on average is exceeded 20 days per year, and sum the sand-transport for these discharges as calculated using the regression relations. The results are shown in Tabel A3-8. This represents the amount or fraction of the total annual sediment transport that is transport during the flood season alone. We have chosen to look at the exceedance of a specific number of days, rather than the exceedance of a fixed discharge value. The choice of a fixed discharge value based on the Baseline data, e.g., 572 m³/s for ES1 (20 days exceedance), would cause more than 190 days of exceedance in scenario Distance Future wet, which means that the river is considered in ‘flood’ for more than 50% of the year. By choosing a fixed time, i.e. 20 days, we find that for the wet Distant Future scenario the flood discharge rises from 572 m³/s to 1556 m³/s. A more profound statistical analysis has not performed here, as these numbers are just for comparison between the scenarios in combination with the numbers for the annual loads shown previously.

Tabel A3- 7 Discharge exceeded for 20 days per year in m³/s (Dark red = equal or more than 100% increase relative to Baseline 1, Dark blue= equal or more than 100% decrease relative to Baseline 1)

	Baseline 1	Historic trended past	Near future 3 mean	Near future 3 wet	Distant future mean	Distant future wet
ES1	572	570	89	770	407	1,556
ES2	608	606	108	780	423	1,580
ES2a	56	56	18	42	33	104
ES3	675	674	131	816	462	1,659
ES4	721	718	146	846	493	1,711
ES4a	34	34	10	28	23	59

	Baseline 1	Historic trended past	Near future 3 mean	Near future 3 wet	Distant future mean	Distant future wet
ES4b	46	46	14	38	31	82
ES5	739	738	153	839	466	1,709
ES5a	9	9	3	7	6	14
ES5b	62	62	11	47	34	126
ES7	445	442	150	392	382	617

Tabel A3- 8 Sand load [tons] transported by flow which are exceeded for 20 days per year, regression HRW

20 day	Baseline 1	Historic trended past	Near future 3 mean	Near future 3 wet	Distant future mean	Distant future wet
ES1	366,813	364,711	11,243	2,660,175	335,479	3,795,971
ES2	124,671	124,308	2,112	803,303	103,010	811,061
ES2a	205,405	204,368	28,532	441,930	159,719	464,418
ES3	253,553	252,539	6,792	1,442,790	209,053	1,439,176
ES4	332,618	332,191	10,008	1,766,112	278,728	1,764,241
ES4a	89,204	89,942	11,106	187,664	80,828	194,613
ES4b	143,308	143,968	8,459	348,246	123,579	425,466
ES5	333,246	331,678	11,243	1,640,672	269,557	1,674,540
ES5a	55,780	54,712	8,664	110,837	50,179	116,284
ES5b	122,106	121,999	2,566	277,785	87,351	299,874
ES7	433,619	432,143	101,206	760,948	448,382	657,973

Interpretation

- The regression relations used here focus on sand transport. The sand fraction is most relevant for morphological changes of the riverbed, islands and lateral sand bars along the rivers. Transport of fines, such as silt and clay, are dependent mainly on the catchment erosion, and therefore do not scale with local flow conditions at the ES sites. The fines contribute mostly to the flood plain deposition, as well as siltation of the lakes and deposition in the Elephant Marsh.
- Note that the basis of the regression equations is the Baseline condition. In case of large changes in hydrology and land use compared to the Baseline, the regression equations become less accurate. For instance, distance future scenarios for wet or dry climate are deviating a lot from the Baseline scenario, as shown in this section. Still, the numbers give an indication of relative impact of hydrological changes on sand transport at the sites.
- Using the regression equations assumes that the sand coverage of the riverbed in the scenarios is equal (equal to Baseline). In the tributaries and parts of the Shire upstream of Kapichira the river is a mixed bed-rock and alluvial channel. In these sections a reduction of catchment erosion, hence a lower supply of sand, may cause the river to erode its sand from the bedrock. This reduction of available sand on the riverbed will cause a reduction of the annual transport proportional to the reduction of the area of exposed sand. This has not been included in the numbers. Therefore, the modelling results of the next section provide support.

- For main channel of Shire (sites ES1, ES2, ES3, ES4, ES5) practically 1/3 of the annual transport of sand occurs during the high flows that occur for 20 days on average. For tributaries this is roughly 50% to 100%.
- For the Distance Future with wet climate, the contribution of floods to the annual load is quite similar to the Baseline 1 percentages, although the total annual load has increased by a factor of 3 to 10 (depending on the location).

Table A3-9 Percentage of sand transport with exceedence 20-day relative to full annual load (the more 'red' the higher the contribution of flood flows).

	Baseline 1	Historic trended past	Near future 3 mean	Near future 3 wet	Distant future mean	Distant future wet
ES1	29%	29%	55%	62%	51%	38%
ES2	27%	27%	100%	56%	58%	30%
ES2a	48%	48%	36%	79%	67%	62%
ES3	28%	28%	100%	54%	59%	29%
ES4	30%	30%	100%	54%	62%	29%
ES4a	62%	62%	72%	83%	75%	68%
ES4b	72%	72%	39%	89%	80%	81%
ES5	30%	30%	100%	54%	68%	29%
ES5a	69%	69%	96%	89%	86%	74%
ES5b	68%	68%	100%	87%	86%	67%
ES7	54%	54%	53%	76%	66%	64%

- The increase (or decrease) of average flow (i.e., more or less volume of water passing in a year) translates to an increase (or decrease) of annual loads. If we look at the relative change of sand transport of each scenario, it can be shown that sand transport changes more rapidly than change in average transport, but that this change collapses well to a weakly non-linear regression line for all the ES sites as shown in Figure A3-2. For instance, an increase of average discharge with 100% (e.g., from 300 m³/s to 600 m³/s) causes an increase of annual sand transport of 200% (e.g., 500 ton/yr to 1,000 ton/yr). Roughly the line in the figure rises with a slope 1:2. For the decreasing discharges (e.g. negative percentages) this line slopes 1:1. Although the plots in Figure A3-2 are based on the regression lines for HRW-calculated loads, a similar plot follows when based on the regression lines for the loads calculated with the Delft3D models.
- Similarly for flood periods, i.e. the condition that is exceeded for max. 20 days/yr we have plotted the total load transported during these 20 days in Figure A3- 3. Also, these results show a reasonable fit to a trendline, but for the higher percentages this line shows more exponential behaviour than the annual plot. Also, it shows that the response for the Near Future 3 is more than twice as strong as for the Distant Future 1 for the same value (%) of change of annual average discharge.

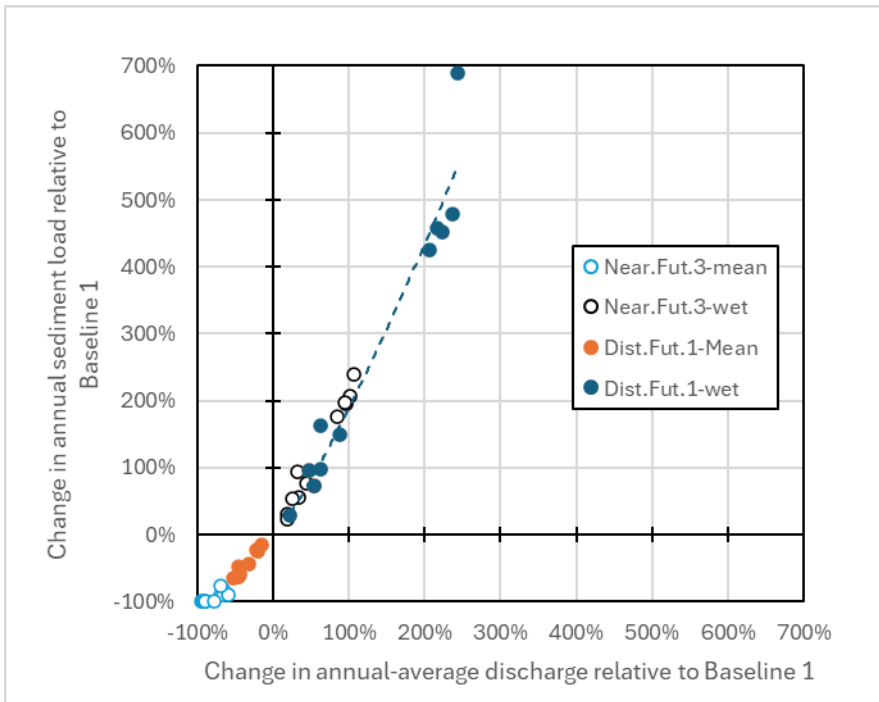


Figure A3- 2 Change in annual sediment load as function of change in average discharge relative to Baseline 1. Each marker corresponds to an ES site. Numbers based on regression of HRW loads for sand.

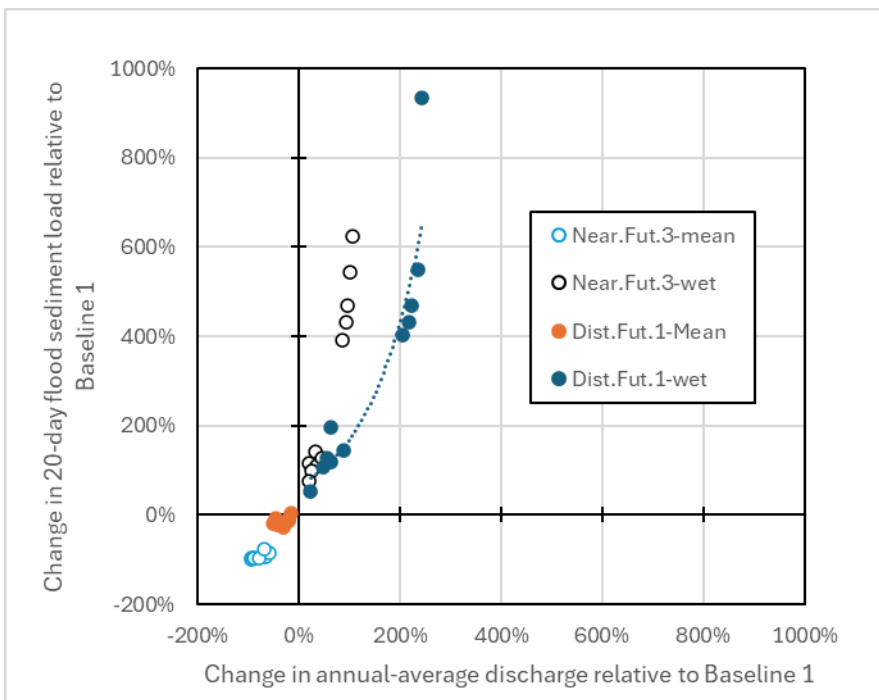


Figure A3- 3 Change in less than 20-days exceeded sediment load (flood conditions) as function of change in average discharge relative to Baseline 1. Each marker corresponds to an ES site. Numbers based on regression of HRW loads for sand.

Based in the relations in Figure A3-2 we can estimate the annual sediment load for all the considered hydrological scenarios. The results are listed in Table A3-9. Although the numbers do not coincide exactly

with those obtained from the actual calculations above (for the considered scenarios), the mutual comparison between the scenarios is valid quite well. Note that relative impacts in the main Shire sites (ES1, ES2, ES3 and ES4, ES5) are more significant (i.e. darker colors) than those of the tributary sites. It is also well visible that for all Near Future scenarios except for EC-Earth (dry) the average discharge and average sand load is increasing in the main Shire stations, while it reduces in all the tributary stations. In the Distant Future this difference is less apparent.

Table B- 9 Overview of annual *sand* load estimated (roughly) from hydrological discharge series for each scenario and per ES site, with values in [Mt/yr]. Blue color indicates lower annual loads than Baseline 1 (reference), red colors mean higher loads than Baseline 1, white means more or less similar sand loads. DF = Distance Future; NF = Near Future.

	ES1	ES2	ES2a	ES3	ES4	ES4a	ES4b	ES5	ES5a	ES5b	ES7
Baseline 1	1.26	0.47	0.43	0.90	1.10	0.14	0.20	1.10	0.08	0.18	0.81
Baseline 2	1.27	0.47	0.43	0.91	1.11	0.14	0.20	1.02	0.08	0.18	0.81
1900 historic	1.22	0.45	0.41	0.87	1.06	0.14	0.20	1.06	0.07	0.17	0.79
NF 1	1.25	0.46	0.35	0.87	1.07	0.14	0.20	0.98	0.08	0.18	0.78
NF 3 Nor	3.19	1.15	0.27	2.07	2.45	0.13	0.17	2.24	0.06	0.14	0.60
NF3 EC Earth	0.08	0.04	0.16	0.09	0.12	0.05	0.07	0.13	0.04	0.04	0.26
NF3 Miroc	6.49	2.33	0.15	4.16	4.87	0.07	0.10	4.61	0.05	0.07	0.36
NF 3 GDL	3.30	1.19	0.32	2.16	2.56	0.13	0.18	2.35	0.07	0.15	0.66
NF 3 MPI	2.28	0.82	0.27	1.48	1.77	0.12	0.17	1.57	0.06	0.14	0.66
NF4 Nor	3.22	1.16	0.27	2.09	2.48	0.13	0.17	2.27	0.06	0.14	0.61
NF4 GFDL	3.31	1.19	0.33	2.17	2.58	0.14	0.19	2.37	0.07	0.15	0.68
NF4 MPI	2.26	0.81	0.28	1.48	1.76	0.13	0.17	1.56	0.07	0.14	0.67
DF1 NOR	0.08	0.03	0.10	0.07	0.11	0.07	0.10	0.07	0.04	0.06	0.37
DF1 GFDL	0.74	0.27	0.21	0.52	0.64	0.10	0.14	0.55	0.06	0.10	0.63
DF1 MPI	4.57	1.66	0.74	3.08	3.69	0.28	0.39	3.48	0.14	0.43	1.05
DS2-Nor	0.08	0.03	0.09	0.07	0.10	0.07	0.09	0.07	0.03	0.06	0.35
DF2 GFDL	0.73	0.27	0.20	0.51	0.63	0.10	0.14	0.54	0.05	0.10	0.61
DF2 MPI	4.55	1.65	0.70	3.06	3.66	0.28	0.38	3.46	0.13	0.43	1.01

A.3.3. Numerical model






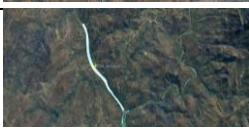


- We developed quasi-3D numerical models for sediment and morphology simulation for the Shire River and for all ES tributary sites.
- The main purpose of the model is to support the response curves for sediment load and morphodynamics in DRIFT.
- The model provides short-term local responses to modified sediment loads and discharges.
- We use the Delft3D modelling system (see text box overleaf).



Delft3D 4 suite

Delft3D is a world-leading 3D modelling suite for investigating hydrodynamics, sediment transport, and water quality and morphology for river, estuarine and coastal environments. It simulates two-dimensional (in either the horizontal or a vertical plane) and three-dimensional flow, sediment transport and morphology, waves, water quality and ecology and can handle the interactions between these processes. The modules Delft3D flow (FLOW), morphology (MOR) and waves (WAVE) are available in open source. The FLOW module, the heart of Delft3D, calculates non-stationary flux and transport phenomena resulting from tidal and meteorological forcing in an adjustable curvilinear grid or spherical coordinates. Delft3D is developed, maintained and supported by Deltares in The Netherlands. For more information: <https://www.deltares.nl/en/software-and-data/products/delft3d-4-suite>

The following box presents an overview of the eight models created for this study.

Sub-model	Extent	Grid	Grid size
Shire-Up (sites ES3, ES4, ES4b)	Shire ES3 to Kapichira and Nkulumadzi ES4b (Shire branch: 10 km long, ES3 at 0.7 km, ES4 at 1 km; Mkulum. branch: 5.5 km, ES4b at 2.8 km)		10436 grid cells
Shire-Down (site ES5)	Down Kapichira to Elephant Marsh (45 km long, ES5 at 13 km, Mwanza at 38 km)		39586 grid cells
Shire-Matope (ES1)	Shire upstream of Matope bridge (2.7 km long, ES1 at 2 km)		4360 grid cells
Lisungwe (ES2a)	Lisungwe upstream of M6 bridge (5.7 km long, ES2a at 2.8 km)		6400 grid cells
Nkulumadzi upstream	Nkulumadzi (1.9 km long, ES4a at 700 m)		2560 grid cells
Likhubula (ES5a)	Likhubula (2.2 km long, ES5a at 1 km)		2880 grid cells
Mwanza (ES5b)	Mwanza (23 km long, ES5b at 14 km)		24300 grid cells
Ruo (ES7)	Ruo (1.5 km, ES7 at 2.1 km, 8 km)		4580 grid cells

Topography

Sources:

- LIDAR measurements of 2023 are used for all dry areas and tributaries.
- Bathymetric measurements (cross sections) are used for the Shire River. Data sets of 2018 and 2023 are considered.

The data are processed towards the Delft3D grid by means of grid-cell averaging (high-resolution LIDAR data) or by triangular interpolation (low-resolution cross-section data). Both data sets were interpolated separately first. LIDAR cannot penetrate the water surface, i.e. for inundated areas it gives the elevation of that water surface rather than the submerged riverbed. Most of the tributaries carried minor discharge during the LIDAR surveys, and the data sufficiently cover the full channel topography. However, the main channel of the Shire and some reaches of the Mwanza and Ruo river were having a reasonable discharge and water surface. For these sections we applied the interpolated cross sections to replace the water-surface by the interpolated bed level.

For the Majete reach of the Shire River, and the tributaries Mwanza and Ruo, the presence of islands, bar, rapids and rocks causes variations in water depth that are not captured by the cross-section survey. We derived a water-surface line (contour) from Google Earth image of April 2023 for positions of banks, rapids, islands and rocks to interpolate between the cross-sections. For the near dry sections of tributaries the Lidar data represents the channels reasonably well. Only for the larger tributaries with some reasonable flow during the Lidar flights, such as Ruo and Mwanza, we considered a correction on Lidar data to derive the elevation of the wet part of the riverbed. The Lidar survey only provides elevation of the water surface and of the dry land surface.

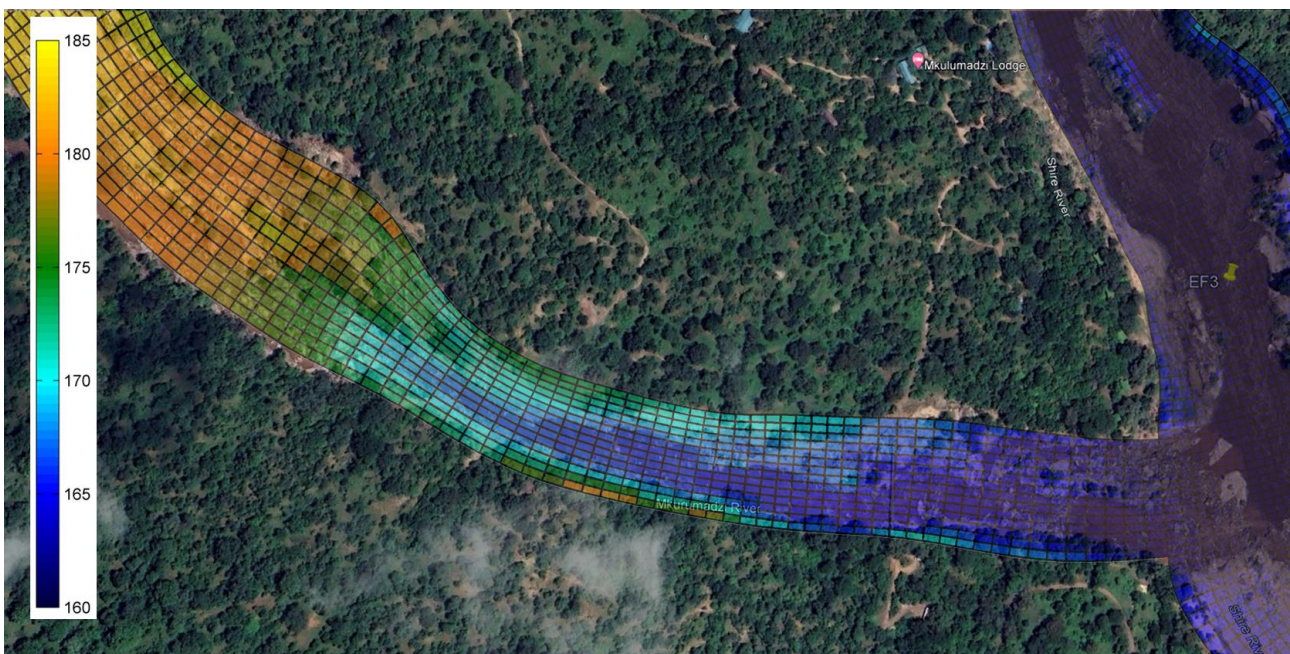


Figure A3- 4 Example of projecting of bed-topography data (LIDAR 2023) on the Delft3D grid, showing the confluence of Nkulumadzi and Shire River.

For Lukhubula upstream (site ES5a) and Mwanza (site ES5b) we had to use the 2017 Lidar data, as these areas were not covered by the 2023 LIDAR flights.

Sediment

We took sediment samples in various tributaries and many of the ES sites. From the sieving curves for these samples, as well as from the data collected by HRW, we can define characteristic diameter (sand fraction) and characteristic fall velocity (fines, i.e. silt and clay) per river section. For sand transport modelling the transport models of Van Rijn (1984) or Engelund and Hansen (1967) are used. These are slightly different than the modified Ackers and White model used by HRW, which is not available in Delft3D, the results seem to correspond reasonably well.

In Table A3-10 we summarise the parameter settings and sediment characteristics used for the different sub models. The median grain size $D_{i,50}$ varies depending on the location, based on variations in coarseness of the mixture in sediment samples, or based on estimates from field observations. For bed-rock sections the initial sediment thickness is taken equal to a small value or derived from an previous spin-up run. In the simulations for these rivers the first 2 years are used to distribute the incoming sediments through the model domain, such that in the 3rd year the model is using a realistic ‘initial state’. Only these 3rd year results were used for further analysis.

Tabel A3- 10 Sediment characteristics and settings used for the sub models in Delft3D.

	Shire-up and Nkulumadzi (ES4b, ES3, ES4)	Shire-down and Eleph. Marsh (ES5)	ES1 Shire Matope	ES2a Lisungwe	ES4a Nkulumadzi; ES5a Lhukubula	ES7 Ruo	ES5b Mwanza
$D_{i,50}$ [μm]	350	250	400	350	500	400	400
Sand-transport	Van Rijn (1984)	Van Rijn (1984)	Van Rijn (1984)	Van Rijn (1984)	Van Rijn (1984)	Van Rijn (1984)	Eng. Hansen
W_s [mm/s]	0.222563	0.222563	1.44	0.222563	0.222563	0.222563	0.222563
ASHld	0.4	0.3	0.4	0.3	0.4	0.4	0.3
Init. sed. thickness [m]	Varying (from spin-up)	Varying (5.0 m in main chann., 0.0 m in flood plain)	0.05	Varying (5.0 m upstr. to 0.0 m downstr.)	0.05	5.0	5.0

The parameter ASHld is used for the selected Talmon et al. transverse-slope effect and acts together with the spiral flow parametrization (in bends) with a multiplication factor for spiral flow of $E_{\text{spiral}} = 1.0$.

Fine sediment is calculated using the Partheniades and Krone concept for sedimentation and erosion and an advection-diffusion solver for concentrations. For the fines all models apply the following parameters: critical shear stress for erosion $\tau_{\text{cr}} = 0.1 \text{ N/m}^2$; Erosion parameter = $0.0001 \text{ kg/m}^2/\text{s}$; eddy diffusivity = $0.5 \text{ m}^2/\text{s}$ or $1.0 \text{ m}^2/\text{s}$.

As we are applying the multiple-fraction approach we were able to use the bookkeeping system of grain-size distribution of under-layers. During sedimentation processes the model can deposit individual layers while storing its distribution of sand and fines. In subsequent erosion events, the erodibility and feed of material depends on the composition of the layer in which the bed is cutting. For the model we allow a maximum of 10 under layers, each having a maximum thickness of 0.2 m. The thickness of the top-layer, i.e. the transport-

or mixing-layer, is taken constant, equal to 1.0 m. The top-layer moves up and down with the bed as it erodes or aggrades, and its composition varies based on the fluxes of sediment transport and to and from the under layers.

Boundary conditions

As we run the Delft3D model for only 3 years, it is relevant to choose a time series of discharges and sediment loads that represents the variation in discharge over a year (low and high flows), and that represents the full 30-year statistics of flows and sediment loads for each scenario. The method we chose is calculating a synthetic hydrograph based on duration of discharges for the 30-year period and use the duration curve to construct an average hydrograph that can be repeated each year. We defined the following 5 steps for each inflow boundary for the sub models defined in this study:

1. For each ES site, determine the discharge-duration curve from the time series of discharges for the WFLOW hydrology for Baseline 1 situation.
2. Construct a smooth 1 year hydrograph, starting at August 1st, with peak on January 30th and ending at August 1st next year. We cut-off the highest peak at discharge levels that occur for periods less than one or two days in the duration curve. These flood events are explored separately.

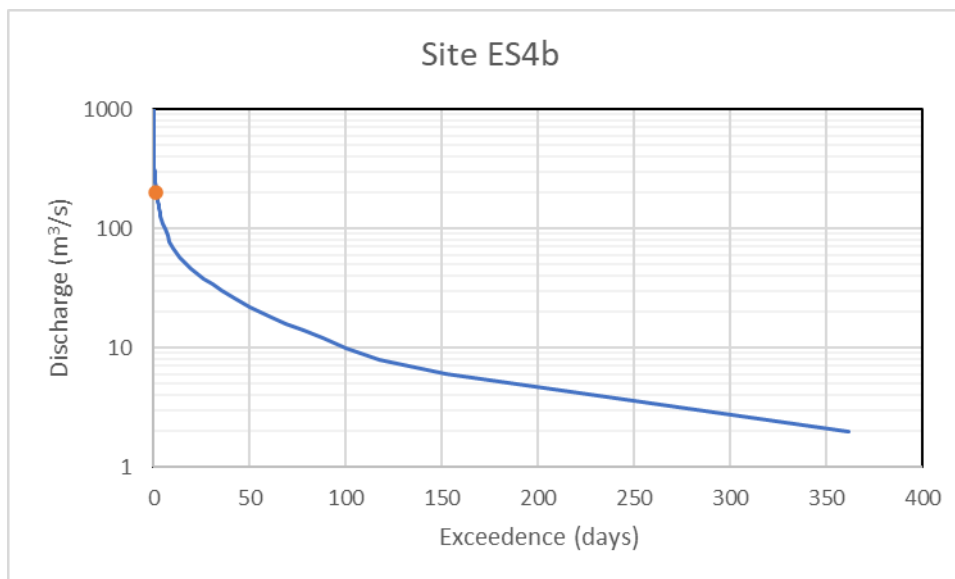


Figure A3- 5 Duration curve (example) for site ES4b for Baseline 1 discharge series from WFLOW. Orange dot is cut-off value used to construct the yearly hydrograph for morphology.

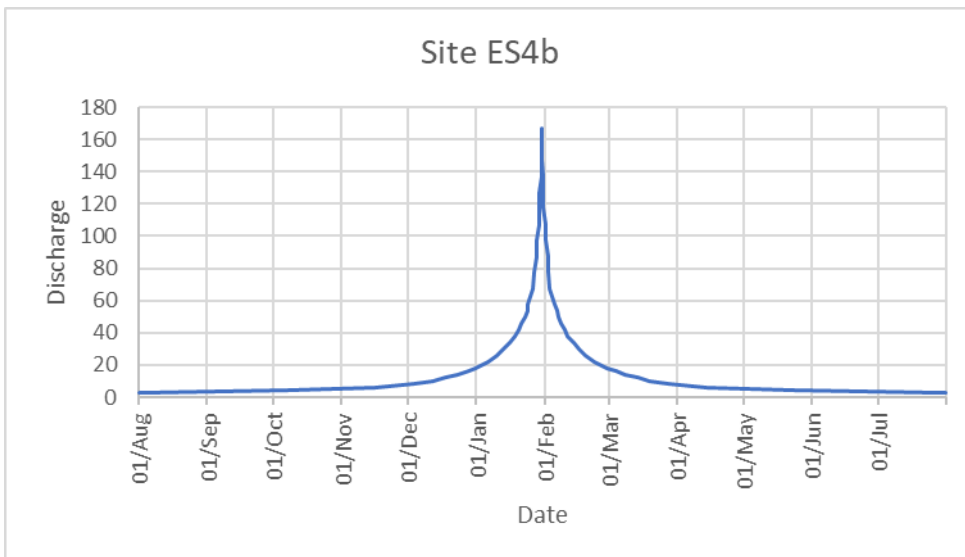


Figure A3- 6 Annual hydrograph (example) for site ES4 derived from the duration curve as shown in Figure A3- 5.

3. Use regression $S(Q)$ and $C(Q)$ relation as obtained for the Baseline runs of HRW to calculate the sand load and fines load for each discharge value in this curve.
4. Calculate the cumulative annual load for this curve by integrating the calculate loads of one year. It is essential to preserve the annual loads as obtained from the HRW sediment study as much as possible. The difference of the synthetic discharge series (based on WFLOW hydrology) and HRW (based on EDF hydrology) cause a difference in annual loads. Therefore use a scaling factor to fit the annual loads as presented by HRW. These scale factors are larger and smaller than 1.0, depending on location and fraction (sand load or fines concentration).

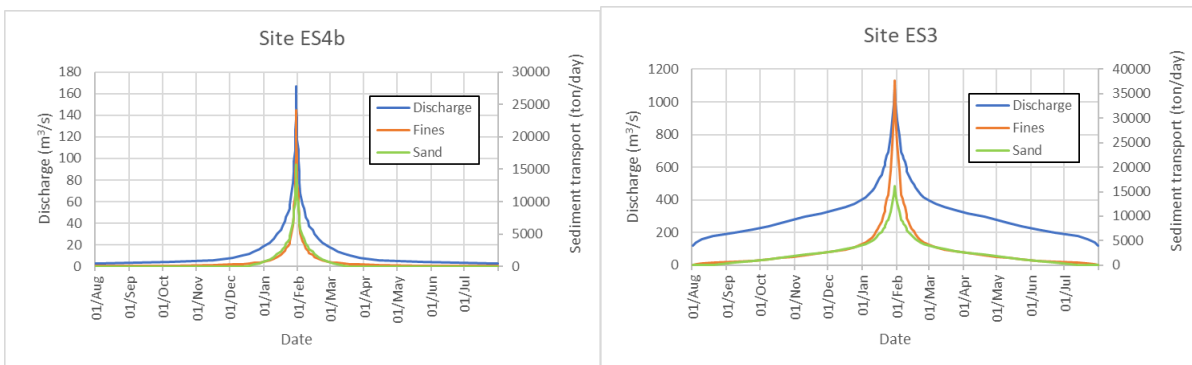


Figure A3- 7 Example of annual time series for discharge and sediment loads produced for sites ES4b and ES3, and imposed to the inflow boundaries of the Shire and Nkulumadzi model upstream of Kapichira HPP

5. Generate time series for boundaries by repeating the annual hydrograph

Calculation settings

- Simulations start at a fictive date 1/1/2024. The peak of the wet period always occurs on 1 July. The runs were carried out for a 3-year period.
- A morphological factor 8 was used to speed-up simulations.

- For the simulations with decreased load we reduced all incoming loads (both sand and fines) of the reference run with 50% (multiplying with 0.5). This reduction applied both to the incoming loads from the Shire River (just upstream of ES3) and from the Nklulumadzi River (upstream of ES4b).
- For the increased loads we increased all loads with 50% (multiplying with a factor 1.5).
- For calculating change in the sand-bar area we calculated cell areas with sediment thickness more than 5 cm. Volumes are calculated by multiplying these cell areas with the thickness.

Hydraulic roughness = Manning = 0.03 m^{1/3}/s

Eddy viscosity = 0.5 m²/s or 1.0 m²/s

Eddy diffusivity = 0.5 m²/s or 1.0 m²/s

Flow time step = 6 s or 3 s

Tuning morphodynamics

Proper calibration of the morphodynamic model requires detailed information on time-dependent evolution of the river bed, as well as the conditions of flow and sediment load that have caused this evolution. However, in the Shire basin such data are not available. The available data are cross-sectional changes for the period 2018 to 2023 at selected cross sections in the main Shire River, as well as satellite images of the planform changes and channel-patterns. Figure A3-8 shows the development of sand bars and bank erosion process simulated and compared to the observed changes in channel platform from satellite images. The locations of the changes were found to coincide well by tuning parameter settings for sediment transport and transverse-slope effects.

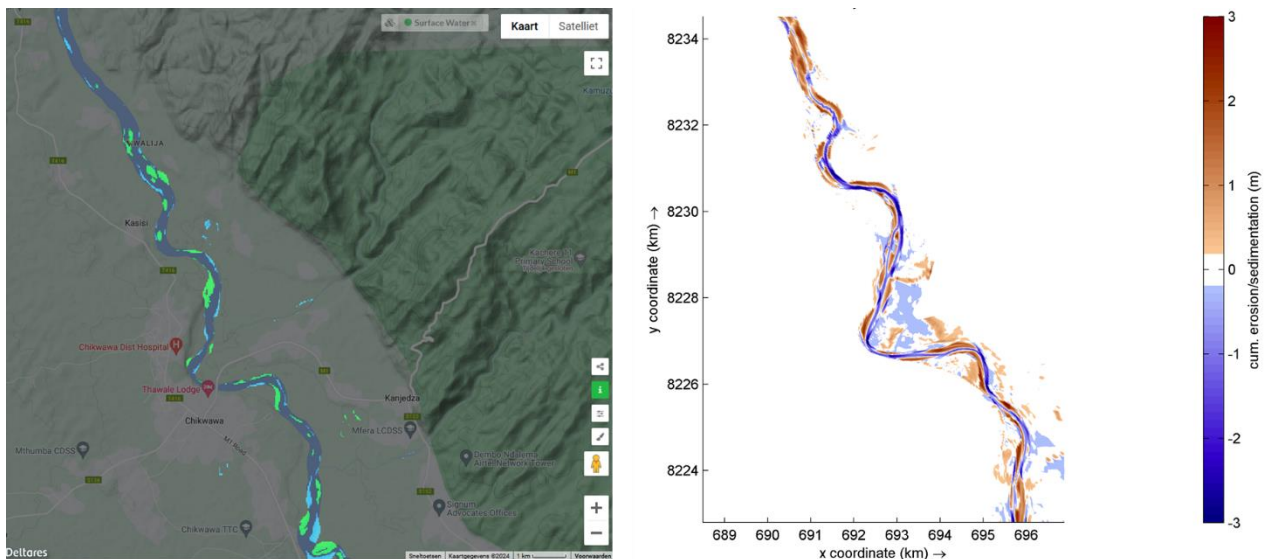


Figure B- 8 Development of main channel of Shire River near Chikwawa (reach Kapichira to Elephant Marsh): left panel shows observed change in channel position from 2000-2023, with blue is land that became water, and green is water that became land; right panel shows the Delft3D simulation for Baseline 1 with blue is erosion and brown is sedimentation.

A similar result can be derived for the tributaries. For the Mwanza River some final results for bed evolution and channel formation are shown in Figure A3-9. Although there is not an exact match with the final channel position in 2022, the nature of the channel patterns is considered to be quite similar. That means the number of channels in cross-section (modes) depending on discharge history (1 to 2 modes) and the length scale of the meandering patterns.

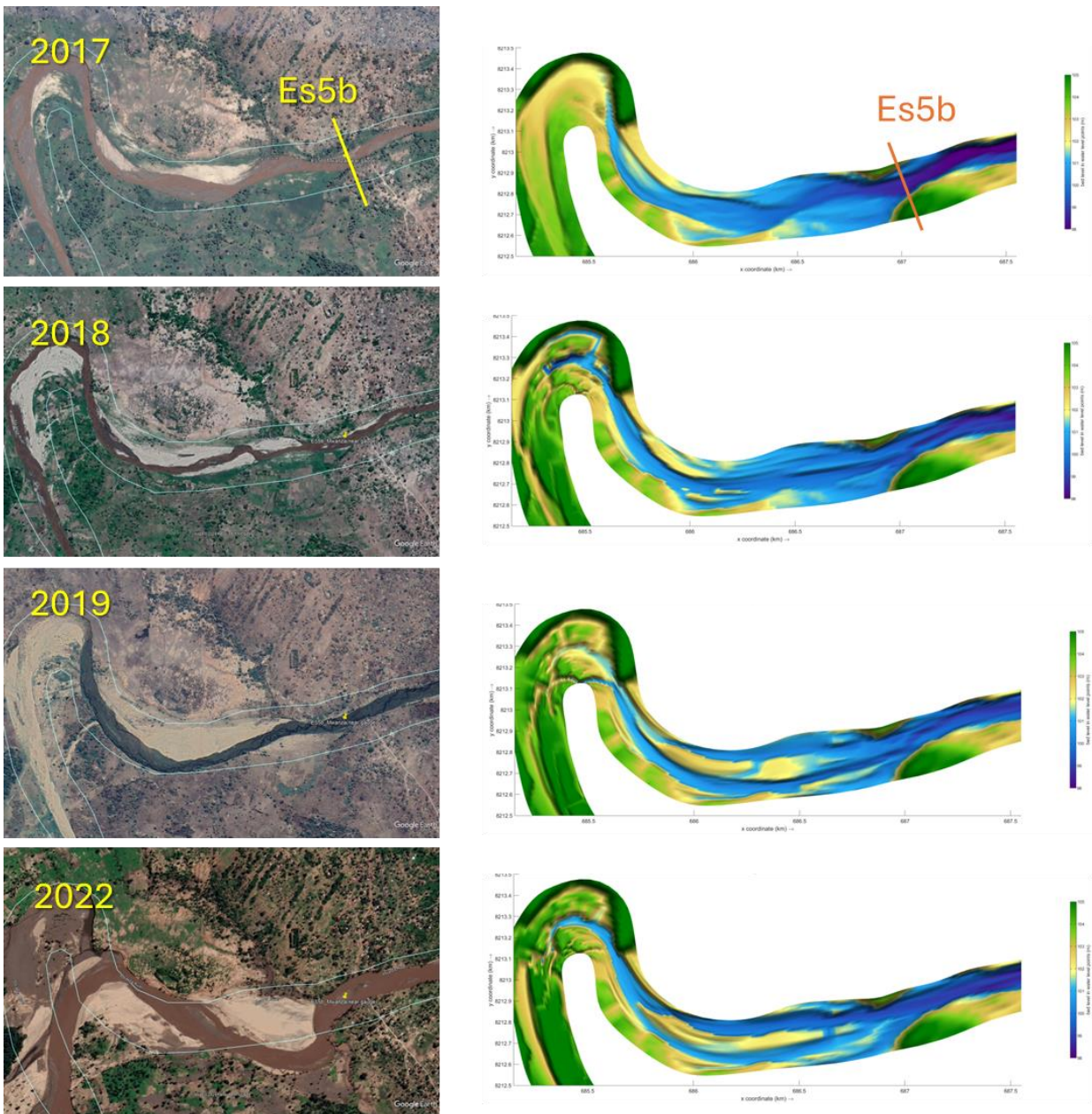


Figure A3- 9 Development of channels in Mwanza River (around site ES5b) from Google Earth and from simulations with the Delft3D model

Also for Ruo River such a comparison was made between the satellite images and the Delft3D simulations in Figure A3-10. The results illustrate the resemblance in formation of channels and bars with specific wave lengths and amplitudes in both model and satellite observations.

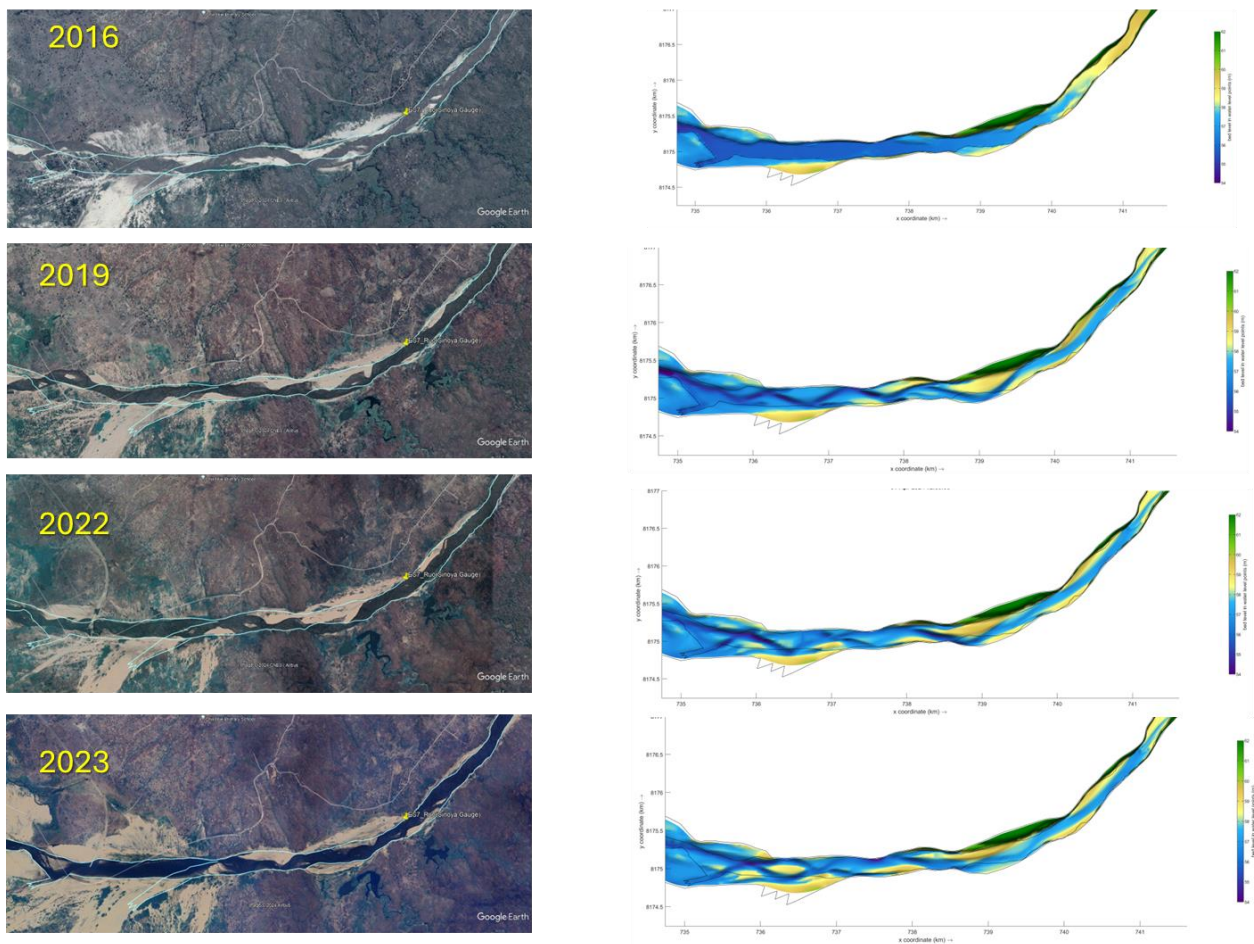


Figure A3-10 Development of channels in Ruo River (around site ES7) from Google Earth and from simulations with the Delft3D model

A.3.4. Sediment loads from the Delft3D model

Analysing the simulations we can make the following general observations:

- In several tribs the response of sediment loads (both sand and fines) is more or less equal to the change in supply of sediments at the inflow boundaries. However, not all tribs and the main stream show this linear response.
- The simulations only last 3 years, hence at locations further downstream the response of changes in boundary conditions has not yet fully developed (especially for the sand fraction). Be careful with interpretation.
- Some sites show strong hysteresis effects.
- Reduction of sediment loads generally leads to a decrease of sand bar volume and area as expected. The impact of Mpatamanga dam (full block of sediment) is more severe than reducing the loads in Shire and Nkulumadzi with 50%.

All results follow from using a schematized average hydrograph, representing the present climate (30-years) from Deltares hydrology. Details of impacts may differ for more extreme conditions, e.g. sand can be deposited or eroded at higher elevations in the cross-section when water levels are higher than our hydrograph.

The following results show the sediment load as function of time at the ES sites for the third year of each 3-year period simulations. The three scenarios are:

1. Reference simulation with sediment loads at boundaries corresponding to those of HRW
2. Simulation with decreased sediment loads, in which we decreased the imposed loads with 50% (multiply with factor 0.5)
3. Simulation with increased sediment loads, in which we increased the imposed loads with 50% (multiply with factor 1.5)

The results show that sites close to boundaries show a faster response to the change in boundary conditions than those further downstream. Especially this holds for the fines, which do not have much storage along the river.

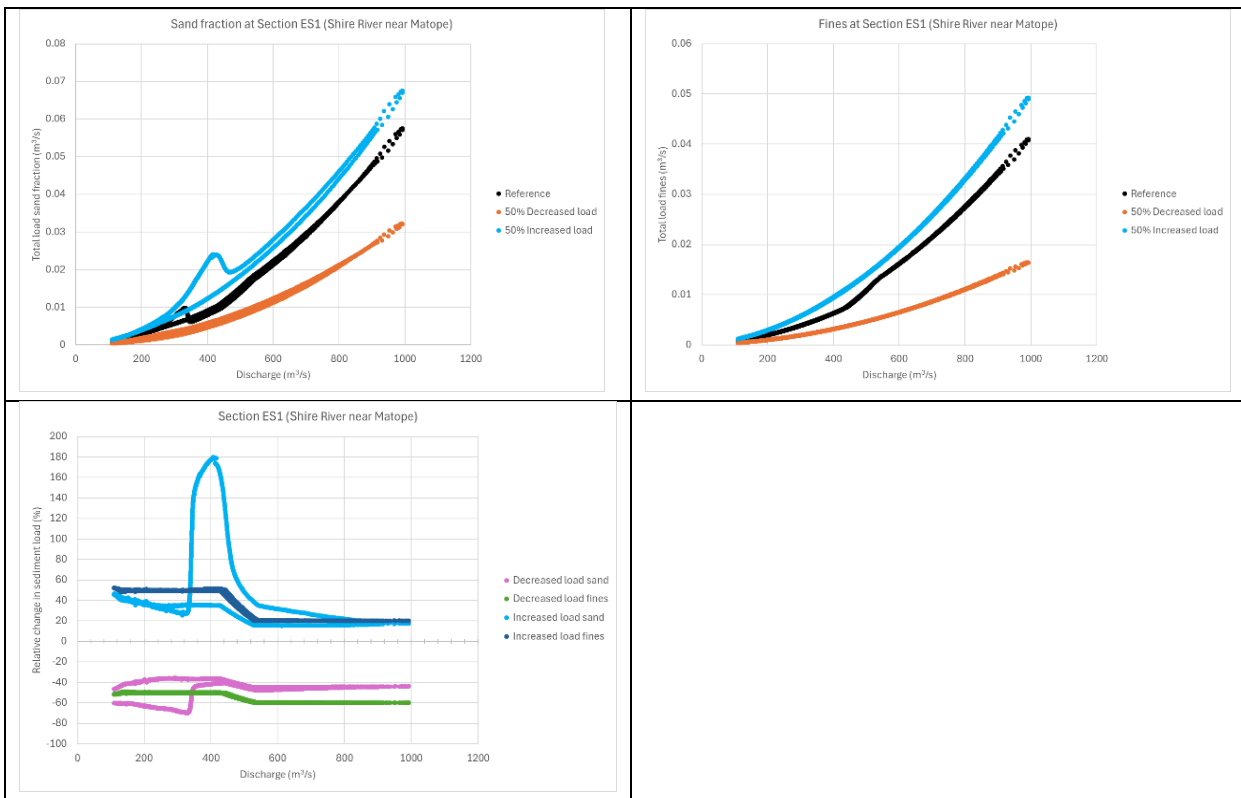


Figure A3- 11 Simulated response of sediment load (sand and fines, m³/s) for site ES1, with 50% increase and decrease of sediment inflow relative to Baseline conditions (reference).

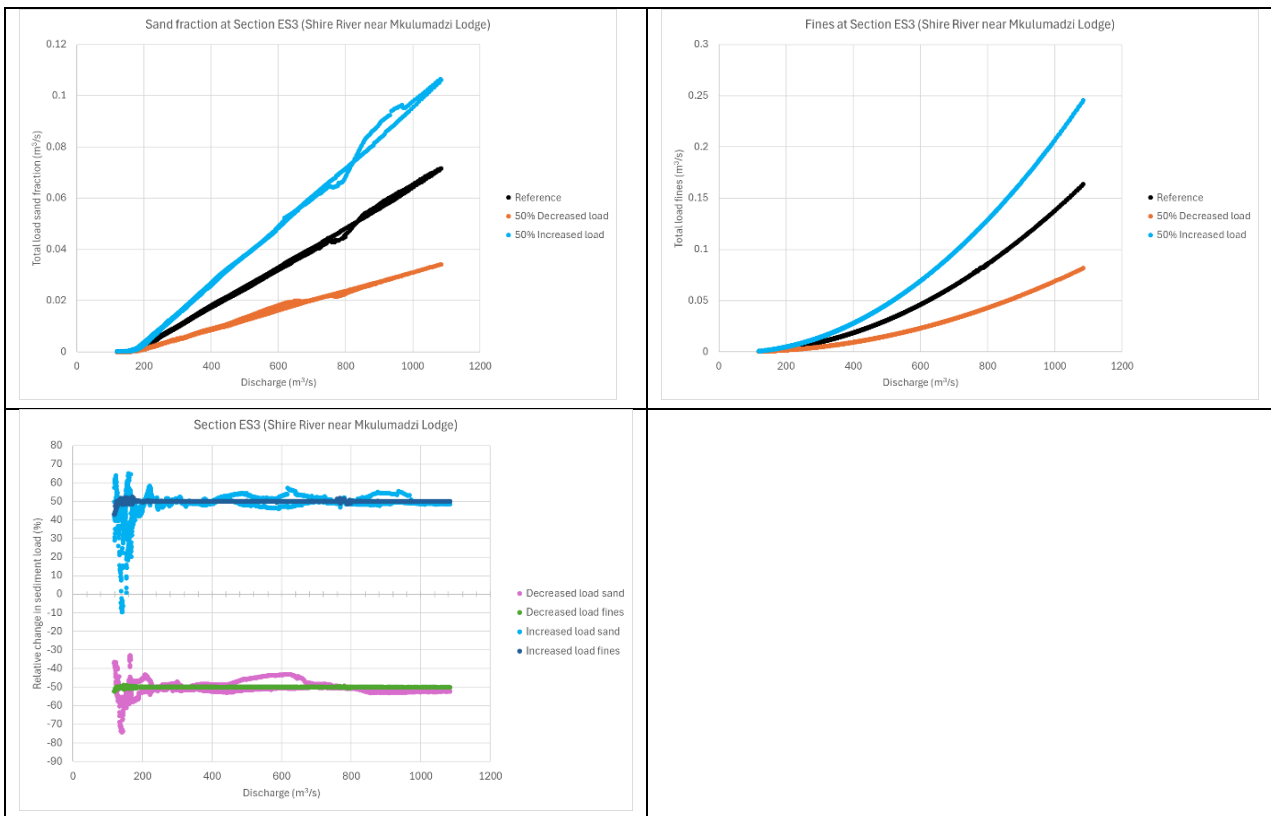


Figure A3- 12 Simulated response of sediment load (sand and fines, m³/s) for site ES3, with 50% increase and decrease of sediment inflow relative to Baseline conditions (reference).

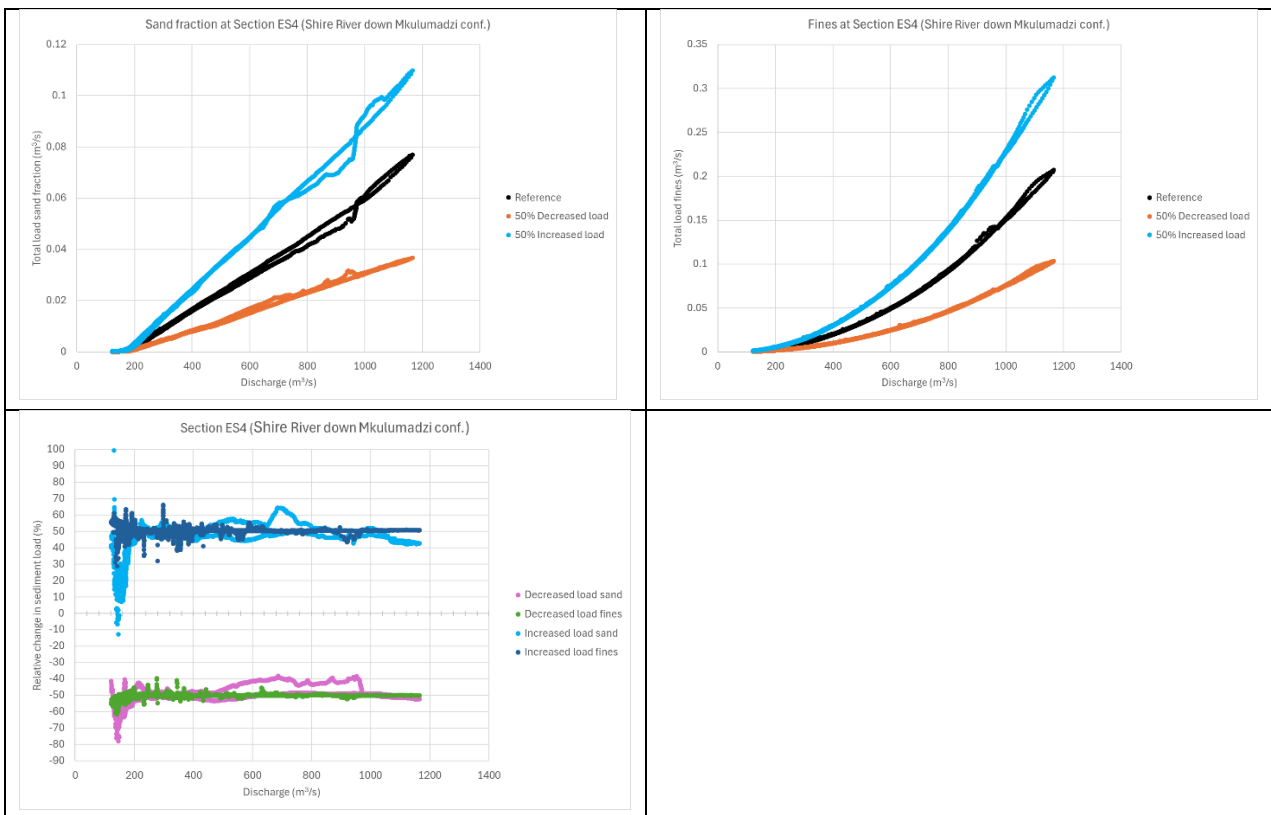


Figure A3- 13 Simulated response of sediment load (sand and fines, m³/s) for site ES4, with 50% increase and decrease of sediment inflow relative to Baseline conditions (reference).

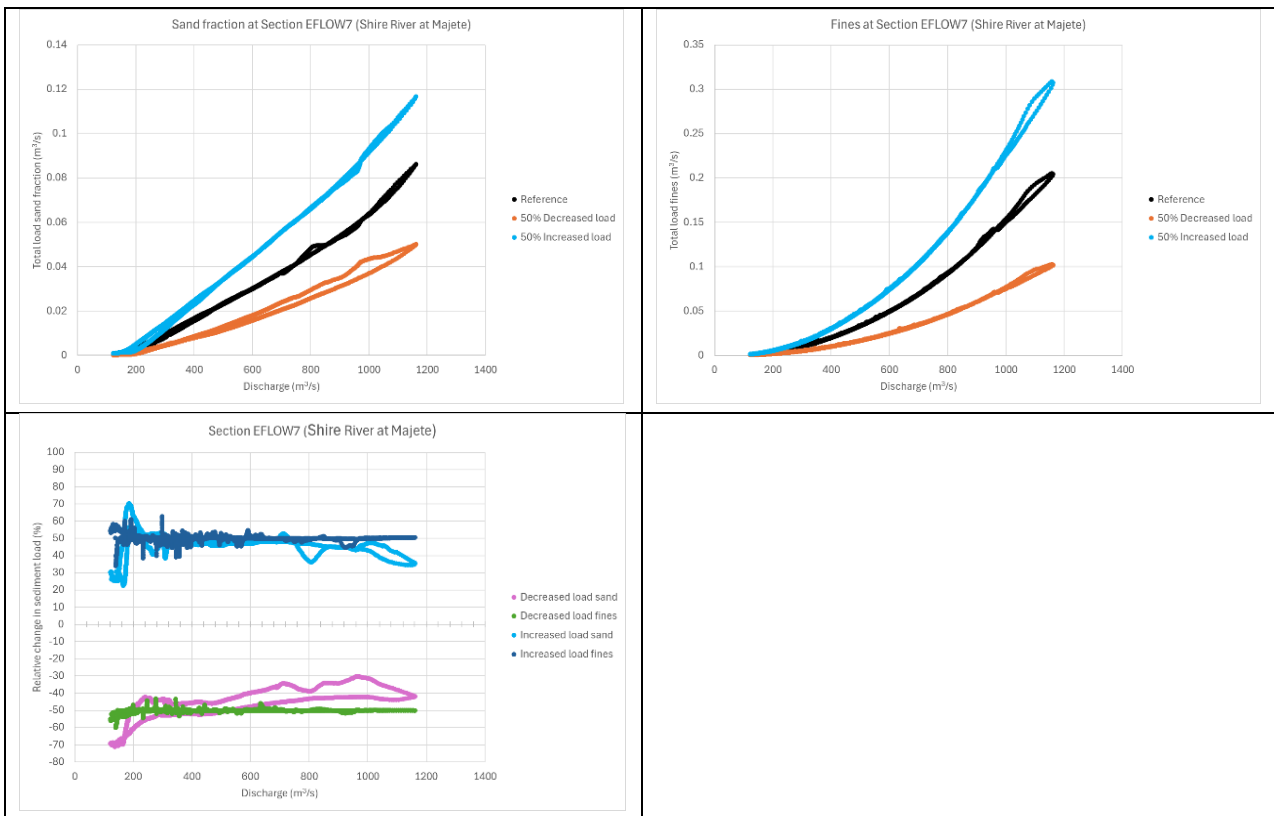


Figure A3-14 Simulated response of sediment load (sand and fines, m³/s) for site Eflow7 (Shire River at Majete, from 2018 Eflow study), with 50% increase and decrease of sediment inflow relative to Baseline conditions (reference).

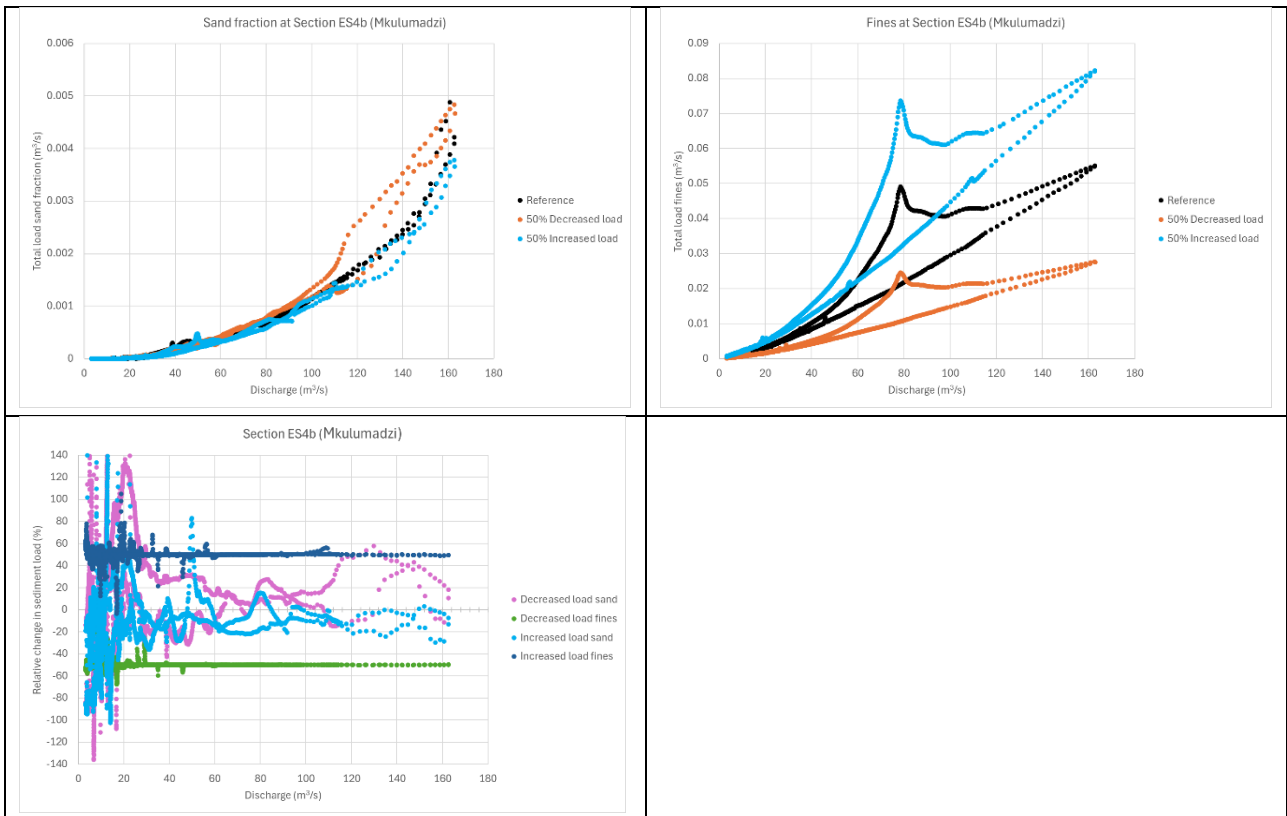


Figure A3-15 Simulated response of sediment load (sand and fines, m³/s) for site ES4, with 50% increase and decrease of sediment inflow relative to Baseline conditions (reference).

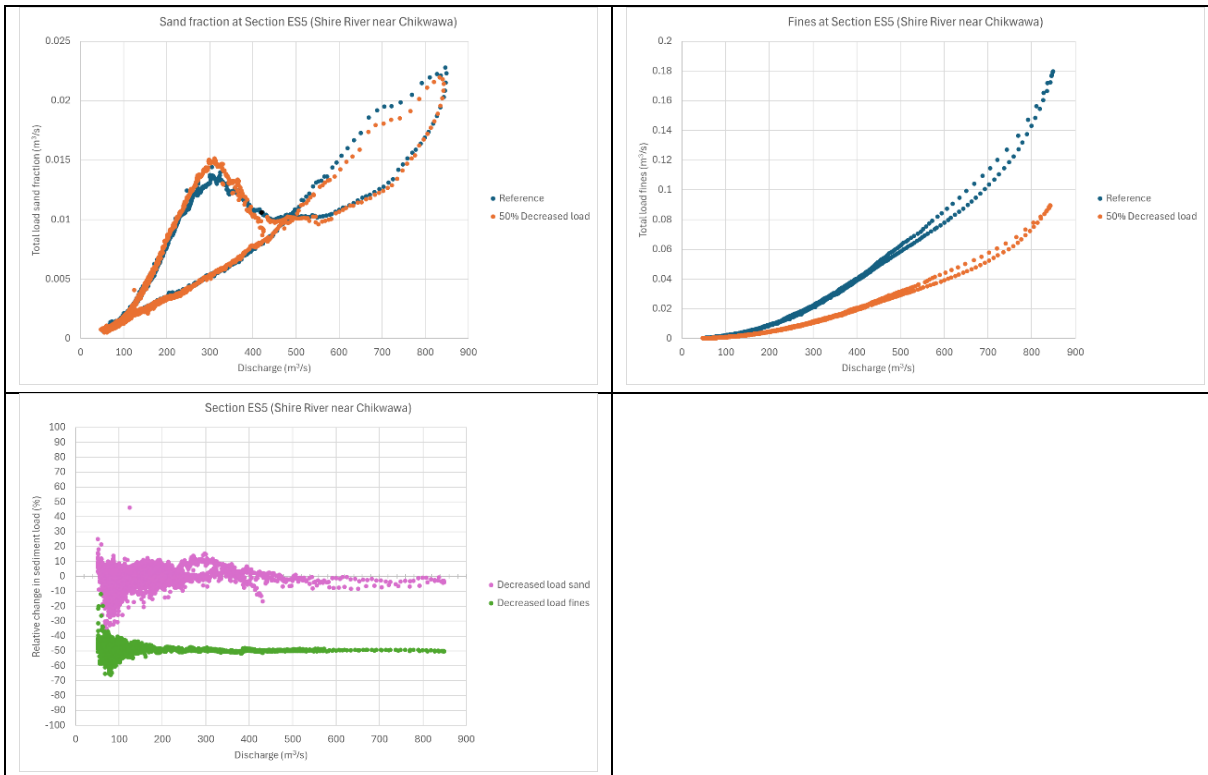


Figure A3- 16 Simulated response of sediment load (sand and fines, m³/s) for site ES5, with 50% decrease of sediment inflow relative to Baseline conditions (reference).

ES5 is just upstream of the Likhubula confluence. In the 5 year run the effect of changing the boundary condition at Kapichira is not yet felt in the sand-transport rates at ES5. The change of supply is absorbed by the section between Kapichira and ES5. Only for the fines the effect is clearly visible. The simulation with increased load is not added to this figure as it was not completed due to massive sedimentation at the upstream end.

The following figures show the inflow of fine sediments into the lakes on the left bank of the Shire near Chikwawa.

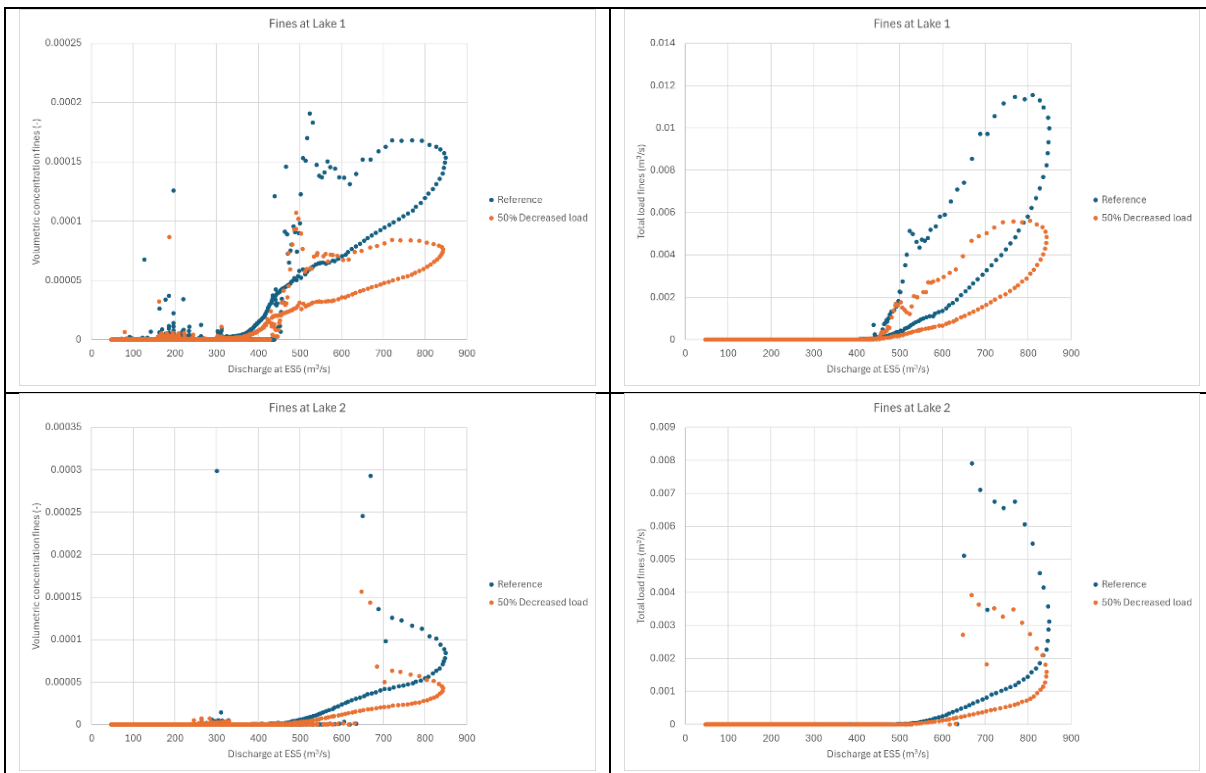


Figure A3- 17 Simulated response of sediment load (sand and fines, m³/s) for site ES5, with 50% decrease of sediment inflow relative to Baseline conditions (reference)

Lake 1 is the upstream lake and Lake 2 the downstream lake. They only receive fines, and only above about 400 to 500 m³/s in the Shire as can be seen from the plots (when flood plains become inundated). In our chosen Baseline scenario about 4,475 ton/year of fines enters Lake 1 during the wet season, and 1,316 ton/year enters Lake 2. In case of 50% increase or decrease at inflow boundaries, the loads at the lakes also increase or decrease with about 50%. Furthermore, it can be seen that only limited amount of silt actually deposits in the Lakes during the flood events.

The following plots show the sediment loads for Baseline and for simulations with reduced and increased sediment inflows from the catchment for the Mwanza tributary (site ES5b), followed by the results for the Lisungwe tributary (site ES2a) and Mklumadzi tributary (site ES4a).

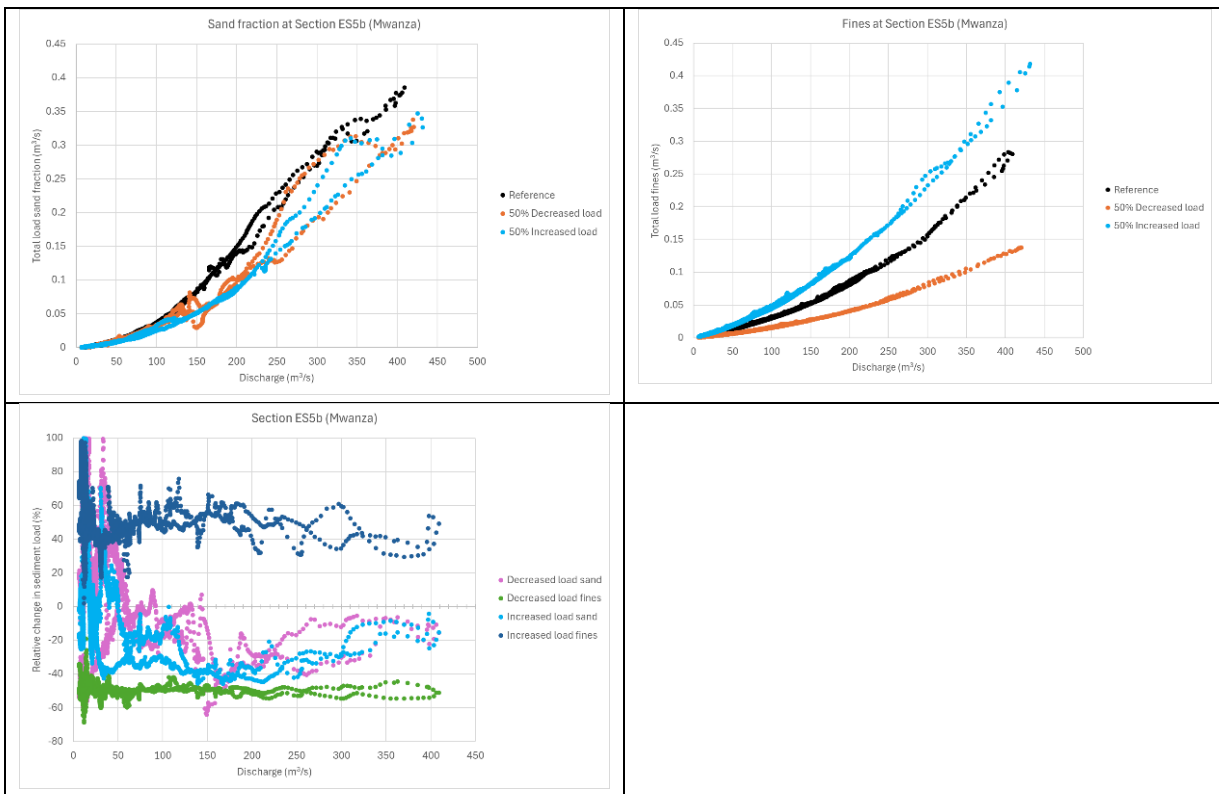


Figure A3- 18 Simulated response of sediment load (sand and fines, m³/s) for site ES5b, with 50% increase and decrease of sediment inflow relative to Baseline conditions (reference).

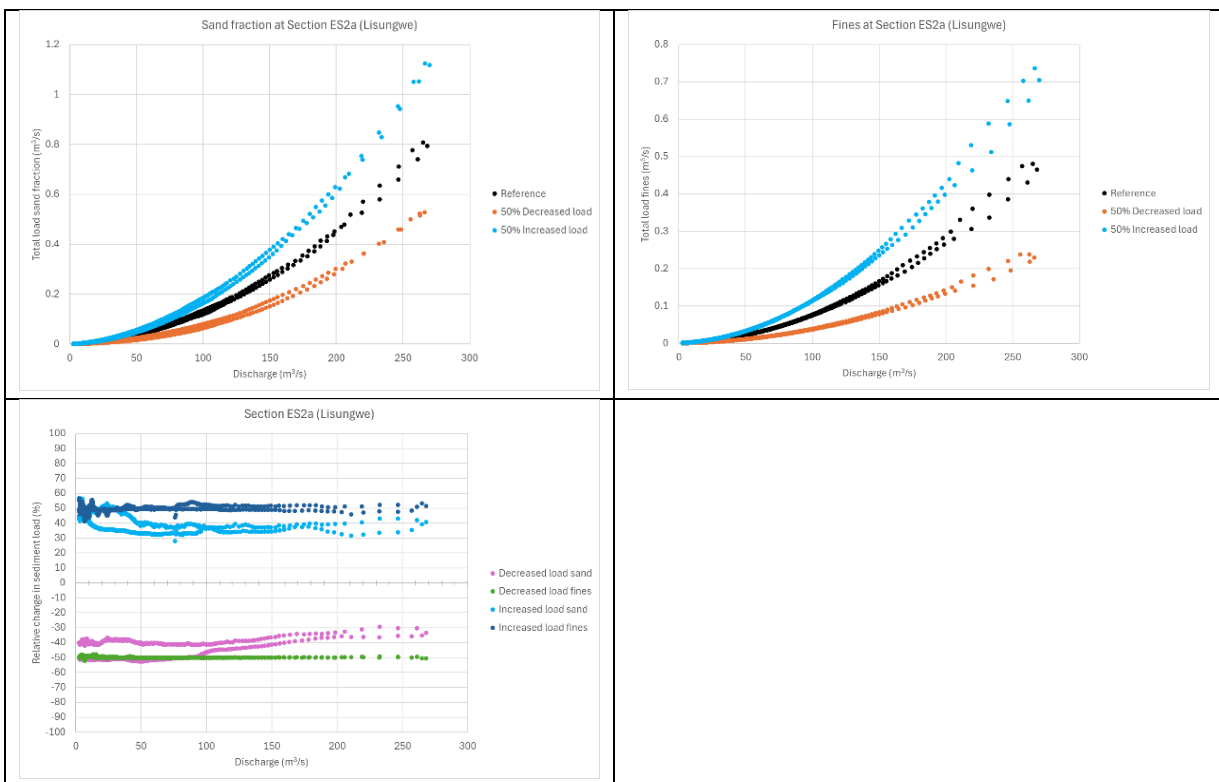


Figure A3- 19 Simulated response of sediment load (sand and fines, m³/s) for site ES2a, with 50% increase and decrease of sediment inflow relative to Baseline conditions (reference).

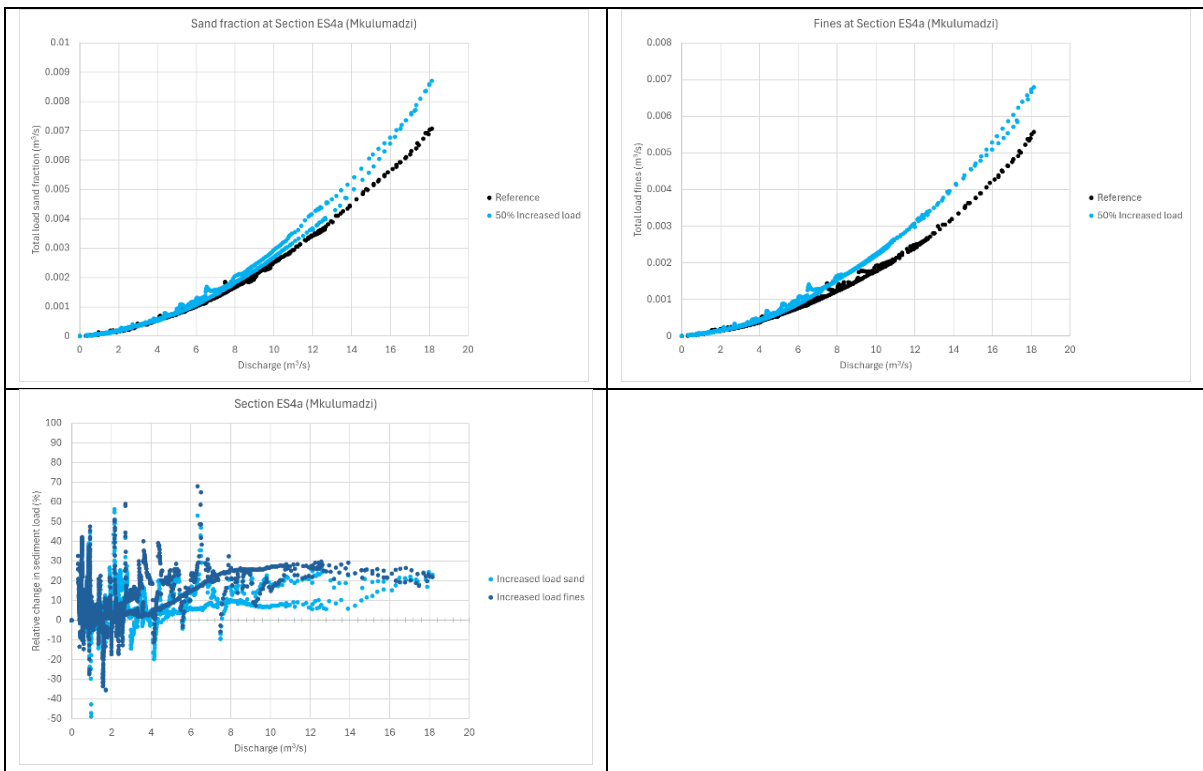


Figure A3- 20 Simulated response of sediment load (sand and fines, m³/s) for site ES4a, with 50% increase of sediment inflow relative to Baseline conditions (reference).

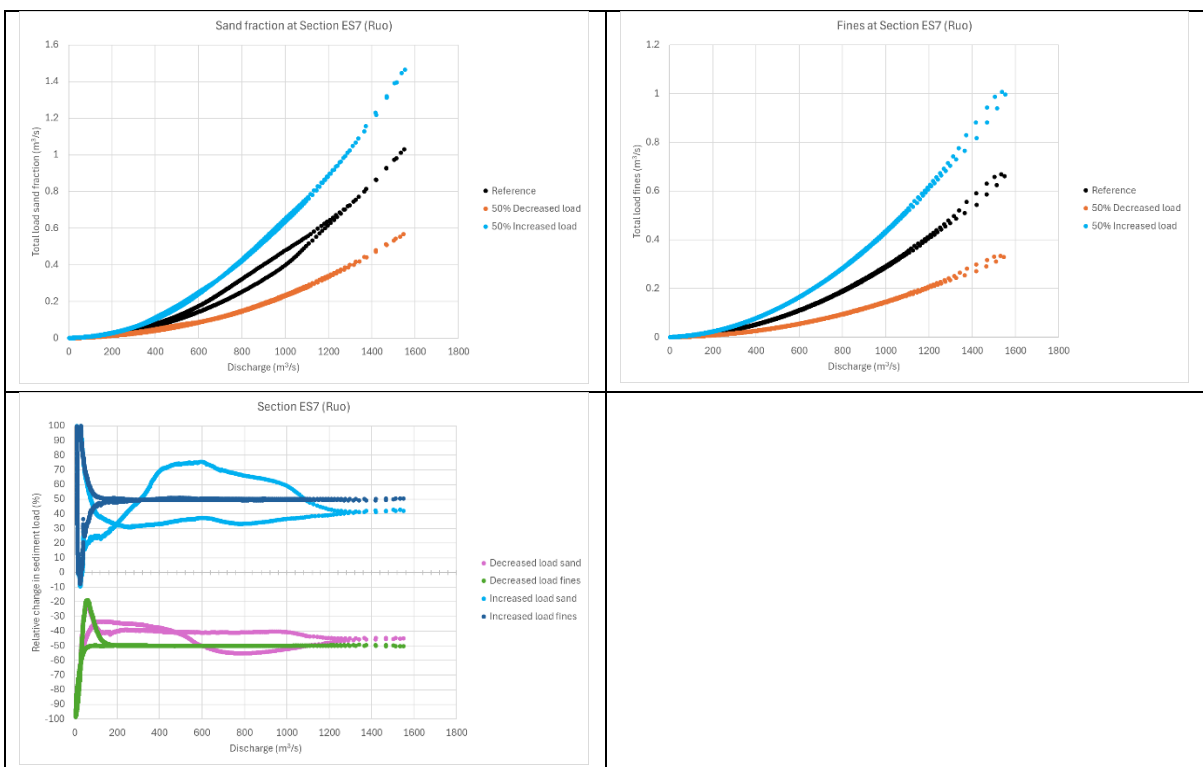


Figure A3- 21 Simulated response of sediment load (sand and fines, m³/s) for site ES2a, with 50% increase and decrease of sediment inflow relative to Baseline conditions (reference).

Generally, the results show that in case of undersupplied conditions (bed rock dominated) channels, the increase or decrease of sediment yield from the catchment with 50% does not give a similar change in the calculated sediment loads at the ES sites, as partially these changes contribute to build-up or erosion of sand bars. Only on the long term (much longer than the 3-year simulation period) a dynamic equilibrium can develop where sand coverage of the river and sand loads are in agreement with the sediment yield.

A.3.5. Calculated sand-bar areas and volumes

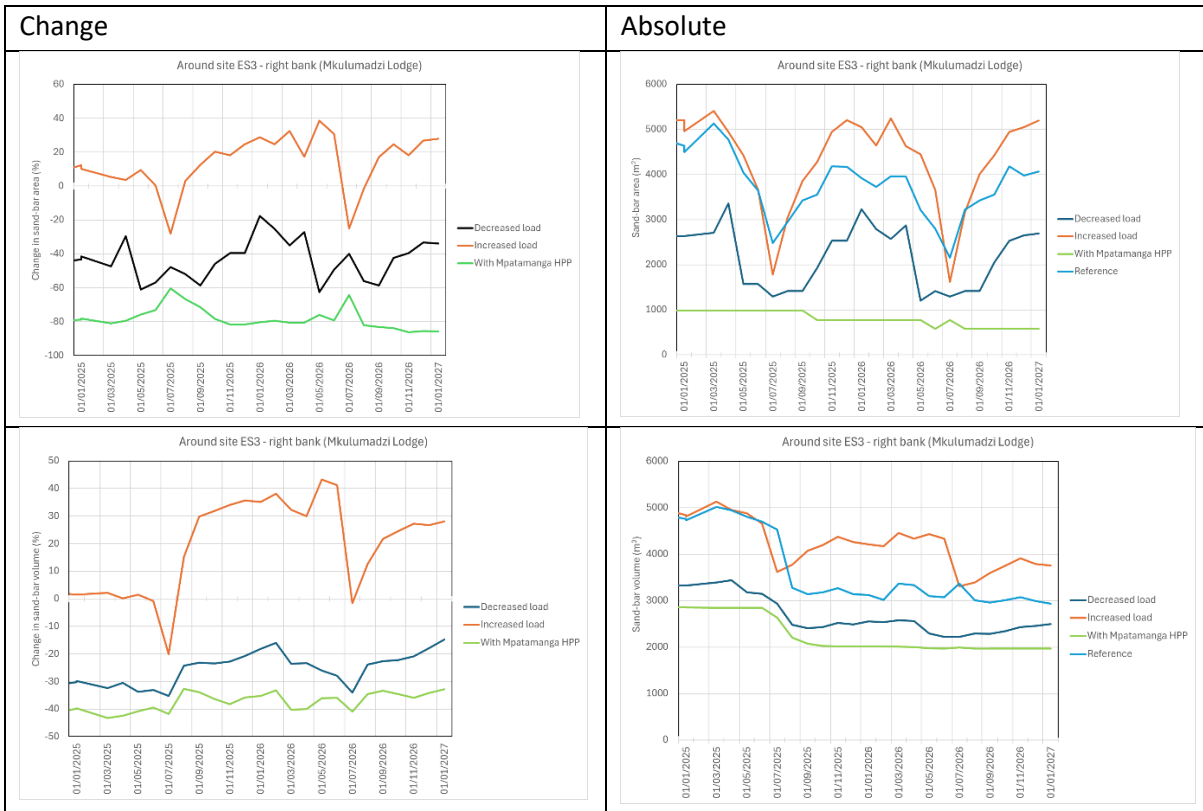
For the model section between Mpatamanga HPP and the Kapichira dam the river channel is a bedrock channel with sand bars. We have simulated the response of sandbars around the ES sites when incoming sediment loads from both Shire and Nkulumadzi are decreased with 50% or increased with 50%, as well as the condition with Mpatamanga HPP (zero sediment load from upstream Shire). We focused on the sand bars that emerge during low flows and have substantial volume, in sections covering a few hundred meters upstream and downstream of the research sites

Method:

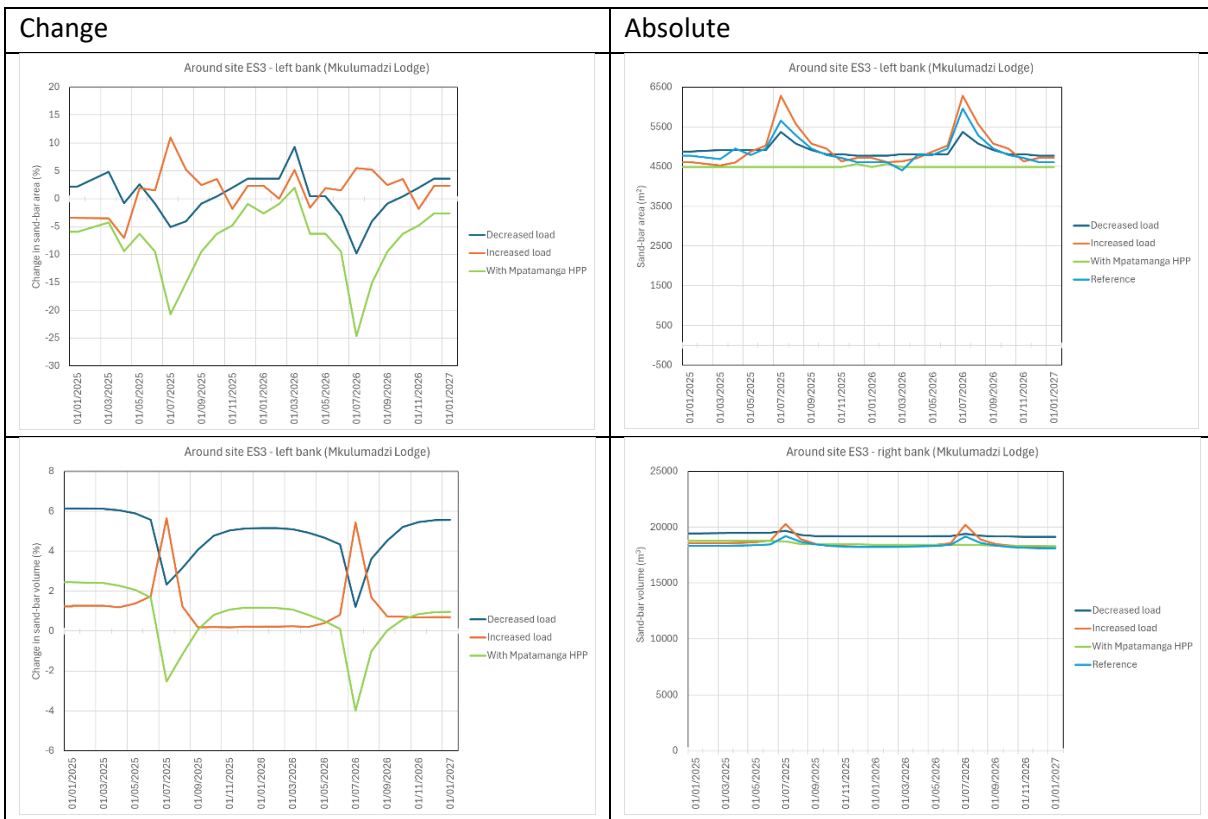
- We count cells with sediment thickness > 5 cm and calculate the volume and area. For the simulations with a 50% increase or decrease, and for Mpatamanga HPP installed, we calculate the change in area and volume relative to the Baseline (reference).
- We simulate 3 years, repeating annual synthetic hydrograph (time series of daily discharges) that was presented in the previous section, and based on the Baseline 1 discharge series derived from WFLOW. Only the results of the 3rd year are used to assess the results.
- The corresponding sediment loads for sand and for fines follow from the regression relations of the HRW series, scaled to reproduce the annual loads reported by the HRW study for the Baseline. The 50% increased or decreased sediment inflow conditions follow from multiplying all sediment-load values (for each time step) with a factor of 1.5 or factor of 0.5.

Table A3-11 and 12 show the results of sand-bar area and volume for the left and right side of the channel near location ES3, which is in front of Nkulumadzi Lodge. The results show that during rising floods the sand bars reduce in volume, but they are refilled during the fall of the flood and the following period. If Mpatamanga HPP is installed, the sand bars on this site reduces roughly with 80%.

Tabel A3- 11 Zone around ES3 right bank, grid cells m=32:46 in longitudinal direction, grid cells n=221-225 in transverse direction. The left column shows % change of sand-bar area and volume for the runs relative to the reference, while right column shows the absolute values of areas and volumes in the chosen zone.



Tabel A3- 12 Zone around ES3 left bank, grid cells m=32:46 in longitudinal direction, grid cells n=231-237 in transverse direction. Left column shows % change of sand-bar area and volume for the runs relative to the reference, while right column shows the absolute values of areas and volumes in the chosen zone.



Note that with the decreased loads we get a relative increase of sand volume on the left bank compared to the reference case. This is shown in Table A3-13 and Figure A3-22: the erosion due to decreased sediment loads is most severe on the right side of the river. The left side shows a few patches of higher levels. This shows that the flow is locally shifting a bit towards the right side, causing a reduction of velocities on the left side.

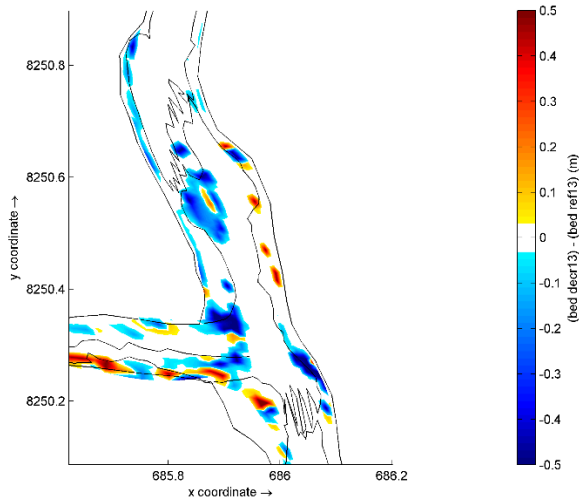
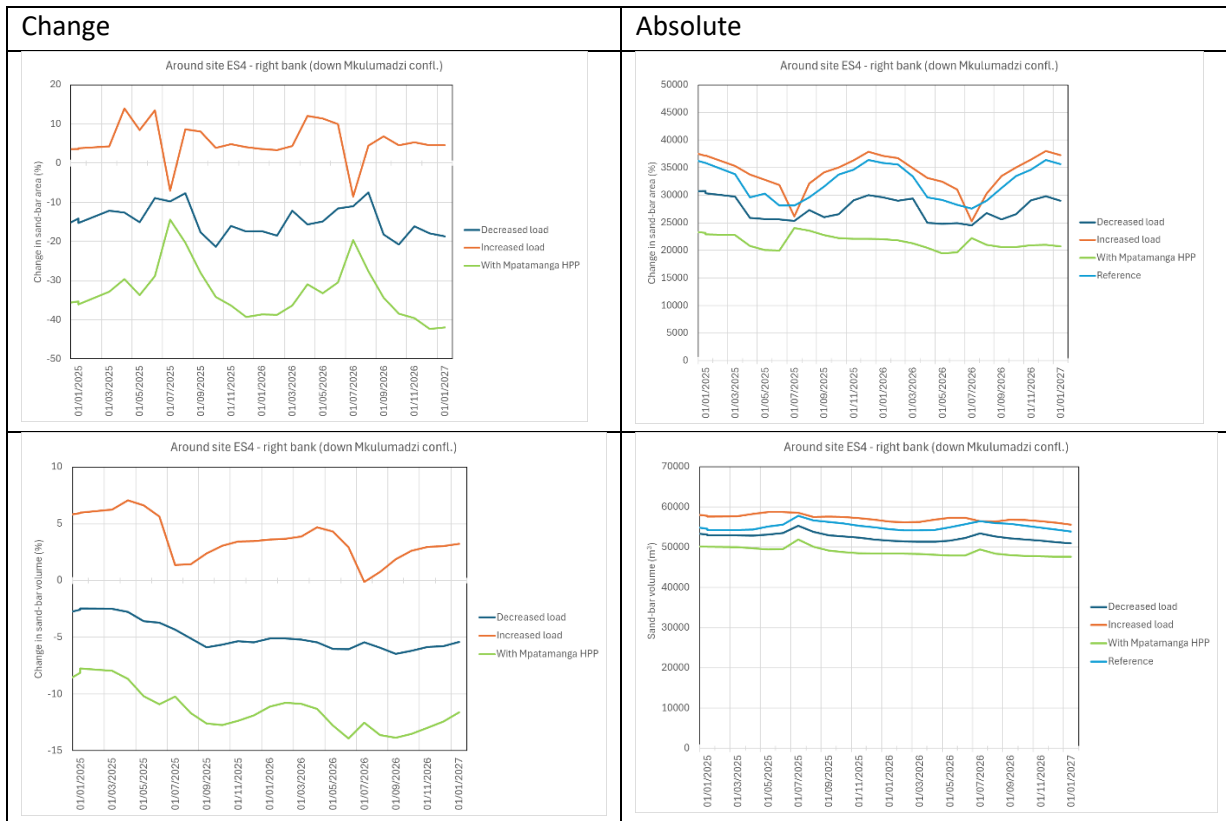
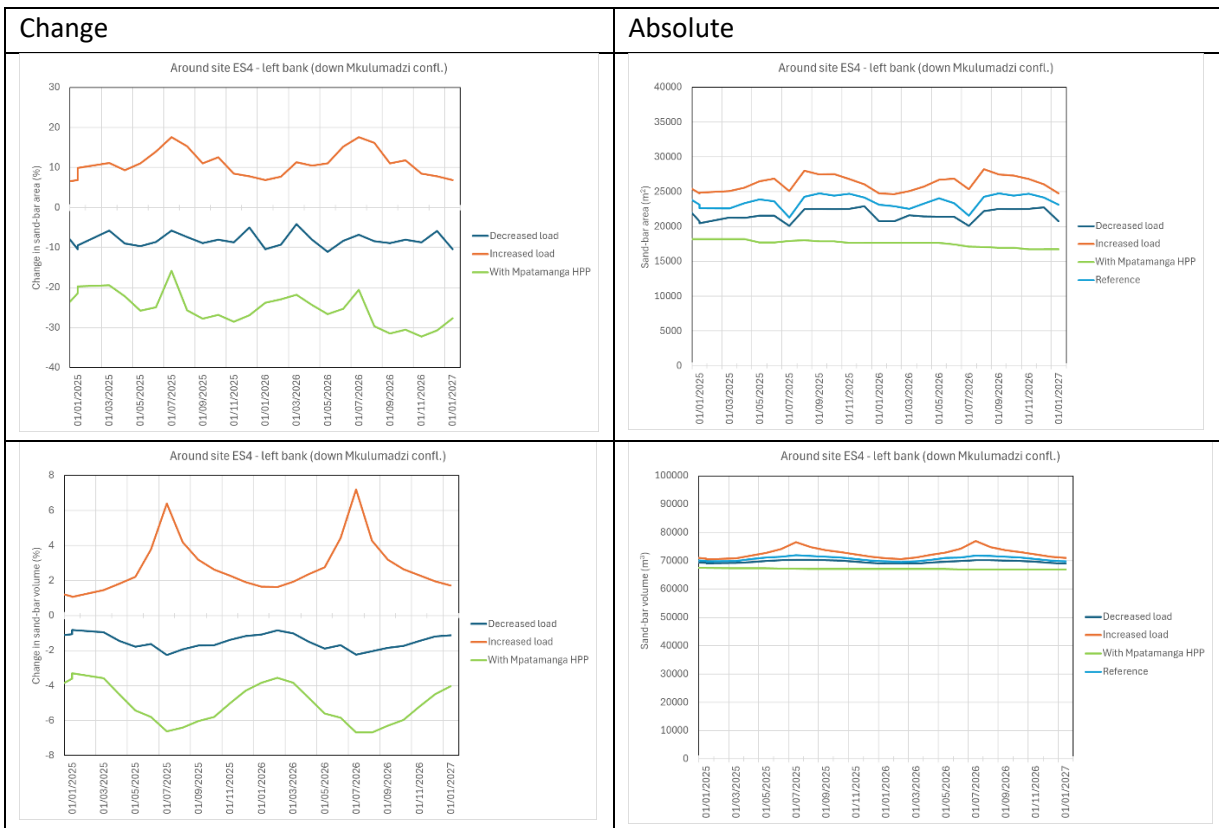


Figure A3- 22 Bed level with decreased loads minus bed level of reference after 1 year. Inner black lines show the contour of the water surface in the present low-flow conditions and the rapids (zigzag lines).

Table A3- 13 Zone around ES4 right bank, grid cells m=57:112 in longitudinal direction, grid cells n=221-225 in transverse direction. Left column shows % change of sand-bar area and volume for the runs relative to the reference, while right column shows the absolute values of areas and volumes in the chosen zone.

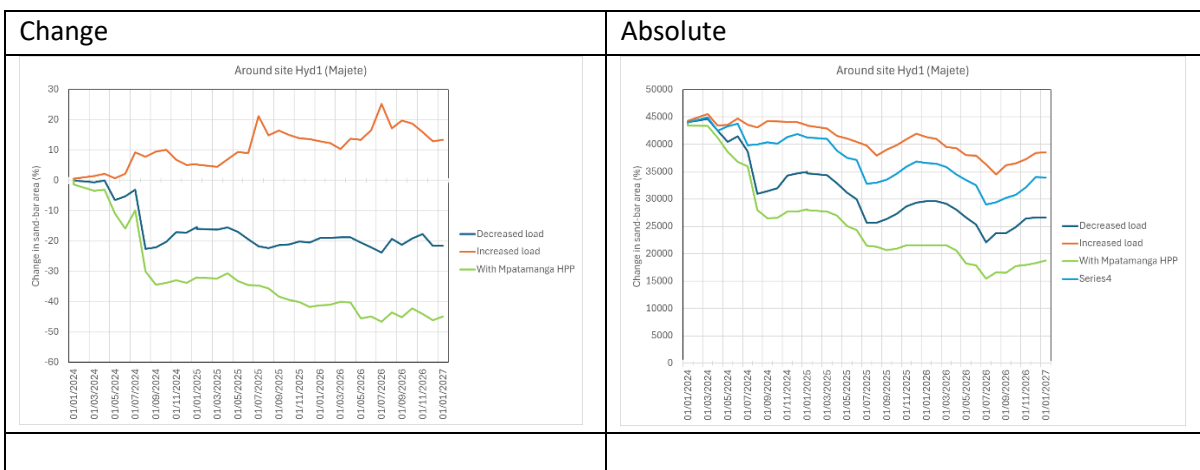


Tabel B- 14 Zone around ES4 left bank, grid cells m=57:112 in longitudinal direction, grid cells n=231-237 in transverse direction. Left column shows % change of sand-bar area and volume for the runs relative to the reference, while right column shows the absolute values of areas and volumes in the chosen zone.



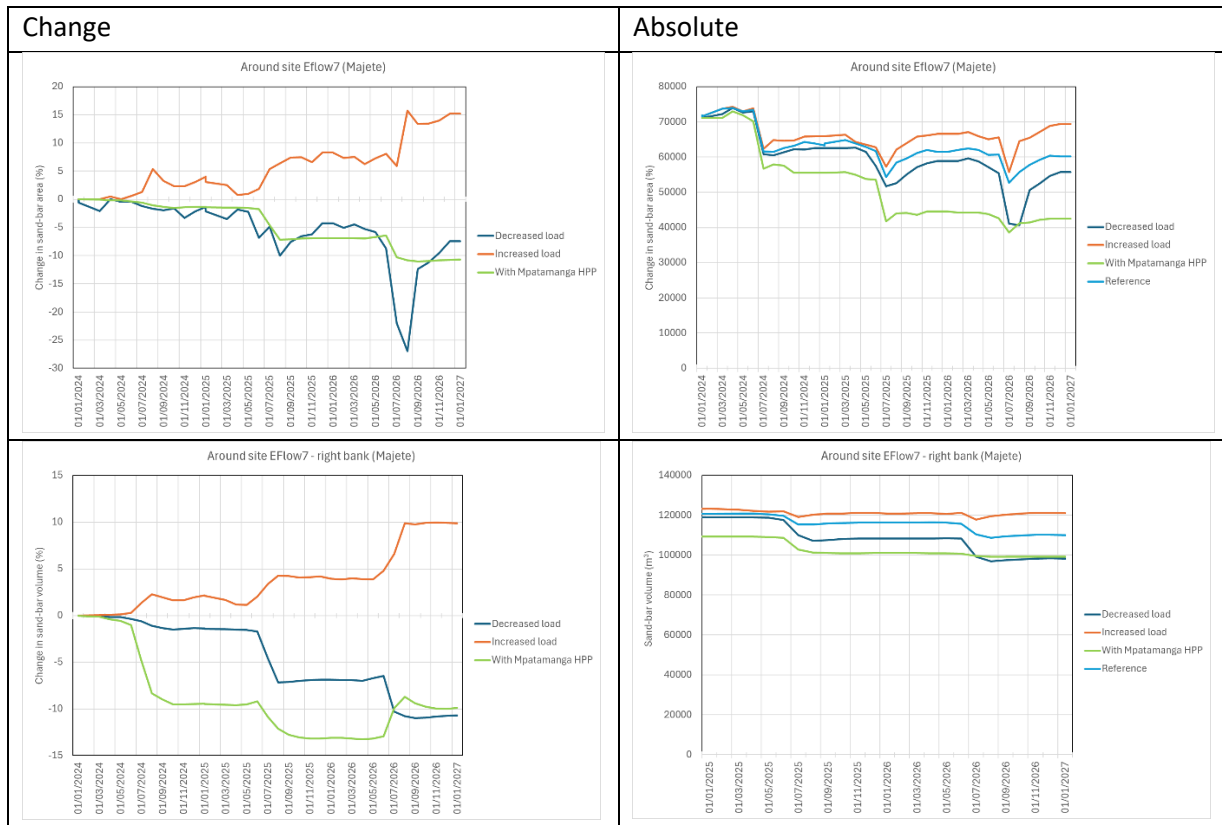
Site Hyd1 is one of the sites where cross-section surveys were carried out during the EFlow 2018 study. The results for this section, downstream of ES4, in Majete Park, are presented in Table A3-15. The simulations show some degradation (eroding) of the sand bars, but it is not clear if this would continue for a longer run.

Tabel A3- 15 Zone around Hyd1 (2018 Eflow survey site) right bank, grid cells m=125:155 in longitudinal direction, grid cells n=221-226 in transverse direction. Left column shows % change of sand-bar area and volume for the runs relative to the reference, while right column shows the absolute values of areas and volumes in the chosen zone.

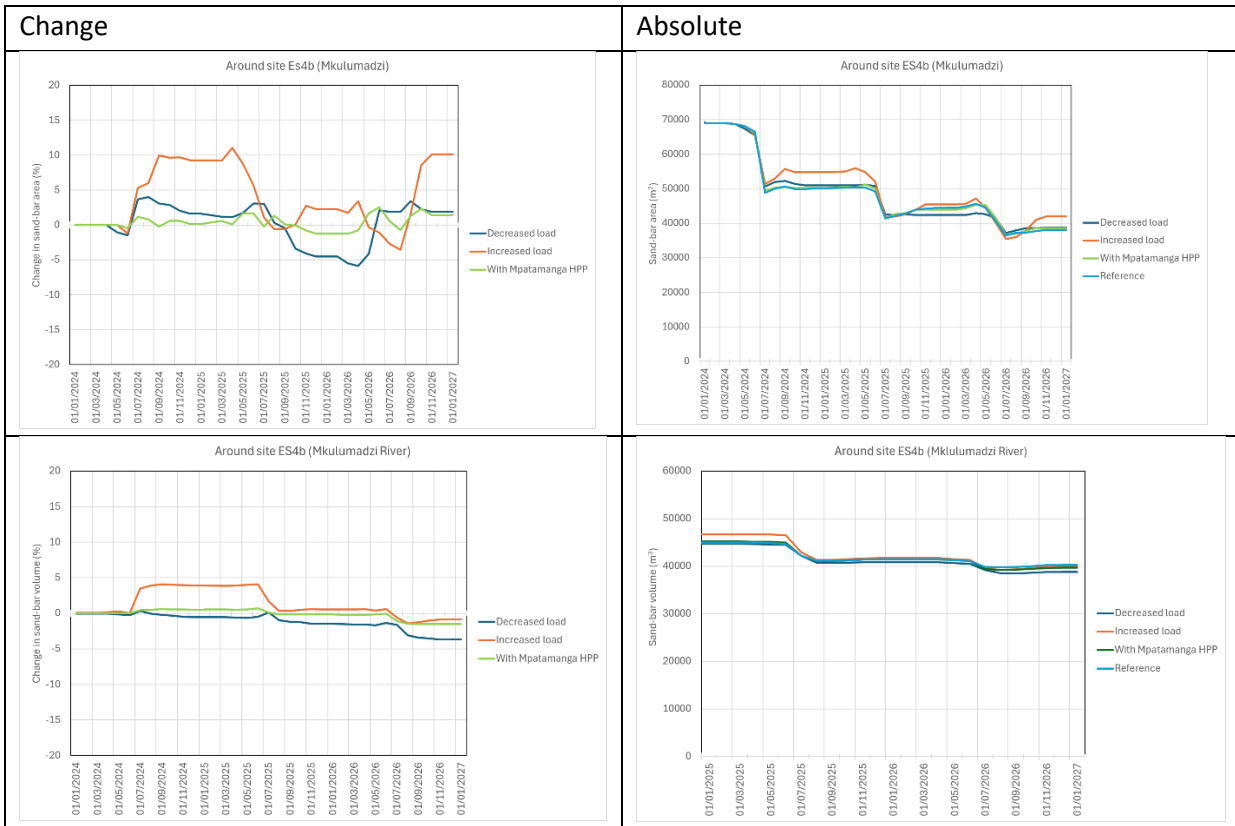


Site Eflow7 is one of the sites where cross-section surveys were carried out during the EFlow 2018 study. The results for this section, just upstream of Kapichira reservoir, in Majete Park, are presented in Table A3-16. The model has not yet reached a stable sand distribution in the considered 3 years: it tends to reduce the initial imposed sand volume in the reference case.

Table A3- 16 Zone around Eflow7 (2018 Eflow survey site) right bank, grid cells m=215:243 in longitudinal direction, grid cells n=221-227 in transverse direction. Left column shows % change of sand-bar area and volume for the runs relative to the reference, while right column shows the absolute values of areas and volumes in the chosen zone.

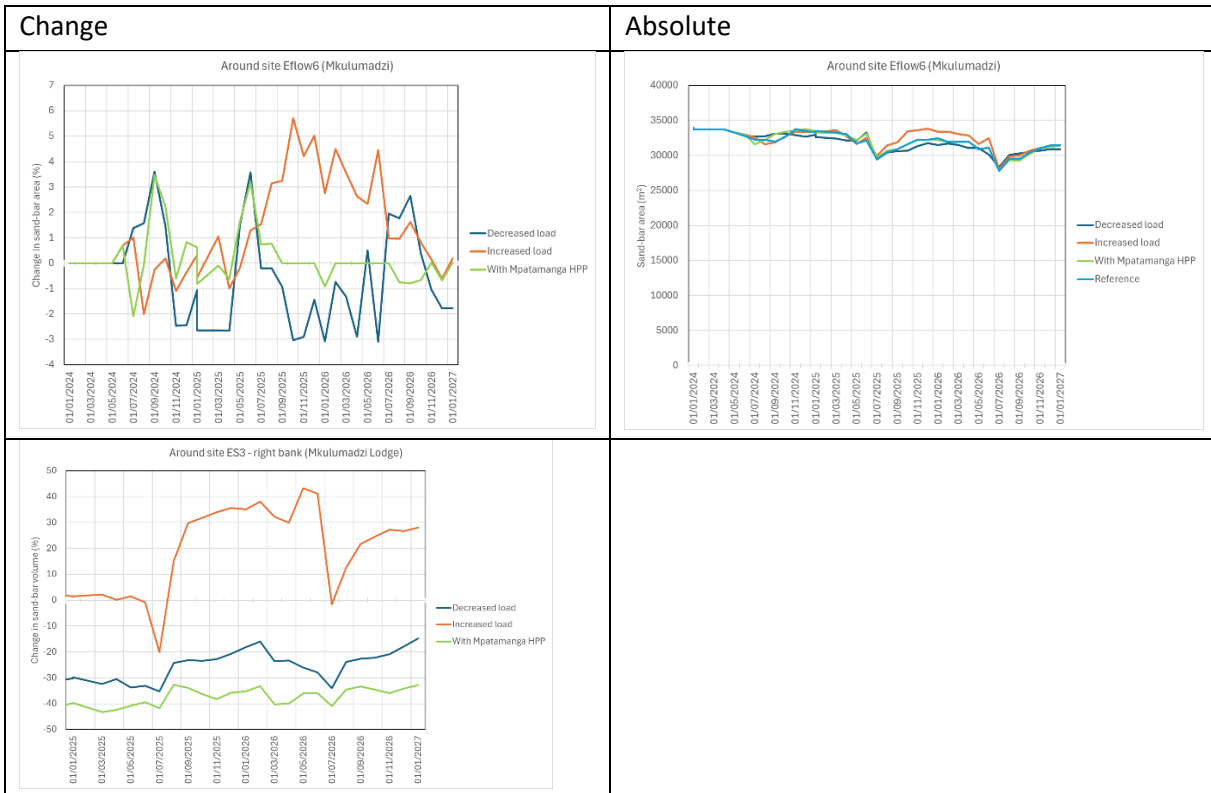


Tabel A3- 17 Zone around ES4b both banks, grid cells m=46:57 in North direction, grid cells n=85-130 in East direction. Left column shows % change of sand-bar area and volume for the runs relative to the reference, while right column shows the absolute values of areas and volumes in the chosen zone.



The model has not yet reached a stable sand distribution in the considered 3 years: it tends to reduce the initial imposed sand volume. The changes between the scenarios are reasonable, but as they are slightly impacted by the supply of eroding sediment from upstream sections, they have to be considered as indicative.

Tabel A3- 18 Zone around Elow6 (survey site from Eflow study 2018) both banks, grid cells m=46:57 in North direction, grid cells n=193-216 in East direction. Left column shows % change of sand-bar area and volume for the runs relative to the reference, while right column shows the absolute values of areas and volumes in the chosen zone.



In the following boxes we have summarised the outcomes per section, per scenario, as well as average over a year, average over the wet period, and averaged over the dry period.

Last year average:	-	ES3 right	ES3 left	ES4 right	ES4 left	Hyd1	Eflow7	ES4b	Eflow6
Area (m ²)	Reference	3,548	4,854	32,300	23,582	32,993	59,647	40,566	30,897
	Decreased load	2,165	4,872	27,241	21,615	26,353	53,825	40,230	30,677
	Increased load	4,314	4,965	33,943	26,157	38,061	65,947	41,867	31,483
	After Mpatamanga	669	4,497	20,893	17,248	18,675	42,670	40,772	30,808
Volume (m ³)	Reference	3,104	18,353	54,945	70,634	38,147	112,815	40,661	47,982
	Decreased load	2,405	19,205	51,815	69,562	32,019	102,809	39,671	47,773
	Increased load	3,958	18,536	56,520	72,711	46,419	120,570	40,554	48,245
	After Mpatamanga	1,986	18,395	48,124	67,001	25,155	100,064	40,321	48,030
Area change (%)	Decreased load	-40	1	-15	-8	-20	-10	-1	-1
	Increased load	20	2	5	11	16	11	3	2
	After Mpatamanga	-80	-7	-35	-27	-43	-28	1	0
Volume change (%)	Decreased load	-22	5	-6	-2	-16	-9	-2	0
	Increased load	28	1	3	3	22	7	0	1
	After Mpatamanga	-36	0	-12	-5	-34	-11	-1	0

Last year wet:	-	ES3 right	ES3left	ES4right	ES4left	Hyd1	Eflow7	ES4b	Eflow6
Area (m ²)	Reference	2,845	5,250	28,485	23,327	31,104	57,419	39,679	29,852
	Decreased load	1,335	5,018	25,278	21,299	24,451	48,571	39,787	29,917
	Increased load	3,223	5,443	29,753	26,813	36,681	62,714	38,962	30,519
	After Mpatamanga	676	4,491	20,566	17,337	17,053	41,577	40,106	29,797
Volume (m ³)	Reference	3,136	18,636	55,768	71,420	38,306	112,817	40,513	47,815
	Decreased load	2,255	19,277	52,498	70,016	32,256	103,236	39,729	47,642
	Increased load	3,868	19,031	56,859	74,758	47,015	119,832	40,413	48,109
	After Mpatamanga	1,978	18,426	48,402	66,996	25,907	100,140	40,241	47,891
Area change (%)	Decreased load	-52	-4	-11	-9	-21	-16	0	0
	Increased load	11	4	4	15	18	9	-2	2
	After Mpatamanga	-75	-14	-28	-26	-45	-28	1	0
Volume change (%)	Decreased load	-28	3	-6	-2	-16	-9	-2	0
	Increased load	24	2	2	5	23	6	0	1
	After Mpatamanga	-37	-1	-13	-6	-32	-11	-1	0

Last year dry:	-	ES3right	ES3left	ES4right	ES4left	Hyd1	Eflow7	ES4b	Eflow6
Area (m ²)	Reference	2,845	4,646	35,562	24,020	33,369	60,253	38,054	31,314
	Decreased load	1,335	4,788	29,306	22,028	26,584	55,356	38,780	30,833
	Increased load	3,223	4,688	37,272	25,880	38,077	69,174	41,920	31,285
	After Mpatamanga	676	4,491	20,880	16,755	18,346	42,482	38,593	31,247
Volume (m ³)	Reference	3,136	18,150	54,355	70,160	36,429	110,170	40,249	47,882
	Decreased load	2,255	19,155	51,259	69,276	30,196	98,329	38,769	47,650
	Increased load	3,868	18,276	56,026	71,558	44,018	121,111	39,909	48,093
	After Mpatamanga	1,978	18,317	47,651	66,947	21,528	99,218	39,642	47,905
Area change (%)	Decreased load	-52	3	-18	-8	-20	-8	2	-2
	Increased load	11	1	5	8	14	15	10	0
	After Mpatamanga	-75	-3	-41	-30	-45	-29	1	0
Volume change (%)	Decreased load	-28	6	-6	-1	-17	-11	-4	0
	Increased load	24	1	3	2	21	10	-1	0
	After Mpatamanga	-37	1	-12	-5	-41	-10	-2	0

A.3.6. Bank erosion / shear stress / deposits at floods

To determine impacts of floods we considered flood simulations with morphodynamics for a cyclone event. At these flood runs we impose a time series of with unsteady discharge, starting at March 1st and continuing till April 1st. The flood is based on WFLOW simulated discharge time-series for March 2019, which is caused by the tropical cyclone Idai. The duration of the flood condition in this simulation is about 1 week, see for instance A3-23.

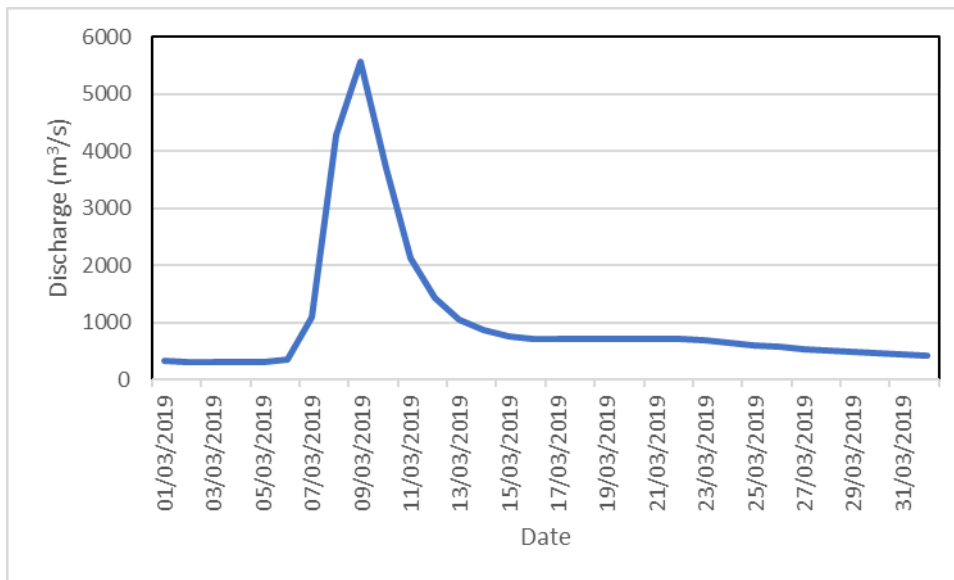


Figure A3-23 Example discharge time series imposed to inflow boundary at Shire ES3 (downstream of Mpatamanga regulation dam).

We simulated these floods only for the two Shire River sub-models downstream of Mpatamanga, as these covers the reaches with potential bank erosion.

The following table provides an overview of peak discharges for each of the inflow boundaries per sub-model. Peak sediment loads follow from the regression relationships (sediment rating, S as function of Q) as derived from the HRW data.

Table A3-19 Qverview of peak discharges for each of the inflow boundaries per sub-model.

Station	Boundary location	Peak flow (m³/s)	Peak sand load (ton/day)	Peak fines conc. (kg/m³)
Sub model "Shire upstream"				
ES3	Shire, downstream Mpatamanga reg. dam	5576	95,529	3,89
ES4b	Nkulumadzi, upstream Shire confluence	856	85,635	7,23
Sub model "Shire downstream"				
ES5	Shire, downstream Kapichira dam	6578	70,490	2,03
ES5a	Lukhubula	202	30,753	9.59
ES5b	Mwanza	659	41,435	3,89

We specifically looked at the erosion and deposition patterns (both of the main channel as on the flood plains) and the shear stresses during the flood peak. The model itself does not calculate the bank erosion accurately as from observations we can see that complex geotechnical failure mechanisms and interaction with vegetation plays a role. These processes cannot be accounted for properly in the model. Based on the morphological and shear-stress maps an estimation can be made of locations that are potentially vulnerable for bank erosion. For the occurrence of bank-erosion we consider 2 potential mechanisms:

1. Zones with high shear stress along banks can cause erosion of sediment particles in the bank zone, and therefore bank retreat.

2. Locations with lateral migration of channels can cause cutting into the banks. Often these are connected to outflanking of meandering channels or by development of a sand bar that forces the flows to ‘attack’ the opposite bank.

The following figures show the results of a projection of maximum shear stresses during the flood peak. Red, orange, yellow and light blue colors are zones with high shear stress (>100 N/m²). Purple colors are moderate shear stresses (high enough to erode sand) and white colors are low shear stress, indicating deposition areas. It should be noted that most erosion can be expected in direction of an increasing shear stress (e.g. when the channel is narrowing), while deposition can be expected in direction of a decreasing shear stress (e.g., flow decay after entering the flood plain). Bank erosion in this context is occurring where zones of high shear stress are found on top of the bank. Bank lines are indicated with white contour lines.

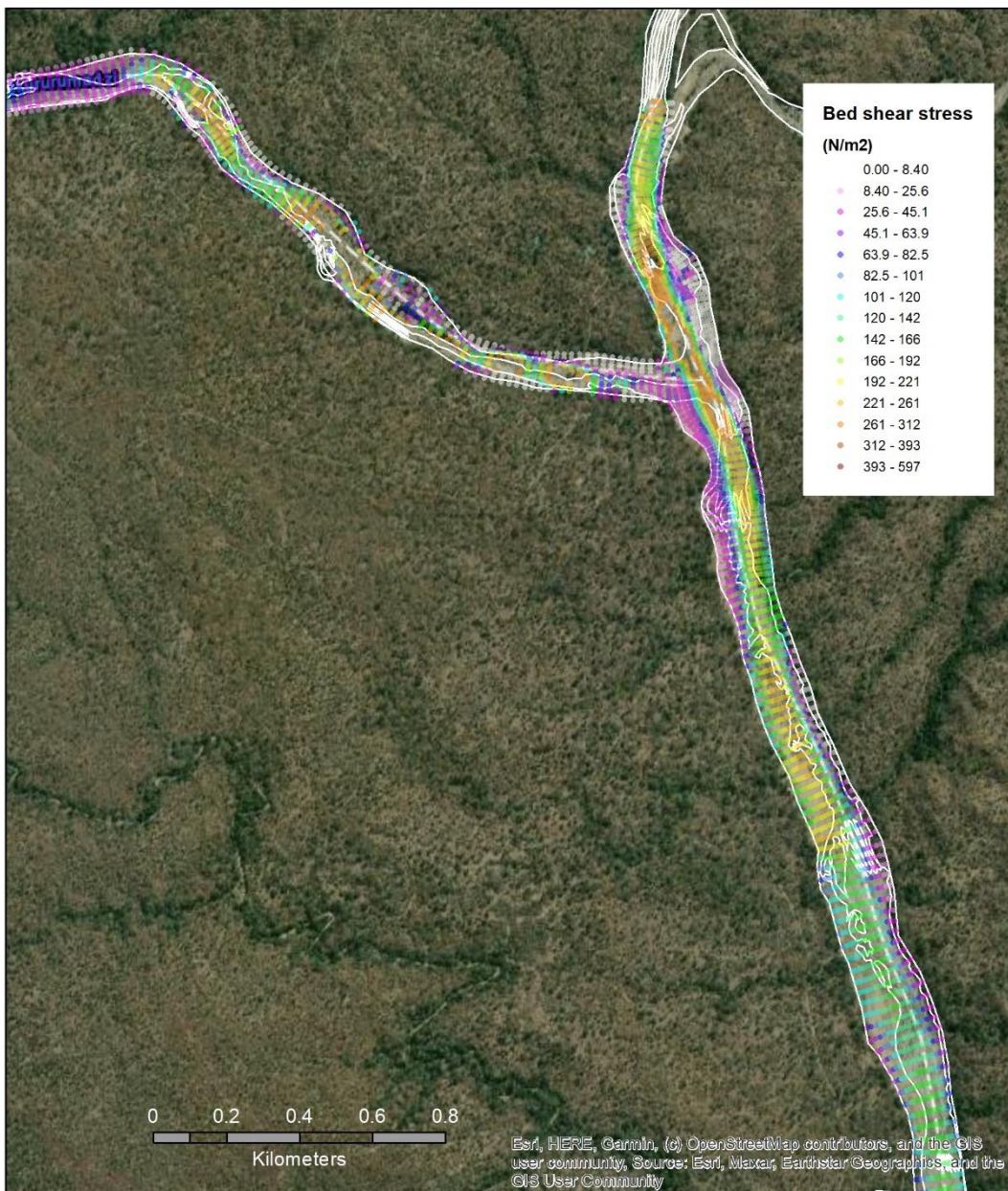


Figure A3- 23 Shear stress magnitude at flood peak, zone around sites ES3, ES4 and ES4b. White lines indicate river bank and rapids.

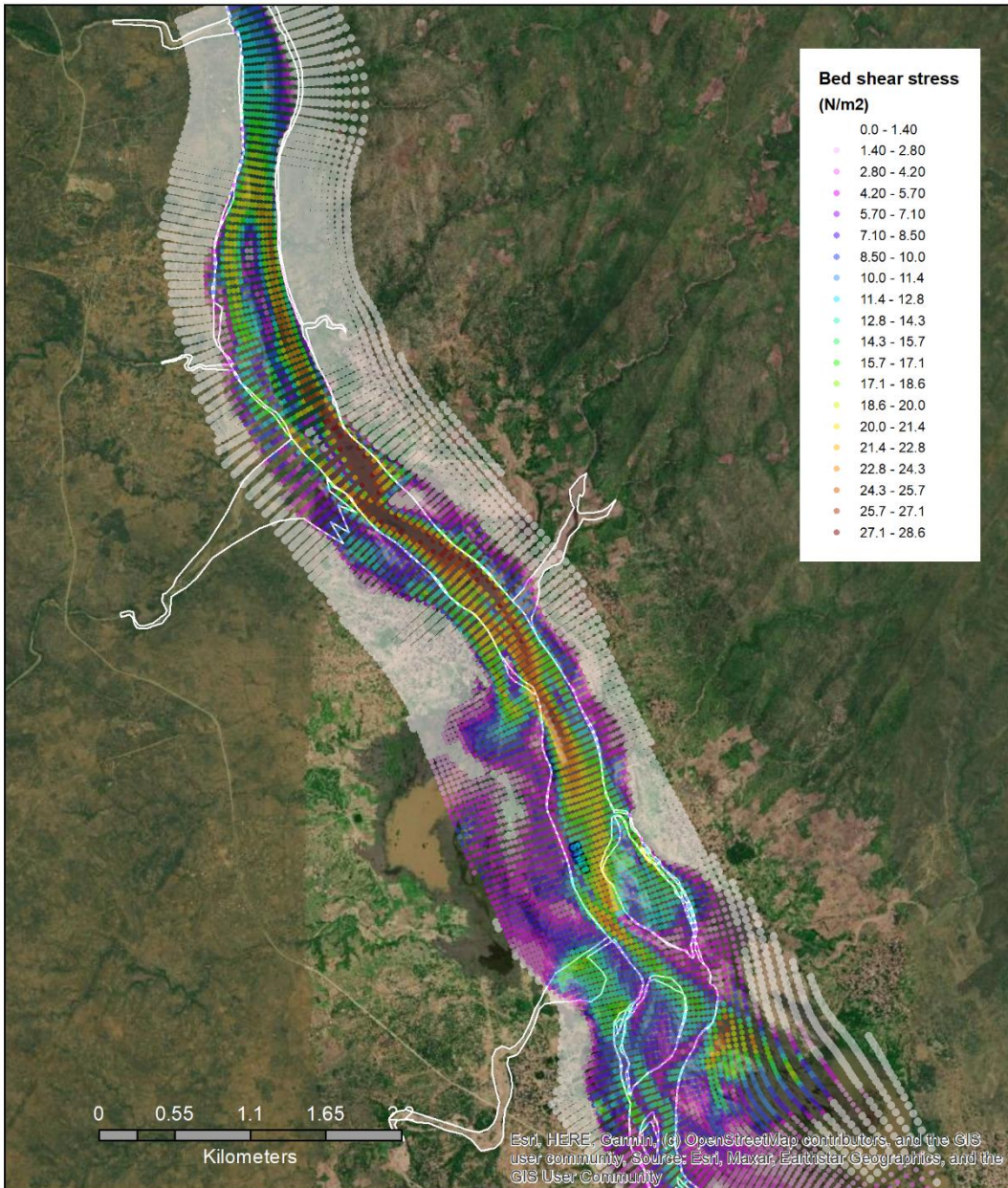


Figure A3- 24 Shear stress magnitude at flood peak, section downstream Kapichira HPP. White lines indicate bank lines.

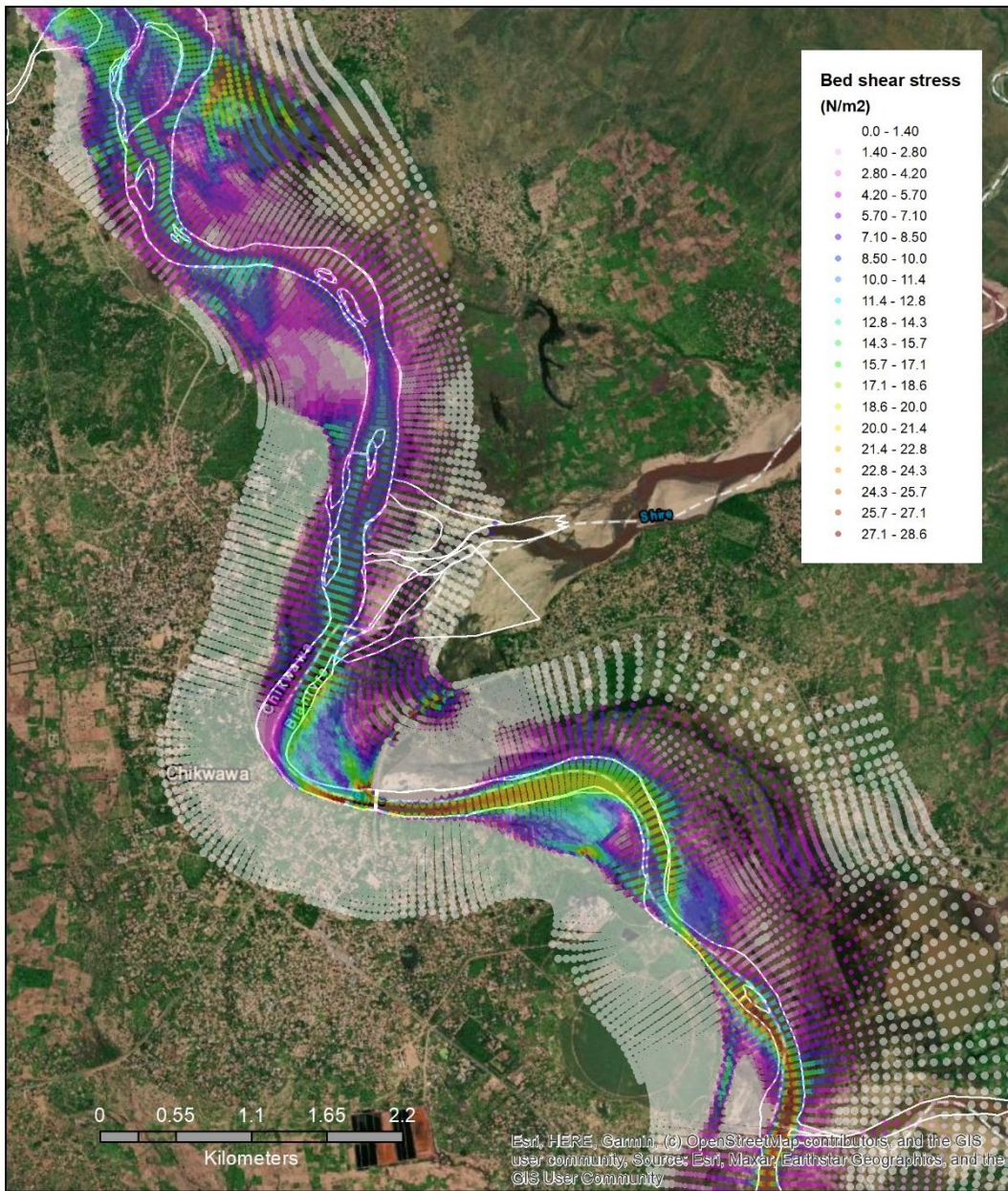


Figure A3- 25 Shear stress magnitude at flood peak, section at Chikwawa, ES5 and upstream end of Elephant Marsh. White lines indicate bank lines.

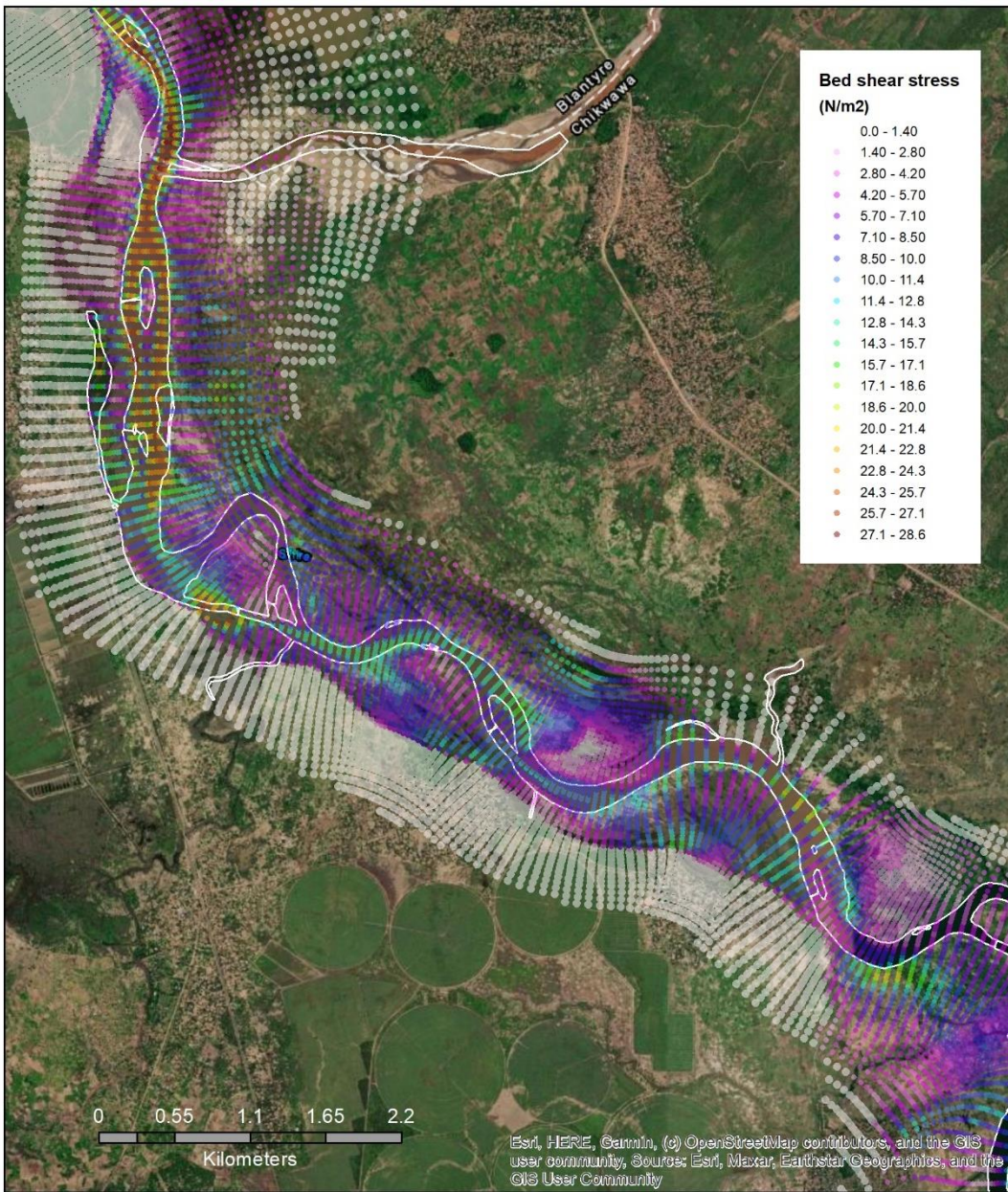


Figure A3- 26 Shear stress magnitude at flood peak, upstream section of Elephant Marsh. White lines indicate bank lines.

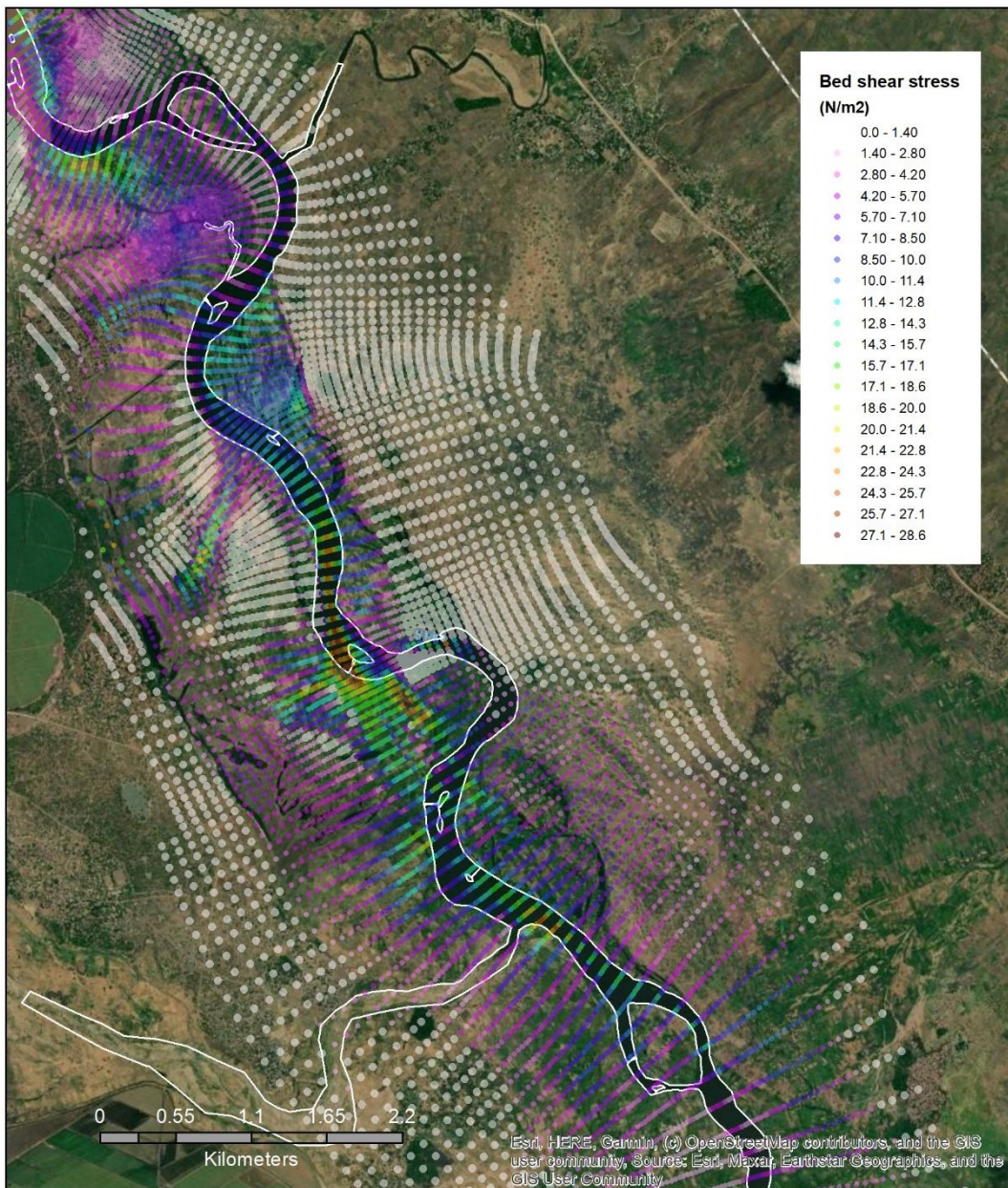


Figure A3- 27 Shear stress magnitude at flood peak, middle reach Elephant Marsh and confluence of Mwanza tributary. White lines indicate bank lines.

The following figures show the results of calculated bed-level change between begin and end of the flood. Positive values (yellow/green) indicate zones of sedimentation, while negative values (blue) indicate zones of erosion. The black contours indicate the present water-surface line and rapids as determined from Google Earth images. These represent the initial (present) position of the channel margins. In these figures it can be seen that sediment deposition occurs along the margins of the main channel, mostly where flows enter the flood plains or over tops the riverbanks. It also shows deep incision of narrow channels into the river bed. Where this incision occurs along banks, there is a risk of bank erosion. However, it is not possible to verify these channel patterns with actual data. Hence, it is relevant to judge these figures carefully.

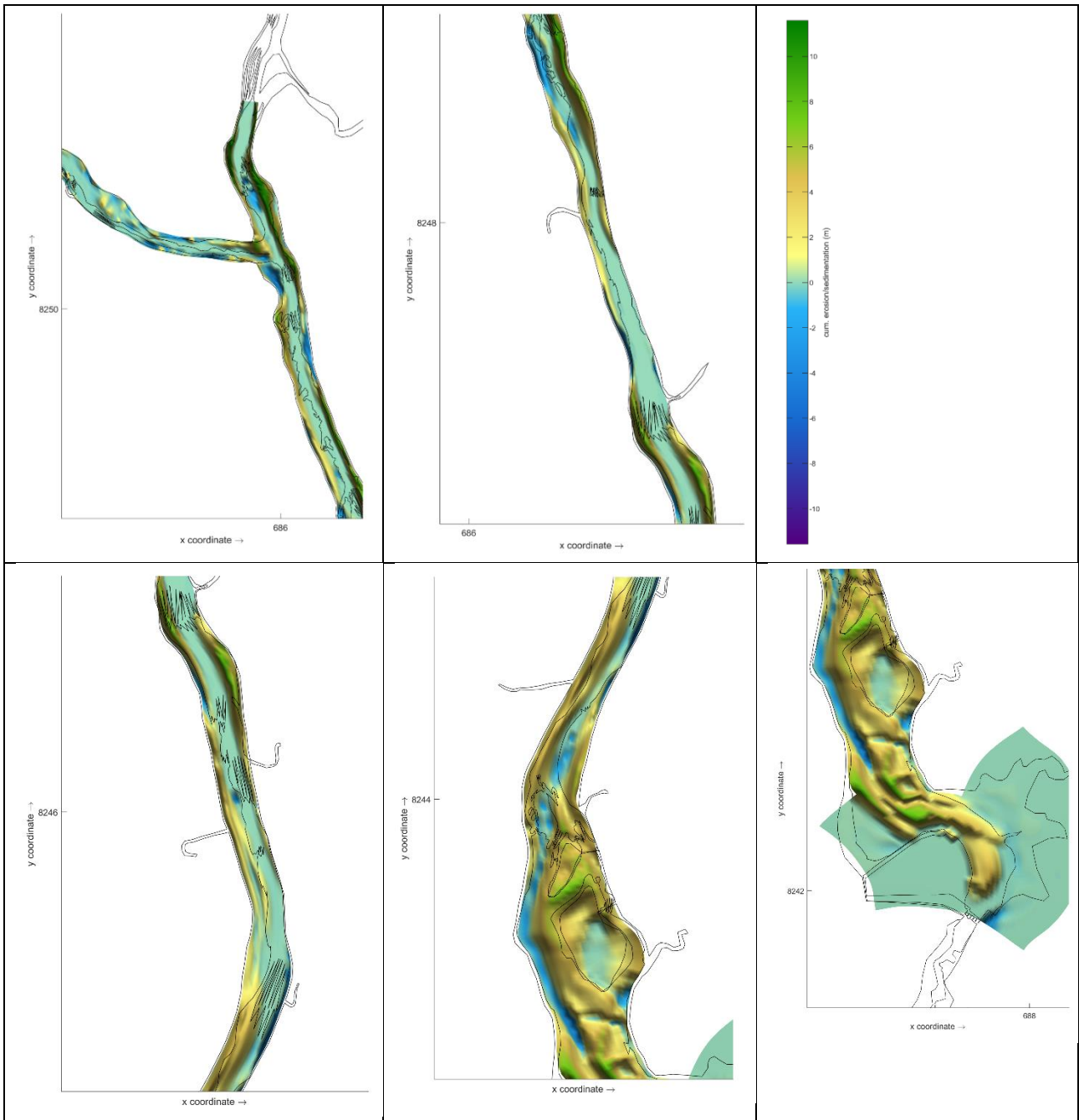


Figure A3- 28 Sedimentation (positive) and erosion (negative) simulated for a cyclone flood event for the reach between Nkulumadzi confluence and Kapichira dam. Black lines indicate riverbanks and rapids.

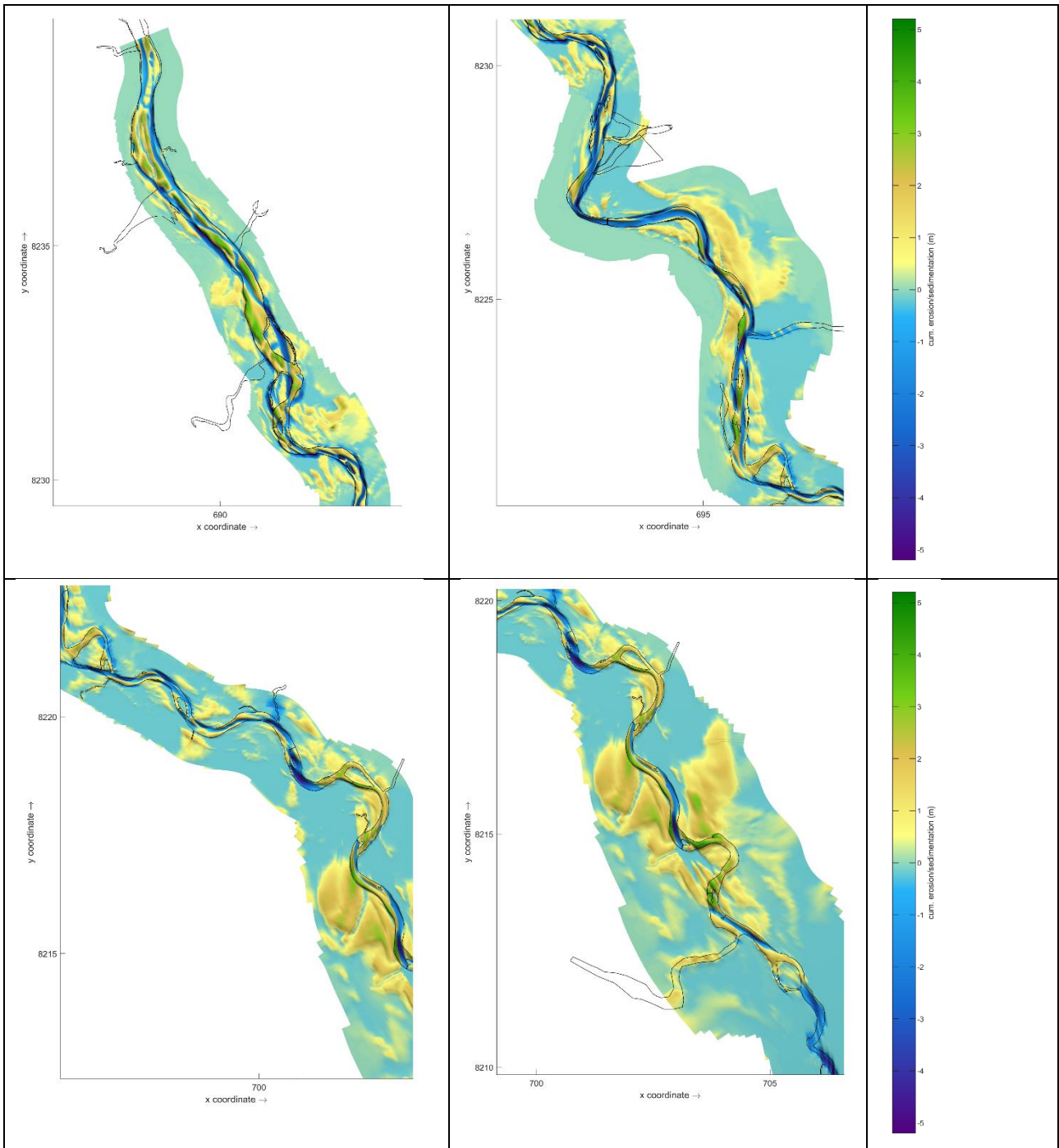


Figure A3- 30 Sedimentation (positive) and erosion (negative) simulated for a cyclone flood event for the reach between Kapichira dam and Elephant Marsh. Black lines indicate river banks.

The results are defined for the present conditions with Baseline sediment loads (extrapolated from the regression relations from HRW simulations).

A.3.7. Synthesis

- Model results and estimations of response of sand loads on discharge series for different scenarios provide general insights on the response of sediment loads in the ES sites.
- Assessment and modelling of soil erosion and sediment yields by HRW provides potential changes of sediment loads and response of river channel downstream of Mpatamanga HPP. However, these results do not link to the scenarios defined for the CIA.
- In this section we combine the results to indicate potential long-term cumulative impacts on sediments, and we draw conclusions on this assessment.

In section A.3.2 we have estimated the annual transport of sand and the total load of the 20-day exceedance of flood discharges. As these results were calculated from regression of loads for Baseline 1, applied to discharge time series for the scenarios, they represent the capacity of the river to transport these sand loads rather than the actual sand load. The latter also depends on availability of sand from upstream inflow (from the catchment) and the availability of sand on the bed (above the bed rock). In section A.3.4 we have explored in more detail the effect of increasing or decreasing the inflow of sand as well as fines with 50% for a relatively short term impact (3 years). This gives us an impression about the significance of such changes in sand load from the catchment and its impact on sand bars and channels. The sensitivity of concentration of fines (at ES sites) to the inflow is much stronger than that of sand, because sand transport is also affected by erosion and sedimentation in the sections upstream of the ES sites. The concentration of fines at all the ES sites scales more directly with inflow and changes in inflow of fines from the catchments.

In the study of HRW an assessment was made of potential changes of soil erosion and sediment delivery to the river on the long term. The study shows that Mpatamanga dam is expected to trap all sand and about 90% of the fines entering the reservoir. The impact to the downstream reach is substantial as shown in Table A3-20, which is an extension of Table A3-1. In this table we assume that sediment yields from tributaries remain the same, while in-channel erosion (calculated with the 1D model of HRW) is replenishing some of the reduced sediment loads between Kapichira and Elpehant Marsh, while the sedimentation in Elephant Marsh is reduced as well.

Table A3- 20 Cumulative annual sediment-transport at relevant confluences in Mt/yr. Numbers between brackets indicate Shire in-channel (or reservoir) erosion (pos.) or deposition (neg.) directly downstream of that confluence, from HRW (2024).

Name	Cumulative loads at confluence (Baseline)		Cumulative loads at confluence (Mpatamanga, 20 years)		Cumulative loads at confluence (Mpatamanga, 100 yrs)	
	Fines [Mt/yr]	Sand [Mt/yr]	Sand [Mt/yr]	Sand [Mt/yr]	Sand [Mt/yr]	Sand [Mt/yr]
Rivi Rivi & Lisanjala	0.34	0.28	0.34	0.28	0.34	0.28
Lirangwe	0.59 [- 0.01]	0.49 [- 0.02]	0.59 [- 0.01]	0.49 [-0.02]	0.59 [- 0.01]	0.49 [-0.02]
• <i>Nkula & Tedzani</i>						
Lisungwe	1.11	0.9	1.11 [-1.01]	0.9 [-0.9]	1.11 [-1.01]	0.9 [-0.9]
• <i>Mpatamanga</i>						
Nkulumadzi	1.35	1.1	0.34 [+0.02]	0.2 [+0.03]	0.34 [+0.01]	0.2 [+0.03]
Lukhubula	1.64 [- 0.01]	1.33 [- 0.02]	0.65 [+0.52]	0.46 [+0.78]	0.64 [+0.30]	0.46 [+0.45]
Mwanza	2.05 [-0.65]	1.49 [- 0.97]	1.59 [- 0.08]	1.42 [- 0.12]	1.05 [- 0.03]	1.09 [- 0.05]
Ruo	2.5	1.32	2.61	2.1	2.12	1.84

Furthermore, HRW explored the overall impact of rainfall erosivity (climate change related) and reforestation scenarios on the sediment yield after 50 years (2070). For land-use and reforestation they investigated six scenarios with different percentages of reforestation at different positions (e.g., targeted areas, hotspots, versus non-targeted). For the erosivity three scenarios were chosen, with 0%, 20%, and 40% increase of erosivity respectively. Continuing present trends, the sediment yield will increase with 25% if climate remain the same, and 50% with 20% increase of rainfall erosivity (i.e. SBRMP, 2017). The sediment yield with present trends can even go up to 75% when erosivity increases to 40%. With targeted hotspots reforestation, a maximum reduction of 40% of sediment yield can be achieved if erosivity remains unchanged.

We used the HRW scenarios to make estimates of possible lack or surplus of sediment yield for ES sites per scenario after a period of 50 years (2070). If sediment supply exceeds the transport capacity, we expect sedimentation, and vice versa we expect erosion, as sand is the fundament of the channels (next to bed rock). The supply is estimated from estimation of change in sediment yield proposed by HRW as above. For the Near Future we assume that the change in sediment yield occurs gradually and can be scaled with a factor 20yr/50yr to apply to 2040 instead of 2070. The results are presented in Table a3-21. We have excluded sites ES1, ES2 and ES5 as these loads appear to depend on erosion and sedimentation processes of the upstream riverbed. For Shire sites ES3 and ES4, near Nkulumadzi confluence, we extracted the annual loss of sediment which deposits in the reservoir (-1.01 Mton/yr).

Judging from Table A3-21 it can be concluded that for most Near Future scenarios the tributaries show a trend for sedimentation as the hydrology in this scenarios show some decrease of discharges. However, this assumes that despite this reduction in flows, the supply of sediment from the catchment remains increasing

(12.5%) or only decreases slightly (-6.5%). For the Distant Future the tributary sites also show some erosion trends depending on the scenario. Most erosion occurs for wet scenarios with the maximum reduction of sediment yield (optimal reforestation). The high deficit of sediment in sites ES3 and ES4 is related to the lack of sand passing through Mpatamanga HPP.

Tabel A3- 19 Estimated annual overload/deficit of sand transport (sand supply minus transport capacity) for ES sites per scenario, prognosis for 2070, in Mt/yr. Color yellow indicates potential sedimentation if supply exceeds transport capacity; green indicates erosion due to undersupplied conditions.

Scenario	Increase of forrest CIA	HRW scen	Incr sed. yield HRW								
CIA	%		%	ES2a	ES3	ES4	ES4a	ES4b	ES5a	ES5b	ES7
NF 1	0	M0	12.5	0.14	-0.87	-0.93	0.02	0.03	0.01	0.02	0.13
NF 3 Nor	0	M0	12.5	0.21	-2.07	-2.31	0.04	0.06	0.03	0.06	0.30
NF3 EC Earth	0	M0	12.5	0.33	-0.09	0.01	0.11	0.15	0.05	0.16	0.64
NF3 Miroc	0	M0	12.5	0.34	-4.16	-4.74	0.10	0.13	0.04	0.14	0.54
NF 3 GDL	0	M0	12.5	0.16	-2.16	-2.43	0.03	0.05	0.02	0.06	0.25
NF 3 MPI	0	M0	12.5	0.21	-1.48	-1.63	0.04	0.06	0.03	0.06	0.25
NF4 Nor	30	M3	-6.5	0.13	-2.26	-2.55	0.01	0.02	0.01	0.03	0.14
NF4 GFDL	30	M3	-6.5	0.07	-2.34	-2.65	0.00	0.00	0.01	0.02	0.07
NF4 MPI	30	M3	-6.5	0.12	-1.65	-1.83	0.01	0.02	0.01	0.02	0.08
DF1 NOR	0	M0	25	0.44	0.04	0.17	0.11	0.15	0.07	0.16	0.64
DF1 GFDL	0	M0	25	0.32	-0.40	-0.36	0.08	0.11	0.04	0.12	0.37
DF1 MPI	0	M0	25	-0.20	-2.96	-3.42	-0.10	-0.14	-0.04	-0.21	-0.04
DF2-Nor	50	M6	-40	0.17	-0.54	-0.54	0.02	0.03	0.02	0.04	0.13
DF2 GFDL	50	M6	-40	0.06	-0.98	-1.07	-0.02	-0.02	0.00	0.00	-0.13
DF2 MPI	50	M6	-40	-0.45	-3.53	-4.10	-0.19	-0.26	-0.08	-0.32	-0.52

For annual load of fines in 2070 we simply apply the change in sediment yield to the numbers in Table A3-21 and Table A3-22. A subdivision for different climate scenarios cannot be made for this table. The change between 2020 and 2070 (50 years) can be considered to develop gradually, hence for intermediate times a proportional increase can be considered.

Tabel A3- 20 Estimation of annual loads of fine sediments in 2070.

ES Site	Name	Type	[Mt/yr]	[Mt/yr]	[Mt/yr]
			Baseline 1	DF 1	DF 2
			2020	2070	2070
			0%	25%	-40%
1	Shire Matope gauge	Fines	0.33	0.41	0.20
2a	Lisungwe	Fines	0.53	0.66	0.32
4a	Nkulumadzi up	Fines	0.17	0.22	0.10
4b	Nkulumadzi down	Fines	0.24	0.30	0.14
5a	Lukhubula upstr	Fines	0.10	0.12	0.06
5b	Mwanza	Fines	0.42	0.53	0.25
7	Ruo	Fines	1.09	1.36	0.65
2	Shire (dwn Tedzani)	Fines	0.58	0.72	0.35
3	Shire down Mpatamange	Fines	1.12	1.40	0.67
4	Shire down Nkulumadzi	Fines	1.36	1.70	0.82
5	Shire up Lukhubula conf	Fines	1.36	1.70	0.82

Some general conclusions can be drawn from the assessments:

- The climate-change scenarios show a relative strong increase of transport capacity of sand in the ES sites compared to Baseline 1 due to increased discharges. The opposite occurs for the mean and dry scenarios. The increase or reduction of annual load and the average load during flood periods is in the order of more than 100% of the original annual load.
- The increase or decrease of transport capacity for the Near Future and Distant Future is strongest in the ES sites in the main Shire River (ES1, ES2, ES3, ES4, ES5).
- In addition, following the HRW prognosis, based on the type and rate of reforestation an increase or reduction of sediment yield from catchment can be compared to the increase or reduction of sediment-transport capacity. It shows that for the Near Future the ES sites in tributaries may remain relatively stable or show some sedimentation. For the Distant Future the tributaries can show erosion depending, specifically for wet climate-change scenarios with a high reforestation. For the ES sites in the main Shire in the Majete area all scenarios show a strong deficit of sand supply due to the entrapment of sand in Mpatamanga reservoir.
- In most cases, if changes occur in the sediment yield from upstream, a delayed response occurs to the transport rates further downstream. The changes from upstream are absorbed by erosion and sedimentation processes in the channel: decreasing supply causes erosion of sand from the bed, replenishing the shortage in the sites further downstream. Only after several years a new equilibrium may develop where sand coverage and sand transport are matching.
- Reduction of sand bar area and volume in bed rock channels is expected in the Shire River between Mpatamanga HPP and Kapichira HPP. The changes range from a few percent to 80 percent reduction depending on the location (and riverbank), as well as the hydrological scenario.
- The two lakes in the Chikwawa region are fed by fine sediments during flood conditions, during overbank flows. The changes in the amount of fines arriving at these lakes responds more or less 1:1

to changes in supply of fines from the catchment. A reduction is expected as 95% of the fines coming from the upstream catchment is expected to be trapped by Mpatamanga HPP.

- Bank erosion is most likely to occur in the reach downstream of Kapichira dam during flood conditions due to gradients in shear stress at these banks, or due to erosion of the riverbed in front of the river banks. The flood simulations provide information on locations with high risk. Actual bank erosion rates cannot be predicted without more detailed field data on geotechnical properties of the banks. The rate of bank erosion can be severe in case of hydropeaking operations of Kapichira dam.
- For prognoses of the volume of sand arriving at Elephant Marsh the simulations by HRW provide necessary input. Specifically, because of erosion in the reach upstream, the short term simulations in this study are not representative for long-term forecast. Reduction or increase of fines arriving at Elephant Marsh can be scaled based on the changes in catchment erosion (referring to HRW scenarios).

A.4. SUPPORTING HYDROPOWER MODELLING AND ASSESSMENT

A.4.1. Summary

Hydropower operation, including operation of Kamuzu Barrage, has been modelled for 10 different scenarios. For each scenario, we have specified the desired output (MW) for each hydropower plant for every hour of the simulation. In the results, we present to which degree we are able to fulfill the specified goals. The results for each hydropower plants are also presented in GWh/year. In addition, we will present lake Malawi water level for each scenario, as well as the flow at Kamuzu Barrage.

The main finding from the simulation is that Lake Malawi freewater is extremely important for all the hydropower plants. When there are several wet or dry years in a row, Kamuzu Barrage regulation is not enough to withhold or release the required amount of water. This can be seen in the years 1995-2000 in the historical simulation, and in the years 2060-2100 in the climate change simulations. When lake Malawi water level is too low, we are not able to release enough water for hydropower generation in Shire river.

Even so, the average generation in scenarios 2, 3, 4.2, 5 and 6 (*reference is made to the scenario numbering in Table 5-1 in Chapter 5*) is 98-99% of the goal generation. This shows that in the historical period, there has in general been enough water for hydropower generation, and if the future is similar to the last 30-years, it should be possible to meet the demand for hydropower most of the time. If Mpatamanga is not built, however, there is both too little capacity in the peak hours, and not enough water in general to produce the required electricity. Scenario 4.1 has an average generation of 83% of the required generation.

In the climate change scenarios, lake Malawi drops beneath the sill in the 2060s, and this has a large impact on hydropower generation. In scenarios 7.1 and 8.1, the average generation is 88% of the goal generation, while in scenarios 9.1 and 10.1, the average generation is less than 50% of the goal generation.

The climate change scenarios also show a large increase in floods in the tributaries, especially in Nkulumadzi. This leads to extreme floods at Kapichira, which could have devastating consequences for the dam. We recommend that the effects of climate change on Shire tributary floods are further examined.

A.4.2. Lake Malawi water level

Scenarios 1-6 all have the same net inflow to lake Malawi, calculated from the historical freewater, see Figure A4-1. Net inflow to Lake Malawi is negative for about half the year, in general from May to December, when the lake evaporation is higher than lake precipitation and inflow to the lake. The seasonality of net inflow to the lake is very clear if we do a statistical analysis of the data series, see Figure A4-2.

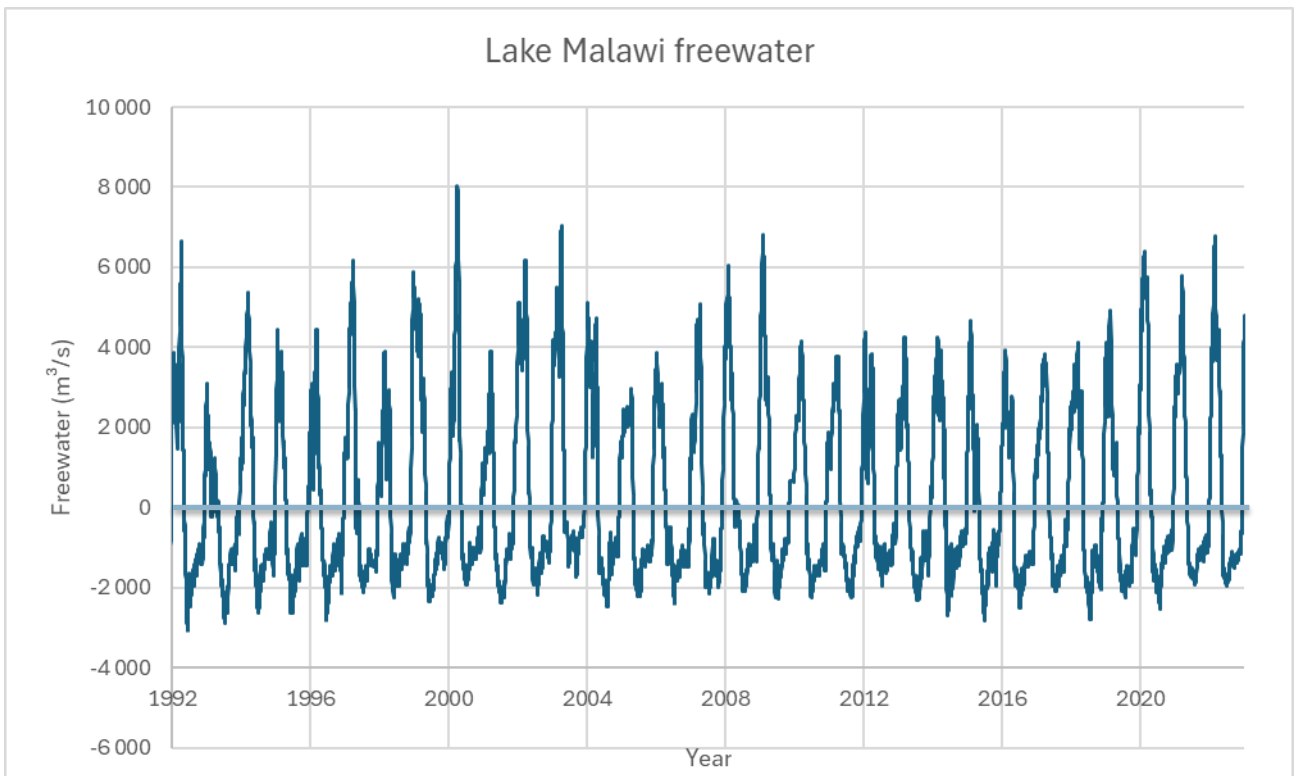


Figure A4-1 . Lake Malawi historical freewater from 1992 to 2023.

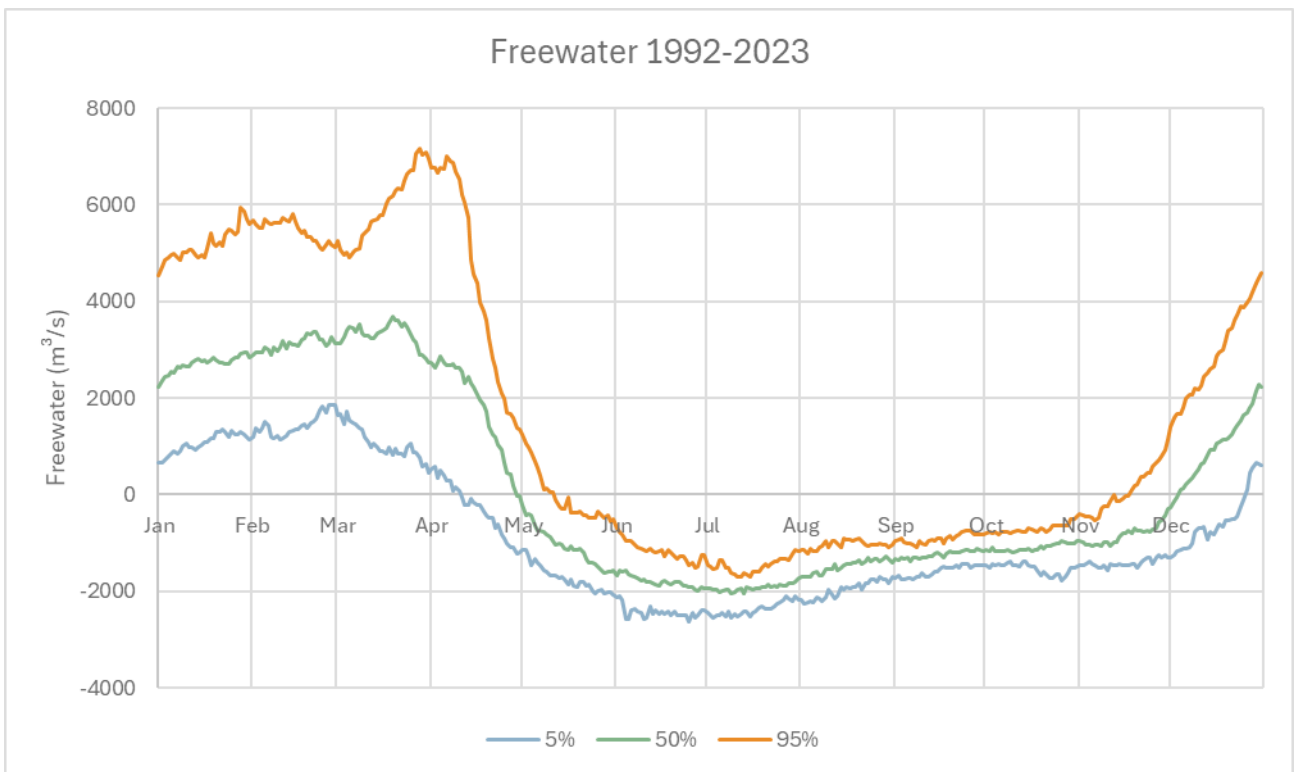


Figure A4-2 Freewater percentiles throughout the year.

Because the net inflow to Lake Malawi is the same for all scenarios that does not include climate change, the difference in lake level between the different scenarios stems from the operation of Kamuzu Barrage in the “Maximum production”, “Flood control” and “Water saving” strategies. Hence, it is the same for all scenarios, except for scenario 1, where Kamuzu Barrage is not included.

If we compare scenario 1 (Sc1 – near natural) and scenario 2 (Sc2 – historical) to the observed water level at Lake Malawi, we can see that the Sc2 lake level in general is higher than the observed water level. This indicates that the historical release has been higher than what we have calculated as the optimum release in the model. During the rehabilitation of the barrage in 2015-2019, the observed water level is the same as in Sc1, which makes sense, as the barrage was not operational in this period (see Figure A4-3).

The lake levels in scenarios 2, 3, 4.2, 5 and 6 are quite similar, as can be seen in Figure A4-4. This is because there are only minor differences in the goal releases between the different scenarios. Also note that the seasonal variation in freewater (Lake Malawi net inflow) determines the seasonal variation in lake level, the regulated outflow is small compared to the large differences between wet season and dry season net inflow.

In Figure A4-5, there is a comparison of lake levels between scenario 4.1 (2030 without Mpatamanga) and scenario 4.2 (2030 with Mpatamanga). Scenario 4.1 requires much higher releases from the barrage, which again leads to lower lake levels.

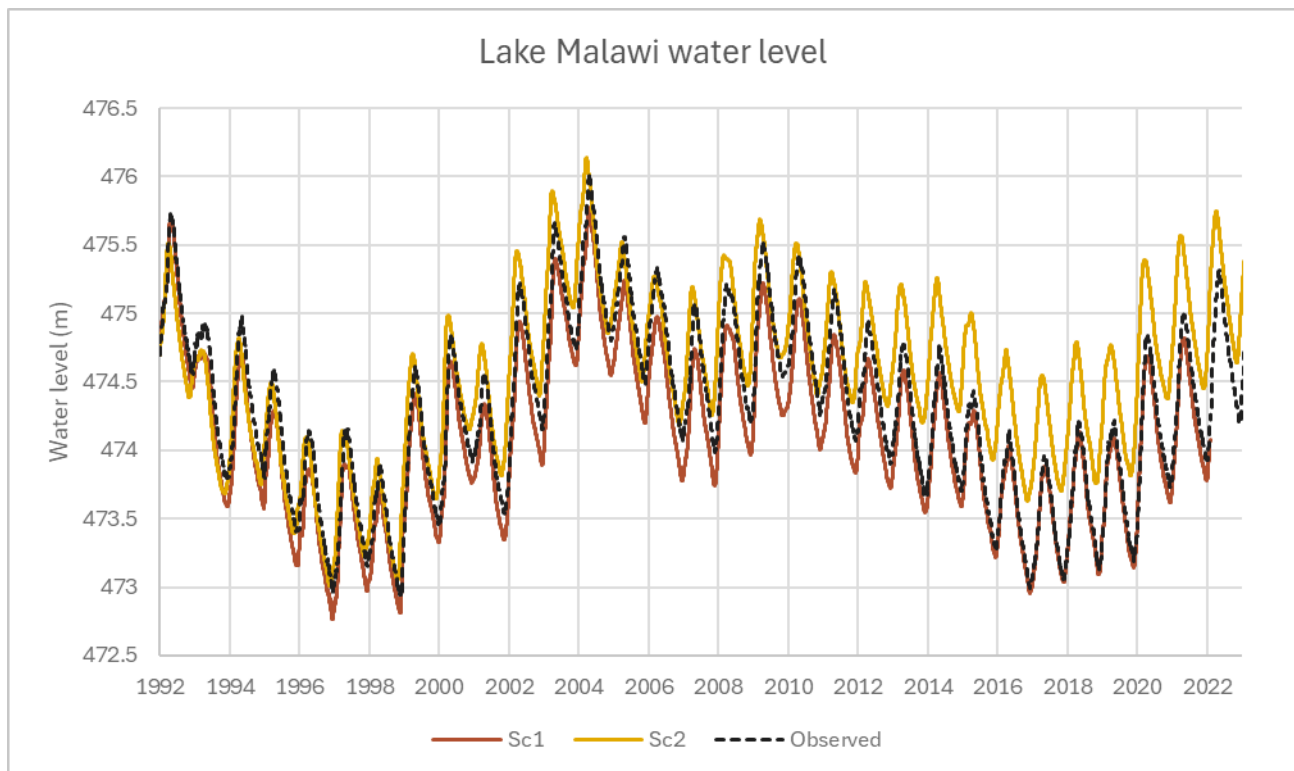


Figure A4-3 . Lake Malawi water levels for scenarios 1 and 2 as well as the observed water level.

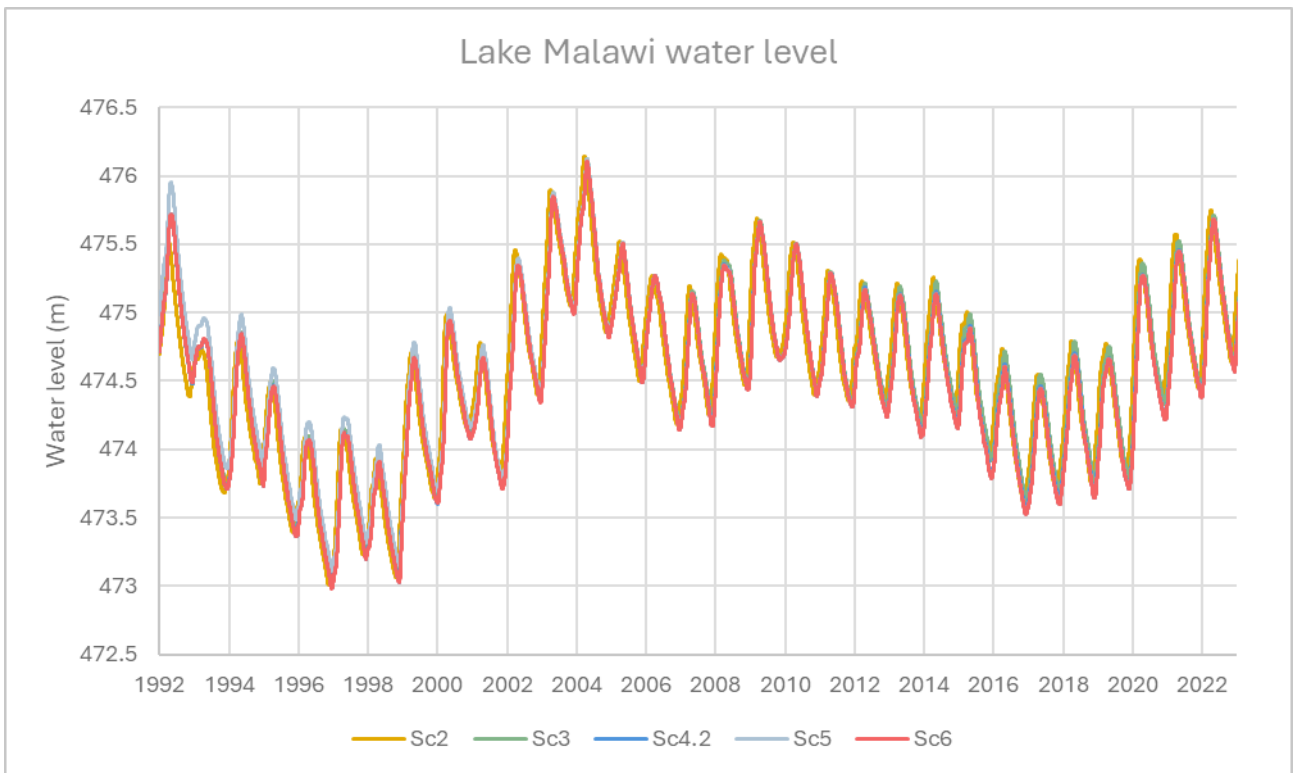


Figure A4-4 Lake Malawi water levels for scenarios 2, 3, 4.2, 5 and 6.

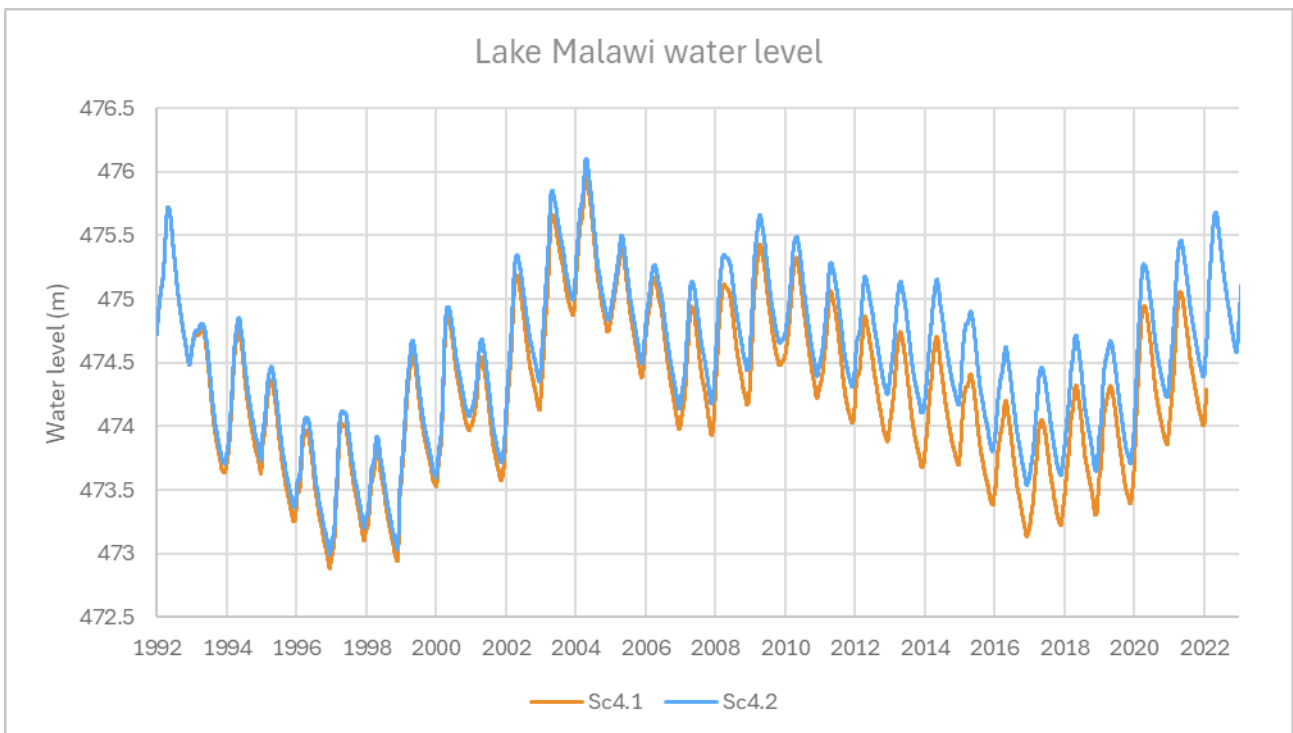


Figure A4-5 Lake Malawi water levels in scenarios 4.1 and 4.2

In the climate change scenarios (both for Near Future-2035 and Distant Future-2070), net inflow to lake Malawi is calculated by DCCMS and bias-corrected by Deltares. The average freewater per year for each of the three chosen GCMs is presented in Figures A4-6 to A4-8.

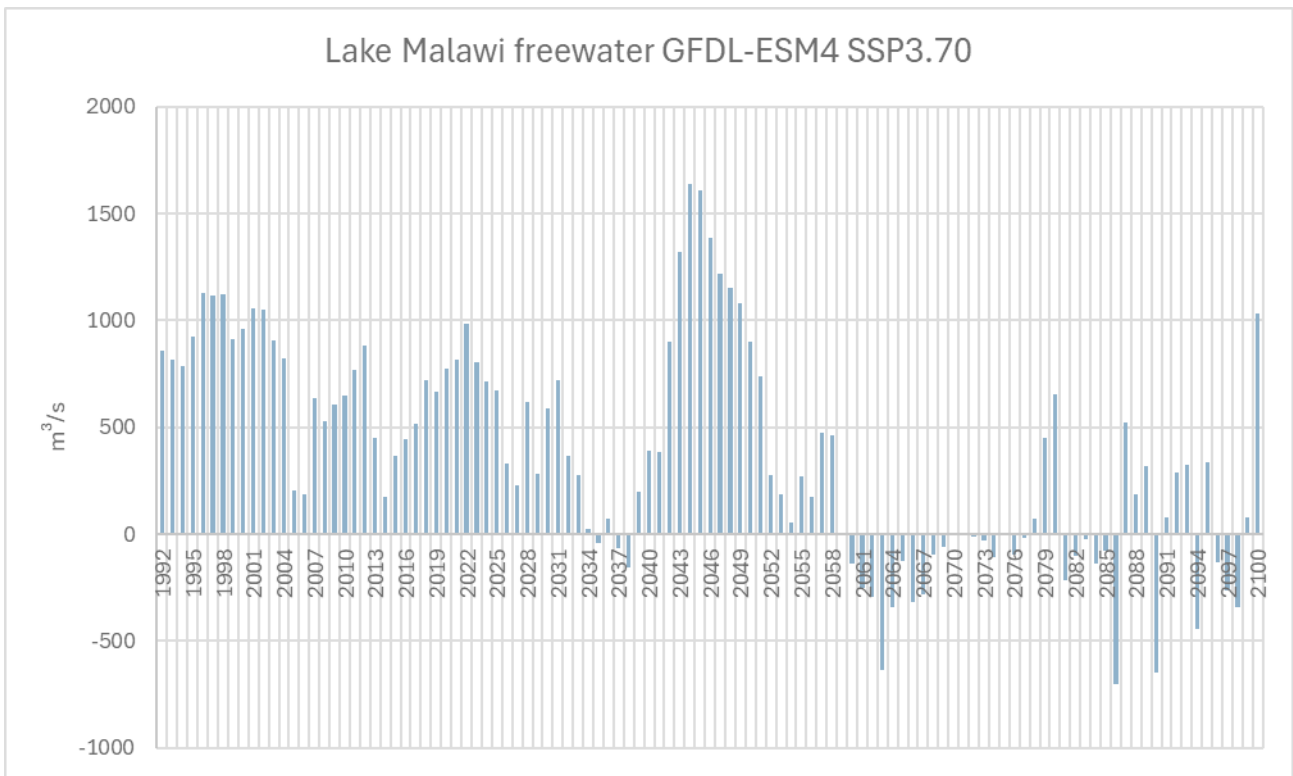


Figure A4-6 Lake Malawi freewater 1992 to 2100 for (mean) GFDL-ESM4 SSP3.70 (bias-corrected to 2077, original data from 2078-2100).

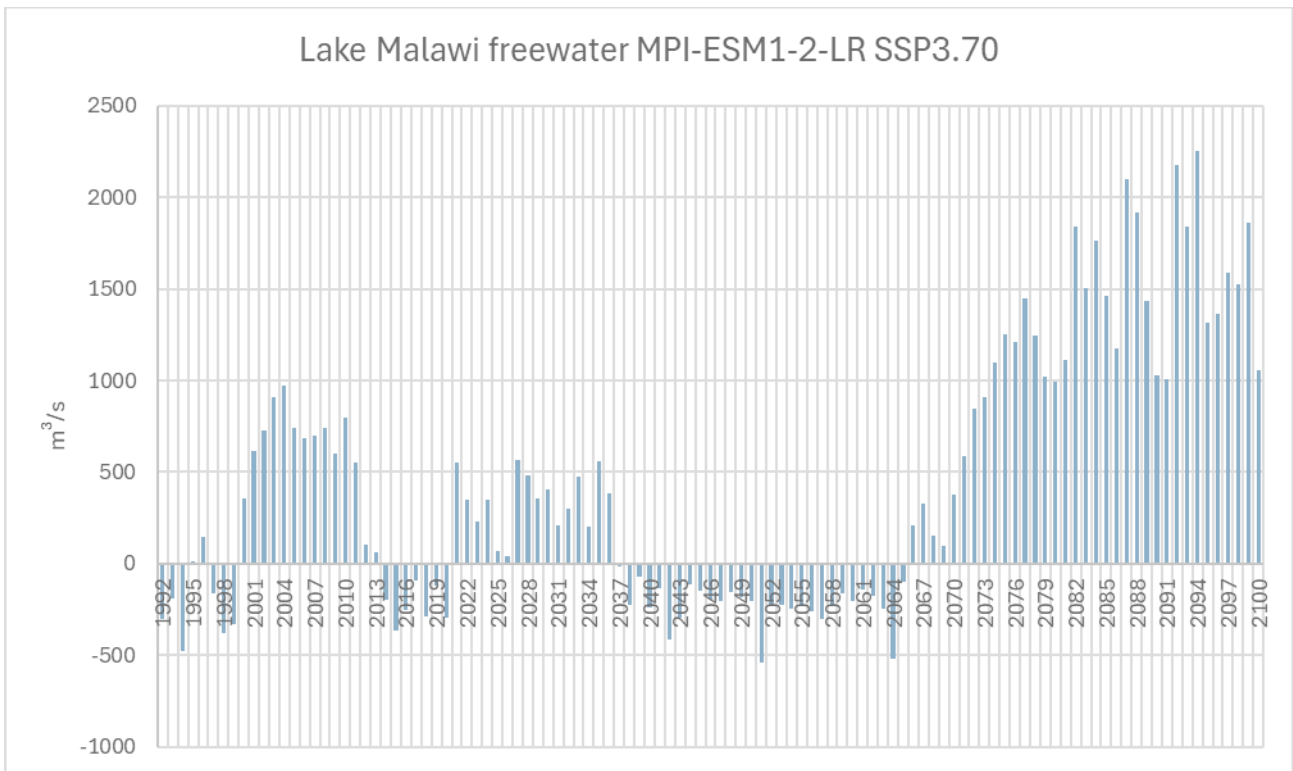


Figure A4-7 Lake Malawi freewater 1992-2100 for (wet) MPI-ESM1-2-LR SSP3.70.

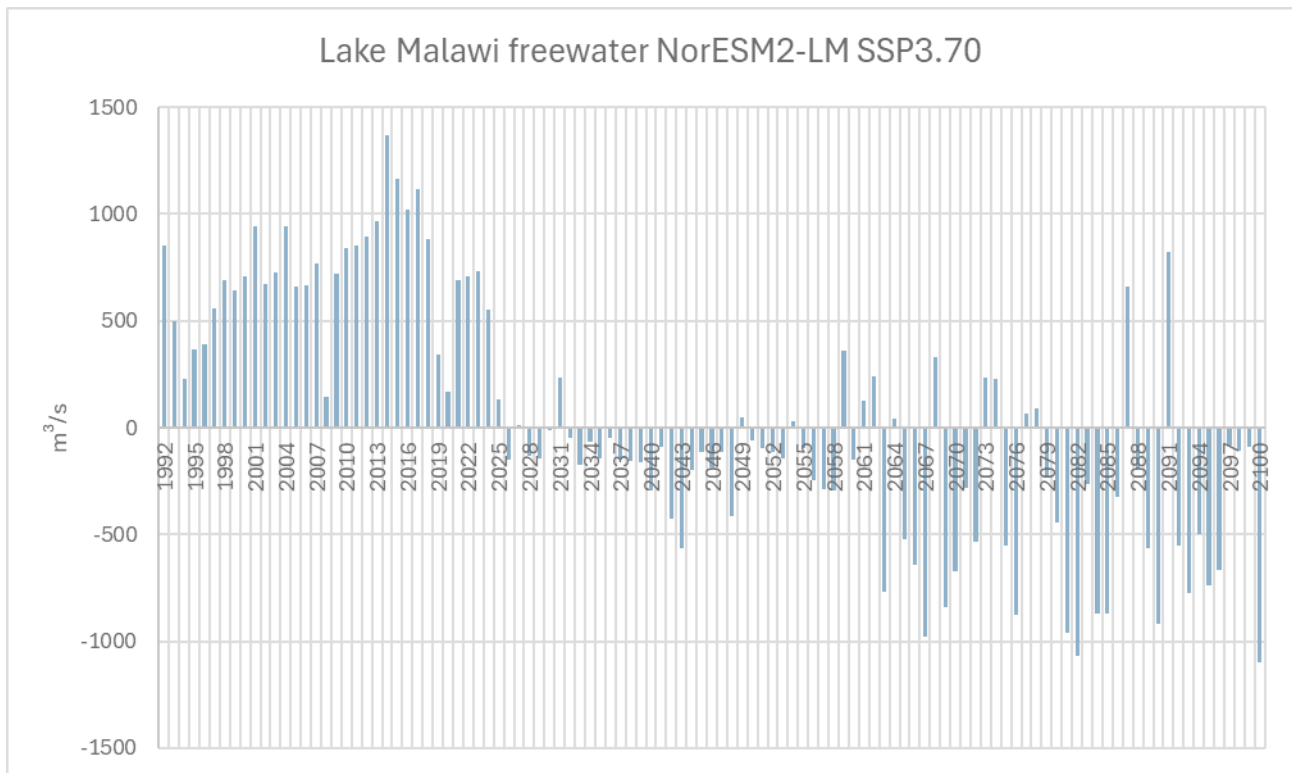


Figure A4-8 Lake Malawi freewater 1992 to 2100 for (dry) NorESM2-LM SSP3.70 (bias-corrected to 2059, original data from 2060-2100).

Many of the GCMs have time periods with negative flows. When this happens several years in a row, Lake Malawi water level can drop below the outlet sill, and flow from the lake becomes zero.

The Lake Malawi outlet sill level is about 2 meters lower than the lowest regulated water level (473.5 m) at around 471.5 m. Neither the DCCMS climate model nor the hydropower (MIKE+) model are designed to investigate what happens if the Lake Malawi level drops below the outlet sill, as neither of the model contains any information about the bathymetry of Lake Malawi or changes in surface area as the lake level drops. We can however do simplified calculations of the lake level based on hydrological routing to investigate which periods will be without outflows in the different climate models. This can be seen in Figures A4-9 to A4-11.

The three different climate models yield very different results. In GFDL-ESM4, the water level first drops below the sill in 2066. The rest of the century, the water level stays around the sill level (+/- 1 m). In the model MPI-ESM1-2-LR, the water level is below the sill in the middle of the century, from 2048 to 2075, but increases again at the end of the century. In the last model, NorESM2-LM, the water level drops below the sill in 2042 and keeps decreasing throughout the century. It is clear that climate change could have a very large impact on Lake Malawi water levels and Shire River flows, but it is unclear exactly what this impact will be. Furthermore, Kamuzu Barrage has very little impact on flows and water levels when the freewater is very large or very small.

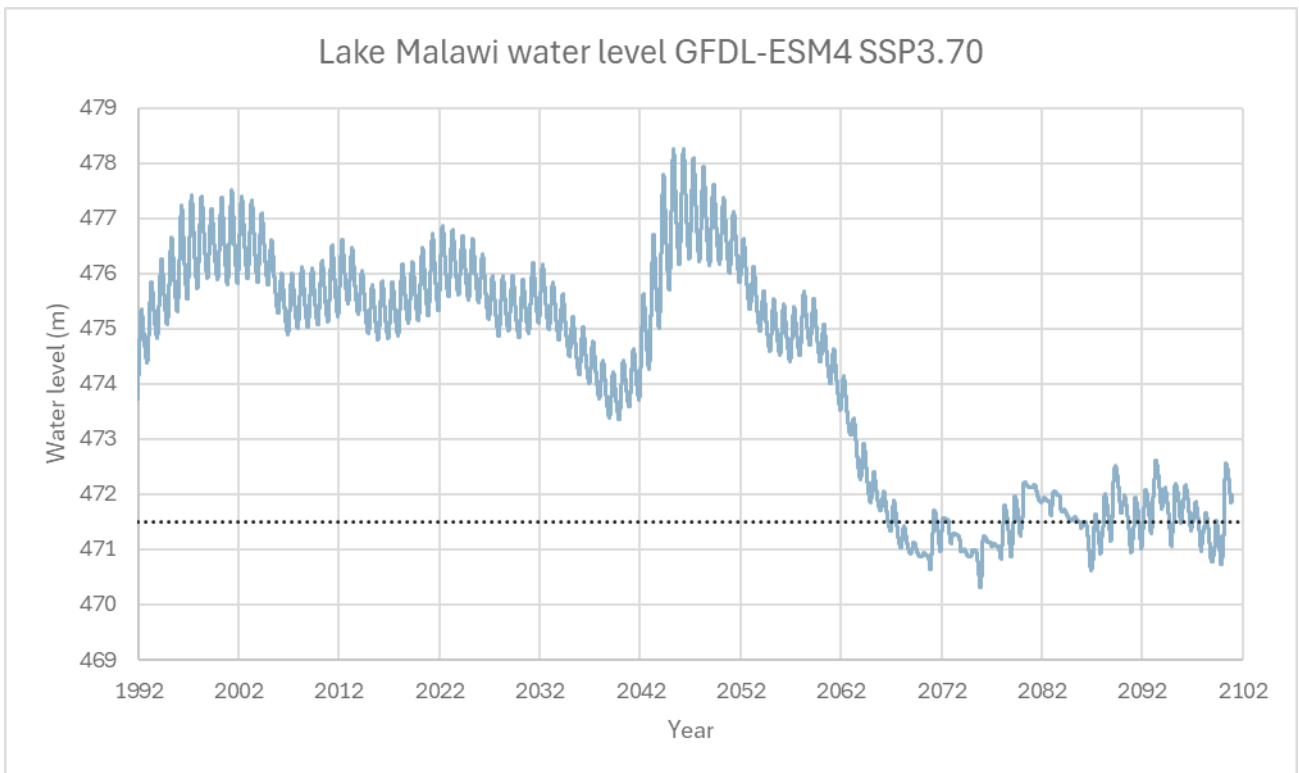


Figure A4-9 *Calculated Lake Malawi water level based on (mean) GFDL-ESM4 SSP3.70. Sill level marked with dotted line.*

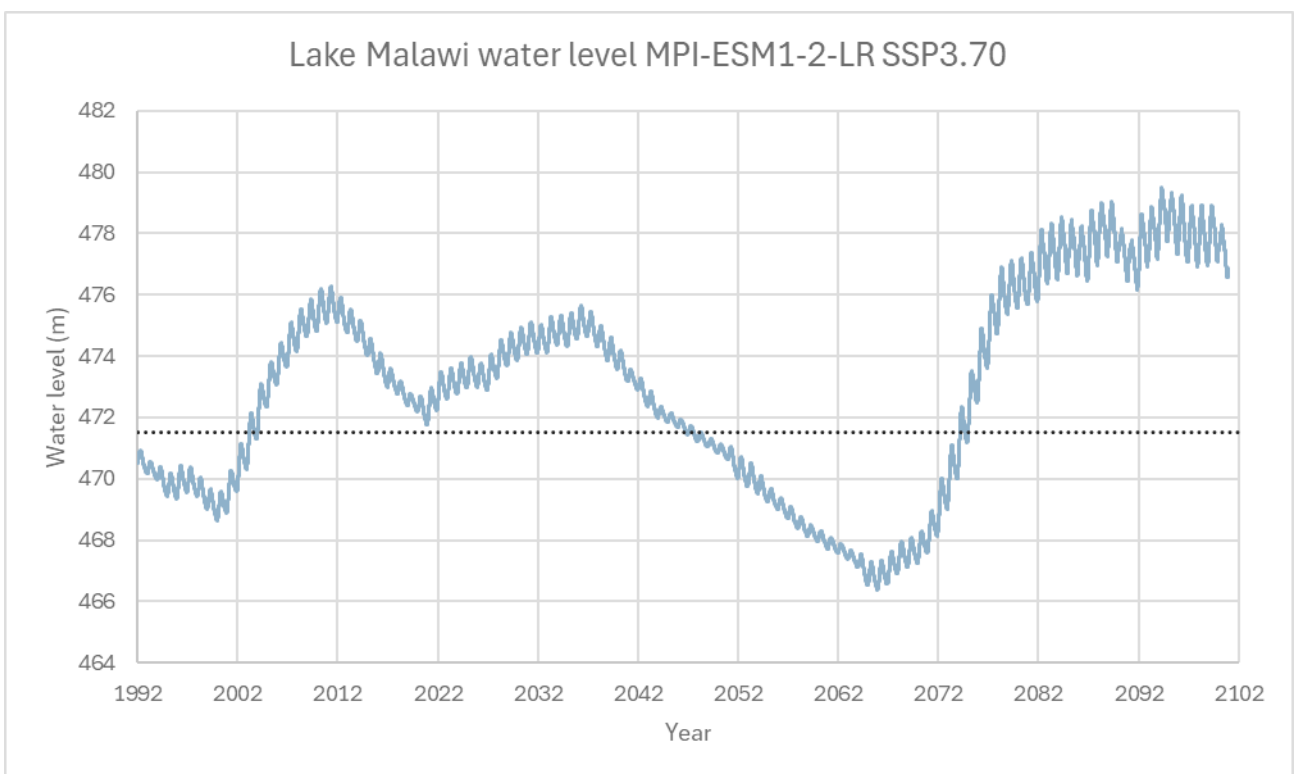


Figure A4-10 *Calculated Lake Malawi water level based on (wet) MPI-ESM1-2-LR SSP3.70. Sill level marked with dotted line.*

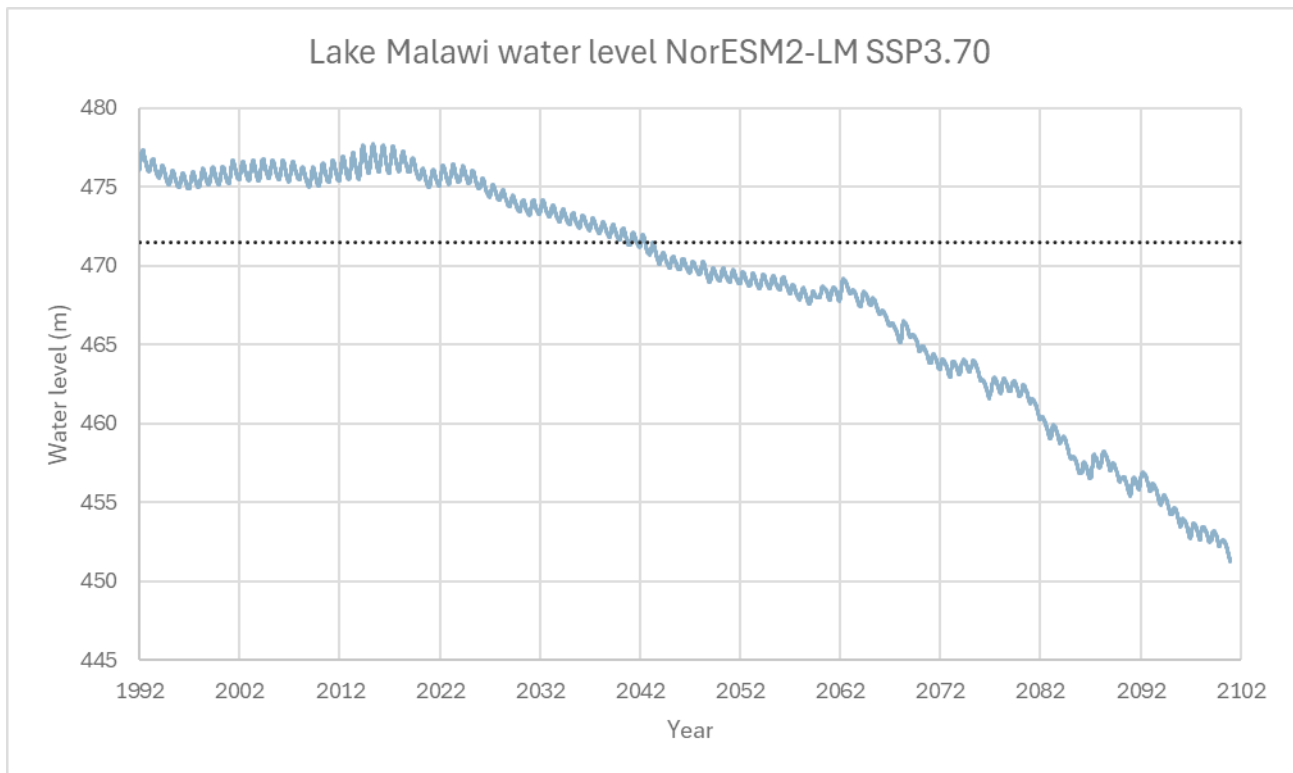


Figure A4-11 *Calculated Lake Malawi water level based on (dry) NorESM2-LM SSP3.70. Sill level marked with dotted line.*

Note that the water levels in Figures A4-9 to A4-11 are different that the water levels in the simulations in Scenarios 7 to 10 (Near Future 3, 4 and Distant Future 1 and 2). This is because the starting water level for all simulations is set to 474.7 m, and the minimum allowed water level in the MIKE model is around 470.

A.4.3. Liwonde (Kamuzu Barrage) flow

Scenarios 1-6

For each scenario except scenario 1 (near natural), outflow from Lake Malawi is regulated by Kamuzu Barrage. The barrage was rehabilitated in 2015-2019, and the operation before the rehabilitation was slightly different from the current operation, but for simplicity, all scenarios assume the current state of the barrage. The optimum release is to hold back water during the wet season and release water during the dry season. However, when the water level is high, it is necessary to release more water to avoid flooding, and when the water level is low, there is not enough water available to release the required amount.

The duration curves in Figure A4-12 summarises how much of the time the release is above the goal release (i.e. flood control operation) and how much of the time the release is below the goal release (i.e. water saving operation). We can see that most scenarios have flood control operation about 25% of the time. How much of the time there is not enough water to fulfill the required release, varies between the scenarios. Scenario 4.1 has too little water ca. 45% of the time, while in the rest of the scenarios there is too little water between 16% and 22% of the time.

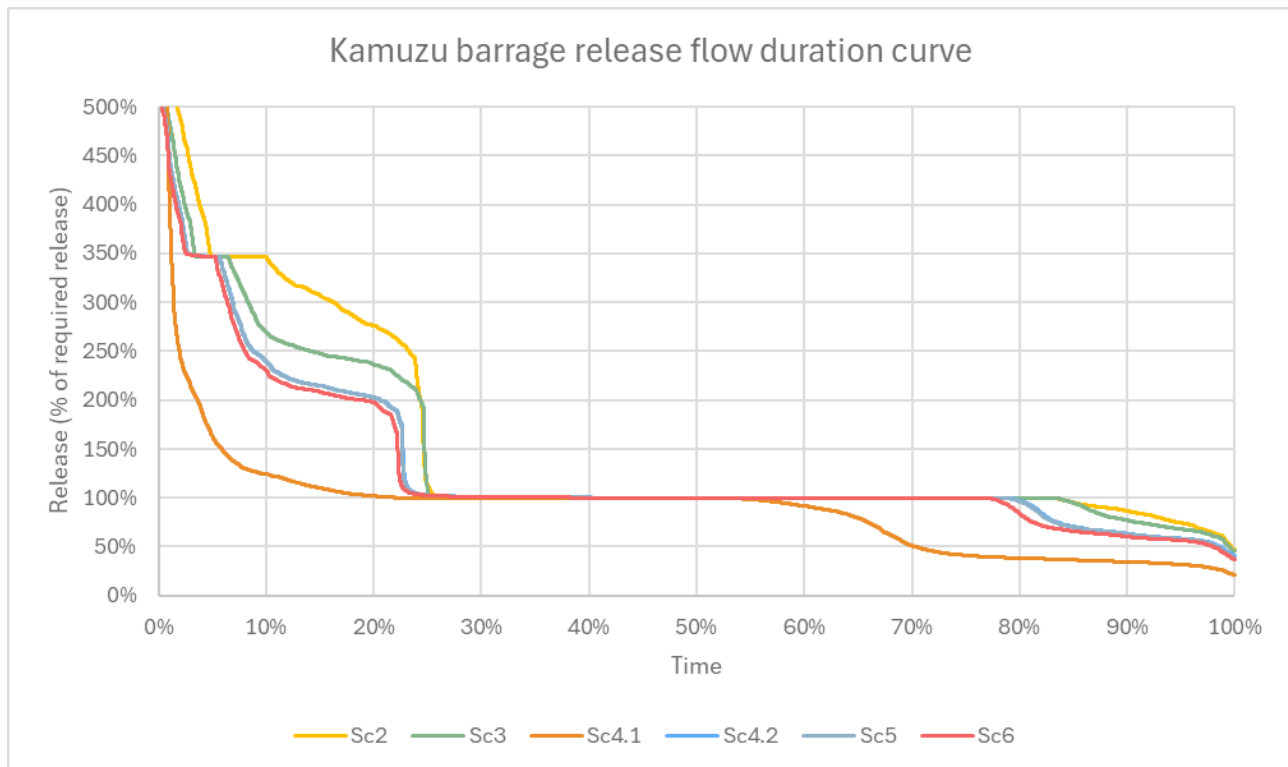


Figure A4-12 Duration curves for Kamuzu Barrage release. Sc4.2 and Sc5 are almost identical.

More detailed results for scenarios 1-6 are included in Figures A4-13 to A4-15. We can see that most scenarios have flood control release in 1992, 2002-2006, 2008-2011 and in 2021-2023. The period with too little water is mostly between 1995 and 2000, but there is also a dry period between 2016 and 2018. Scenario 4.1 requires higher releases than the other scenarios and has too little water from 2015 to 2020 in addition to 1995-2000.

As can be seen, a minimum release of 130 m³/s is implemented in all scenarios, even if the required release is smaller. This is based on the minimum flow suggested in the Final report for the detailed design of Kamuzu Barrage (Norplan 2013), but a minimum release is not implemented in the current KABOM tool. The minimum release has some impact on scenario 2, where the required release is often lower than 130 m³/s, but the impact on the other scenarios is small.

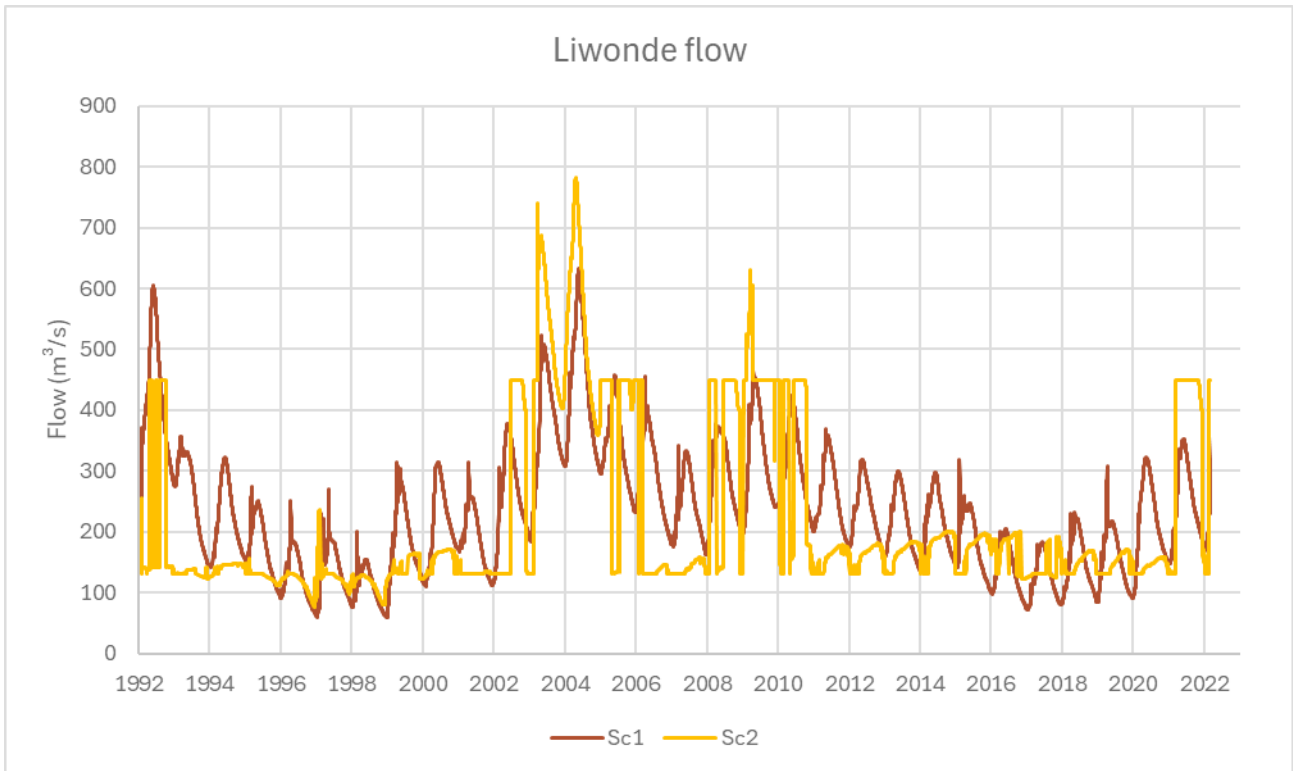


Figure A4-13 *Liwonde flow for scenarios 1 and 2.*

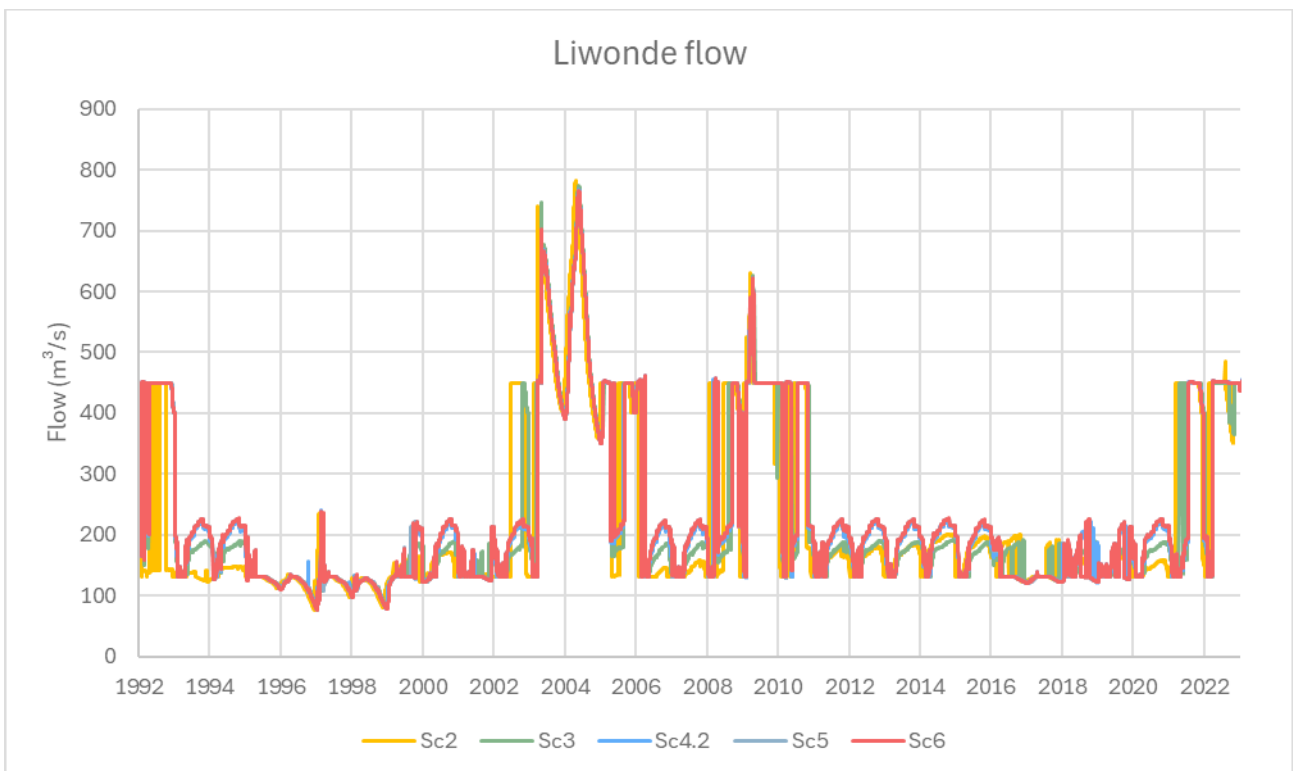


Figure A4-14 *Liwonde flow for scenarios 2, 3, 4.2, 5 and 6.*

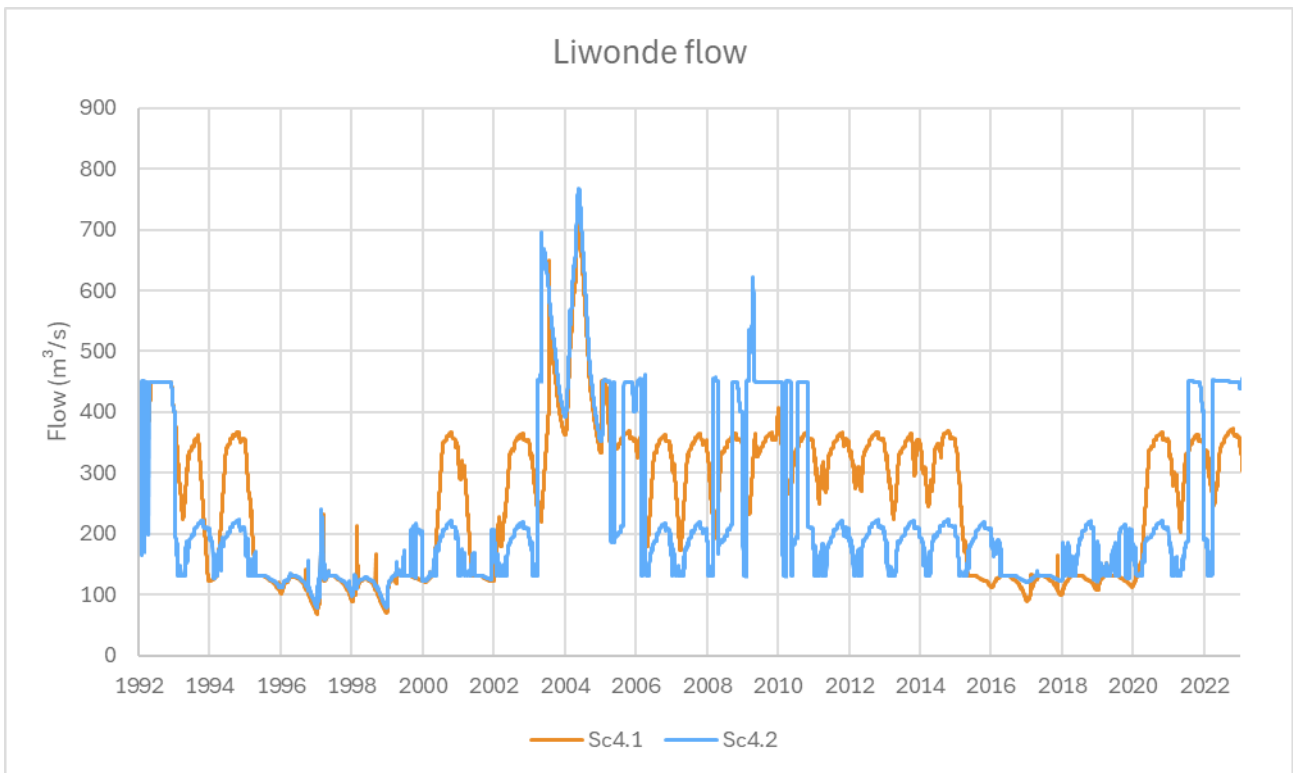


Figure A4-15 *Liwonde flow for scenarios 4.1 and 4.2.*

Climate Change Scenarios

In the climate change scenarios, Kamuzu Barrage has very little influence on the flow, as the flow is either very high or very low. Duration curves for the climate change scenarios are shown in Figure A4-16.

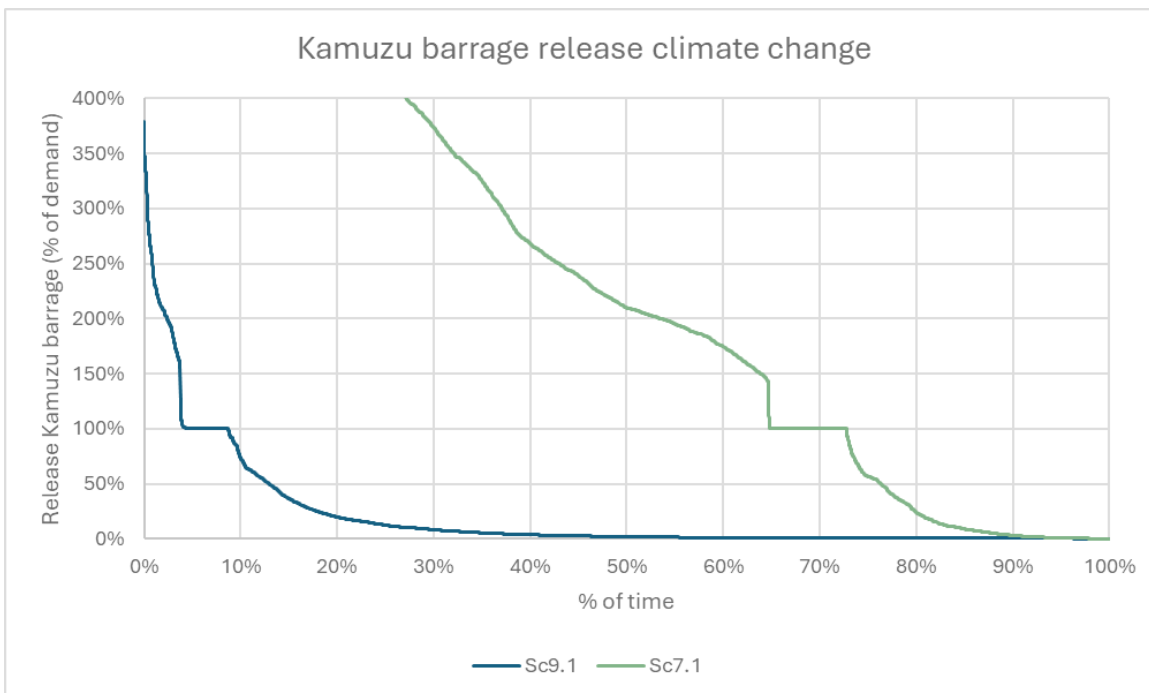


Figure A4-16 *Duration curves for Kamuzu Barrage release for the climate change scenarios. 8.1 and 10.1⁵³ are very similar to 7.1 and 9.1.*

⁵³ The scenario numbers 7.1, 8.1, 9.1 and 10.1 refers to the mean climate change scenarios of the main scenarios 7, 8, 9 and 10.

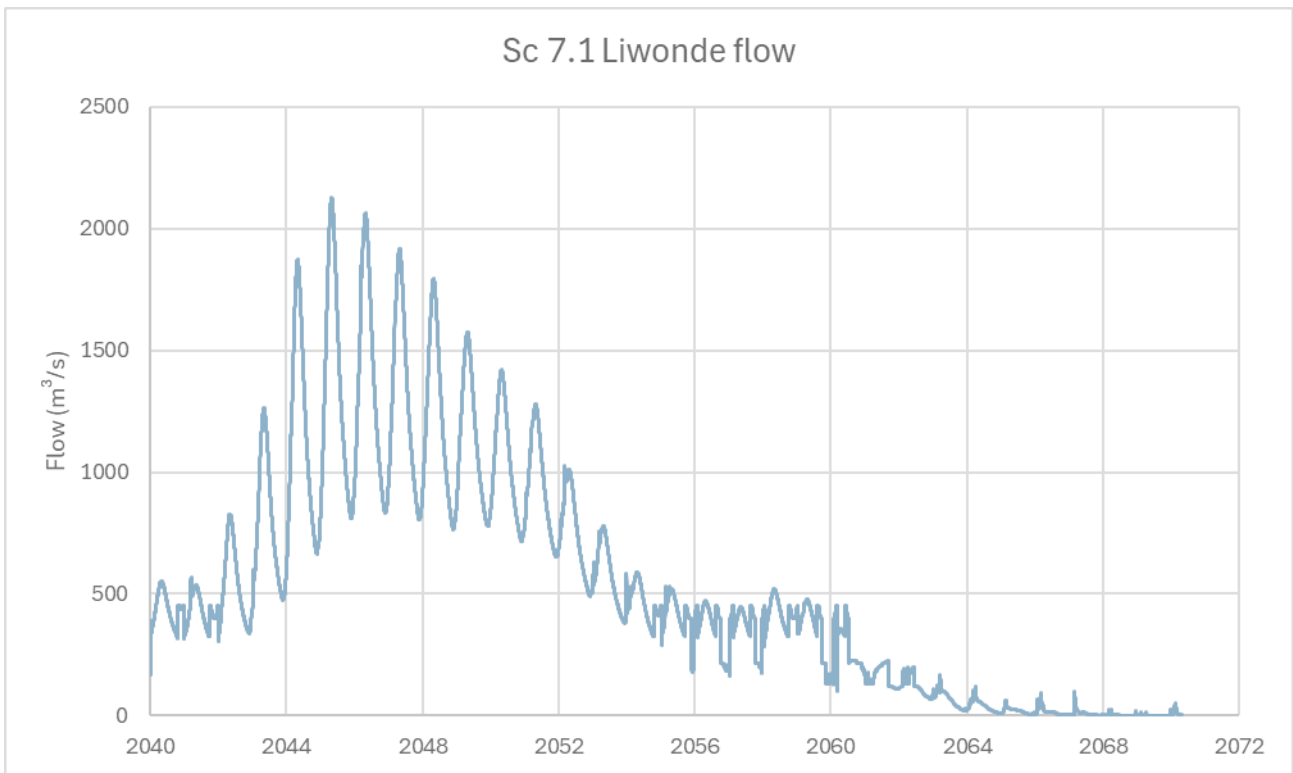


Figure A4-17 *Liwonde flows for scenario 7.1.*

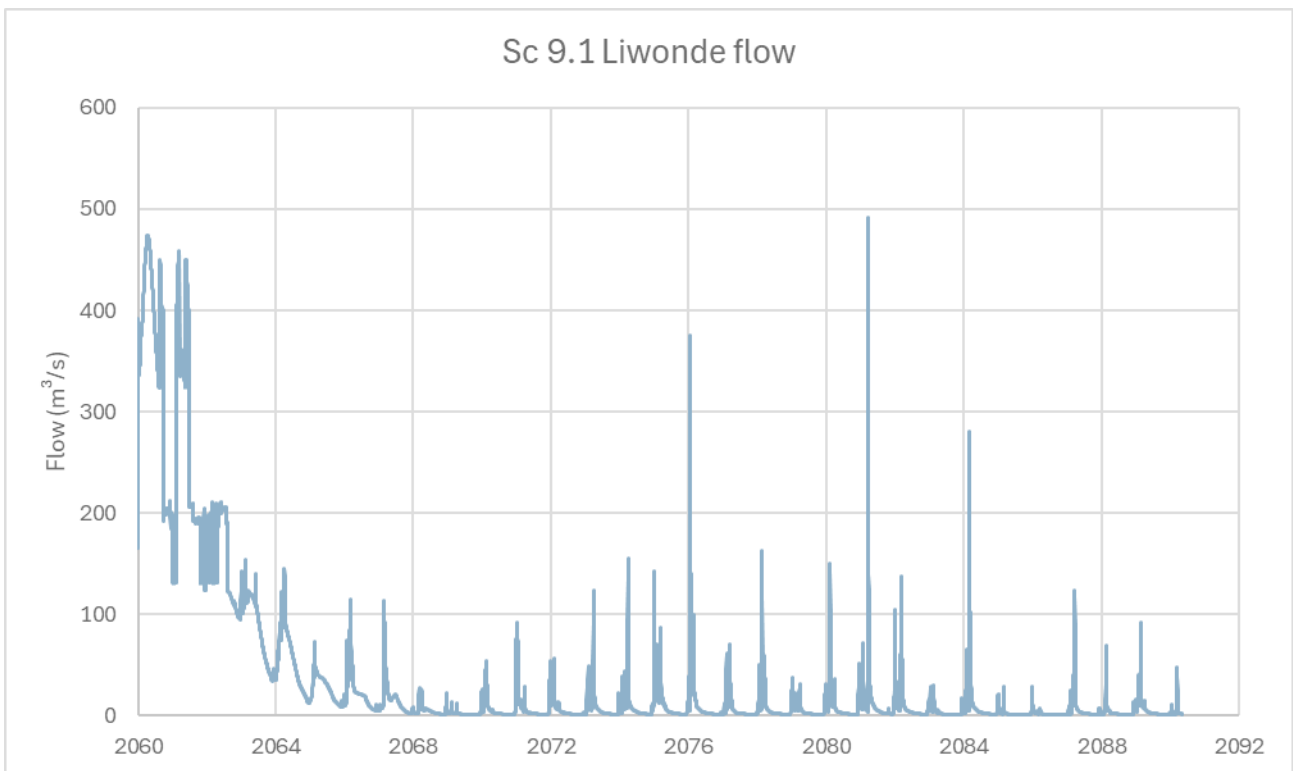


Figure A4-18 *Liwonde flows for scenario 9.1.*

The differences between scenario 7.1 and 9.1 is because of differences in initial water level in lake Malawi. After 2065, the lake Malawi water level is very low, and the gates are kept in an open position. The flow comes from the local tributaries downstream the lake Malawi outlet.

Flow delay from Kamuzu Barrage to downstream dams

When there is a change in release at Kamuzu Barrage, it takes a while before the change can be observed at the downstream dams. The delay in the model is about 24 hours for Nkula and about 30 hours for Kapichira.

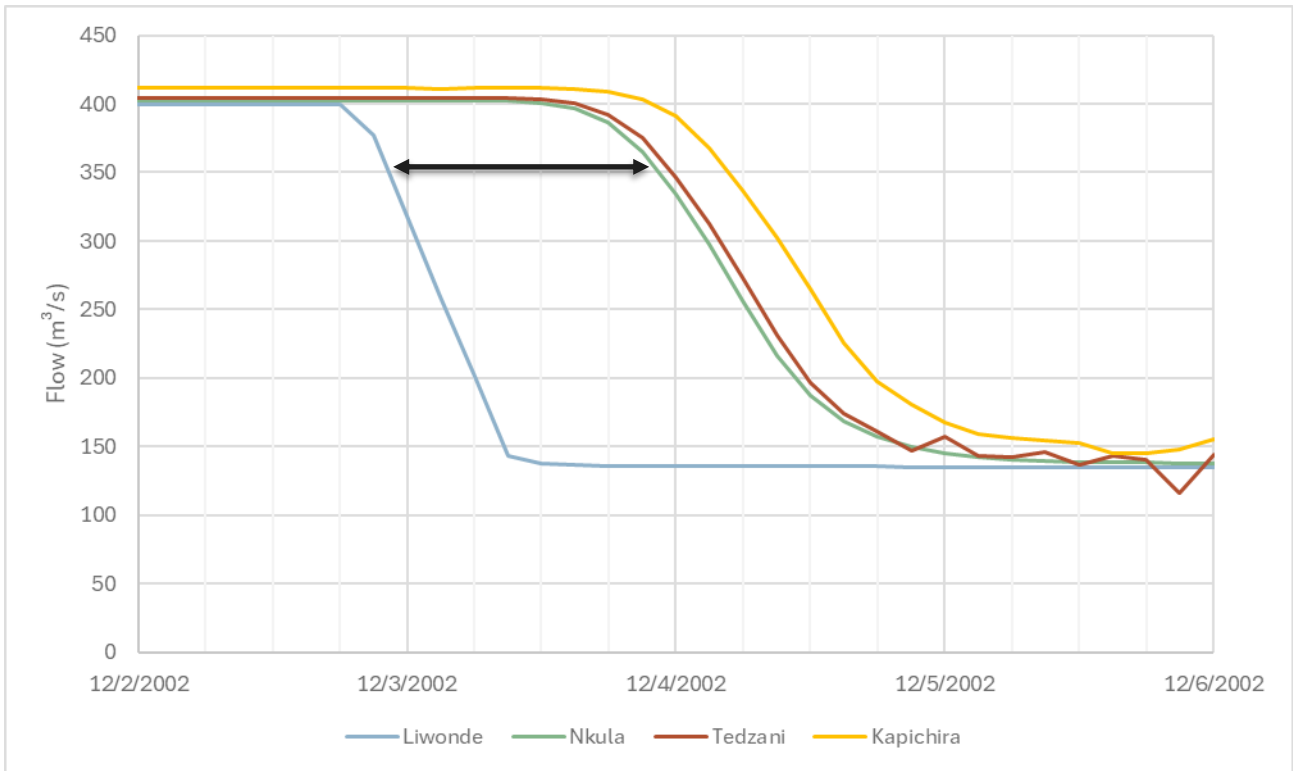


Figure A4-19 Flow at Liwonde and upstream Nkula, upstream Tedzani and upstream Kapichira after a change of flow at Liwonde.

A.4.4. Hydropower generation

About the results

The hydropower generation results only reflect whether there is enough water available for generation. We have not taken into account downtime for maintenance and repairs, shut-downs when the tailwater level is too high to be able to generate, shut-downs during floods due to high sediment loads and/or too much debris or any other events that could affect the power generation. The purpose of the modelling is to be able to compare the different scenarios, the results in GWh and MW should not be used for any other purposes.

Scenario 2 (Historical)

Figure A4-20 to A4-23 shows modelled hydropower generation compared to the generation goal. In scenario 2, the average annual generation is 99% of the goal generation. In 22 of the 32 years, the modelled generation is at least 99% of the goal generation. In 9 years, the generation is 95-99% of the goal generation, while one year (1998) has a modelled generation that is 86% of the goal generation. The years with less generation correspond to the years with water saving release at Kamuzu Barrage.

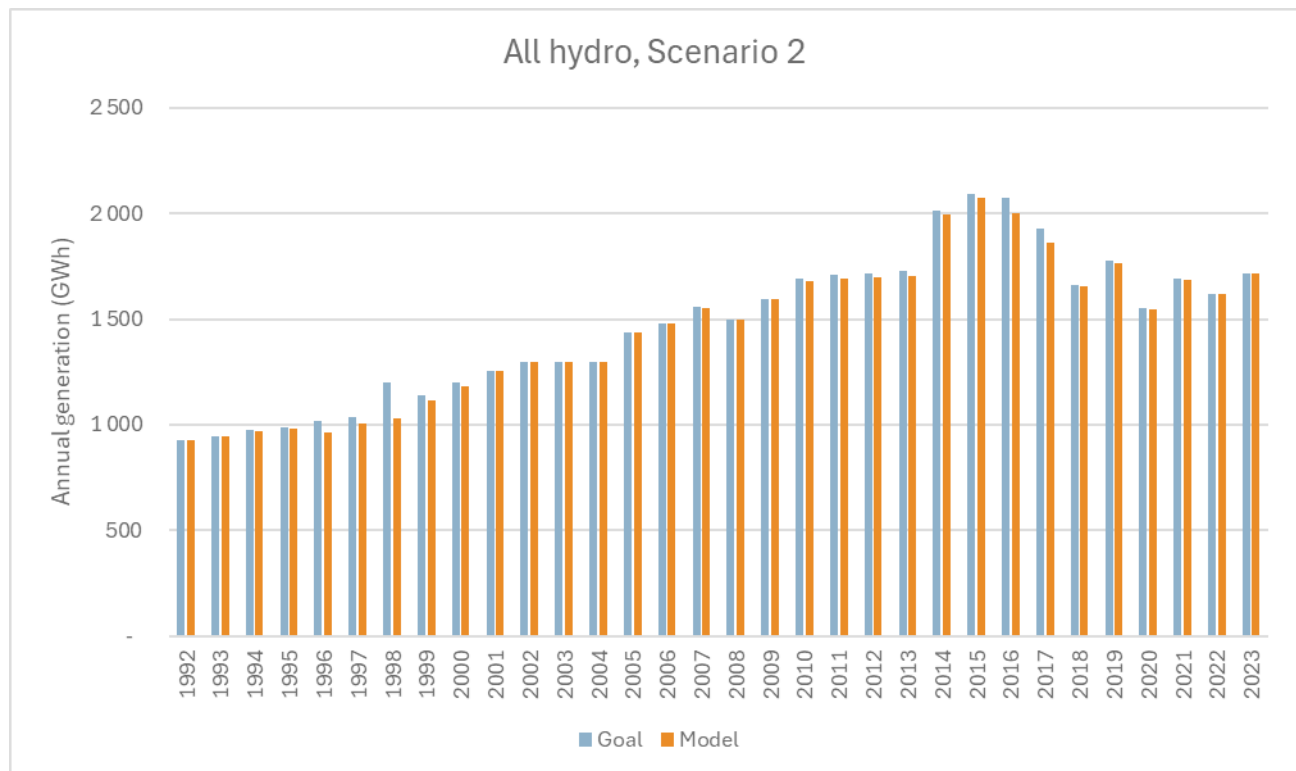


Figure A4-20 Comparison between modelled generation and the generation goal for each year of scenario 2. 2023 results are extrapolated.

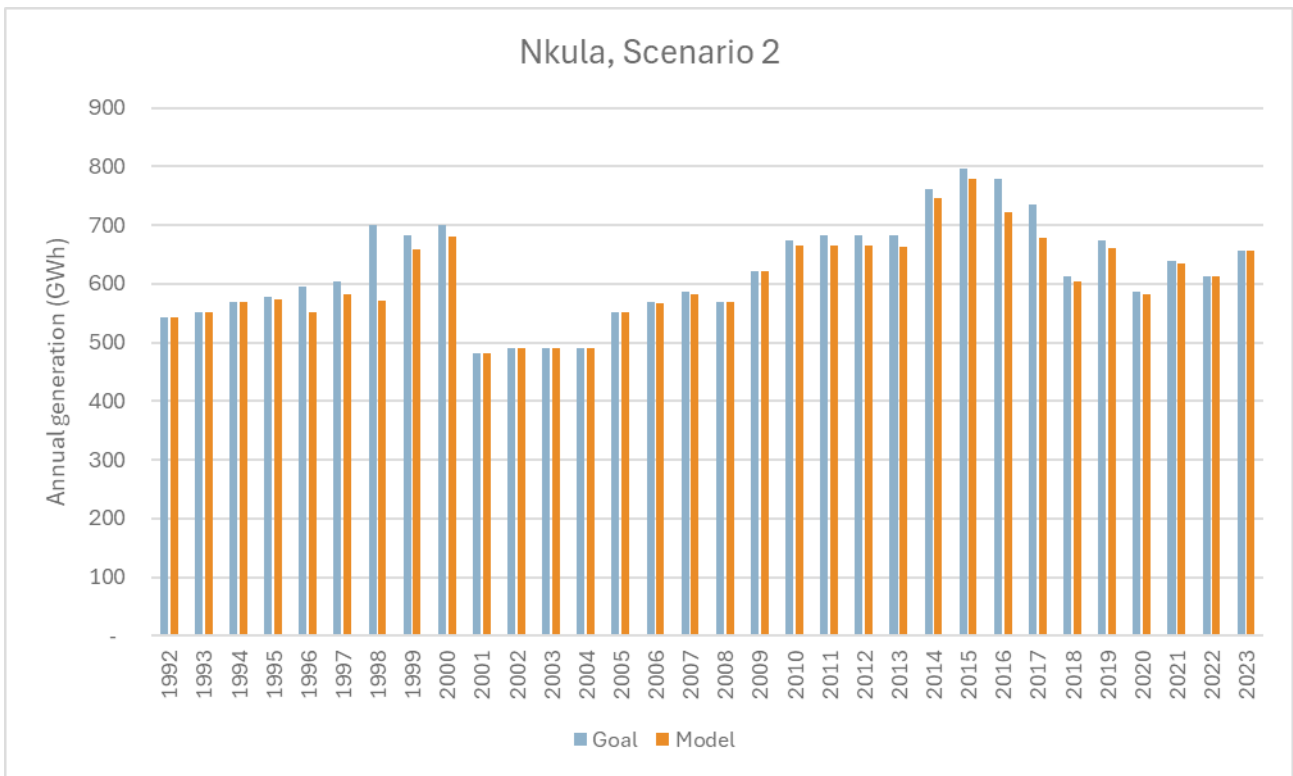


Figure A4-21 Comparison between modelled generation and the generation goal at Nkula for each year of scenario 2. 2023 results are extrapolated.

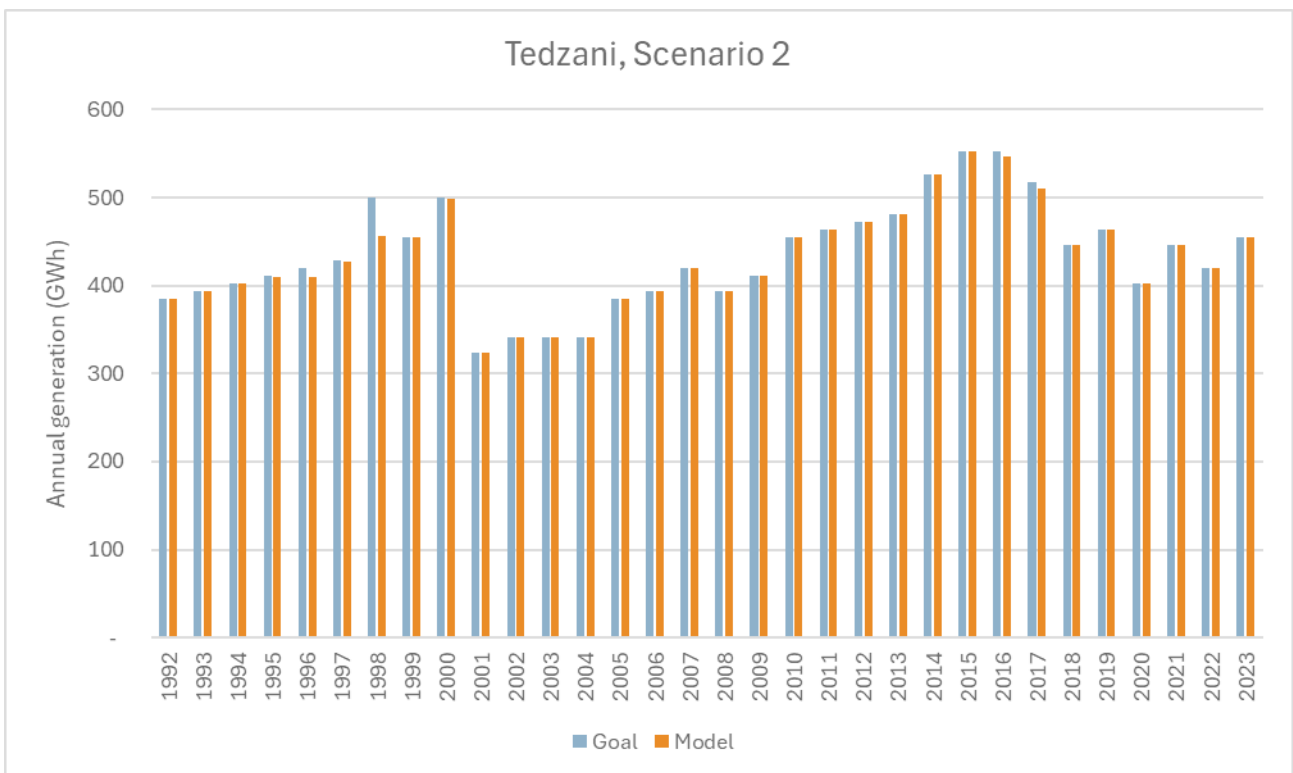


Figure A4-22 Comparison between modelled generation and the generation goal at Tedzani for each year of scenario 2. 2023 results are extrapolated.

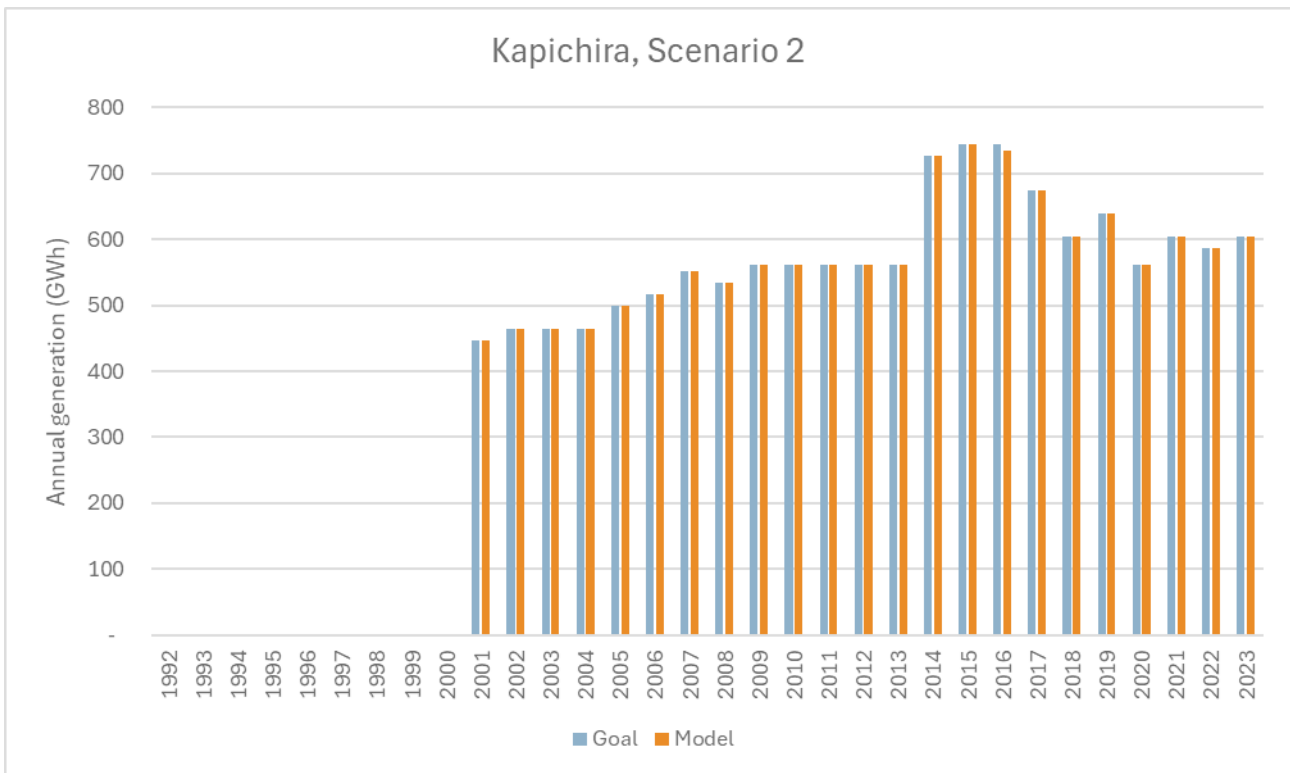


Figure A4-23 Comparison between modelled generation and the generation goal at Kapichira for each year of scenario 2. 2023 results are extrapolated.

Scenario 3 (Baseline 1 - 2023)

Scenario 3 has the same generation goal each year and the variation from year-to-year comes from hydrology. In scenario 3, the average annual generation is around 99% of the goal generation. In scenario 3, 24 out of 32 years, the modelled generation is at least 99% of the goal generation. The three years with the lowest generation are 1995 (95%), 1996 (92%) and 1998 (90%). This is related to a dry period from 1995 to 2000 (see Liwonde flows).

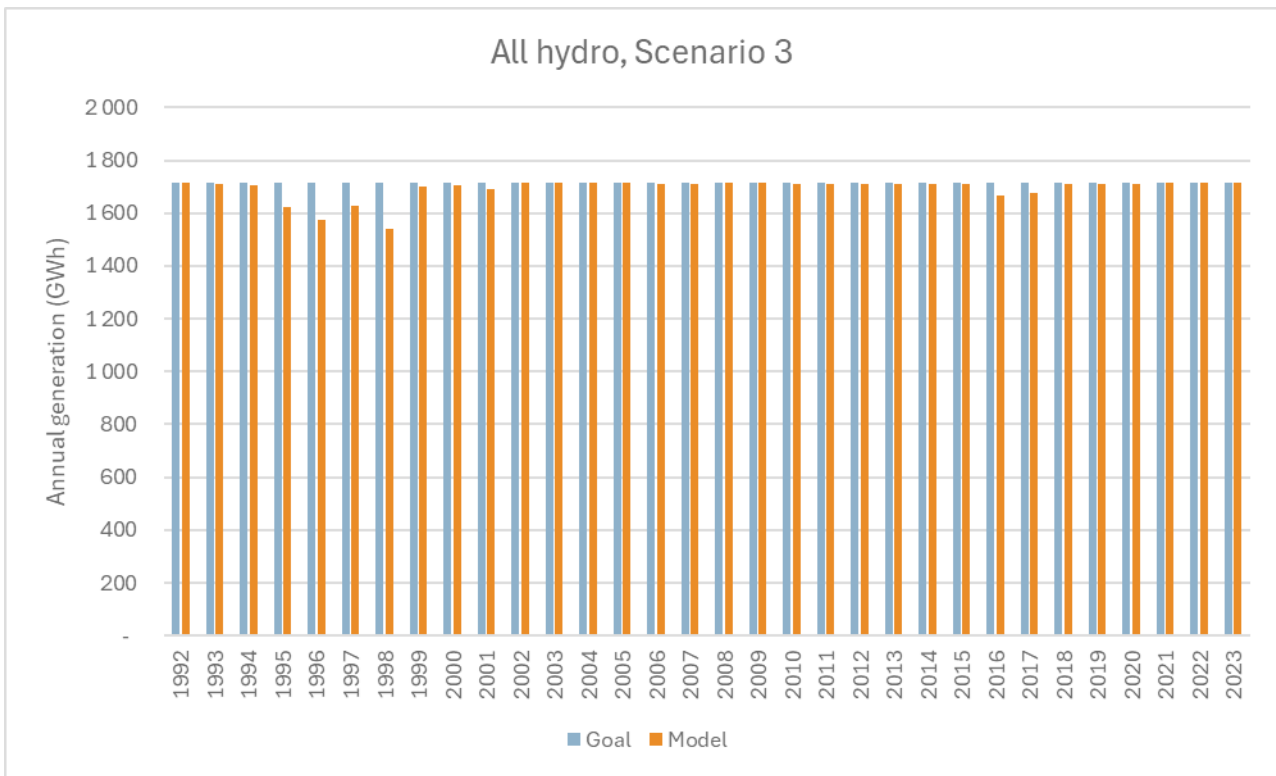


Figure A4-24 Comparison between modelled generation and the generation goal for each year of scenario 3. 2023 results are extrapolated.

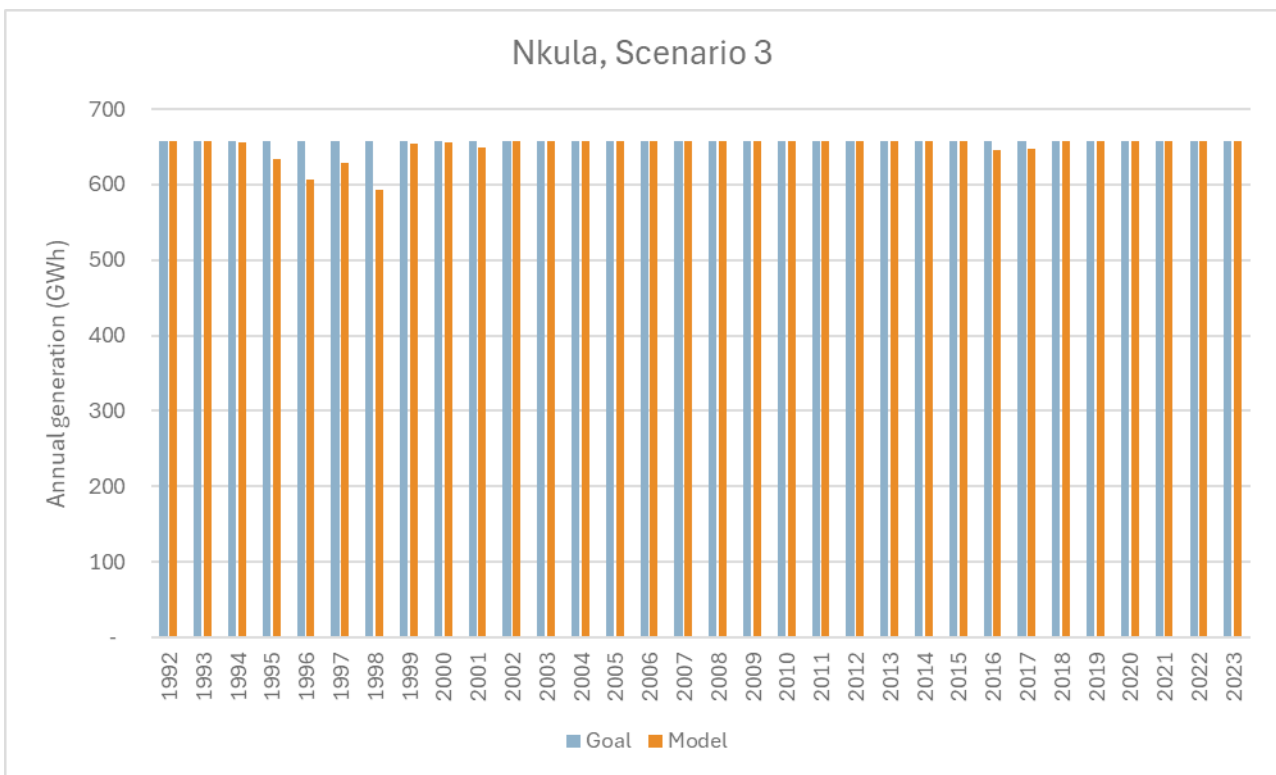


Figure A4-25 Comparison between modelled generation and the generation goal for Nkula for each year of scenario 3. 2023 results are extrapolated.

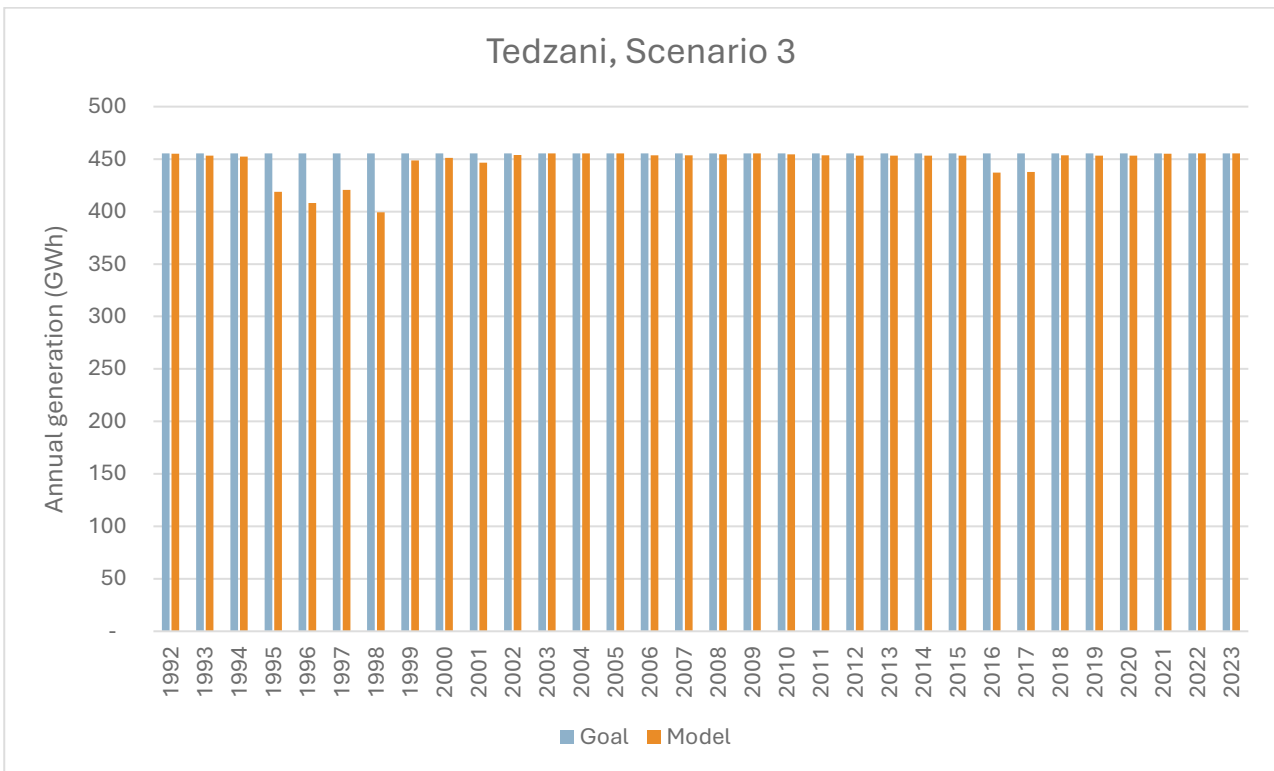


Figure A4-26 Comparison between modelled generation and the generation goal for Tedzani for each year of scenario 3. 2023 results are extrapolated.

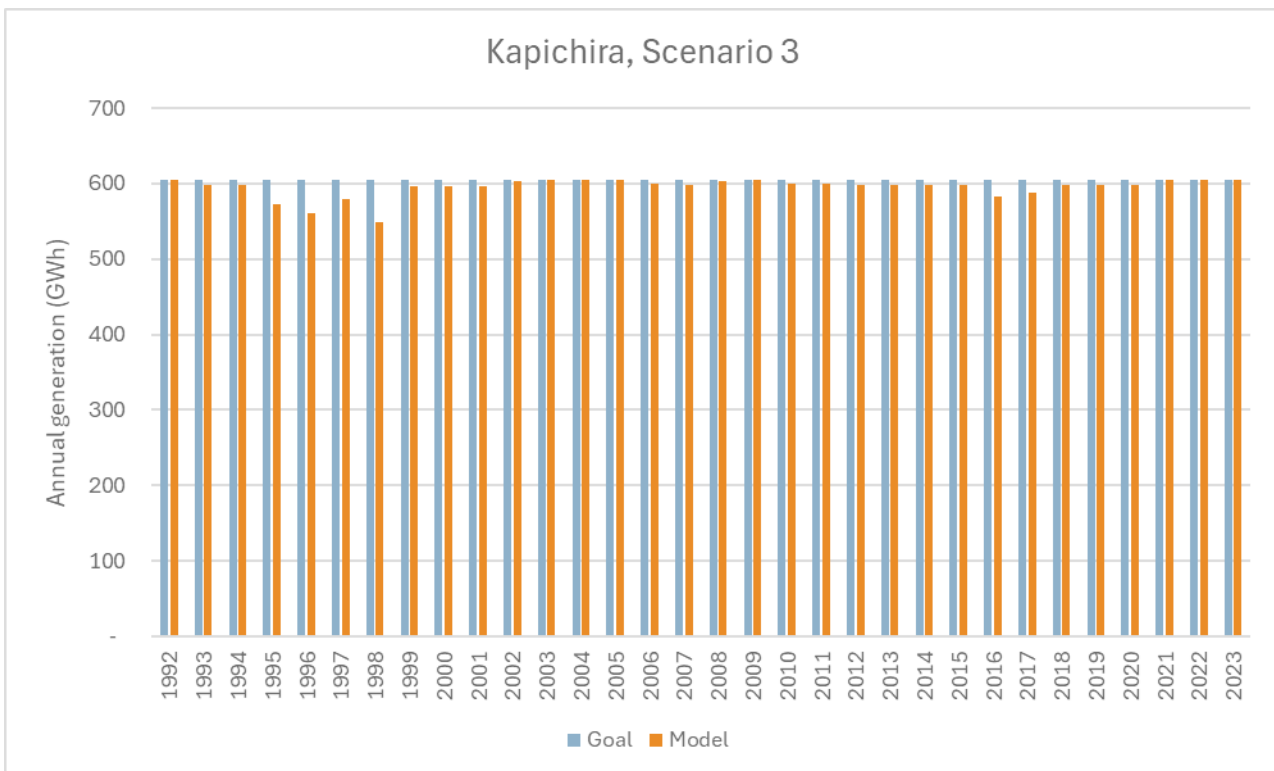


Figure A4-27 Comparison between modelled generation and the generation goal for Kapichira for each year of scenario 3. 2023 results are extrapolated.

Scenario 4.1 (Baseline 2 – 2030 – without Mpatamanga)

In scenario 4.1 there is enough water 18 out of 32 years. In 8 out of the 32 years, the generation is less than 80% of the goal generation. On average, the generation is 91% of the goal generation.

Note that in scenario 4.1, there is load-shedding during peak hours for all years, as the capacity of the hydropower plants is insufficient to meet the peak demand. The sum of the missing capacity is around 620 MWh per day, which is about 10% of the hydropower generation. This means that the average generation in scenario 4.1 is actually only 83% of what is needed to satisfy the demand. Without load-shedding during peak hours, the annual goal generation would have been 2556 GWh.

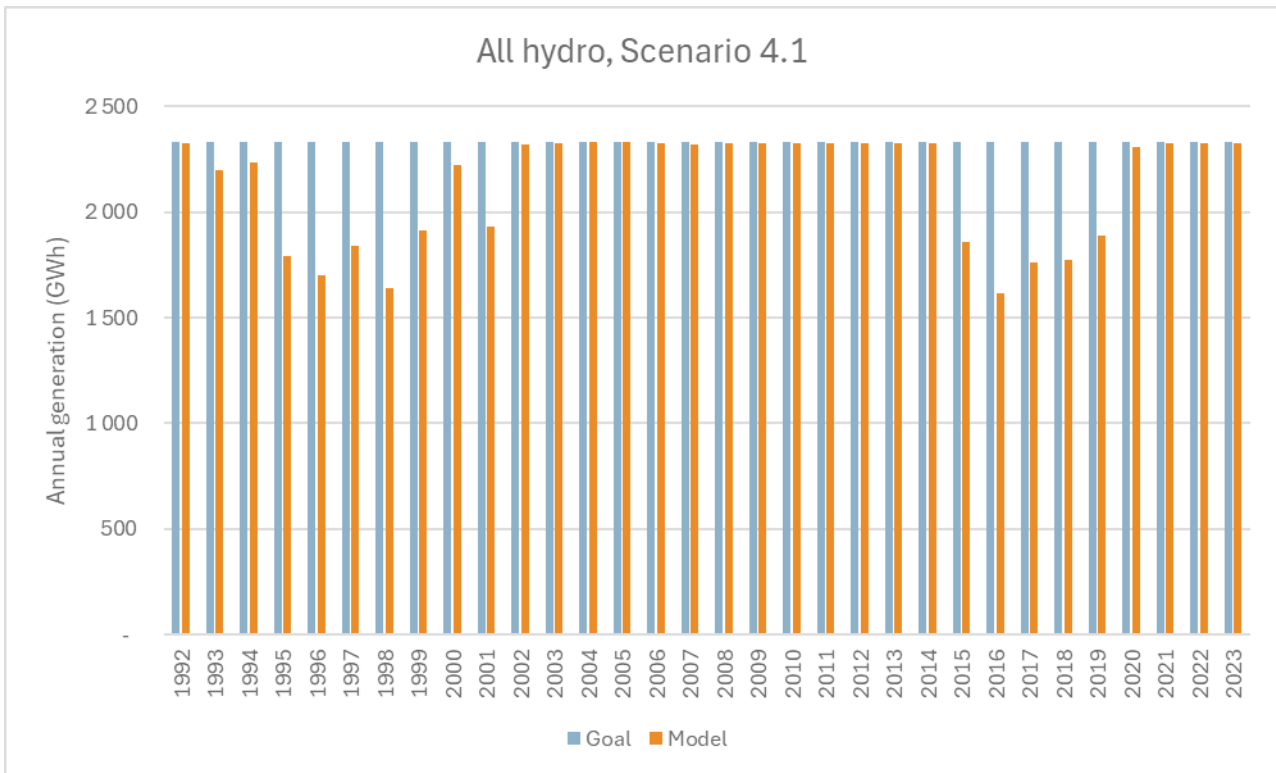


Figure A4-28 Comparison between modelled generation and the generation goal for each year of scenario 4.1. 2023 results are extrapolated.

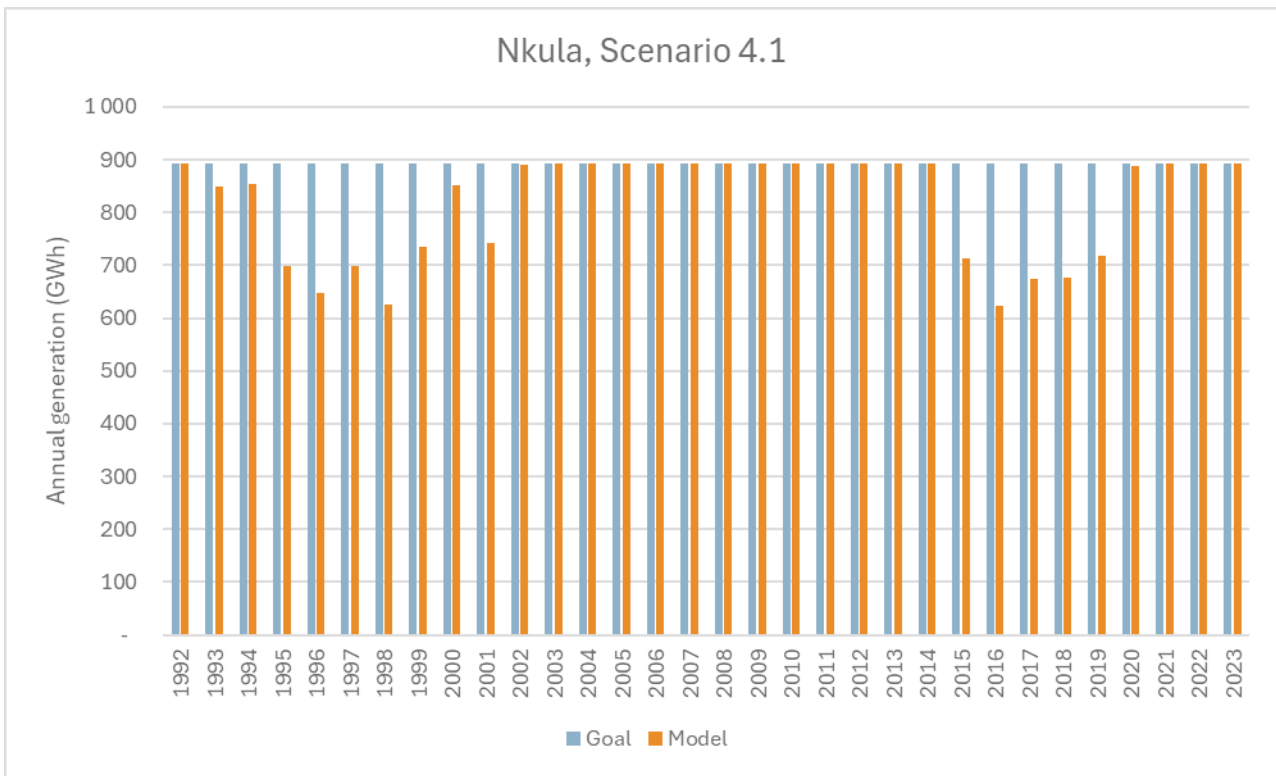


Figure A4-29 Comparison between modelled generation and the generation goal for Nkula for each year of scenario 4.1. 2023 results are extrapolated.

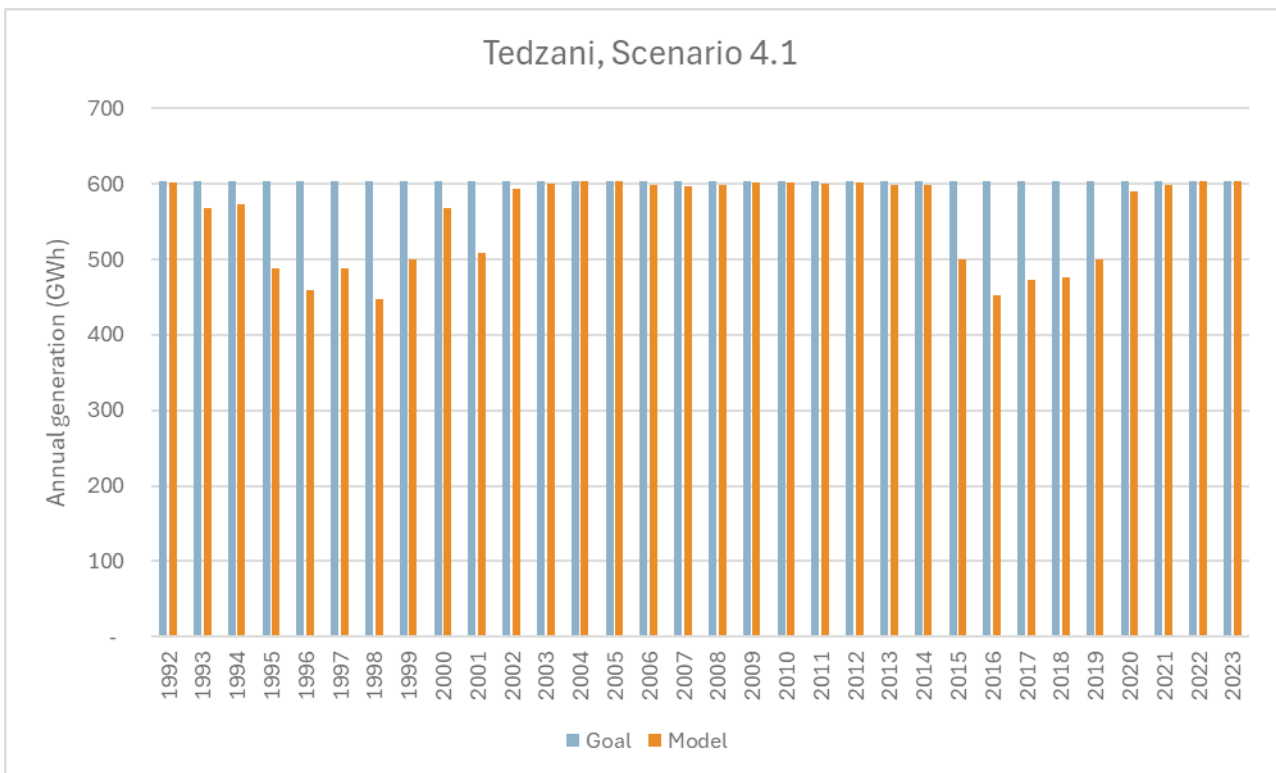


Figure A4-30 Comparison between modelled generation and the generation goal for Tedzani for each year of scenario 4.1. 2023 results are extrapolated.

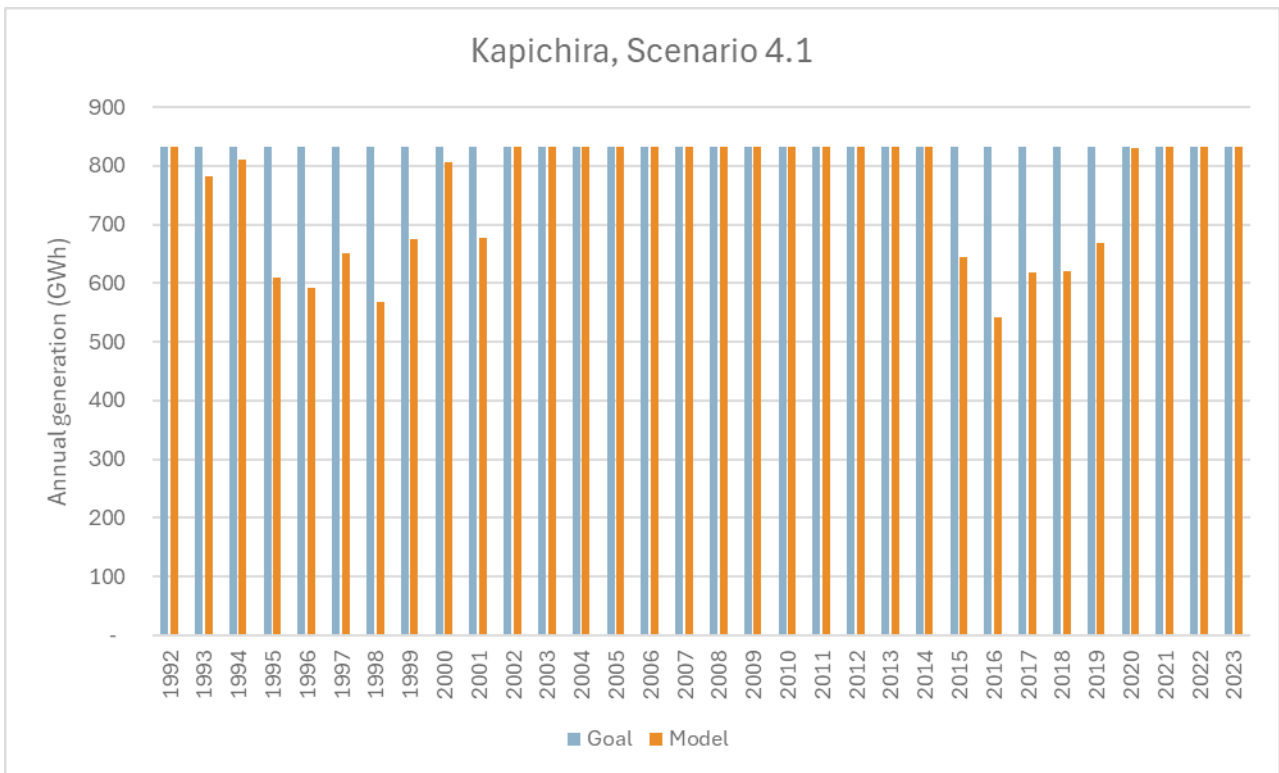


Figure A4-31 Comparison between modelled generation and the generation goal for Kapichira for each year of scenario 4.1. 2023 results are extrapolated.

Scenario 4.2 (Baseline 2 – 2030 – with Mpatamanga)

In scenario 4.2, the average annual generation is just shy of 99% of the goal generation. In 24 out of 32 years, the generation is more than 99% of the goal generation. The lowest generation is in 1998, with 90% of the goal generation.

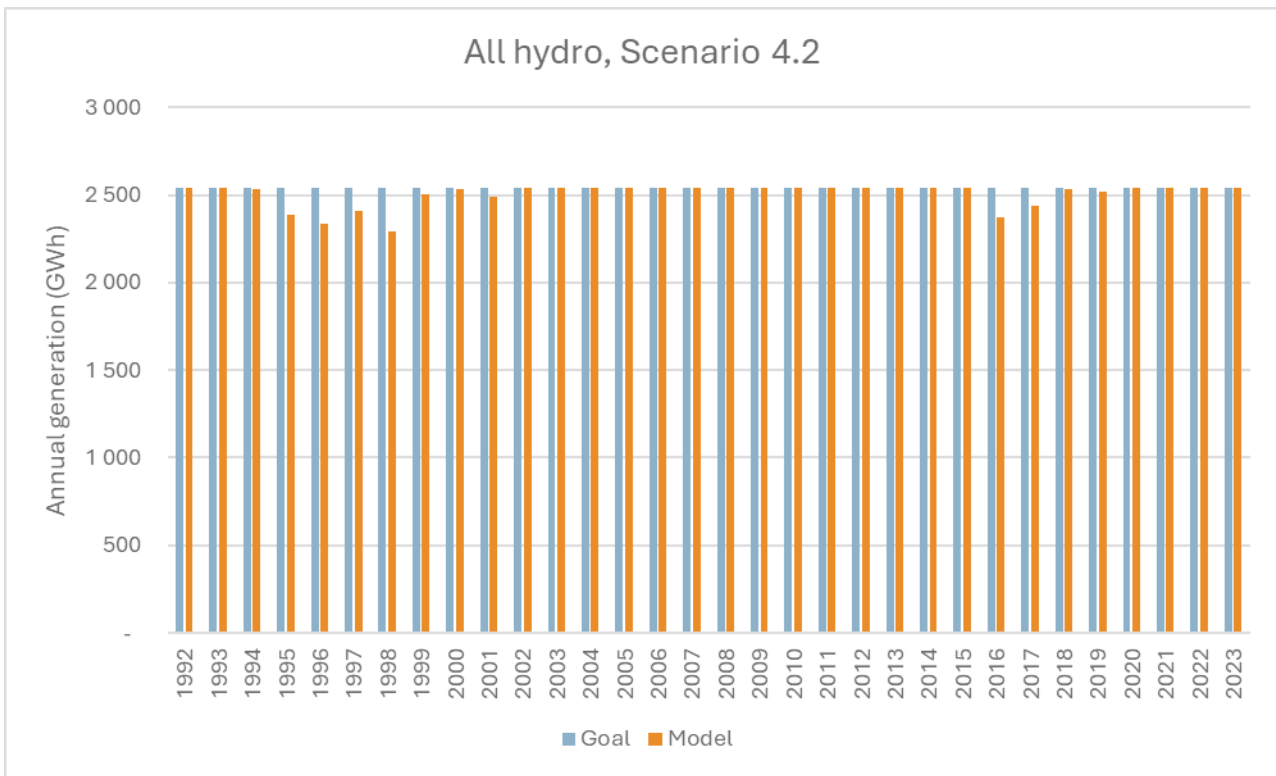


Figure A4-32 Comparison between modelled generation and the generation goal for each year of scenario 4.2. 2023 results are extrapolated.

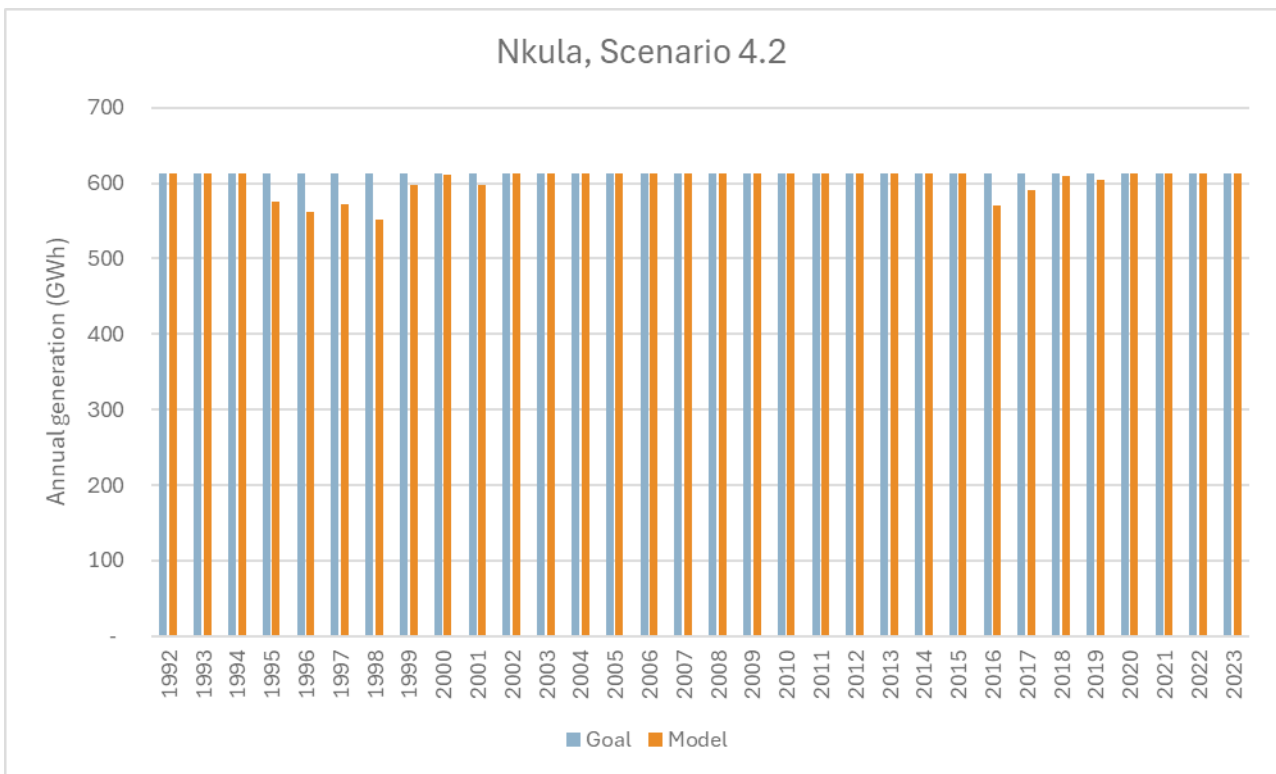


Figure A4-33 Comparison between modelled generation and the generation goal for Nkula for each year of scenario 4.2. 2023 results are extrapolated.

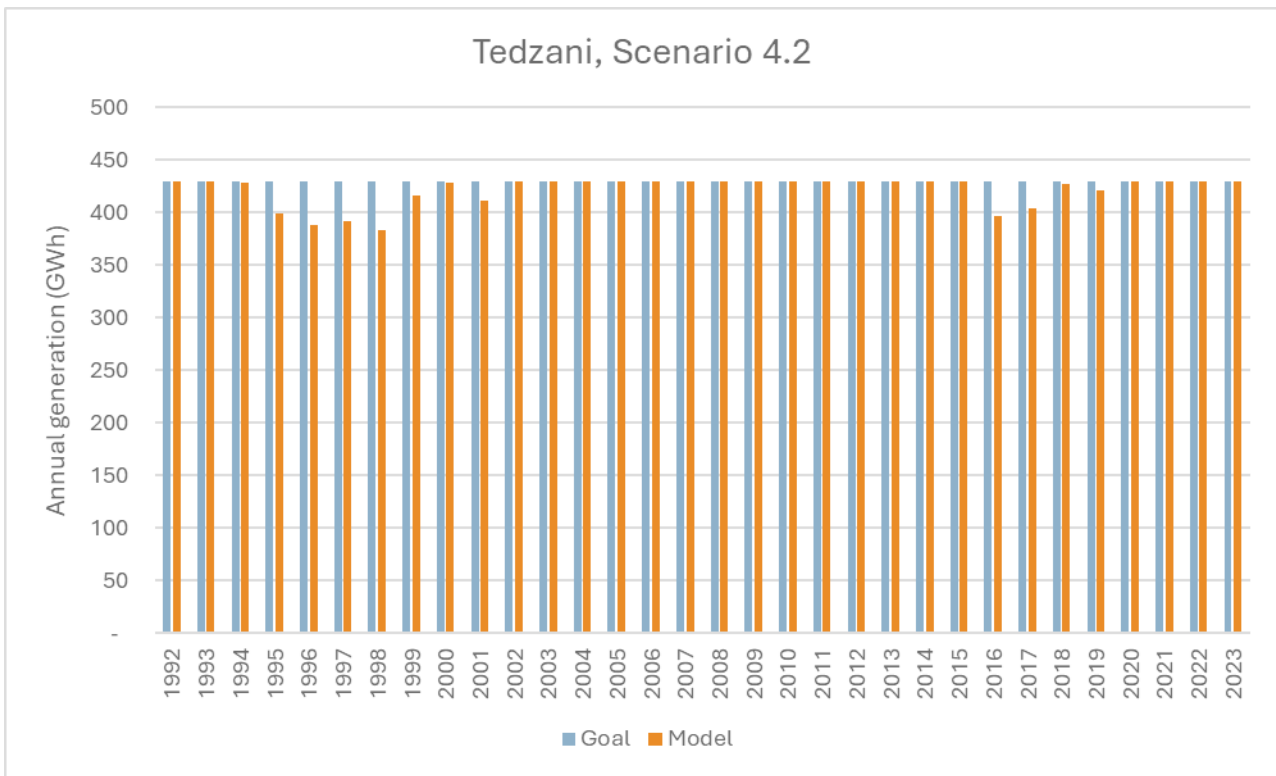


Figure A4-34 Comparison between modelled generation and the generation goal for Tedzani for each year of scenario 4.2. 2023 results are extrapolated.

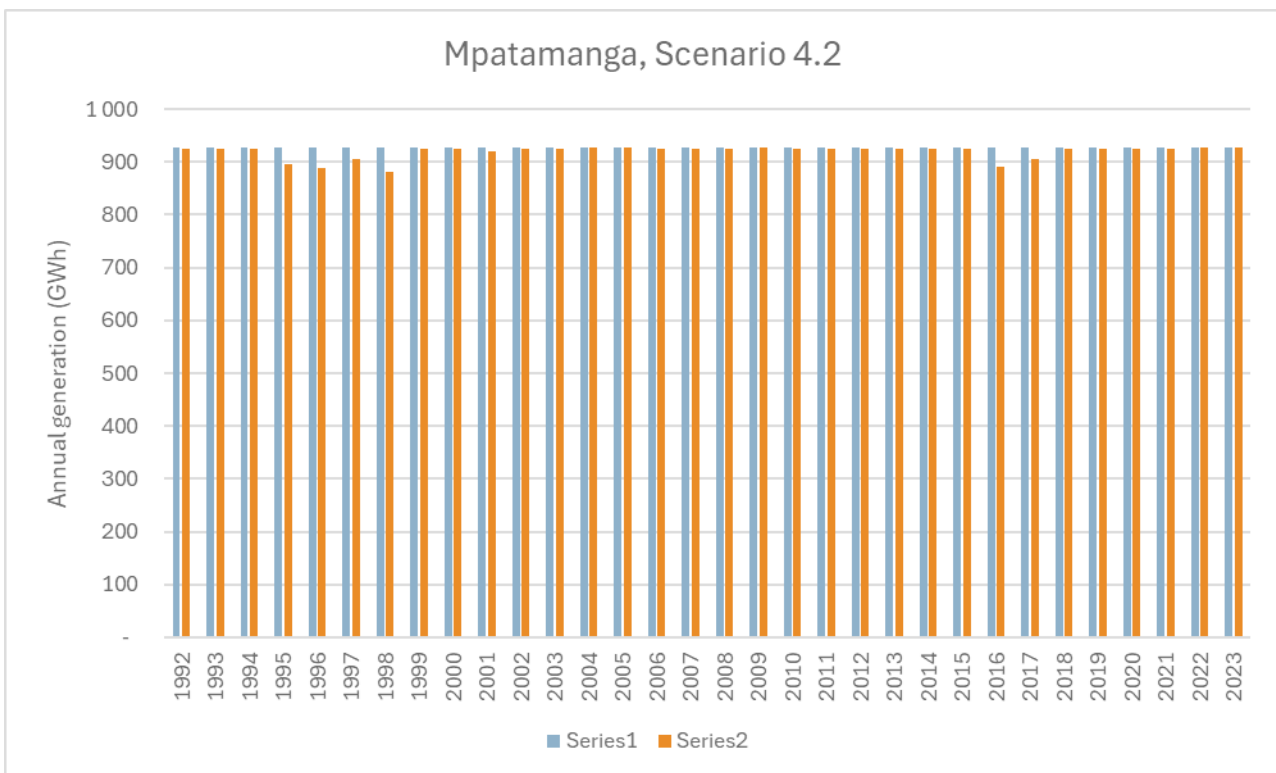


Figure A4-35 Comparison between modelled generation and the generation goal for Mpatamanga for each year of scenario 4.2. 2023 results are extrapolated.

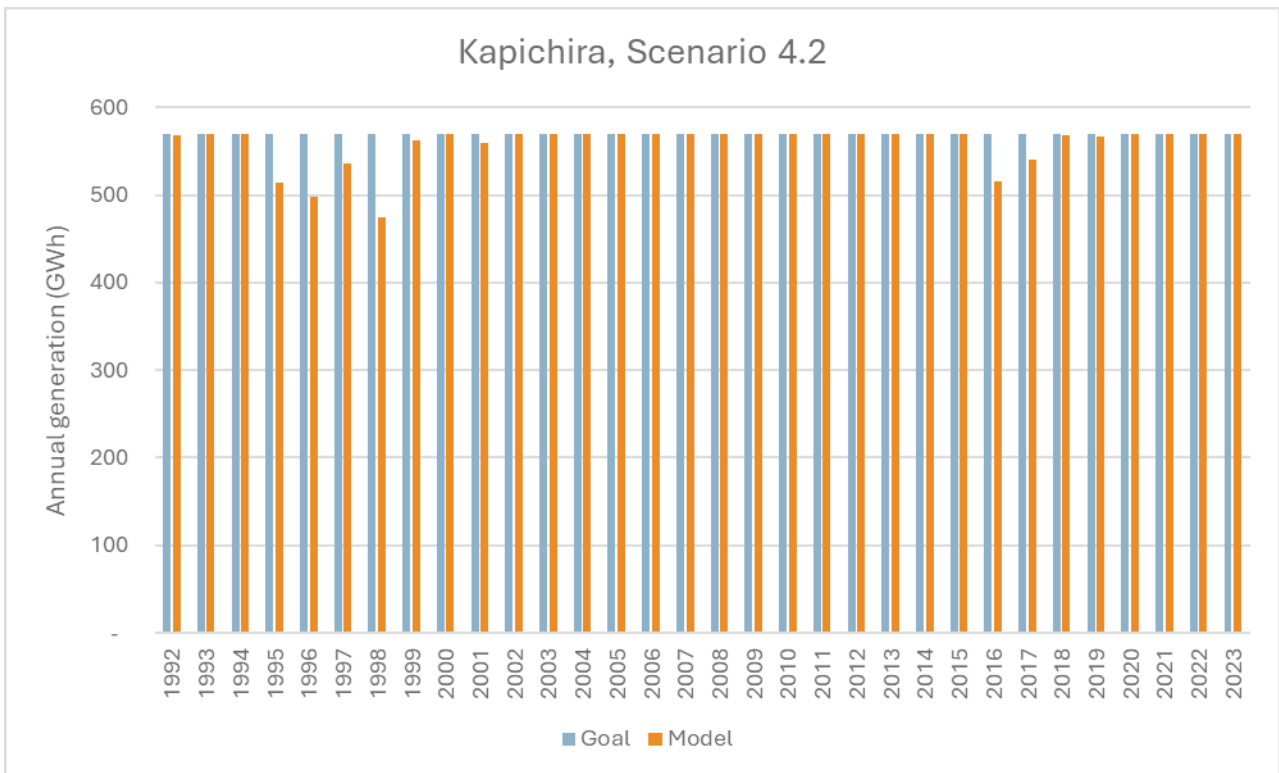


Figure A4-36 Comparison between modelled generation and the generation goal for Kapichira for each year of scenario 4.2. 2023 results are extrapolated.

Scenario 5 (Near Future 1 – 2035 Business as Usual)

In scenario 5, the average annual generation is 98% of the goal generation. In 21 out of 32 years, the generation is more than 99% of the goal generation. The lowest generation is in 1998, at 90% of the goal generation.

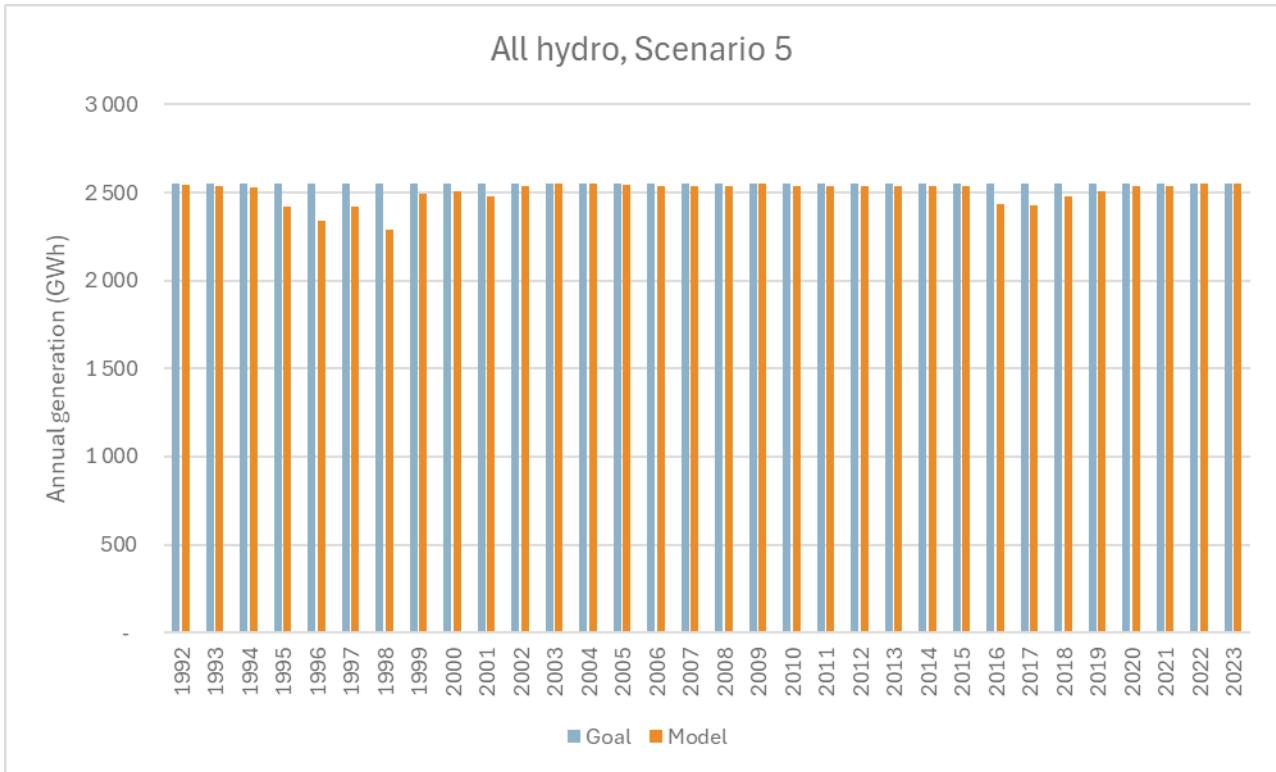


Figure A4-37 Comparison between modelled generation and the generation goal for each year of scenario 5. 2023 results are extrapolated.

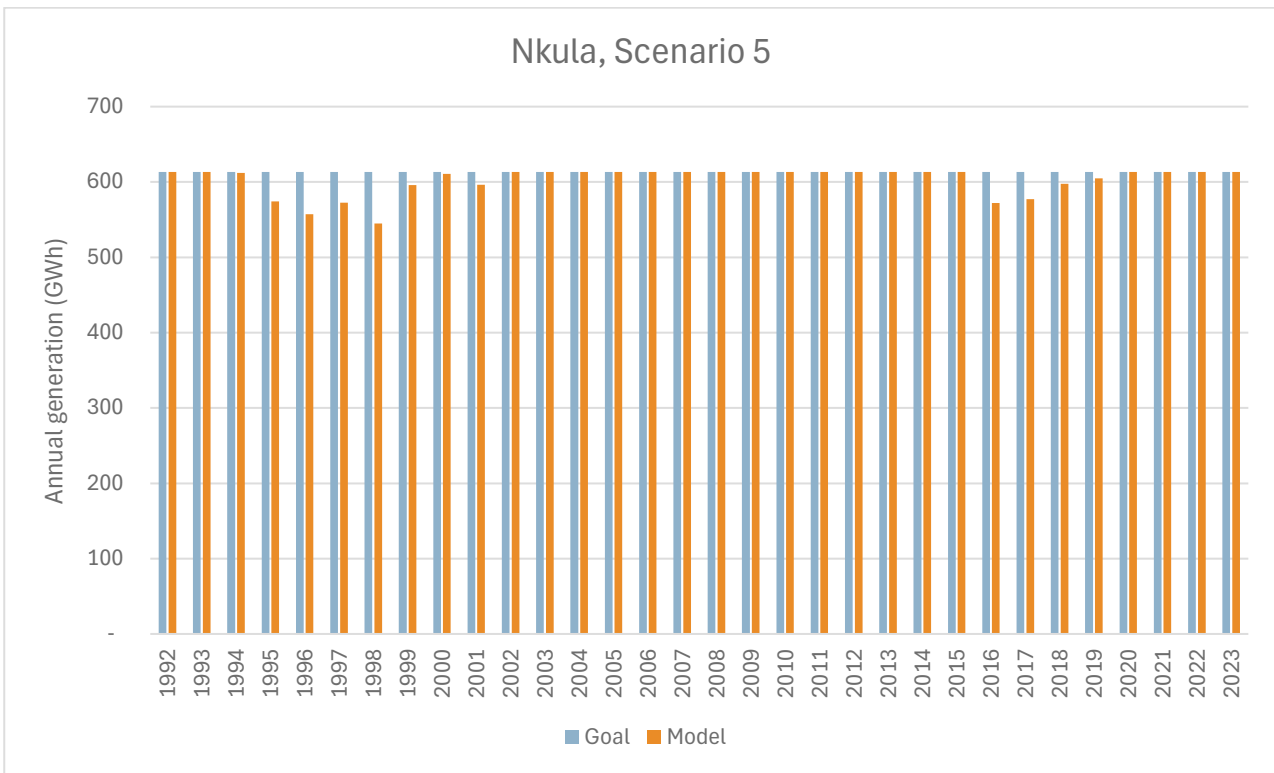


Figure A4-38 Comparison between modelled generation and the generation goal for Nkula for each year of scenario 5. 2023 results are extrapolated.

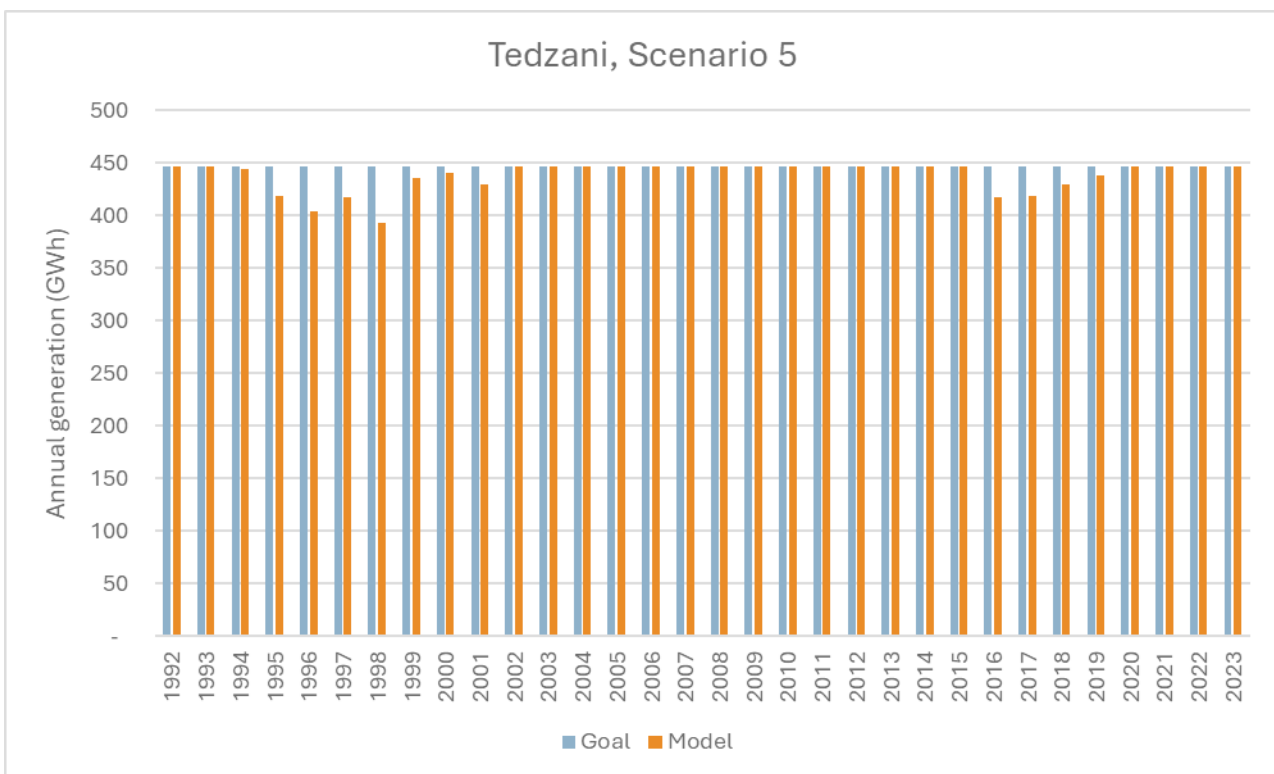


Figure A4-39 Comparison between modelled generation and the generation goal for Tedzani for each year of scenario 5. 2023 results are extrapolated.

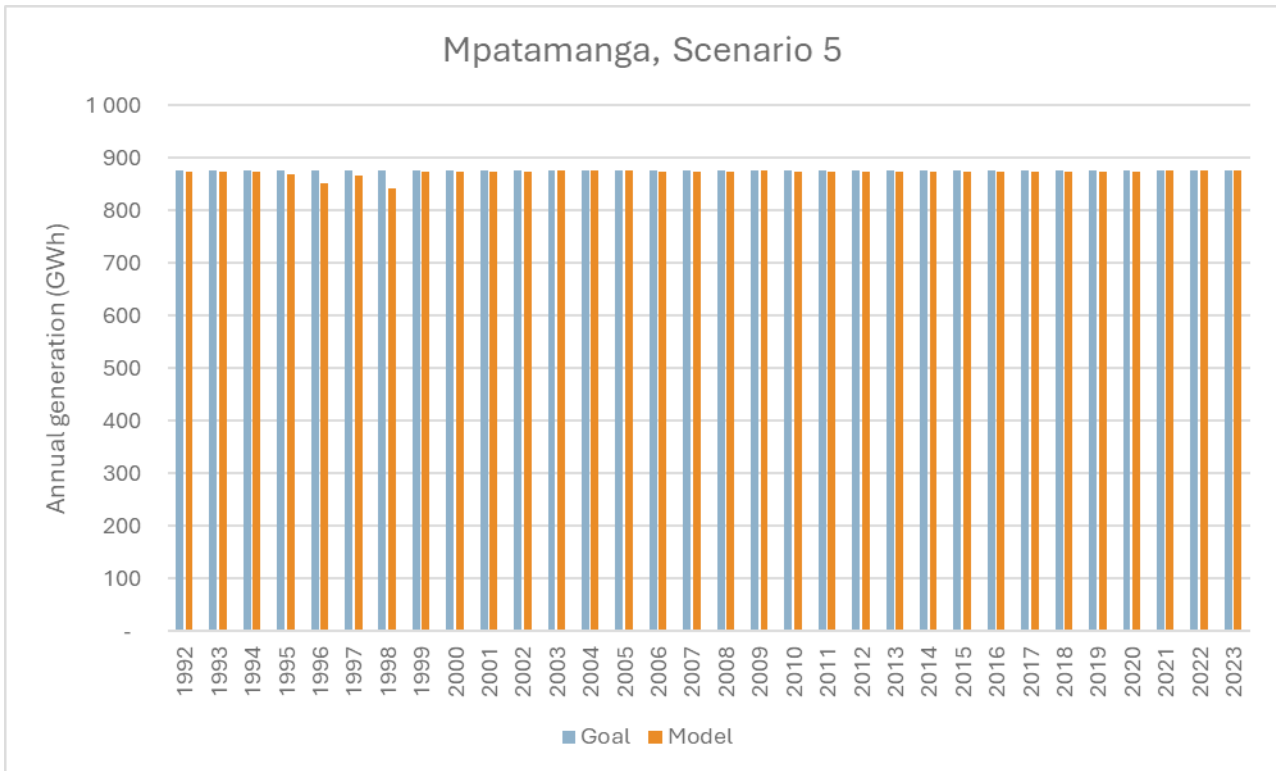


Figure A4-40 Comparison between modelled generation and the generation goal for Mpatamanga for each year of scenario 5. 2023 results are extrapolated.

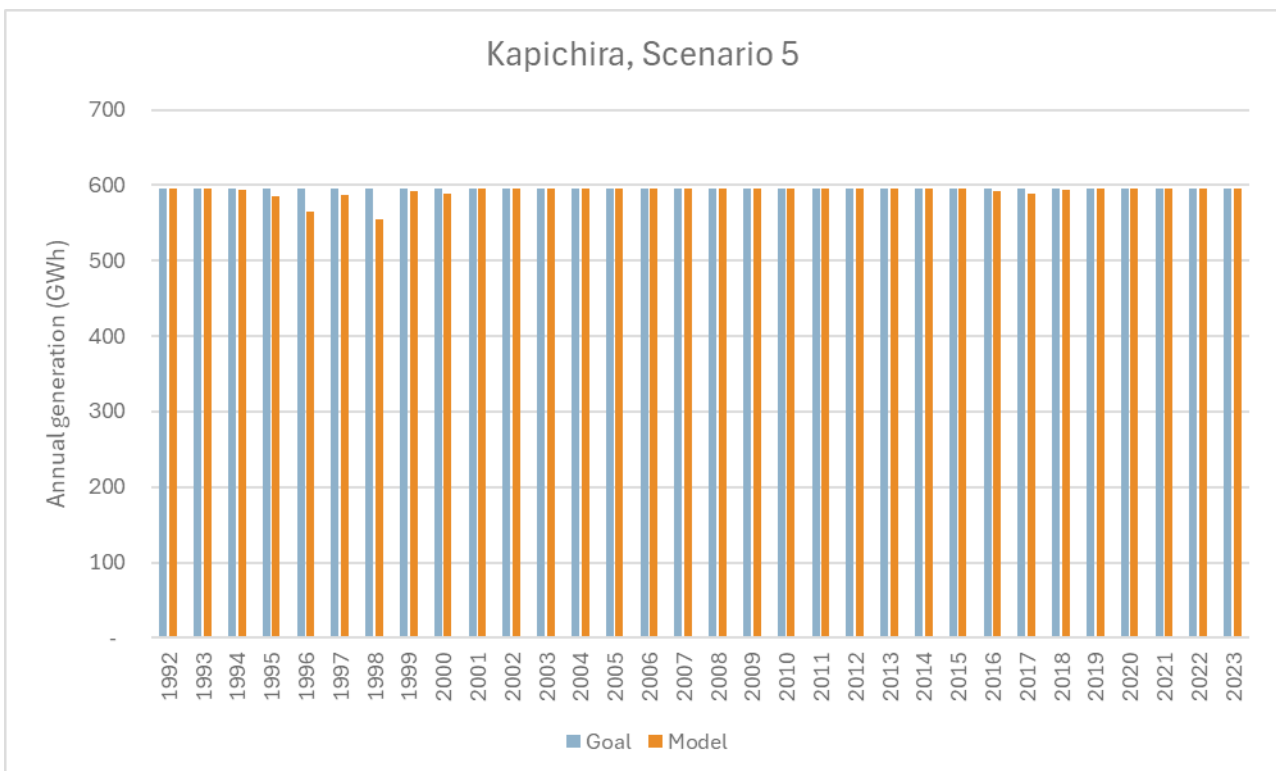


Figure A4-41 Comparison between modelled generation and the generation goal for Kapichira for each year of scenario 5. 2023 results are extrapolated.

Scenario 6 (Near Future 2 – 2035 BAU + Joint Dams Operation)

When it comes to hydropower generation, there is not much difference between scenario 5 and 6. In scenario 6, the average annual generation is 98% of the goal generation. In 22 out of 32 years, the generation is more than 99% of the goal generation. The lowest generation is in 1998, at 89% of the goal generation.

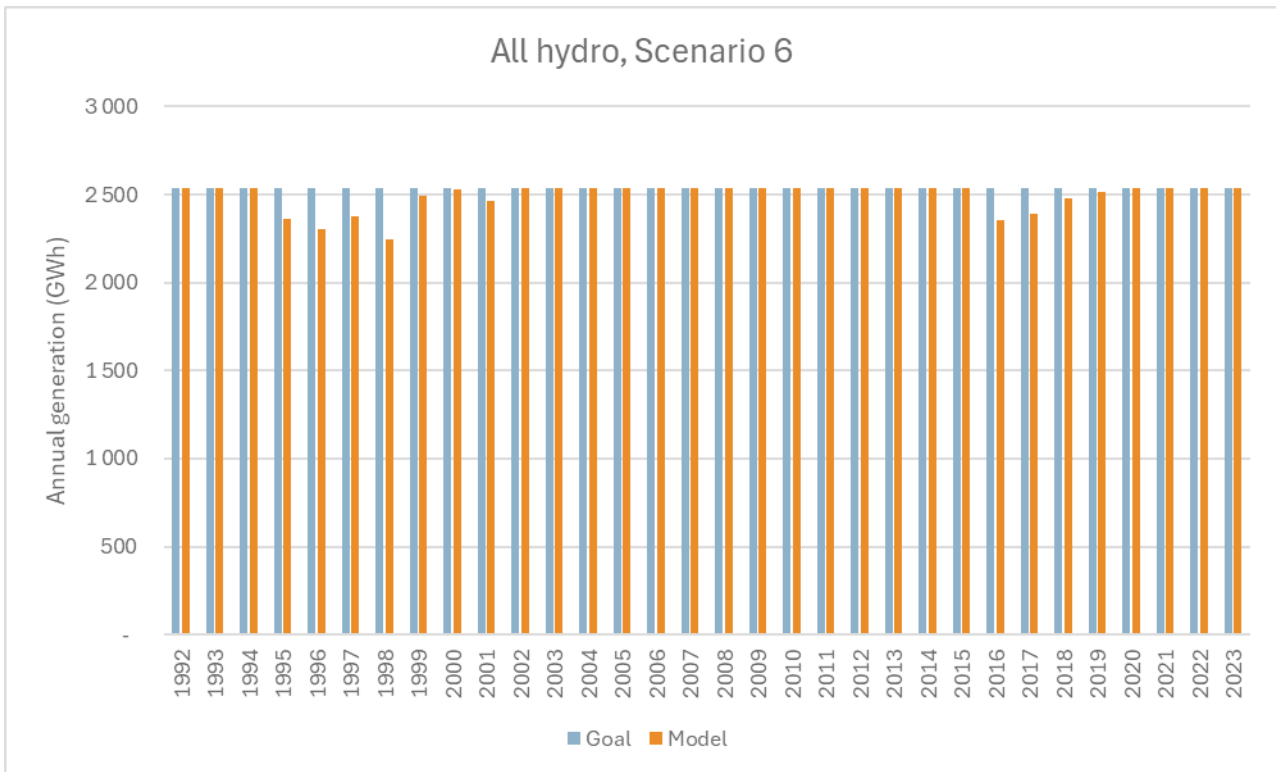


Figure A4-42 Comparison between modelled generation and the generation goal for each year of scenario 6. 2023 results are extrapolated.

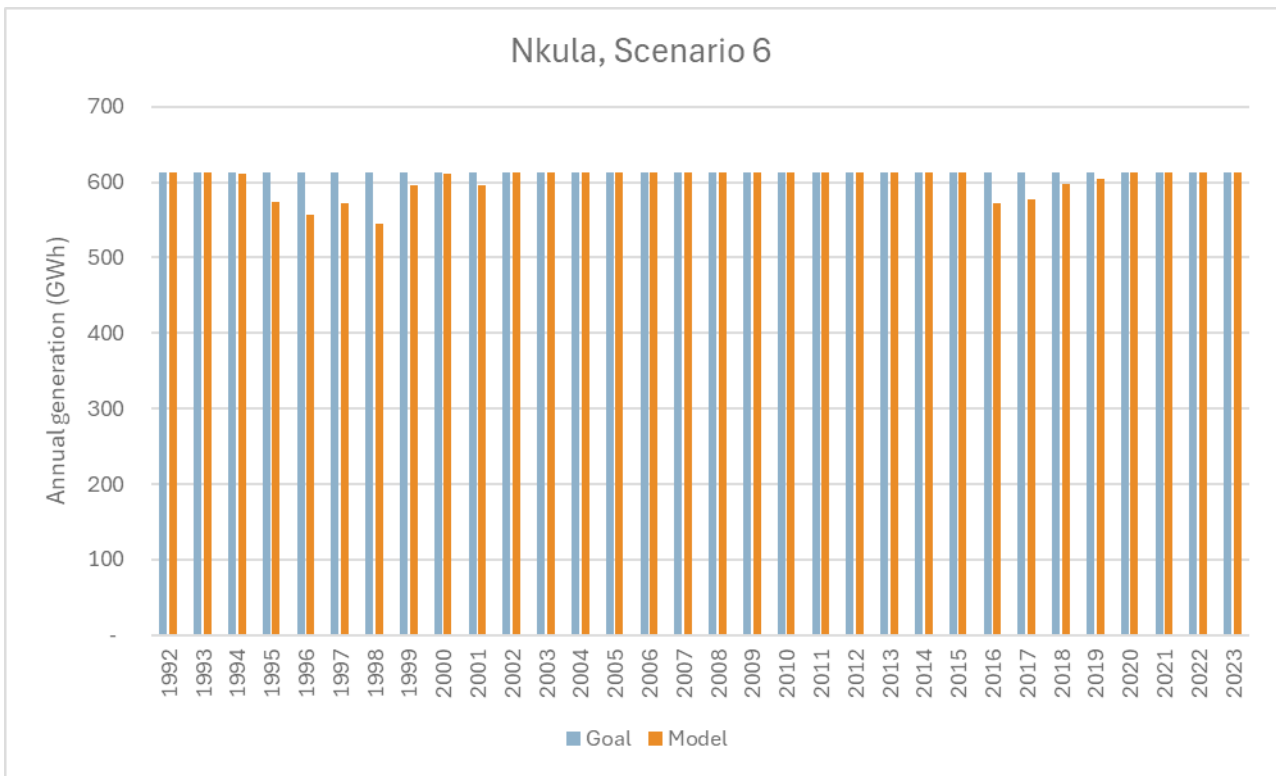


Figure A4-43 Comparison between modelled generation and the generation goal for Nkula for each year of scenario 6. 2023 results are extrapolated.

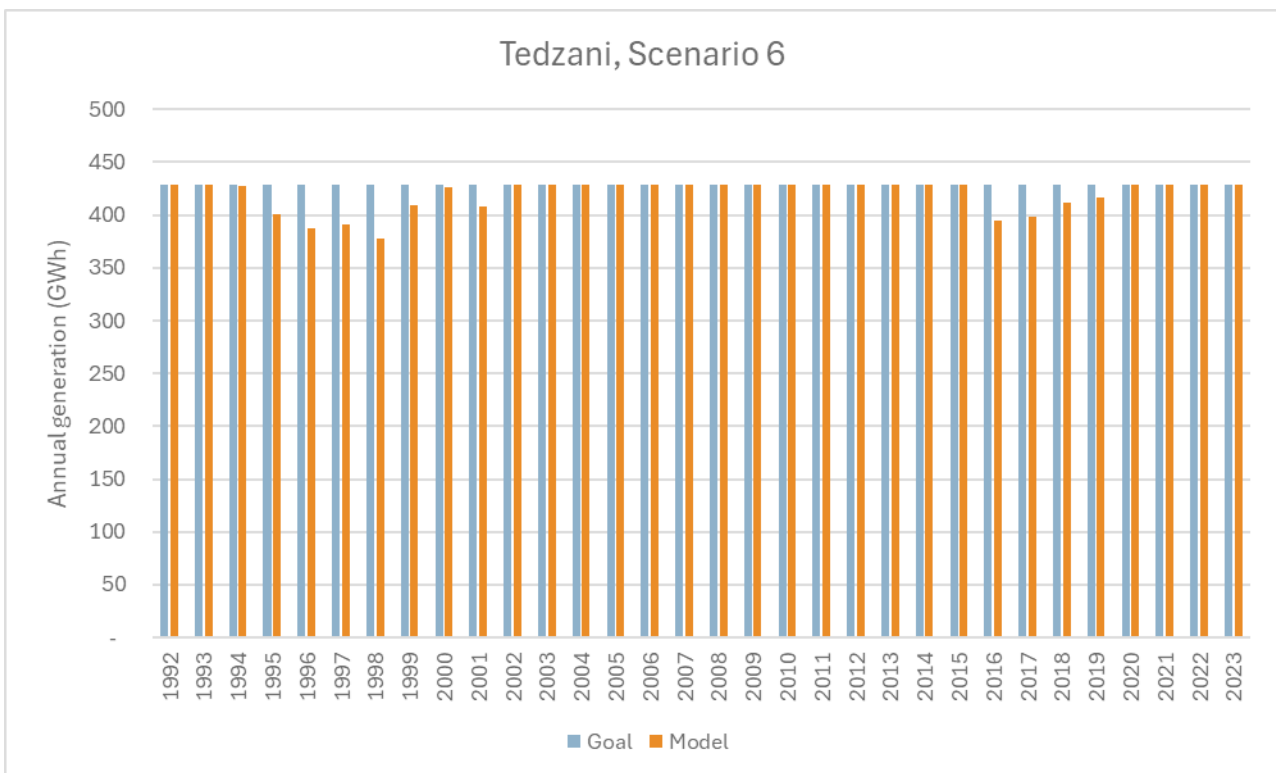


Figure A4-44 Comparison between modelled generation and the generation goal for Tedzani for each year of scenario 6. 2023 results are extrapolated.

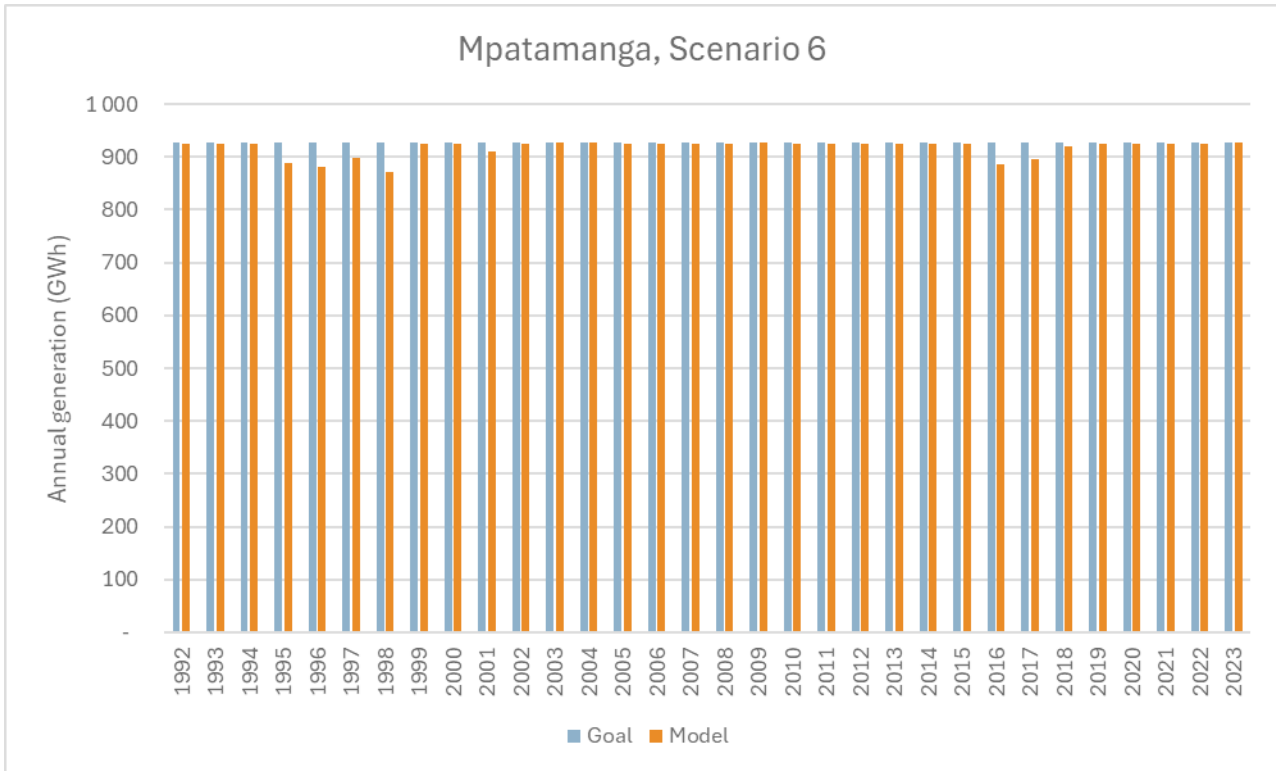


Figure A4-45 Comparison between modelled generation and the generation goal for Mpatamanga for each year of scenario 6. 2023 results are extrapolated.

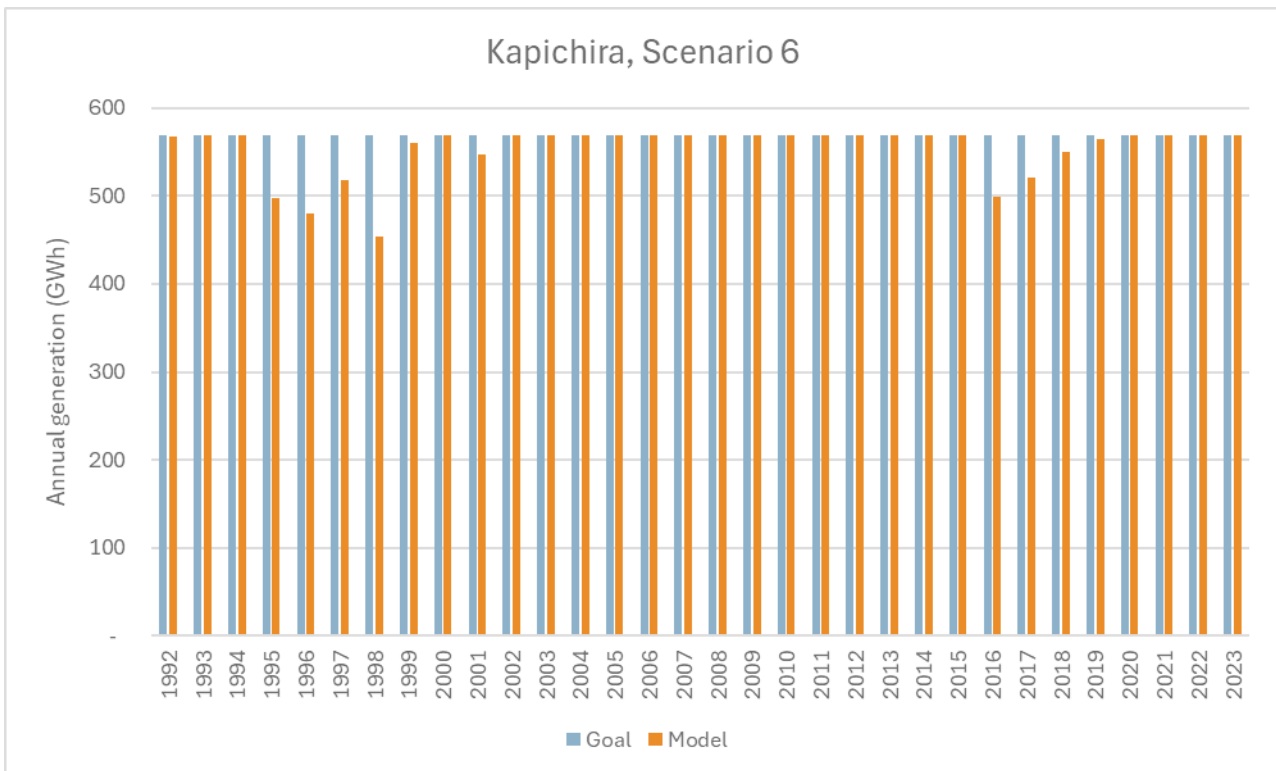


Figure A4-46 Comparison between modelled generation and the generation goal for Kapichira for each year of scenario 6. 2023 results are extrapolated.

Scenario 7.1 (Near Future 3 – 2035 BAU+JDO+ Climate Change⁵⁴)

Scenario 7.1 is the first climate change scenario, spanning from 2040 to 2070. The first half of this time period is marked by high lake Malawi freewater, which also is apparent in the hydropower results. From 2040 to 2060, the hydropower generation is at least 99% of the goal generation. In the last half of the period, the freewater becomes negative, which greatly reduced lake Malawi outflow. Kamuzu Barrage is in water saving mode from 2061 and after 2065 flow through the barrage is only local flow, there is no flow from the lake. This greatly affects Nkula and Tedzani, where the generation is reduced to 20% of the goal generation. Downstream Mpatamanga and Kapichira receive more local inflow and are able to operate at 50-60% even in the dryest years.

The average annual power generation for scenario 7.1 is 88%.

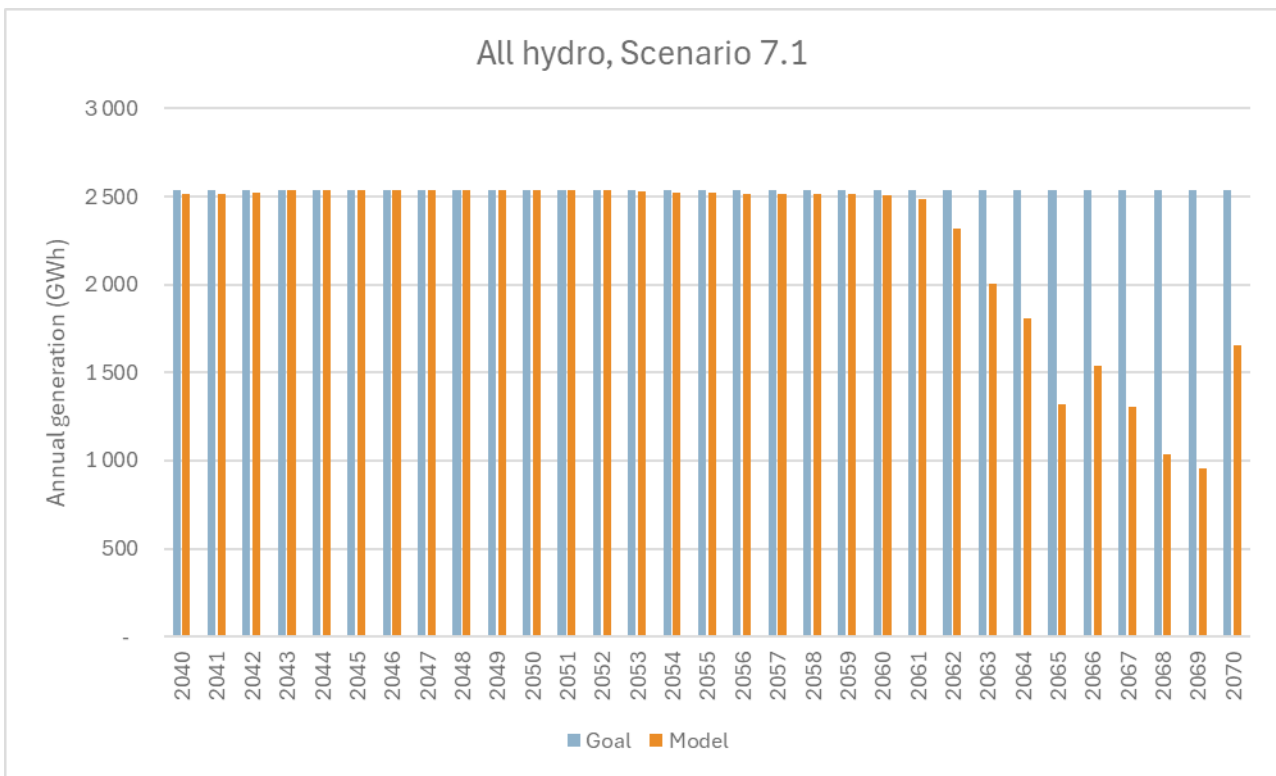


Figure A4-47 Comparison between modelled generation and the generation goal for each year of scenario 7.1.

⁵⁴ Scenario 7.1 (as well as 8.1, 9.1 and 10.1) uses the mean climate change scenario results.

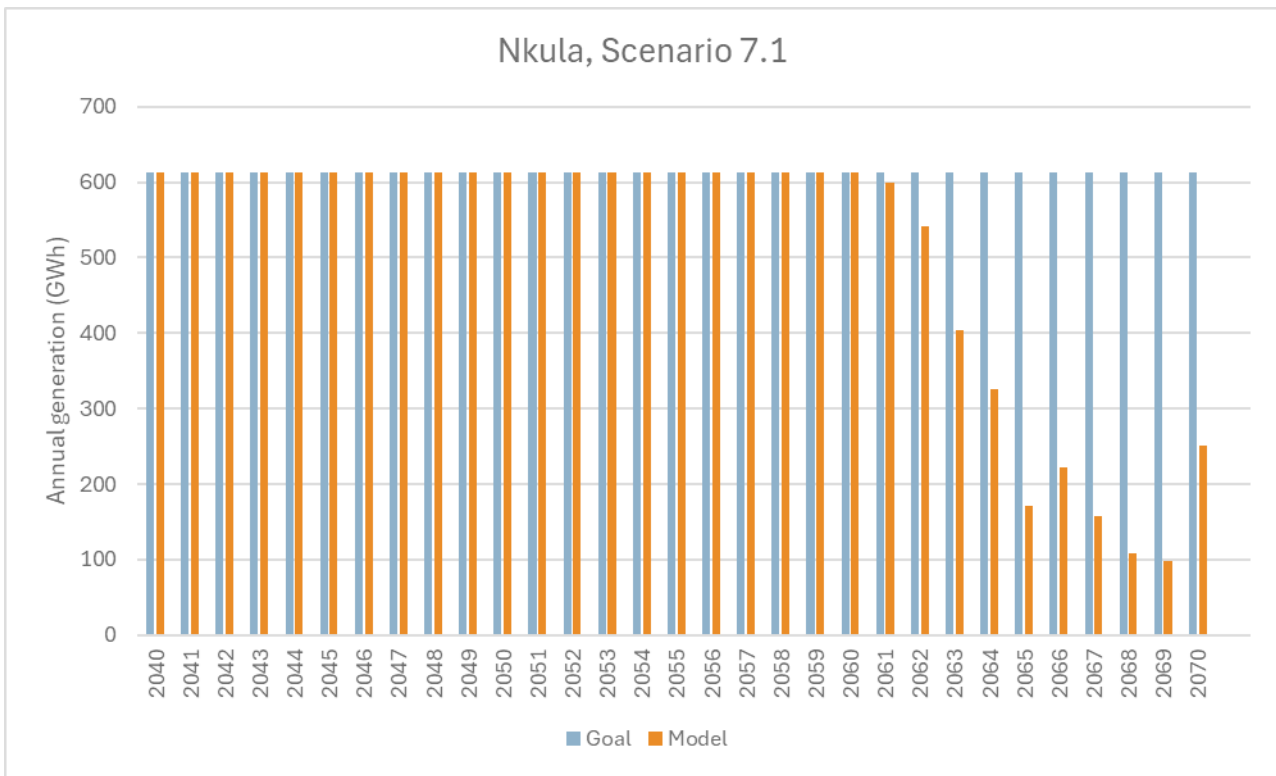


Figure A4-48 Comparison between modelled generation and the generation goal for Nkula for each year of scenario 7.1.

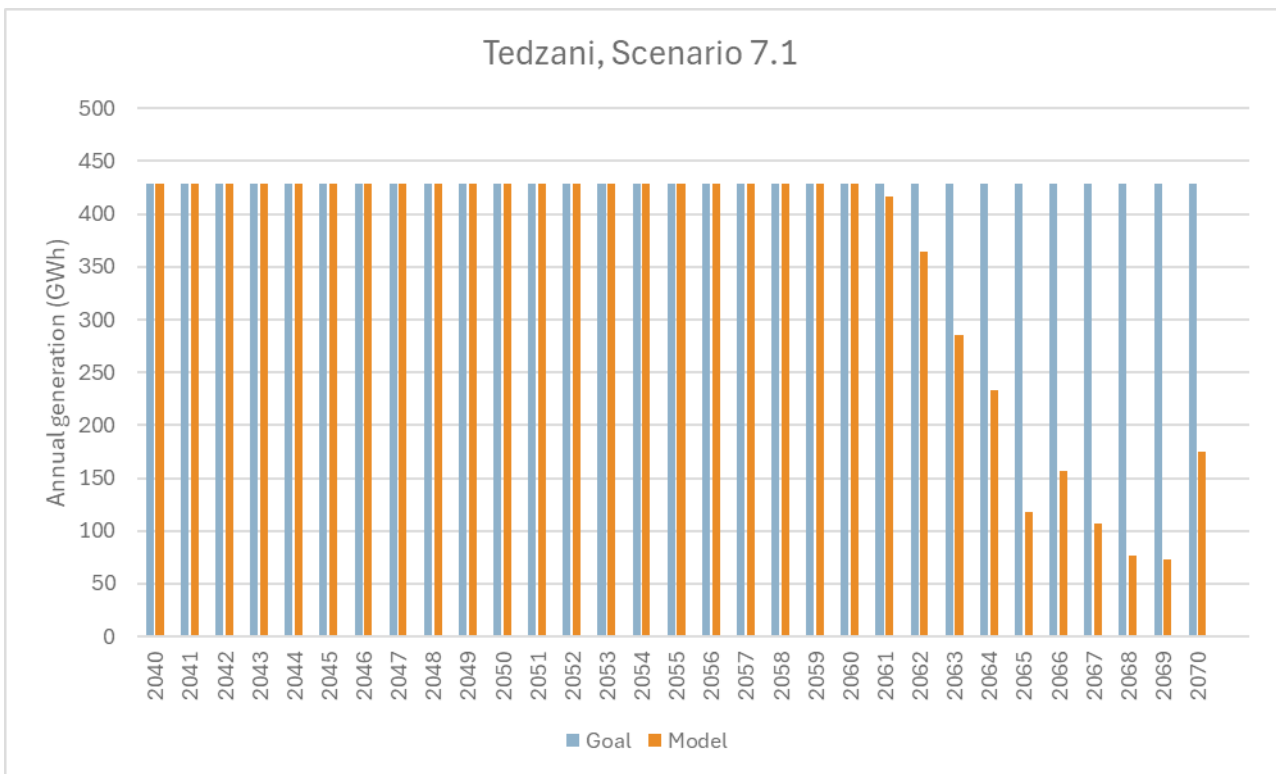


Figure A4-49 Comparison between modelled generation and the generation goal for Tedzani for each year of scenario 7.1.

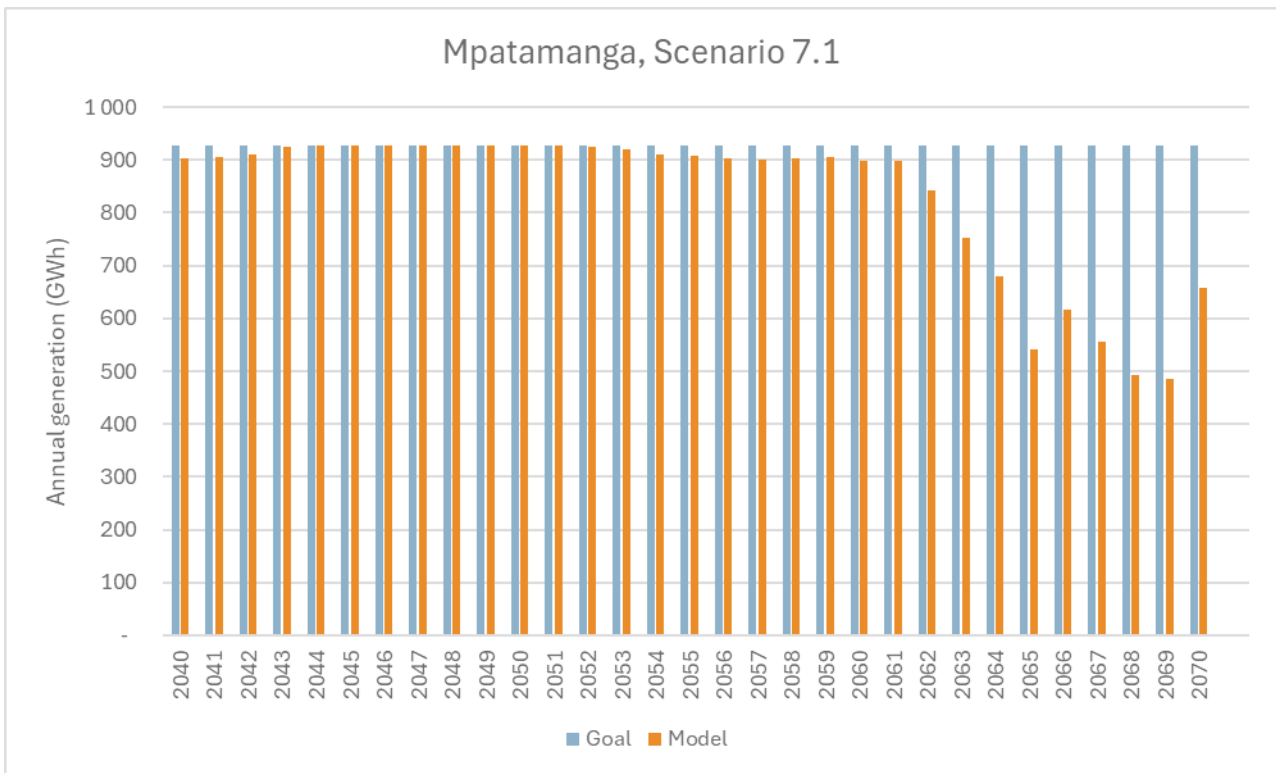


Figure A4-50 Comparison between modelled generation and the generation goal for Mpatamanga for each year of scenario 7.1.

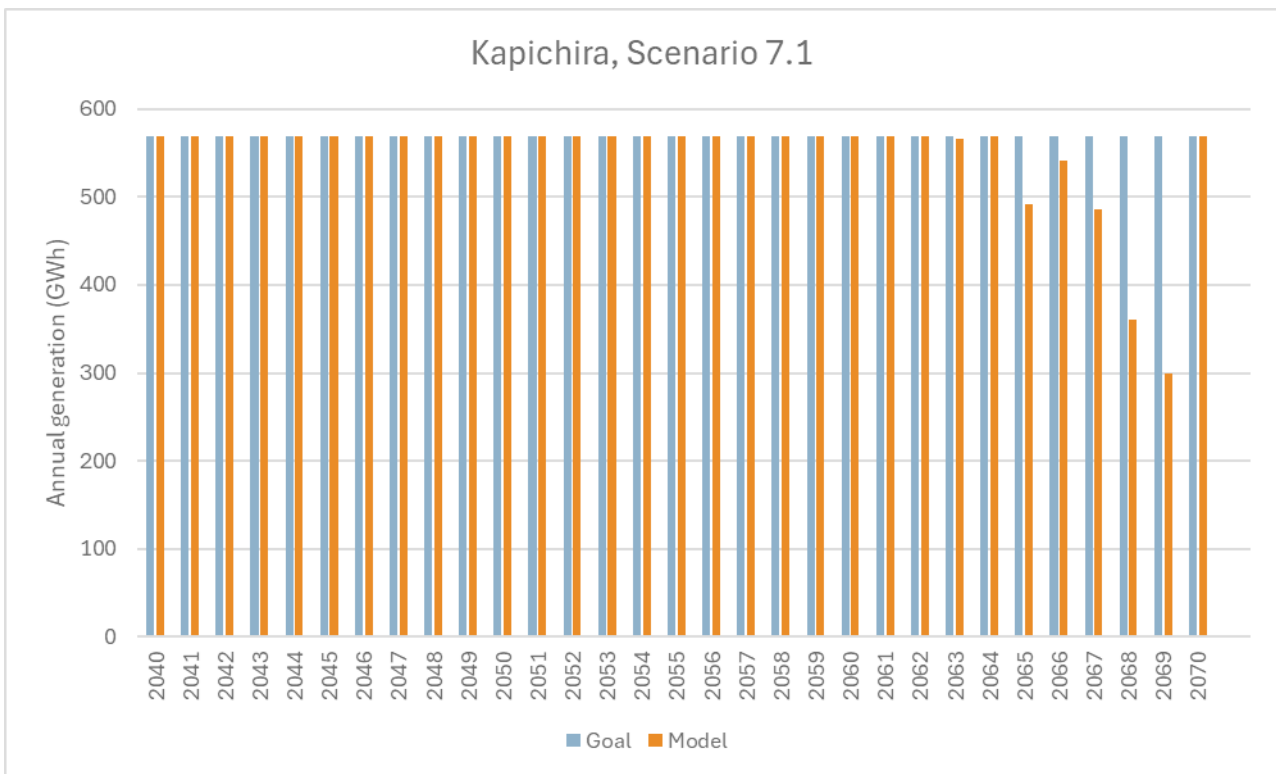


Figure A4-51 Comparison between modelled generation and the generation goal for Kapichira for each year of scenario 7.1.

Scenario 8.1 (Near Future 4 – 2035 JDO + CC + Sustainable Pathway)

The differences between scenario 7.1 and 8.1 when it comes to hydropower generation are negligible. The results presented for scenario 7.1 are also valid for scenario 8.1.

Scenario 9.1 (Distant Future 1 – 2070 BAU + JDO + CC)

Scenario 9.1 is the second climate change scenario, spanning from 2060 to 2100. Malawi freewater is generally low the entire period, and this has a large impact on the hydropower generation. Except for the first few years, the generation is far below the goal generation. On average, the power generation is 49% of the goal generation.

The largest reduction is for Nkula and Tedzani, where the generation is on average 28% of the goal generation. For Mpatamanga, the generation is 55% of the goal generation, while at Kapichira, the generation is 78% of the goal generation.

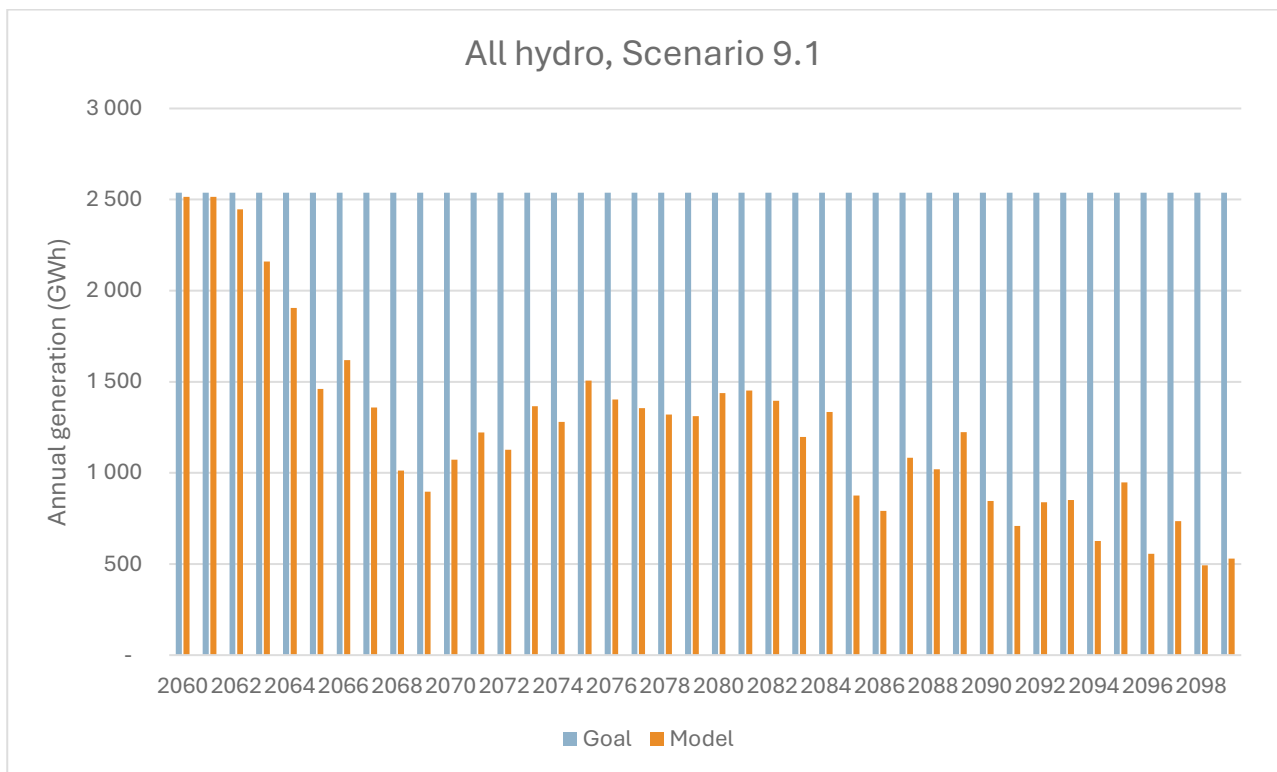


Figure A4-52 Comparison between modelled generation and the generation goal for each year of scenario 9.1.

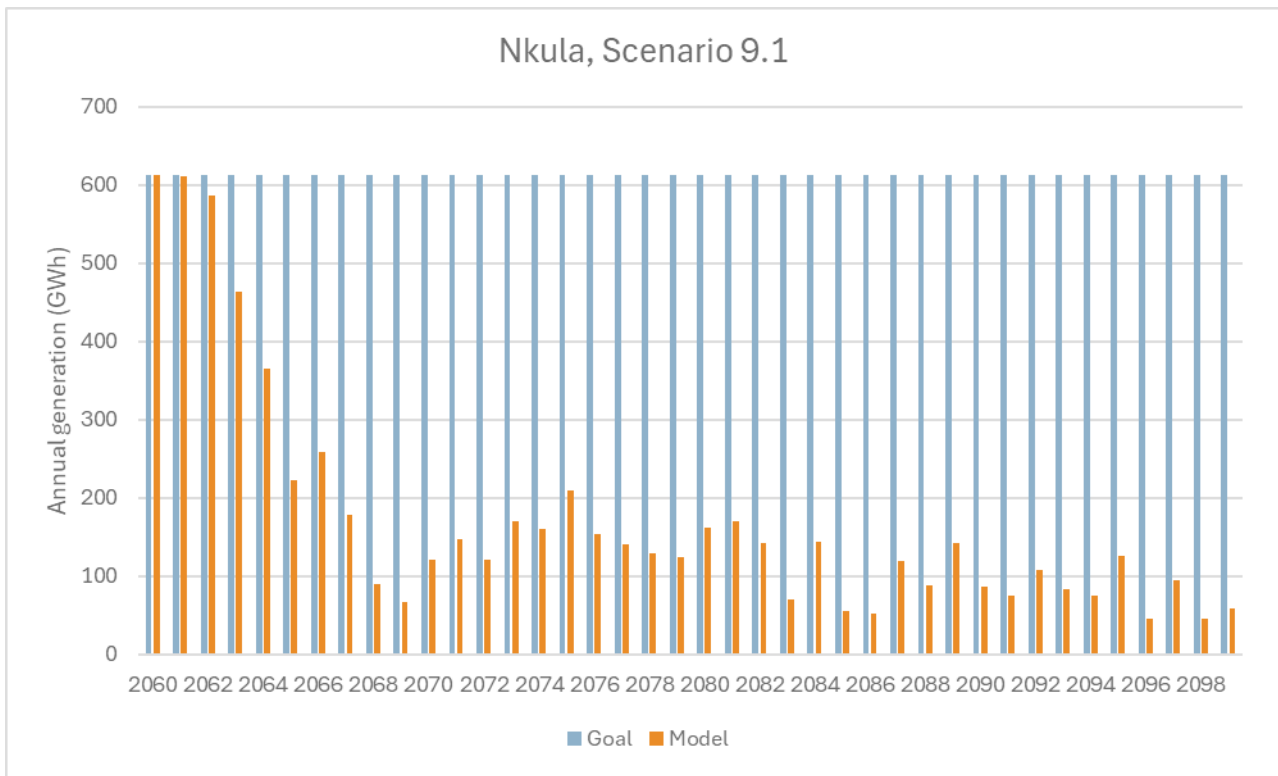


Figure A4-53 Comparison between modelled generation and the generation goal for each year of scenario 9.1.

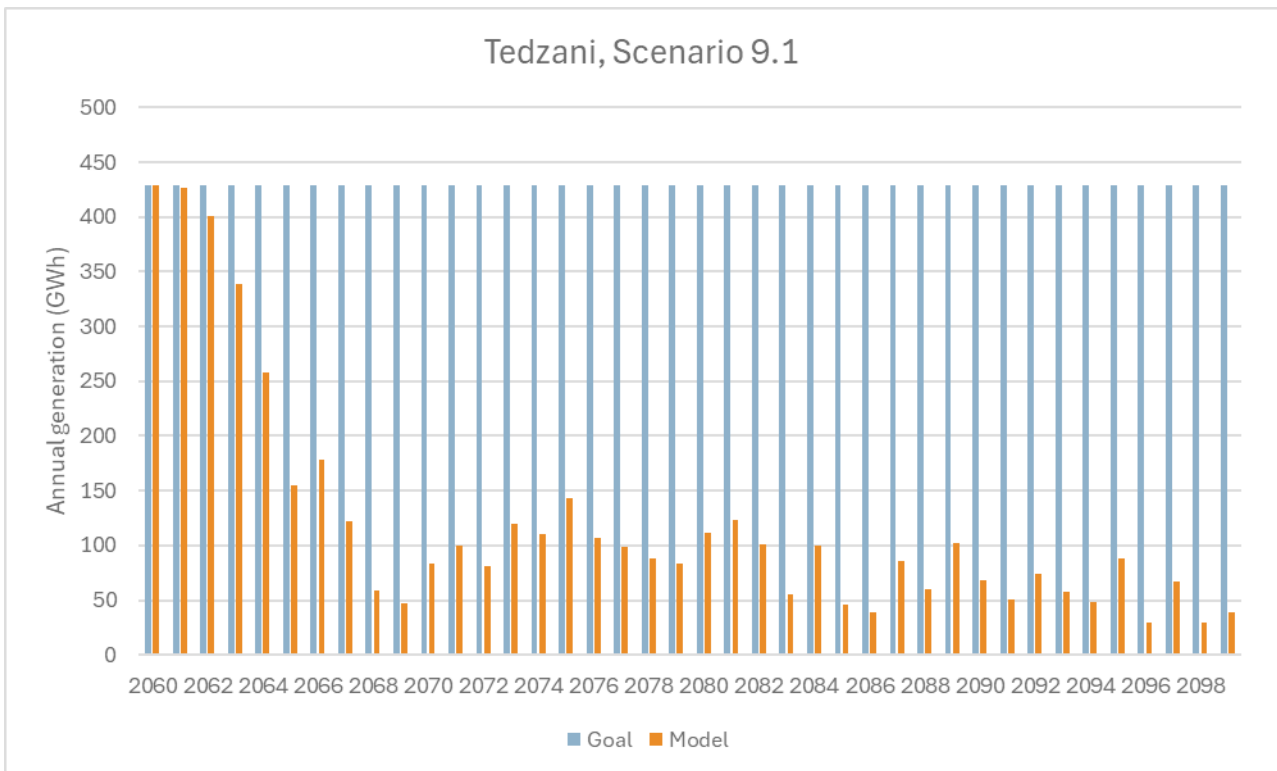


Figure A4-54 Comparison between modelled generation and the generation goal for each year of scenario 9.1.

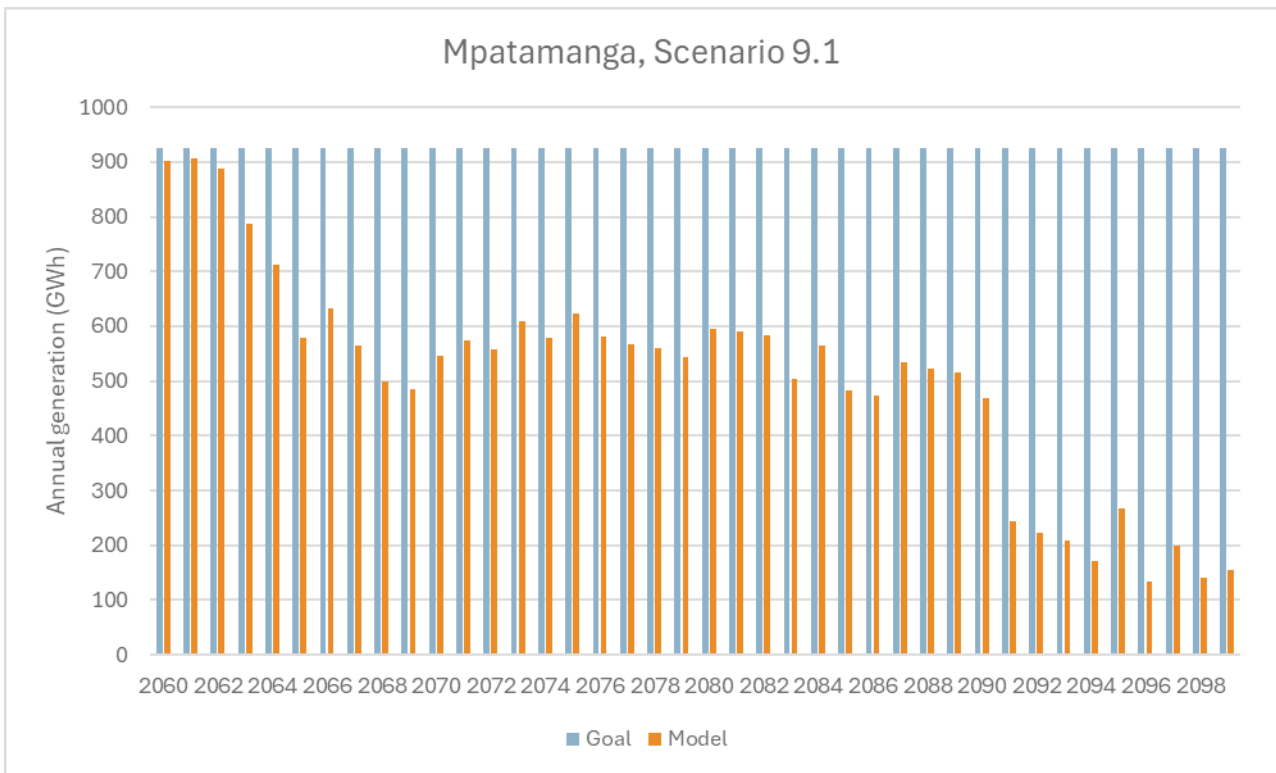


Figure A4-55 Comparison between modelled generation and the generation goal for each year of scenario 9.1.

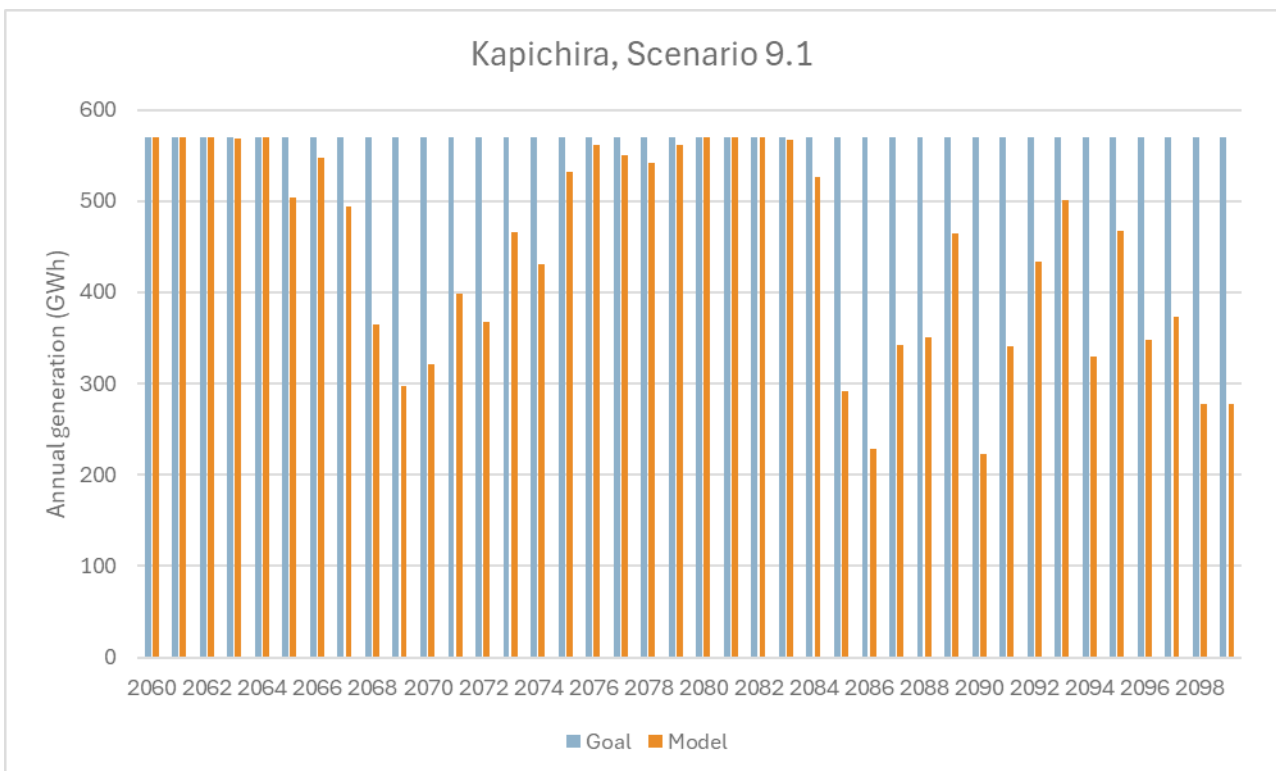


Figure A4-56 Comparison between modelled generation and the generation goal for each year of scenario 9.1.

Scenario 10.1 (Distant Future 2 – 2070 JDO + CC + Sustainable Pathway)

The differences between scenario 9.1 and 10.1 when it comes to hydropower generation are negligible. The results presented for scenario 9.1 are also valid for scenario 10.1.

A.4.5. Dam safety

The dam break at Kapichira caused by tropical storm Ana in 2022 is a reminder of the severe consequences that inadequate flood diversion capacity could have. To better understand the floods in Shire River, we have analysed the largest floods in each scenario for each dam. This is summarised in the table below. Some scenarios have very similar flood sizes, and these are put together in the table. The table also includes some information about the design flood of the dams where we have available information.

For scenarios 2-6, the largest flood at Kamuzu Barrage is at the end of the simulation (1. May 2023), related to high Lake Malawi water levels. At Nkula and Tedzani, the largest flood is in March 2023, and is caused by a combination of high flows at Kamuzu Barrage and local flood in the downstream tributaries. About 700 m³/s of the flow comes from Kamuzu Barrage, and closing the barrage gates during the flood could have reduced the flood peaks at Nkula and Tedzani to some degree. At Mpatamanga and Kapichira, the largest flood is in March 2019. During this flood, the flow at Kamuzu Barrage is very low, and flow comes mainly from the tributaries.

The climate change scenarios, 7-10, have larger floods than scenarios 2-6. Especially in tributary Nkulumadzi, the floods are extreme, leading to enormous floods at Kapichira. The modelled floods are 3-4 times the capacity of the flood gates at Kapichira, and floods of this magnitude would without doubt cause dambreak at Kapichira. Note that the flow in this climate change scenario is just one out of many combinations of development pathways and global climate models, and floods in the future may be different than the predictions from this model, but the results are still worrying, and we strongly recommend to further study the effects of climate change on floods in the Shire tributaries, and especially Nkulumadzi river.

Table A4-0-1 Maximum modelled flood for each dam and each scenario.

	Sc 2/3/4	Sc 5/6	Sc7/8	Sc9/10	Design flood
Kamuzu Barrage	800	800	2 000	600	1600/2400 Q ₁₀₀₀ /PMF
Nkula	2 000	1 900	3 400	2 900	
Tedzani	2 000	1 900	3 400	2 900	
Mpatamanga	3 400	3400	4 600	3 900	3700/6000 Q _{10 000} /PMF
Kapichira	4 200	4 800	32 000	22 000	8 800

A.5. ASSESSMENT OF POWER GENERATION AND OPTIMIZATION

A.5.1. Hydropower Development and Operation

Electricity demand

Peak demand

In order to model the operation of the Shire River dams, we need to know the historical and forecasted peak electricity demand. Peak demand from 1992 to 2042 used in the modelling can be seen in Figure A5-1. For the time period 2012-2042, the source is (Ministry of Energy, 2023), while the time period 1992-2011 is based on (Taulo, Gondwe, & Sebitosi, 2015) and (Gamula, Hui, & Peng, 2013).

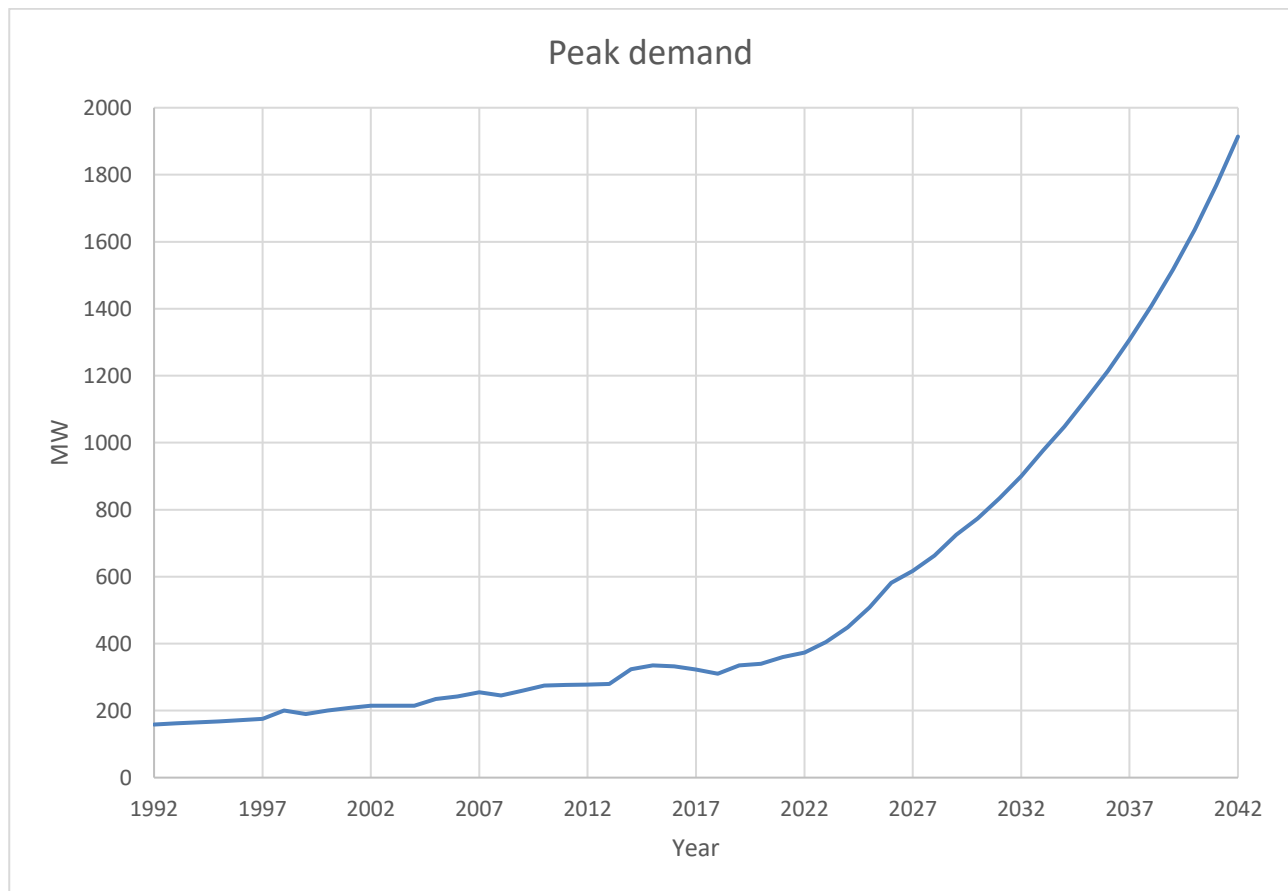


Figure A5-9 Historical (1992-2022) and forecasted (2023-2042) peak demand.

Generation pattern

The three major power-generating dams on the Shire today, Nkula, Tedzani and Kapichira provide the main sources of power for Malawi. EGENCO provided two periods with production data to give an insight to the present demand and its patterns. The figures below show an analysis of these datasets.

If we compare the sent-out energy with the peak demand in (Ministry of Energy, 2023), we find a ratio between average demand and peak demand of between 0.70 and 0.76. This is a bit lower than we can observe from the hydropower generation data for January 2022 and September 2023, where the ratio between the daily generation and peak generation is on average 0.78. There may be other sources of

electricity that could have contributed during the peak hours, but unfortunately, we do not have any information about this.

We can see from the January 2022 and September 2023 generation, that there are two distinct peaks in power generation, one in the morning around 6 am, and one evening around 7 pm. There is also a smaller peak around noon. Based on this, as well as the daily load curve presented in (Norplan, 2013), we have created the daily load curve presented in Figure A5-3. This load curve has a ratio between average demand and peak demand of 0.76 and is used for all years, scaled based on the peak demand.

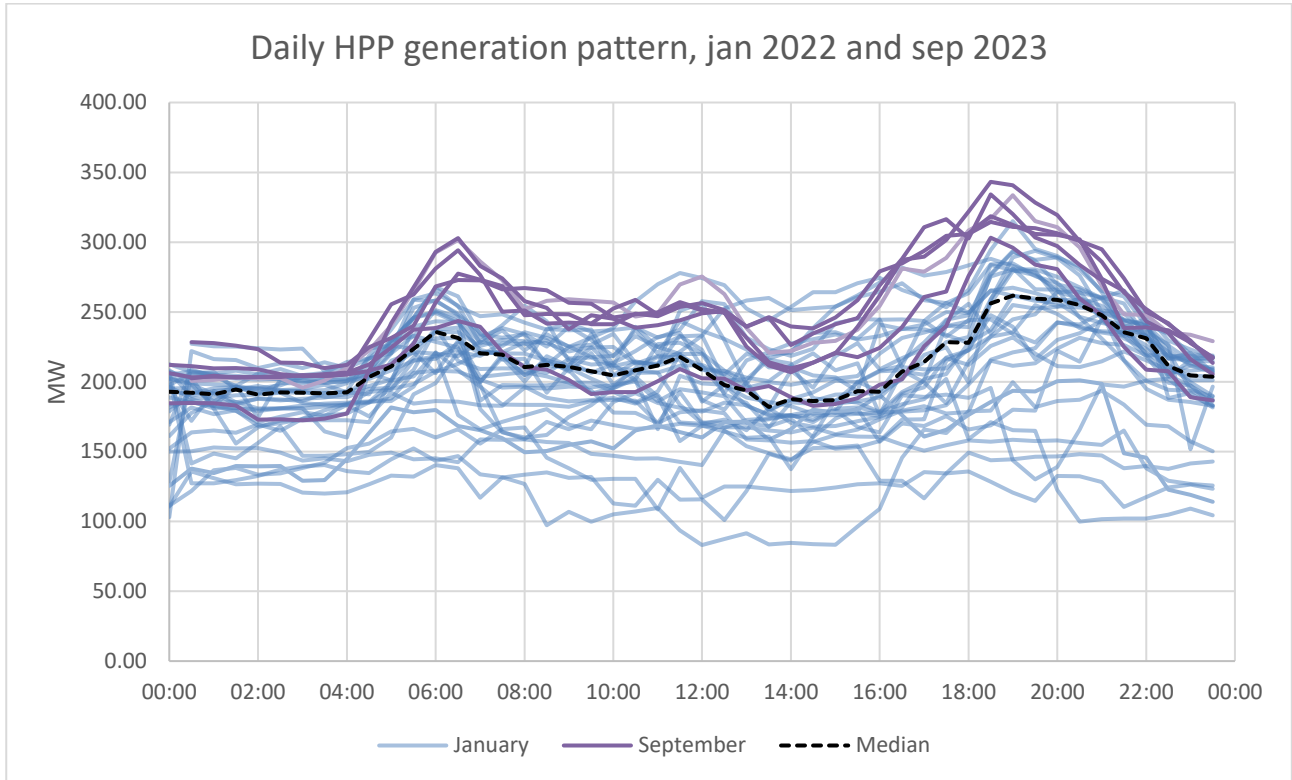


Figure A5-10 Daily hydropower generation for each day in January 2022 and six days in September 2023.

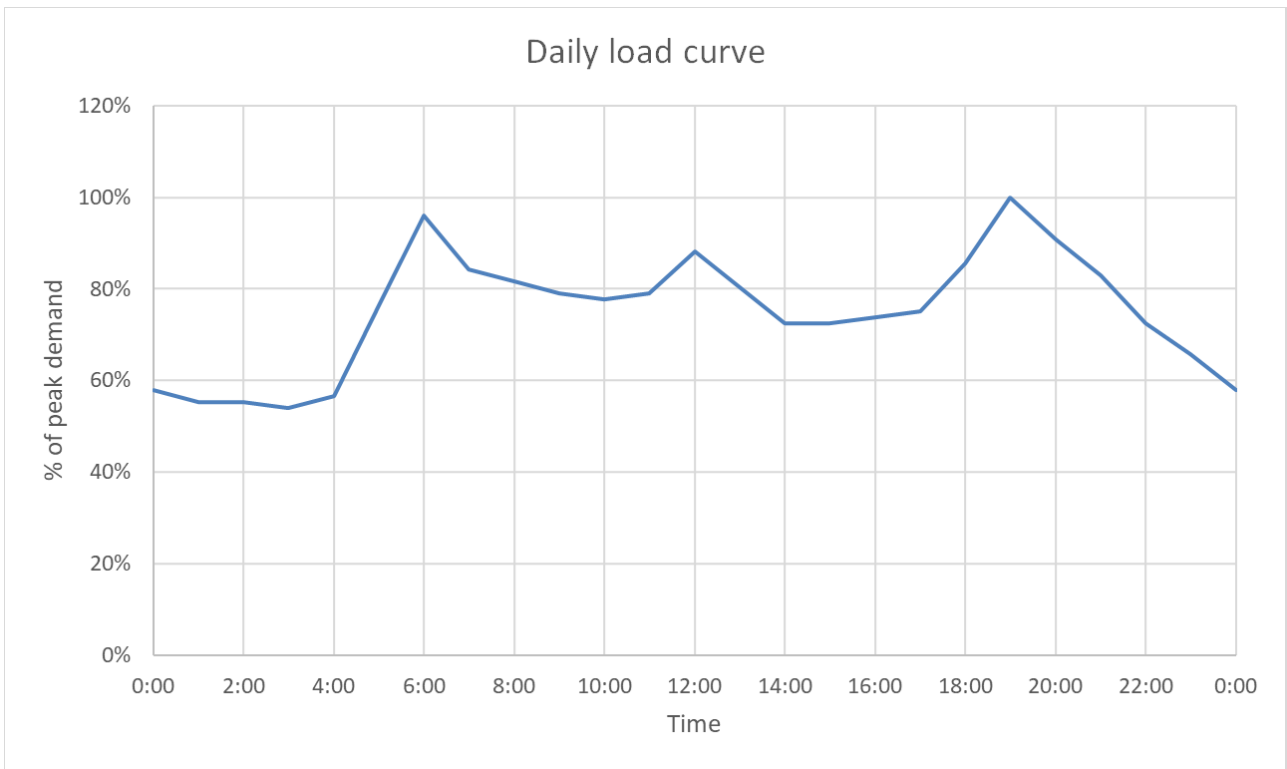


Figure A5-11 Daily load curve.

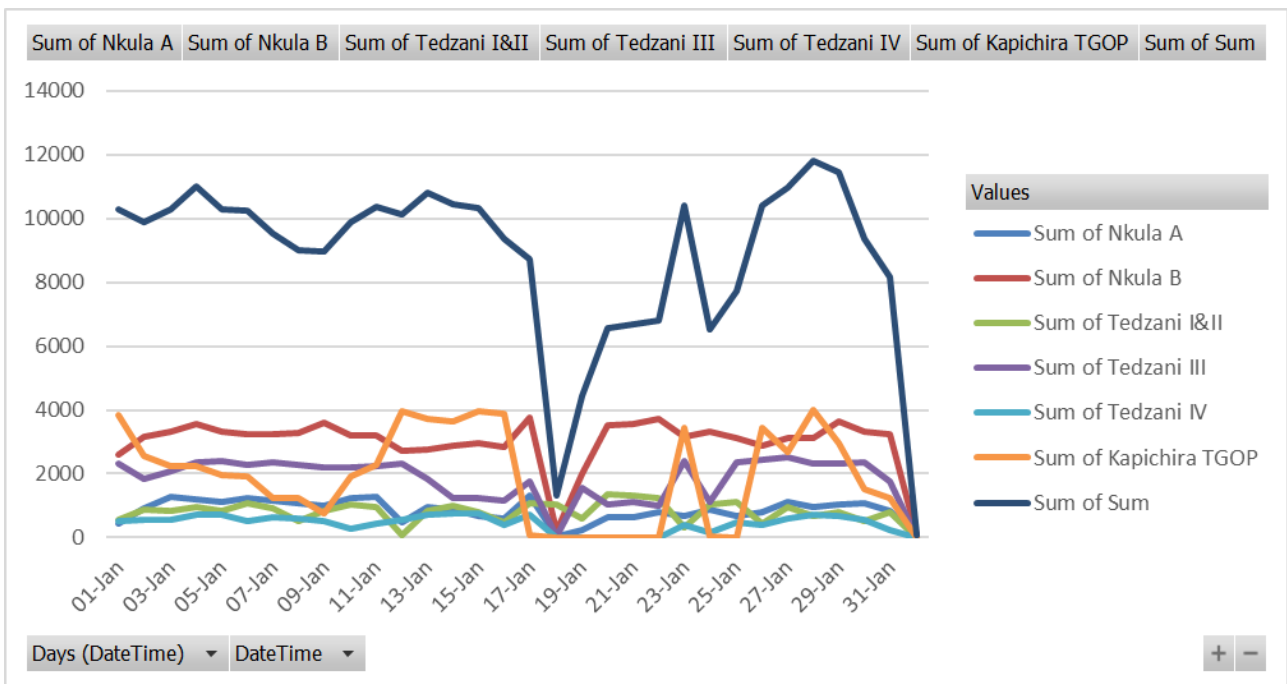


Figure A5-12 Generation patterns over the whole of January 2022.

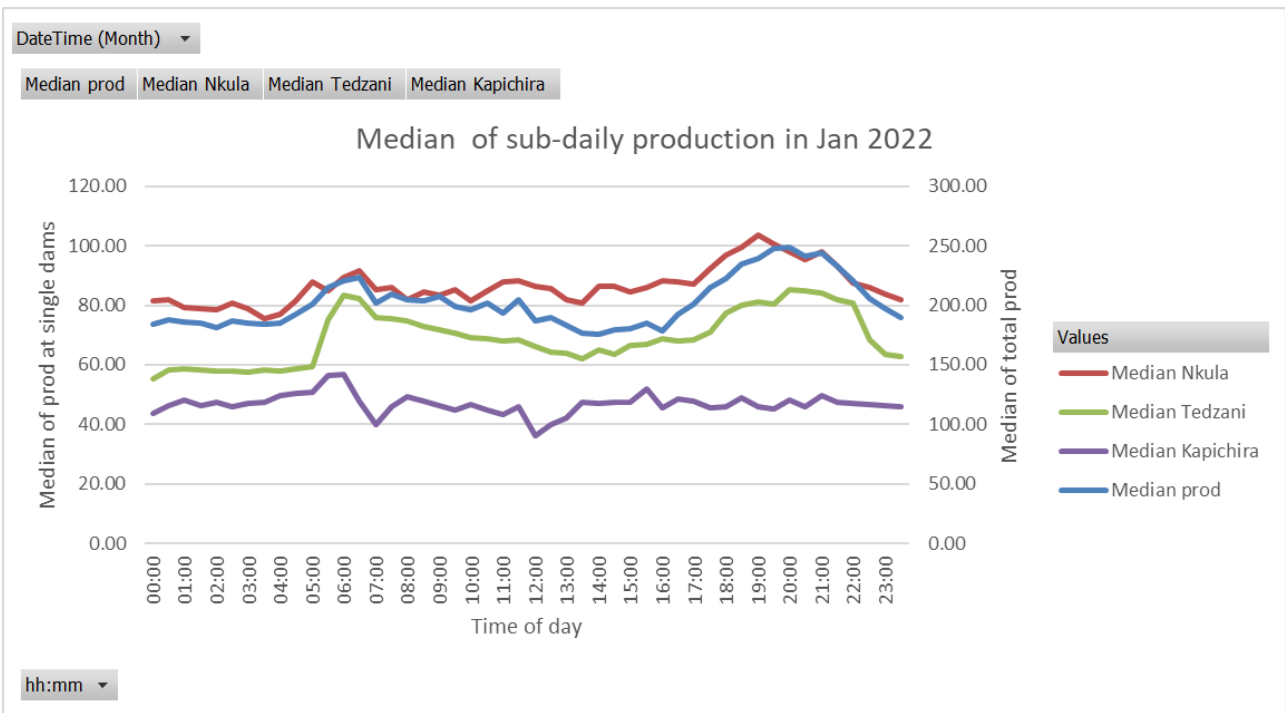


Figure A5-13 Median of sub-daily production at each dam, calculated with data from January 2022.

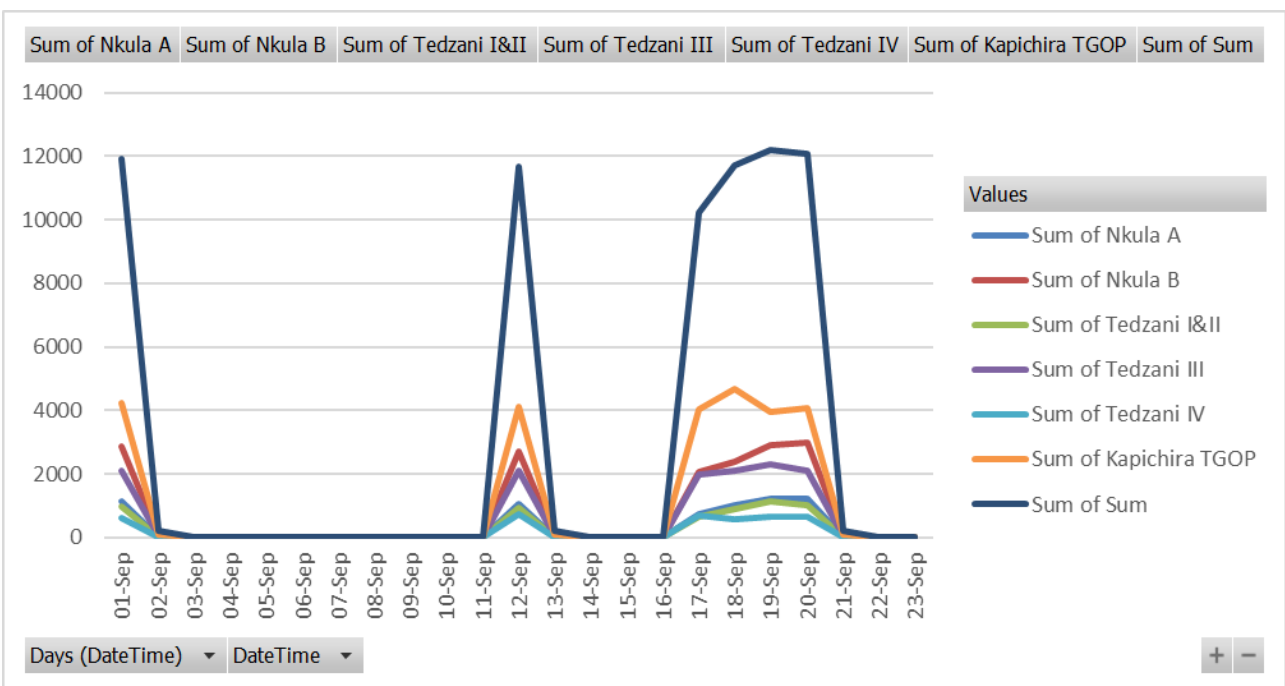


Figure A5-14 Total production at each dam and generator during Sep 2023.

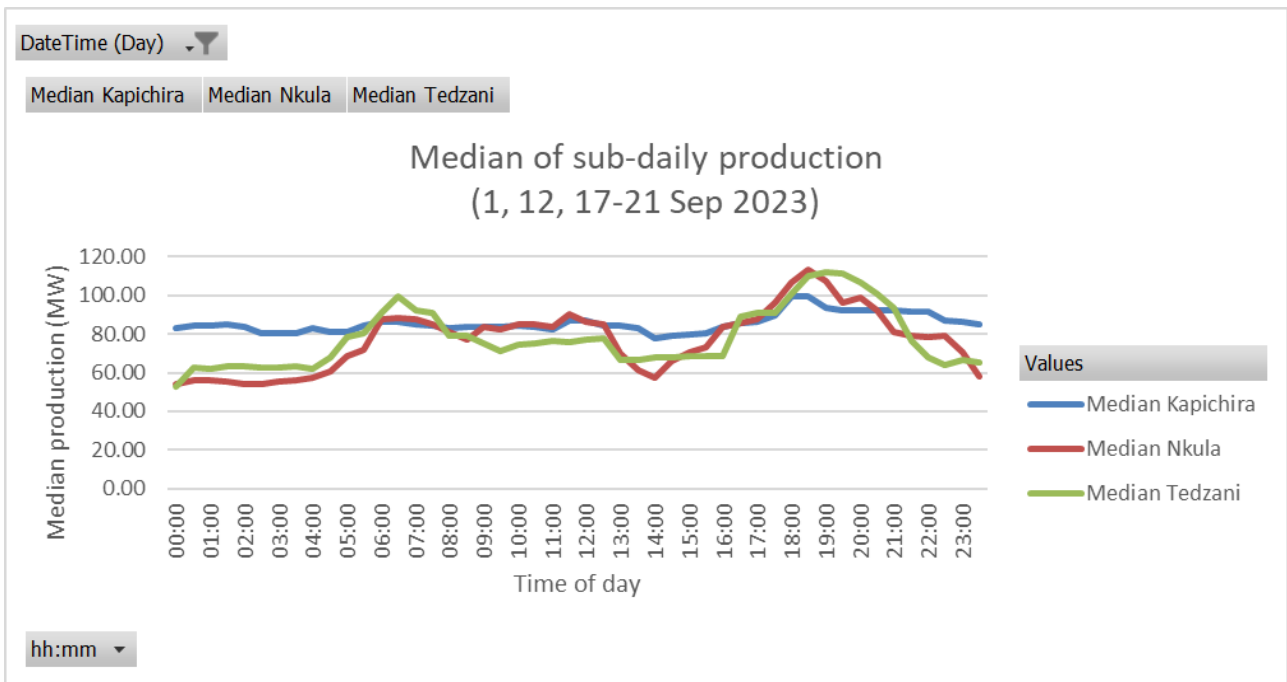


Figure A5-15 Median of sub-daily production at each dam, calculated from data from Sep 2023, considering only days with production.

Electricity generation

Hydropower

Table A5-1 below lists the hydropower plants as well as their capacity and commissioning data. Only hydropower plants that feed into the National grid are included. In the future scenario, only Mpatamanga is included. There are several other planned hydropower plants, including Kholombidzo HPP (210 MW), Fufu HPP (260 MW) and Songwe HPP (180 MW), but currently none of the projects have financing, and it is unknown if or when they will be built. As the expected construction time for these plants would be around 5 years, it is unlikely that they will be completed before 2030.

Table A5-0-2 Hydropower plants, their capacity and commissioning year.

Name	Capacity	Commissioned
Nkula A+B	124 MW	1992 (final machine)
Tedzani I+II	40 MW	Before 1992
Tedzani III	62 MW	1995
Kapichira I	64 MW	2001
Kapichira II	64 MW	2014
Tedzani IV	19 MW	2021
Mpatamanga	350 MW	2030

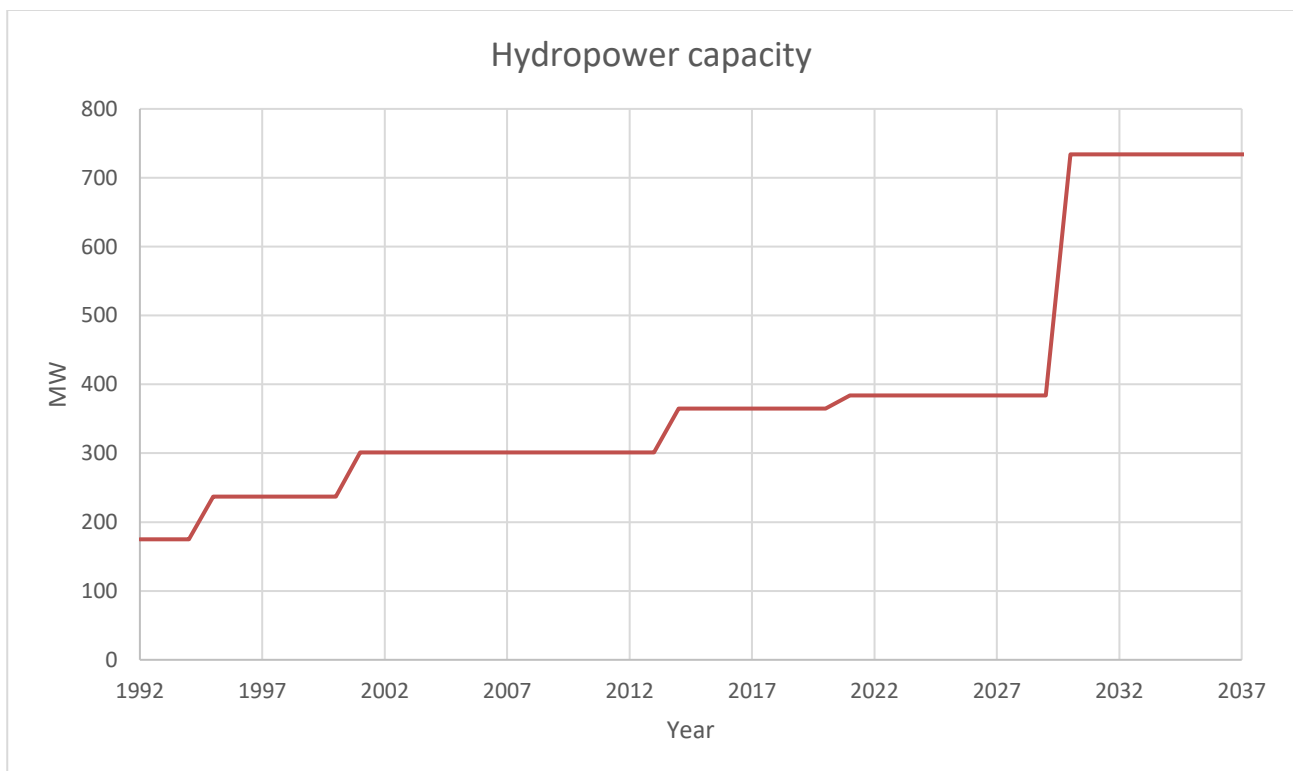


Figure A5-16 Development of hydropower capacity.

Solar PV

Malawi has a large potential for solar power, and the recent years have seen a surge of grid-connected solar plants. We have included power plants that are operational or under construction as well as projects that have confirmed financing. Given the current rapid development of solar PV globally, it is likely that the development scenario that we use is conservative.

Table A5-0-3. Solar power plants, their capacity and (expected) commissioning year.

Name	Capacity	Commissioned
Salima	60 MW	2022
Golomoti	20 MW	2022
Nkhotakota phanes	21 MW +17 MW	2023 2024
Bwengu	50 MW	2024
Nanjoka	10 MW +10 MW +30 MW	2025 2027 2029
Dwanga	55 MW	2025
Nkhoma Deka	50 MW	2026
Other	+15% each year	2031 onwards

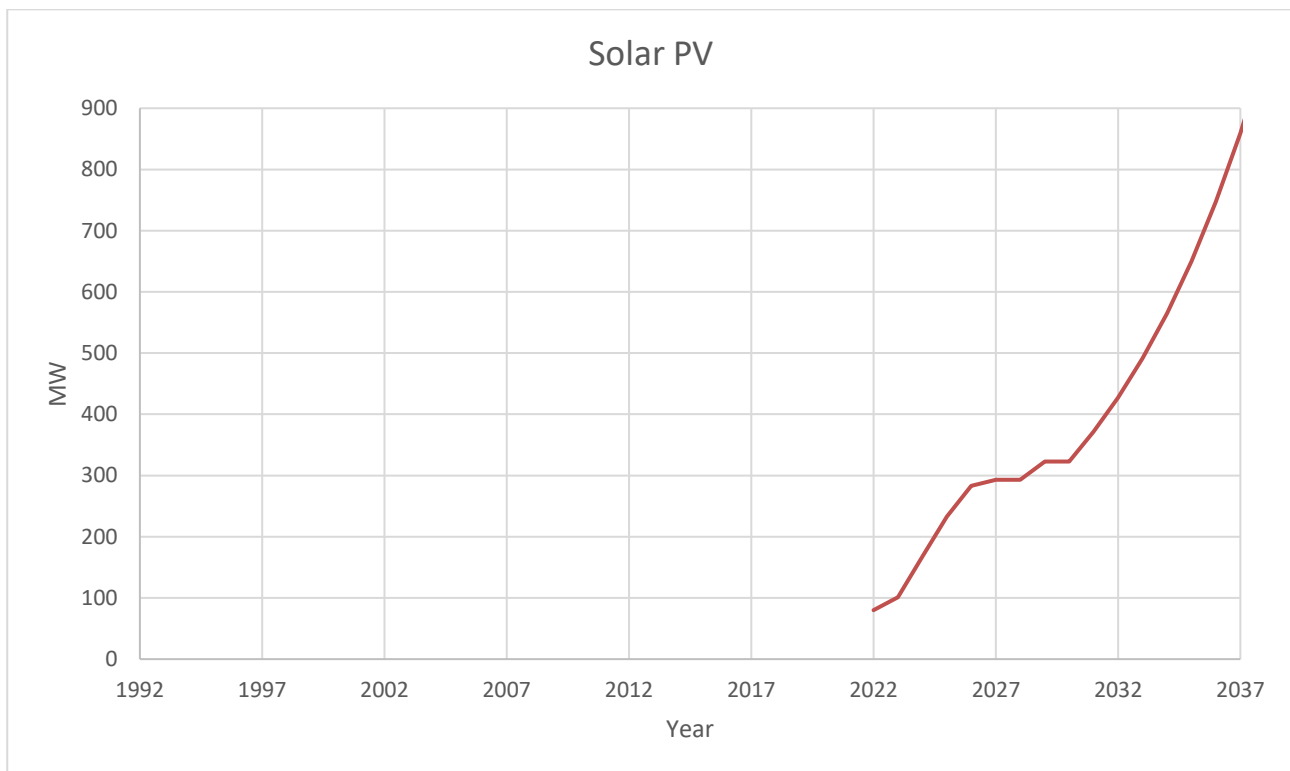


Figure A5-17 Assumed development of solar power capacity.

Other energy sources

EGENCO operates several diesel power plants that are used as emergency power supply or used to provide additional capacity during peak hours. Their current capacity is 53 MW⁵⁵. As diesel power plants are expensive, it is likely that they will be phased out when other electricity sources become available.

There are several planned fossil fuel plants in Malawi, including 300 MW Kam'mwamba coal project, 100 MW Rukuru coal project and 30 MW Salima natural gas project. The status of these projects is uncertain.

Malawi also has a significant potential for wind energy, most recently analysed by (Cgisale & Lee, 2024), but no projects have been developed. 50 MW Mzimba wind farm was originally planned to be commissioned in 2023, but the current status of the project is unknown.

Because of the large uncertainty when it comes to the development of thermal, gas and wind power, we have chosen to keep the capacity of other electricity generation to 53 MW also in the future.

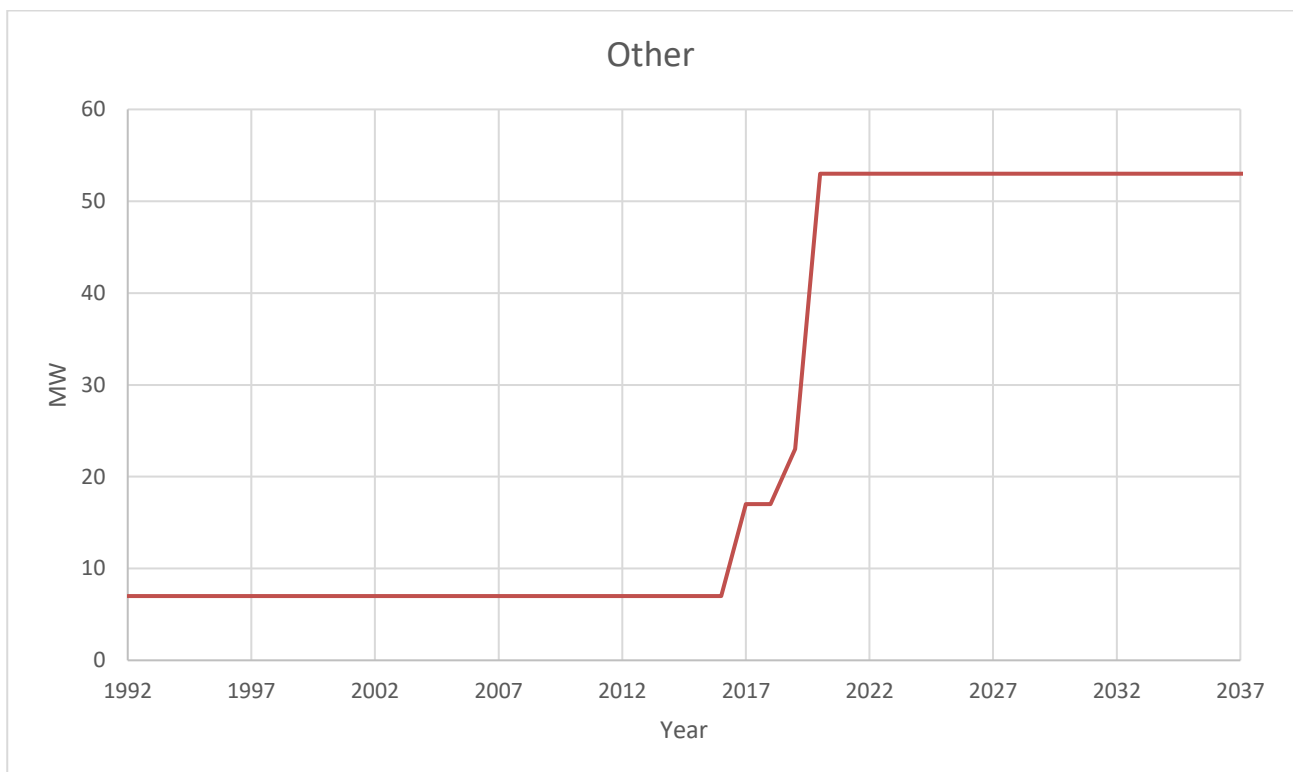


Figure A5-18 Assumed development of other electricity generation capacity.

⁵⁵ <https://www.energy.gov.mw/statistics/>

Import

The transboundary transmission capacity is currently very low, at just 27 MW (7 MW from Mozambique and 20 MW from Zambia). When the Mozambique-Malawi power transmission interconnection project (MOMA) has been completed, the capacity will increase with 120 MW. The final capacity of the MOMA interconnection will be 500 MW, but this is currently not possible due to bottlenecks in Mozambique.

A second interconnection with Zambia is also planned and is currently at feasibility stage. The transmission line will have a capacity of 500 MW. We have assumed that the commissioning will be in 2031. An interconnection with Tanzania in the North is at an earlier planning stage and is not included in the model.

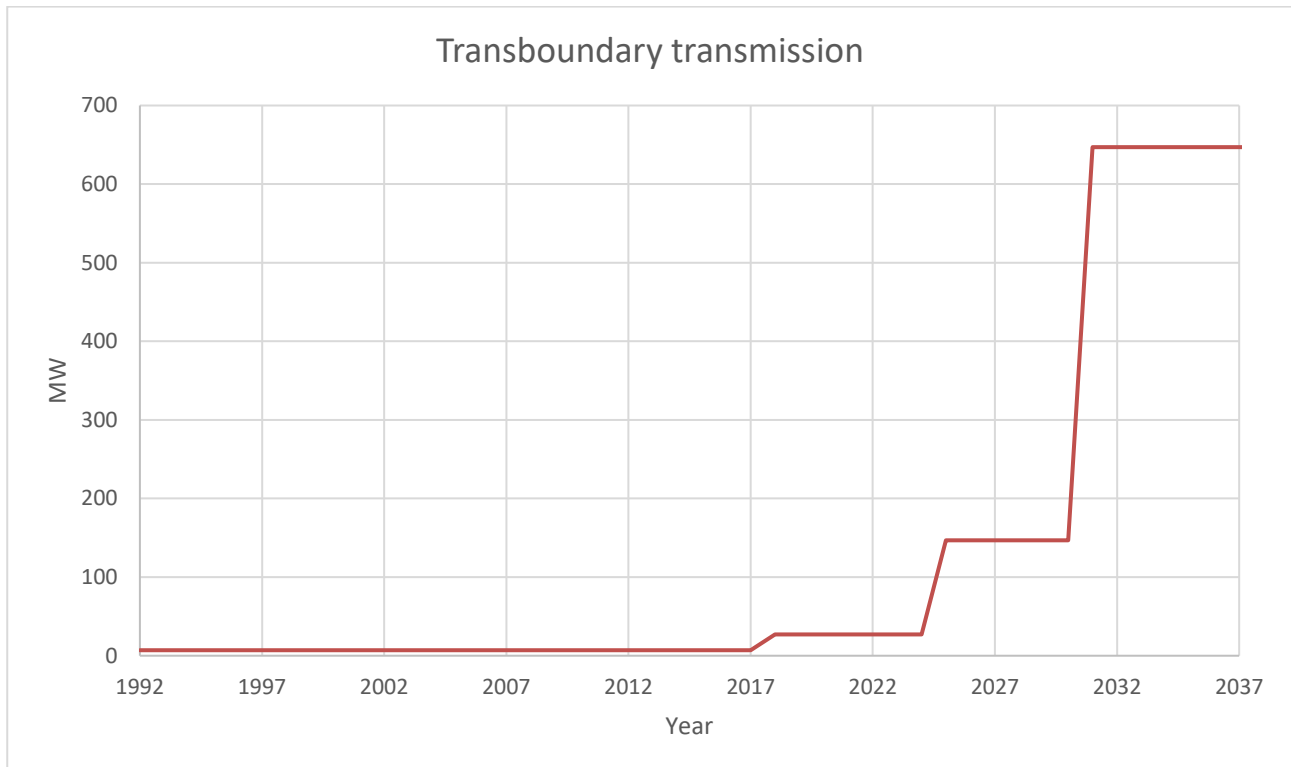


Figure A5-19 Expected development of transboundary transmission capacity.

Power Optimization Assessment

Solar PV

We have assumed that all Solar PV follows the same generation profile, but that there will be some variations from month-to-month, with lower generation in the months Dec-Mar. There is no generation during the night, from 7 PM to 6 AM. The chosen generation profiles are presented in Figure A5-12.

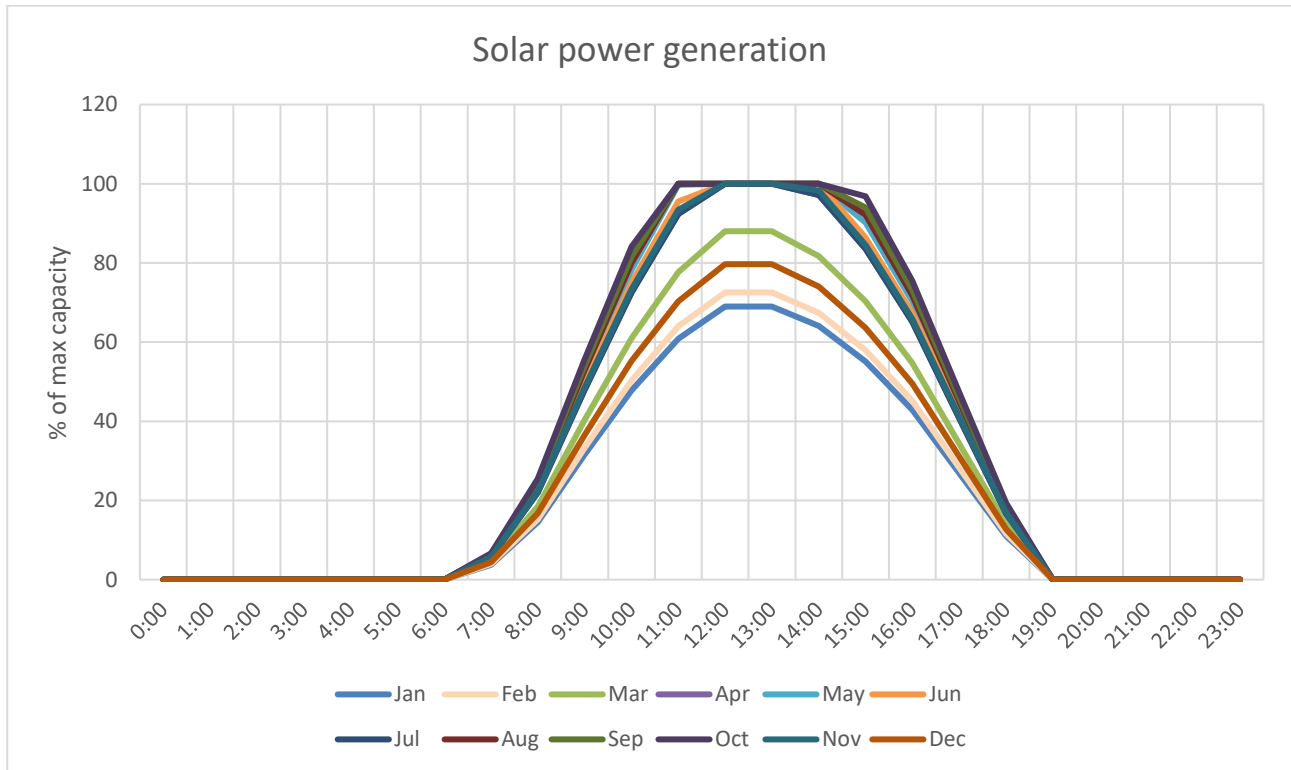


Figure A5-20 Solar power generation profile.

Other electricity generation and imports

We have assumed that other electricity generations (i.e. anything but solar PV and hydro) produce base load. Furthermore, we assume that the transboundary transmission lines will import electricity to Malawi at full capacity at all times.

Hydropower

In the system that we have outlined, only the hydropower plants have the flexibility to regulate electricity generation to meet demands. This is mostly true for the current system, but this might change in the future with an increase in transmission capacity and a possible connection to the South-African Power Pool. This is however beyond the scope of this study. In Figure A5-13 and Figure A5-14 we can see how the increased solar power decreases hydropower generation in the middle of the day, but during the peak hours in the morning and the evening, solar power does not contribute.

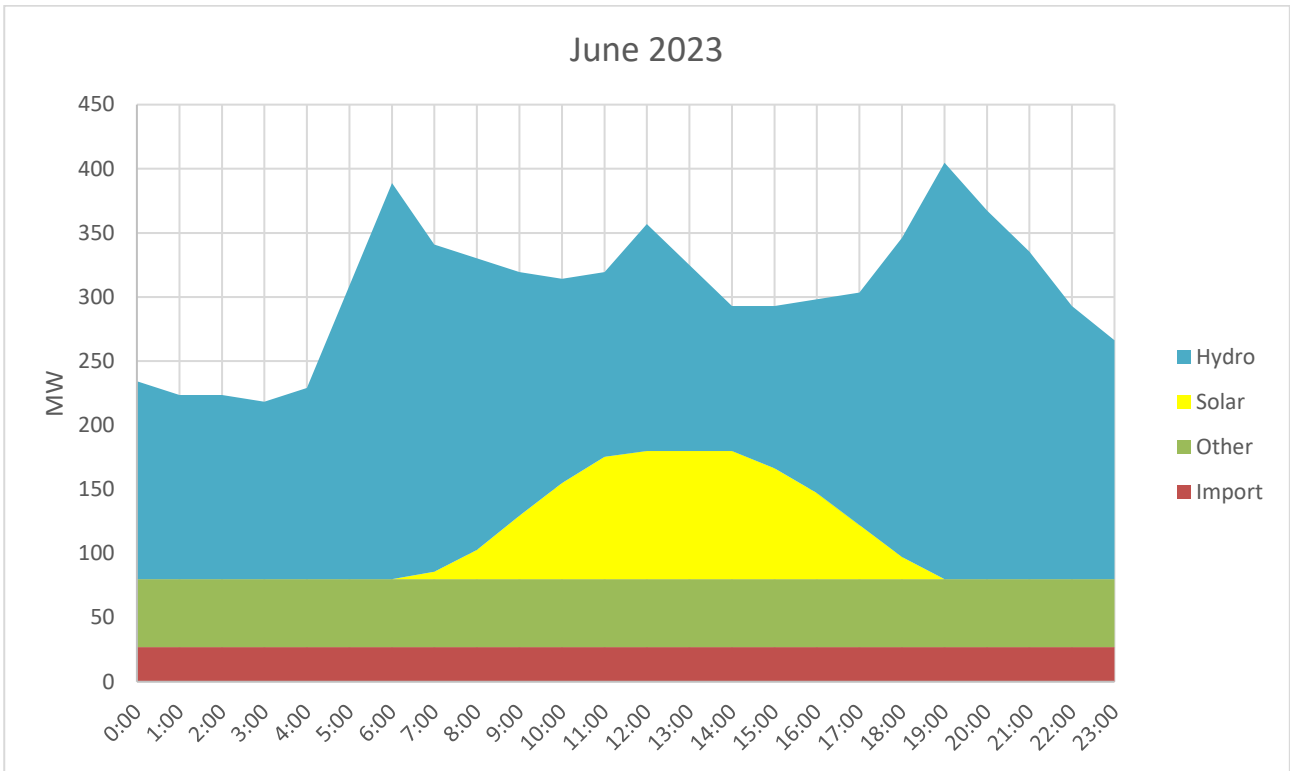


Figure A5-21. Ideal generation each hour for June 2023 (Baseline Scenario 1). “Other” and “import” are base load, while solar PV generates according to the solar flux. Hydro fills the gap between the demand and the other power sources.

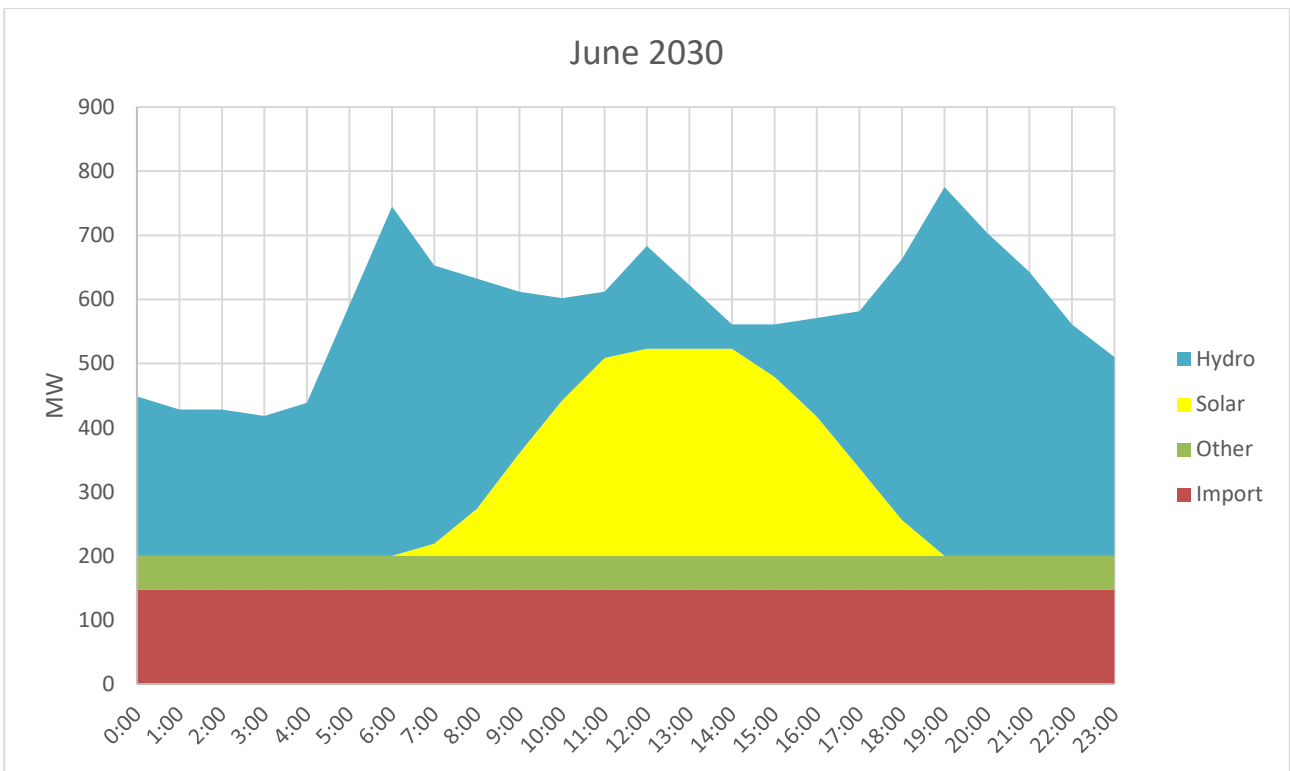


Figure A5-22. Ideal generation each hour for June 2030 (Baseline Scenario 2.2, with Mpatamanga). “Other” and “import” are base load, while solar PV generates according to the solar flux. Hydro fills the gap between the demand and the other power sources.

Technical details of the hydropower plants

The Shire River reservoirs have suffered from siltation. Dredging operations were done in 2018-2020, but recent floods Ana and Freddy have added new sediments to the reservoirs. The current storage capacity of the is unknown, as no bathymetric surveys have been performed. The cross sections in the hydraulic models are unfortunately not detailed enough to be able to provide information about the actual storage. As a simplification, active storage volume at Nkula, Tedzani and Kapichira has been assumed to be around ¼ of the original storage volumes given on the EGENCO website. This allows for some limited peaking operations, as has been observed downstream of Tedzani.

If the actual active volumes are significantly lower, this will greatly impact the hydropower operation as well as the necessary flow release from Kamuzu Barrage.

Table A5-0-4. Technical details used in the modelling.

HPP	Capacity (MW)	Design flow (m ³ /s)	Original storage volume (Mm ³) ⁵⁶	Assumed active reservoir volume (Mm ³)
Nkula (all)	135	265	3	0.75
Tedzani (all)	121	339	2	0.4
Mpatamanga	309	550	58 active 272 total	58
Mpatamanga regulating	41	272	8.2 active 11 total	8.2
Kapichira (all)	128	272	3.5 active 9 total	0.9

Optimization of hydropower operation

The hydropower plants should be operated in such a way that the electricity demand is met. In addition, we try to utilise the available storage capacity in order to be able to meet the demand also when the flow in the river is low.

One example can be seen in Figures A5-15 to A5-17. This is one day in January for Baseline Scenario 1 (scenario 3 in the figure). Here, we find that 170 m³/s is the minimum flow in the river required to be able to meet the electricity demand. The average turbine flow is about 152 m³/s, but the storage volume in the dams is insufficient to be able to use all the water effectively, thus the minimum flow is about 10% higher than what it could have been with more available storage. If there was no available storage, however, the required flow in the river would have been 250 m³/s, as this is the turbine flow during the peak hours.

⁵⁶ Information from <https://www.egenco.mw/portfolio/>

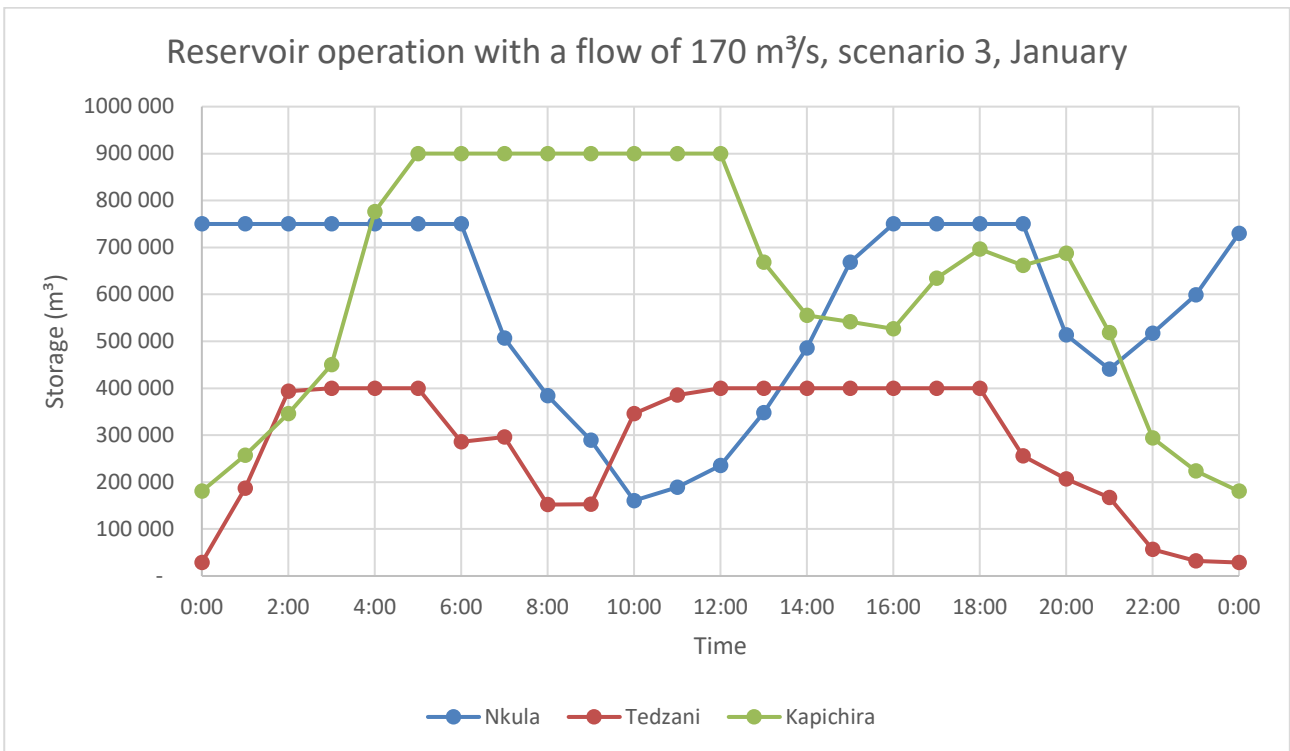


Figure A5-23 Inter-day changes in storage volume for one day in January with river flow of 170 m³/s.

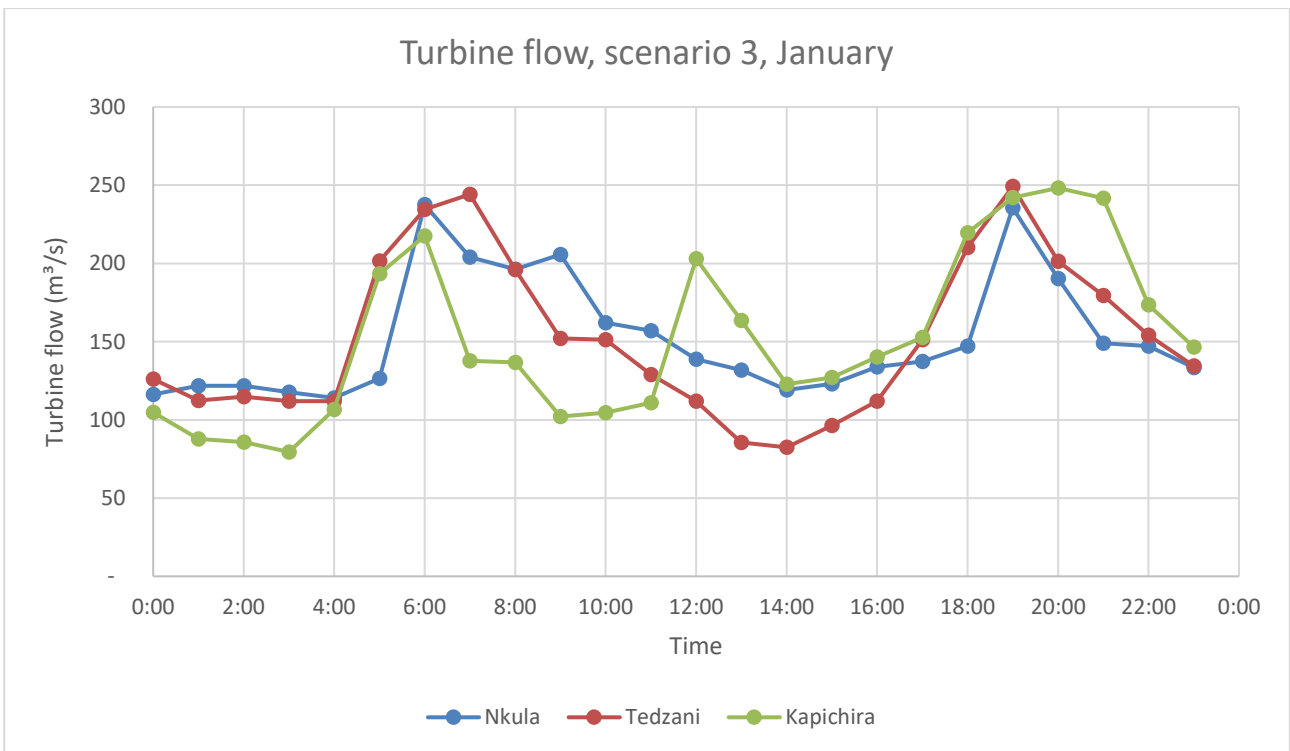


Figure A5-24 Flow through the turbines in one day in January for the baseline scenario.

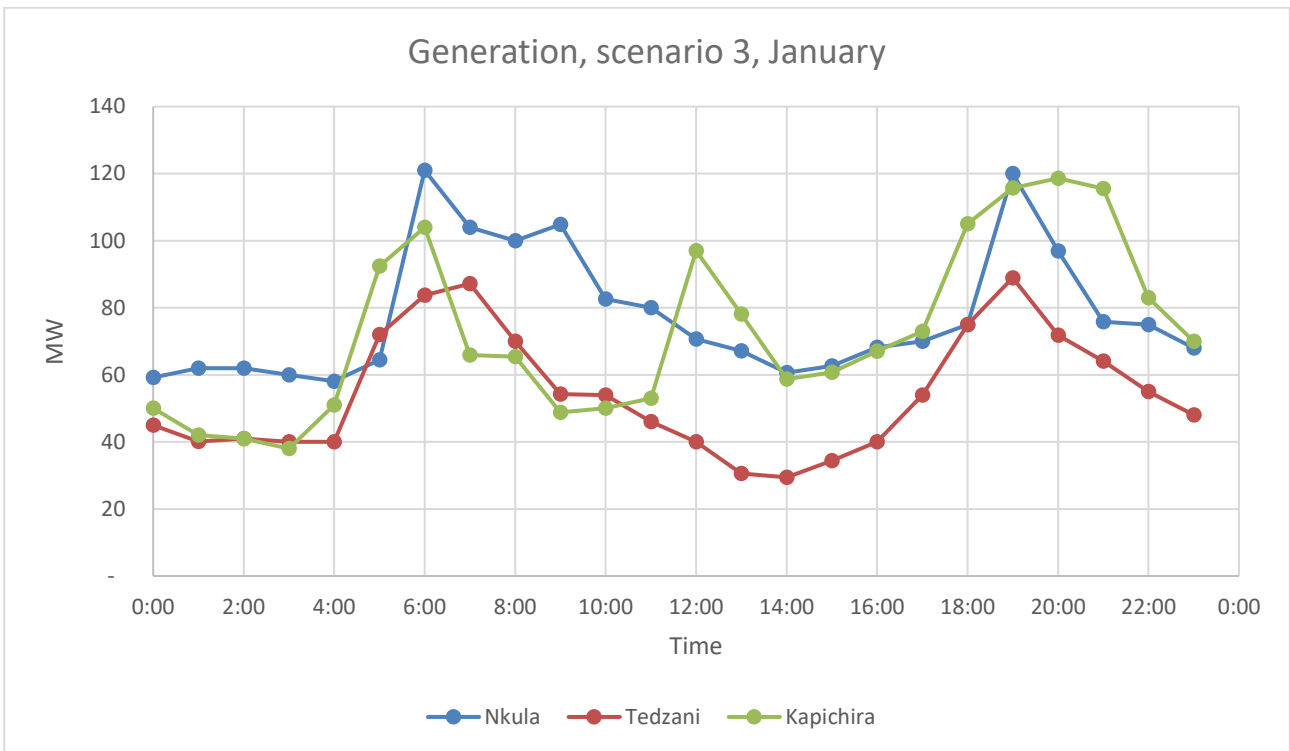


Figure A5-25 Hydropower generation, baseline scenario, January.