ECOLOGICAL RISK ASSESSMENT FRAMEWORK FOR THE INTEGRATED SUSTAINABLE MANAGEMENT OF THE TRANSBOUNDARY WATER RESOURCES OF THE INCOMATI BASIN, SOUTHERN AFRICA

G.C. O'Brien, M. Wade, V. Wepener, J. MacKenzie. R. Stassen, B. van der Waal, G. Diedericks, V. Dlamini, A. van der Merwe, A. Kaiser-Reichel, L. van Rensburg, S. Gerber and T. McNeil

TT 938/24

Ecological risk assessment framework for the integrated sustainable management of the transboundary water resources of the Incomati basin, Southern Africa

Report to

the Water Research Commission

by

G.C. O'Brien, M. Wade, V. Wepener, J. MacKenzie. R. Stassen, B. van der Waal, G. Diedericks, V. Dlamini, A. van der Merwe, A. Kaiser-Reichel, L. van Rensburg, S. Gerber and T. McNeil (Editors)

WRC report no. TT 938/24

ISBN 978-0-6392-0633-2

June 2024

Obtainable from
Water Research Commission
Bloukrans Building, Lynnwood Bridge Office Park
4 Daventry Street
Lynnwood Manor
PRETORIA

hendrickm@wrc.org.za or download from www.wrc.org.za

The publication of this report emanates from a WRC project titled *Risk framework for multiple stressors and integrated sustainable management of the transboundary water resources of the Incomati Basin, southern Africa.* (WRC Project No C2021/2022-00512).

EXECUTIVE SUMMARY

The University of Mpumalanga (UMP) in collaboration with Charles Sturt University, North West University, the Incomati Usuthu Catchment Management Agency, Ara-Sul, Department of Water and Sanitation in South Africa, Department of Water Affairs in Eswatini and the Incomati Water Course Committee has undertaken a study to establish a risk assessment framework to evaluate the effect of multiple stressors and the integrated sustainable management of the transboundary water resources of the Incomati Basin, southern Africa. The study was co-funded by the Water Research Commission (WRC) of South Africa, the Incomati-Usuthu Catchment Management Agency (IUCMA) and National Research Foundation (NRF) of South Africa and was undertaken in collaboration with stakeholders of the Incomati Basin in South African, Eswatini and Mozambique. The aim of the study is to establish a risk assessment framework to evaluate the effect of multiple stressors and contribute to the integrated sustainable management of the transboundary water resources of the Incomati Basin. The objectives of the project were as follows:

1. Review available knowledge of the features and processes of water resources, including ecological infrastructure, and multiple flow, water quality, habitat alerting and other anthropogenic stressors and natural environmental drivers affecting the wellbeing of resources in the Incomati Basin, southern Africa.
2. Develop a socio-ecological risk assessment framework for the water resources and communities of the Incomati Basin. This will represent the multiple stressors (flow, water quality, habitat, climate change and alien invasive species for example) and their synergistic effects on the wellbeing of the rivers and linked ecosystems (wetlands, floodplains, lakes and dams and estuary) and ecosystem services using the Relative Risk Assessment – Bayesian Network (RRA-BN) probability modelling approach.
3. Implement the risk assessment framework to update and integrate environmental flows and provide evidence-based probabilistic water resources protection measures (synonymous with Resource Quality Objectives and/or Sustainable Development Goals Targets) for the Incomati Basin, southern Africa. Implementation will be tested in the Kaap River sub-basin as a case study.
4. Establish a risk-based monitoring and adaptive management framework for the protection and allocation of water resources and trade-off consideration in the Incomati Basin.

The outcome of this study is a probabilistic risk framework that will dovetail with water resources management in the region including the Resource Directed Measures activities of the Department of Water and Sanitation (DWS) and IUCMA in South Africa. This innovative regional-scale probabilistic modelling approach will support policy development and implementation of sustainable water resource management requirements in the region and can be applied to other shared basins throughout the region.

The socio-ecologically important water resources of the Incomati Catchment are being used excessively and their condition is still deteriorating. This results in water stress in South Africa and Mozambique, affecting numerous vulnerable human communities. Although Integrated Water Resource Management policies are in place, South African water law dominates the management and development activities in the basin, with limited transboundary collaboration with Eswatini and Mozambique. Presently there are no environmental flow (e-flow) and non-flow stressor basin scale management frameworks that support sustainable water resource use and protection. These frameworks can contribute to water resource use protection measures, resource allocation in the context of protection requirements and a monitoring and adaptive management plan for sustainability. Risk assessment developments in Africa that provide an understanding of the socio-ecological consequences of multiple stressors, e-flows and non-flow variable requirements for water resources and support evidence-based trade-off decisions and water allocation decisions will make a significant contribution to the sustainable management of this water resource. The

water resources of the Incomati Catchment, southern Africa, are socio-ecologically important and support the livelihoods of > 2.5 million South Africans and > 1 million Mozambicans. The Incomati Basin is a biodiversity hotspot for the region with many intact ecosystems, primarily in the Kruger National Park. Numerous stressors threaten the wellbeing of the vulnerable ecosystems and associated human communities in the Incomati Basin who totally depend on the water resources for their livelihoods. The development of the water resources in the basin need to be sustainable and well managed to ensure that a sustainable balance between the use and protection of water resources in the basin is established.

Through this study we have established an Ecological Risk Assessment-based framework using the Relative Risk Model (RRM) and Bayesian Networks (BN) to support the holistic management of multiple stressors to socio-ecological features (or endpoints) of water resources in the Incomati Basin. This will contribute to the sustainable use and protection of the resources in the basin, and the livelihoods of our vulnerable African communities.

The Incomati River basin is located in the south-eastern part of Africa and occupies portions of Eswatini, Mozambique and South Africa. The Incomati includes the Komati, Crocodile, Sabie, Massintoto and Uanetze Rivers and the Incomati floodplain and estuary. This report describes the holistic environmental flow (e-flow) determination and framework approach, PROBFLO, (O'Brien *et al.*, 2018) that will be implemented to establish e-flows for all the selected sites of the study. PROBLFO combines Relative-Risk Modelling (RRM) and the use of Bayesian Networks (BNs) in a BN-RRM approach to:

- determine the flow requirements of selected indicators components of ecosystems,
- evaluate the synergistic effects of e-flow scenarios to ensure they are suitable in a holistic context, and
- characterise and evaluate the relative risk of flow and non-flow stressors to social and ecological water resources on regional scales to contribute to water resource sustainability management.

The implementation of PROBFLO includes in particular: (i) The e-flows required to sustain healthy functioning aquatic ecosystems (maintain fish, vegetation and invertebrate communities), and (ii) the social consequences of altered flow scenarios, including e-flow scenarios. This is available to stakeholders for the consideration of the socio-ecological consequences of multiple scenarios including trade-off implications associated with different scenarios and opportunities to attain a sustainable balance between the use and protection of water resources (e-flows) while maintaining critical provisioning and cultural ecosystem services.

The ecological risk assessment approach adopted in the study includes the 10 procedural steps of the PROBFLO model. This includes the need to identify the vision, or, in the regional context, the classes associated with use or protection targets for the resources on a suitable spatial scale. We used the Integrated Units of Analysis scale to ensure alignment between our risk assessment and existing policies and legislation. For this we needed to align the use and protection vision of the Incomati Basin in Mozambique which resulted in use and/or protection focus information for the whole basin. The determination of e-flows for the Incomati Basin was based on the ecological endpoints selected for the study (fish, freshwater macroinvertebrates and aquatic and riparian vegetation), which also represented the supporting services in the study. In addition the risk of altered flows and non-flow stressors were provided for provisioning, regulatory and cultural services so that all ecosystem services could be considered in the framework. The basic conceptual model used for the risk assessment was established for the case study and depicts how the existing *sources* (use activities of change (dam development, etc.) lead to *stressors* on the river (altered timing of flows, volumes of water, etc.)). These in turn affect either the instream, riparian or floodplain *habitats*, where most of the *receptors* (instream biota, etc.) will be impacted. These risk pathways from sources, stressors to receptors within habitats drive what we care about in the basin and where these attributes occur represented in the study as socio-ecological *endpoints* (supply of water for subsistence agriculture, biodiversity maintenance, etc.). The conceptual model was expanded into BN models for each endpoint and adjusted to be representative of each site/reach of river considered in the study. The BNs consist of nodes that represent socio-ecological variables or attributes of the rivers and the people who depend on these systems. Nodes are selected and used to represent how the system will be exposed to stressors (integrated into the cumulative response of the socio-ecological system). The nodes represent various physical, chemical, biological/social and ecological attributes of each reach of the Incomati Basin considered in the study. Links between nodes represent the risk pathways that conform to the source, stressors, habitat, receptor and endpoint relationship described in the conceptual model of the study. Links or conditional probabilities include flow-ecosystem and other stressor-ecosystem relationships and flow-ecosystem service and other stressor-ecosystem service relationships. Both the state of the variables (input nodes) and the conditional probabilities (relationships) are established for the study through field sampling, evidence collection and analysis and using available knowledge and/or, if required, justified solicitations. This ensures that the process is evidence driven and uncertainty analyses can be carried out and incorporated into the outcomes of the study. Forty-two reaches of the rivers of the basin were selected to represent the basin (Figure ES-1). The size of the Incomati Basin and need for evidence for the risk assessment, as well as resources available for the study and historical knowledge of the socio-ecological system resulted in the division three categories, namely *Mega sites* where multiple (> 2) surveys were carried out, *Supplementary* sites where at least two (high flow vs. low flow) comprehensive surveys were carried out and *Other sites* where biological and some physical assessments were carried out for the study.

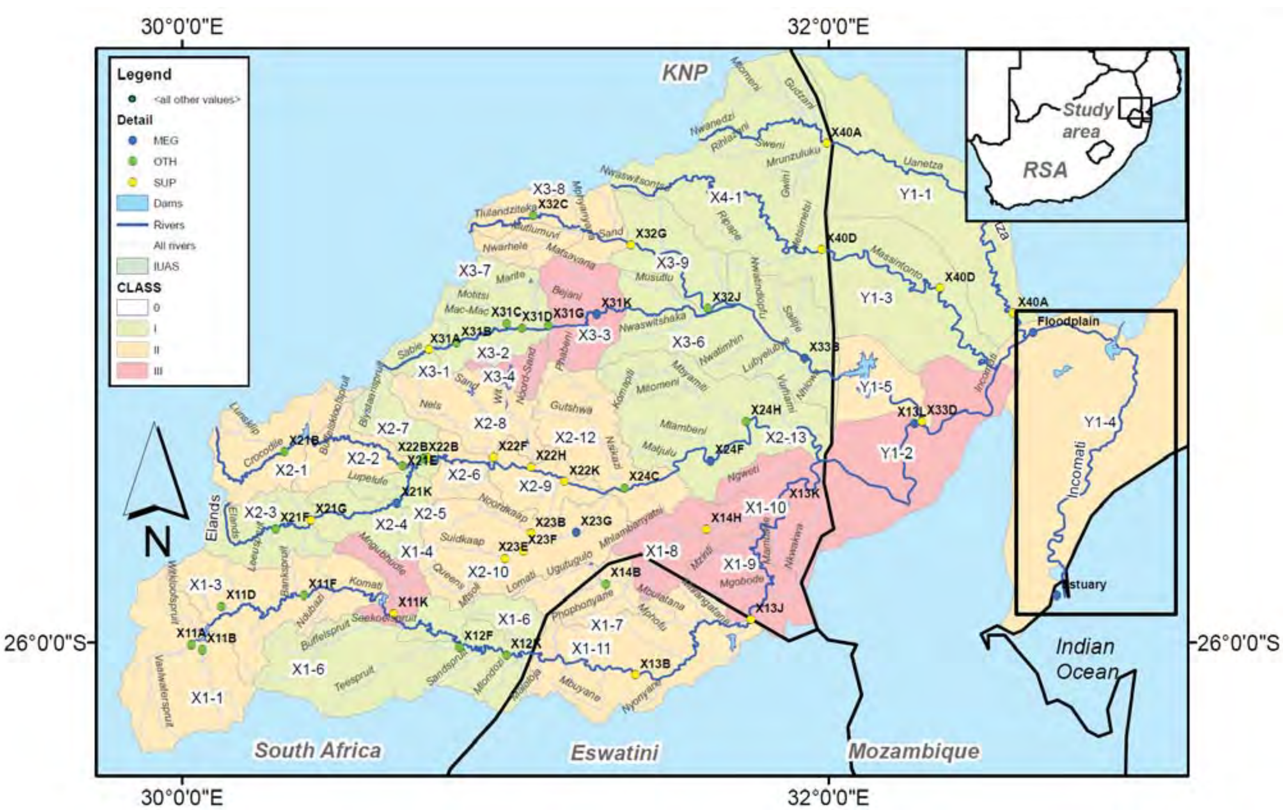


Figure ES-1: The Incomati Basin with Integrated Units of Analysis, management classes, major rivers and sampling sites selected for the risk assessment study.

The assessment resulted in the provision of e-flow (volume, timing, duration and frequency) requirements aligned to existing legislation, determined e-flows (reserve) for the basin. This iterative process included using *independent flow requirements* for different ecosystem components used to generate an initial e-flow scenario, then running the PROBFLO risk models and adjusting the flow requirements to provide acceptable *integrated synergistic* flow requirements. Summaries of the e-flows required to sustain ecosystems in the basin are provided in Table ES-1.

Table ES-1: E-flow requirement summary for the sites considered in the study.

SITE NAME	nMAR (MCM)	FINAL E-FLOW AS PERCENTAGE OF NMAR			
		BASE FLOW	DROUGHT FLOWS	HIGH FLOWS*	TOTAL E-FLOWS
UANETZA CATCHMENT					
X40B Uanetza	20.4	13.84	0.79	18.34	32.18
Y40C Uanetza	46.8	9.67	0.79	5.99	15.66
MASSINTONTO CATCHMENT					
X40D Massintonto	30.6	13.24	0.36	13.22	26.46
Y40B Massintonto	61.2	10.36	0.36	6.61	16.97
SABIE CATCHMENT					
X31A Sabie	98.1	39.77	15.63	6.04	45.81
X31C Mac-Mac	63.3	34.77	13.27	7.0	41.77
X31D Sabie	280.2	37.14	11.29	5.48	42.62
X31G Marite	157.2	24.25	8.79	7.74	31.99
X31K Sabie	541.8	27.60	18.20	14.04	41.64
X32H Sand	128.4	24.82	9.24	5.76	30.58
X32J Sand	142.4	23.70	9.21	4.37	28.07
X33B Sabie	744.7	38.84	16.45	16.02	54.86
Y40F Sabie	745.8	20.56	12.16	7.96	28.52
CROCODILE CATCHMENT					
X21B Crocodile	84.3	33.40	13.11	7.84	41.24
X21E Crocodile	211.6	29.95	12.08	6.61	36.56
X21F Elands	36.0	34.40	12.98	5.63	40.03
X21G Elands	81.5	36.50	18.49	16.37	52.87
X21K Elands	218.9	30.74	13.87	22.77	53.51
X22A Houtbosloop	68.9	22.43	14.14	9.01	31.44
X22B Crocodile	584.3	27.13	17.10	8.82	35.95
X22F Nels	129.9	20.10	10.93	10.78	30.88
X22H White River	50.4	15.24	7.94	17.30	32.54
X22K Crocodile	866.5	25.11	13.05	7.16	32.27
X23B Noordkaap	52.1	24.36	13.72	8.27	32.63
X23E Queens	29.5	23.77	13.27	8.79	32.56
X23F Suidkaap	105.3	24.35	13.24	10.42	34.77
X23G Kaap	181.2	19.19	12.29	14.99	34.18
X24C Nsikazi	54.6	32.11	12.73	9.0	41.11
X24F Crocodile	1 186.2	15.17	12.57	9.68	24.85
X24G Mbyamiti	16.5	12.47	0.90	6.29	18.76

SITE NAME	nMAR (MCM)	FINAL E-FLOW AS PERCENTAGE OF NMAR			
		BASE FLOW	DROUGHT FLOWS	HIGH FLOWS*	TOTAL E-FLOWS
KOMATI CATCHMENT					
X11B Boesmanspruit	62.8	17.77	6.49	9.58	27.35
X11D Klein Komati	81.4	13.15	6.67	1.71	14.86
X11F Komati	168.8	21.34	7.66	5.25	26.59
X11J Gladdespruit	80.8	13.60	9.20	5.01	15.61
X12K Komati	355.9	14.48	8.48	5.44	19.92
X13B Komati	859.5	11.75	2.29	2.62	14.37
X13J Komati	1 025.4	15.11	11.21	10.73	25.84
X13K Komati	1 376.7	13.93	9.43	7.29	21.22
X14D Lomati	111.2	21.31	13.86	9.44	30.75
X14H Lomati	264.3	15.35	9.05	8.25	23.60
INCOMATI CATCHMENT					
Y40A Incomati	2 615.5	16.15	11.24	7.47	23.62
Y40E Incomati floodplain	2000 m^3s^{-1} floods are required irregularly (once every three years).				

* Please note that the actual floods as specified in the report should be used and not only the percentage.

The risk to the supporting services (fish, vegetation and macroinvertebrates) for the four scenarios considered in the study including: (A) natural flows, (B) present day flows, (C) e-flows and (D) future sustained drought flows are included in Figure ES-2, Figure ES-3 and Figure ES-4. Results include changes in risk between the scenarios considered. Outcomes show that there has been a considerable change in risk between historical conditions and present day. The risk associated with e-flows to supporting services is included and demonstrates how the provision of e-flows will generally improve ecosystem conditions. Note non-flow drivers of change including, for example, the impact of barriers in the Komati River in the results. The drought scenario results demonstrate continued deterioration of the ecosystem if e-flows are not implemented. These outcomes can contribute to decision-making in the basin and demonstrate the value (cost-benefit) of e-flows and managing non-flow variables on a holistic scale in the Incomati Basin.

The risk assessment approach has been used to model the socio-ecological system of the rivers in the Incomati Basin. The models are evidence driven and require an understanding of the state of a range of environmental variables of the rivers and how the chemical and physical attributes of the rivers interact with the biological and social aspects of the rivers we care about. In the study 41 sub-catchment areas of the Incomati Basin were delineated, and risk models for each of the 41 sub-basins were developed and used to generate the risk of multiple stressors in the study. The 41 sub-basin areas or risk regions include sampling sites where chemical, physical, biological and social evidence was obtained for the risk assessment. The risk assessment models were applied to supporting services and other ecosystem services (provisioning, cultural and regulatory services) in the study. The supporting services represent the key attributes of the ecosystem including the fish, macro-invertebrates and riparian vegetation. The risk assessment to the supporting services were used to generate the environmental flow requirements for the 41 reaches in the study area. The risk to the supporting, provisioning, regulatory and cultural services were considered in the study to demonstrate the relative risk of risk regions/sub-basin areas throughout the Incomati Basin using the natural, present day, environmental flows and drought scenarios.

This risk assessment has been completed using available and collected social and ecological evidence with multiple partners from the Incomati Basin over a three-year period. We have aligned available information, improved our understanding of the hydrology of the basin, and provided new data to fill in gaps in our understanding. In the study we have identified and described resource users, the nature of their resource use and threat of their synergistic activities to the ecological and social attributes of the rivers of the basin that we care about. We have identified physical, chemical stressors and the impacts of river connectivity loss and disturbance to wildlife impacts from alien invasive fauna and flora in the basin. We have characterised our aquatic biodiversity and how our ecosystems and the people who depend on these ecosystems; have, are and may be affected my multiple stressors. We have provided a framework for stakeholders that has provided e-flow and associated non-flow drivers of change needed to achieve a holistic sustainable balance between the use and protection of water resources in the basin. This framework allows stakeholders to identify stressors, evaluate their impact/s and address excessive use and abuse of our water resources. We finally have developed a framework that allows stakeholders to consider other regulators and their water resource management, to allow stakeholders of the shared resource to work together to share and manage resources across the basin. This framework is adaptable and can be used in an iterative manner with machine learning capabilities from implementation monitoring to grow and improve projections for improved application in the future.

The results of the risk assessment include the likely risk scores aligned to zero, low, moderate and high risk along a continuum from 0 to 100. The risk scores are validated, robust and inversely proportional to the state or health of the rivers being considered. In addition, the risk assessment provides information on the probability of high risk (unsustainable/failure of that socio-ecological attribute) to each endpoint for each scenario considered in the study. The results generally demonstrate a trend between the natural scenario and present-day scenarios for each variable considered. The environmental flow requirements established in the study are aligned to the vision for the sustainable balance between the use and protection of the resource. The risk to the social and ecological endpoints associated with the e-flow requirements are on occasion better than present, showing that recovery of the system will occur if the e-flows are implemented. On other occasions the present state of the resource is better than the e-flow requirement risk outcomes, this suggests use of the resource can increase. The drought scenario generally demonstrates how risk will increase if an extended drought occurs, possibly aligned to a climate change scenario for the region.

The risk assessment outcomes of the study are provided on a regional scale (41 sub-basins in the catchment) and available for stakeholders to identify areas that have been developed beyond the threshold of sustainability. The outcomes also provide environmental flow on a comprehensive scale throughout the basin. The risk assessment also provides users with information on the probable socio-ecological consequences of not providing environmental flows and/or managing water resource use in the region. Finally in the study demonstrated how this approach can be implemented and contribute to the development of a monitoring/implementation tool and allow stakeholders to identify and manage the drivers or sources of risk.

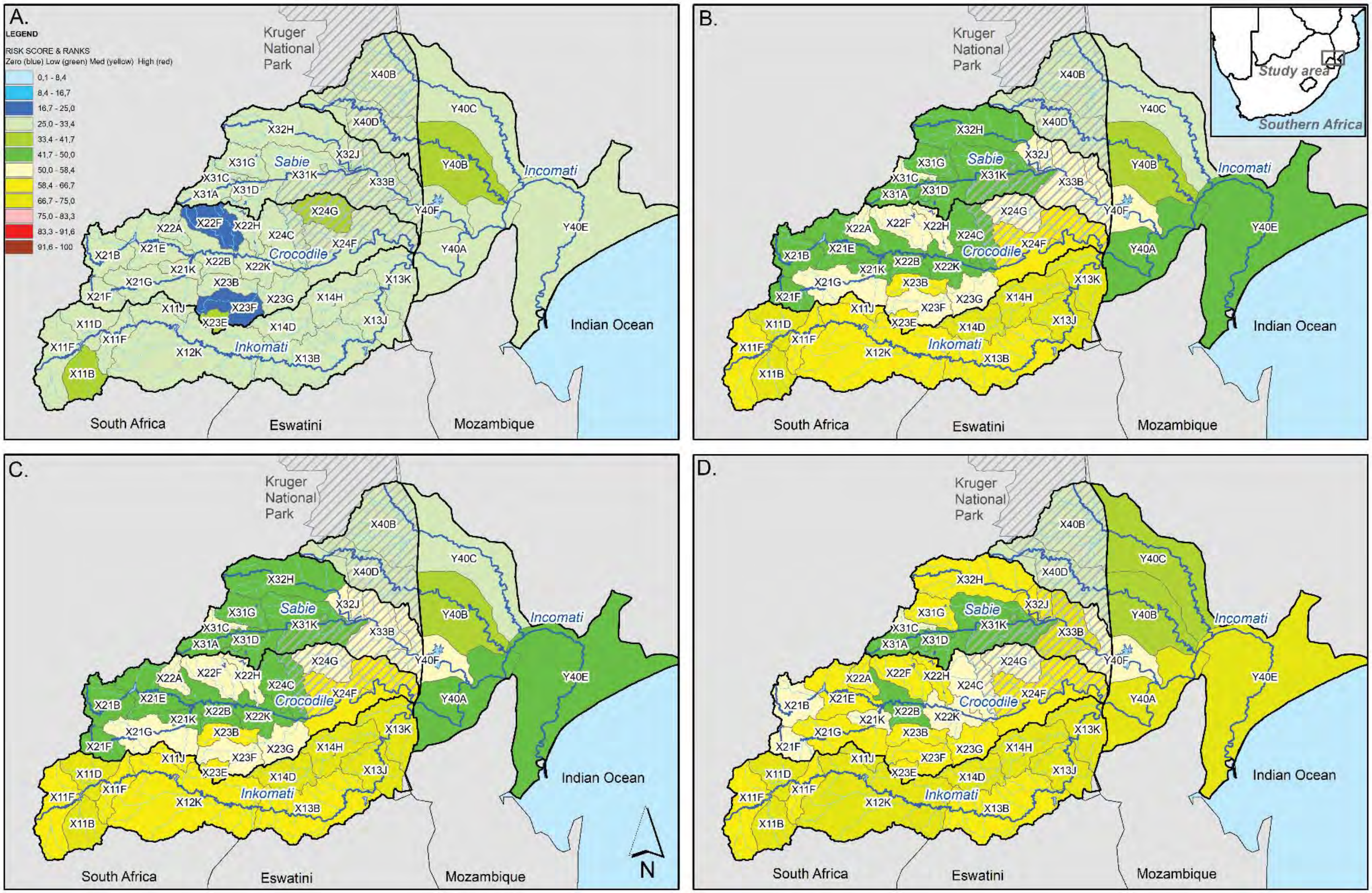


Figure ES-2: Relative risk scores to FISH-ECO-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed.

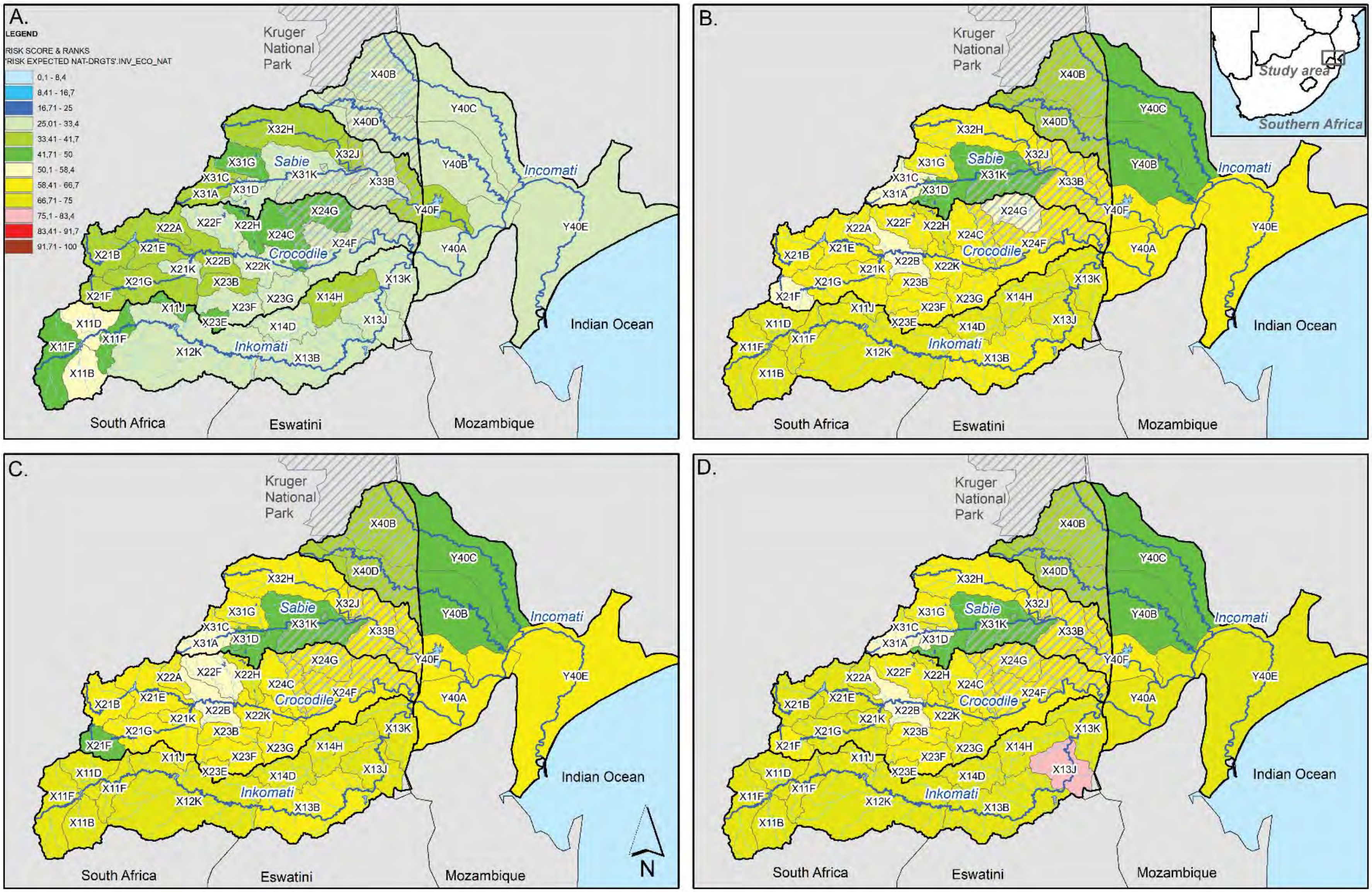


Figure ES-3: Relative risk scores to INV-ECO-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed.

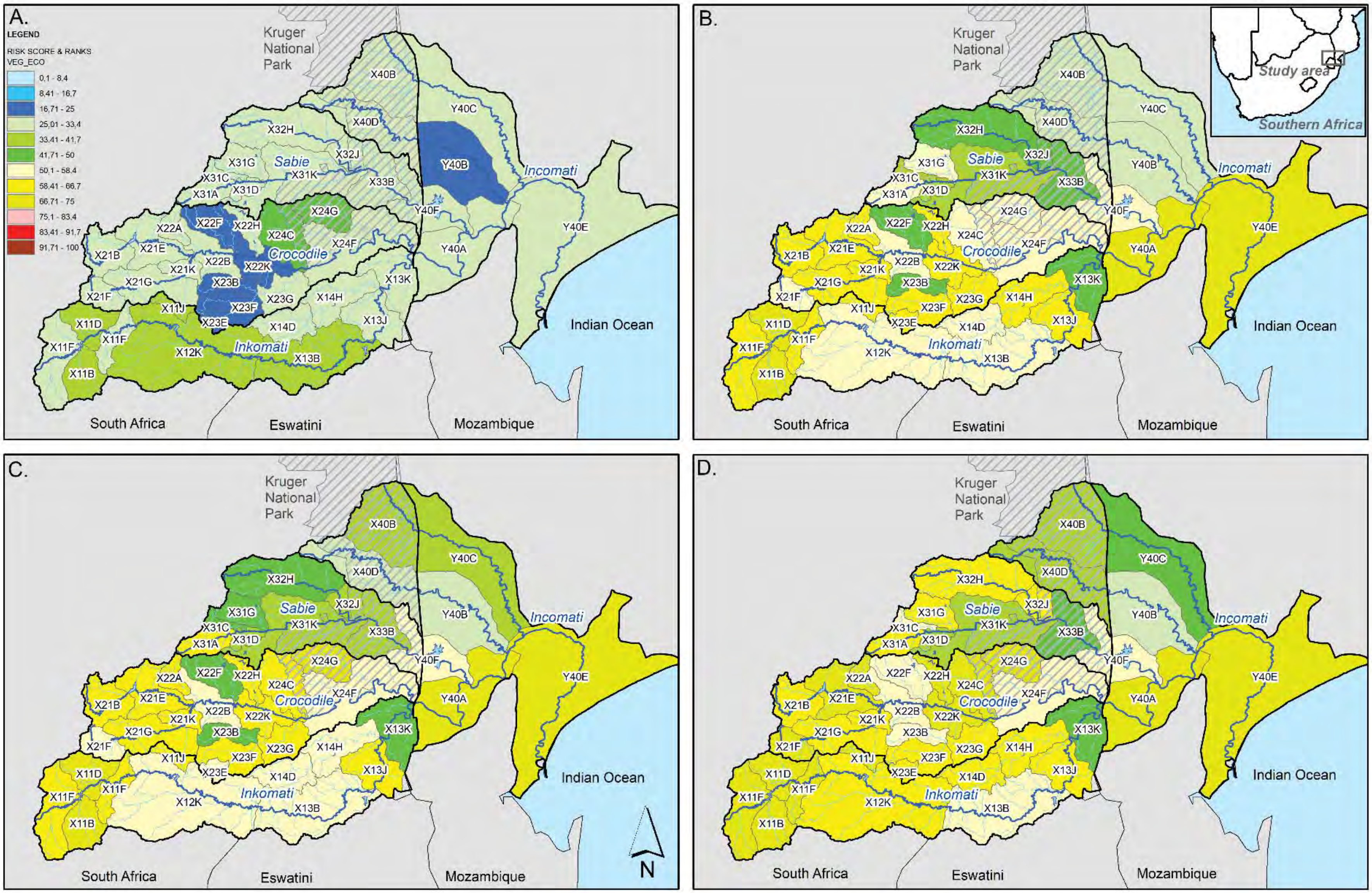


Figure ES-4: Relative risk scores to VEG-ECO-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed.

TABLE OF CONTENTS

EXECUTIVE SUMMARY iii

1 INTRODUCTION 1

1.1 Background 2

2 THE PROBFLO APPROACH 5

2.1 OVERVIEW 5

2.2 STEP 6: CALCULATE RISK 7

2.2.1 Bayesian network design 7

2.2.2 Current condition evaluation 8

2.2.3 Determine the flow-ecosystem relationships and conditional probabilities 10

2.2.4 Generation of flow scenarios 11

2.2.5 Evaluation of the integrated risk of preliminary e-flow requirements 12

2.2.6 Determining probable risk 13

2.2.7 Evaluation of integrated risk 14

2.3 STEP 7: UNCERTAINTY EVALUATION 15

2.3.1 Sensitivity of findings 15

2.3.2 Integrated risk to ecosystems 15

3 RESULTS 17

3.1 STEP 1: VISIONING EXERCISE 17

3.2 STEP 2: MAPPING AND DATA ANALYSIS 21

3.2.1 Regional management of water resources 22

3.2.1.1 Water resources protection measures in South Africa 23

3.2.1.2 Water resources protection measures in Eswatini 25

3.2.1.3 Water resources protection measures in Mozambique 26

3.2.2 Drivers of ecosystem change 26

3.2.2.1 Water quality 26

3.2.2.2 Hydrology 27

3.2.2.3 Geomorphology 29

3.2.3 Responses to ecosystem change 29

3.2.3.1 Fish 29

3.2.3.1.1 The Sabie River system 30

3.2.3.1.2 The Crocodile River system 30

3.2.3.1.3 The Komati River system 30

3.2.3.1.4 Connectivity barriers in the Incomati Catchment 31

3.2.3.2 Macroinvertebrates 32
3.2.3.2.1 Komati Sub-Catchment (X1) 32
3.2.3.2.2 Crocodile Sub-Catchment (X2) 33
3.2.3.2.3 Sabie-Sand Sub-Catchment (X3) 34
3.2.3.3 Riparian vegetation 34
3.2.3.4 Ecosystem services 35
3.3 STEP 3: RISK REGION SELECTION 36
3.4 STEP 4: CONCEPTUAL MODEL 42
3.5 STEP 5: RANKING SCHEME 49
3.6 STEP 6: CALCULATING RISK 50
3.6.1 DRIVERS OF ECOSYSTEM CHANGE 50
3.6.1.1 WATER QUALITY AND ECOTOXICOLOGY 50
3.6.1.1.1 Water quality and ecotoxicological approach 50
3.6.1.1.2 Water quality status 52
3.6.1.1.2.1 Sabie catchment 52
3.6.1.1.2.2 Crocodile catchment 54
3.6.1.1.2.3 Komati catchment 58
3.6.1.1.2.4 Incomati catchment 60
3.6.1.2 HYDROLOGY 61
3.6.1.2.1 Hydrological information 61
3.6.1.2.2 Ecological detail available 61
3.6.1.3 HYDRAULICS AND GEOMORPHOLOGY 67
3.6.1.3.1 Methodology 67
3.6.1.3.2 Results 69
3.6.2 RESPONSES TO ECOSYSTEM CHANGE 83
3.6.2.1 FISH AND FISHERIES 83
3.6.2.1.1 Introduction 83
3.6.2.1.2 Materials and Methods 85
3.6.2.1.2.1 Ethics 85
3.6.2.1.2.2 Study area 85
3.6.2.1.2.3 Fish sampling 85
3.6.2.1.2.4 Fish water quality 86
3.6.2.1.2.5 The ecological wellbeing of the fish 86
3.6.2.1.2.6 Statistics 87

3.6.2.1.3 Fish Results 87
3.6.2.1.3.1 Uanetza Catchment 87
3.6.2.1.3.2 Massintonto Catchment 89
3.6.2.1.3.3 Sabie Catchment 92
3.6.2.1.3.4 Crocodile Catchment 96
3.6.2.1.3.5 Komati Catchment 103
3.6.2.1.3.6 Incomati Catchment 107
3.6.2.1.3.7 Estuary 110
3.6.2.1.3.8 Redundancy Analyses 111
3.6.2.1.4 Fish discussion 116
3.6.2.1.4.1 Fish communities and Fish Respond Assessment Index 116
3.6.2.1.4.2 Redundancy analyses 117
3.6.2.1.4.3 Estuary 119
3.6.2.1.5 Fish conclusion 119
3.6.2.2 MACRO- AND MICRO-INVERTEBRATES 120
3.6.2.2.1 Background 120
3.6.2.2.2 Taxa Selected as Indicators 121
3.6.2.2.2.1 Flow Indicators 122
3.6.2.2.2.2 Water Temperature 123
3.6.2.2.2.3 Electrical Conductivity 126
3.6.2.2.3 Macroinvertebrate Results 128
3.6.2.2.3.1 Present Ecological Status 128
3.6.2.2.4 Macroinvertebrate discussion 129
3.6.2.3 RIPARIAN VEGETATION 130
3.6.2.3.1 In Situ Data Collection 130
3.6.2.3.2 Biotic data collected: 131
3.6.2.3.3 Driver / abiotic data collected: 131
3.6.2.3.4 Present Ecological State: 132
3.6.2.3.5 Flow Requirements: 134
3.6.2.3.5.1 Deriving CPTs: 138
3.6.2.3.6 Riparian vegetation results 140
3.6.2.3.6.1 PES & Activation Discharge 141
3.6.2.3.6.1.1 Nels River (X22F NELS) 141
3.6.2.3.6.1.2 Crocodile River (X22F CROC) 143

3.6.2.3.6.1.3 Elands at Nsinini (X21K ELANDS) 146
3.6.2.3.6.1.4 Elands at SAPPI (X21E ELANDS) 149
3.6.2.3.6.1.5 Noordkaap River (X23B NOORDKAAP) 154
3.6.2.3.6.1.6 Suidkaap River (X23F SUIDKAAP) 157
3.6.2.3.6.1.7 Queens River at Barberton (X23E QUEENS) 160
3.6.2.3.6.1.8 Gladdespruit River (X11K GLADDESPRUIT) 163
3.6.2.3.6.1.9 Kaap River at Honeybird (X23G KAAP) 166
3.6.2.3.6.1.10 Sabie River at Merry Pebbles (X31A SABIE) 170
3.6.2.3.6.1.11 Sabie River at Skurukwane (X31M SABIE) 173
3.6.2.3.6.1.12 Sabie River at Lower Sabie (X33B SABIE) 176
3.6.2.3.6.1.13 Lomati River (X14H LOMATI) 179
3.6.2.3.6.1.14 Komati River (X13K KOMATI) 182
3.6.2.3.6.1.15 Crocodile River at Van Graan (X24F CROC) 184
3.6.2.3.6.1.16 Lower Komati River in Mozambique (above Sabie confluence) 187
3.6.2.3.6.1.17 Sabie River in Mozambique (DS Curumano Dam) 189
3.6.2.3.6.1.18 Incomati Floodplain (Riverine section within floodplain) 192
3.6.2.3.6.2 Vegetation Flow Requirements 194
3.6.2.4 ECOSYSTEM SERVICES 207
3.6.2.4.1 Introduction 207
3.6.2.4.2 Methodology 207
3.6.2.4.3 Limitations of the Report 208
3.6.2.4.4 Ecosystem services in different sites along the Incomati Basin 208
3.6.2.4.4.1 Uanetza catchment 208
3.6.2.4.4.2 Massintonto catchment 208
3.6.2.4.4.3 Sabie catchment 209
3.6.2.4.4.4 Crocodile catchment 210
3.6.2.4.4.5 Komati catchment 213
3.6.2.4.4.6 Incomati catchment 215
3.6.2.4.5 Provisioning 215
3.6.2.4.5.1 Provisioning of water for commercial irrigation 215
3.6.2.4.5.2 Provisioning for subsistence agriculture and livelihoods 216
3.6.2.4.5.3 Livestock riparian grazing 216
3.6.2.4.5.4 Fisheries 216
3.6.2.4.5.5 Handicraft plants, fuelwood and sand mining 217

3.6.2.4.6 Regulating services 217
3.6.2.4.6.1 Flow and water quality regulation 217
3.6.2.4.6.2 Flood attenuation services 218
3.6.2.4.7 Supporting services 218
3.6.2.4.8 Cultural 219
3.6.2.4.8.1 Spiritual and cultural use 219
3.6.2.4.8.2 Education and research 219
3.6.2.4.8.3 Ecotourism 219
3.6.2.4.9 Ecosystem services conclusion 220
3.6.3 ENVIRONMENTAL FLOWS FOR THE INCOMATI BASIN 220
3.6.4 RISK OF FLOWS TO ECOSYSTEM SERVICES ASSESSMENT 229
3.6.4.1 Supporting Services 229
3.6.4.1.1 FISH-ECO-END endpoint 231
3.6.4.1.2 INV-ECO-END endpoint 236
3.6.4.1.3 VEG-ECO-END endpoint 241
3.6.4.2 Provisioning Services 246
3.6.4.2.1 SUB-FISH-END endpoint 246
3.6.4.2.2 SUB-VEG-END endpoint 252
3.6.4.2.3 LIV-VEG-END endpoint 257
3.6.4.2.4 DOM-WAT-END endpoint 262
3.6.4.3 Regulatory Services 267
3.6.4.3.1 FLO-ATT-END endpoint 267
3.6.4.3.2 RIV-ASS-END endpoint 272
3.6.4.3.3 WAT-DIS-END endpoint 277
3.6.4.3.4 RES-RES-END endpoint 282
3.6.4.4 Cultural Services 287
3.6.4.4.1 REC-SPIR-END endpoint 287
3.6.4.4.2 TOURISM-END endpoint 292
3.7 STEP 7: UNCERTAINTY EVALUATION 297
3.7.1 Sensitivity of findings 297
3.7.2 Integrated risk to ecosystems 299
3.7.2.1 Supporting Services 299
3.7.2.2 Provisioning Services 301
3.7.2.3 Regulatory Services 303

3.7.2.4 Cultural Services 305
4 IMPLEMENTATION 307
4.1 STEP 8: HYPOTHESES ESTABISHMENT 307
4.2 STEP 9: TEST HYPOTHESES 310
4.3 STEP 10: COMMUNICATION 319
5 CONCLUSION 320
6 REFERENCES 321
7 ANNEXURE 1 334
7.1 Supporting Services 334
7.1.1 FISH-ECO-END endpoint 334
7.1.2 INV-ECO-END endpoint 339
7.1.3 VEG-ECO-END endpoint 344
7.2 Provisioning Services 349
7.2.1 SUB-FISH-END endpoint 349
7.2.2 SUB-VEG-END endpoint 354
7.2.3 LIV-VEG-END endpoint 359
7.2.4 DOM-WAT-END endpoint 364
7.3 Regulatory Services 369
7.3.1 FLO-ATT-END endpoint 369
7.3.2 RIV-ASS-END endpoint 374
7.3.3 WAT-DIS-END endpoint 379
7.3.4 RES-RES-END endpoint 384
7.4 Cultural Services 389
7.4.1 REC-SPIR-END endpoint 389
7.4.2 TOURISM-END endpoint 394
8 ANNEXURE 2 399
8.1 Kaap River sub-basin 399
8.1.1 Determination of the Present Ecological State for the Kaap sub-basin 407
8.1.1.1 Driver Components for the Kaap sub-basin 408
8.1.1.2 Response Components for the Kaap sub-basin 410
8.1.2 Outcomes of the assessment for the Kaap sub-basin 411
8.1.2.1 Driver Components for the Kaap sub-basin 411
8.1.2.2 Response Components for the Kaap sub-basin 418
8.1.3 Discussion for the Kaap sub-basin 428

List of Tables

Table ES-1: E-flow requirement summary for the sites considered in the study. ____________________ vi

Table 3-1: Guidelines used to delineate the present ecological state categories based on observed and expected intolerance ratings (Kleynhans, 2008). ____________________ 17

Table 3-2: Proposed preliminary classes for quaternary catchments in Mozambique and Eswatini and rationale for their selection to align with existing South African classification. ____________________ 18

Table 3-3: Endpoints selected for the Incomati Risk Framework study. ____________________ 21

Table 3-4: Permitted volume of water withdrawals according to the Tripartite Interim Agreement (TIA) of the Incomati basin (2002). ____________________ 23

Table 3-5: Preliminary guidelines for determining the integrated unit of analysis class for a scenario (DWAF, 2007). ____________________ 24

Table 3-6: Ecological Water Requirements in the Sabie River catchment (Louw, 2007) ____________________ 28

Table 3-7: Ecostatus summary of MIRAI results for the Komati sub-catchment between 2014 and 2021 ____________________ 33

Table 3-8: Ecostatus summary of MIRAI results for the IUCMAs regular sampling sites located in the Crocodile sub-catchment. ____________________ 33

Table 3-9: Ecostatus summary of MIRAI results for the IUCMAs regular sampling sites located in the Sabie-Sand sub-catchment. ____________________ 34

Table 3-10: List of sites to be included in the ecological risk assessment framework and associated recommended ecological category per site (DWS 2019). ____________________ 39

Table 3-11: Ranking scheme selected for the Incomati Basin risk assessment study (O'Brien et al., 2018) ____________________ 50

Table 3-12: Comparison between historical and current water quality at sites within the Sabie catchment. Historical data are represented as the mean and range for the period, while current water quality data are represented by the average for the two sampling years. N/A represents no available data. ____________________ 53

Table 3-13: Comparison between historical and current water quality for sites in the Crocodile catchment. Historical data are represented as the mean and range for the period, while current water quality data are represented by the average for the two sampling years. N/A represents no available data. ____________________ 55

Table 3-14: Comparison between historical and current water quality for sites in the Komati catchment. Historical data are represented as the mean and range for the period, while current water quality data are represented by the average for the two sampling years. N/A represents no available data. ______ 58

Table 3-15: Comparison between historical and current water quality at Y40A Incomati River upstream of the Sabie River confluence). Historical data are represented as the mean and range for the period, while current water quality data are represented by the average for the two sampling years. N/A represents no available data. ____________________ 60

Table 3-16: Summary of information available per e-flow site (ML-Baseflows, MH-freshets, floods) __ 61

Table 3-17: Summary of ecological baseflow requirements for selected percentiles per e-flow site __ 64

Table 3-18: Particle size classes for site descriptions (adapted from Gordon et al. (2004) and Rowntree (2015)). 69
Table 3-19: Summary of the hydraulic information available per e-flow site (X1' is the Komati system, X2' the Crocodile and X3' the Sabie system) 70
Table 3-20: Summary of the hydraulic output in terms of depth and resultant velocity classes per e-flow site (X1' is the Komati system, X2' the Crocodile and X3' the Sabie system) 72
Table 3-21: Geomorphic flow requirements for X33B Sabie River at Lower Sabie 80
Table 3-22: Geomorphic flow requirements for X31K Sabie River 80
Table 3-23: Geomorphic flow requirements for X21K Elands 81
Table 3-24: Geomorphic flow requirements for X23G Kaap 81
Table 3-25: Geomorphic flow requirements for Y40A Incomati upstream of the Sabie confluence 82
Table 3-26: Geomorphic flow requirements for X24F Croc Van Graan 82
Table 3-27: Geomorphic flow requirements for X13J Komati at the Border 83
Table 3-28: Habitat classification based on velocity-depth classes proposed by Kleynhans (2007) 86
Table 3-29: Substrate classification adapted from Rowntree et al. (2000) 86
Table 3-30: Cover type rates adapted from Kleynhans (2007) 86
Table 3-31: Species richness and abundance of fishes obtained from sites in the Uanetza Catchment during the 2023 surveys. The Ecological status of fish communities is also included. 88
Table 3-32: Species richness and abundance of fishes obtained from sites in the Massintonto Catchment during the 2021 and 2023 surveys. The Ecological status of fish communities is also included. 90
Table 3-33: Species richness and abundance of fishes obtained from sites in the Sabie Catchment during the 2021, 2022 and 2023 surveys. The Ecological status of fish communities is also included. 93
Table 3-34: Species richness and abundance of fishes obtained from sites in the Crocodile Catchment during the 2020, 2021, 2022 and 2023 surveys. The Ecological status of fish communities is also included. 98
Table 3-35: Species richness and abundance of fishes obtained from sites in the Komati Catchment during the 2020 to 2023 surveys. The Ecological status of fish communities is also included. 104
Table 3-36: Species richness and abundance of fishes obtained from sites in the Incomati Catchment during the 2022 surveys. The Ecological status of fish communities is also included. 108
Table 3-37: Species richness and abundance of fishes obtained from sites in the Incomati Estuary during the 2022 surveys. 111
Table 3-38. List of the velocity preferences of some aquatic macroinvertebrate species. An aterisk (*) indicate source as Matthew (1968). 122
Table 3-39: Perceived species average water temperature preferences based on field observations, distribution records, and the WRC Dallas (2009) report and Dallas & Rivers-Moore (2012). Average water temperature categories are based on (Rivers-Moore et al., 2004) 124
Table 3-40: A list of additional information used to guide preferences of aquatic macroinvertebrates to flow, physical- and chemical habitat within the Incomati system. 125
Table 3-41: Summary of in situ electrical conductivity measurements associated with the presence of the aquatic nymphs of three Odonata species and one Ephemeroptera. 126
Table 3-42: Records of some of the environmental conditions Tricorythus species encountered in headwater streams of the Incomati basin. 126

Table 3-43: Aquatic macroinvertebrate indicator taxa considered during the macroinvertebrate assessment, and taxa recommended for consideration 127
Table 3-44: List of sites selected with PES indicated, and change compared to Recommended Class (REC) and previous data (if available) indicated by arrows as improved of deterioration. 129
Table 3-45: Description of generic riparian vegetation sub-zones. 133
Table 3-46: Metrics that are rated in VEGRAI 4 (with modification). 133
Table 3-47: Generic riparian zone indicators that are frequently used to determine environmental flows. 135
Table 3-48: General responses to flow by generic indicators. 136
Table 3-49: General guideline of criteria to consider for flood determination. 138
Table 3-50: High and low flow requirements for riparian vegetation at the Crocodile River site X24F Crocodile. 139
Table 3-51: Derived CPT from flow requirements for the Crocodile River site X24F Crocodile for high flows (VEG_ECO_DEP_HF) and low flows (VEG_ECO_DEP_LF). 140
Table 3-52: PES score and category with the main reasons for the score for the Nels River (X22F NELS). 142
Table 3-53: Intensity and extent of impacts on riparian vegetation at the Nels River (X22F NELS). 142
Table 3-54: Activation discharge measurements (m^3/s) for indicator species / guilds at the Nels River site (X22F NELS). 143
Table 3-55: PES score and category with the main reasons for the score for the Crocodile River (X22F CROC). 144
Table 3-56: Intensity and extent of impacts on riparian vegetation at the Crocodile River (X22F CROC). 145
Table 3-57: Activation discharge measurements (m^3/s) for indicator species / guilds at the Crocodile River (X22F CROC). 146
Table 3-58: PES score and category with the main reasons for the score for the Elands River (X21K ELANDS). 148
Table 3-59: Intensity and extent of impacts on riparian vegetation at the Elands River (X21K ELANDS). 148
Table 3-60: Activation discharge measurements (m^3/s) for indicator species / guilds at the Elands River site (X21K ELANDS). 149
Table 3-61: PES score and category with the main reasons for the score for the Elands River (X21E ELANDS). 151
Table 3-62: Intensity and extent of impacts on riparian vegetation at the Elands River (X21E ELANDS). 152
Table 3-63: Activation discharge measurements (m^3/s) for indicator species / guilds at the Elands River along cross-section 1 (X21E ELANDS). 152
Table 3-64: Activation discharge measurements (m^3/s) for indicator species / guilds at the Elands River along cross-section 2 (X21E ELANDS). 153
Table 3-65: Activation discharge measurements (m^3/s) for indicator species / guilds at the Elands River along cross-section 3 (X21E ELANDS). 154
Table 3-66: PES score and category with the main reasons for the score for the Noordkaap River (X23B NOORDKAAP). 156

Table 3-67: Intensity and extent of impacts on riparian vegetation at the Noordkaap River (X23B NOORDKAAP). 156
Table 3-68: Activation discharge measurements (m^3/s) for indicator species / guilds at the Noordkaap River (X23B NOORDKAAP). 157
Table 3-69: PES score and category with the main reasons for the score for the Suidkaap River (X23F SUIDKAAP). 159
Table 3-70: Intensity and extent of impacts on riparian vegetation at the Suidkaap River X23F SUIDKAAP). 159
Table 3-71: Activation discharge measurements (m^3/s) for indicator species / guilds at the Suidkaap River (X23F SUIDKAAP). 160
Table 3-72: PES score and category with the main reasons for the score for the Queens River (X23E QUEENS). 161
Table 3-73: Intensity and extent of impacts on riparian vegetation at the Queens River (X23E QUEENS). 162
Table 3-74: Activation discharge measurements (m^3/s) for indicator species / guilds at the Queens River (X23E QUEENS). 162
Table 3-75: PES score and category with the main reasons for the score for the Gladdespruit River (X11K GLADDESPRUIT). 164
Table 3-76: Intensity and extent of impacts on riparian vegetation at the Gladdespruit River (X11K GLADDESPRUIT). 165
Table 3-77: Activation discharge measurements (m^3/s) for indicator species / guilds at the Gladdespruit River (X 11K GLADDESPRUIT). 165
Table 3-78: PES score and category with the main reasons for the score for the Kaap River (X23G KAAP). 167
Table 3-79: Intensity and extent of impacts on riparian vegetation at the Kaap River (X23G KAAP). 168
Table 3-80: Activation discharge measurements (m^3/s) for indicator species / guilds at the Kaap River at Honeybird cross-section 1 (X23G KAAP). 168
Table 3-81: Activation discharge measurements (m^3/s) for indicator species / guilds at the Kaap River at Honeybird cross-section 2 (X23G KAAP). 169
Table 3-82: Activation discharge measurements (m^3/s) for indicator species / guilds at the Kaap River at Honeybird cross-section 3 (X23G KAAP). 169
Table 3-83: PES score and category with the main reasons for the score for the Sabie River (X31A SABIE). 171
Table 3-84: Intensity and extent of impacts on riparian vegetation at the Sabie River (X31A SABIE). 172
Table 3-85: Activation discharge measurements (m^3/s) for indicator species / guilds at the Sabie River (X31A SABIE). 173
Table 3-86: PES score and category with the main reasons for the score for the Sabie River (X31M SABIE). 174
Table 3-87: Intensity and extent of impacts on riparian vegetation at the Sabie River (X31M SABIE). 175
Table 3-88: Activation discharge measurements (m^3/s) for indicator species / guilds at the Sabie River site (X31M SABIE). 175

Table 3-89: PES score and category with the main reasons for the score for the Sabie River (X33B SABIE). 177
Table 3-90: Intensity and extent of impacts on riparian vegetation at the Sabie River (X33B SABIE). 177
Table 3-91: Activation discharge measurements (m^3/s) for indicator species / guilds at the Lower Sabie, cross-section 1 (X33B SABIE). 178
Table 3-92: Activation discharge measurements (m^3/s) for indicator species / guilds at the Lower Sabie, cross-section 2 (X33B SABIE). 178
Table 3-93: Activation discharge measurements (m^3/s) for indicator species / guilds at the Lower Sabie, cross-section 3 (X33B SABIE). 179
Table 3-94: PES score and category with the main reasons for the score for the Lomati River (X14H LOMATI). 181
Table 3-95: Intensity and extent of impacts on riparian vegetation at the Lomati River (X14H LOMATI). 181
Table 3-96: Activation discharge measurements (m^3/s) for indicator species / guilds at the Lomati River (X14H LOMATI). 182
Table 3-97: PES score and category with the main reasons for the score for the Komati River (X13K KOMATI). 183
Table 3-98: Intensity and extent of impacts on riparian vegetation at the Komati River (X13K KOMATI). 184
Table 3-99: PES score and category with the main reasons for the score for the Crocodile River (X24F CROCODILE). 186
Table 3-100: Intensity and extent of impacts on riparian vegetation at the Crocodile River (X24F CROCODILE). 186
Table 3-101: Activation discharge measurements (m^3/s) for indicator species / guilds at the Crocodile River site (X24F CROCODILE). 187
Table 3-102: PES score and category with the main reasons for the score the Komati River ((KOMATI in MOZ above Sabie confluence). 188
Table 3-103: Intensity and extent of impacts on riparian vegetation at the Komati River ((KOMATI in MOZ above Sabie confluence). 189
Table 3-104: Activation discharge measurements (m^3/s) for indicator species / guilds at the Komati River ((KOMATI in MOZ above Sabie confluence). 189
Table 3-105: PES score and category with the main reasons for the score for the Sabie River (SABIE in MOZAMBIQUE). 191
Table 3-106: Intensity and extent of impacts on riparian vegetation at the Sabie River (SABIE in MOZAMBIQUE). 191
Table 3-107: Activation discharge measurements (m^3/s) for indicator species / guilds at the Sabie River (SABIE in MOZAMBIQUE). 192
Table 3-108: PES score and category with the main reasons for the score for the Komati River (river section within floodplain). 193
Table 3-109: Intensity and extent of impacts on riparian vegetation at the Komati River (river section within floodplain). 193
Table 3-110: Activation discharge measurements (m^3/s) for indicator species / guilds at the Komati River (river section within floodplain). 194

Table 3-111: High and low flow requirements for riparian vegetation at the X40B Uanetza River site. 195

Table 3-112: High and low flow requirements for riparian vegetation at the X40D Massintonto site. _ 195

Table 3-113: High and low flow requirements for riparian vegetation at sites within the Sabie catchment. ______ 196

Table 3-114: High and low flow requirements for riparian vegetation at sites within the Komati catchment. ______ 199

Table 3-115: High and low flow requirements for riparian vegetation at the Y40A Incomati site. ____ 206

Table 3-116: Integrated freshet/ flood requirements as included in DRM for e-flow site. __________ 221

Table 3-117: E-flow requirement summary for the sites considered in the study. ________________ 225

Table 3-118: Summary of the present ecological state for biological components considered in the study aligned to the target ecological state for each component using A-F ecological categories where A = Natural, B= largely Natural, C = moderate modified, D = largely modified but still sustainable and F = critically modified and unsustainable. ______ 227

Table 3-119: Sensitivity of findings for the FISH-ECO-ENDPOINT for the natural, present, e-flow and drought scenarios. ______ 298

Table 4-1: The target ecological category for the biophysical nodes within the Kaap River Catchment and Resource Quality Objectives for the habitat and biota of the Kaap River biophysical node (DWS, 2016) ______ 313

Table 4-2: Resource Quality Objectives for water quality (ecological and user) for the Kaap River biophysical node (DWS, 2016) ______ 314

Table 4-3: Key hydrological Resource Quality Objectives for the Kaap River biophysical node (DWS, 2016) ______ 314

Table 4-4: Name of major water resource users known to occur in the study area and considered in the study.______ 316

Table 8-1: Summary of the name and description of the six ecological categories used in the Ecoclassification procedure for the Water quality, Habitat, Fish, Invertebrates and Ecostatus (Kleynhans & Louw, 2007). ______ 408

Table 8-2: Water quality variables assessed during the study. ______ 409

Table 8-3: In situ water quality results for all sites assessed during the high flow survey, October 2021. ______ 412

Table 8-4: Macroinvertebrate species collected during the 2021 October high flow survey ________ 419

Table 8-5: Biotope ratings for all sites sampled during the 2021 October high flow survey_________ 422

Table 8-6: Historical SASS data from the River Health Program database for sites sampled in the Kaap River catchment between 1993-2010 ______ 423

Table 8-7: Table of fishes expected to occur in the Kaap River including resident and potential migratory species associated with the Crocodile River (Source Scott et al., 2006). ______ 425

Table 8-8: Table of the fish species collected in the study and the results of the FRAI assessment including the adjusted scores with classes. ______ 427

List of Figures

Figure ES-1: The Incomati Basin with Integrated Units of Analysis, management classes, major rivers and sampling sites selected for the risk assessment study. v

Figure ES-2: Relative risk scores to FISH-ECO-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed. ix

Figure ES-3: Relative risk scores to INV-ECO-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed. x

FigureES-4: Relative risk scores to VEG-ECO-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed. xi

Figure 1-1: Schematic diagram of the socio-ecological system of a Southern African river similar to what will be considered in the study 1

Figure 2-1: The PROBFLO framework including the 10 procedural steps that were implemented in the Incomati Basin study 6

Figure 2-2: Example of a Bayesian network with green nodes representing input environmental variable information related to the exposure of the system by multiple stressors; yellow nodes integrate input information to represent the exposure of the large system; the pink node represents the potential for the activity to occur in a Risk Region that represents the effects part of the risk model and the blue node represents the endpoint. 8

Figure 2-3: Current condition evaluation including characterization of physico-chemical dynamics of ecosystem for holistic e-flow assessment associated with each reach of the system considered. 9

Figure 2-4: Indicator species, populations and community responses to drivers representing flow-ecosystem relationships for holistic e-flow determination. Note: flow-ecosystem stacked area graphs include ideal or pristine, sustainable, or suitable, threshold of potential concern and unsustainable or unsuitable conditions in the graphs. 10

Figure 2-5: Flow-ecosystem relationships for indicators provided to the hydrologist as requirements for indicators to establish preliminary (indicator-based) e-flow scenario. 12

Figure 2-6: Use of flow-ecosystem relationships and non-flow ecosystem relationships to establish Bayesian Network probabilistic models for reach/multiple-reaches of ecosystems represented through connected models for holistic e-flow determination. 13

Figure 2-7: Bayesian Networks applied to determine probable risk of multiple flow and non-flow stressors to model endpoints that represent the ecosystem in an acceptable condition. Relative risk of natural, present day and preliminary (indicator-based) e-flow scenarios evaluated. 14

Figure 2-8: Bayesian Networks evaluation of risk of multiple stressors to preliminary (indicator-based) e-flow requirements and revise to establish "integrated, holistic" e-flow requirements. This adaptive process can be applied through multiple iterations to result in a suitable "integrated, holistic" e-flow for each reach which is also integrated/synchronised between sites/reaches. 15

Figure 3-1: Proposed classes for the whole Incomati Basin based on the vision 19

Figure 3-2: The main rivers and tributaries of the Incomati River Basin in southern Africa. The different colours are an indication of the river orders in the Basin, the colour green being the lowest river order and red the highest river order. 22

Figure 3-3: Classification and target ecological category for integrated units of analysis within the Incomati Basin, South Africa. From National Water Act (36/1998): Classes of Water Resources and Resource Quality objectives for the Catchments of the Inkomati. Act no 1616 of 2016. 25

Figure 3-4: Ratings of water quality modification that occur in the Incomati Basin 27

Figure 3-5: The different environmental water requirement sites, gauging weirs and dams in the Incomati River Basin South Africa. 28

Figure 3-6: Map of the Incomati Basin showing the different geozones. 29

Figure 3-7: The number of Red List Fish species for the different river systems in the Incomati-Basin. 31

Figure 3-8: Gauging weirs and large dams within the Incomati basin (O'Brien et al., 2019). 32

Figure 3-9: Map of the sub-basins and risk regions for the Incomati Basin risk assessment study 37

Figure 3-10: The Incomati Basin with Integrated Units of Analysis, management classes, major rivers and sampling sites selected for the risk assessment study. 41

Figure 3-11: Conceptual model of the socio-ecological system for the Incomati Basin 42

Figure 3-12: Conceptual model of the socio-ecological system for the Incomati Basin. (A. supporting services, B. provisioning services, C. regulatory services and D. cultural services 43

Figure 3-13: Maintain fish communities extract of the conceptual model 44

Figure 3-14: Bayesian network developed using Netica software for the Incomati Basin. (A: Supporting services, B: Provisioning Services, C: Regulatory services, D: Cultural services) Green nodes represent input environmental variable information related to the exposure of the system by multiple stressors. Yellow nodes integrate input information to represent the exposure of the large system. The pink node represents the potential for subsistence fishermen to occur in a Risk Region that represents the effects part of the risk model. The blue node represents the endpoint. 46

Figure 3-15: Bootstrap regression (501 replicates) applied to a sample SSD and 95% certainty for HC1 and 5, 25 and 50% point-wise percentiles for HC5 were calculated through bootstrap regression with data superimposed (closed circles). Data are acute toxicity effect concentration (LC50) endpoints for copper, n=25, extracted from the aquatic toxicity information retrieval (ECOTOX) database. 52

Figure 3-16: Depth-velocity classes of hydraulic habitats for fish. Figure copied from Birkhead (2010). 68

Figure 3-17: The A) Depth and B) Velocity ranges from different habitats samples where fish species were collected in the Uanetza Catchment. 89

Figure 3-18: The depth ranges from different habitats where fish were collected in the Massintonto Catchment. 92

Figure 3-19: The A) Depth and B) Velocity ranges from different habitats where fish species in the Sabie Catchment were collected. 96

Figure 3-20: The A) Depth and B) Velocity ranges from different habitats where fish species in the Crocodile Catchment were collected. 102

Figure 3-21: The A) Depth and B) Velocity ranges from different habitats where fish species in the Komati Catchment were collected. 107

Figure 3-22: The A) Depth and B) Velocity ranges from different habitats where fish species in the Incomati Catchment were collected. 110

Figure 3-23: Redundancy analysis biplot based on the fish communities among the different main river catchments for all the sampling efforts. A total of 70.3% of the total variation were presented in this analysis with 52% explained on axis 1 and 18.3% explained on axis 2. 112

Figure 3-24: Redundancy analysis biplot based on the Intra-river catchment analyses for each of the regions in the main river catchments for all sampling efforts and fish communities. A total of 42.2% of the total variation were presented in this analysis with 25.1% explained on axis 1 and 16.1% explained on axis 2. 113

Figure 3-25: Redundancy analysis biplot based on the Velocity-Depth analyses for all sampling efforts and fish communities. A total of 83% of the total variation were presented in this analysis with 55.2% explained on axis 1 and 24.8% explained on axis 2. 114

Figure 3-26: Redundancy analysis biplot based on the Water quality analyses for all sampling efforts and fish communities. A total of 85.7% of the total variation were presented in this analysis with 48.1% explained on axis 1 and 37.6% explained on axis 2. 115

Figure 3-27: Redundancy analysis biplot based on the Substrate diversity analyses for all sampling efforts and fish communities. A total of 63.9% of the total variation were presented in this analysis with 43.5% explained on axis 1 and 20.4% explained on axis 2. A) Illustrate associations between fish species, river region and substrate diversity, B) illustrate association between fish species and substrate diversity. 115

Figure 3-28: Redundancy analysis biplot based on the Cover features analyses for all sampling efforts and fish communities. A total of 63.9% of the total variation were presented in this analysis with 43.5% explained on axis 1 and 20.4% explained on axis 2. 116

Figure 3-29: Survey setup – Leica Tcr403 power total station on tripod 131

Figure 3-30: Example of cross-section profile with elevation 132

Figure 3-31: Site photographs (left; looking US-top and downstream-bottom) and an indication of site placement on satellite imagery (right; Bing ©) for the Nels River (X22F NELS). 141

Figure 3-32: Site photographs (left; looking US-top and downstream-bottom) and an indication of site placement on satellite imagery (right; Bing ©) for the Crocodile River (X22F CROC). 144

Figure 3-33: Site photographs (left; looking US-top and downstream-bottom) and an indication of site placement on satellite imagery (right; Bing ©) for the Elands River (X21K ELANDS). 147

Figure 3-34: Site photographs (left; looking US-top and downstream-bottom) and an indication of site placement on satellite imagery (right; Bing ©) for the Elands River (X21E ELANDS). 151

Figure 3-35: Site photographs (left; looking US-top and downstream-bottom) and an indication of site placement on satellite imagery (right; Bing ©) for the Noordkaap River (X23B NOORDKAAP). 155

Figure 3-36: Site photographs (left; looking across the channel) and an indication of site placement on satellite imagery (right; Bing ©) for the Suidkaap River (X23F SUIDKAAP). 158

Figure 3-37: Site photographs (left; looking US) and an indication of site placement on satellite imagery (right; Bing ©) for the Queens River (X23E QUEENS). 161

Figure 3-38: Site photographs (left; looking across the channel) and an indication of site placement on satellite imagery (right; Bing ©) for the Gladdespruit River (X11K GLADDESPRUIT). 164

Figure 3-39: Site photographs (left; looking US-top and downstream-bottom) and an indication of site placement on satellite imagery (right; Bing ©) for the Kaap River (X23G KAAP). 167

Figure 3-40: Site photographs (left; looking US-top and downstream-bottom) and an indication of site placement on satellite imagery (right; Bing ©) for the Sabie River (X31A SABIE). 171

Figure 3-41: Site photographs (left; looking US-top and downstream-bottom) and an indication of site placement on satellite imagery (right; Bing ©) for the Sabie River (X31M SABIE). 174

Figure 3-42: Site photographs (left; looking across the channel) and an indication of site placement on satellite imagery (right; Bing ©) for the Sabie River (X33B SABIE). 176
Figure 3-43: Site photographs (left; looking US-top and downstream-bottom) and an indication of site placement on satellite imagery (right; Bing ©) for the Lomati River (X14H LOMATI). 180
Figure 3-44: Site photographs (left; looking US-top and downstream-bottom) and an indication of site placement on satellite imagery (right; Bing ©) for the Komati River (X13K KOMATI). 183
Figure 3-45: Site photographs (left; looking US-top and downstream-bottom) and an indication of site placement on satellite imagery (right; Bing ©) for the Crocodile River (X24F CROCODILE). 185
Figure 3-46: Site photographs (left; looking US-top and downstream-bottom) and an indication of site placement on satellite imagery (right; Bing ©) for the Komati River ((KOMATI in MOZ above Sabie confluence). 188
Figure 3-47: Site photographs (left; looking US-top and downstream-bottom) and an indication of site placement on satellite imagery (right; Bing ©) for the Sabie River (SABIE in MOZAMBIQUE). 190
Figure 3-48: Site photographs (left; looking US-top and downstream-bottom) and an indication of site placement on satellite imagery (right; Bing ©) for the Komati River (river section within floodplain). .. 193
Figure 3-49: Queens River hiking trail site photograph 212
Figure 3-50: Fibre harvested at the Incomati estuary for house building and handicraft. 217
Figure 3-51: The medium and high relative risk scores for the FISH-ECO-END endpoint for the Uanetza catchment for each scenario (Natural, Present, E-Flow and Drought). 231
Figure 3-52: The medium and high relative risk scores for the FISH-ECO-END endpoint for the Massintonto catchment for each scenario (Natural, Present, E-Flow and Drought). 231
Figure 3-53: The medium and high relative risk scores for the FISH-ECO-END endpoint for the Sabie catchment for each scenario (Natural, Present, E-Flow and Drought). 232
Figure 3-54: The medium and high relative risk scores for the FISH-ECO-END endpoint for the Crocodile catchment for each scenario (Natural, Present, E-Flow and Drought). 233
Figure 3-55: The medium and high relative risk scores for the FISH-ECO-END endpoint for the Komati catchment for each scenario (Natural, Present, E-Flow and Drought). 234
Figure 3-56: The medium and high relative risk scores for the FISH-ECO-END endpoint for the Incomati catchment for each scenario (Natural, Present, E-Flow and Drought). 234
Figure 3-57: The high relative risk scores to FISH-ECO-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought). 235
Figure 3-58: The medium and high relative risk scores for the INV-ECO-END endpoint for the Uanetza catchment for each scenario (Natural, Present, E-Flow and Drought). 236
Figure 3-59: The medium and high relative risk scores for the INV-ECO-END endpoint for the Massintonto catchment for each scenario (Natural, Present, E-Flow and Drought). 236
Figure 3-60: The medium and high relative risk scores for the INV-ECO-END endpoint for the Sabie catchment for each scenario (Natural, Present, E-Flow and Drought). 237
Figure 3-61: The medium and high relative risk scores for the INV-ECO-END endpoint for the Crocodile catchment for each scenario (Natural, Present, E-Flow and Drought). 238
Figure 3-62: The medium and high relative risk scores for the INV-ECO-END endpoint for the Komati catchment for each scenario (Natural, Present, E-Flow and Drought). 239
Figure 3-63: The medium and high relative risk scores for the INV-ECO-END endpoint for the Incomati catchment for each scenario (Natural, Present, E-Flow and Drought). 239

Figure 3-64: The high relative risk scores to INV-ECO-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought). 240
Figure 3-65: The medium and high relative risk scores for the VEG-ECO-END endpoint for the Uanetza catchment for each scenario (Natural, Present, E-Flow and Drought). 241
Figure 3-66: The medium and high relative risk scores for the VEG-ECO-END endpoint for the Massintonto catchment for each scenario (Natural, Present, E-Flow and Drought). 241
Figure 3-67: The medium and high relative risk scores for the VEG-ECO-END endpoint for the Sabie catchment for each scenario (Natural, Present, E-Flow and Drought). 242
Figure 3-68: The medium and high relative risk scores for the VEG-ECO-END endpoint for the Crocodile catchment for each scenario (Natural, Present, E-Flow and Drought). 243
Figure 3-69: The medium and high relative risk scores for the VEG-ECO-END endpoint for the Komati catchment for each scenario (Natural, Present, E-Flow and Drought). 244
Figure 3-70: The medium and high relative risk scores for the VEG-ECO-END endpoint for the Incomati catchment for each scenario (Natural, Present, E-Flow and Drought). 244
Figure 3-71: The high relative risk scores to VEG-ECO-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought). 245
Figure 3-72: The medium and high relative risk scores for the SUB-FISH-END endpoint for the Uanetza catchment for each scenario (Natural, Present, E-Flow and Drought). 247
Figure 3-73: The medium and high relative risk scores for the SUB-FISH-END endpoint for the Massintonto catchment for each scenario (Natural, Present, E-Flow and Drought). 247
Figure 3-74: The medium and high relative risk scores for the SUB-FISH-END endpoint for the Sabi catchment for each scenario (Natural, Present, E-Flow and Drought). 248
Figure 3-75: The medium and high relative risk scores for the SUB-FISH-END endpoint for the Crocodile catchment for each scenario (Natural, Present, E-Flow and Drought). 249
Figure 3-76: The medium and high relative risk scores for the SUB-FISH-END endpoint for the Komati catchment for each scenario (Natural, Present, E-Flow and Drought). 250
Figure 3-77: The medium and high relative risk scores for the SUB-FISH-END endpoint for the Incomati catchment for each scenario (Natural, Present, E-Flow and Drought). 250
Figure 3-78: The high relative risk scores to SUB-FISH-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought). 251
Figure 3-79: The medium and high relative risk scores for the SUB-VEG-END endpoint for the Uanetza catchment for each scenario (Natural, Present, E-Flow and Drought). 252
Figure 3-80: The medium and high relative risk scores for the SUB-VEG-END endpoint for the Massintonto catchment for each scenario (Natural, Present, E-Flow and Drought). 252
Figure 3-81: The medium and high relative risk scores for the SUB-VEG-END endpoint for the Sabie catchment for each scenario (Natural, Present, E-Flow and Drought). 253
Figure 3-82: The medium and high relative risk scores for the SUB-VEG-END endpoint for the Crocodile catchment for each scenario (Natural, Present, E-Flow and Drought). 254
Figure 3-83: The medium and high relative risk scores for the SUB-VEG-END endpoint for the Komati catchment for each scenario (Natural, Present, E-Flow and Drought). 255
Figure 3-84: The medium and high relative risk scores for the SUB-VEG-END endpoint for the Incomati catchment for each scenario (Natural, Present, E-Flow and Drought). 255

Figure 3-85: The high relative risk scores to SUB-VEG-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought). 256
Figure 3-86: The medium and high relative risk scores for the LIV-VEG-END endpoint for the Uanetza catchment for each scenario (Natural, Present, E-Flow and Drought). 257
Figure 3-87: The medium and high relative risk scores for the LIV-VEG-END endpoint for the Massintonto catchment for each scenario (Natural, Present, E-Flow and Drought). 257
Figure 3-88: The medium and high relative risk scores for the LIV-VEG-END endpoint for the Sabie catchment for each scenario (Natural, Present, E-Flow and Drought). 258
Figure 3-89: The medium and high relative risk scores for the LIV-VEG-END endpoint for the Crocodile catchment for each scenario (Natural, Present, E-Flow and Drought). 259
Figure 3-90: The medium and high relative risk scores for the LIV-VEG-END endpoint for the Komati catchment for each scenario (Natural, Present, E-Flow and Drought). 260
Figure 3-91: The medium and high relative risk scores for the LIV-VEG-END endpoint for the Incomati catchment for each scenario (Natural, Present, E-Flow and Drought). 260
Figure 3-92: The high relative risk scores to LIV-VEG-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought) 261
Figure 3-93: The medium and high relative risk scores for the DOM-WAT-END endpoint for the Uanetza catchment for each scenario (Natural, Present, E-Flow and Drought). 262
Figure 3-94: The medium and high relative risk scores for the DOM-WAT-END endpoint for the Massintonto catchment for each scenario (Natural, Present, E-Flow and Drought). 262
Figure 3-95: The medium and high relative risk scores for the DOM-WAT-END endpoint for the Sabie catchment for each scenario (Natural, Present, E-Flow and Drought). 263
Figure 3-96: The medium and high relative risk scores for the DOM-WAT-END endpoint for the Crocodile catchment for each scenario (Natural, Present, E-Flow and Drought). 264
Figure 3-97: The medium and high relative risk scores for the DOM-WAT-END endpoint for the Komati catchment for each scenario (Natural, Present, E-Flow and Drought). 265
Figure 3-98: The medium and high relative risk scores for the DOM-WAT-END endpoint for the Incomati catchment for each scenario (Natural, Present, E-Flow and Drought). 265
Figure 3-99: The high relative risk scores to DOM-WAT-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought). 266
Figure 3-100: The medium and high relative risk scores for the FLO-ATT-END endpoint for the Uanetza catchment for each scenario (Natural, Present, E-Flow and Drought). 267
Figure 3-101: The medium and high relative risk scores for the FLO-ATT-END endpoint for the Massintonto catchment for each scenario (Natural, Present, E-Flow and Drought). 267
Figure 3-102: The medium and high relative risk scores for the FLO-ATT-END endpoint for the Sabie catchment for each scenario (Natural, Present, E-Flow and Drought). 268
Figure 3-103: The medium and high relative risk scores for the FLO-ATT-END endpoint for the Crocodile catchment for each scenario (Natural, Present, E-Flow and Drought). 269
Figure 3-104: The medium and high relative risk scores for the FLO-ATT-END endpoint for the Komati catchment for each scenario (Natural, Present, E-Flow and Drought). 270
Figure 3-105: The medium and high relative risk scores for the FLO-ATT-END endpoint for the Incomati catchment for each scenario (Natural, Present, E-Flow and Drought). 270

Figure 3-106: The high relative risk scores to FLO-ATT-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought). 271
Figure 3-107: The medium and high relative risk scores for the RIV-ASS-END endpoint for the Uanetza catchment for each scenario (Natural, Present, E-Flow and Drought)........ 272
Figure 3-108: The medium and high relative risk scores for the RIV-ASS-END endpoint for the Massintonto catchment for each scenario (Natural, Present, E-Flow and Drought). 272
Figure 3-109: The medium and high relative risk scores for the RIV-ASS-END endpoint for the Sabie catchment for each scenario (Natural, Present, E-Flow and Drought)........ 273
Figure 3-110: The medium and high relative risk scores for the RIV-ASS-END endpoint for the Crocodile catchment for each scenario (Natural, Present, E-Flow and Drought)........ 274
Figure 3-111: The medium and high relative risk scores for the RIV-ASS-END endpoint for the Komati catchment for each scenario (Natural, Present, E-Flow and Drought)........ 275
Figure 3-112: The medium and high relative risk scores for the RIV-ASS-END endpoint for the Incomati catchment for each scenario (Natural, Present, E-Flow and Drought)........ 275
Figure 3-113: The high relative risk scores to RIV-ASS-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought). 276
Figure 3-114: The medium and high relative risk scores for the WAT-DIS-END endpoint for the Uanetza catchment for each scenario (Natural, Present, E-Flow and Drought)........ 277
Figure 3-115: The medium and high relative risk scores for the WAT-DIS-END endpoint for the Massintonto catchment for each scenario (Natural, Present, E-Flow and Drought). 277
Figure 3-116: The medium and high relative risk scores for the WAT-DIS-END endpoint for the Sabie catchment for each scenario (Natural, Present, E-Flow and Drought)........ 278
Figure 3-117: The medium and high relative risk scores for the WAT-DIS-END endpoint for the Crocodile catchment for each scenario (Natural, Present, E-Flow and Drought)........ 279
Figure 3-118: The medium and high relative risk scores for the WAT-DIS-END endpoint for the Komati catchment for each scenario (Natural, Present, E-Flow and Drought)........ 280
Figure 3-119: The medium and high relative risk scores for the WAT-DIS-END endpoint for the Incomati catchment for each scenario (Natural, Present, E-Flow and Drought)........ 280
Figure 3-120: The high relative risk scores to WAT-DIS-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought). 281
Figure 3-121: The medium and high relative risk scores for the RES-RES-END endpoint for the Uanetza catchment for each scenario (Natural, Present, E-Flow and Drought)........ 282
Figure 3-122: The medium and high relative risk scores for the RES-RES-END endpoint for the Massintonto catchment for each scenario (Natural, Present, E-Flow and Drought). 282
Figure 3-123: The medium and high relative risk scores for the RES-RES-END endpoint for the Sabie catchment for each scenario (Natural, Present, E-Flow and Drought)........ 283
Figure 3-124: The medium and high relative risk scores for the RES-RES-END endpoint for the Crocodile catchment for each scenario (Natural, Present, E-Flow and Drought)........ 284
Figure 3-125: The medium and high relative risk scores for the RES-RES-END endpoint for the Komati catchment for each scenario (Natural, Present, E-Flow and Drought)........ 285
Figure 3-126: The medium and high relative risk scores for the RES-RES-END endpoint for the Incomati catchment for each scenario (Natural, Present, E-Flow and Drought)........ 285

Figure 3-127: The high relative risk scores to RES-RES-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought). 286
Figure 3-128: The medium and high relative risk scores for the REC-SPIR-END endpoint for the Uanetza catchment for each scenario (Natural, Present, E-Flow and Drought)..... 287
Figure 3-129: The medium and high relative risk scores for the REC-SPIR-END endpoint for the Massintonto catchment for each scenario (Natural, Present, E-Flow and Drought). 287
Figure 3-130: The medium and high relative risk scores for the REC-SPIR-END endpoint for the Sabie catchment for each scenario (Natural, Present, E-Flow and Drought)..... 288
Figure 3-131: The medium and high relative risk scores for the REC-SPIR-END endpoint for the Crocodile catchment for each scenario (Natural, Present, E-Flow and Drought)..... 289
Figure 3-132: The medium and high relative risk scores for the REC-SPIR-END endpoint for the Komati catchment for each scenario (Natural, Present, E-Flow and Drought)..... 290
Figure 3-133: The medium and high relative risk scores for the REC-SPIR-END endpoint for the Incomati catchment for each scenario (Natural, Present, E-Flow and Drought)..... 290
Figure 3-134: The high relative risk scores to REC-SPIR-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought). 291
Figure 3-135: The medium and high relative risk scores for the TOURISM-END endpoint for the Uanetza catchment for each scenario (Natural, Present, E-Flow and Drought)..... 292
Figure 3-136: The medium and high relative risk scores for the TOURISM-END endpoint for the Massintonto catchment for each scenario (Natural, Present, E-Flow and Drought). 292
Figure 3-137: The medium and high relative risk scores for the TOURISM-END endpoint for the Sabie catchment for each scenario (Natural, Present, E-Flow and Drought)..... 293
Figure 3-138: The medium and high relative risk scores for the TOURISM-END endpoint for the Crocodile catchment for each scenario (Natural, Present, E-Flow and Drought)..... 294
Figure 3-139: The medium and high relative risk scores for the TOURISM-END endpoint for the Komati catchment for each scenario (Natural, Present, E-Flow and Drought)..... 295
Figure 3-140: The medium and high relative risk scores for the TOURISM-END endpoint for the Incomati catchment for each scenario (Natural, Present, E-Flow and Drought)..... 295
Figure 3-141: The high relative risk scores to TOURISM-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought). 296
Figure 3-142: Relative risk scores to supporting services per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed..... 300
Figure 3-143: Relative risk scores to provisioning services per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed..... 302
Figure 3-144: Relative risk scores to regulatory services per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed..... 304

Figure 3-145: Relative risk scores to cultural services per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed. 306

Figure 4-1: Schematic diagram to show parts of the modified Bayesian Networks designed to model the risk of altered flows, water quality and habitat to a river ecosystem. Risk components included and causal risk exposure and effect relationships included. 308

Figure 4-2: Schematic diagram to show parts of the modified Bayesian Networks designed to model the risk of altered flows, water quality and habitat to a river ecosystem. Highlighted areas demonstrate add-ons to model drivers of potential changes in flows and habitats. 309

Figure 4-3: Schematic diagram to show parts of the modified Bayesian Networks designed to model the risk of altered flows, water quality and habitat to a river ecosystem. Highlighted areas demonstrate add-ons to model drivers of potential changes in water quality. 309

Figure 4-4: Schematic diagram to show parts of the modified Bayesian Networks designed to model the risk of altered flows, water quality and habitat to a river ecosystem. Highlighted areas demonstrate add-ons to model drivers of potential changes in water quality. All add-ons included. 310

Figure 4-5: The Kaap River sub-basin considered for the implementation of the adaptive risk management framework for the study. 311

Figure 4-6: Location and nature of the land use activities in the Kaap River sub-basin. 315

Figure 4-7: Outcomes of the present ecological state assessment of the Kaap River Catchment. Compare these results to the outcomes of the risk assessment (Figure 3-143). 317

Figure 4-8: Outcomes of the risk assessment framework to demonstrate the implementation of the tool in the Kaap River sub-basin. Compare with Figure 3-143. All risk results in “moderate risk rank” 317

Figure 4-9: Graph of the risk of sources to the Kaap River sub-basin ecosystem for the Noordkaap (X23B), Suidkaap (X23F), Queens River (X23R) and the Kaap River (X23G). 318

Figure 7-1: Relative risk scores to FISH-ECO-END for the Uanetza catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 334

Figure 7-2: Relative risk scores to FISH-ECO-END for the Massintonto catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 334

Figure 7-3: Relative risk scores to FISH-ECO-END for the Sabie catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 335

Figure 7-4: Relative risk scores to FISH-ECO-END for the Crocodile catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 336

Figure 7-5: Relative risk scores to FISH-ECO-END for the Komati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 337

Figure 7-6: Relative risk scores to FISH-ECO-END for the Incomati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 337

Figure 7-7: Relative risk scores to FISH-ECO-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed. 338

Figure 7-8: Relative risk scores to INV-ECO-END for the Uanetza catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 339

Figure 7-9: Relative risk scores to INV-ECO-END for the Massintonto catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 339

Figure 7-10: Relative risk scores to INV-ECO-END for the Sabie catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 340

Figure 7-11: Relative risk scores to INV-ECO-END for the Crocodile catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 341

Figure 7-12: Relative risk scores to INV-ECO-END for the Komati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 342

Figure 7-13: Relative risk scores to INV-ECO-END for the Incomati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 342

Figure 7-14: Relative risk scores to INV-ECO-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed. 343

Figure 7-15: Relative risk scores to VEG-ECO-END for the Uanetza catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 344

Figure 7-16: Relative risk scores to VEG-ECO-END for the Massintonto catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 344

Figure 7-17: Relative risk scores to VEG-ECO-END for the Sabie catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 345

Figure 7-18: Relative risk scores to VEG-ECO-END for the Crocodile catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 346

Figure 7-19: Relative risk scores to VEG-ECO-END for the Komati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 347

Figure 7-20: Relative risk scores to VEG-ECO-END for the Incomati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 347

Figure 7-21: Relative risk scores to VEG-ECO-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed. 348

Figure 7-22: Relative risk scores to SUB-FISH-END for the Uanetza catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 349

Figure 7-23: Relative risk scores to SUB-FISH-END for the Massintonto catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 349

Figure 7-24: Relative risk scores to SUB-FISH-END for the Sabie catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 350

Figure 7-25: Relative risk scores to SUB-FISH-END for the Crocodile catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 351

Figure 7-26: Relative risk scores to SUB-FISH-END for the Komati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 352

Figure 7-27: Relative risk scores to SUB-FISH-END for the Incomati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 352

Figure 7-28: Relative risk scores to SUB-FISH-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed....353

Figure 7-29: Relative risk scores to SUB-VEG-END for the Uanetza catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed....354

Figure 7-30: Relative risk scores to SUB-VEG-END for the Massintonto catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed....354

Figure 7-31: Relative risk scores to SUB-VEG-END for the Sabie catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed....355

Figure 7-32: Relative risk scores to SUB-VEG-END for the Crocodile catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed....356

Figure 7-33: Relative risk scores to SUB-VEG-END for the Komati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed....357

Figure 7-34: Relative risk scores to SUB-VEG-END for the Incomati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed....357

Figure 7-35: Relative risk scores to SUB-VEG-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed....358

Figure 7-36: Relative risk scores to LIV-VEG-END for the Uanetza catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed....359

Figure 7-37: Relative risk scores to LIV-VEG-END for the Massintonto catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed....359

Figure 7-38: Relative risk scores to LIV-VEG-END for the Sabie catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed....360

Figure 7-39: Relative risk scores to LIV-VEG-END for the Crocodile catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 361

Figure 7-40: Relative risk scores to LIV-VEG-END for the Komati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 362

Figure 7-41: Relative risk scores to LIV-VEG-END for the Incomati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 362

Figure 7-42: Relative risk scores to LIV-VEG-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 363

Figure 7-43: Relative risk scores to DOM-WAT-END for the Uanetza catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 364

Figure 7-44: Relative risk scores to DOM-WAT-END for the Massintonto catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 364

Figure 7-45: Relative risk scores to DOM-WAT-END for the Sabie catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 365

Figure 7-46: Relative risk scores to DOM-WAT-END for the Crocodile catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 366

Figure 7-47: Relative risk scores to DOM-WAT-END for the Komati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 367

Figure 7-48: Relative risk scores to DOM-WAT-END for the Incomati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 367

Figure 7-49: Relative risk scores to DOM-WAT-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed........ 368

Figure 7-50: Relative risk scores to FLO-ATT-END for the Uanetza catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 369

Figure 7-51: Relative risk scores to FLO-ATT-END for the Massintonto catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 369

Figure 7-52: Relative risk scores to FLO-ATT-END for the Sabie catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 370

Figure 7-53: Relative risk scores to FLO-ATT-END for the Crocodile catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 371

Figure 7-54: Relative risk scores to FLO-ATT-END for the Komati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 372

Figure 7-55: Relative risk scores to FLO-ATT-END for the Incomati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 372

Figure 7-56: Relative risk scores to FLO-ATT-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 373

Figure 7-57: Relative risk scores to RIV-ASS-END for the Uanetza catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 374

Figure 7-58: Relative risk scores to RIV-ASS-END for the Massintonto catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 374

Figure 7-59: Relative risk scores to RIV-ASS-END for the Sabie catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 375

Figure 7-60: Relative risk scores to RIV-ASS-END for the Crocodile catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 376

Figure 7-61: Relative risk scores to RIV-ASS-END for the Komati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed ... 377

Figure 7-62: Relative risk scores to RIV-ASS-END for the Incomati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed ... 377

Figure 7-63: Relative risk scores to RIV-ASS-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed ... 378

Figure 7-64: Relative risk scores to WAT-DIS-END for the Uanetza catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed ... 379

Figure 7-65: Relative risk scores to WAT-DIS-END for the Massintonto catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed ... 379

Figure 7-66: Relative risk scores to WAT-DIS-END for the Sabie catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed ... 380

Figure 7-67: Relative risk scores to WAT-DIS-END for the Crocodile catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed ... 381

Figure 7-68: Relative risk scores to WAT-DIS-END for the Komati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed ... 382

Figure 7-69: Relative risk scores to WAT-DIS-END for the Incomati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed ... 382

Figure 7-70: Relative risk scores to WAT-DIS-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed ... 383

Figure 7-71: Relative risk scores to RES-RES-END for the Uanetza catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed ... 384

Figure 7-72: Relative risk scores to RES-RES-END for the Massintonto catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 384

Figure 7-73: Relative risk scores to RES-RES-END for the Sabie catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 385

Figure 7-74: Relative risk scores to RES-RES-END for the Crocodile catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 386

Figure 7-75: Relative risk scores to RES-RES-END for the Komati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 387

Figure 7-76: Relative risk scores to RES-RES-END for the Incomati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 387

Figure 7-77: Relative risk scores to RES-RES-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 388

Figure 7-78: Relative risk scores to REC-SPIR-END for the Uanetza catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 389

Figure 7-79: Relative risk scores to REC-SPIR-END for the Massintonto catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 389

Figure 7-80: Relative risk scores to REC-SPIR-END for the Sabie catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 390

Figure 7-81: Relative risk scores to REC-SPIR-END for the Crocodile catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 391

Figure 7-82: Relative risk scores to REC-SPIR-END for the Komati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed 392

Figure 7-83: Relative risk scores to REC-SPIR-END for the Incomati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed ... 392

Figure 7-84: Relative risk scores to REC-SPIR-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed ... 393

Figure 7-85: Relative risk scores to TOURISM-END for the Uanetza catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed ... 394

Figure 7-86: Relative risk scores to TOURISM-END for the Massintonto catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed ... 394

Figure 7-87: Relative risk scores to TOURISM-END for the Sabie catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed ... 395

Figure 7-88: Relative risk scores to TOURISM-END for the Crocodile catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed ... 396

Figure 7-89: Relative risk scores to TOURISM-END for the Komati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed ... 397

Figure 7-90: Relative risk scores to TOURISM-END for the Incomati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed ... 397

Figure 7-91: Relative risk scores to TOURISM-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed ... 398

Figure 8-1: The NKAAP-ENOUS site on the Noordkaap River drone photo. ... 399

Figure 8-2: The NKAAP-CONSR site on the Noordkaap River with weir and downstream view ... 400

Figure 8-3: The NKAAP-CONFL site on the Noordkaap River with A) bank erosion and B) upstream view ... 401

Figure 8-4: The SKAAP-GLENT site on the Suidkaap River. ... 401

Figure 8-5: The SKAAP-R40RD site on the Suidkaap River with downstream view (Drone photo). ... 402

Figure 8-6: The QUEEN-SELAP site on the Queens Rivers with a top view. ... 403

Figure 8-7: The QUEEN-R40RD site on the Queens River with and downstream view ... 403

Figure 8-8: The SKAAP-UPWWT site on the Suidkaap River with A) upstream view and B) cross section 404
Figure 8-9: The SKAAP-DNWWT site on the Suidkaap River with upstream view. 405
Figure 8-10: The SKAAP-BMINE site on the Suidkaap River with A) downstream view and B) view from the bridge 405
Figure 8-11: The KAAPR-EURIK site on the Kaap River with A) downstream view and B) view of the bridge 406
Figure 8-12: The KAAPR-JOELK site from a top and downstream view. 406
Figure 8-13: The LOUWS-REVOL site on the Louws River with A) view of riparian vegetation downstream and B) upstream view 407
Figure 8-14:The KAAPR-UCROC site on the Kaap River with an upstream view from the bridge. 407
Figure 8-15: Example of the biological band for North Eastern Highlands – Upper (Dallas, 2007) 410
Figure 8-16: In situ water quality results for sites monitored bi-weekly from March to July 2021 with A) pH, B) Dissolved Oxygen (mg/L), C) Electrical conductivity (mS/cm), D) Temperature. 413
Figure 8-17: Trends in nutrients A) ammonium, B) nitrate, C) nitrite, D) phosphate from March 2021 to February 2022. 414
Figure 8-18: Trends in IUCMA data for total nitrates and nitrites from 2016 to 2022 414
Figure 8-19: Trends in IUCMA data for phosphates from 2016 to 2022 415
Figure 8-20: Trends in IUCMA data for ammonia from 2016 to 2022 415
Figure 8-21: Trends in A) chlorides and B) sulphates from March 2021 to February 2022. 416
Figure 8-22: Trends in IUCMA data for sulphates from 2016 to 2022 416
Figure 8-23: Trends in A) turbidity and B) alkalinity from March 2021 to February 2022 417
Figure 8-24: Trends in IUCMA data for total suspended solids from 2016 to 2022 417
Figure 8-25: Trends in IUCMA data for COD from 2016 to 2022 417

This page was intentionally left blank

1 INTRODUCTION

The University of Mpumalanga (UMP) has undertaken a study to establish a risk assessment framework to evaluate the effect of multiple stressors and the integrated sustainable management of the transboundary water resources of the Incomati Basin, southern Africa. The project was co-funded by the Water Research Commission (WRC) of South Africa, the Incomati-Usuthu Catchment Management Agency (IUCMA) and National Research Foundation (NRF) of South Africa and was undertaken in collaboration with stakeholders of the Incomati Basin in South African, Eswatini and Mozambique. This included scientists from UMP and North-West University (NWU) with collaborative activities from Eduardo Mondlane University (EMU) and stakeholders of the use and protection of the resources including the IUCMA, South African National Parks (SANPARKS) and Mpumalanga Parks and Tourism (MTPA).

The aim of the project is to establish a risk assessment framework to evaluate the effect of multiple stressors and contribute to the integrated sustainable management of the transboundary water resources of the Incomati Basin through the implementation of the following objectives.

1. Review available knowledge of the features and processes of water resources including ecological infrastructure, and multiple flow, water quality, habitat alerting and other anthropogenic stressors and natural environmental drivers affecting the wellbeing of resources in the Incomati Basin, southern Africa (Figure 1-1).
2. Develop a socio-ecological risk assessment framework for the water resources and communities of the Incomati Basin. This will represent the multiple stressors (flow, water quality, habitat, climate change and alien invasive species for example) and their synergistic effects on the wellbeing of the rivers and linked ecosystems (wetlands, floodplains, lakes and dams and estuary) and ecosystem services using the Relative Risk Assessment – Bayesian Network (RRA-BN) probability modelling approach.
3. Implement the risk assessment framework to update and integrate environmental flows and provide evidence based probabilistic water resources protection measures (synonymous with Resource Quality Objectives and/or Sustainable Development Goals Targets) for the Incomati Basin, southern Africa. Implementation will be tested in the Kaap River sub-basin as a case study.
4. Establish a risk-based monitoring and adaptive management framework for the protection and allocation of water resources and trade-off consideration in the Incomati Basin.

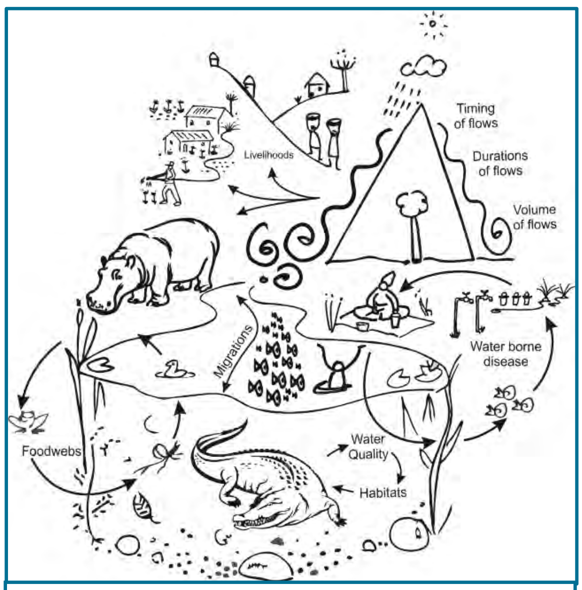


Figure 1-1: Schematic diagram of the socio-ecological system of a Southern African river similar to what will be considered in the study

The outcome of this study is a probabilistic risk framework that will dovetail with water resources management in the region including the Resource Directed Measures activities of the Department of Water and Sanitation (DWS) and IUCMA in South Africa. This innovative regional-scale probabilistic modelling approach will support policy development and implementation of sustainable water resource management requirements in the region and can be applied to other shared basins throughout the region.

1.1 Background

The socio-ecologically important water resources of the Incomati Catchment are being used excessively and their condition is still deteriorating (Dayaram *et al.*, 2018; SANBI 2018; O'Brien *et al.*, 2019). This is resulting in water stress in South Africa and Mozambique, affecting numerous vulnerable human communities (Hellegers *et al.*, 2009). Although Integrated Water Resource Management policies are in place, South African water law dominates the management and development activities in the basin, with limited transboundary collaboration with Eswatini and Mozambique.

Presently there are no environmental flow (e-flow) and non-flow basin scale management frameworks that support sustainable water resource use and protection. These frameworks can contribute to water resource protection measures, resource allocation in the context of protection requirements and a monitoring and adaptive management plan for sustainability (O'Brien *et al.*, 2019; O'Brien *et al.*, in press).

Risk assessment developments in Africa that provide an understanding of the socio-ecological consequences of multiple stressors, e-flows and non-flow variable requirements for water resources and support evidence-based trade-off and water allocation decisions will make a significant contribution to the sustainable management of this water resource (O'Brien *et al.*, 2019). Risk assessments approaches being developed in South Africa have been successful in other basins in Africa and these frameworks can uplift the vulnerable communities who depend on them and contribute to the protection of the ecosystems we rely on.

The water resources of the Incomati Catchment, southern Africa, are socio-ecologically important and support the livelihoods of > 2.5 million South Africans and > 1 million Mozambicans (Anderson, 2005; Rogers *et al.*, 2007; Schreiner *et al.*, 2010). The Incomati Basin is a biodiversity hotspot for the region with many intact ecosystems, primarily in the Kruger National Park (Jewitt and Görgens, 2000a; Jewitt and Görgens, 200b; Riddell *et al.*, 2014). The aquatic fauna of the basin includes endemic species and Congolese species attributed to historical connections between the Congo River and Limpopo River, and the Limpopo River and Incomati River that still connect during floods (Chikozho, 2005; Stankiewicz and De Wit, 2006). Many of these species that occurred in both the Limpopo and Incomati River catchments are now restricted to; and provided with refuge in the Incomati Basin alone (O'Brien *et al.*, 2019).

The ecosystems of the Incomati catchment in South Africa in particular are relatively well known (Van Wyk, 1996; Kotze *et al.*, 2006; Kleynhans and Louw, 2012; Diedericks *et al.*, 2013; Kleynhans *et al.*, 2013; Kotze *et al.*, 2013; O'Brien *et al.*, 2014). The ecosystems of the Incomati River in Mozambique have also received attention, but relatively less compared to those in South Africa (Diedericks *et al.*, 2013; LeMarie *et al.*, 2006 for example).

The knowledge of the ecological attributes of these ecosystems includes information on the ecosystem services that many vulnerable human communities depend on in the catchment. The provisioning, regulating, cultural and supporting services of the wetlands, rivers, lakes (and dams), aquifers and estuary are extensive and support many vulnerable communities, some of whom are totally dependent on these important services (De Lange *et al.*, 2010; Nel *et al.*, 2013). The rivers of the Incomati Catchment flow from the eastern edge of the Highveld, across the Great Southern African Escarpment which is the region's most important water source area (Nel *et al.*, 2013) from where the majority of the water in the basin originates. Numerous stressors threaten the wellbeing of these services and require adequate management methods to ensure that a sustainable balance between the use and protection of water resources in the basin is maintained (Dickens *et al.*, 2019).

Water resource use activities make a significant contribution to the economies of South Africa and Mozambique and vary across the basin resulting in multiple stressors. These include primarily extensive flow (Ramoelo *et al.*, 2007; Hellegers *et al.*, 2009), water quality (Du Plessis, 2019; Sawunyama and Slaughter, 2018; Williams *et al.*, 2010) and habitat alterations (Sawunyama, 2013) that are managed through regional water management legislation; and alien invasive species, disturbance to wildlife and climate variability stressors that are primarily governed through environmental management legislation. These stressors have been attributed to the deterioration of the habitat and ecosystems in the Incomati Basin (Dayaram *et al.*, 2018; SANBI 2018 for example) that require urgent attention to maintain social and ecological objectives established for the basin (Chikozho, 2005; Schreiner *et al.*, 2010; DWS 2016; DWS 2019) for sustainability (Dickens *et al.*, 2019).

South African legislation dominates sustainable water resource management of the basin and includes the implementation of the Resource Directed Measures of the National Water Act (108 of 1998) (Basson and Rossouw, 2003; Brown and Woodhouse, 2004; Colvin *et al.*, 2008; De Lange *et al.*, 2010; Denby *et al.*, 2016; Wilkinson *et al.*, 2015; DWS 2016; DWS 2019). In South Africa the DWS and IUCMA (Chibwe *et al.*, 2012; Rogers and Luton, 2016; Roux *et al.*, 2010) have been established to implement the National Water Act of South Africa (Act 108 of 1998) and are primary custodians of water resources management in South Africa and the Incomati-Usuthu Water Management Area respectively.

Relative to South Africa, water resource management in Mozambique and Eswatini is limited. In Mozambique, ARA-SUL implement the water resource management aspects of the Mozambique National Constitution (1990) and the Water Law (Law 16/91, of August 3, 1991). In Eswatini the ministry of Natural Resources and Energy through their Department of Water Affairs implement the Water Act of 2003.

Resource sharing and cooperative governance of flows in the transboundary basin has been established with many opportunities and constraints (Chikozho, 2005; Schreiner *et al.*, 2010; Mehta *et al.*, 2014). Global Sustainable Development Goals (SDG) have been established to contribute to the management of water resources on multiple spatial scales (Dickens *et al.*, 2019). New methods including Resource Quality Objective (RQO) approaches and supporting holistic water resource management frameworks have been established to manage transboundary water resources on multiple spatial scales (Dickens *et al.*, 2019; Lynch *et al.*, 2019; O'Brien *et al.*, 2019). These approaches have the ability to represent the spatial and temporal variability of ecosystems, and the dynamics of multiple stressors that are often synergistic, affecting numerous socio-ecological features of the resources that we care for. These scenario-based approaches can contribute to water resource allocation and protection measures, to evaluate trade-offs between the use and protection of resources and optimisation of service delivery and/or ecological infrastructure for the benefit of the resources and the people who depend on them.

This report presents an Ecological Risk Assessment-based framework (O'Brien and Wepener, 2012; O'Brien *et al.*, 2019; Vezi *et al.*, 2019), developed using the Relative Risk Model (RRM) and Bayesian Networks (BN) to support the holistic management of multiple stressors to socio-ecological features (or endpoints) of water resources in the Incomati Basin for the sustainable use and protection of our resources, and the livelihoods of our vulnerable communities. This was achieved by undertaking a collaborative study between the University of Mpumalanga, the Incomati-Usuthu Catchment Management Agency and South African National Parks, with Eswatini and Mozambique (Eduardo Montlane University) partners and at least five post-graduate students from the region. The three-phase study was undertaken in South Africa, Eswatini and Mozambique over a three year period.

This process involved multiple stakeholders and societal considerations (consider Anderson, 2005; Rogers *et al.*, 2007) and included institutional development through training workshops and post-graduate training of staff of stakeholders. This process will contribute to Human Capacity Development in the Water Sector and transformation of historical methods and redressing historical access to and use of resources, and result in new, innovative products and services including a transboundary framework for water resource management that will support sustainable development, ecological infrastructure and sustainable economic development (e.g. Macaringue, 2014) in the region.

The approach and outcomes of the study are present in this report under the following sections:

- Section 2: The PROBFLO approach – this section provides a detailed description of the ten procedural steps of the PROBFLO approach undertaken during the study.
- Section 3: Results – this section provides the results of Steps 1-7 of the PROBFLO procedural steps completed during the study. This includes:
    - The detailed results of the of extensive field assessments undertaken throughout the Incomati Basin in 2021-2023. These results describe the status quo of the ecosystem and the Present Ecological State (PES) in terms of the drivers of change (water quality and ecotoxicity, hydrology and hydraulics and geomorphology) and the biological responses to those changes (fish, aquatic macroinvertebrates and aquatic vegetation).
    - The outcomes of the e-flow determination for rivers within the Incomati Basin
    - The relative risk that changes in flow can potentially have on the ecosystem services provided by these rivers. This is based on four different flow scenarios, namely: natural flow (NAT), present day flow (PRES), e-flow (EFLOW) and drought conditions (DRGT).
- Section 4: Implementation – this section provides the outcomes of the Steps 8-10 that details the implementation of the risk framework in the Kaap catchment.
- Section 5: Conclusion – closing remarks of the outcome of the whole study.

Additional graphs displaying the results of the risk assessment are provided in an Annexure at the end of the report and additional supplementary information will be provided as Excel spreadsheets.

2 THE PROBFLO APPROACH

2.1 OVERVIEW

This section describes the holistic environmental flow (e-flow) determination and framework approach, PROBFLO, (O'Brien *et al.*, 2018) that was implemented during this study. PROBLFO combines Relative-Risk Modelling (RRM) and the use of Bayesian Networks (BNs) in a BN-RRM approach to:

- determine the flow requirements of selected indicator components of the ecosystems,
- evaluate the synergistic effects of e-flow scenarios to ensure they are suitable in a holistic context, and
- characterise and evaluate the relative risk of flow and non-flow stressors to socially and ecologically important water resources on regional scales to contribute to sustainable water resource management.

The PROBFLO approach is based on ten procedural (RRM) steps (Figure 2-1 – O'Brien *et al.*, 2018). Broadly, the procedural steps of the risk assessment include the establishment of a vision (step 1) for the water resources being evaluated which resulted in the selection of social endpoints associated with the maintenance of the livelihoods of local communities, and ecological endpoints that address biodiversity and ecosystem processes of the resources. Thereafter a literature review was undertaken for the study area and maps were established of water resources and associated ecosystem services (step 2). The study area was then divided spatially into geographical risk regions to represent the dynamics of the ecosystems and allow endpoints to be evaluated in a relative, spatially meaningful manner (step 3). In step 4, conceptual models that demonstrate the causal risk pathways from identified sources (including anthropogenic and natural activities/events) to stressors (water quality, flow and habitat modifications for example), socio-ecological receptors in multiple habitats to endpoints, were developed. A ranking scheme was established for the study to represent the condition of each variable of the study and risk to endpoints (step 5) and then the risk was calculated (step 6) using Microsoft ® Excel, NeticaTM to generate Bayesian Networks and integrated using Monte Carlo procedures undertaken with Oracle® Crystal BallTM software to randomise and integrate risk probabilities. Some important aspects of uncertainty testing were included in this assessment (step 7). This approach is optimised when integrated into an adaptive plan, framework or application. Causal risk pathways and/or relationships, and risk projections from the model can be tested and improved if additional evidence is obtained to test/validate the model (step 8). This step incorporates monitoring of the socio-ecological system of interest in an assessment (step 9). In this study the demonstration of how the approach can be further developed into a multiple stressor monitoring/management framework has been demonstrated in the Kaap River sub-catchment (sub-basin code X23). The last step of the approach is to communicate the outputs of the risk assessment and generate good practice recommendations for future sustainable management and risk mitigation (step 10). Steps 6 to 7 require further detail as they pertain to the use of the RRM and BN probability modelling.

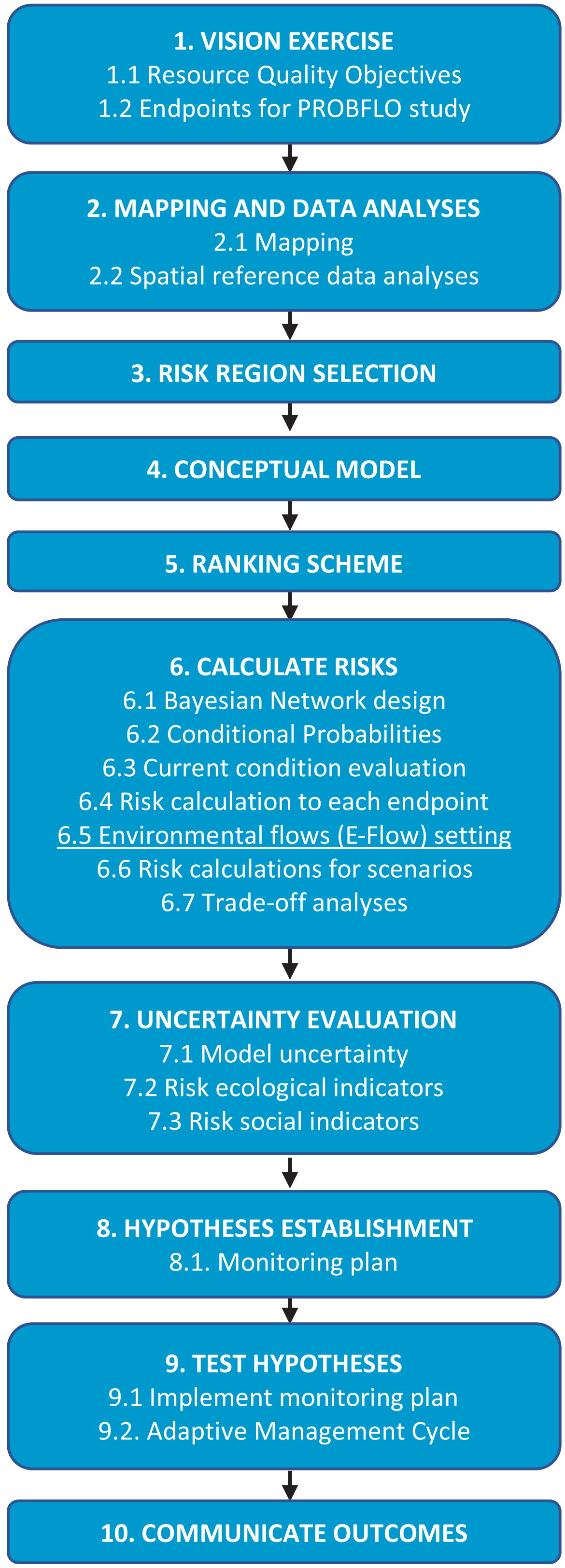


Figure 2-1: The PROBFLO framework including the 10 procedural steps that were implemented in the Incomati Basin study

2.2 STEP 6: CALCULATE RISK

2.2.1 Bayesian network design

Bayesian risk methods that evaluate the magnitudes and probabilities of multiple stressors associated with anthropogenic activities, or hazards, that affect the social and/or ecological attributes of water resources have been established globally (Ayre and Landis., 2012; O'Brien *et al.*, 2019a). These methods incorporate Bayesian statistics that evaluate a hypothesis based on given evidence, which differs from classical, or frequentist statistics that evaluate the probability of the evidence given a hypothesis (Ayre and Landis., 2012). BNs incorporate Bayesian statistics in graphical, hierarchical, probabilistic models of multiple stressors that use conditional probability distributions to describe relationships between the variables of the model (Ayre and Landis., 2012; O'Brien *et al.*, 2019). BN models have been used to represent knowledge of how multiple stressors interact to evaluate the cumulative or synergistic effects of these stressors to socio-ecological endpoints of water resources (Marcot *et al.*, 2001; Borsuk *et al.*, 2004; Marcot *et al.*, 2006a; Pollino *et al.*, 2007a; Ayre and Landis., 2012; O'Brien *et al.*, 2019a; 2020; 2021).

The causal BN model developed for this assessment includes a range of nodes that represent indicator components of the socio-ecological system, linked by arrows that demonstrate causal relationships between variables. The models are causal and from the left-hand side to the right-hand side input environmental variability is interpreted and integrated to represent how the endpoints respond to changes (example Figure 2-2). This structure incorporates the ecological risk assessment framework where the risk exposure is represented by the input green and yellow nodes. This represents how the ecosystem is threatened by flow and non-flow stressors. The pink nodes introduce risk region or site dynamics which represent the exposure pathways of the risk framework. All input nodes are evidence based and use existing, or collected (in this study), and modelled data to represent a flow (or non-flow for water quality and geomorphology characteristics) relationship with ecological variables. All of the child nodes are conditional to the parent nodes and integrate response relationship distributions in the form of parent nodes using conditional probability tables (CPT) or rules that represent how the data is integrated. The CPTs combine the causal relationships between nodes and describe the conditional probabilities between the occurrence of states in the parent exposure nodes and the resulting probabilities of states in the child exposure node.

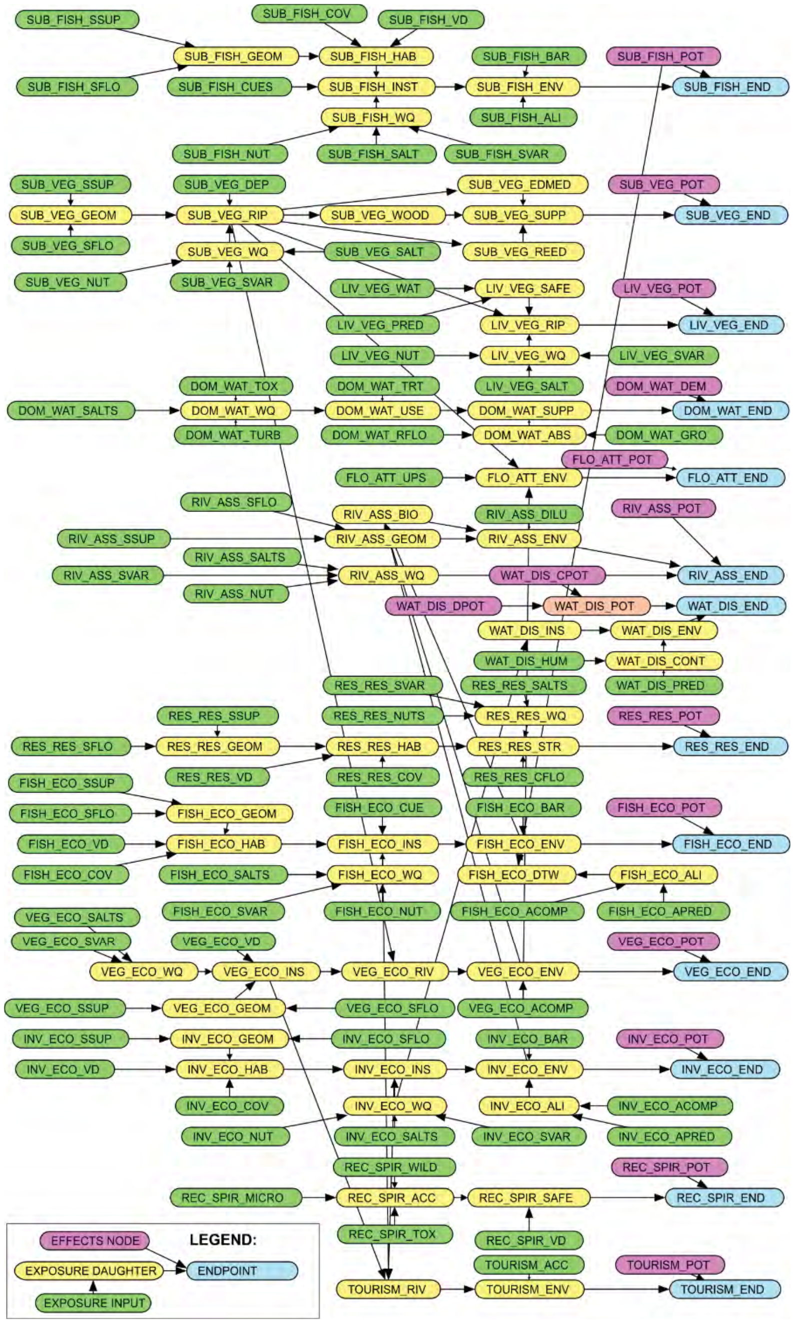


Figure 2-2: Example of a Bayesian network with green nodes representing input environmental variable information related to the exposure of the system by multiple stressors; yellow nodes integrate input information to represent the exposure of the large system; the pink node represents the potential for the activity to occur in a Risk Region that represents the effects part of the risk model and the blue node represents the endpoint.

2.2.2 Current condition evaluation

The physico-chemical dynamics of the ecosystem are considered for each reach of river (Figure 2-3). Flow gauging data and rainfall information is used to establish hydrological statistics for the resource being evaluated. Statistics representing natural, present and base flow conditions including the durations, volumes, timing and frequencies of flow are determined. These statistics are summarised into different formats including flow exceedance tables that are foundational to scenario evaluations.

The flow dynamics of each river reach are described to represent the habitat dynamics which can be achieved through hydraulic modelling. In holistic e-flow determination assessments, at least a cross section (one dimensional – 1d), or multiple cross sections (multiple 1d sections) or best of all, an integrated model at a reach scale (two dimensional – 2d), are used for the hydraulic modelling. For this study 1d hydraulic modelling was completed for all the SUP sites (Figure 2-3) and 2d modelling for the MEG sites on the Sabie River and Crocodile River X24F and X33B (Figure 3-10). These models facilitate the evaluation of changes in flows as related to habitat characteristics including depths, levels, wetted area, velocities and turbulence of flow within the water column. Hydraulic models and associated hydro-dynamic or fluid-mechanics information is used to describe the availability and/or condition of instream and riparian habitat/s through association with flow variability and geomorphological processes. These models can also be used to evaluate future habitat characteristics that could result from predicted e-flow scenarios.

Historical and natural water quality variability of the water resource being considered is also required as foundational information in an e-flow assessment. The data is usually based on available historical vs. present trends in the ionic concentrations of salt, nutrient, and toxicants of interest in the study area due to natural geological features of the resource, including naturally high salinities and serpentine soils for example, and anthropogenic activities resulting in water quality stressors. In holistic e-flow determination studies the relationships between river flows and water quality constituents through, for example, dilution flows required to provide suitable ecosystem conditions is required. Summer freshet flows can also be considered to flush nuisance water quality constituents or maintain the quality of refuge pools in rivers during dry, low flow conditions. River flows also support groundwater recharge which in-turn will result in groundwater linked pools in rivers during dry periods or reduce ground water intrusion if the quality of that aquifer is undesirable.

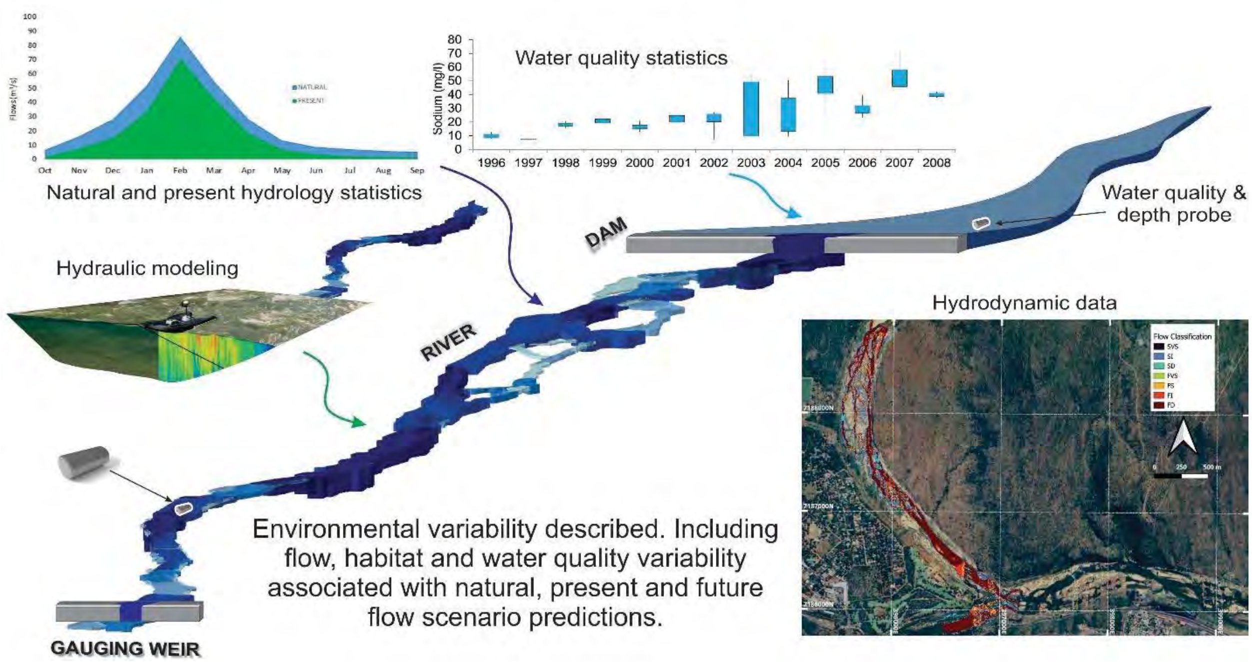


Figure 2-3: Current condition evaluation including characterization of physico-chemical dynamics of ecosystem for holistic e-flow assessment associated with each reach of the system considered.

2.2.3 Determine the flow-ecosystem relationships and conditional probabilities

With a good understanding of the habitat characteristics of a river reach, floodplain, lake and/or estuarine resource being considered in a PROBFLO assessment, holistic flow-ecosystem relationships that characterise a sustainable ecosystem are determined in Step 3. Here a range of ecosystem lines of evidence (LoEs) are used to identify species, populations and community indicators that represent the ecosystem and their preferences for the volume, timing, duration, and frequencies of flows. In this study, fish, macroinvertebrates and aquatic and riparian vegetation were selected to represent the riverine ecosystems. Holistic e-flow assessments have previously established these ecosystem components as foundational components to consider in e-flow assessments. For specific case studies, amphibians, microbes and /or regulator ecosystem services can be included in e-flow assessments to represent functioning sustainable ecosystems.

The application of these indicators results in a range of flow-ecosystem relationships which in the PROBFLO process are presented as rule or conditional probability tables. In order to represent the flow-ecosystem relationships graphically, the rule and conditional probability relationships are represented in stacked area charts that represent the ecological components as areas stacked in relation to discharge. The stacked area charts used to represent the relationships are cumulative areas and always add up to 100%. These are divided into ranks that relate, for example, to ideal or pristine (synonymous with zero risk rank), sustainable or suitable (synonymous with low-risk rank), threshold of potential concern (synonymous with moderate-risk rank) and unsustainable or unsuitable conditions (synonymous with high-risk rank) in the graphs (see Figure 2-4).

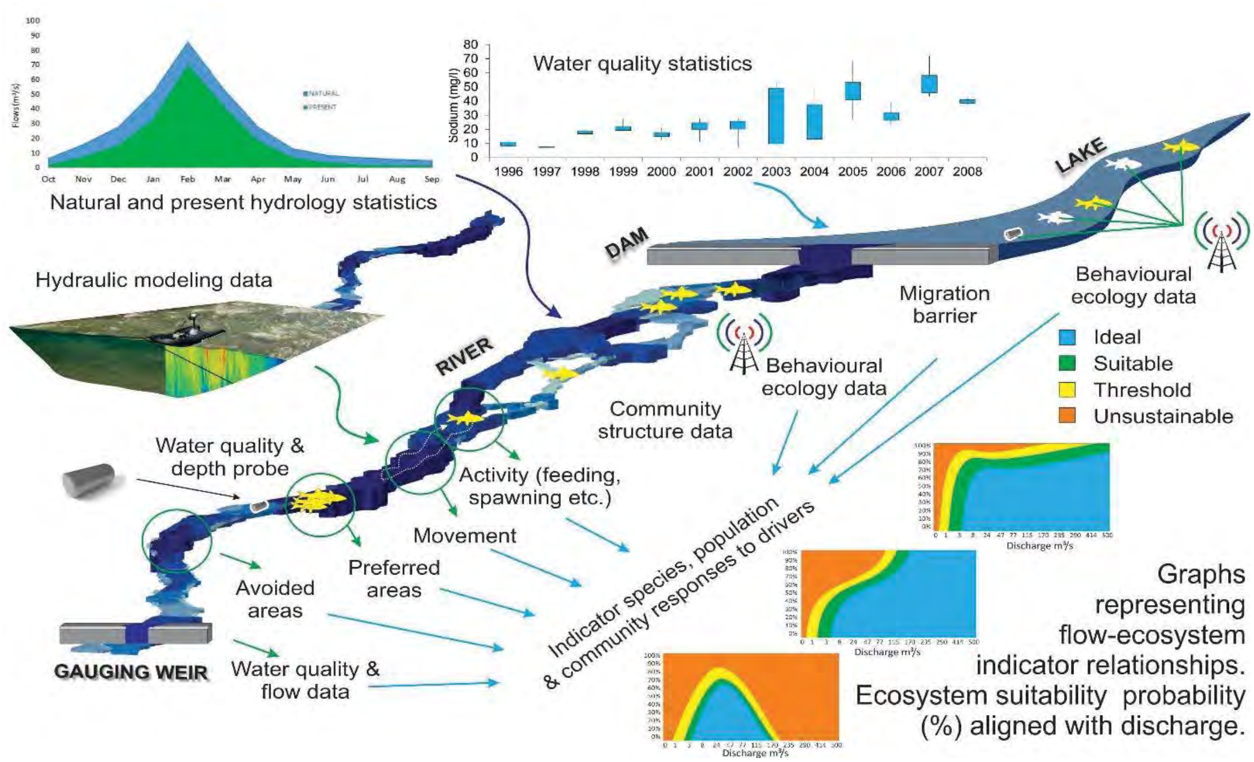


Figure 2-4: Indicator species, populations and community responses to drivers representing flow-ecosystem relationships for holistic e-flow determination. Note: flow-ecosystem stacked area graphs include ideal or pristine, sustainable, or suitable, threshold of potential concern and unsustainable or unsuitable conditions in the graphs.

The flow-ecosystem relationship data includes species, populations and community requirement/preference information for the volume, duration, frequency and timing (e.g. seasonality) of flows. In a PROBFLO assessment habitat depth and velocity requirements are generated to:

- maintain refuge areas for species,
- provide access for migration, spawning and recruitment,
- optimise water quality conditions of instream habitats,
- optimise levels required to inundate cover features, and
- facilitate recruitment of indicator riparian plants.

Additional data pertaining to sediment flows, habitat conditions and the movement and deposition of sediments is considered. These relationships can also consider the timing and duration of flows to ensure that they are aligned to seasonal life-cycle activities of indicator species. With this evidence of the requirements or preferences of ecosystem indicators, and knowledge of the use or protection focus of the vision for the resource, multiple ecosystem requirements can be generated to contribute to the determination of e-flows. These indicator requirements often pertain to life-cycle processes of indicator species including for example the habitat for indicator species to spawn in, recruit from, grow in and/or migrate between. These habitats associated with the timing of life-cycle attributes results in the volume, timing, duration, and frequency of flows to maintain these indicators.

For the e-flow determination, the state of the indicators is extracted to generate the flow requirements and the ranking scheme established for the study corresponds to the state of the indicators as described in Table 3-11. If the vision for the resource is use focused the requirements associated with the moderate risk rank range are used while if the vision is protection focused, then the low rank range is usually considered to generate flow requirements for each indicator. In these assessments a range of requirements generated from indicator species, populations and communities is summarised to represent the drought, base low, base high, freshet and flood requirements for each site. The hydrologist thus obtains indicator requirements pertaining to the volume, timing, duration, and frequency of flows for each site associated with drought, base low and high flows, freshets and floods.

2.2.4 Generation of flow scenarios

The flow-ecosystem relationships are used as controls to generate a flow scenario that meets these isolated requirements provided (see Figure 2-5). Consider however that these requirements are generated independently and are only integrated by the hydrologist to represent an initial e-flow requirement. Consideration of the potential synergistic effects of altered flows and combinations of the independent requirements still needs to be considered. The PROBFLO approach is a holistic assessment that then considers the integrated requirements, or synergistic effects of the indictor e-flow requirements using the Relative Risk Model (RRM) and Bayesian Network approach described below (see Figure 2-6 to Figure 2-8).

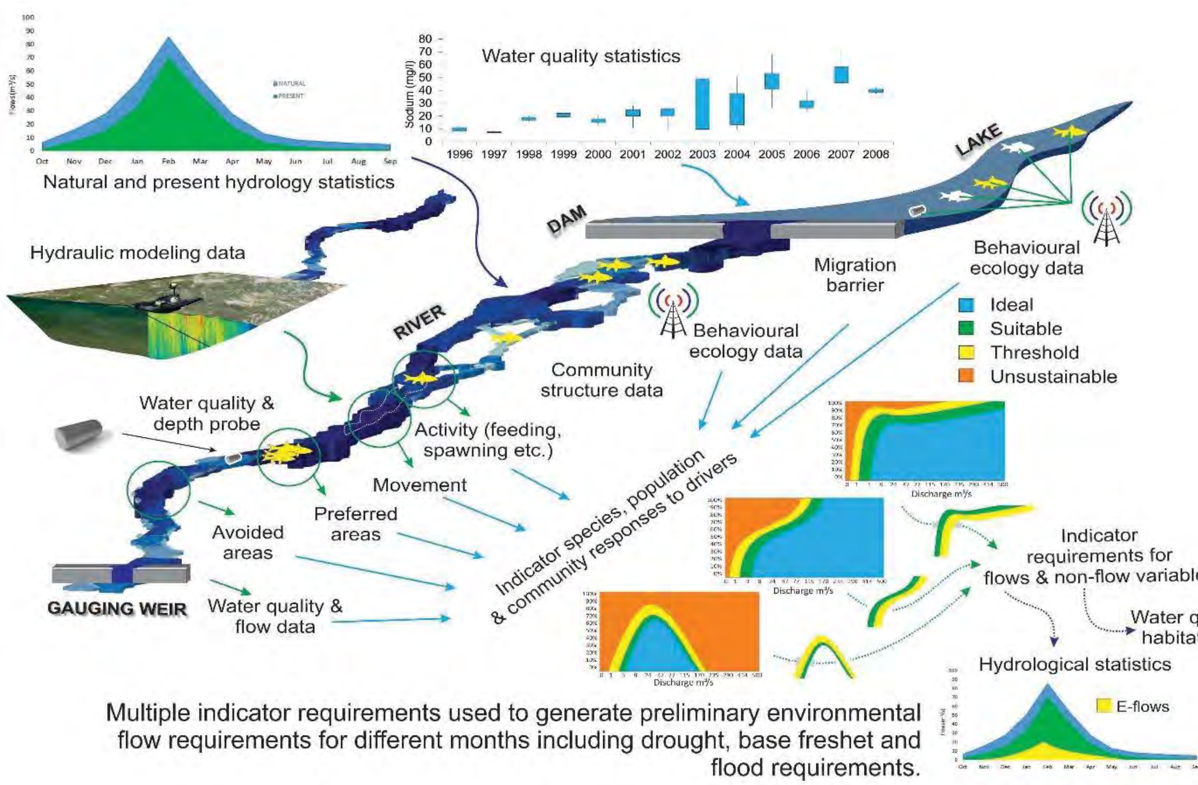


Figure 2-5: Flow-ecosystem relationships for indicators provided to the hydrologist as requirements for indicators to establish preliminary (indicator-based) e-flow scenario.

2.2.5 Evaluation of the integrated risk of preliminary e-flow requirements

The knowledge of the socio-ecological system representing each reach of river in the case study, and links between sites to represent upstream and downstream relationships, is used to evaluate the integrated risk of preliminary e-flow requirements, to ensure that they meet the integrated ecosystem requirements (Figure 2-6). This is achieved using Bayesian Network (BN) probabilistic modelling methods using the Norsys Netica tool. This holistic probability modelling approach is used here to evaluate the integrated risk associated with the preliminary e-flow requirements to provide for maintaining ecosystem services.

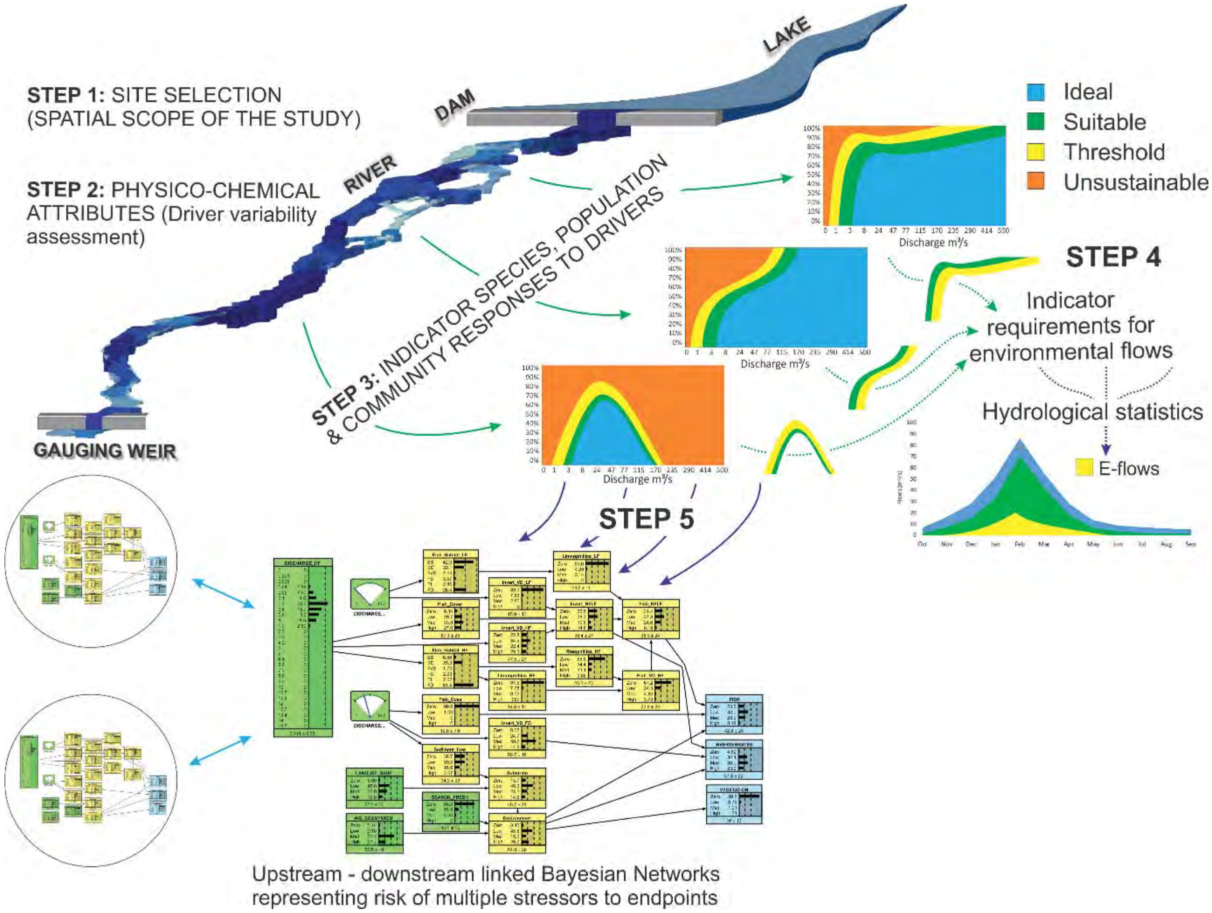


Figure 2-6: Use of flow-ecosystem relationships and non-flow ecosystem relationships to establish Bayesian Network probabilistic models for reach/multiple-reaches of ecosystems represented through connected models for holistic e-flow determination.

2.2.6 Determining probable risk

Next, all the flow indicator components of the ecosystem used to establish preliminary e-flow requirements are integrated into the BN (Figure 2-7). The same rules or conditional probability tables (represented as stacked area graphs) are integrated into the model and combined to represent ecosystem components using additional conditional probability tables. The risk projections using the same ranking system (ideal to unsustainable) are used to represent the outputs of the models.

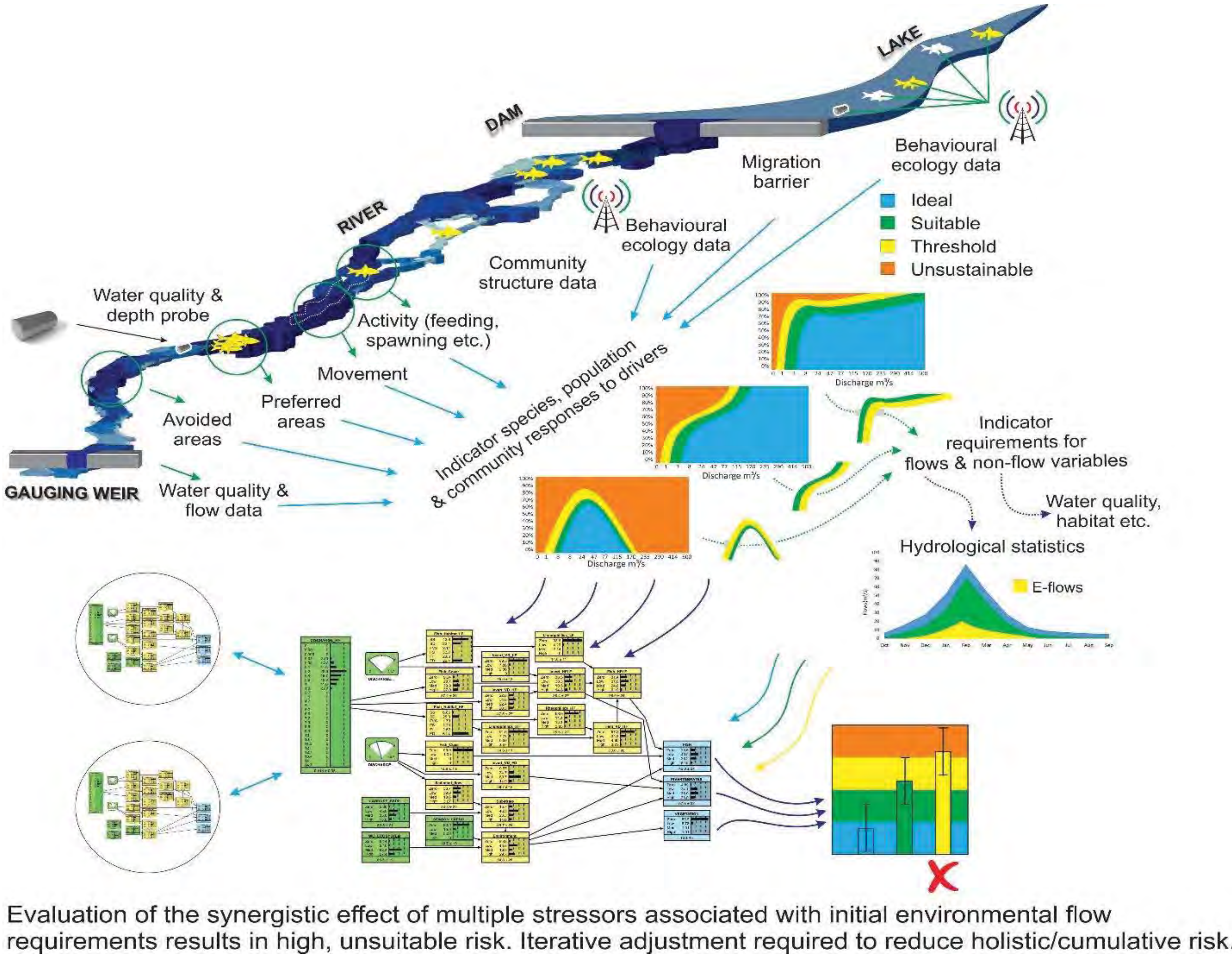


Figure 2-7: Bayesian Networks applied to determine probable risk of multiple flow and non-flow stressors to model endpoints that represent the ecosystem in an acceptable condition. Relative risk of natural, present day and preliminary (indicator-based) e-flow scenarios evaluated.

2.2.7 Evaluation of integrated risk

The integrated risk to the ecological endpoints is evaluated (Figure 2-8) which allows for the consideration of the suitability of the indicator requirements to determine the preliminary e-flows. If the integrated risk is suitable and aligns to the vision for the reach of river these e-flows are considered accepted as suitable integrated e-flow requirements for the site. If the evaluation of the preliminary risk results in a risk score that is too high, then an iterative process is followed to amend the flow requirements provided into the hydrological statistical model to update the preliminary e-flows which can be re-evaluated. Here any potential discrepancies between preliminary e-flows where indicators are considered independently, compared to the holistic, integrated model results, need to be addressed. During this process new flow requirements can be generated and tested resulting in an acceptable, evidence-based risk profile that can meet the vision for the resource considered and from which suitable e-flows are determined.

Take note, that while the uncertainty associated with isolated indicator requirements may be low-to moderate and uncertainty can increase through the use of the integrated probabilistic model, this can be mitigated/reduced through monitoring and testing and improved through iterative or adaptive modelling processes. This integrated approach meets good international, holistic e-flow determination considerations and conforms to the precautionary approach to water resources management.

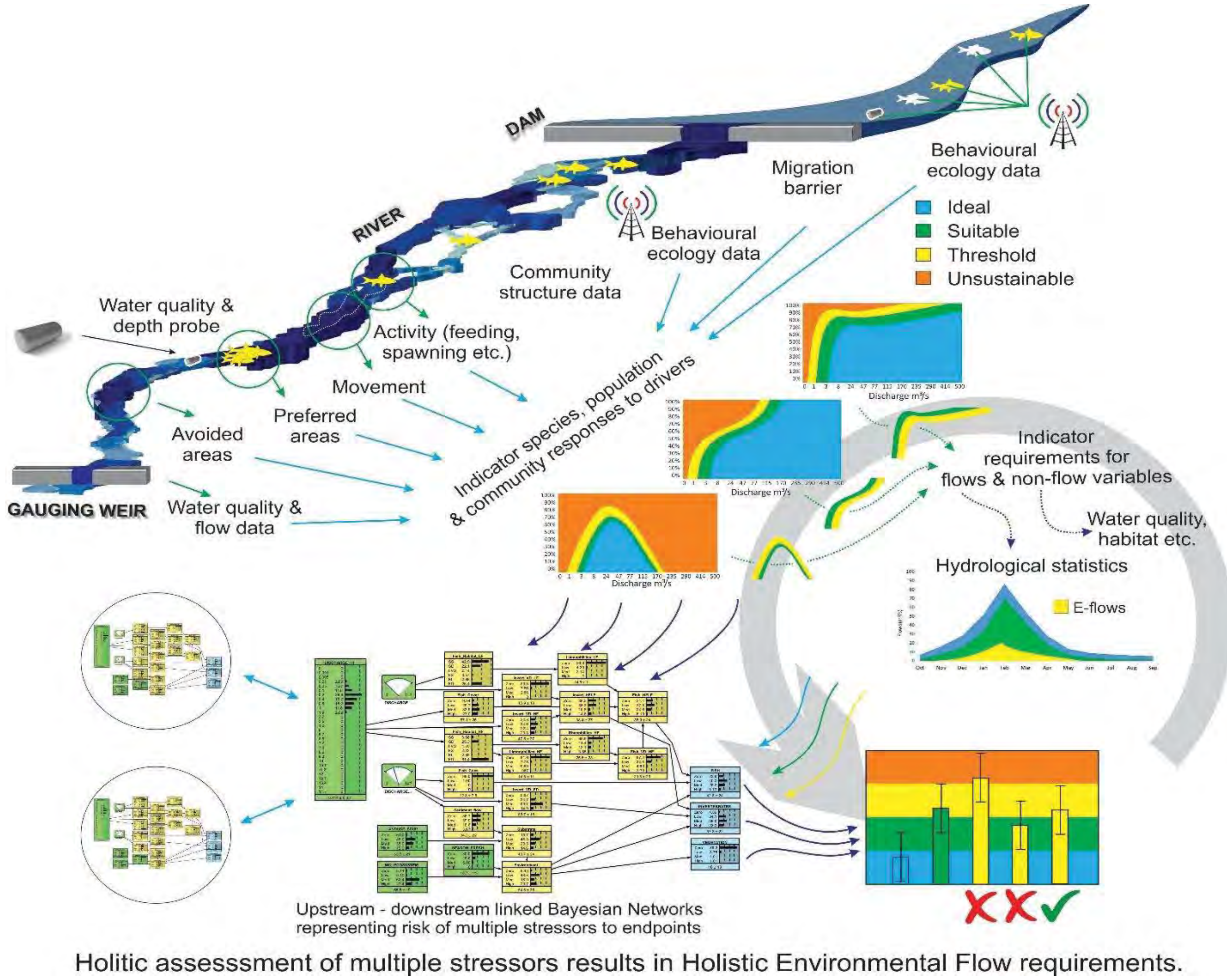


Figure 2-8: Bayesian Networks evaluation of risk of multiple stressors to preliminary (indicator-based) e-flow requirements and revise to establish "integrated, holistic" e-flow requirements. This adaptive process can be applied through multiple iterations to result in a suitable "integrated, holistic" e-flow for each reach which is also integrated/synchronised between sites/reaches.

2.3 STEP 7: UNCERTAINTY EVALUATION

2.3.1 Sensitivity of findings

The PROBFLO approach includes the evaluation of uncertainty so as to identify key drivers in the model and sources of uncertainty that may be impacting on the overall uncertainty of the model (Ayre and Landis, 2012). The results of this evaluation provide context to the stakeholders and contribute to the decision-making process in E-flow assessment studies. For this case study, the "Sensitivity to Findings" tool of Netica was used to evaluate input variables.

2.3.2 Integrated risk to ecosystems

The approach adopted is to integrate the risk scores into ecosystem service categories as described in detail in O'Brien *et al.* (2018) and includes the use of Oracle Crystal Ball ® software. The risk profiles of each endpoint per ecosystem service category have been combined through addition where risk ranks (zero, low, moderate and high) have been assigned to each of the 1 000 random iterations, based on the risk distribution outcomes of the RRM-BN assessment.

For example, for each scenario where the wellbeing of the fish (FISH-ECO-END), invertebrates (INV-ECO-END) and riparian vegetation (VEG-ECO-END) endpoints are combined, their risk profiles which may include, for example for FISH-ECO-END for NAT scenario, 66.4% chance of a zero risk rank and a 16.5% chance of a low risk rank with an 8.5% and 8.4% chance of a moderate and high risk rank respectively. Using this information the Monte Carlo assessment assigns a rank score of 25 to the FISH-ECO-END 66.4% of the time and for low 16.5% of the time, etc. for the 1 000 random iterations. These scores are then randomly added to the ranks associated with the frequency distribution of the INV-ECO-END and VEG-ECO-END endpoints.

This approach is somewhat conservative as any risk outcome between 0 and 25 is allocated a zero risk rank (25) etc., with any score between 75 and 100 allocated a high risk rank (100) for the integration. This approach has been established as a suitable risk endpoint integration approach where there are no links between co-variables or endpoints of each ecosystem service that can be modelled using the RRM-BN. This approach is only used to communicate the probable socio-ecological consequences of altered flow and non-flow stressors per ecosystem category.

3 RESULTS

3.1 STEP 1: VISIONING EXERCISE

E-flows represent the target or condition of a river which needs to be aligned to the desired balance between the use and protection of water resources, or the "vision" of the resource. On a regional scale, to achieve an overall sustainable balance between the use and protection of water resources some areas may be allocated for "high but sustainable" use and other areas may be assigned a "low use and protect" scenario, where together they at a regional scale allow sufficient protection of the resource for regional sustainability. In this context, the ecological classification of ecological category (A=pristine to F=critically modified) system is used (Table 3-1 – Kleynhans and Louw, 2008). The Visioning exercise therefore included a review of the Classification of water resources within the basin, results of Reserve determinations and set RQOs for rivers within South Africa. A workshop was held with representatives from Mozambique and Eswatini to establish a preliminary Vision for the Incomati catchment in their respective countries that aligned with the Vision in South Africa. Table 3-2 and Figure 3-1 present the results of the aligned classification process for the Incomati Basin.

Table 3-1: Guidelines used to delineate the present ecological state categories based on observed and expected intolerance ratings (Kleynhans, 2008).

Category	Description
A	**Natural**, unmodified, or approximating natural conditions.
B	**Largely Natural** with few modifications. A change in community characteristics may have taken place but species richness and presence of intolerant species indicate little modification.
C	**Moderately Modified**. A lower-than-expected species richness and presence of most intolerant species. Some impairment of health may be evident at the lower limit of this class.
D	**Largely Modified**. A clearly lower than expected species richness and absence or much lowered presence of intolerant and moderately intolerant species. Impairment of health may become more evident at the lower limit of this class.
E	**Seriously Modified**. A strikingly lower than expected species richness and general absence of intolerant and moderately intolerant species. Impairment of health may become very evident.
F	**Critically Modified**. An extremely lowered species richness and absence of intolerant and moderately intolerant species. Only tolerant species may be present with a complete loss of species at the lower limit of the class. Impairment of health generally very evident.

Table 3-2: Proposed preliminary classes for quaternary catchments in Mozambique and Eswatini and rationale for their selection to align with existing South African classification.

Proposed Class		Rationale
		Mozambique
Y1-1	Class I	The upstream quaternary catchment (X4-1) in South Africa is classified as a Class I and the land-use in the downstream quaternary catchment (Y1-1) is thought to be able to sustain this Class.
Y1-2	Class III	The upstream quaternary catchment (X1-10) in South Africa is classified as a Class III and it would be difficult to improve the class of the downstream catchment (Y1-2) in Mozambique.
Y1-3	Class I	The upstream quaternary catchment (X4-1) in South Africa is classified as a Class I and the land-use in the downstream quaternary catchment (Y1-3) is thought to be able to sustain this Class.
Y1-4	Class II	Lower Incomati River and Estuary sub-basin. Preliminary class proposed as a Class II associated with the high dependence of a large population of people with associated urban and peri-urban communities, light industry, agriculture and subsistence harvesting requirements. While the state of the lower river, floodplain and estuary is unknown the ecological importance is high and this class represents a balance between the need to use and protect this resource.
Y1-5	Class II	Although the upstream quaternary catchment (X3-6) in South Africa is classified as a Class I, the Corumana Dam and the associated agriculture, hydropower generation and peri-urban communities in this catchment will result in it being classified as a Class II.
		Eswatini
X1-11	Class II	Komati River where human peri-urban community and associated diverse water resource use activities, with the dam itself influential in the establishment of a Class II. This class acknowledges the need to sustainably use and protect vulnerable ecosystems in the Integrated Unit of Analysis (IUA).
X1-12	Class II	Upper Lomati River above Driekoppies Dam where human peri-urban community and associated diverse water resource use activities, with the dam itself influential in the establishment of a Class II. This class acknowledges the need to sustainably use and protect vulnerable ecosystems in the IUA.

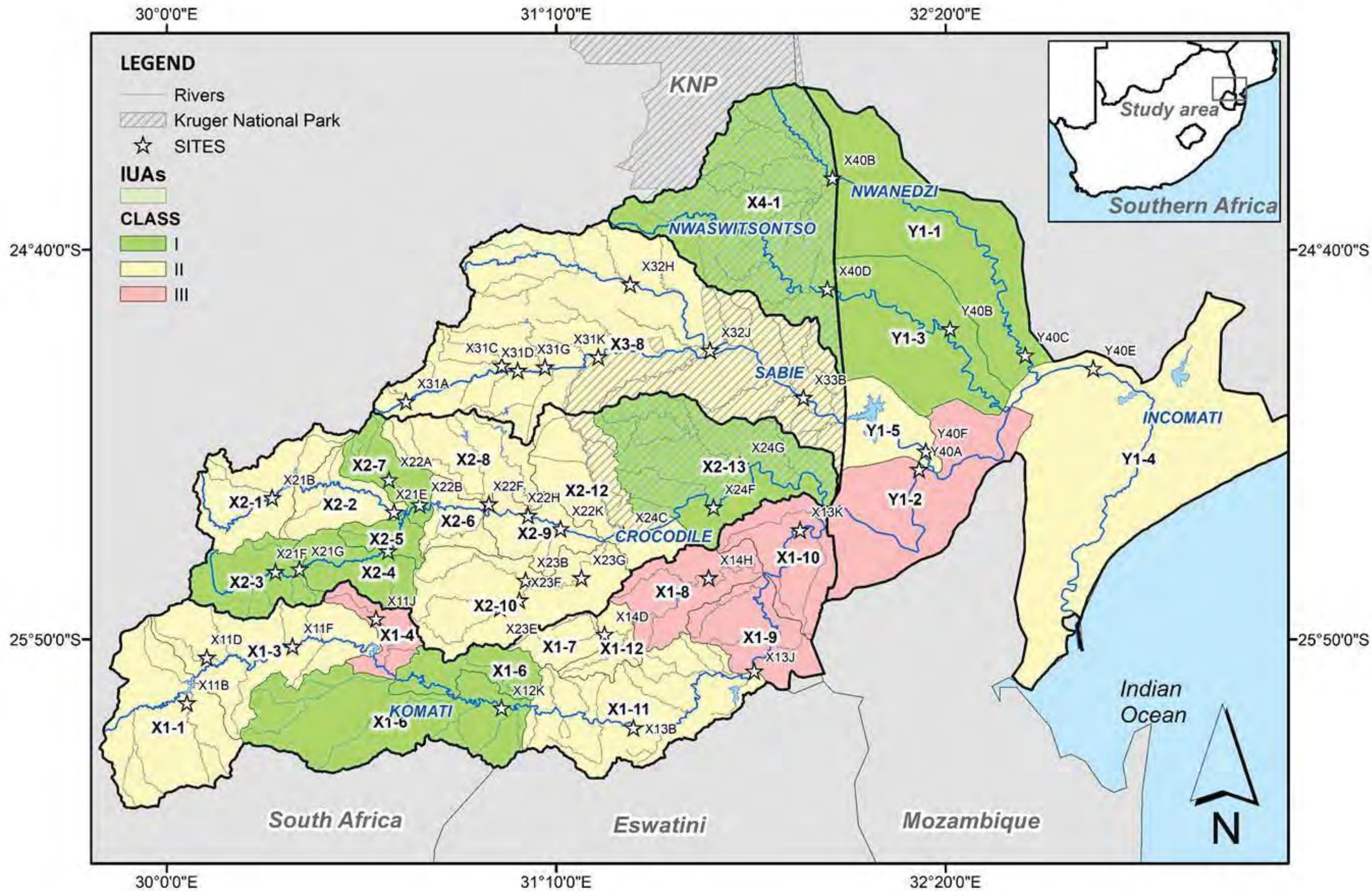


Figure 3-1: Proposed classes for the whole Incomati Basin based on the vision

The determination of e-flows for the Incomati Basin is based on support provided primarily by river flow to the ecosystem services associated with the river and these services (supporting, provisioning, regulatory and cultural services) were selected as the endpoint for the study.

Supporting services are those that are necessary in the production of other ecosystem services and play a crucial role to maintain them (Rodríguez, 2005). They also contribute directly and indirectly to the wellbeing and livelihoods of people. The ability of ecosystems to provide habitat for species, produce biomass, soil and atmospheric oxygen are some examples of supporting services, while the abundance of biodiversity may also be considered a supporting service. For this study, the maintenance of fish, invertebrates and vegetation were selected as endpoints for the supporting ecosystem services as these were also used to determine the e-flows for each sub-basin.

Provisioning services are the tangible products that people obtain from ecosystems, and they include food, water, raw materials, energy and genetic resources and most often are considered as the most fundamental benefits of nature to livelihoods (Darwall et al*.,* 2009). The provisioning services considered most important for the Incomati basin and selected as endpoints are the maintaining of fisheries and plants for livelihoods, the maintaining of plants for domestic livestock and the maintaining of water for domestic use.

The prevention and mitigation of natural disasters such as floods and human induced impacts like pollution of water bodies are some of the regulating service benefits that are derived from ecosystems (MEA 2005). The endpoints chosen to represent these ecosystem services included flood attenuation, river assimilation, water-borne diseases and resource resilience. River assimilation is the ability for the water resources to dilute pollution, whereas resource resilience is the extent of disturbance that a system can tolerate before it deteriorates into a different state.

The last ecosystem services considered are cultural services, which are the non-material benefits that people obtain from nature, which include recreation, aesthetic enjoyment, physical and mental health benefits and spiritual experiences (MEA 2005). The two endpoints selected for this service are maintaining water resources for recreational and spiritual activities, as well as for tourism.

The complete list of endpoints selected for the study includes both social and ecological (supporting service) endpoints that are supported by e-flows (Table 3-3). All of these endpoints are included in the BN-RRM assessment to evaluate the socio-ecological effects of altered flows in the study to support the implementation of e-flows and consideration of trade-offs between the use and protection of water resources in the basin. Only the Supporting services are used directly for estimation of e-flows as these are the flows that support the ecosystem directly.

Table 3-3: Endpoints selected for the Incomati Risk Framework study.

Ecological Service	Endpoint
Supporting services	Maintain fish communities to ensure a healthy ecosystem (FISH-ECO-END)
	Maintain invertebrate communities to ensure a healthy ecosystem (INV-ECO-END)
	Maintain vegetation communities to ensure a healthy ecosystem (VEG-ECO-END)
Provisioning services	Maintaining fisheries for livelihoods (SUB-FISH-END)
	Maintain plants for livelihoods (SUB-VEG-END)
	Maintain plants for domestic livestock (LIV-VEG-END)
	Maintain water for domestic use (DOM-WAT-END)
Regulatory services	Flood attenuation services (FLO-ATT-END)
	River assimilation capacity (RIV-ASS-END)
	Limit water borne diseases (WAT-DIS-END)
	Resource resilience (RES-RES-END)
Cultural services	Maintain recreation and spiritual activities (REC-SPIR-END)
	Maintain tourism (TOURISM-END)

3.2 STEP 2: MAPPING AND DATA ANALYSIS

The Incomati River basin is located in the south-eastern part of Africa and occupies portions of Eswatini, Mozambique and South Africa and includes the Komati, Crocodile, Sabie, Massintoto and Uanetze Rivers and the Incomati floodplain and estuary The highest river order on the South Africa side of the Basin is a 4, namely the Komati, Sabie and Crocodile River systems but as these rivers confluences in Mozambique the Incomati river order changes to a 6 (Figure 3-2).

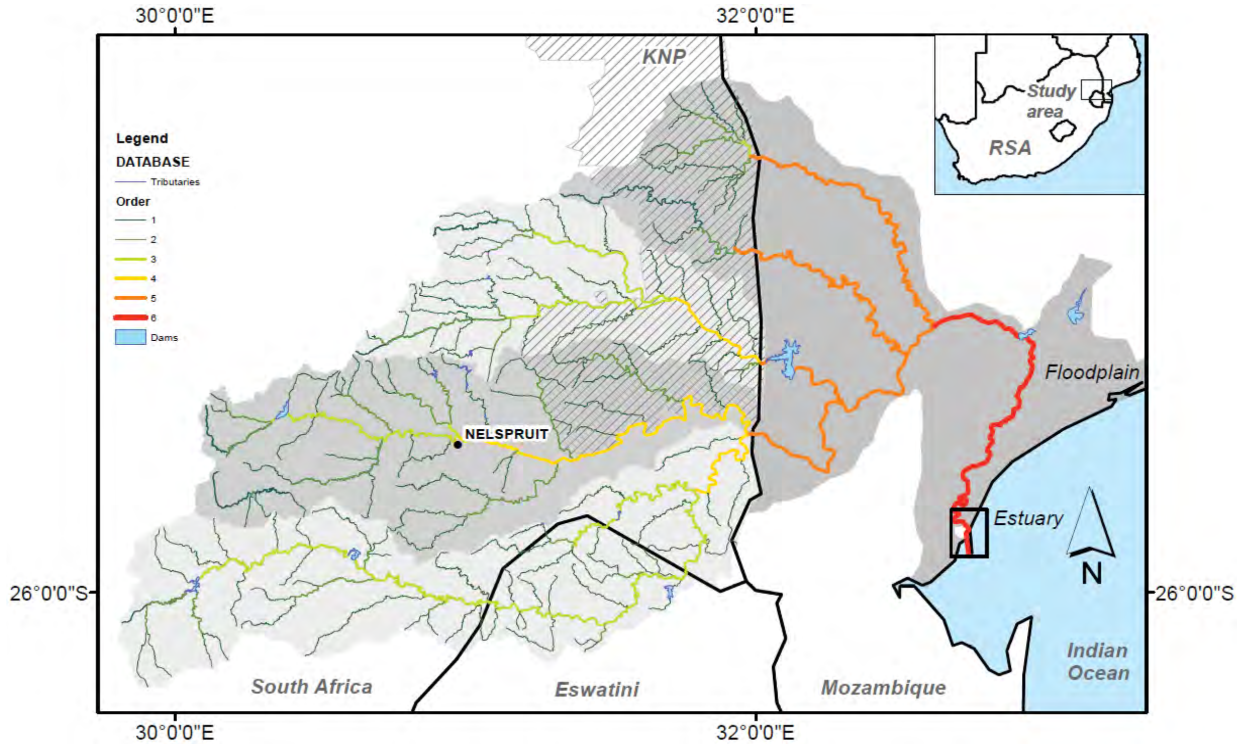


Figure 3-2: The main rivers and tributaries of the Incomati River Basin in southern Africa. The different colours are an indication of the river orders in the Basin, the colour green being the lowest river order and red the highest river order.

3.2.1 Regional management of water resources

The governments of Mozambique, South Africa and Eswatini have been working together on the management of the shared water resources and have carried out joint studies of common interest through the Tripartite Permanent Technical Committee (TPTC), which was established in 1983 and the signed Interim IncoMaputo Agreement (IIMA) of 2002. The agreements' aims are to ensure the protection and sustainable utilisation of the water resources of the Incomati watercourses. Based on the trilateral agreement between Eswatini, Mozambique and South Africa a total water withdrawal by human activities, directly or indirectly from the Incomati Basin and its tributaries was agreed upon to be shared amongst the countries as specified in Table 3.4.

Table 3-4: Permitted volume of water withdrawals according to the Tripartite Interim Agreement (TIA) of the Incomati basin (2002).

Country	First priority (domestic, livestock and industry (million m^3/yr)	Irrigation (million m^3/yr)
Mozambique	19	280
South Africa	336.6	786
Eswatini	22	261

Each country has legislation that prescribes the protection of all water resources in each country. South Africa has the National Water Act of 1998, that prescribes the protection of water resources through resource-directed measures which includes Resource Classification, Reserve Determination and Resource Quality Objectives. In Eswatini, the Water Act of (2003) and the Draft Water Pollution Control Regulations in Swaziland are key legislations that set water pollution standards. The water law (law 16/91) in Mozambique in chapter IV, prioritises the protection of water resources as a way to maximize the benefits of water use and to protect the environment.

3.2.1.1 Water resources protection measures in South Africa

To ensure the protection of water resources, related to their use, development, conservation, management and control, as described within Chapter 3 of the National Water Act (NWA – Act No. 36 of 1998), Resource Directive Measures (RDM) were established for South Africa.

Resource Directive Measures (RDM) are measures used by the Department of Water and Sanitation (DWS) to ensure the protection of water resources, related to their use, development, conservation, management and control, as described within Chapter 3 of the National Water Act (NWA – Act No. 36 of 1998). These protection measures include, the development of a Classification System for water resources (Chapter 3, Part 1 – NWA, 1998); the classification of significant water resources and determining Resource Quality Objectives (RQOs) (Chapter 3, Part 2 – NWA, 1998) and determination of the Reserve for all significant water resources (Chapter 3, Part 3 – NWA, 1998). The Classification System enables the establishment of a class towards which the resource must be managed to ensure the long-term balance between use, protection, future uses, equitable access and international obligations (DWA, 2011). To determine the class for a water resource, a vision for that resource is required to understand how the water resource is to be used (Table 3-5). The reserve includes the quantity and quality requirements of the water resource to meet both basic human needs and to protect the aquatic ecosystem. The classification aspects come together in the description of the RQOs that assist in the management of a water resource (DWA, 2011).

Table 3-5: Preliminary guidelines for determining the integrated unit of analysis class for a scenario (DWAF, 2007).

IUA class		Percentage Ecological Category (EC) representation at units represented by biophysical nodes in an IUA				
		≥A/B	≥B	≥C	≥D	<D
Class I: Minimally used. The configuration of ecological categories of the water resources within a catchment results in an overall water resource condition that is minimally altered from its pre-development condition.		≥40	≥60	≥80	≥99	
Class II: Moderately used. The configuration of ecological categories of the water resources within a catchment results in an overall water resource condition that is moderately altered from its pre-development condition.			≥40	≥70	≥95	
Class III: Heavily used. The configuration of ecological categories of the water resources within a catchment results in an overall water resource condition that is significantly altered from its pre-development condition.	Either			≥30	≥80	
	Or				100	

A water classification study for the Incomati Basin was undertaken in 2013-2014 using scenario evaluation process to determine the Water Resources Classes (DWS, 2014). The resultant Water Resource Classes per IUA and target Ecological Category (EC) were gazetted in December 2016 (DWS, 2016) and indicate that almost all of the IUAs in the Komati River system were classified as a Class II or Class III with only X1-6 (All tributaries downstream of Vygeboom Dam in X1-6 excluding the Gladdespruit) classified as a Class I (Figure 3-3). The IUAs within the Crocodile River system were all classified as either Class I or Class II. Similar results were recorded for the Sabie-Sand catchment expect X3-4 (Sabaan, Noord-Sand, Bejani, Saringwa, Musutlu rivers) was classified as Class III. The Nwanedzi and Mwaswitsontso Rivers were classified as Class 1.

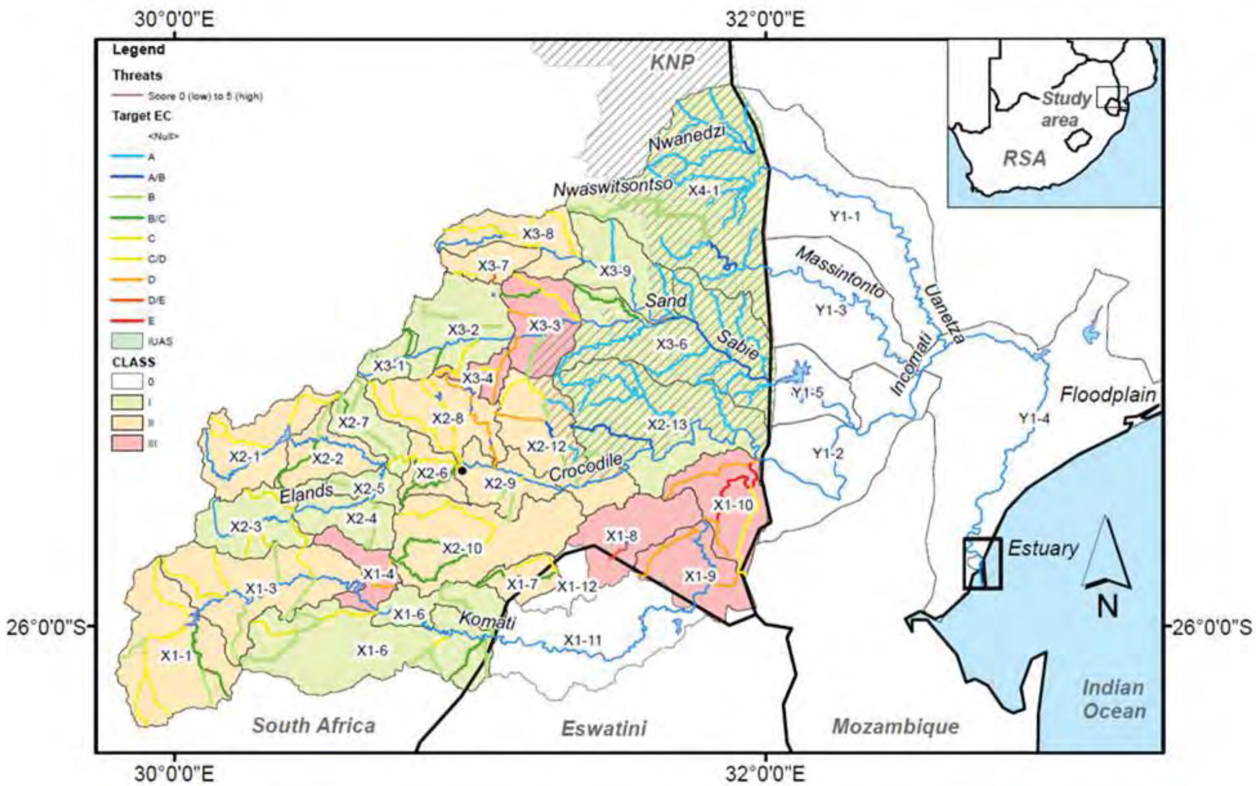


Figure 3-3: Classification and target ecological category for integrated units of analysis within the Incomati Basin, South Africa. From National Water Act (36/1998): Classes of Water Resources and Resource Quality objectives for the Catchments of the Inkomati. Act no 1616 of 2016.

3.2.1.2 Water resources protection measures in Eswatini

The Kingdom of Eswatini's water resources use and management are governed by the Water Act of 2003. The Water Act integrates and decentralizes water management and forms a strong foundation for Integrated Water Resources Management. The Act integrates and decentralises water management by establishing the National Water Authority and River Basin Authorities to empower basin stakeholders in the management of their water resources. Each River Basin authority ensures that, the water quality of each water body under its jurisdiction meets the water quality objectives. The Water Act (2003) and the Water Pollution Control Regulations of 1999 are key legislations setting the Water Quality Objectives. The water quality objectives are based on different water quality parameters to be maintained in each water body, to ensure a high level of protection for the environment and for human health. These water quality objectives are to be reviewed at least once in every five years to ensure that they are appropriate and adequate to ensure a high level of protection. To ensure that the quality of surface water in the country conforms to the water quality objectives, the country's Water Pollution Control Regulations of 1999 also stipulates the allowable effluent discharge limits for water resources based on specified water quality parameters with specific monitoring schedules.

3.2.1.3 Water resources protection measures in Mozambique

Water Policy and Act, regulation regarding Standards for Environmental Quality and the Discharge of Effluent (Decree no. 18/2004) were established. The regulations define the quality and effluent emission standards for receiving bodies of water, treatment technologies, systems and methods. The regulations require the location of discharge points and ensuring that, there is no change to water quality in the receiving body. The receiving surface water body or aquifer where the effluent will be discharged must be identified together with the discharge point, quantity, volume and frequency, as well as the nature and composition per volume unit of effluent.

3.2.2 Drivers of ecosystem change

3.2.2.1 Water quality

There have been water quality challenges in the Incomati in South Africa which have always been mainly due to industrial and mining activities and the poor state of water services authorities' sewage infrastructure. Pollution of the resource is caused due to contamination of sewage (e.g. from overflows, spills and leakages or by discharge of untreated/partially treated sewage into the resource); and decanting of mining effluents or leachate into the water resources as well as solid waste especially nappies. Microbial pollution remains a human health risk, especially to the vulnerable rural communities that use the river water for domestic, religious, cultural and recreational purposes. Deteriorating water quality on certain Ecological Water Requirements sites especially microbiological quality has largely been attributed to inadequate compliance, monitoring and enforcement, weak cooperative governance.

Water quality ratings for the different catchments have been determined along the length of the Sub Quaternary reach. The different ranking and categories descriptions are as for instream habitat modification. The parts of the rivers and tributaries that flow through the Kruger National Park instream habitat modification are in references condition (Rating of 0) or only a small impact have been observed (Rating of 1) as shown in Figure 3-4. The river sections of the Crocodile and Incomati Rivers before the confluences in impacted by altered water quality (Rating of 4). The Crocodile River mainstem, parts of the Sabie and Komati Rivers water quality modification is generally present with a clearly detrimental impact on habitat quality, diversity, size, and variability (Rating of 3).

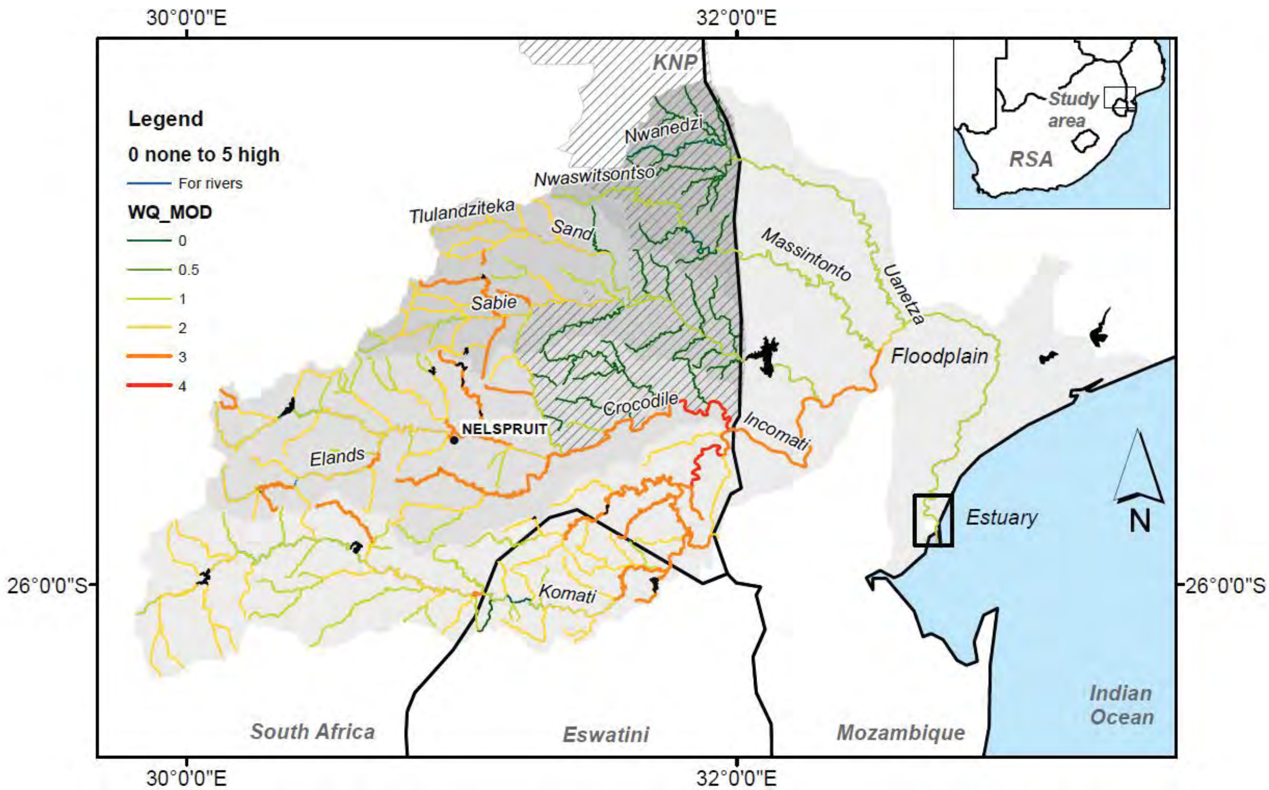


Figure 3-4: Ratings of water quality modification that occur in the Incomati Basin

3.2.2.2 Hydrology

There are 61 gauging weirs in the Incomati River Basin and mostly located along the EWR sites as shown in Figure 3-5. These gauging weirs are used to determine the discharge and water level of rivers at these locations (Wessels and Rooseboom 2009).

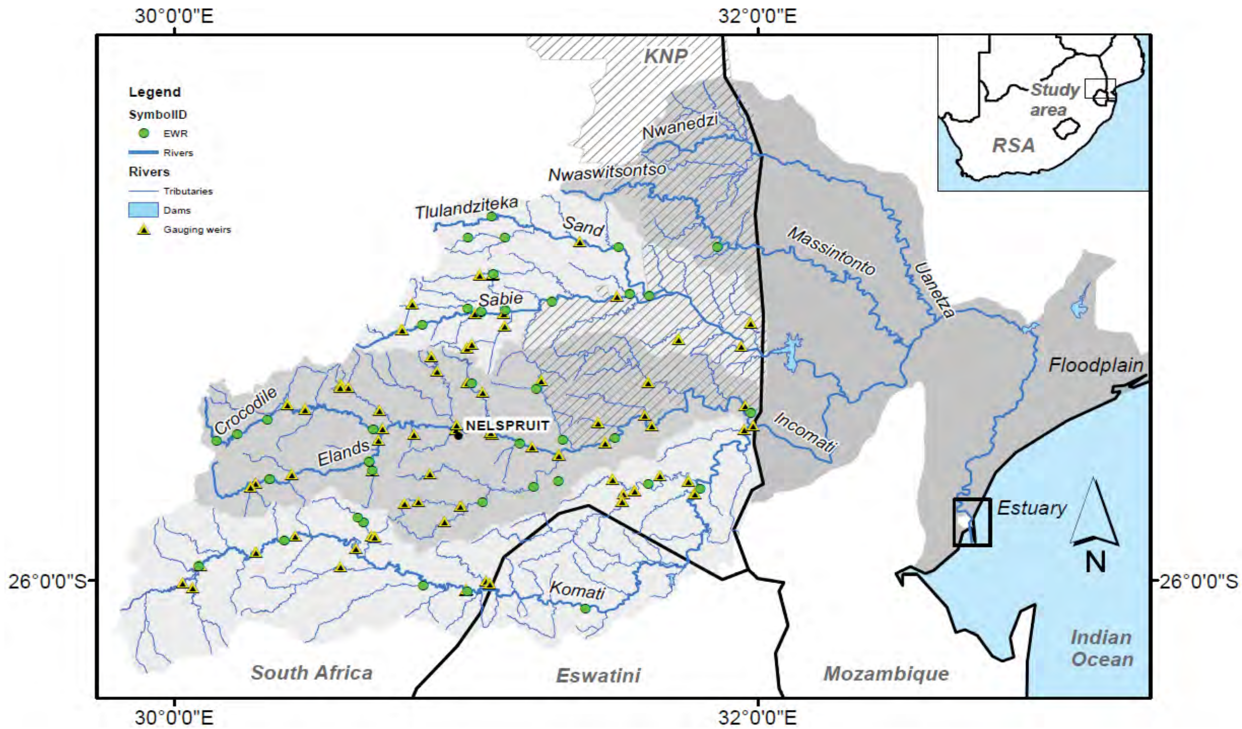


Figure 3-5: The different environmental water requirement sites, gauging weirs and dams in the Incomati River Basin South Africa.

Ecological Water Requirements for the different parts of the Incomati in South Africa, have been determined and approved by DWAF in the Sabie catchment (Table 3-6) and these used in all water resources simulations.

Table 3-6: Ecological Water Requirements in the Sabie River catchment (Louw, 2007)

Sub-catchment	Natural streamflow (million m^3/a)	Ecological Reserve		
		Ecological Management Class	Average requirement (million m^3/a)	% of Natural streamflow
Upper Sabie	617	C	257	41%
Maritsane	210	C	86	41%
Sand River	232	C	95	40%
Lower Sabie	961	B	44	44%

According to South Africa's current operating rule with respect to cross-border flows, 45% of the requirements are met from the Crocodile River while the remaining 55% is supplied from the Komati system. These international requirements are regarded as high priority water use at the end of the Crocodile catchment. According to Marlloy (Unknown) without the ecological Reserve the international flow requirements cannot be met without implementing curtailment rules within the Crocodile catchment. It can also be noted that relative to the natural flow, these comprehensive Reserves are much lower than the estimated Reserve requirements of the Crocodile River catchment. In 2017, the Incomati-Usuthu catchment reserve was updated and gazetted to improve confidence in the reserve estimates (DWS, 2017).

3.2.2.3 Geomorphology

Geomorphological processes operate over a wide range of temporal and spatial scales, from the catchment to the channel bar and from geological time to the individual flood event. Although the channel and its associated habitats is the focus of ecological research, it is important to place the channel network in the context of the catchment which supplies the water and sediment which are conveyed through the channel, and hence the energy and materials necessary to form the channel. Frissell el al.'s (1986) model was used as a template for the development of a South African river classification system. South Africa uses this hierarchical framework which enables the linkages between the catchment and channel to be modelled over a range of spatial scales (Rowntree and Wadeson, 1999). The Incomati Basin has been divided into seven different geomorphic zones as shown in Figure 3-6.

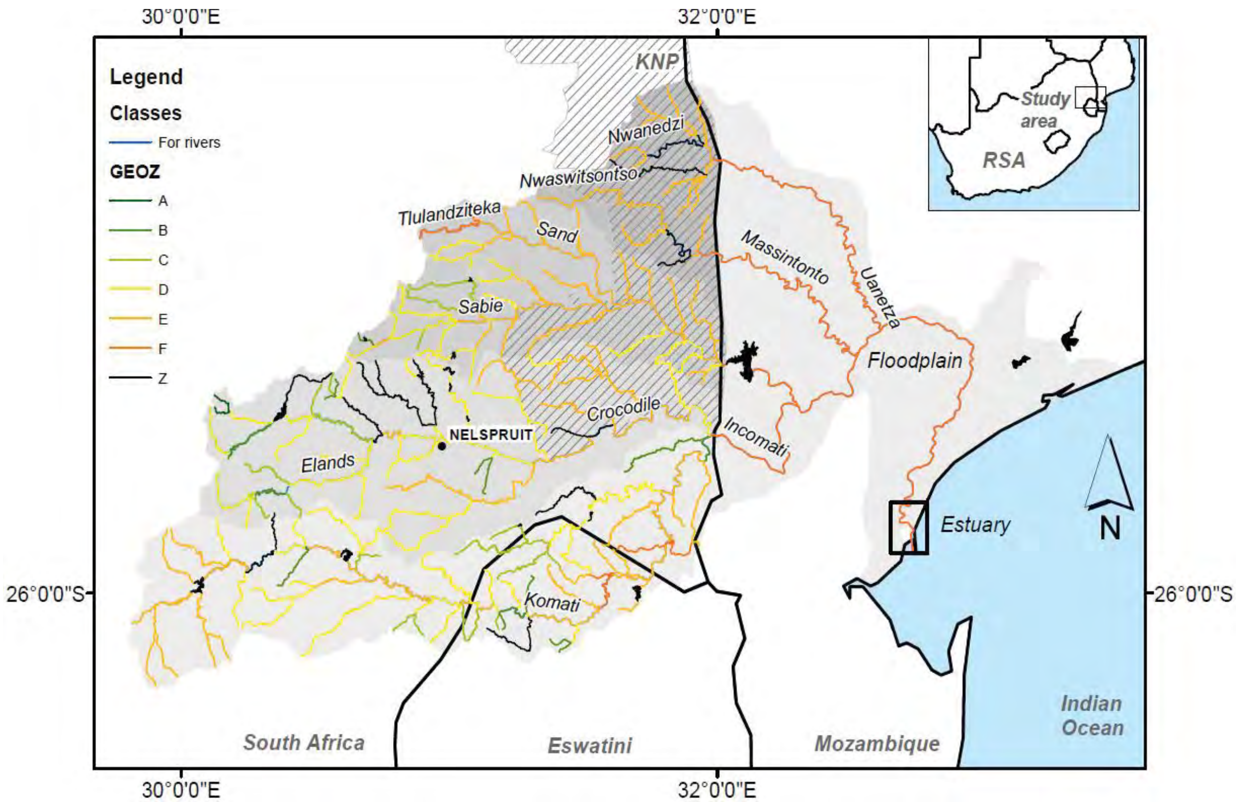


Figure 3-6: Map of the Incomati Basin showing the different geozones.

3.2.3 Responses to ecosystem change

3.2.3.1 Fish

The Incomati fish fauna demonstrate a Zambezian origin characterised by high endemism and species with restricted ranges (Kleynhans *et al.,* 2015). The Incomati Catchment in South Africa supports an estimated 55 species of fish distributed in different parts of the catchment (Darwall *et al.,* 2011; Kleynhans *et al.,* 2015). Two species are critically endangered in the Incomati Catchment *Kneria* spp. 'South Africa' *Chiloglanis bifurcus*, one endangered (*Chetia brevis*), two vulnerable *Chiloglanis emarginatus*, *Oreochromis mossambicus*, and the rest least concern or insufficient data (Figure 3-7)(IUCN 2021).

3.2.3.1.1 The Sabie River system

Previous studies show that, the Sabie River is currently classified as one of the most pristine systems in the Incomati Catchment due to high biodiversity and re-establishment of migratory pathways and fish species that have preserved ecological functionality in this system (Kleynhans, 1986; Roux *et al.,* 2016; O'Brien, Burnett and Petersen, 2018a; O'Brien, Burnett and Petersen, 2018b). The Sabie River has 46 known re-occurring fish species (Roux *et al*., 2016). This system is under some pressure from sedimentation, domestic water-abstraction, forestry, irrigation and illegal sand mining (Okello *et al*., 2015). In the lower reaches, physical barriers pose problems for migratory fish species, as important catadromous migratory species such as Anguillid eels are considered absent throughout the system, although little is known about their populations (O'Brien *et al.,* 2019).

3.2.3.1.2 The Crocodile River system

The Crocodile River system, with more than 49 recurrent fish species, is ecologically one of the most important and biodiverse river systems in the Incomati Catchment (Kleynhans *et al.,* 2015). The main threats on this river is domestic water use abstraction industrial and mining activity, forestation and irrigation (Kleynhans *et al*., 2015; Okello *et al.,* 2015). The system is considered to be connected although multiple barriers with and without fishways occur in the river system.

3.2.3.1.3 The Komati River system

A total of 43 re-occurring fish species occur within the Komati River system (Kleynhans *et al*., 2015).The Komati River system is the most stressed river system in the catchment due to irrigation water abstraction, return flows, mining and industrial water use, afforestation, and domestic water usage (in both South Africa and Eswatini) (Okello *et al.,* 2015). The water quality conditions are deteriorating (O'Brien *et al.,* 2019). Physical barriers in this river system and its tributaries affect the aquatic ecosystems and the pathways of important migratory fish (Kleynhans *et al*., 2015).

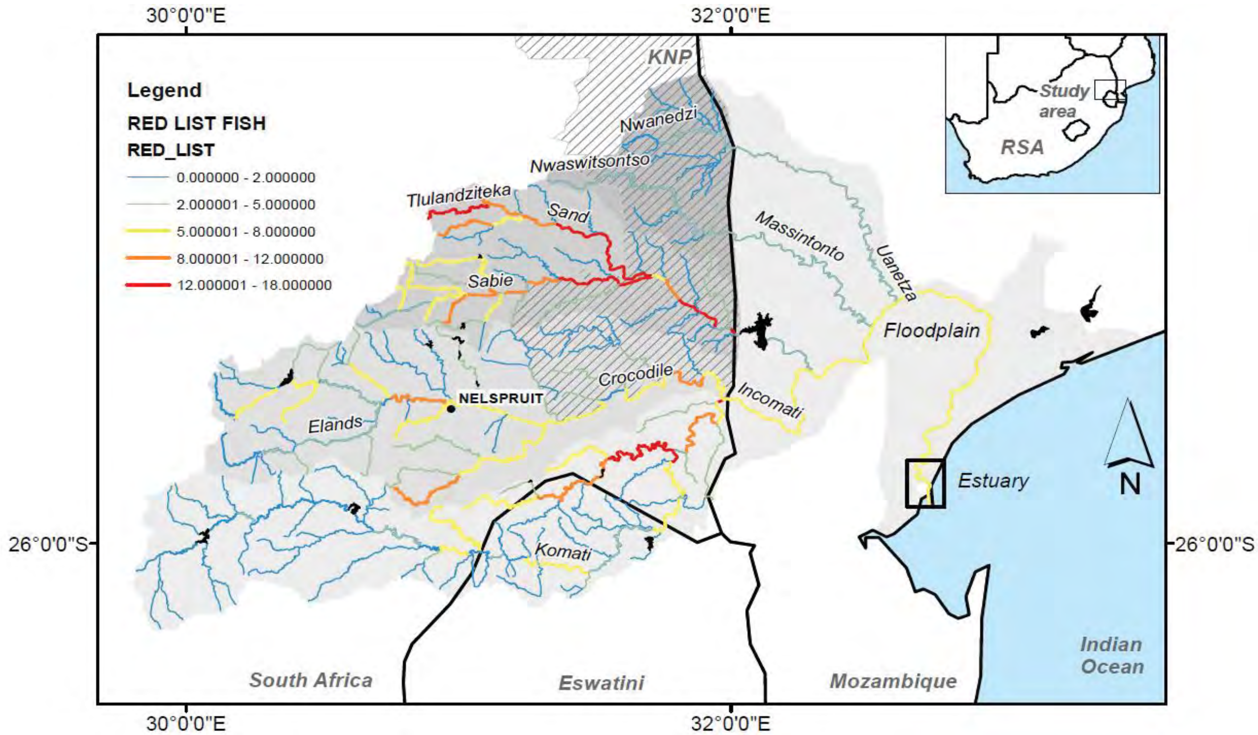


Figure 3-7: The number of Red List Fish species for the different river systems in the Incomati-Basin.

3.2.3.1.4 Connectivity barriers in the Incomati Catchment

Increasing agricultural growth and irrigation demands have led to the establishment of major dams and informal farm dams within the Incomati Basin (Figure 3-8) (Jackson, Woodford and Weyl, 2016; O'Brien *et al*., 2019). The Incomati Basin has a total of 12 major dams with > 200 informal dams (O'Brien *et al*., 2019). The two major dams that were built in this basin were the Maguga Dam in Swaziland and the Driekoppies Dam located in the Lower Incomati Basin on the Lomati River in South Africa. The Driekoppies Dam was established in 1998, and this dam was established within the reach of the Lomati River, which is a part of the Incomati River. Gauging weirs have also been constructed to regulate flow, water withdrawal and control flooding with the purpose of suppling water for irrigation (Silva *et al.,* 2018; O'Brien *et al.,* 2019). Barriers affect the migration of catadromous species, like Anguillid eels, upstream in search of suitable habitats for the completion of their life cycle and potamodromous species, like yellowfish, to feeding or spawning grounds (Branco *et al.,* 2017). Apart from blocking the migration of fish, barriers (any physical anthropogenic structure) actively change the river flow through changes to the duration, rate, frequency, and timing of water availability (Jumani *et al*., 2019). The Incomati Water Management Area (WMA) placed more than 10 fish passages for connectivity and migration of fish but none are in a functional state (Bok *et al*., 2007; O'Brien *et al*., 2019).

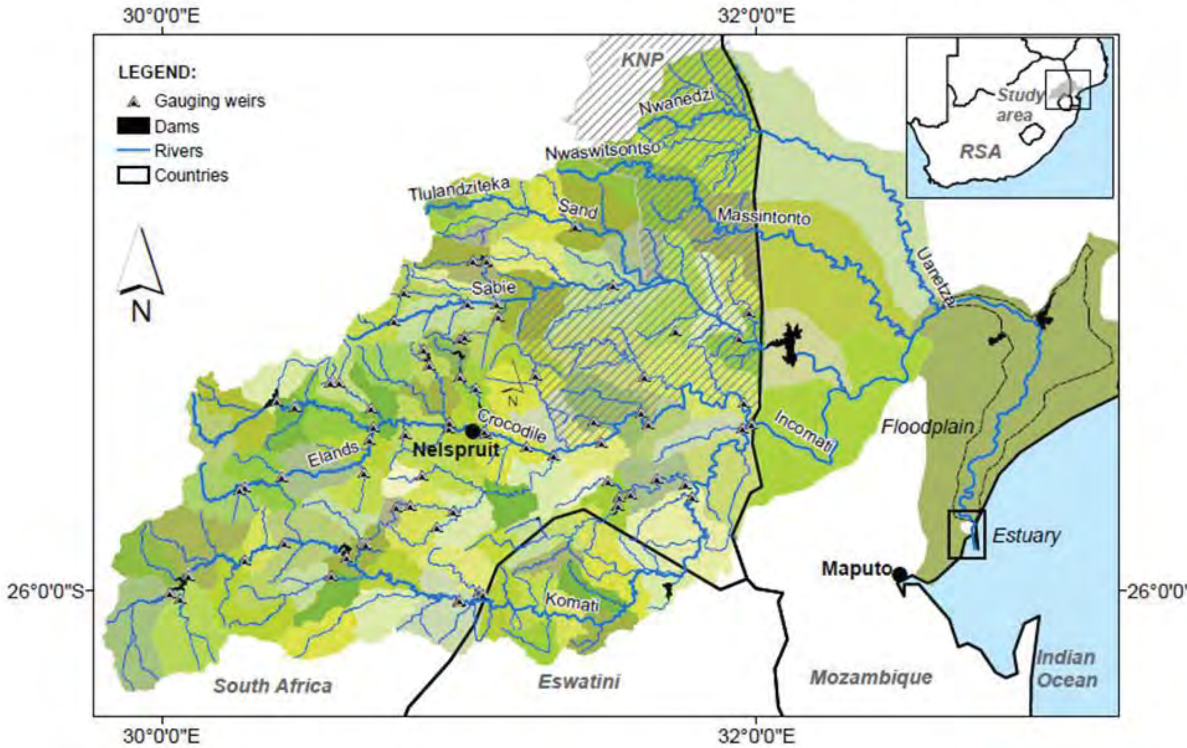


Figure 3-8: Gauging weirs and large dams within the Incomati basin (O'Brien et al., 2019).

3.2.3.2 Macroinvertebrates

Several ecosystem status surveys have been carried out by the IUCMA in different sub-catchments of the Incomati Basin in South Africa since 2012 using macroinvertebrates as indicators. The surveys use South African Scoring System version 5 (SASS5) with the Macroinvertebrate Response Assessment Index (MIRA), which are integrated with other indices to provide an integrated Ecostatus per sub-quaternary reach (Kleynhans and Louw, 2008). The ecological status for the different sub-catchments of the Incomati Basin in South Africa based on the MIRAI and SASS 5 is explain in the following sections.

3.2.3.2.1 Komati Sub-Catchment (X1)

Results provided by the IUCMA for present ecological status using MIRAI from macroinvertebrates data sampled in the Komati sub-catchment are summarised in Table 3-7. The results indicate deterioration, with sites shifting from 30% of sites in 2014 categorised largely natural to natural, and 100% of sites as moderately impaired to severely impaired in 2021. Results in 2014 and 2021 were mainly dominated by sites with conditions rated better than moderate (i.e. C category), while the 2017, 2019, 2020 and 2021 results are dominated by moderate to poor conditions (i.e. C to D category).

Table 3-7: Ecostatus summary of MIRAI results for the Komati sub-catchment between 2014 and 2021.

KOMATI SUB-CATCHMENT (X1)		SAMPLING YEAR					
		2014	2017	2018	2019	2020	2021
IUCMA PES (Aquatic Macroinvertebrates)	A	0%	0%	0%	0%	0%	0%
	A/B	4%	0%	0%	0%	0%	0%
	B	25%	0%	23%	0%	0%	0%
	B/C	17%	14%	41%	5%	0%	0%
	C	50%	86%	32%	86%	78%	83%
	C/D	0%	0%	0%	9%	17%	13%
	D	4%	0%	5%	0%	4%	4%
	D/E						
	E						
	None						
No of Sites		24	14	22	22	23	24
% Of Total Sampled		100%	58%	92%	92%	96%	100%
% On Main channel		38%	21%	41%	41%	39%	38%
% On Tributaries		63%	79%	59%	59%	61%	63%

3.2.3.2.2 Crocodile Sub-Catchment (X2)

Results provided by the IUCMA for present ecological status using MIRAI from macroinvertebrates data sampled in the Crocodile sub-catchment are summarised in Table 3-8. The 2017, 2019 and 2021 represented more sampling points, excluding the sites within the Kruger National Park. Overall, the results indicate deterioration, with sites shifting from 49 to 39% of sites in 2014 and 2017 above C-category, to 100% of sites in C-category and below from 2019 onwards.

Table 3-8: Ecostatus summary of MIRAI results for the IUCMAs regular sampling sites located in the Crocodile sub-catchment.

CROCODILE SUB-CATCHMENT (X2)		SAMPLING YEAR						
		2012	2016	2017	2018	2019	2020	2021
IUCMA PES (Aquatic Macroinvertebrates)	A	0%	0%	0%	0%	0%	0%	0%
	A/B	9%	0%	4%	0%	0%	0%	0%
	B	36%	0%	13%	0%	0%	0%	0%
	B/C	14%	10%	22%	0%	0%	0%	0%
	C	36%	81%	57%	75%	78%	68%	74%
	C/D	0%	10%	4%	25%	13%	18%	17%
	D	5%	0%	0%	0%	9%	14%	9%
	D/E							
	E							
	None							
No of Sites		22	21	23	20	23	22	23
% Of Total Sampled		92%	88%	96%	83%	96%	92%	96%
% Main channel		36%	33%	35%	40%	30%	32%	30%
% Tributaries		64%	67%	65%	60%	70%	68%	70%

3.2.3.2.3 Sabie-Sand Sub-Catchment (X3)

Results obtained for the Sabie-Sand sub-catchment are summarised in Table 3-9. The 2011 and 2016 biomonitoring represented more sampling points whereas the IUCMAs internal biomonitoring represents a few selected sites in South Africa, excluding the Kruger National Park (KNP) sites. Overall, the results indicate deterioration, with sites shifting from 85 to 54% of sites in 2011 and 2016 above C-category, to 100% of sites in C-category and below from 2017 onwards. Between 2017 and 2021, no site was in the A or B categories.

Table 3-9: Ecostatus summary of MIRAI results for the IUCMAs regular sampling sites located in the Sabie-Sand sub-catchment.

SABIE-SAND SUB-CATCHMENT (X3)		SAMPLING YEAR						
		2011	2016	2017	2018	2019	2020	2021
IUCMA PES (Aquatic Macroinvertebrates)	A	0%	0%	0%	0%	0%	0%	0%
	A/B	15%	7%	0%	0%	0%	0%	0%
	B	62%	20%	0%	0%	0%	0%	0%
	B/C	8%	27%	9%	0%	0%	0%	0%
	C	15%	27%	82%	91%	93%	88%	89%
	C/D	0%	0%	9%	9%	7%	12%	11%
	D	0%	20%	0%	0%	0%	0%	0%
	D/E							
	E							
	None							
No of Sites		13	15	11	11	15	17	18
% Of Total Sampled		72%	83%	61%	61%	83%	94%	100%
% Main channel		38%	33%	36%	36%	33%	29%	28%
% Tributaries		62%	67%	64%	64%	67%	71%	72%

3.2.3.3 Riparian vegetation

The Incomati Basin is affected by multiple stressors due to activities taking place upstream of the Basin. Altered flows is one of the stressors affecting the Basin due to impoundments and presence of multiple abstraction points that reduces flow regimes in the downstream areas (Soko and Gyedu-Ababio, 2019). The altered flow regimes result in sediments fluxes which is also a stressor on its own. Dams alter natural flow regimes and trap sediment which changes the historical channel dynamics, fluvial geomorphology and aquatic vegetation disturbance in the downstream of the river (Zaimes *et al*., 2019). In most cases, the changes have major consequences on the aquatic vegetation due to the rapid changes they cause which include bank erosion, undercut banks and exposed vegetation roots (Lytle & Poff, 2004). Altered flows can also cause vegetation dislodging as well as substrate alteration as many aquatic species rely on consistent flow patterns (Lytle & Poff, 2004). Increased flow can also promote invasive plant species spreading by getting it washed to the downstream of the river (Lytle & Poff, 2004). Species richness decline is also associated with modified high flows, as species not adapted to high flow can easily be wiped out (Lytle & Poff, 2004).

Flow alteration also has the potential to interact with water temperature by decreasing groundwater recharge and consequently lead to reduced cold groundwater inputs to rivers, potentially increasing stream temperatures (Lytle & Poff, 2004). The increase in water temperature can cause harm to the vegetation of the stream, especially temperature sensitive species as different vegetation species have different preferences (Lytle & Poff, 2004).

Mining taking place upstream of the Incomati Basin also adds to the list of stressors by contaminating the water with heavy metals that tempers with the water quality of the Basin (Soko, 2019). Mining also affects the aquatic vegetation in the Incomati Basin (Dupon, 1986). The stripping of the Earth during the mining process directly destroys the vegetation. The loose waste produced that is mostly deposited on steep slopes in rugged areas makes it more prone to erosion by water and wind (Dupon, 1986). The loose deposited material gets washed to the nearest rivers, where it forms a thick layer that buries the vegetation in the river, mostly the one located on the river banks (Dupon, 1986).

In addition, the mined mineral's effects on the environment differs depending on the mined mineral (Dupon, 1986). For example, nickel is associated with causing detrimental effects on the aquatic vegetation in rivers. It is known to cause stunted growth as well as difficulty in regeneration on plants that are contaminated with the nickel mineral (Dupon, 1986).

Furthermore, agricultural activities are also identified as contributors to multiple stressors in rivers (Withers *et al*., 2014). The application of fertilizers on agricultural lands leads to contamination of rivers by the fertilizers due to the leaching process (Withers *et al*., 2014). The timing of the application of the fertilizers by the farmers determines the impacts that will be caused. For example, the application of fertilizers in a rain season will results in the contamination of the nearest rivers with large quantities of fertilizers (Withers *et al*., 2014).

Overabundance of agricultural nutrients, especially nitrogen and phosphorus lead to overgrowth of algae and other aquatic plants in the river (Zhang *et al*., 2016). When the overabundant algae dries out, they are decomposed by bacteria that causes anoxia, causing large-scale die-offs of fish and other organisms (Zhang *et al*., 2016). Algal blooms caused by presence of nutrients in rivers can also lead to the overgrowth of toxic species of algae such as blue-green algae (Zhang *et al.,* 2016). The blue-green algae are known to cause skin rashes, nausea and respiratory problems in humans. Furthermore, animals that drink from affected water bodies are also susceptible to illness and death.

3.2.3.4 Ecosystem services

The Incomati Basin main stem, tributaries, wetlands and the estuary downstream in Mozambique, provide number of ecosystem services that are of importance to the people living along the catchment. Across the Incomati River Basin, there are a number of rural communities which primarily depend on these provisioning ecosystem services for their livelihood. There are also highly developed agriculture areas, in different parts of the basin which include, Komati, Crocodile and Sabie where sugar cane farming is mostly common. However, these agricultural farms are also detrimental to the water quality as they have resulted in pollution downstream. Moreover, there have also been high abstraction levels which have reduced amount of water available for downstream users. The upstream abstractions and developments in the Incomati River basin have had an impact on maintaining the Incomati estuary's habitat as it depends on seasonal freshwater pulses that cause the modest flooding of the floodplains which enhances the estuary's yield of shrimp, fish, fuel wood and other goods and services. As a result, the communities which rely on these water-related goods and services are affected. Besides these provisioning ecosystem services, the wetlands and estuary regulate high flow and floods and act as carbon storage. There are some areas around the basin which are important for tourism and aesthetic values.

3.3 STEP 3: RISK REGION SELECTION

Risk regions were selected for the study to align with the IUAs established for the South African portion of the basin and expanded into Eswatini and Mozambique. This allows alignment of this risk assessment with existing South African Legislation and alignment across the borders of South Africa, Eswatini and Mozambique. There have been are some exceptions to the selection of Risk Regions where for example large IUAs such as the Nels/White River IUA was separated into two risk regions one for the Nels and another for the White River. This is so the risk regions can align with the scenarios and problems that are being addressed in the study. Risk regions were also determined for Mozambique as the Mozambican legislation does not allow for the establishment of IUAs.

These risk regions allow the outputs of the study to be presented at a spatial scale with multiple regions compared in a relative manner. Through this approach, the dynamism of different regions can be incorporated into the study and allow for a holistic assessment of flow and non-flow variables. The approach can address spatial and temporal relationships of variables between risk regions, such as the downstream effect of a source of stress on multiple risk regions, in the context of the assimilative capacity of the ecosystem or the requirements of ecosystem response components, e.g. fish. The results of the PROBFLO assessment will be reported under the 42 risk regions identified in the Incomati Basin (Figure 3-9).

Once the risk regions were determined, sites were selected that were representative of the river reaches in the Incomati Basin where associated ecosystems could be used to determine the environmental flows (e-flows) required to maintain ecosystem services (regulatory, supporting, provisioning and cultural services). Criteria for site selection for the collection of data was normally based on biophysical characteristics and included representativeness of the reach considered, access to the site for bio-physical surveys, existing data, especially hydrological, and local and regional land use or resource development scenarios. Data from the sites was required to determine the flow-ecosystem and non-flow stressor and ecosystem relationships.

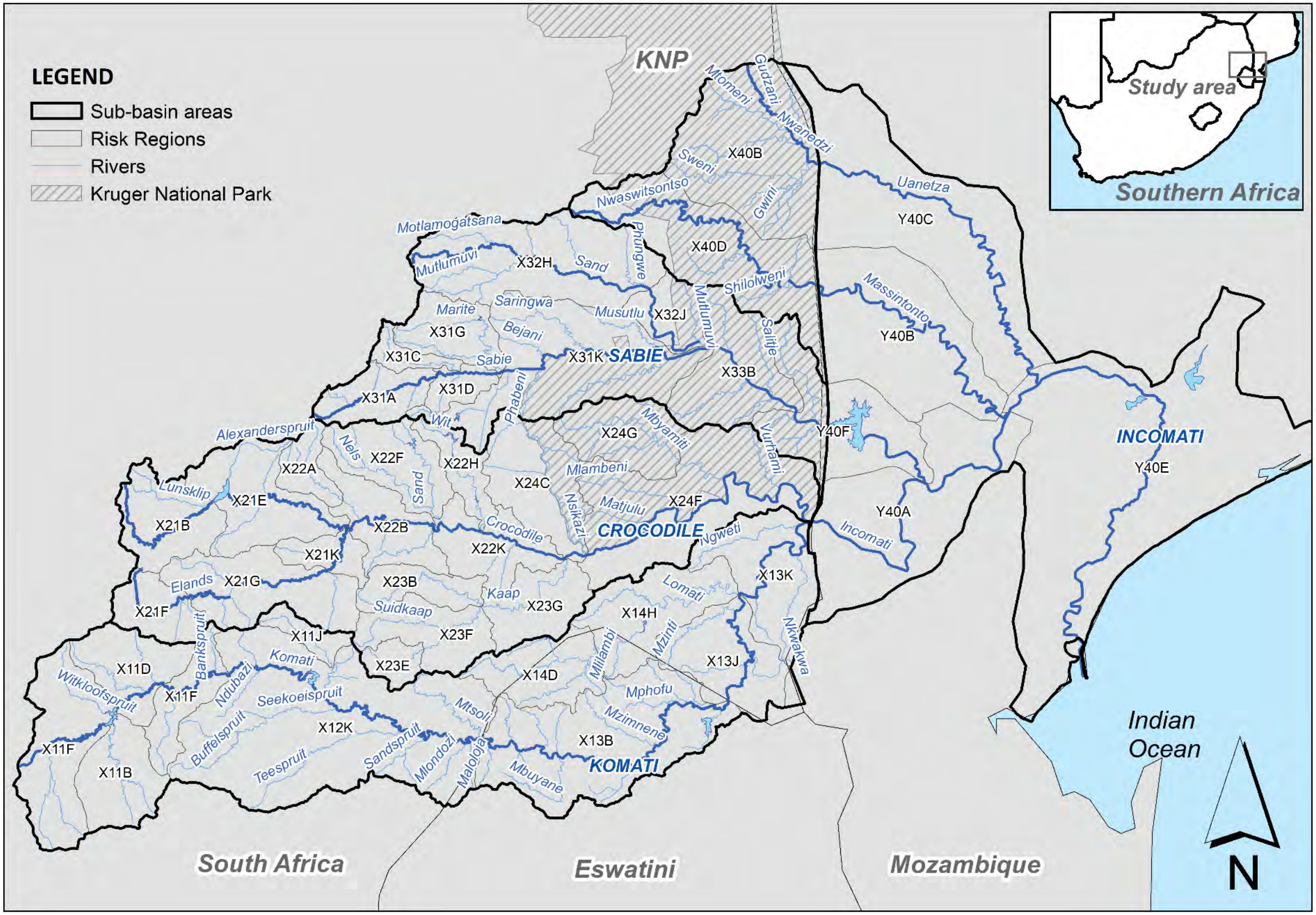


Figure 3-9: Map of the sub-basins and risk regions for the Incomati Basin risk assessment study

A total of 40 sites were selected but the size of the Incomati Basin resulted in the division of sites into different categories to optimize the field surveys. The sampling sites were divided into three different categories, namely Mega (MEG) sites (Supplementary (SUP) sites) and Other (OTH) sites (Table 3-10). The seven Mega sites were surveyed over a longer period and included an extensive reach of river (> 2.2 km) to allow for greater detail, with each site taking about 2-3 days to complete and multiple (> 2) surveys were carried out. More rapid assessments were undertaken at the seventeen SUP sites where at least two (high flow vs. low flow) comprehensive survey was carried out. Desktop assessments, with some additional biological and physical assessments, were undertaken for an additional fourteen OTH sites that were located in sub-catchments that complimented the Mega or Support sites. Figure 3-10 illustrates the location of all these sites located in South Africa, Mozambique and Eswatini.

Table 3-10: List of sites to be included in the ecological risk assessment framework and associated recommended ecological category per site (DWS, 2019).

SITE NAME	CATEGROTY	IUA	CLASS	REC	CODE	RIVER	DESCRIPTION	LATITUDE	LONGITUDE
					UANETZA CATCHMENT				
X40B Uanetza	SUP	X4-1U	1	B	X40B	Uanetza	Uanetza KNP seasonal	-24.451542	31.994502
Y40C Uanetza	SUP	Y1-1	1	C	Y40C	Uanetza	Uanetza in Mozambique	-24.982093	32.571741
					MASSINTONTO CATCHMENT				
X40D Massintonto	SUP	X4-1M	1	B	X40D	Massintonto	Massintonto KNP seasonal	-24.783770	31.978932
Y40B Massintonto	SUP	Y1-3	1	C	Y40B	Massintonto	Massintonto in Mozambique	-24.903239	32.346172
					SABIE CATCHMENT				
X31A Sabie	SUP	X3-1	1	B	X31A	Sabie	Sabie River at Merry pebbles	-25.121000	30.717000
X31C Mac-Mac	OTH	X3-2	1	B	X31C	Mac-Mac	MacMac/Mac Mac/4	-25.013330	31.004050
X31D Sabie	OTH	X3-2	1	B	X31D	Sabie	2Sabie at EWR-S	-25.027920	31.051660
X31G Marite	OTH	X3-2	1	B/C	X31G	Marite	Marite/Marite/5	-25.017950	31.133280
X31K Sabie	MEG	X3-3	3	B	X31K	Sabie	Sabie/KNP/3	-24.987590	31.292870
X32H Sand	SUP	X3-8	2	B	X32H	Sand	Sand River at Exeter	-24.769709	31.388545
X32J Sand	OTH	X3-9	1	B	X32J	Sand	Sand at EWR-S8	-24.967420	31.627340
X33B Sabie	MEG	X3-6	1	B	X33B	Sabie	Sabie River at Lower Sabie	-25.109384	31.907326
Y40F Sabie	SUP	Y1-5	2	C/D	Y40F	Sabie	Sabie River in Mozambique	-25.269875	32.273776
					CROCODILE CATCHMENT				
X21B Crocodile	OTH	X2-1	2	B	X21B	Crocodile	Crocodile at EWR-C2	-25.409250	30.315920
X21E Crocodile	OTH	X2-2	2	B/C	X21E	Crocodile	Crocodile at EWR-C3	-25.452110	30.681080
X21F Elands	OTH	X2-3		B	X21F	Elands	Elands River at Emgwenya	-25.631000	30.325700
X21G Elands	SUP	X2-4	1	B	X21G	Elands	Elands River at Nsinini	-25.623031	30.397948
X21K Elands	MEG	X2-5	1	C	X21K	Elands	Elands River at Roodewal	-25.569221	30.662930
X22A Houtbosloop	OTH	X2-7	1	C	X22A	Houtbosloop	Houtbosloop	-25.355160	30.665910
X22B Crocodile	SUP	X2-6	2	C	X22B	Crocodile	Rivulets	-25.430069	30.757960
X22F Nels	SUP	X2-8	2	C/D	X22F	Nels	Nels at UMP	-25.428142	30.965178
X22H White River	SUP	X2-8	2	D	X22H	White River	Lower White River	-25.462396	31.082854
X22K Crocodile	SUP	X2-9	2	C	X22K	Crocodile	Crocodile at Kanyamazane	-25.501687	31.180050
X23B Noordkaap	SUP	X2-10N	2	C	X23B	Noordkaap	Noordkaap	-25.656522	31.075219
X23E Queens	SUP	X2-10Q	2	B/C	X23E	Queens	Queens	-25.739860	30.998596

SITE NAME	CATEGROTY	IUA	CLASS	REC	CODE	RIVER	DESCRIPTION	LATITUDE	LONGITUDE
X23F Suidkaap	SUP	X2-10S	2	C	X23F	Suidkaap	Suidkaap	-25.716048	31.056677
X23G Kaap	MEG	X2-10K	2	C	X23G	Kaap	Kaap River at Honeybird	-25.649406	31.242640
X24C Nsikazi	OTH	X2-12	2	B	X24C	Nsikazi	Nsikazi	-25.521647	31.368499
X24F Crocodile	MEG	X2-13	1	C	X24F	Crocodile	Crocodile at Van Graan	-25.438058	31.637947
X24G Mbyamiti	OTH	X2-13	1	B	X24G	Mbyamiti	Mbyamiti	-25.312103	31.716999
KOMATI CATCHMENT									
X11B Boesmanspruit	OTH	X1-1	2	B/C	X11B	Boesmanspruit	Boesmanspruit	-26.024106	30.060851
X11D Klein Komati	OTH	X1-3	2	C	X11D	Klein Komati	Klein Komati (possible new site)	-25.887745	30.120044
X11F Komati	OTH	X1-3	2	C	X11F	Komati	Komati at EWR-K1	-25.854210	30.376640
X11J Gladdespruit	SUP	X1-4	3	D	X11J	Gladdespruit	Gladdespruit	-25.771720	30.627170
X12K Komati	OTH	X1-6	1	D	X12K	Komati	Komati at EWR-K2	-26.038810	31.003140
X13B Komati	SUP	X1-11	2	D	X13B	Komati	Komati River at Silingani	-26.098390	31.398750
X13J Komati	MEG	X1-9	3	D	X13J	Komati	Komati weir below Eswatini	-25.928497	31.759773
X13K Komati	SUP	X1-10	3	D	X13K	Komati	Lower Komati River	-25.505497	31.897398
X14D Lomati	OTH	X1-7	2	C	X14D	Lomati	Lomati	-25.818599	31.311799
X14H Lomati	SUP	X1-8	3	C	X14H	Lomati	Lomati River at Kleindoringkop	-25.649450	31.623200
INCOMATI CATCHMENT									
Y40A Incomati	MEG	Y1-2	3	C/D	Y40A	Incomati	Incomati in Mozambique	-25.324015	32.253866
Y40E Flood Incomati		Y1-4	2	B/C	Y40E	Incomati	Incomati Floodplain	-25.022089	32.775812

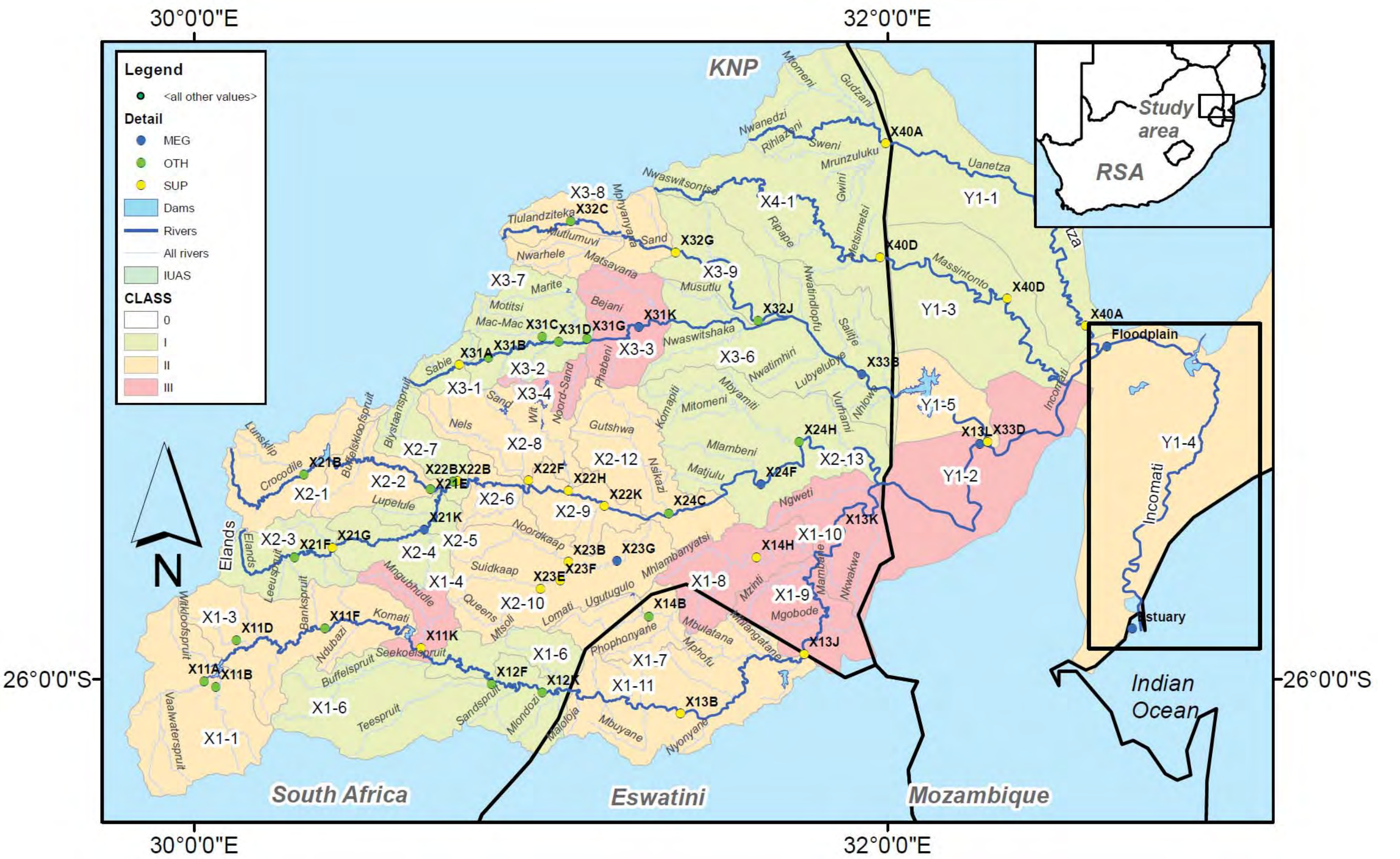


Figure 3-10: The Incomati Basin with Integrated Units of Analysis, management classes, major rivers and sampling sites selected for the risk assessment study.

3.4 STEP 4: CONCEPTUAL MODEL

The basic conceptual model that is used is shown in Figure 3-11, and depicts how the SOURCES (use activities of change (dam development, etc.) lead to STRESSORS on the river (altered timing of flows, volumes of water, etc.). These in turn affect either the instream, riparian or floodplain HABITATS, where most of the RECEPTORS (Instream biota, etc.) will be impacted. These in turn impact on socio-ecological ENDPOINTS (supply of water for agriculture, biodiversity, etc.).

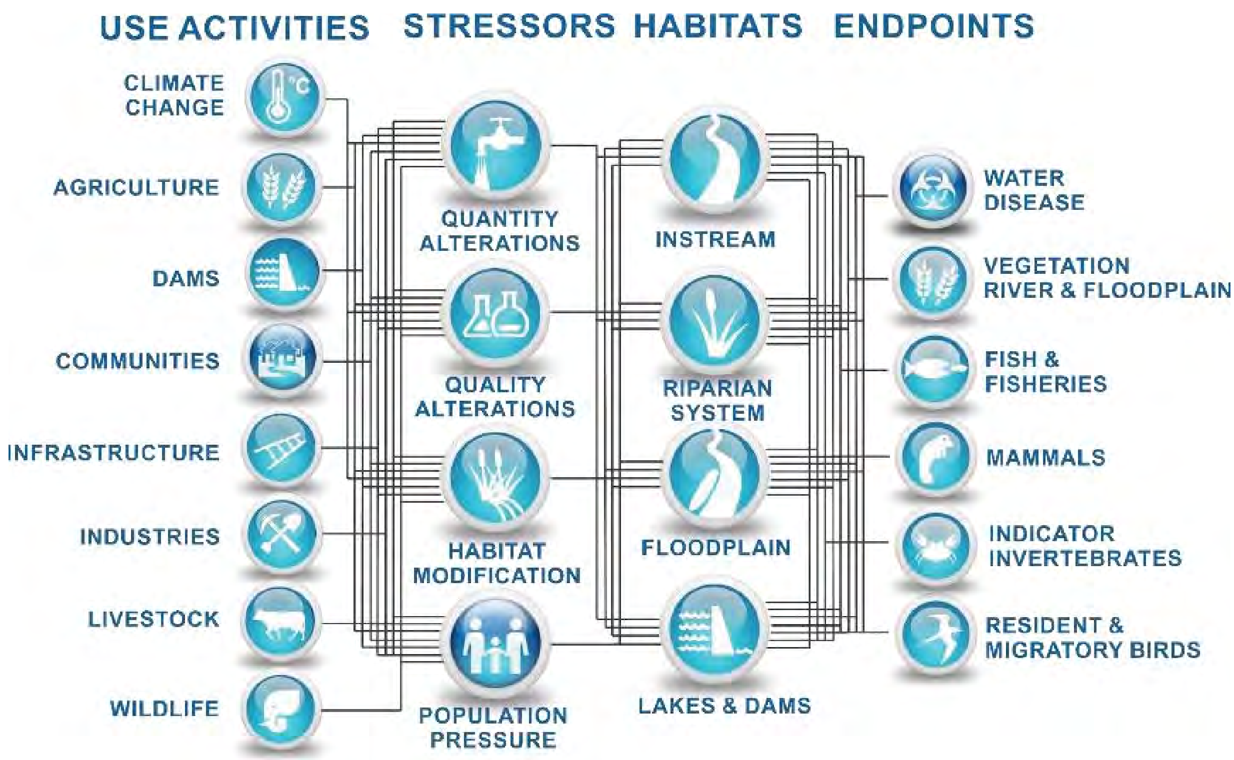


Figure 3-11: Conceptual model of the socio-ecological system for the Incomati Basin

The generalized conceptual model in Figure 3-11 is expanded specifically for this study and is shown in Figure 3-12. What is shown here is produced using mind-mapping software (FreeMind), which is done for purely illustrative purposes as the detailed map was built in Bayesian Network (BN) software (Norys Netica). Important to note is while the natural sequence of model development and the direction of stress on the ecosystem would be from left to right in this model, when we determine relationships we start working from the right and move towards the left. Thus, for each Endpoint (shaded below), those factors required to support that Endpoint are documented (i.e. the yellow and pink nodes), and so on moving to the left. The links between variables indicate that one variable is conditionally dependent on the other.

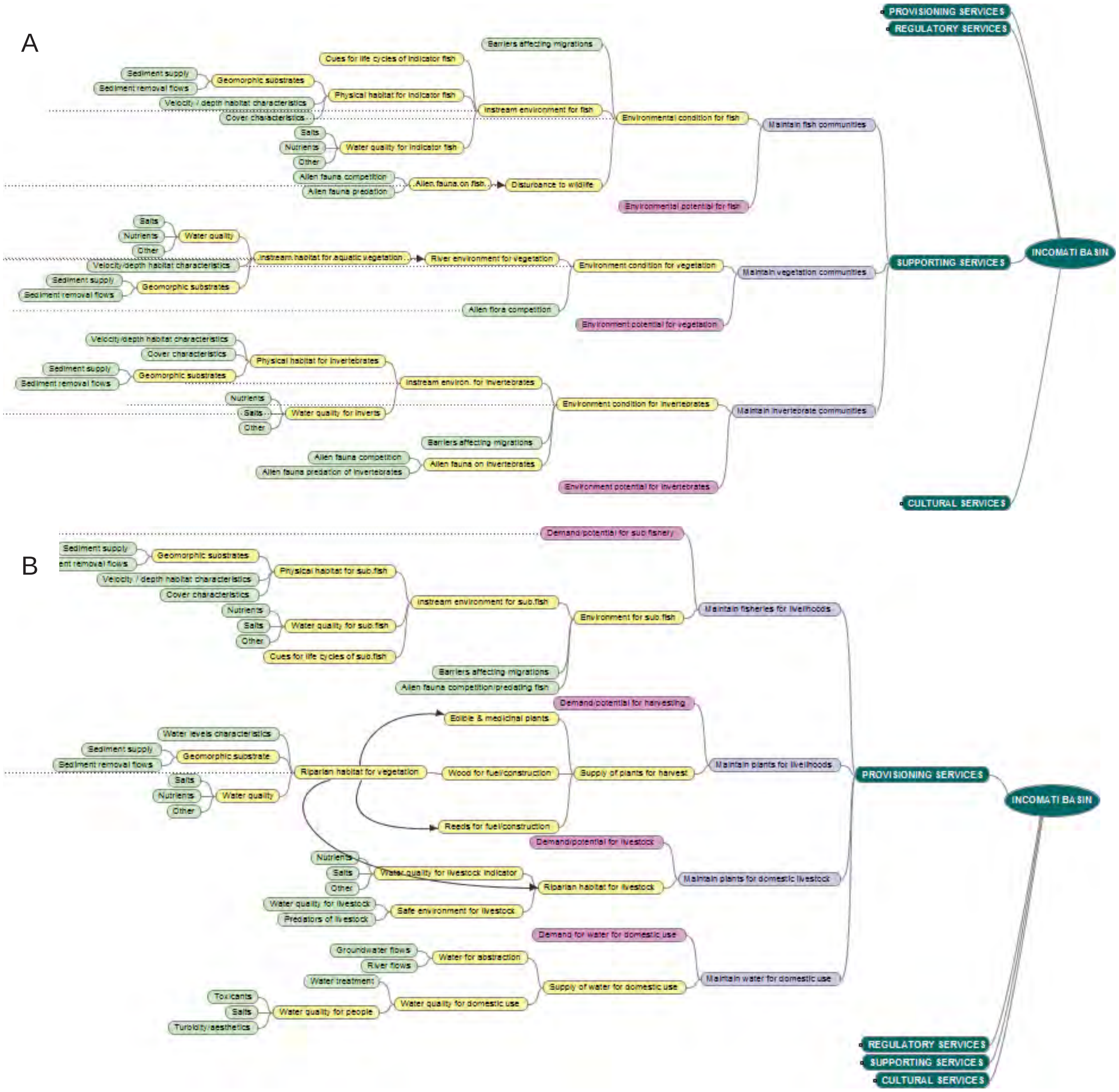


Figure 3-12: Conceptual model of the socio-ecological system for the Incomati Basin. (A. supporting services, B. provisioning services, C. regulatory services and D. cultural services

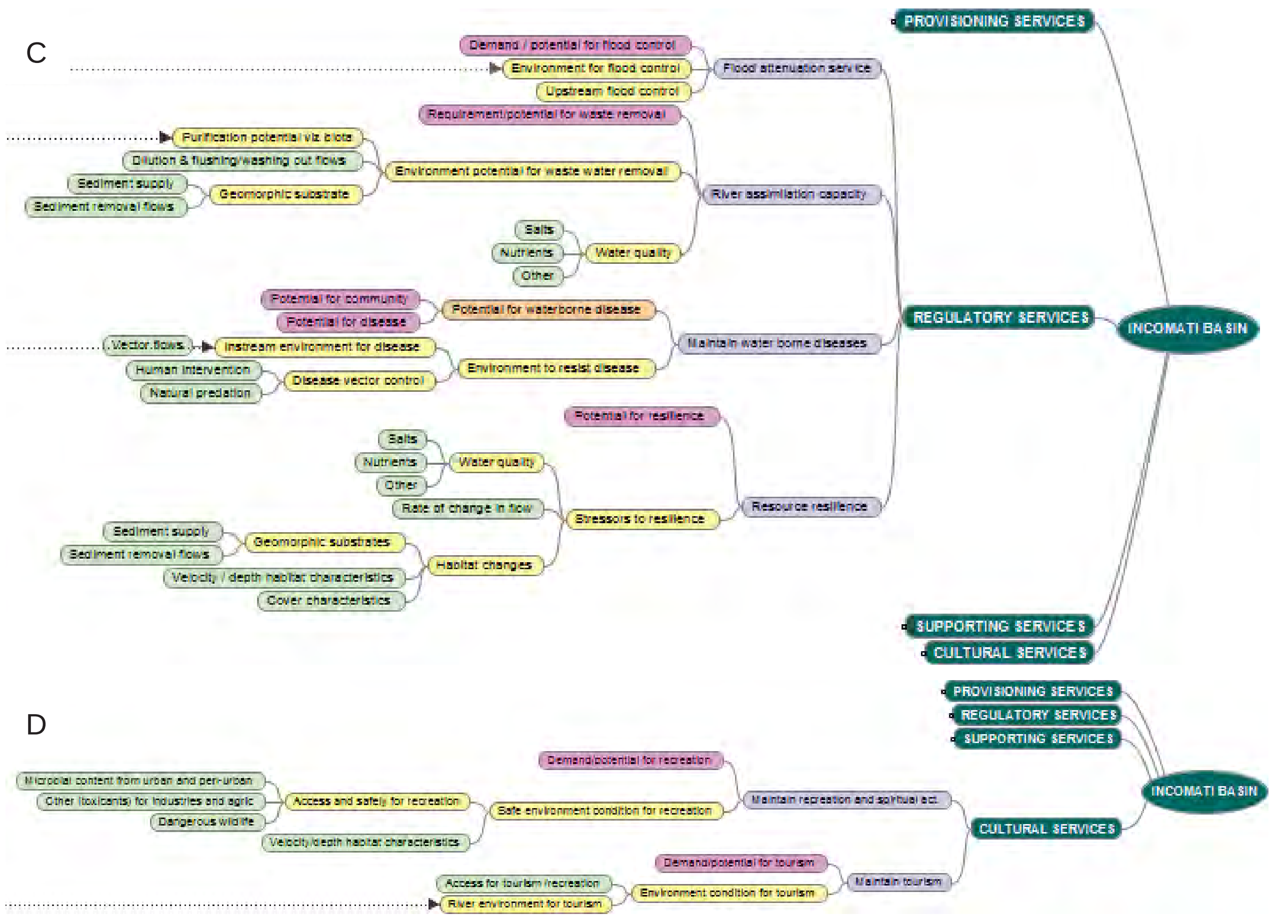


Figure 3-12 (Continued): Conceptual model of the socio-ecological system for the Incomati Basin. (A. supporting services, B. provisioning services, C. regulatory services and D. cultural services

Figure 3-13 is an extract taken from the conceptual model and to explain it, it is necessary to start from the right-hand side, with the determination of the risk of multiple flow (and non-flow) stressors to the ecosystem services endpoints.

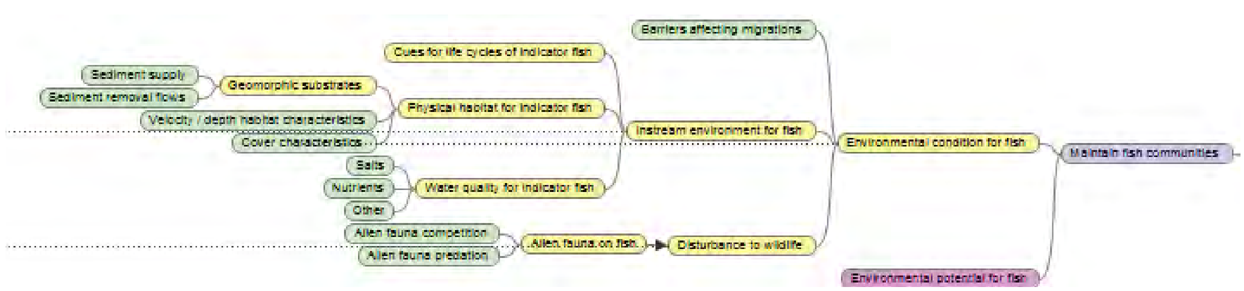


Figure 3-13: Maintain fish communities extract of the conceptual model

- The risk to the fish endpoint (MAINTAIN FISH COMMUNITY NODE) is a function of the environmental conditions that support or pose a threat to fish (ENVIRONMENTAL CONDITION

FOR FISH NODE) and the potential diversity and sensitivity of fishes that may occur at the site (ENVIRONMENTAL POTENTIAL FOR FISH NODE). The data available to represent the potential for fish is available from historical data and survey results from the study area.

- The ENVIRONMENTAL CONDITIONS node is a function of the presence of, and potential for, barriers to affect river connectivity and fish migrations (BARRIERS AFFECTING FISH MIGRATION NODE), INSTREAM ENVIRONMENT FOR FISH and DISTURBANCE TO WILDLIFE potential which is in itself a function of alien fauna (ALIEN FAUNA ON FISH).
- The data required for barriers to fish movement has been derived from a dam database, while the instream environment for fish itself is a function of CUES FOR LIFE CYCLE ACTIVITIES for fish, the PHYSICAL HABITAT FOR INDICATOR FISH and WATER QUALITY REQUIREMENTS FOR FISH. The cue node represents our knowledge of the flow requirement of migratory and summer (high flow) spawning fishes and the instream habitat characteristics of the river for these cues based on the volume and timing of flows. Available and new information obtained in this study that represents the timing and volume of water required for these indicator fish, has been used to establish a flow-ecosystem relationship that will query available flow data and represent the suitability of flows for those species.
- The PHYSICAL HABITAT FOR INDICATOR FISH node is a function of the geomorphic substrate (NODE) characteristics, velocity/depth habitat characteristics (NODE) of indicator fishes and cover characteristics (NODE) for indicator fishes. The WATER QUALITY INDICATOR FOR FISH node represents the overall condition of water quality including consideration of the salts, nutrients and other (system variables and toxicants).

All input nodes are evidence-based and use existing or collected (in this study) and modelled data to represent a flow (or non-flow for water quality and geomorphology characteristics) relationship with ecological variables. All of the daughter nodes are conditional to the parent nodes and integrate response relationship distributions in the form of parent nodes using Conditional Probability Tables or rules that represent how the data is integrated. These relationships are also all presented as evidence for the model. These relationships are then represented in a BN model (Figure 3-14) using the Norys Netica software. The structure incorporates the ecological risk assessment framework where the risk exposure is represented by the input green and yellow nodes. This represents how the ecosystem is threatened by flow and non-flow stressors. The pink nodes introduce risk region or site dynamics which represents the exposure pathways of the risk framework.

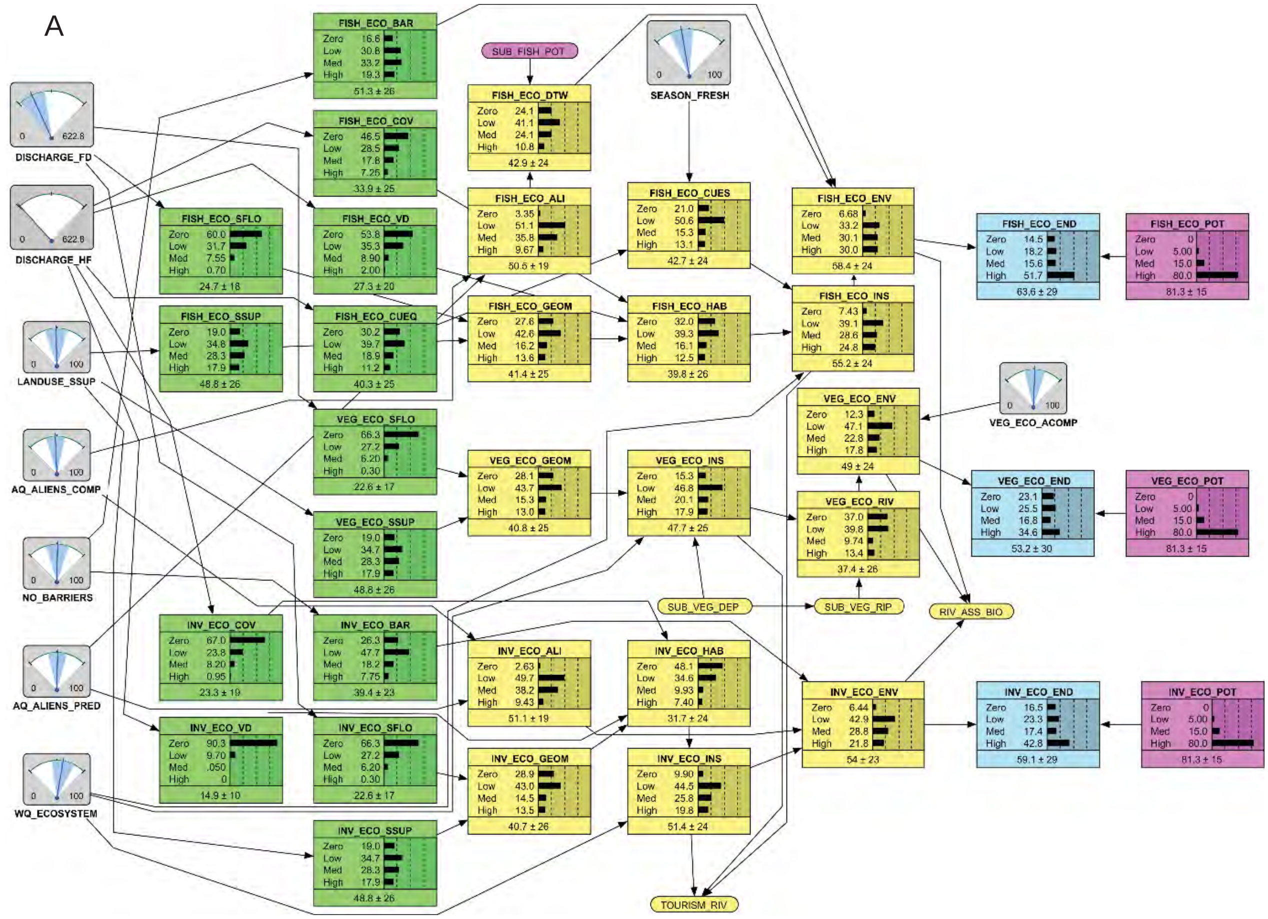


Figure 3-14: Bayesian network developed using Netica software for the Incomati Basin. (A: Supporting services, B: Provisioning Services, C: Regulatory services, D: Cultural services) Green nodes represent input environmental variable information related to the exposure of the system by multiple stressors. Yellow nodes integrate input information to represent the exposure of the large system. The pink node represents the potential for subsistence fishermen to occur in a Risk Region that represents the effects part of the risk model. The blue node represents the endpoint.

B

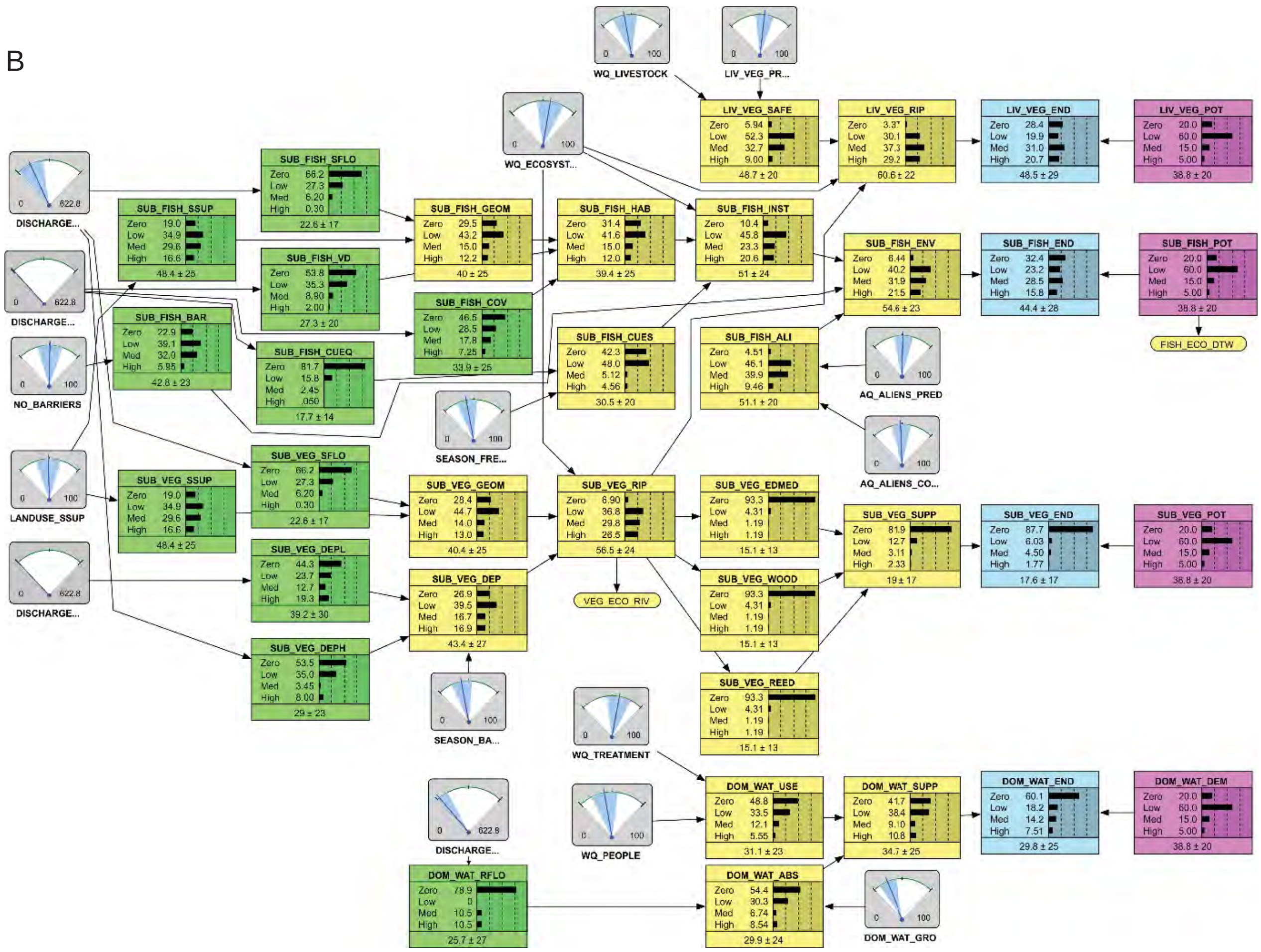


Figure 3-14 (Continued): Bayesian network developed using Netica software for the Incomati Basin. (A: Supporting services, B: Provisioning Services, C: Regulatory services, D: Cultural services) Green nodes represent input environmental variable information related to the exposure of the system by multiple stressors. Yellow nodes integrate input information to represent the exposure of the large system. The pink node represents the potential for subsistence fishermen to occur in a Risk Region that represents the effects part of the risk model. The blue node represents the endpoint.

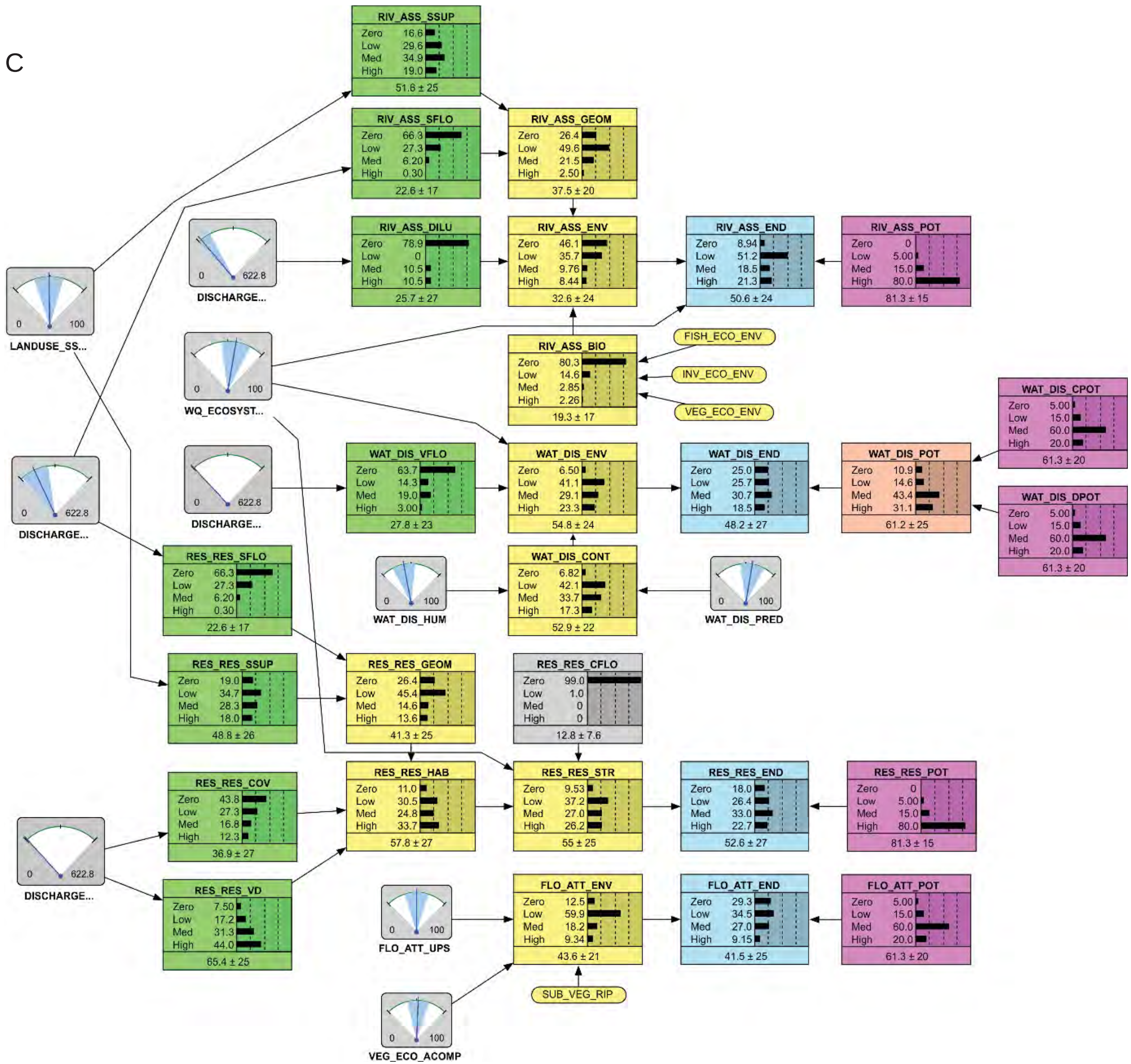


Figure 3-14 (Continued): Bayesian network developed using Netica software for the Incomati Basin. (A: Supporting services, B: Provisioning Services, C: Regulatory services, D: Cultural services) Green nodes represent input environmental variable information related to the exposure of the system by multiple stressors. Yellow nodes integrate input information to represent the exposure of the large system. The pink node represents the potential for subsistence fishermen to occur in a Risk Region that represents the effects part of the risk model. The blue node represents the endpoint.

D

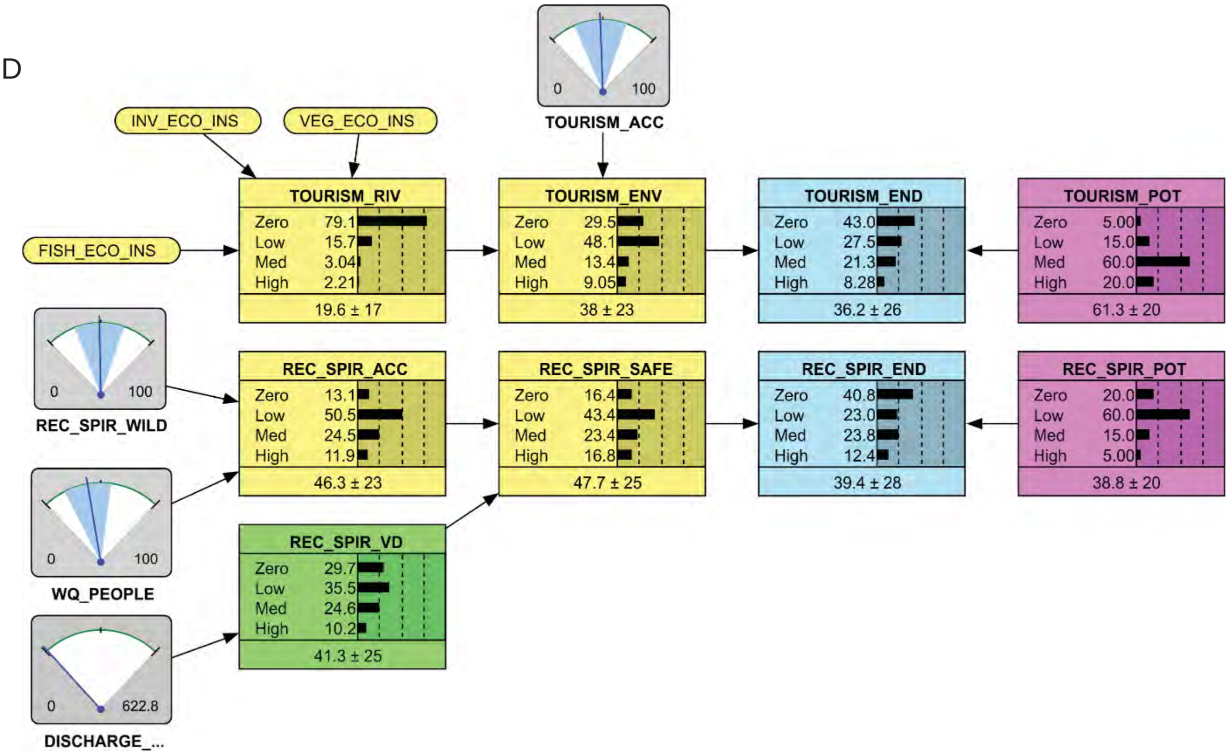


Figure 3-14 (Continued): Bayesian network developed using Netica software for the Incomati Basin. (A: Supporting services, B: Provisioning Services, C: Regulatory services, D: Cultural services) Green nodes represent input environmental variable information related to the exposure of the system by multiple stressors. Yellow nodes integrate input information to represent the exposure of the large system. The pink node represents the potential for subsistence fishermen to occur in a Risk Region that represents the effects part of the risk model. The blue node represents the endpoint.

3.5 STEP 5: RANKING SCHEME

The ranking scheme allows for the calculation of relative risk for each endpoint and represents the range of well-being conditions, levels of impacts and management ideals as detailed in Table 3-11 (O'Brien *et al.*, 2018; Wade *et al.*, 2020). These ranks are based on the four states traditionally used in RRM, namely zero, low, moderate and high (Colnar & Landis, 2007; O'Brien and Wepener, 2012; Hines & Landis, 2014). Zero risk usually represents a reference state with low-risk states representing management targets with little impact. Moderate-risk states represent partially suitable ecosystem conditions that usually warrant management/mitigation measures to avoid high-risk conditions that are deemed unacceptable. The incorporation of BN modelling into PROBFLO, allows the approach to incorporate the variability between ranks as a percentage for each rank. Indicator flow and non-flow variables are selected (linked to endpoints), and unique measures and units of measurement are converted into and represented by ranks for integration in BN assessments (O'Brien *et al.*, 2018).

Table 3-11: Ranking scheme selected for the Incomati Basin risk assessment study (O'Brien et al., 2018)

State and score	Description
Zero (0-0.25)	Pristine/baseline/reference state with no impact or risk compared to the pre-anthropogenic source establishment
Low (0.26-0.5)	Largely natural state with low impact /risk, ideal range of sustainable ecosystem use
Moderate (0.51-0.75)	Moderate use/risk/impact or modified state representing a threshold of potential concern and possible failure threshold
High (0.76-1)	Significantly altered/impaired state with unacceptably high impact/risk

3.6 STEP 6: CALCULATING RISK

3.6.1 DRIVERS OF ECOSYSTEM CHANGE

This section provides a summary of the status quo of the factors that are directly affected by land-use changes and developments, as well as by climate change, and have a direct impact on the instream and riparian ecosystem. Each of these factors are pivotal in understanding what drives the system, so that the required amounts of water at the right time can be estimated. These drivers of ecosystem change include; water quality and ecotoxicity, hydrology and hydraulics and geomorphology.

3.6.1.1 WATER QUALITY AND ECOTOXICOLOGY

3.6.1.1.1 Water quality and ecotoxicological approach

Water quality can be defined as the combined effect on a 'user' of the physical attributes and chemical constituents of a waterbody or sample of water. The idea of water "quality" is a human construct, implying value or usefulness, with the quality of any sample of water being dependent on the point of view of the 'user'. Water quality differs from continent to continent, and region to region, as a result of differences in climate, geomorphology, geology and soils, and biotic composition. The variables used to measure water quality can be grouped into three categories – physical, chemical, and microbiological.

The aim of this section is to provide a summary of the available water quality data / information to undertake the eFlow water quality assessment, identify the data gaps and provide insight into the data analysis for inclusion into the conditional probability tables (CPTs) that are crucial to the development of the Bayesian risk model. Historical data were obtained from the Department of Water and Sanitation Water Management System (WMS) data base, current water quality data were supplied by the IUCMA and for sites where no data were available, water samples were collected and analysed in the laboratories of the Water Research Group (NWU).

Sub-surface water samples were collected in triplicate in 250 mL acid-washed polypropylene bottles. Samples were frozen and kept at -20°C until further analyses. In the laboratory water samples were thawed and analysed using Merck photometric test kits. Samples were tested for nitrates (NO_3^{2-} as N) (09713), nitrite (NO^{2-} as N) (*Merck photometric test kit no:* 14776), sulphate (SO_4^{2-}) (*Merck photometric test kit no:* 14791), turbidity (measured in NTU), chemical oxygen demand (COD) (*Merck photometric test* *kit no:* 01796), chloride (Cl^-) (*Merck photometric test kit no:* 14897), ammonium (NH_4^+ as N) (*Merck photometric test kit no:* 14752) and inorganic phosphate (PO_4^{2-} as P) (*Merck photometric test kit no:* 14848) using a Merck Pharo 100 Spectroquant.

Defrosted water samples (50 mL) were filtered through pre-weighed cellulose nitrate filter paper (0.45 µm pore size). Filtered samples were transferred to 50 mL volumetric flasks and then acidified to 1% nitric acid using 50 µL of 65% nitric acid. Metal concentrations were determined using Inductively coupled plasma mass spectrometry (ICP-MS) (Agilent technologies, 7500CE) for the following metals Ag, Al, As, B, Ba, Ca, Cd, Co, Cu, Fe, K, Mg, Mn, Mo, Ni, Pb, Ti, Se, Sr, U, V and Zn. Chromium concentrations were measured with a PerkinElmer Analyst 900 graphite furnace atomic adsorption spectrophotometer (GF-AAS) equipped with Zeeman-effect background correction. All metal concentrations are expressed as mg/L and µg/L.

To address the toxicological consequences of exposure to pollutants of concern a species sensitivity distribution (SSD) approach was used. An SSD is a probabilistic model for the variation of the sensitivity of biological species for one particular toxicant or a set of toxicants. The toxicity endpoint considered may be acute or chronic in nature. The models are probabilistic in that in their basic form the species sensitivity data are only analysed with regard to their statistical variability. The aim of a SSD analysis is to determine a chemical concentration protective of most species in the environment. Usually a point estimate known as the HC5 (hazardous concentration for 5% of species), or the 95% protection level (Van Straalen and Van Rijn, 1998) is calculated. SSDs are constructed using a cumulative plot of logarithmically transformed toxicity endpoints (e.g. NOECs or LC50s) against rank assigned percentiles for each value to which a statistical distribution is fitted.

The level of protection chosen for deriving the guideline trigger levels for the Australian and New Zealand water quality guidelines, was protection of 95% of species with a 95% level of certainty, at least where there were sufficient data to satisfy the requirements of the method. The Dutch use a 95% level of protection with 50% certainty (95,50), whereas the Danish suggest a 95,95 approach. There will always be the criticism that 95% level of protection may not protect normal ecosystem functions and may not protect important or keystone species (ANZECC 2000). This type of criticism can be levelled at any approach. It can be overcome by increasing the level of protection to 99% but this would markedly increase the level of uncertainty in the tail of the distribution. For the purposes of this study, HC1 and HC5 with varying levels of certainty were calculated for all the toxicants of concern, using both the acute (LC50) and chronic (EC50) data sets. For the purposes of this study the four fitness for use classes were allocated percentile hazard concentrations (HCp's), or conversely protection concentrations with different levels of certainty for each class. A brief summary of the selection of the different HCp's and corresponding fitness for use classes is given below (Figure 3-15):

- The 99% level with 50% certainty (HC1, 50) represents conditions in a "Good" class.
- The 95% level of protection and between 75 and 95% certainty (HC5, 5-25) represents a slightly modified class – "Tolerable" system. A 95% level of protection, should be sufficient to protect the ecosystem provided keystone species are considered (it should be emphasised that increasing the certainty level from 50% to 95%, i.e. 95,95 results in a condition which, in practice, would actually protect considerably more than 95% of species in most cases and frequently over 99%).
- The 95% level of protection and between 50 and 75% certainty (HC5, 25-50) represents a moderately modified class – "Poor" system.
- The 95% level of protection with less than 50% certainty (HC5, > 50) represents an unacceptably modified class – "Unacceptable" system.

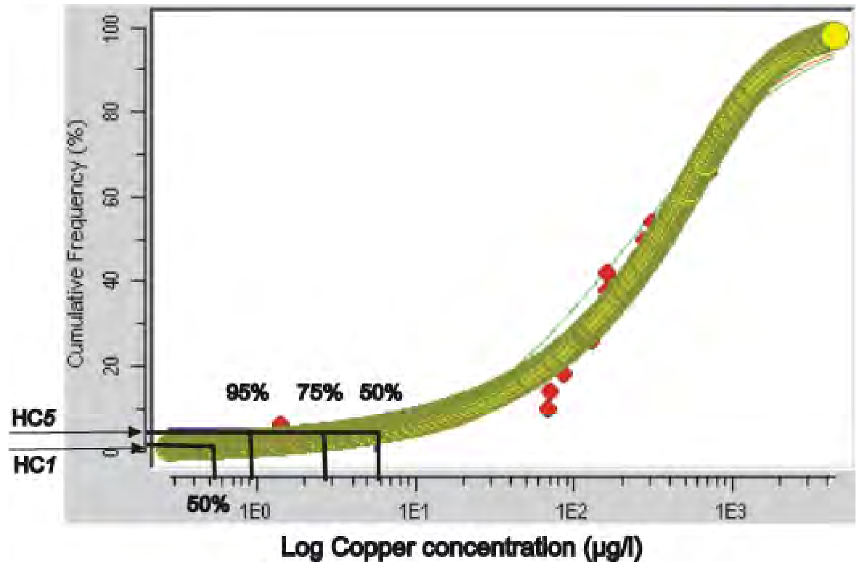


Figure 3-15: Bootstrap regression (501 replicates) applied to a sample SSD and 95% certainty for HC1 and 5, 25 and 50% point-wise percentiles for HC5 were calculated through bootstrap regression with data superimposed (closed circles). Data are acute toxicity effect concentration (LC50) endpoints for copper, n=25, extracted from the aquatic toxicity information retrieval (ECOTOX) database.

In this study the only two toxicants that exceeded Target Water Quality Guidelines (TWQGs) were As and Mn at limited sites in the Kaap River tributary of the Crocodile River. Therefore, these are the only metals that are provided for the relevant sites in this report.

3.6.1.1.2 Water quality status

The historical and current water quality status of the selected sites are presented in the following tables as well as the available RQOs for the and the DWS TWQGs. Note that there were no data for the Uanetsa and Massintonto sites in the Kruger National Park and Mozambique. However taking into consideration that the catchments are localised within the KNP, it is unlikely that the water quality would deteriorate due to anthropogenic activities.

3.6.1.1.2.1 Sabie catchment

The historical and current water quality status for sites in the Sabie catchment are provided in Table 3-12. Water quality variables that were responsible for a decrease in the water quality at the X31A and X31K Sabie sites was elevated E. coli counts. The X32H Sand site also recorded elevated E. coli counts, as well as elevated turbidity and ammonia levels. The X33B Sabie site recorded high E. coli counts and slightly elevated nutrients that are most likely the result of large mammals (e.g. high density hippo pods). The water quality issues are the lower Y40F Sabie site are likely to be elevated E. coli counts when considering upstream levels that were recorded. However, the role of Corumana Dam in acting as sink is not known.

Table 3-12: Comparison between historical and current water quality at sites within the Sabie catchment. Historical data are represented as the mean and range for the period, while current water quality data are represented by the average for the two sampling years. N/A represents no available data.

Site	Historical	Current	RQOs
X31A Sabie River (EWR-S1)			
Sampling period	2007-2019	2022-2023	
EC (µS/cm)	107 (50-1180)	45.3	≤ 300 µS/m (95th percentile)
pH	7.59 (5.89-8.32)	7.64	
Na (mg/L)	1.53 (1.5-2)	N/A	
K (mg/L)	2.08 (1.3-2.09)	N/A	
Cl (mg/L)	2.5 (0.35-35)	N/A	
SO_4^{2-} (mg/L)	2.5 (1.5-25)	N/A	
$NO_2 + NO_3$ (mg/L)	0.178 (0.025-16)	0.24	
PO_4^{2-} (mg/L)	0.05 (0.005-2.9)	< 0.01	≤ 0.015 mg/L (50th percentile)
NH_4^+ (mg/L)	0.025 (0.025-4.6)	0.1	
Turbidity	N/A	N/A	10% variation from background levels
E. coli (cfu/ 100 mL)	N/A	770	< 130 cfu / 100 mL
X31K Sabie River (X3-4)			
Sampling period	2006-2019	2022-2023	
EC (µS/cm)	129 (47-80.9)	95	≤ 300 µS/m (95th percentile)
pH	7.74 (6.27-9.2)	7.27	
Na (mg/L)	6.64 (6.57-6.7)	N/A	
K (mg/L)	2.02 (1.87-2.16)	N/A	
Cl (mg/L)	8 (2.5-82)	N/A	
SO_4^{2-} (mg/L)	2.5 (1.5-17)	N/A	
$NO_2 + NO_3$ (mg/L)	0.236 (0.025-4.4)	0.41	
PO_4^{2-} (mg/L)	0.05 (0.005-8.3)	0.01	≤ 0.025 mg/L (50th percentile)
NH_4^+ (mg/L)	0.1 (0.025-27.5)	0.065	
Turbidity	N/A	N/A	10% variation from background levels
E. coli (cfu/ 100 mL)	N/A	1553	< 130 cfu / 100 mL
X32H Sand River (EWR-S8)			
Sampling period	1977-2018	2022-2023	
EC (µS/cm)	157 (49-458)	171	≤ 400 µS/m (95th percentile)
pH	7.66 (5.94-855)	7.48	
Na (mg/L)	17.3 (3.04-59)	N/A	
K (mg/L)	1.29 (0.15-5.97)	N/A	
Cl (mg/L)	14.4 (3.7-68.7)	N/A	
SO_4^{2-} (mg/L)	4.4 (0.6-49.8)	N/A	
$NO_2 + NO_3$ (mg/L)	0.04 (0.005-1.68)	0.32	
PO_4^{2-} (mg/L)	0.021 (0.003-0.986)	0.041	≤ 0.125 mg/L (50th percentile)
NH_4^+ (mg/L)	0.04 (0.015-0.145)	0.172	
Turbidity	N/A	103	10% variation from background levels
E. coli (cfu/ 100 mL)	N/A	> 2420	< 130 cfu / 100 mL

Site	Historical	Current	RQOs
		X31A Sabie River (EWR-S1)	
		X33B Sabie River (X3-5)	
Sampling period	1983-2019	2022-2023	
EC (µS/cm)	145 (68-828)	91.13	≤ 420 µS/m (95th percentile)
pH	7.76 (5.21-9.03)	7.33	
Na (mg/L)	8.2 (3.1-66.7)	14.2	
K (mg/L)	1.32 (0.15-7.05)	2.39	
Cl (mg/L)	9.6 (1.5-80.7)	14.6	
SO_4^{2-} (mg/L)	6.36 (0.6-50.5)	9.5	
NO_2 + NO_3 (mg/L)	0.084 (0.005-4.33)	0.28	
PO_4^{2-} (mg/L)	0.015 (0.003-0.232)	0.016	≤ 0.125 mg/L (50th percentile)
NH_4^+ (mg/L)	0.05 (0.015-0.65)	0.061	
Turbidity	N/A	70.7	10% variation from background levels
E. coli (cfu/ 100 mL)	N/A	1259	< 130 cfu / 100 mL
		Y40F Sabie River (lower Sabie)	
Sampling period	N/A	2022-2023	
EC (µS/cm)	N/A	205	≤ 420 µS/m (95th percentile)
pH	N/A	7.53	
Na (mg/L)	N/A	N/A	
K (mg/L)	N/A	N/A	
Cl (mg/L)	N/A	21	
SO_4^{2-} (mg/L)	N/A	7.5	
NO_2 + NO_3 (mg/L)	N/A	0.54	
PO_4^{2-} (mg/L)	N/A	0.08	≤ 0.125 mg/L (50th percentile)
NH_4^+ (mg/L)	N/A	0.02	
Turbidity	N/A	6	10% variation from background levels
E. coli (cfu/ 100 mL)	N/A	N/A	< 130 cfu / 100 mL

3.6.1.1.2.2 Crocodile catchment

The historical and current water quality status for sites in the Crocodile catchment are provided in Table 3-13. Water quality variable that is responsible for a decrease in the water quality at the X21K Eland site is high *E. coli* counts. Historically the EC at this site has been exceeded but the most recent water quality data show compliance with the RQO. Elevated *E. coli* counts were also recorded at all the other sites within the catchment except for the X22F Nels river site where only slightly elevated nutrient levels were recorded. The X21G Elands site also showed slightly elevated nutrient, specifically ammonia. The X23E Queens and X23B Noordkaap sites both had borderline elevated EC with the X23B Noordkaap site also displaying elevated PO_4 levels. The X23K Kaap site slightly elevated EC and elevated nutrients. Metals remain with TWQGs and SSD for As, Mn and Fe. The X23F Suidkaap site had the poorest water quality with elevated nutrients and As exceeding the RQO and displaying moderate toxicity based on the SSD curves for metals.

Table 3-13: Comparison between historical and current water quality for sites in the Crocodile catchment. Historical data are represented as the mean and range for the period, while current water quality data are represented by the average for the two sampling years. N/A represents no available data.

Site	Historical	Current	RQOs
X21G Elands River – RQOs for the Elands River (EWR-E1)			
Sampling period	1972-2019	2022-2023	
EC (µS/cm)	198 (46-895)	140	≤ 300 µS/m (95th percentile)
pH	8.01 (3.91-8.7)	7.54	
Na (mg/L)	7.3 (1-73.5)	N/A	
K (mg/L)	0.86 (0.15-6.43)	N/A	
Cl (mg/L)	6.1 (1.5-126)	N/A	
SO_4^{2-} (mg/L)	8.8 (2-110)	N/A	
$NO_2 + NO_3$ (mg/L)	0.119 (0.02-1.93)	0.27	
PO_4^{2-} (mg/L)	0.018 (0.003-1)	0.016	≤ 0.025 mg/L (50th percentile)
NH_4^+ (mg/L)	0.02 (0.015-0.333)	0.122	
Turbidity	N/A	55.1	10% variation from background levels
E. coli (cfu/ 100 mL)	N/A	2420	< 130 cfu / 100 mL
X21K Elands River – RQOs for the Elands River (X2-5)			
Sampling period	2004-2019	2022-2023	
EC (µS/cm)	428 (10.1-710)	243	≤ 550 µS/m (95th percentile)
pH	8.04 (6.7-8.75)	7.56	
Na (mg/L)	35.1 (5-107)	18.1	
K (mg/L)	1.17 (0.6-2.55)	N/A	
Cl (mg/L)	40.8 (7.08-580)	11.8	
SO_4^{2-} (mg/L)	73.2 (5-228)	43.2	
$NO_2 + NO_3$ (mg/L)	0.2 (0.025-3)	0.25	
PO_4^{2-} (mg/L)	0.05 (0.005-1.7)	0.011	≤ 0.025 mg/L (50th percentile)
NH_4^+ (mg/L)	0.05 (0.025-0.76)	0.089	
Turbidity	N/A	33.1	10% variation from background levels
E. coli (cfu/ 100 mL)	N/A	2420	< 130 cfu / 100 mL
X22B Crocodile River – RQOs for the Crocodile River			
Sampling period	2006-2019	2022-2023	
EC (µS/cm)	238 (89-942)	189	≤ 550 µS/m (95th percentile)
pH	7.9 (6.78-8.71)	7.8	6.5-8.5
Na (mg/L)	13.4 (3.4-23)	N/A	
K (mg/L)	1.97 (1-2.42)	N/A	
Cl (mg/L)	17 (3.21-210)	8.3	
SO_4^{2-} (mg/L)	23 (5-90)	N/A	
$NO_2 + NO_3$ (mg/L)	0.2 (0.025-30)	0.16	
PO_4^{2-} (mg/L)	0.05 (0.003-5.1)	< 0.01	≤ 0.025 mg/L (50th percentile)
NH_4^+ (mg/L)	0.06 (0.025-0.56)	0.064	
Turbidity	N/A	7.72	10% variation from background levels
E. coli (cfu/ 100 mL)	N/A	210	< 130 cfu / 100 mL

Site	Historical	Current	RQOs
X22F Nels River – RQOs for the Nels River			
Sampling period	2004-2018	2022-2023	
EC (µS/cm)	234 (57-708)	98	≤ 300 µS/m (95th percentile)
pH	7.8 (5.29-8.55)	7.78	6.5-8.5
Na (mg/L)	13.5 (7.6-17.6)	N/A	
K (mg/L)	2 (0.7-2.4)	N/A	
Cl (mg/L)	16.4 (4.69-62)	17.9	
SO_4^{2-} (mg/L)	19 (2-156)	50	
NO_2 + NO_3 (mg/L)	0.3 (0.025-38.7)	0.89	
PO_4^{2-} (mg/L)	0.05 (0.005-1.8)	0.049	≤ 0.025 mg/L (50th percentile)
NH_4^+ (mg/L)	0.15 (0.025-1.3)	0.12	
Turbidity	N/A	15	10% variation from background levels
E. coli (cfu/ 100 mL)	N/A	N/A	< 130 cfu / 100 mL
X22H White River – RQOs for the White River			
Sampling period	2015-2019	2022-2023	
EC (µS/cm)	282 (181-399)	19	≤ 550 µS/m (95th percentile)
pH	7.71 (6.62-8.24)	7.55	6.5-8.5
Na (mg/L)	N/A	N/A	
K (mg/L)	N/A	N/A	
Cl (mg/L)	N/A	N/A	
SO_4^{2-} (mg/L)	N/A	N/A	
NO_2 + NO_3 (mg/L)	N/A	0.4	
PO_4^{2-} (mg/L)	0.05 (0.05-1.2)	0.036	≤ 0.125 mg/L (50th percentile)
NH_4^+ (mg/L)	N/A	0.083	
Turbidity	N/A	15	10% variation from background levels
E. coli (cfu/ 100 mL)	N/A	816	< 130 cfu / 100 mL
X22K Crocodile River – RQOs for the Crocodile River (EWR C4)			
Sampling period	2006-2018	2022-2023	
EC (µS/cm)	240 (66-381)	183	≤ 550 µS/m (95th percentile)
pH	7.7 (6.32-8.43)	7.33	6.5-8.5
Na (mg/L)	13.6 (7.16-80.5)	N/A	
K (mg/L)	2.13 (1-2.59)	N/A	
Cl (mg/L)	17.1 (5.48-31)	N/A	
SO_4^{2-} (mg/L)	23 (10.6-52)	N/A	
NO_2 + NO_3 (mg/L)	0.7 (0.025-2.8)	0.84	
PO_4^{2-} (mg/L)	0.101 (0.005-7.8)	0.041	≤ 0.025 mg/L (50th percentile)
NH_4^+ (mg/L)	0.13 (0.025-48.1)	0.173	
Turbidity	N/A	24.9	10% variation from background levels
E. coli (cfu/ 100 mL)	N/A	> 2420	< 130 cfu / 100 mL
X23B Noordkaap River – RQOs for the Noordkaap River			
Sampling period	2006-2018	2022-2023	
EC (µS/cm)	300 (121-997)	256	≤ 300 µS/m (95th percentile)

Site	Historical	Current	RQOs
pH	7.9 (6.7-8.4)	7.67	6.5-8.5
Na (mg/L)	15.6 (10.2-24.9)	N/A	
K (mg/L)	1.91 (1-2.51)	N/A	
Cl (mg/L)	14.1 (8.69-34)	N/A	
SO_4^{2-} (mg/L)	30 (6.3-211)	19.9	
$NO_2 + NO_3$ (mg/L)	0.4 (0.025-5.6)	< 0.1	
PO_4^{2-} (mg/L)	0.05 (0.005-7.96)	0.034	≤ 0.025 mg/L (50th percentile)
NH_4^+ (mg/L)	0.135 (0.025-1.3)	0.072	
Turbidity	N/A	24.9	10% variation from background levels
E. coli (cfu/ 100 mL)	N/A	179	< 130 cfu / 100 mL
X23E Queens River – RQOs for the Queens River			
Sampling period	2006-2018	2022-2023	
EC (µS/cm)	169 (58-397)	279	≤ 300 µS/m (95th percentile)
pH	7.72 (5.24-9.06)	7.67	6.5-8.5
Na (mg/L)	7.1 (1-33.6)	N/A	
K (mg/L)	0.5 (0.06-3.61)	N/A	
Cl (mg/L)	5 (1.5-45)	N/A	
SO_4^{2-} (mg/L)	6.64 (1.5-35.9)	N/A	
$NO_2 + NO_3$ (mg/L)	0.064 (0.005-0.878)	0.74	
PO_4^{2-} (mg/L)	0.005 (0.003-1.26)	0.013	≤ 0.075 mg/L (50th percentile)
NH_4^+ (mg/L)	0.025 (0.015-0.175)	0.071	
Turbidity	N/A	N/A	10% variation from background levels
E. coli (cfu/ 100 mL)	N/A	980	< 130 cfu / 100 mL
X23F Suidkaap River – RQOs for the Suidkaap River			
Sampling period	1966-2018	2022-2023	
EC (µS/cm)	144 (60-399)	383	≤ 300 µS/m (95th percentile)
pH	7.74 (5.89-9.18)	7.6	6.5-8.5
Na (mg/L)	10.7 (1-23)	N/A	
K (mg/L)	0.7 (0.15-4.95)	N/A	
Cl (mg/L)	5.8 (1-50.1)	N/A	
SO_4^{2-} (mg/L)	4.9 (1.3-35.9)	81.3	
$NO_2 + NO_3$ (mg/L)	0.11 (0.02-0.529)	1.18	
PO_4^{2-} (mg/L)	0.017 (0.003-6.24)	0.11	≤ 0.075 mg/L (50th percentile)
NH_4^+ (mg/L)	0.025 (0.015-0.276)	0.6	
Turbidity	N/A	N/A	10% variation from background levels
E. coli (cfu/ 100 mL)	N/A	1553	< 130 cfu / 100 mL
Arsenic (mg/L)	N/A	0.03	< 0.02 mg/L
X23K Kaap River – RQOs for the lower reaches of the Kaap River			
Sampling period	2008-2019	2022-2023	
EC (µS/cm)	428 (84.2-870)	388	≤ 300 µS/m (95th percentile)
pH	8.04 (6.97-8.52)	7.91	
Na (mg/L)	35.1 (12.4-23.6)	N/A	

Site	Historical	Current	RQOs
K (mg/L)	1.17 (1-2.9)	N/A	
Cl (mg/L)	40.8 (8.88-26)	N/A	
SO_4^{2-} (mg/L)	73.2 (2.5-180)	66.6	
$NO_2 + NO_3$ (mg/L)	0.6 (0.025-8.4)	1.12	≤ 1.0 mg/L (50th percentile)
PO_4^{2-} (mg/L)	0.05 (0.005-8.48)	0.049	≤ 0.075 mg/L (50th percentile)
NH_4^+ (mg/L)	0.1 (0.025-2.7)	0.208	
Turbidity	N/A	18.7	10% variation from background levels
E. coli (cfu/ 100 mL)	N/A	435	< 130 cfu / 100 mL
X24F Crocodile River – RQOs for the Crocodile River (X2-13)			
Sampling period	1983-2019	2022-2023	
EC (µS/cm)	326 (95.4-1320)	299	≤ 550 µS/m (95th percentile)
pH	8.01 (5.4-8.98)	7.63	
Na (mg/L)	22 (4.08-183)	21.4	
K (mg/L)	1.49 (0.48-10)	N/A	
Cl (mg/L)	17.4 (5.1-114)	15.3	
SO_4^{2-} (mg/L)	20.5 (1-102)	66.6	
$NO_2 + NO_3$ (mg/L)	0.586 (0.005-11.3)	1.53	
PO_4^{2-} (mg/L)	0.027 (0.003-5.4)	0.055	≤ 0.125 mg/L (50th percentile)
NH_4^+ (mg/L)	0.05 (0.015-7.1)	0.281	
Turbidity	N/A	26.3	10% variation from background levels
E. coli (cfu/ 100 mL)	N/A	1553	< 130 cfu / 100 mL

3.6.1.1.2.3 Komati catchment

The historical and current water quality status for sites in the Komati catchment are provided in Table 3-14. Water quality variable that is responsible for a decrease in the water quality at both the X11K Gladdespruit and the X13B Komati site is slightly elevated *E. coli* counts. The X13J Komati site recorded high *E. coli* counts and elevated turbidity while the X13K Komati and X14H Lomati site both had slightly elevated *E. coli* counts and slightly elevated EC.

Table 3-14: Comparison between historical and current water quality for sites in the Komati catchment. Historical data are represented as the mean and range for the period, while current water quality data are represented by the average for the two sampling years. N/A represents no available data.

Site	Historical	Current	RQOs for EWRG-1
X11K Gladdespruit – RQOs for EWRG-1			
Sampling period	2015-2019	2022-2023	
EC (µS/cm)	252 (50-836)	295	≤ 400 µS/m (95th percentile)
pH	7.82 (6.43-8.36)	7.61	
Na (mg/L)	N/A	N/A	
K (mg/L)	N/A	N/A	
Cl (mg/L)	N/A	N/A	
SO_4^{2-} (mg/L)	33.8 (1.06-118)	86.6	

Site	Historical	Current	RQOs for EWRG-1
$NO_2 + NO_3$ (mg/L)	N/A	0.64	
PO_4^{2-} (mg/L)	0.05 (0.05-0.05)	< 0.01	≤ 0.02 mg/L (50th percentile)
NH_4^+ (mg/L)	N/A	0.075	
Turbidity	N/A	6.46	10% variation from background levels
E. coli (cfu/ 100 mL)	N/A	272	< 130 cfu / 100 mL
X13B Komati River – RQOs for the Komati River			
Sampling period	2004	2022-2023	
EC (µS/cm)	118 (100-135)	167	≤ 225 µS/m (95th percentile)
pH	7.69 (7.45-7.94)	7.85	
Na (mg/L)	8.28 (8.11-8.45)	N/A	
K (mg/L)	1.4 (1.06-1.73)	N/A	
Cl (mg/L)	4.72 (2.5-6.94)	4.42	
SO_4^{2-} (mg/L)	3 (3-3)	14.6	
$NO_2 + NO_3$ (mg/L)	0.184 (0.171-0.198)	0.21	
PO_4^{2-} (mg/L)	0.012 (0.012-0.012)	0.012	≤ 0.015 mg/L (50th percentile)
NH_4^+ (mg/L)	0.015 (0.015-0.015)	0.068	
Turbidity	N/A	4.15	10% variation from background levels
E. coli (cfu/ 100 mL)	N/A	326	< 130 cfu / 100 mL
X13J Komati River – RQOs for the lower reaches of the Komati River			
Sampling period	2006-2019	2022-2023	
EC (µS/cm)	267 (136-341)	186	≤ 850 µS/m (95th percentile)
pH	8.02 (6.6-8.86)	7.73	
Na (mg/L)	14.4 (14.4-14.5)	39.9	
K (mg/L)	2.06 (1.76-.39)	1.47	
Cl (mg/L)	20 (8.1-99)	13.3	
SO_4^{2-} (mg/L)	6.71 (3-13)	14.3	
$NO_2 + NO_3$ (mg/L)	0.3 (0.025-7)	0.4	≤ 1.0 mg/l (50th percentile)
PO_4^{2-} (mg/L)	0.05 (0.005-0.85)	< 0.01	≤ 0.125 mg/l (50th percentile)
NH_4^+ (mg/L)	0.1 (0.025-4.4)	0.08	
Turbidity	N/A	315	10% variation from background levels
E. coli (cfu/ 100 mL)	N/A	770	< 100 cfu / 100 mL
X13K Komati River – RQOs for the Komati River			
Sampling period	1993-2017	2022-2023	
EC (µS/cm)	556 (106-1060)	336	≤ 850 µS/m (95th percentile)
pH	8.29 (7.08-9.26)	7.93	
Na (mg/L)	44.8 (6.52-96.8)	N/A	
K (mg/L)	1.56 (0.5-4.82)	N/A	
Cl (mg/L)	53.2 (9-171)	4.42	
SO_4^{2-} (mg/L)	23.3 (4.11-50.6)	14.6	
$NO_2 + NO_3$ (mg/L)	0.356 (0.02-1.48)	0.71	
PO_4^{2-} (mg/L)	0.024 (0.005-0.331)	< 0.01	≤ 0.015 mg/L (50th percentile)
NH_4^+ (mg/L)	0.049 (0.015-0.246)	0.07	

Site	Historical	Current	RQOs for EWRG-1
Turbidity	N/A	9.91	10% variation from background levels
E. coli (cfu/ 100 mL)	N/A	89	< 130 cfu / 100 mL
X14H Lomati River RQOs for EWR L-1			
Sampling period	1993-2017	2022-2023	
EC (µS/cm)	316 (171-406)	336	≤ 300 µS/m (95th percentile)
pH	7.99 (7.9-813)	7.73	
Na (mg/L)	22.8 (10-27.2)	N/A	
K (mg/L)	1.64 (1.08-1.12)	N/A	
Cl (mg/L)	30.5 (11.6-38.1)	N/A	
SO_4^{2-} (mg/L)	8.13 (6.07-13.1)	N/A	
$NO_2 + NO_3$ (mg/L)	0.0.592 (0.286-0.822)	0.72	≤ 1 mg/L (50th percentile)
PO_4^{2-} (mg/L)	0.012 (0.012-0.028)	0.014	≤ 0.015 mg/L (50th percentile)
NH_4^+ (mg/L)	0.015 (0.015-0.015)	0.077	
Turbidity	N/A	24.4	10% variation from background levels
E. coli (cfu/ 100 mL)	N/A	1203	< 130 cfu / 100 mL

3.6.1.1.2.4 Incomati catchment

The historical and current water quality status for the Y40A Incomati site in the Incomati catchment is provided in Table 3-15. Water quality variables that are responsible for a decrease in the water quality at this site are expected to be high *E. coli* counts as influenced by the upper catchment. The higher EC is related to increased salinity originating via sea spray deposition. This is also reflected in the higher Na and Cl levels and should be regarded as normal occurrence.

Table 3-15: Comparison between historical and current water quality at Y40A Incomati River upstream of the Sabie River confluence). Historical data are represented as the mean and range for the period, while current water quality data are represented by the average for the two sampling years. N/A represents no available data.

Site	Historical	Current	RQOs for the lower reaches of the Komati River
Y40A Incomati River			
Sampling period	N/A	2022-2023	
EC (µS/cm)	N/A	1057	
pH	N/A	8.32	
Na (mg/L)	N/A	37.32	
K (mg/L)	N/A	1.86	
Cl (mg/L)	N/A	69	
SO_4^{2-} (mg/L)	N/A	26	
$NO_2 + NO_3$ (mg/L)	N/A	0.31	
PO_4^{2-} (mg/L)	N/A	< 0.075	
NH_4^+ (mg/L)	N/A	0.035	
Turbidity	N/A	13.3	
E. coli (cfu/ 100 mL)	N/A	N/A	

3.6.1.2 HYDROLOGY

This section provides a short summary of the hydrology data available for the quantification of the e-flows at the selected sites, level of detail available from the ecologists for fish, macroinvertebrates, riparian vegetation and geomorphology that guided the quantification and a summary of the results. The detailed time series (baseline hydrology and e-flows) are available as electronic files.

3.6.1.2.1 Hydrological information

The monthly natural (reference) and present day time series were obtained from a number of catchment studies undertaken for the Incomati catchment. The data is for the period 1920 to 2016 for all the rivers in South Africa and the Sabie River in Mozambique. These studies include:

- IUCMA, 2020. Update of the hydrology of the Crocodile Catchment.
- IUCMA, 2021. Update of the hydrology of the Sabie Catchment.
- IUCMA, 2021. Update of the hydrology of the Komati Catchment.

The data for the other selected e-flow sites in Mozambique is for the period 1920 to 2009 and is based on results from the WRSM2000 model and WR2012 study.

The natural flow time series were used as the base for the quantification of the e-flows and where available, observed data from gauging weirs close to the e-flow sites were used to guide the setting of the freshets and floods in terms of magnitude, timing and duration. Baseflow separation using the approach developed by Smakhtin (2001) was undertaken with the natural flows to provide further indication of the low flow requirements for the various rivers. This information is especially useful where groundwater contribution to rivers is high.

The detailed hydrology will be made available as supplementary information.

3.6.1.2.2 Ecological detail available

Table 3-10 lists all the sites where the e-flows were quantified. Various levels of detailed data and information from surveys was available for the quantification. The selected sites were divided into three groups, namely (i) MEGa sites where the most information was available, (ii) SUPport sites where at least biological information was available and at some sites riparian vegetation and (iii) OTHer sites where the quantification was based on fish requirements only. Table 3-16 provides a summary of the information available per e-flow site. The ecological data was provided for the 50th and 99.9th percentile for all the months for fish and macroinvertebrates and for selected months for riparian vegetation. Freshets and floods were specified for all the components.

Table 3-16: Summary of information available per e-flow site (ML-Baseflows, MH-freshets, floods)

IUA	Quat_ Code	Site name	Latitude	Longitude	Fish		Inverts		RipVeg	Geom
MEGa sites					**ML**	**MH**	**ML**	**ML**	**MH**	**MH**
X1-10	X13J	MEG X13J Komati	-25.928497	31.759773	Y	Y	Y	Y		Y
Y1-2	X13L	MEG X13L Incomati u/s Sabie	-25.322458	32.267084	Y	Y	Y	Y	Y	Y
X2-4	X21K	MEG X21K Elands	-25.568653	30.662729	Y	Y	Y	Y	Y	Y
X2-10K	X23G	MEG X23G Kaap	-25.659497	31.218960	Y	Y	Y	Y	Y	Y
X2-13	X24F	MEG X24F Crocodile	-25.438667	31.634839	Y	Y	Y	Y	Y	Y

IUA	Quat_ Code	Site name	Latitude	Longitude	Fish		Inverts		RipVeg	Geom
X3-6	X31K	MEG X31K Sabie	-24.985084	31.281805	Y	Y	Y	Y	Y	Y
X3-6LS	X33B	MEG X33B Sabie	-25.121522	31.926245	Y	Y	Y	Y	Y	Y
SUPport sites										
X1-4	X11K	SUP X11K Gladdespruit	-25.910419	30.653615	Y	Y	Y	Y	Y	Only for meg sites
X1-1	X13D	SUP X13D Komati	-26.100477	31.402217	Y	Y				
X1-9	X13J	SUP X13K Komati	-25.928516	31.759672	Y	Y	Y	Y		
X1-8	X14H	SUP X14H Lomati	-25.649954	31.622312	Y	Y	Y	Y	Y	
X2-3	X21G	SUP X21G Elands	-25.621588	30.398138	Y	Y	Y	Y	Y	
X2-6	X22B	SUP X22B Crocodile	-25.429708	30.757919	Y	Y	Y	Y	Y	
X2-8N	X22F	SUP X22F Nels	-25.427432	30.964353	Y	Y	Y	Y	Y	
X2-8W	X22H	SUP X22H White River	-25.457741	31.079465	Y	Y	Y	Y	Y	
X2-9	X22K	SUP X22K Crocodile	-25.501972	31.183361	Y	Y	Y	Y	Y	
X2-10N	X23B	SUP X23B Noordkaap	-25.661912	31.078689	Y	Y	Y	Y	Y	
X2-10Q	X23E	SUP X23E Queens	-25.739958	30.998512	Y	Y	Y	Y	Y	
X2-10S	X23F	SUP X23F Suidkaap	-25.716222	31.056600	Y	Y	Y	Y	Y	
X3-1	X31A	SUP X31A Sabie	-25.093875	30.763868	Y	Y	Y	Y	Y	
X3-3E	X32G	SUP X32H Sand	-24.769709	31.388545	Y	Y	Y	Y		
Y1-5	X33D	SUP X33D Sabie	-25.316521	32.290041	Y	Y	Y	Y	Y	
X4-1U	X40A	SUP X40A Uanetza in SA	-24.455261	31.994505	Y	Y	Y	Y	Y	
X4-1M	X40D	SUP X40D Massintonto in SA	-24.783770	31.978932	Y	Y	Y	Y	Y	
OTHer sites										
X1-1	X11B	OTH X11B Boesmanspruit	-26.023406	30.061365	Y	Y			Only for MEG&SUP sites	Only for MEG sites
X1-3	X11D	OTH X11D Klein Komati	-25.888018	30.120710	Y	Y				
X1-2	X11F	OTH X11F Komati	-25.854333	30.376639	Y	Y				
X1-5	X12K	OTH X12K Komati	-26.038806	31.003139	Y	Y				
X1-7	X14D	OTH X14D Lomati	-25.818972	31.311388	Y	Y				
X2-1	X21B	OTH X21B Crocodile	-25.410503	30.315460	Y	Y				
X2-2	X21E	OTH X21E Crocodile	-25.452111	30.681083	Y	Y				
X2-3	X21F	OTH X21F Elands	-25.648564	30.289394	Y	Y				
X2-7	X22B	OTH X22B Houtbosloop	-25.431013	30.747065	Y	Y				
X2-12	X24C	OTH X24C Nsikazi	-25.522125	31.368514	Y	Y				
X2-13	X24H	OTH X24H Mbyamiti	-25.316210	31.745376	Y	Y				

IUA	Quat_ Code	Site name	Latitude	Longitude	Fish		Inverts		RipVeg	Geom
X3-2	X31C	OTH X31C Mac-Mac	-25.013333	31.003889	Y	Y				
X3-3	X31D	OTH X31D Sabie	-25.027778	31.051389	Y	Y				
X3-3	X31G	OTH X31G Marite	-25.017778	31.133056	Y	Y				
X3-9	X32J	OTH X32J Sand	-24.967222	31.626944	Y	Y				
Y1-1	X40A	OTH X40A Uanetza	-24.982093	32.571741	Y	Y				
Y1-3	X40D	OTH X40D Massintonto	-24.903239	32.346172	Y	Y				

Indicator species (fish, macroinvertebrates, and riparian vegetation), populations and communities were identified for the e-flow sites to represent the ecosystem and were used to determine preliminary e-flow requirements. Floods required for the shaping of the river channels and movement of sediments were specified by the geomorphologist at all the MEGa sites where higher confidence results were obtained. The requirements as specified by the ecologists for baseflows (50th percentile) and drought flows (minimum, 99.9th percentile) as well as the natural baseflows are provided for each MEGa e-flow site in the Table 3-17 below. The information for the SUPport and OTHer e-flow sites are available electronically.

Table 3-17: Summary of ecological baseflow requirements for selected percentiles per e-flow site

Percentiles	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	
Elands River (MEG_X21K)													
50	1.400	1.400	2.500	4.300	4.300	2.500	2.500	1.400	1.400	1.400	1.400	1.400	Fish
50	1.508	3.044	5.365	7.923	8.264	6.825	4.900	2.935	1.721	1.277	1.045	1.100	Inverts
50					3.710							1.030	Vegetation
50	1.827	2.272	2.871	3.623	4.039	3.998	4.085	3.523	2.901	2.307	1.874	1.725	Baseflows
99.9	0.340	0.340	1.100	1.100	1.100	1.100	1.100	0.650	0.650	0.650	0.650	0.650	Fish
99.9					1.300	1.250	1.250	1.150				0.650	Inverts
99.9	> 0	> 0	> 0	> 0	> 0	> 0	> 0	> 0	> 0	> 0	> 0	> 0	Vegetation
99.9	1.118	1.385	1.475	1.916	2.074	2.087	2.192	2.054	1.611	1.416	1.333	1.089	Baseflows
Kaap River (MEG_X22G)													
50	0.900	0.900	1.920	1.920	1.920	1.920	1.920	1.920	0.900	0.900	0.900	0.900	Fish
50				2.700	2.800	2.400	2.200					0.850	Inverts
50					3.390							0.800	Vegetation
50	2.229	2.634	3.013	3.295	3.453	3.555	3.545	3.428	3.332	2.979	2.569	2.330	Baseflows
99.9	0.580	0.580	0.580	0.580	0.580	0.580	0.580	0.580	0.580	0.580	0.580	0.580	Fish
99.9				0.950	0.960	0.960	0.900					0.750	Inverts
99.9	> 0	> 0	> 0	> 0	> 0	> 0	> 0	> 0	> 0	> 0	> 0	> 0	Vegetation
99.9	1.487	1.513	1.676	1.738	1.753	1.811	1.909	1.884	1.758	1.565	1.443	1.442	Baseflows
Crocodile River (MEG_X24F)													
50	3.400	3.400	11.300	14.800	14.800	14.800	11.300	3.400	3.400	3.400	3.400	3.400	Fish
50				23.000	31.000	23.000	13.500					2.900	Inverts
50					14.370							5.050	Vegetation
50	11.879	13.823	16.896	20.028	21.786	22.816	22.589	20.346	18.297	15.267	12.750	11.536	Baseflows
99.9	1.100	1.100	1.100	3.400	3.400	3.400	1.100	1.100	1.100	1.100	1.100	1.100	Fish

Percentiles	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	
99.9				4.500	4.600	4.800	4.500					2.800	Inverts
99.9	> 0	> 0	> 0	> 0	> 0	> 0	> 0	> 0	> 0	> 0	> 0	> 0	Vegetation
99.9	6.341	7.622	9.061	10.161	10.369	10.799	10.995	10.576	9.551	8.406	7.675	6.523	Baseflows
Sabie River (MEG_X31K)													
50	4.200	4.200	8.000	11.100	11.100	11.100	8.000	4.200	4.200	4.200	4.200	4.200	Fish
50				10.800	14.100	12.500	10.900					4.600	Inverts
50					6.000							2.360	Vegetation
50	6.347	6.859	8.081	9.460	10.434	10.773	10.879	10.125	9.372	8.703	7.655	6.956	Baseflows
99.9	2.200	2.200	2.200	3.200	3.200	3.200	2.200	2.200	2.200	2.200	2.200	2.200	Fish
99.9				3.900	4.100	4.200	4.000					3.200	Inverts
99.9	> 0	> 0	> 0	> 0	> 0	> 0	> 0	> 0	> 0	> 0	> 0	> 0	Vegetation
99.9	4.306	4.619	4.883	5.235	5.417	5.616	5.944	5.894	5.687	4.940	4.591	4.296	Baseflows
Sabie River (MEG_X33B)													
50	5.900	5.900	8.000	11.100	11.100	11.100	8.000	5.900	5.900	5.900	5.900	5.900	Fish
50				13.300	16.000	14.400	12.900					5.700	Inverts
50					14.480							4.470	Vegetation
50	8.491	9.163	10.699	12.300	13.503	14.027	14.031	13.116	12.311	11.193	10.189	9.151	Baseflows
99.9	2.200	2.200	2.200	3.200	5.000	5.000	3.200	2.200	2.200	2.200	2.200	2.200	Fish
99.9				4.700	4.800	5.000	4.700					3.700	Inverts
99.9	> 0	> 0	> 0	> 0	> 0	> 0	> 0	> 0	> 0	> 0	> 0	> 0	Vegetation
99.9	5.293	5.696	6.259	6.776	6.951	7.153	7.515	7.470	6.892	6.076	5.689	5.308	Baseflows
Komati River (MEG_X13J)													
50	2.300	4.800	7.500	15.000	15.000	15.000	7.500	4.800	4.800	4.800	2.300	2.300	Fish
50				6.200	6.900	7.000	6.800					2.800	Inverts
50	7.511	9.952	12.159	15.317	17.304	17.391	17.831	16.467	14.572	10.382	7.960	7.035	Baseflows
99.9	1.000	1.000	1.000	4.800	4.800	4.800	1.000	1.000	1.000	1.000	1.000	1.000	Fish

Percentiles	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	
99.9				3.200	3.500	3.500	3.400					1.300	Inverts
99.9	> 0	> 0	> 0	> 0	> 0	> 0	> 0	> 0	> 0	> 0	> 0	> 0	Vegetation
99.9	4.531	5.231	5.319	7.068	7.814	7.590	7.676	7.543	6.194	4.871	4.527	4.294	Baseflows
Incomati River (MEG_X13L)													
50	6.500	10.800	17.200	31.000	31.000	31.000	17.200	10.800	10.800	6.500	6.500	6.500	Fish
50				7.659	8.652	8.695	8.915					3.500	Inverts
50					22.000							2.360	Vegetation
50	23.428	28.614	34.025	40.349	46.071	46.798	47.206	43.140	39.551	31.269	25.754	22.951	Baseflows
99.9	4.000	4.000	4.000	10.800	10.800	10.800	4.000	4.000	4.000	4.000	4.000	4.000	Fish
99.9				3.500	3.900	3.800	3.700					2.200	Inverts
99.9	> 0	> 0	> 0	> 0	> 0	> 0	> 0	> 0	> 0	> 0	> 0	> 0	Vegetation
99.9	13.954	16.535	17.445	20.220	21.783	21.809	22.528	22.205	19.214	16.045	15.240	13.685	Baseflows

3.6.1.3 HYDRAULICS AND GEOMORPHOLOGY

3.6.1.3.1 Methodology

This study includes previously surveyed sites (done by Drew Birkhead) for the Incomati, Crocodile and Sabie Rivers where possible. Unfortunately, many of the benchmarks from the previous studies have been lost and the channel shape has changed, reducing the opportunity to build on the previous work. Where resurveys were not possible, the old data were adopted to increase the spatial cover. Where new sites were selected, Google Earth was used to explore the reach for sections/sites that were preferred from a hydraulics perspective. These preferences included features suitable for one-dimensional hydraulic modelling such as: simple channel cross-section; relatively straight and uniform channel form; constant reach gradient; control feature that can be accounted for in the modelling; relatively stable channel form (this was a challenge for the sand bed rivers); critical habitat for the biota considered. These identified points and aerial images were transferred onto a GPS enabled tablet to aid with finding and deciding on sites in the field.

A single cross-section was surveyed for each mega, support and 'other' site in order to capture critical hydraulic habitats that are sensitive to flow. Survey benchmarks were established for all sites. Data gathering consisted of transect selection and demarcation, survey of the topography along the transect (perpendicular to flow); survey of water levels, energy gradient and historical flood marks; and measurement of depth and velocity along each transect as recommended by Rowlston, Jordanova and Birkhead (2008). Land-based surveying was done with survey-grade equipment (Leica Total Station). For sites with deep and fast-flowing water with potential wildlife dangers, a SonTek River Surveyor M9/S5 using acoustic doppler technology was used to survey the bathymetry and velocity profile which was tied back into the rest of the terrestrial survey of the cross-section.

At sites where the flow was deep and/or with wildlife danger, discharge was determined using the SonTek River Surveyor M9/S5 acoustic doppler profiler which also captured depth and velocity at a large number (> 10) of verticals per point along each transect. For very shallow depths where the River Surveyor cannot capture meaningful data, a handheld electromagnetic OTT MFPro was used to capture velocity data. The channel was divided into at least 20 verticals to capture depth and flow velocity data to calculate discharge and capture the diversity of depth-velocity classes for shallower sites (Gordon *et al.*, 2004).

All modelling was based on a single observation resulting in low confidence results. Historical modelling by Drew Birkhead was based on multiple observations, resulting in higher confidence in the data, but it is likely that the channel shape has changed, reducing the confidence in the historical data accurately representing the current hydraulics.

In the office, discharge, energy slope and transect data were extracted from the field observations. Roughness was calculated using the Mannings n formula based on the measured data (Gordon *et al.*, 2004). To extrapolate the observed hydraulic data to other stage levels so that a continuous rating function could be determined for a wide range of discharges, 1-dimensional hydraulic modelling of higher flows was undertaken using the Mannings formula (Hirschowitz *et al.*, 2007). Steady state hydraulic modelling was used as it is appropriate for reserve type determinations where we assume steady flow and negligible changes in vegetation resistance (Birkhead, 2010). Output from the modelling and field measurements were plotted with CurveExpert 1.4 to develop a power function that best described the discharge-stage relationship for each transect using Equation 1.1.

$$y = aQ^b + c$$ Equation 1.1

Where y is the height/stage above the thalweg channel and Q is discharge. A and b are curve-shape variables, whereas c is the y-axis intercept (c = 0 for critical/riffle habitat).

HABFLO, a 1 dimensional free-ware empirical hydraulic habitat-flow simulation model, was used to derive frequency distribution data for the various hydraulic habitats as recommended by Hirschowitz *et al.* (2007). HABFLO is designed to simulate flow-dependent, ecologically relevant hydraulic data for environmental flow determinations (Birkhead, 2010). HABFLO flow-depth frequency distribution calculations are based on the work of Lamouroux *et al.* (1995) and apply to riffle habitats. As the Incomati River and some of its tributaries are mostly low topography sand bed rivers, the model output might have a low confidence level.

The hydraulic habitat classes were defined at a range of depths and slow and fast velocities for fish and invertebrates (Figure 3-16) as recommended by Birkhead (2010).

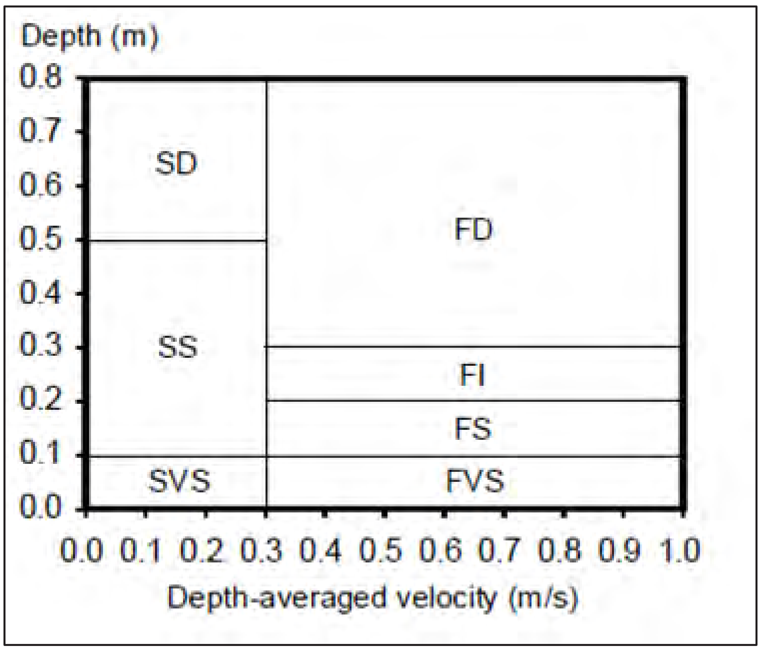


Figure 3-16: Depth-velocity classes of hydraulic habitats for fish. Figure copied from Birkhead (2010).

Field surveys were limited to 2 to 5 hours due to logistical challenges and largely executed by Rivers of Life staff. The data reduction and hydraulic modelling and reporting had a time budget of < 5 hours per site.

Field data were collected for the mega sites using the following field method where possible:

- River cross-sections and channel slope were surveyed with survey-grade equipment. This allowed detailed geomorphological cross-sections to be drawn for each site indicating the position of key morphological features (benches, banks, floodplain, etc.), substrate composition and physical habitats (riffles, pools, lateral sand bars, marginal zones, etc.).

- Sediment from the riverbed was described using the Eijkelkamp Sand Ruler (for homogenous sand-sized particles), laboratory sieve analysis for gravel samples or in-field by tape measure analysis (for larger gravel and cobble particles). For the larger particles (gravel and cobble), a sample of 100 randomly selected particles was measured along the b-axis to determine the D16, D50 and D84 (Gordon *et al.*, 2004). Table 3-18 defines the particle size classes for the substrate descriptions in the field.

Table 3-18: Particle size classes for site descriptions (adapted from Gordon et al. (2004) and Rowntree (2015)).

Wentworth size class	Grain diameter (mm)	Feel or analogy
Very large boulder	2048-4096	Compact car
Large boulder	1024-2048	Small trailer
Medium boulder	512-1024	Wheel barrow
Small boulder	256-512	Day pack
Large cobble	128-256	Soccer ball
Small cobble	64-128	Coffee mug
Coarse gravel	16-64	Cricket ball
Medium gravel	8-16	Golf ball
Fine gravel	2-8	Pea
Coarse sand	0.5-2	Brown sugar
Medium sand	0.125-0.500	White sugar
Fine sand	0.063-0.125	Caster sugar
Silt	0.002-0.063	Silky
Clay	< 0.002	Sticky

The bed sediment survey was used to assess the instream flow requirements for the sites. Flows to maintain habitat diversity are based on inundating the target habitat type to a depth sufficient to enable processes associated with the physical characteristics of the habitat. This habitat maintenance is a function of sediment movement and/or deposition at/on each of the various geomorphological features. Sediment mobility for heterogenous sediment is based on the entrainment ratio (shear stress/critical shear stress > 1) for the larger sediment (D84) for that position of the channel (Komar, 1996; Rowntree, 2015). The discharge/depth required to achieve a shear stress/critical shear stress ratio > 2 for the D50 was calculated for each geomorphic habitat type. These water levels/discharge to mobilise and maintain the geomorphic habitat types were used to set flow requirements in combination with inundating key habitat features. This formed the basis for prescribing EFR requirements for freshets and floods.

3.6.1.3.2 Results

The site and hydraulic data are presented in Table 3-19. The detailed output from this study's hydraulic modelling is available in electronic spreadsheets, with the key visual velocity depth distribution presented in Table 3-20.

Table 3-19: Summary of the hydraulic information available per e-flow site (X1' is the Komati system, X2' the Crocodile and X3' the Sabie system)

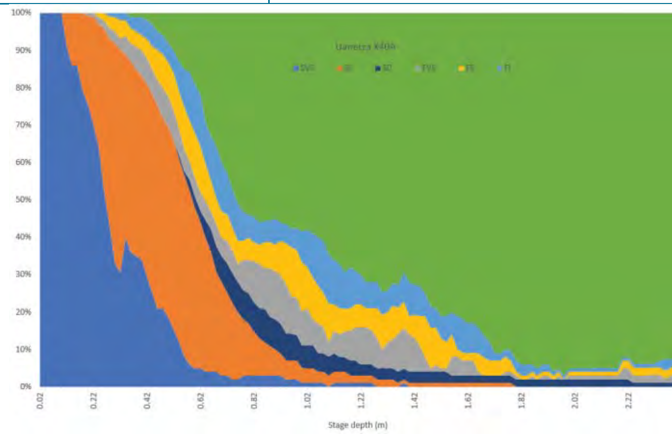
IUA	Quat_ Code	Site name	Latitude	Longitude	Date collected	Observations	Rating curve			Slope
							a	b	c	m/m
UANETZA CATCHMENT										
X4-1U	X40A	X40A Uanetza in SA	-24.455261	31.994505	2023	1	0.485	0.251	0.0	0.0151
MASSINTONTO CATCHMENT										
X4-1M	X40D	X40D Massintonto in SA	-24.783770	31.978932	2023	1	0.666	0.2856	0.0	0.000152
SABIE CATCHMENT										
X3-1	X31A	X31A Sabie	-25.093875	30.763868	2022	1	0.3495	0.497	0.0	0.01214
X3-2	X31C	X31C Mac-Mac	-25.013333	31.003889	DB (2008)	3	0.567	0.244	0.000	0.024
X3-3	X31D	X31D Sabie	-25.027778	31.051389	DB (2008)	4	0.272	0.404	0.000	0.0048
X3-3	X31G	X31G Marite	-25.017778	31.133056	DB (2008)	3	0.524	0.234	0.000	0.008
X3-6	X31K	X31K Sabie	-24.985084	31.281805	DB (2007)	6	2D model			
X3-6LS	X33B	X33B Sabie	-25.121522	31.926245	2022	1	0.3579	0.345	0.0	0.00093
Y1-5	X33D	X33D Sabie	-25.316521	32.290041	2022	1	0.2501	0.4933	0.0	0.0020
X3-3E	X32G	X32H Sand	-24.769709	31.388545	2023	1	0.6107	0.3312	0.0	0.00561
X3-9	X32J	X32J Sand	-24.967222	31.626944	DB (2008)	3	0.424	0.303	0.000	0.003
CROCODILE CATCHMENT										
X2-1	X21B	X21B Crocodile	-25.410503	30.315460	DB (2007)	3	0.332	0.262	0.000	0.0054
X2-2	X21E	X21E Crocodile	-25.452111	30.681083	DB (2007)	5	0.244	0.433	0.263	0.008
X2-3	X21G	X21G Elands Waterval Boven	-25.621588	30.398138	2023	1	0.764	0.276	0.0	0.00867
X2-4	X21K	X21K Elands	-25.568653	30.662729	2023	1	0.42001	0.348	0.0	0.0222
X2-6	X22B	X22B Crocodile	-25.429708	30.757919	2023	1	0.3437	0.4104	0.0	0.003067
X2-7	X22B	X22B Houtbosloop	-25.431013	30.747065	DB (2008)	1	0.437	0.346	0.000	0.007
X2-8N	X22F	X22F Nels	-25.427432	30.964353	2023	1	0.5306	0.2951	0.0	0.00985
X2-8W	X22H	X22H White River	-25.457741	31.079465	2023	1	0.8187	0.2355	0.0	0.0044
X2-9	X22K	X22K Crocodile	-25.501972	31.183361	2022	1	0.6877	0.3146	0.0	0.000703
X2-10N	X23B	X23B Noordkaap	-25.661912	31.078689	2023	1	0.679	0.3057	0.0	0.01527

IUA	Quat_ Code	Site name	Latitude	Longitude	Date collected	Observations	Rating curve			Slope
X2-10Q	X23E	X23E Queens	-25.739958	30.998512	2023	1	0.6156	0.3432	0.0	0.00493
X2-10S	X23F	X23F Suidkaap	-25.716222	31.056600	2022	1	0.576	0.424	0.0	0.00392
X2-10K	X23G	X23G Kaap	-25.659497	31.218960	2022	1	0.6770	0.3920	0.0	0.0152
X2-12	X24C	X24C Nsikazi	-25.522125	31.368514	2023	1	0.2257	0.3685	0.0	0.00334
X2-13	X24F	X24F Crocodile	-25.438667	31.634839	2023	1	0.8217	0.2379	0.0	0.00109
X2-13	X24H	X24H Mbyamiti	-25.316210	31.745376	2023	1	0.3246	0.3357	0.0	0.00356
KOMATI CATCHMENT										
X1-1	X11B	X11B Boesmanspruit	-26.023406	30.061365	2023	1	0.356	0.489	0.0	0.0173
X1-3	X11D	X11D Klein Komati	-25.888018	30.120710	2023	1	0.3227	0.4325	0.0	0.2346
X1-2	X11F	X11F Komati (DB K1)	-25.854333	30.376639	DB (2004)	5	0.217	0.433	0.123	0.0124
X1-4	X11K	X11K Gladdespruit	-25.910419	30.653615	2022	1	0.677	0.392	0.0	0.0152
X1-5	X12K	X12K Komati (DB K2)	-26.038806	31.003139	DB (2004)	9	0.421	0.321	0.0	0.0043
X1-10	X13J	X13J Komati	-25.928497	31.759773	2023	1	0.2337	0.482	0.0	0.00205
X1-9	X13K	X13K Komati	-25.928516	31.759672	2023	1	0.395	0.316	0.0	0.00604
X1-8	X14H	X14H Lomati	-25.649954	31.622312	2022	1	0.881	0.3153	0.0	0.00128
INCOMATI CATCHMENT										
Y1-2	Y40A	Y40A Incomati u/s Sabie	-25.322458	32.267084	2022	1	0.3666	0.5312	0.0	0.000586

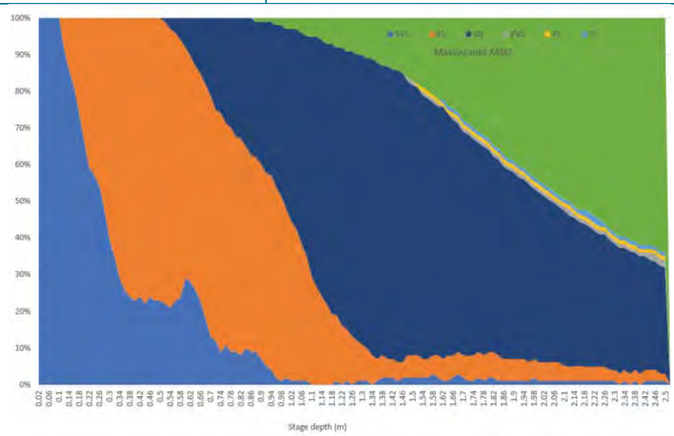
DB represents historical data with rating curve for low flows only

Table 3-20: Summary of the hydraulic output in terms of depth and resultant velocity classes per e-flow site (X1' is the Komati system, X2' the Crocodile and X3' the Sabie system)

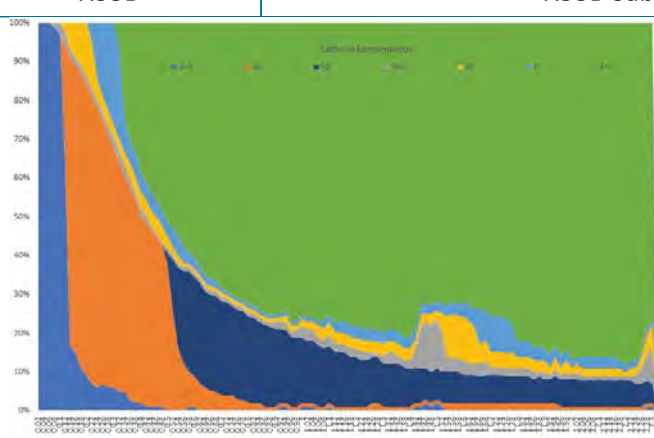
IUA	Quat_Code	Site name
UANETZA CATCHMENT		
X4-1U	X40A	X40A Uanetza in SA



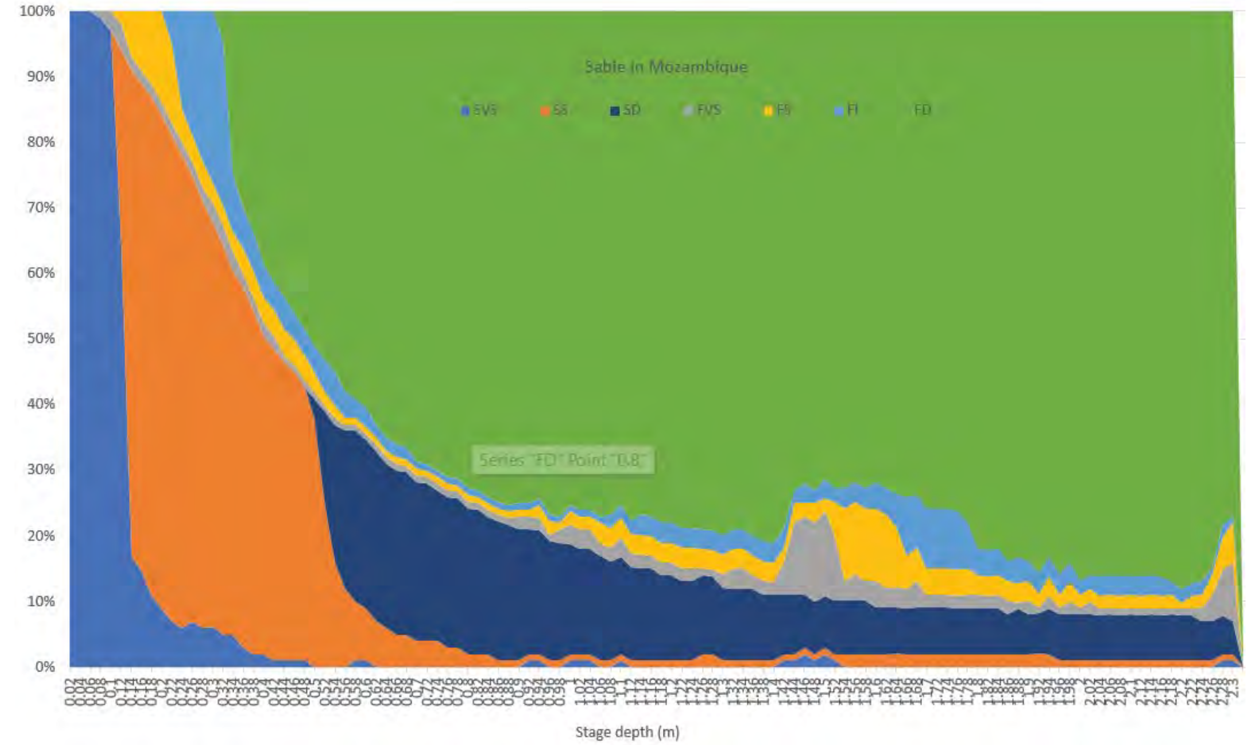
IUA	Quat_Code	Site name
MASSINTONTO CATCHMENT		
X4-1M	X40D	X40D Massintonto in SA



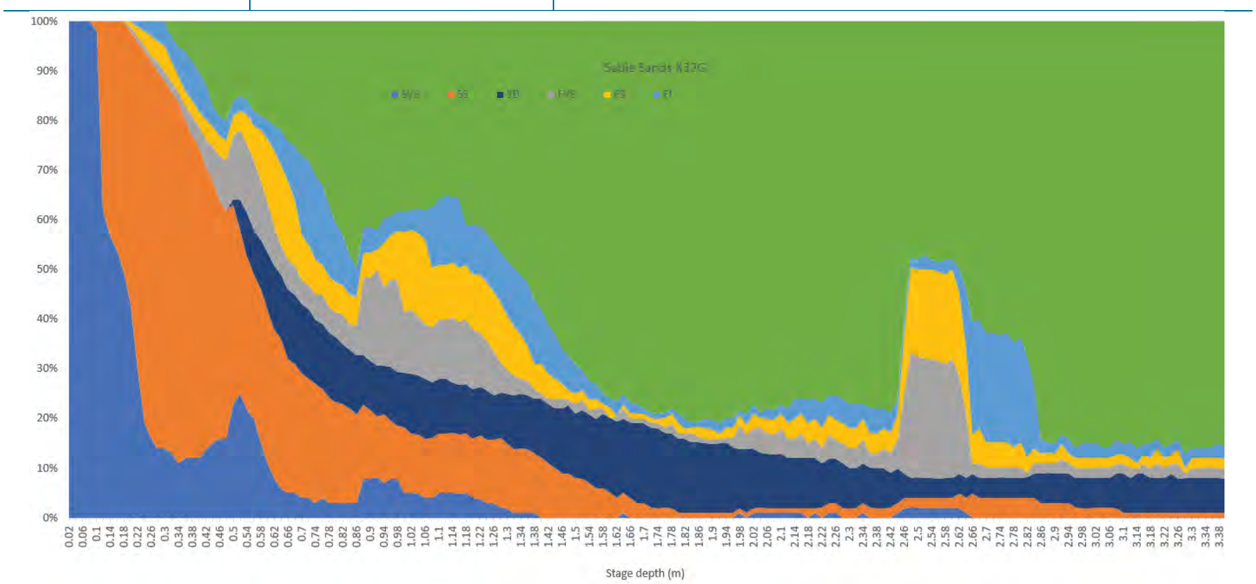
IUA	Quat_Code	Site name
SABIE CATCHMENT		
X3-6LS	X33B	X33B Sabie



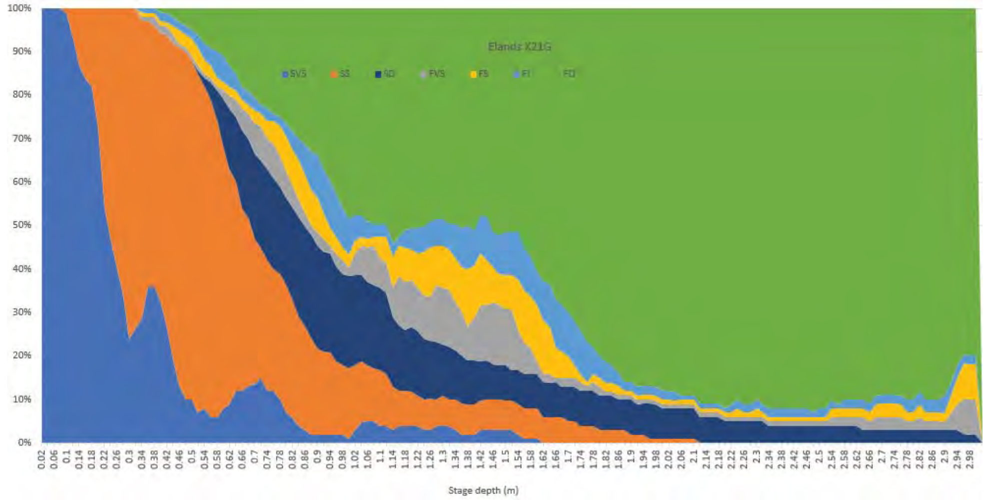
IUA	Quat_Code	Site name
Y1-5	X33D	X33D Sabie



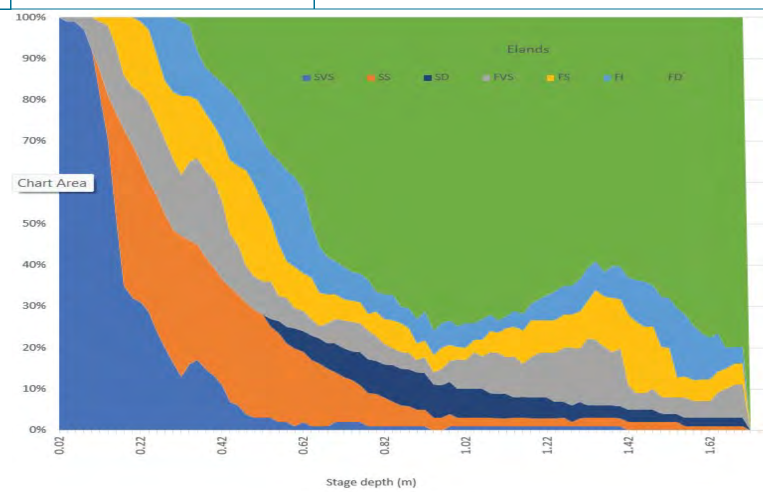
IUA	Quat_Code	Site name
X3-3E	X32G	X32H Sand



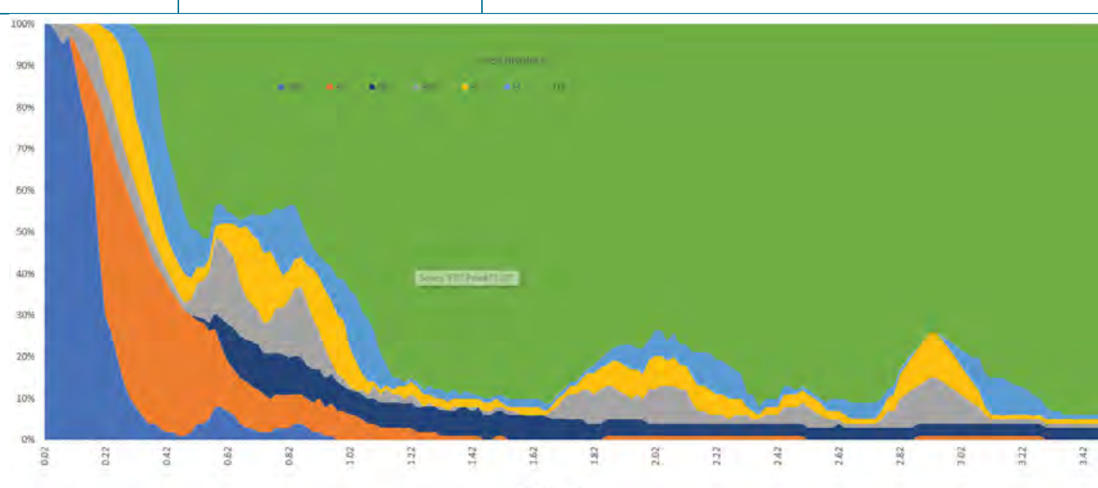
IUA	Quat_Code	Site name
CROCODILE CATCHMENT		
X2-3	X21G	X21G Elands Waterval Boven



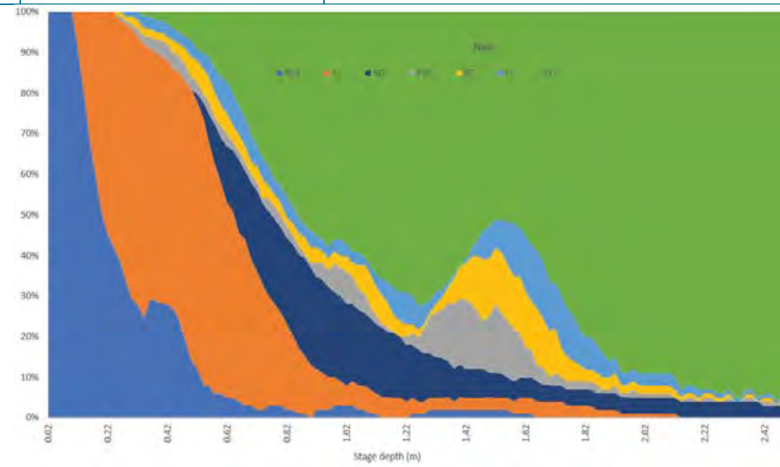
IUA	Quat_Code	Site name
X2-4	X21K	X21K Elands



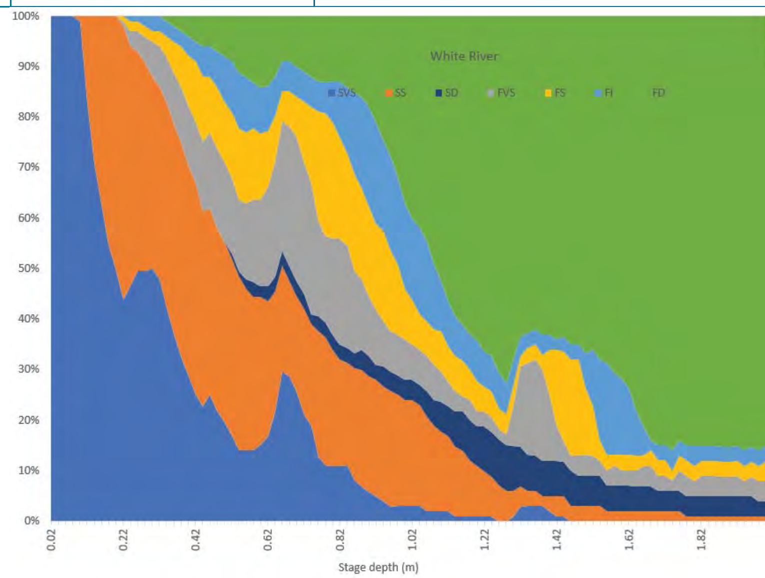
IUA	Quat_Code	Site name
X2-6	X22B	X22B Crocodile



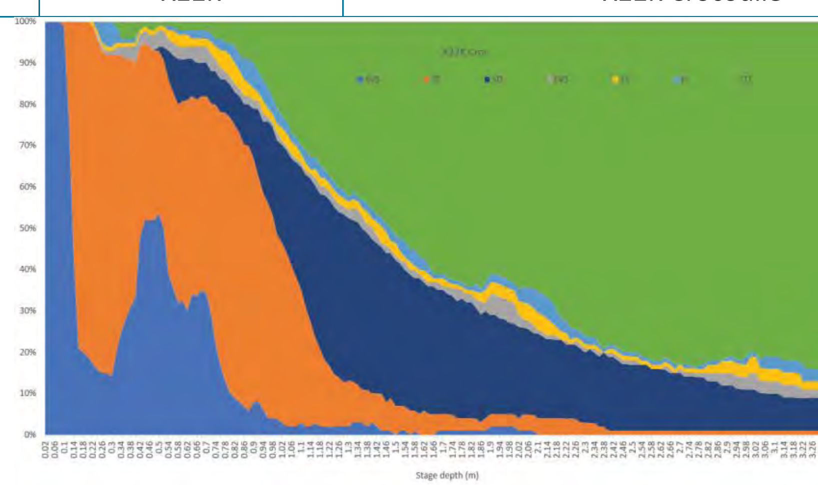
IUA	Quat_Code	Site name
X2-8N	X22F	X22F Nels



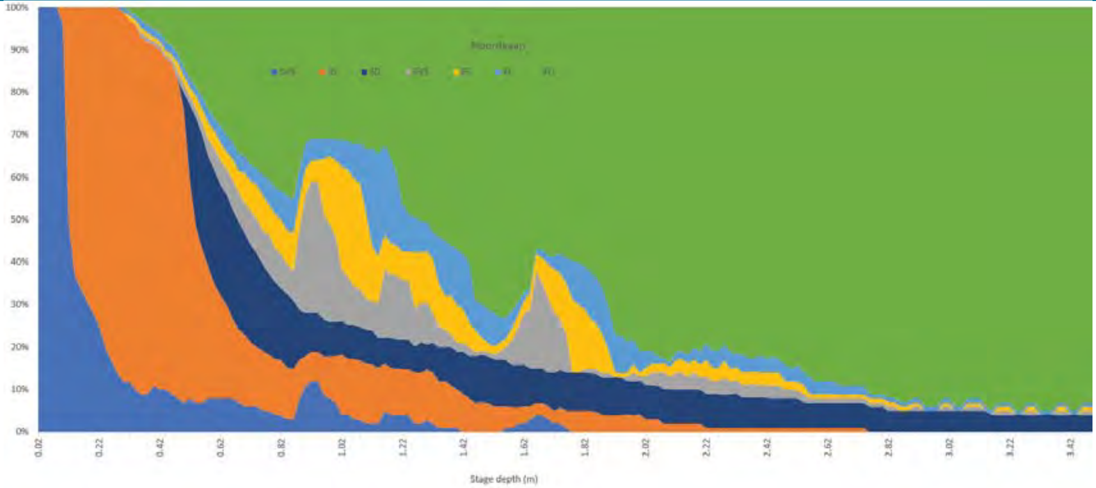
X2-8W	X22H	X22H White River



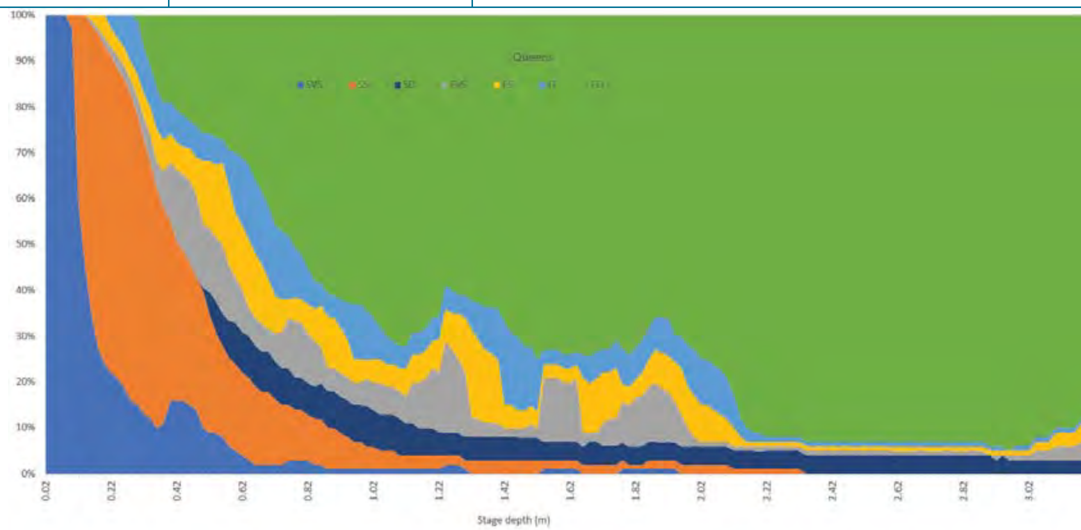
X2-9	X22K	X22K Crocodile



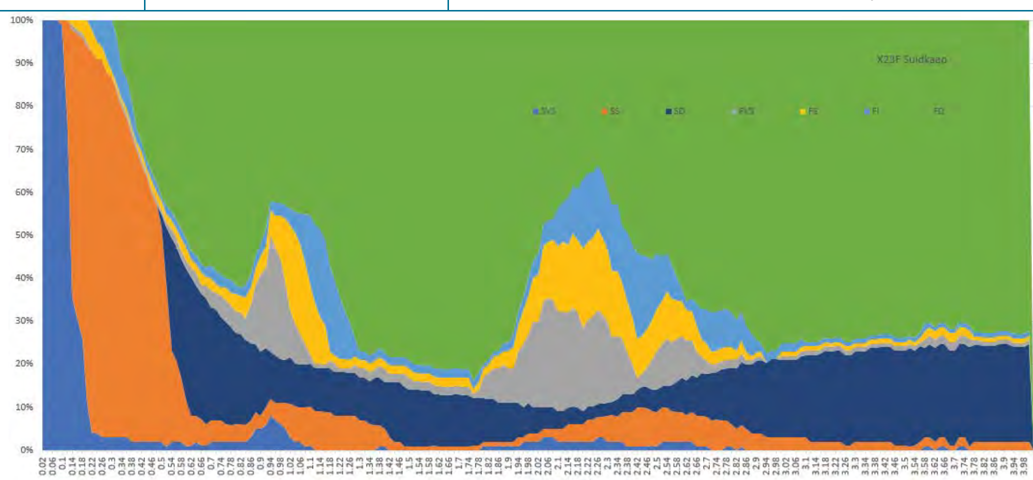
IUA	Quat_Code	Site name
X2-10N	X23B	X23B Noordkaap



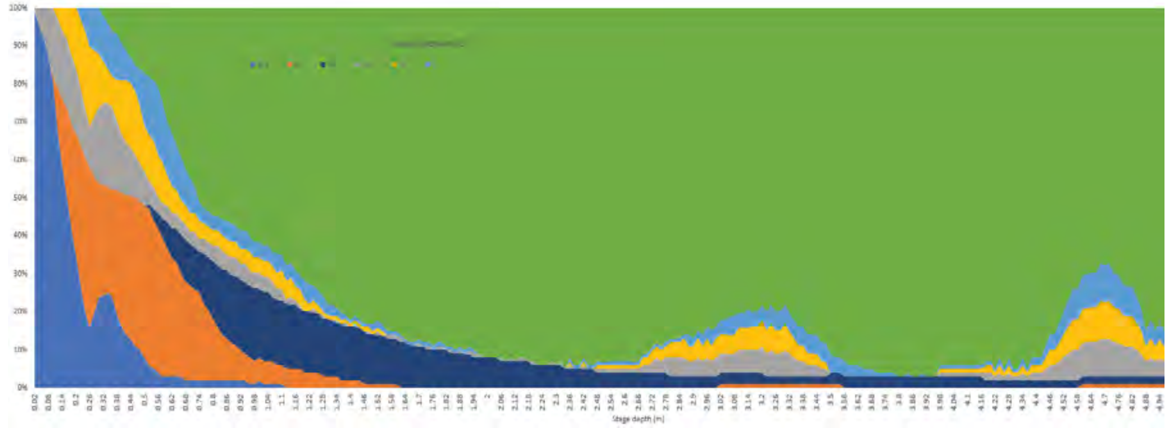
IUA	Quat_Code	Site name
X2-10Q	X23E	X23E Queens



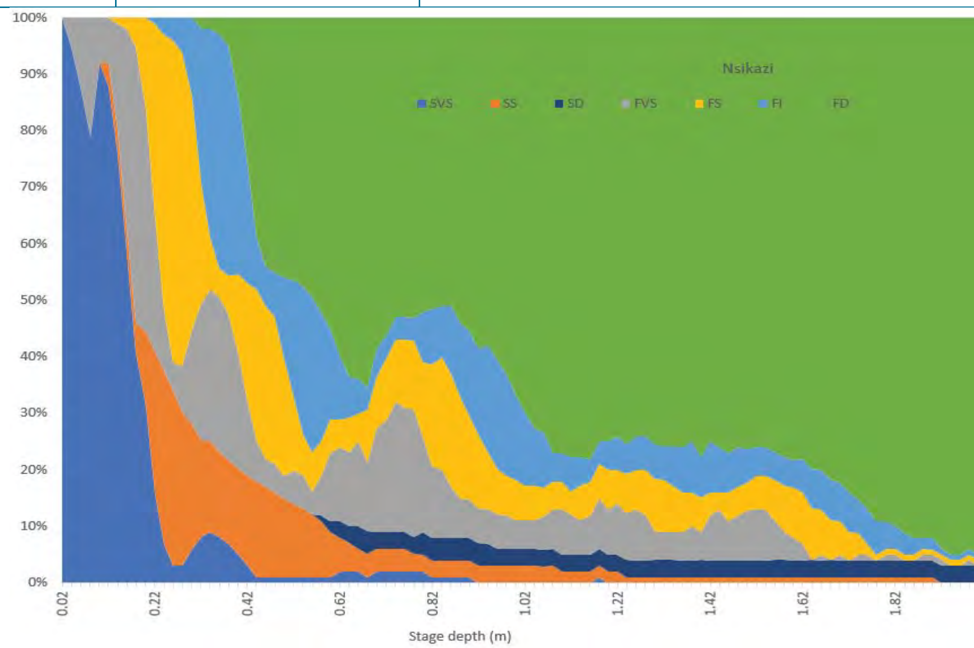
IUA	Quat_Code	Site name
X2-10S	X23F	X23F Suidkaap



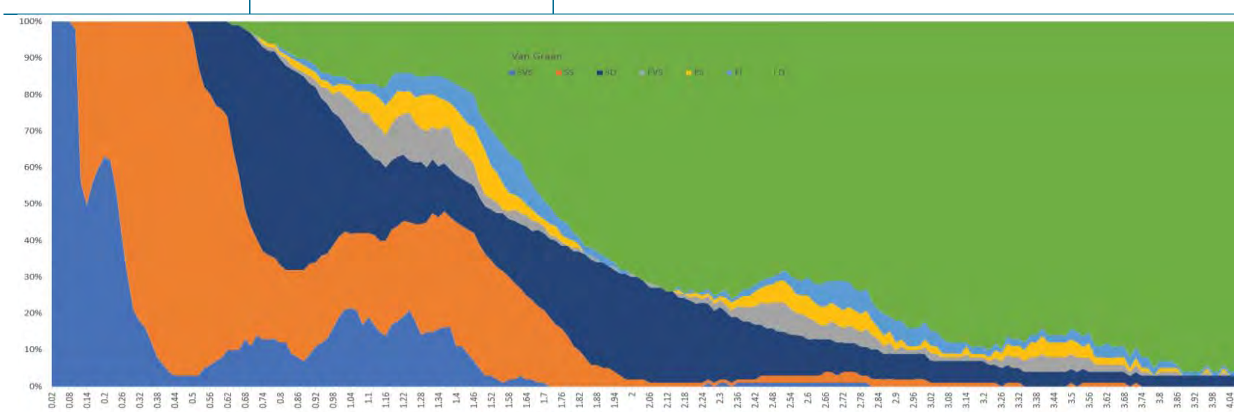
IUA	Quat_Code	Site name
X2-10K	X23G	X23G Kaap



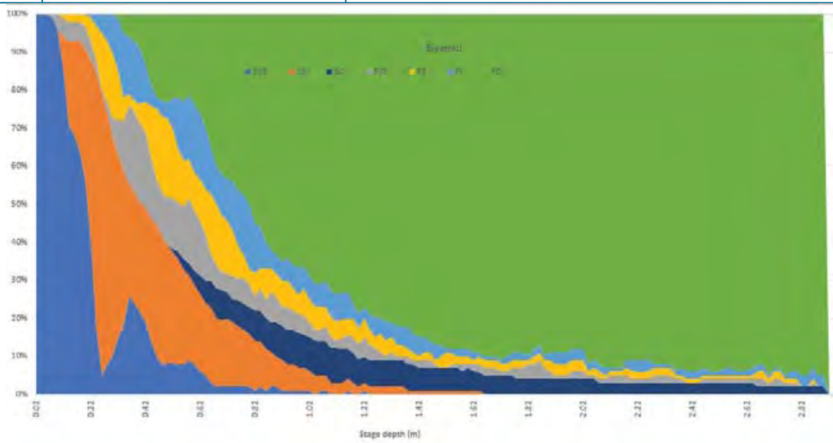
IUA	Quat_Code	Site name
X2-12	X24C	X24C Nsikazi



IUA	Quat_Code	Site name
X2-13	X24F	X24F Crocodile

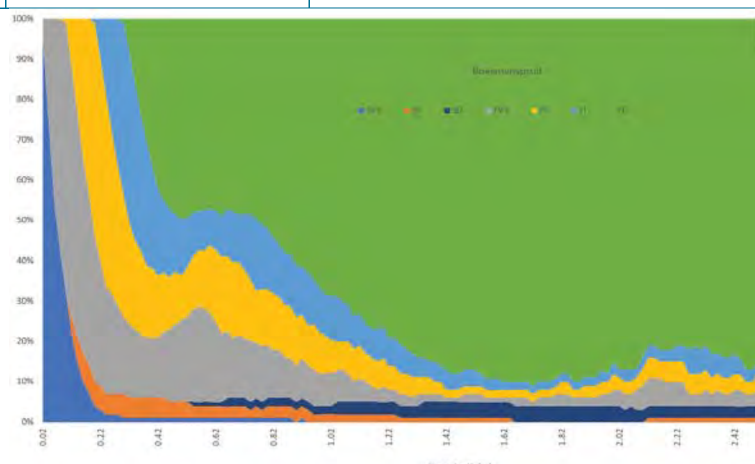


IUA	Quat_Code	Site name
X2-13	X24H	X24H Mbyamiti

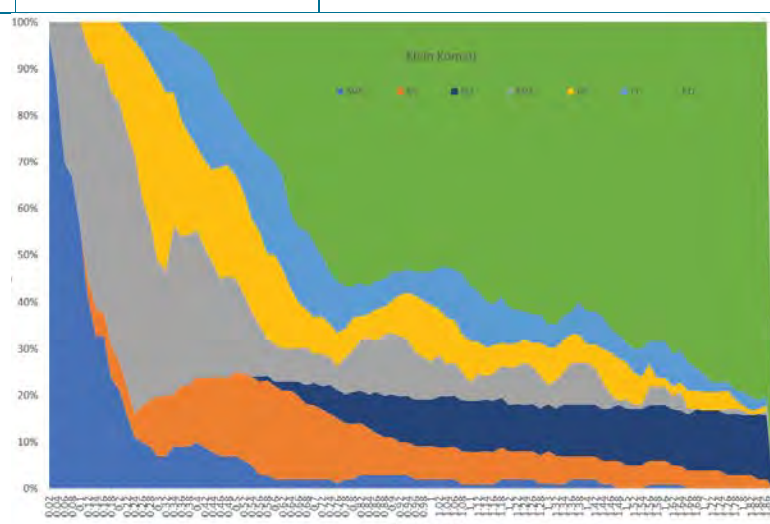


KOMATI CATCHMENT

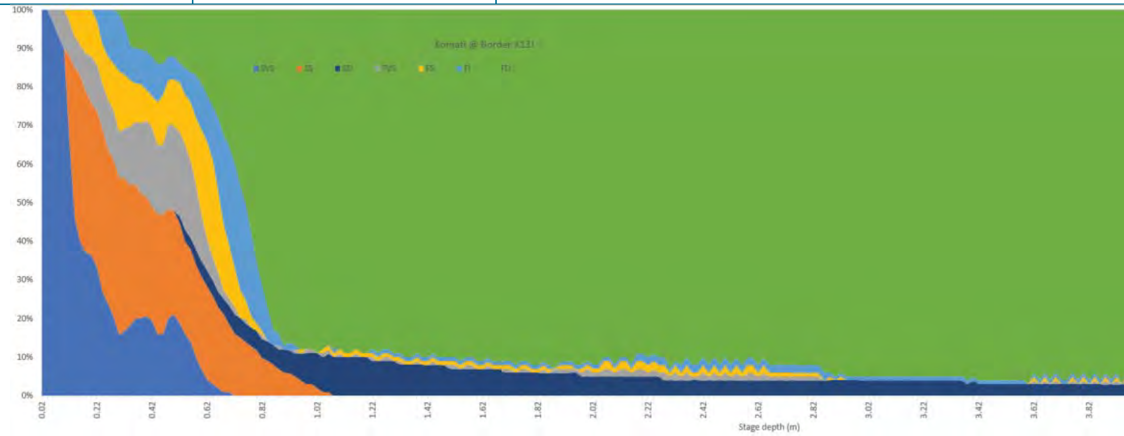
IUA	Quat_Code	Site name
X1-1	X11B	X11B Boesmanspruit



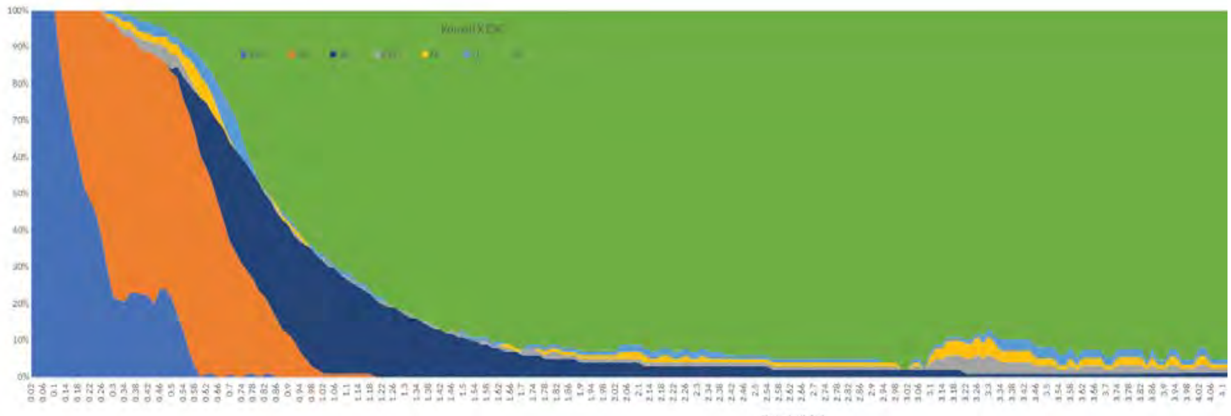
IUA	Quat_Code	Site name
X1-3	X11D	X11D Klein Komati



IUA	Quat_Code	Site name
X1-10	X13J	X13J Komati

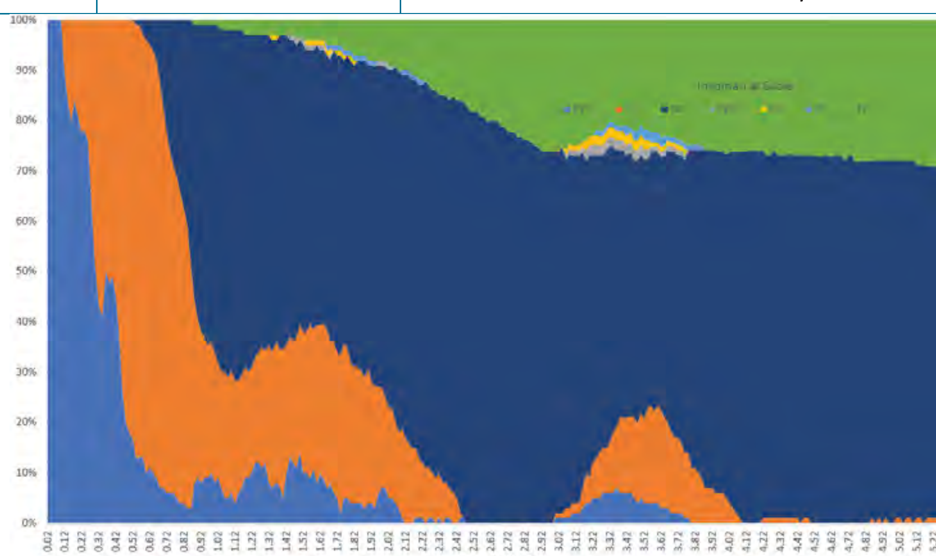


X1-9	X13K	X13K Komati



INCOMATI CATCHMENT

Y1-2	Y40A	Y40A Incomati u/s Sabie



The geomorphic input to the flow requirements is presented in Table 3-21 to Table 3-27. The sediment flow relationships were modelled around these geomorphic requirements, with the flows below and above the requirements introducing more risk and the range between the flows listed below posing a low risk. The timing and frequency of the flows pose another risk element, with specified flows too infrequent or too frequent adding risk to the habitat maintenance.

Table 3-21: Geomorphic flow requirements for X33B Sabie River at Lower Sabie

Freshets / Floods	Units	Geomorph	Comments
Class 1	cumecs	33	Mobilise coarse sand on bed (1.2 m deep)
	daily average/ peak	Ave	
	Number of days	5	
	Months	4 within-year floods in the wet season	
Class 2	cumec	na	
	daily average/ peak		
	Number of days		
	Months		
Class 3	cumec	250-313	Inundate flood benches, mobilise sand on flood benches and medium gravel on bed (2.4-2.6 m)
	daily average/ peak	Peak	
	Number of days	5	
	Months	1:2 year	

Table 3-22: Geomorphic flow requirements for X31K Sabie River

Freshets / Floods	Units	Geomorph	Comments
Class 1	cumecs	13	Mobilise gravel in deep anastomosing channels (1 m)
	daily average/ peak	Ave	
	Number of days	3	
	Months	4 within-year floods in the wet season	
Class 2	cumec	84	Mobilise medium gravel in anastomosing channels (2 m)
	daily average/ peak	Peak	
	Number of days	5	
	Months	annual flood (wettest month)	
Class 3	cumec	355	Inundate flood benches and mobilise small cobble (4.1 m)
	daily average/ peak	Peak	
	Number of days	5	
	Months	1:2	
	daily average/ peak		
	Number of days		
	Months		

Table 3-23: Geomorphic flow requirements for X21K Elands

Freshets / Floods	Units	Geomorph	Comments
Class 1	cumecs	na	
	daily average/ peak		
	Number of days		
	Months		
Class 2	cumec	38	Inundate floodbench to deposit fine sediment (1.5 m)
	daily average/ peak	peak	
	Number of days	3	
	Months	annual flood (wettest month)	
Class 3	cumec	140	Mobilise coarse gravel on bed and bars (2.3 m)
	daily average/ peak	Peak	
	Number of days	5	
	Months	annual flood (wettest month)	
Class 4	cumec	317	Mobilise small cobble on bed (3 m)
	daily average/ peak	Peak	
	Number of days	5	
	Months	01:05	

Table 3-24: Geomorphic flow requirements for X23G Kaap

Freshets / Floods	Units	Geomorph	Comments
Class 1	cumecs	8	'Mobilise small cobble (1.5 m)
	daily average/ peak	Average	
	Number of days	2	
	Months	Nov, Jan, Feb March	
Class 2	cumec	na	
	daily average/ peak		
	Number of days		
	Months		
Class 3	cumec	66	Deposit sand on bedrock ledge (3.5 m)
	daily average/ peak	Peak	
	Number of days	5	
	Months	01:02	
Class 4	cumec	na	
	daily average/ peak		
	Number of days		
	Months		

Table 3-25: Geomorphic flow requirements for Y40A Incomati upstream of the Sabie confluence

Freshets / Floods	Units	Geomorph	Comments
Class 1	cumecs	31	Mobilise fine gravels on the bed (2.3 m)
	daily average/ peak	Average	
	Number of days	5	
	Months	4 within-year floods in the wet season	
Class 2	cumec	202	Inundate flood bench and deposit medium sand on it (3.9 m)
	daily average/ peak	Peak	
	Number of days	5	
	Months	Annual flood	
Class 3	cumec	800	Inundate Higher floodbench along left bank and deposit fine sand (5.5 m)
	daily average/ peak	Peak	
	Number of days	5	
	Months	1:2/3 flood	

Table 3-26: Geomorphic flow requirements for X24F Croc Van Graan

Freshets / Floods	Units	Geomorph	Comments
Class 1	cumecs	16	Inundate lower flood benches (1.6 m)
	daily average/ peak	Ave	
	Number of days	5	
	Months	4 within-year floods in the wet season	
Class 2	cumec	63	Mobilise medium gravel on bed (2.2 m)
	daily average/ peak	Peak	
	Number of days	3	
	Months	annual flood (wettest month)	
Class 3	cumec	390	Inundate higher flood bench to deposit sand and mobilise medium gravel on lower benches (3.4 m)
	daily average/ peak	Peak	
	Number of days	5	
	Months	01:02	
Class 4	cumec	2740	Inundate higher flood benches to deposit fine sediment along margins (5.4 m)
	daily average/ peak	Peak	
	Number of days	5	
	Months	Feb	

Table 3-27: Geomorphic flow requirements for X13J Komati at the Border

Freshets / Floods	Units	Geomorph	Comments
Class 1	cumecs	11	Initiate fine gravel (D50 of 6 mm, D84 of 12 mm) movement 0.8 m
	daily average/ peak	Average	
	Number of days	4	
	Months	4 within-year floods in the wet season	
Class 2	cumec	200	Inundate flood bench and allow sand deposition (3.0 m)
	daily average/ peak	Average	
	Number of days	5	
	Months	Annual	
Class 3	cumec	400	Inundate flood bench to deposit sand (4.2 m)
	daily average/ peak	Peak	
	Number of days	5	
	Months	1 in 2	

3.6.2 RESPONSES TO ECOSYSTEM CHANGE

The drivers of ecosystem change (water quality and ecotoxicity, hydrology, hydraulics and geomorphology) all exert their influence over the instream and riparian ecosystem. Indicators for fish, macro-invertebrates and the riparian vegetation were all used to describe the present state of the ecosystem and provided evidence that could be used to determine the relationship between the drivers of change and the response of the ecosystem. The categories listed in Table 3-1 were used to describe the state of the rivers within the Incomati Basin.

3.6.2.1 FISH AND FISHERIES

3.6.2.1.1 Introduction

Continued population growth, land transformations, intensified agriculture and industrial diversification coupled with climate change and unsuccessful law enforcement are threatening and degrading biodiversity and ecosystems worldwide (Allan, 2004; Allan *et al*., 2005; Dudgeon *et al*., 2006). Degrading ecosystems and biodiversity loss, hinders the functionality and ability of the ecosystem to provide ecosystem services to human communities (Holmlund and Hammer, 1999; Daily, 2000; Hooper *et al.,* 2005). Freshwater fish species provide numerous resources and ecosystem services to human communities (Dudgeon *et al.,* 2006; Dudgeon, 2010). Fish from lakes and rivers supply human communities with a valuable, self-sustainable food source, allows for water purification, nutrient cycling and recreational activities (Rodríguez *et al.,* 2006). Despite the multiple advantages human communities gain from freshwater ecosystems and the ecological value of fishes, these freshwater ecosystems are constantly used, overused, and abused (Skelton *et al.*, 1995; Dudgeon *et al.,* 2006).

The consistent overuse and anthropogenic pressure on freshwater bodies have caused the quality of southern African river systems to reach its lowest level of functionality over the past fifteen years (Woodborne *et al.,* 2012; Dabrowski and De Klerk, 2013). According to the Environmental Performance Index (2020), South Africa is ranked 94th in the world (out of 180 countries) due to the poor management and conservation efforts of its river systems. A trade-off now exists between the use and maintenance of a healthy and diverse freshwater ecosystem and the use of the rivers by human communities.

Fish species are used and highlighted as ecological indicators due to their relatively long lifespan, broad habitat requirements, mobility, wide range of trophic levels within the ecosystem and social importance to human communities (Rapport 1989). Changes in fish community composition either through taxonomic compositions, life history traits or functional traits can all affect the ecosystem functionality (Zhao *et al*., 2016). For these reasons, ecosystem functioning is largely dependent on the responses of freshwater fish as it reflects the amount of degradation that specific ecosystem has undergone (Das and Chakrabarty, 2007; Zhao *et al.,* 2016).

Various monitoring tools (multiple Lines of Evidence (LoE)) are incorporated and used to inform management agencies on the impacts environmental drivers (pollution, habitat change, flow alteration, overutilisation) have on the health and functionality of freshwater ecosystems (Fausch *et al.,* 1990; Ansara-Ross *et al.,* 2008). A multivariate statistical approach (e.g. Redundancy Analysis ordination technique (RDA)) is used to evaluate the composition of fish communities and drivers of change. It predicts, summarises and provides the environmental condition of communities and identifies important drivers of a community that can be used to identify and evaluate impacts (O'Brien *et al.,* 2009, Wepener *et al.,* 2011). Other assessments include the Fish Response Assessment Index (FRAI) that has been established as a commonly used index of the condition of attributes of fish communities in South Africa (Kleynhans, 2007). The purpose of this assessment is to measure the biological integrity from the attributes of a river based on the fish assemblages of the river (Kleynhans, 2007; Kleynhans and Louw, 2007). The output of the assessment is the present ecological state of the fish communities based on the A-F category, where “A” represents an ‘unmodified natural’ system and “F” is a ‘critically/extremely modified’ system (Kleynhans and Louw, 2007). The use of multiple LoEs allows the evaluation of wellbeing of ecosystems to provide a greater level of certainty as individual indices alone are not robust. If the correct monitoring and management strategies are implemented and linked, freshwater ecosystems can be protected in a manner that would ensure continuity of ecosystem services and associated processes upon which human communities depend (Ashton, 2010).

The Incomati River Catchment is a semi-arid, transboundary catchment located in the south-eastern parts of South Africa, northern parts of Eswatini and southern parts of Mozambique (Kleynhans *et al.,* 2015). Main river sub-catchments within the Incomati include the Sabie-, Crocodile-, Komati- and Incomati Rivers. These main rivers were exposed to different land use and water-use changes form as early as the 1950s (Hallowes *et al*., 2010). The Sabie River system is currently classified as one of the most pristine southern African ecosystems due to the high species diversity it maintains (O’Brien *et al*., 2018a, O’Brien *et al*., 2018b). Ecosystems within the Sabie River have re-established functionality through fish migrations, primarily from the Crocodile- and Komati Rivers (Kleynhans, 1986). The Crocodile River system is an ecologically important and biologically diverse river system with at least 49 fish species that occur frequently throughout the river (Kleynhans *et al*., 2015). The Crocodile River is in a moderately modified ecological condition with flow reductions and poor water quality across the river (Soko and Gyedu-Ababio, 2015). In contrast to the Crocodile and Sabie Rivers, the water quality conditions of the Upper Komati River is in a fairly good state, while the lower reaches are in a poor state due to multiple stressors (Kleynhans *et al*., 2015, O’Brien *et al*., 2019). The Incomati River flows through Mozambique when all three major rivers above have converged, forms a floodplain and then flows into the Indian Ocean at a discharge of 100-200 m^3s^{-1}. The Incomati River is largely influenced by overutilisation for resources, upstream flow alterations and invasive species.

Growing agriculture, forestry and urbanisation over the past two decades, were identified as some of the main drivers of increased water scarcity in the catchment (Saraiva Okello *et al.,* 2015, O’Brien *et al.,* 2019). Unprotected areas (excluding KNP) in the Incomati Catchment are extensively transformed into plantations/woodlots, sugarcane croplands and urban/industrial areas. The increasing agricultural growth and irrigation demand has led to the establishment of 12 major dams and more than 200 informal farm dams (Jackson, Woodford and Weyl, 2016; O’Brien *et al.,* 2019). Among these are gauging weirs constructed to regulate flow, water withdrawal and control flooding (Silva *et al.,* 2018; O'Brien *et al.,* 2019). The dams and gauging weirs are anthropogenic barriers that hinder the migration of fish (Branco *et al.,* 2017; Silva *et al.,* 2018; O'Brien *et al.,* 2019). The Incomati Water Management Area (WMA) has more than 10 fish passages constructed on these barriers to improve connectivity and migration of fish, but none are in a functional state (Bok *et al.,* 2007; O'Brien *et al.,* 2019). These transformations continue to cause change to the climate, weather patterns, energy and water transportation, alter species distribution, and reduce viable habitats (Sleeter *et al*., 2018).

This study aimed to determine the overall state of fish communities in the Incomati River Catchment. The multiple LoE used in this study included the Fish Response Assessment Index (FRAI) (Kleynhans and Louw, 2007) and Multivariate statistics (Redundancy Analysis). The multivariate analysis was used to validate the FRAI results and to provide insight into what the main drivers of change were for the catchment.

3.6.2.1.2 Materials and Methods

3.6.2.1.2.1 Ethics

The project and procedures were sanctioned by the ethical committee of the University of Mpumalanga Animal Science Research Ethics Committee (project number AS/GOBrien 01-280122). For sampling in the Kruger National Park, the project was registered with South Africa National Parks (SS840). The project also obtained permits from Mpumalanga Parks and Tourism (Permit MPB. 5789).

3.6.2.1.2.2 Study area

Forty-four sites were selected in the Incomati River Basin (Table 3-10). The sites were selected based on historical data available (EWR studies conducted at the site previously), sites on the tributaries, the mainstem of the Uanetza, Massintonto, Sabie, Crocodile, Komati and Incomati Catchments. The sites include the floodplain and estuary. Sites were in South Africa, Eswatini, and Mozambique and included sampling in protected areas (Kruger National Park). Each site was divided into different efforts based on the habitat and velocity depth classes available (Table 3-28) as proposed by Kleynhans *et al*. (2007). One site was sampled in the Uanetza and Massintonto Catchment, 8 sites were sampled in the Sabie River Catchment, 16 sites were sampled in the Crocodile River Catchment and 9 sites were sampled in the Komati/Incomati River Catchment.

3.6.2.1.2.3 Fish sampling

Fish communities were sampled at the different sampling sites in the Incomati River Catchment during different sampling events from April 2021 to July 2023. There was no available water at the X40BM Uanetza and X40DM Massintonto sites and thus no fish community data were collected. X13D Komati and X32J Sand were not sampled due to time constraints, but this gap has been filled with historical data. Historical data from 2020 and 2021 were used to fill in any gaps in available data. Fish communities were sampled using various active (cast net, running seine net, electro-fisher, generator, angling techniques) and passive (fyke nets) sampling methods based on different habitats available (Oliveira *et al.*, 2014). The diversity, abundances, and size (standard length) of sampled fish were documented as catch per unit effort along with the associated habitat variability. This included three depths (mm) and velocities (m/s) measurements per unit effort measured with a transparent velocity head rod (TVHR: Ground truth Consulting, Hilton KwaZulu-Natal) (Table 3-28), the substrate distributions (%) (percentage silt, mud, and, gravel, cobble, boulders, bedrock) were estimated per unit effort based on the classification of Fouché (2009) and Rowntree *et al*. (2000)(Table 3-29), and cover types were identified (undercut bank, substrate, depth, marginal vegetation, aquatic vegetation, overhanging vegetation, roots, other) and their extent estimated and scored as adapted from Fouché (2009) and Kleynhans (2007) (Table 3-30).

Table 3-28: Habitat classification based on velocity-depth classes proposed by Kleynhans (2007)

Flow-Depth Class	Velocity (m/s)	Depth (m)
Slow-deep (SD)	Less than 0.3	0.5 and deeper
Fast-deep (FD)	0.3 and above	0.5 and deeper
Slow-shallow (SS)	Less than 0.3	Less than 0.5
Fast-Shallow (FS)	0.3 and above	Less than 0.5

Table 3-29: Substrate classification adapted from Rowntree et al. (2000).

Substrate class	Size (mm)	Practical description (used in the field)
Silt and clay	< 0.06	Powdery or soapy, grains not visible
Sand	0.06-2	Individual grains visible
Gravel	2-64	From thumb to the size of an adult fist
Cobbles	64-256	From a fist to smaller than an adult head
Boulder	> 256	Larger than an adult head
Bedrock	N/A	

Table 3-30: Cover type rates adapted from Kleynhans (2007).

Description	Relative ecological value/abundance score	Occurrence (% of the area covered)
None	0	0
Rare	1	0-5
Sparse	2	6-25
Common/Moderate	3	25-75
Abundant	4	75-90
Very abundant	5	90-100

3.6.2.1.2.4 Fish water quality

At each site, the surface water samples were collected from the water column with 1 L polypropylene (PP) bottle as described by Musselman (2012). These samples were analysed at Northwest University. The constituents included calcium (Ca), chloride (Cl^-), potassium (K), magnesium (Mg^+), sodium (Na), ammonium nitrogen (NH_4^+- N), nitrate-nitrogen/nitrite nitrogen (NO_3^- -N/ NO_2^- -N), orthophosphate (PO_4^{3-}) and sulphates (SO_4^{2-}) and chlorophyll a. Physiochemical water quality variables including temperature (°C), pH, dissolved oxygen (mg/L), oxygen saturation (%) and electrical conductivity (µS/cm^2) were measured in situ at each sampling site in the different sites. The measurements were taken using a WTW Water Quality meter.

3.6.2.1.2.5 The ecological wellbeing of the fish

The present ecological state of the Incomati River Catchment was determined through the Fish Response Assessment Index (FRAI) (Kleynhans, 2007). The DWS has developed the FRAI approach which is a multiple-criteria decision analyses model in Microsoft®(Kleynhans and Louw, 2007; Kleynhans, 2007). The eight-step process of the FRAI methodology was used to obtain modelled and adjusted FRAI scores (FRAI I), score each metric, and assess which altered driver component contributed to the ecological state obtained at each site.

3.6.2.1.2.6 Statistics

In this study direct or constrained analyses were undertaken that involved overlaying captured variance of the explanatory environmental variables onto fish sample and taxa ordination diagrams. The linear response mode used to achieve this is a redundancy analysis (RDA), a derivative of principle component analyses (PCA) using the Canoco version 4.5 software package (Ter Braak, 1994). Because abundance data were available, the data were transformed using a Log X+2 - transformation (Van den Brink *et al*., 2003).

3.6.2.1.3 Fish Results

During the surveys from May 2020 to October 2023, 362 sampling efforts were carried out, resulting in the collection of 5042 fish from 40 sites selected for the study (Table 3-31- Table 3-37).

There was no available water at the SUP X40A Uanetza and SUP X40D Massintonto sites and thus no fish community data were collected. X13D Komati and X32J Sand were not sampled due to time constraints, but this gap has been filled with data from 2020 and 2021. Forty-five of the expected 52 different freshwater species, and four alien invasive species were collected during the survey. The Crocodile Catchment had the highest abundances of fish (n=2575) and the Uanetza Catchment had the lowest abundances of fish (n=54). The Sabie Catchment had the highest freshwater fish species richness present (35 fish species) followed by the Crocodile Catchment (34 fish species).

The invasive species caught were *Gambusia affinis* (2 sites, n=3), *Micropterus salmoides* (3 sites, n=7) and *Cyprinus carpio* (1 site, n=2). Possible *O. mossambicus* and *Oreochromis niloticus* hybrids were also recorded (1 site, n= 21). Thirty-five catchment scale migrators (*Anguilla bengalensis, Anguilla mossambica* and *Anguilla marmorata*) were found at X24F Crocodile and Y1-4 Floodplain but were expected at all of the sites, during the survey. *Oreochromis mossambicus* (IUCN category Vulnerable), *Anguilla bengalensis labiata, Anguilla mossambica* (IUCN category Near Threatened), *Serranochromis meridianus* (IUCN category Endangered) and *Chiloglanis bifurcus* (IUCN category Critically Endangered), were the only species with the IUCN category above least concerned that were sampled during the survey. Other species with critically endangered status (Kneria sp. 'South Africa', Chetia brevis) were not collected.

3.6.2.1.3.1 Uanetza Catchment

The X40B Uanetza site was sampled in June 2023, with a total of six sampling efforts (Table 3-31), resulting in the abundances of 54 fish from two species. There was no available water at the X40BM Uanetza thus no fish community data were collected. Two of the expected 20 different species and no alien invasive species were collected during the survey.

Oreochromis mossambicus (n=53) were the most abundant fish species caught during the survey. *Clarias gariepinus* (n=1) were the least abundant fish species caught.

The overall well-being of the fish communities was in a largely modified state (Class C) (Table 3-32). This is a seasonal river that was sampled during the low flow period so only hardy species like *O. mossambicus and C. gariepinus* were expected to occur.

Table 3-31: Species richness and abundance of fishes obtained from sites in the Uanetza Catchment during the 2023 surveys. The Ecological status of fish communities is also included.

Scientific Names	Sites	X40B Uanetza
	Sampling Year	2023
	Season	LF
	Efforts	6
	Abbreviations	
Anguilla bengalensis	ALAB	
Anguilla marmorata	AMAR	
Anguilla mossambica	AMOS	
Amphilius natalensis	ANAT	
Amphilius uranoscopus	AURA	
Enteromius afrohamiltoni	BFRI	
Enteromius annectens	BANN	
Enteromius anoplus	BANO	
Enteromius crocodilensis	BARG	
Enteromius eutaenia	BEUT	
Brycinus imberi	BIMB	
Labeobarbus marequensis	BMAR	
Enteromius paludinosus	BPAU	
Labeobarbus polylepis	BPOL	
Enteromius radiatus	BRAD	
Enteromius toppini	BTOP	
Enteromius trimaculatus	BTRI	
Enteromius unitaeniatus	BUNI	
Enteromius viviparus	BVIV	
Chiloglanis anoterus	CANO	
Chiloglanis bifurcus	CBIF	
Clarias gariepinus	CGAR	1
Chiloglanis paratus	CPAR	
Chiloglanis pretoriae	CPRE	
Chiloglanis swierstrai	CSWI	
Gambusia affinis	GAFF	
Glossogobius callidus	GCAL	
Glossogobius giuris	GGIU	
Hydrocynus vittatus	HVIT	
Labeo congoro	LCON	
Labeo cylindricus	LCYL	
Labeo molybdinus	LMOL	
Labeo rosae	LROS	
Labeo ruddi	LRUD	
Micralestes acutidens	MACU	
Mesobola brevianalis	MBRE	
Marcusenius macrolepidotus	MMAC	
Micropterus salmoides	MSAL	
Oreochromis mossambicus	OMOS	53
Oreochromis niloticus	ONIL	

Scientific Names	Sites	X40B Uanetza
	Sampling Year	2023
	Season	LF
	Efforts	6
	Abbreviations	
Opsaridium peringueyi	OPER	
Petrocephalus wesselsi	PCAT	
Pseudocrenilabrus philander	PPHI	
Schilbe intermedius	SINT	
Serranochromis meridianus	SMER	
Synodontis zambezensis	SZAM	
Tilapia rendalli	TREN	
Tilapia sparrmanii	TSPA	
Labeobarbus nelspruitensis	VNEL	
Xiphophorus helleri	XHEL	
FRAI Assessment		73.4
FRAI Ecological Category		C
Total Abundance		54
Species Richness		2

In the Uanetza Catchment the dominant fish category that was collected was limnophilic (pool-loving species). On average, fish species were collected between 130-400 mm of depth with some individuals collected at a maximum depth of 550 mm (Figure 3-17A). The majority of the fish were collected between 0.4-0.7 m/s velocity habitats with some individuals collected at a maximum velocity of 0.8 m/s (Figure 3-17B).

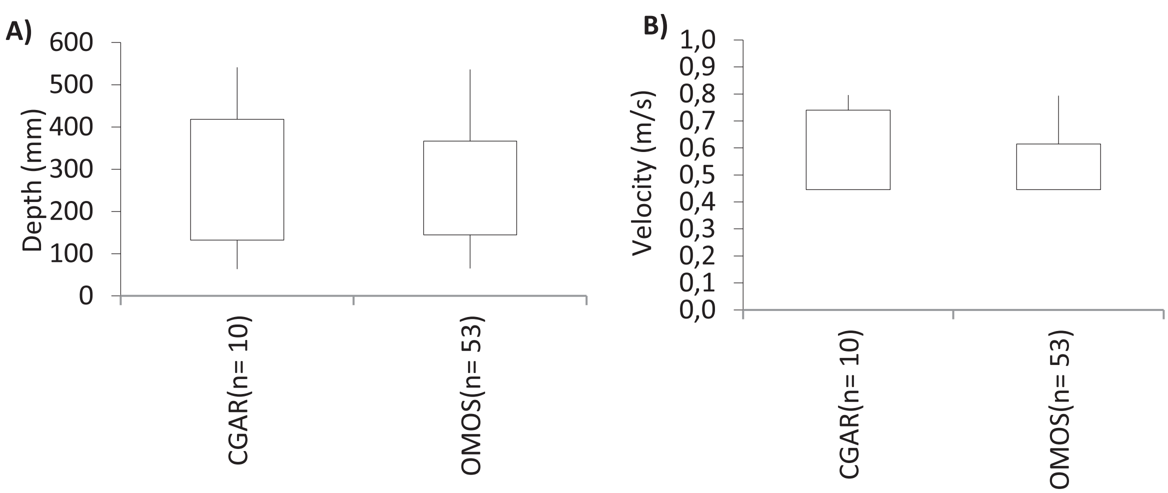


Figure 3-17: The A) Depth and B) Velocity ranges from different habitats samples where fish species were collected in the Uanetza Catchment.

3.6.2.1.3.2 Massintonto Catchment

The X40D Massintonto Catchment site was sampled in March 2021 and June 2023, with a total of 10 sampling efforts (Table 3-32), resulting in the fish abundances of 167 and 151 respectively. The species richness was seven and four fish respectively. There was no available water at the X40DM Massintonto thus no fish community data were collected. Seven of the expected 22 different species and no alien invasive species were collected during the survey.

Oreochromis mossambicus (n=220) and *Labeo ruddi* (n=45 only during high flow survey) were the most abundant fish species caught during the surveys. *Labeo molybdinus* (n=1) and *Enteromius trimaculatus* (n=6) were the least abundant fish species caught.

The overall well-being of the fish communities was in a moderately modified state (Class C) for both surveys (Table 3-32). This is a seasonal river, and the higher abundances of migratory species were expected during the high flow compared to the low flow season. The low abundances of some of the species (like *Enteromius trimaculatus*) collected during the low flow could be species that got stuck in the pools with the water drying up.

Table 3-32: Species richness and abundance of fishes obtained from sites in the Massintonto Catchment during the 2021 and 2023 surveys. The Ecological status of fish communities is also included.

Scientific Names	Sites	X40D Massintonto	
	Sampling Year	2021	2023
	Season	HF	LF
	Efforts	4	6
	Abbreviations		
Anguilla bengalensis	ALAB		
Anguilla marmorata	AMAR		
Anguilla mossambica	AMOS		
Amphilius natalensis	ANAT		
Amphilius uranoscopus	AURA		
Enteromius afrohamiltoni	BFRI	12	
Enteromius annectens	BANN		
Enteromius anoplus	BANO		
Enteromius crocodilensis	BARG		
Enteromius eutaenia	BEUT		
Brycinus imberi	BIMB		
Labeobarbus marequensis	BMAR		
Enteromius paludinosus	BPAU		
Labeobarbus polylepis	BPOL		
Enteromius radiatus	BRAD		
Enteromius toppini	BTOP		
Enteromius trimaculatus	BTRI	5	1
Enteromius unitaeniatus	BUNI		
Enteromius viviparus	BVIV	8	16
Chiloglanis anoterus	CANO		
Chiloglanis bifurcus	CBIF		
Clarias gariepinus	CGAR	5	3
Chiloglanis paratus	CPAR		
Chiloglanis pretoriae	CPRE		
Chiloglanis swierstrai	CSWI		
Gambusia affinis	GAFF		
Glossogobius callidus	GCAL		
Glossogobius giuris	GGIU		

Scientific Names	Sites	X40D Massintonto	
	Sampling Year	2021	2023
	Season	HF	LF
	Efforts	4	6
	Abbreviations		
Hydrocynus vittatus	HVIT		
Labeo congoro	LCON		
Labeo cylindricus	LCYL		
Labeo molybdinus	LMOL	3	
Labeo rosae	LROS		
Labeo ruddi	LRUD	45	
Micralestes acutidens	MACU		
Mesobola brevianalis	MBRE		
Marcusenius macrolepidotus	MMAC		
Micropterus salmoides	MSAL		
Oreochromis mossambicus	OMOS	89	131
Oreochromis niloticus	ONIL		
Opsaridium peringueyi	OPER		
Petrocephalus wesselsi	PCAT		
Pseudocrenilabrus philander	PPHI		
Schilbe intermedius	SINT		
Serranochromis meridianus	SMER		
Synodontis zambezensis	SZAM		
Tilapia rendalli	TREN		
Tilapia sparrmanii	TSPA		
Labeobarbus nelspruitensis	VNEL		
Xiphophorus helleri	XHEL		
FRAI Assessment			69,8
FRAI Ecological Category			C
Total Abundance			167
Species Richness			7

In the Massintonto Catchment the dominant fish category that was collected was rheophilic (fastflow-loving species), although no riffles where present at the site and fish species were collected from various pool habitats. On average, fish species were collected between 160-500 mm of depth with some individuals collected at a maximum depth of 730 mm (Figure 3-18). *Labeo molybdinus* and *Labeo ruddi* individuals were only collected in pools with a depth less than 200 mm deep. No riffles or faster flowing habitats were observed at the site in the catchment as this is a seasonal flowing river. No relationship between species collected and velocity ranges were made as all velocities were 0 m/s.

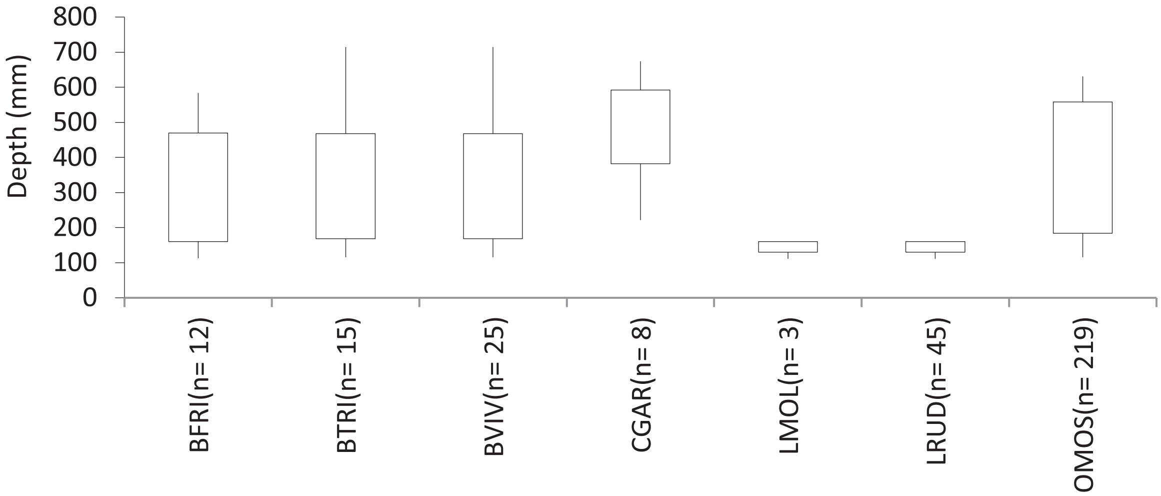


Figure 3-18: The depth ranges from different habitats where fish were collected in the Massintonto Catchment.

3.6.2.1.3.3 Sabie Catchment

During the surveys from July 2020 to July 2023, 83 sampling efforts (Table 3-33) were carried out, resulting in the abundances of 1065 fish from eight sites in the Sabie Catchment. Thirty-five of the expected 45 different species and one alien invasive species were collected during the surveys. X31K Sabie was the site with the highest abundance of fish (n=284) during the 2022 survey and X31G Marite was the site with the lowest abundance of fish (n= 3). X32H Sand (n=20) and X31K Sabie (n=19) were the sites with the highest species richness followed by X33B Sabie (n=10). X31A Sabie (one fish species) and X31G Marite (two fish species) had the lowest species richness of the fish present.

Labeobarbus marequensis (6 sites), *Enteromius eutaenia* (5 sites) and *Chiloglanis paratus* (5 sites), were collected at most of the sites. *Enteromius eutaenia* (n=109), *Chiloglanis paratus* (n= 97), and *Labeo molybdinus*(n=82) were the most abundant fish species caught during the survey. *Serranochromis meridianus* (n=1), *Enteromius afrohamiltoni* (n=1), and *Petrocephalus wesselsi* (n=1) were the least abundant fish species caught.

The invasive species caught were *Gambusia affinis* (2 sites, n=9). No catchment scale migrators (*Anguilla bengalensis, Anguilla mossambica and Anguilla marmorata*) were found although they were expected at most of the sites, during the survey. *Oreochromis mossambicus* (IUCN category Vulnerable) and *Serranochromis meridianus* (IUCN category Endangered), were the only species with the IUCN category above least concerned that were sampled during the survey. Other species with critically endangered (Kneria sp. 'South Africa', *Chetia brevis*) were not collected.

The FRAI scores obtained indicate that there is a large change in the fish community structure of the Sabie Catchment (Table 3-33). Over the catchment and sampling period, all the sites were in a moderately modified (Class C) state. During the present study, the main impacts that could cause changes in fish community included, barriers, poor water quality, altered flows and overexploitation.

Table 3-33: Species richness and abundance of fishes obtained from sites in the Sabie Catchment during the 2021, 2022 and 2023 surveys. The Ecological status of fish communities is also included.

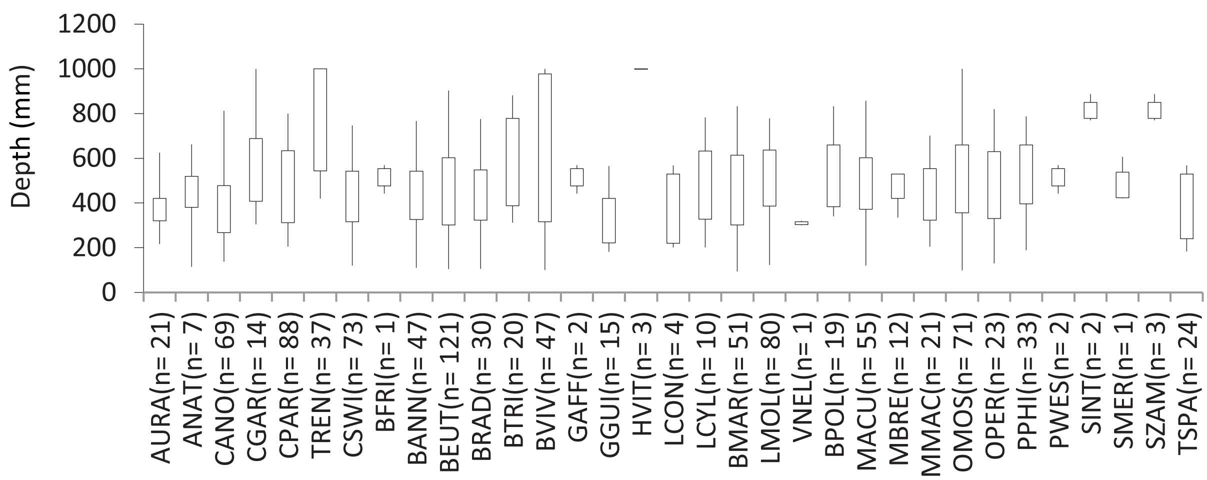
Sites		**X31A Sabie**	**X31C Mac Marites**		**X31D Sabie**	**X31G Marite**	**X31K Sabie**			**X32H Sand**	**X33B Sabie**	**X33D Sabie**
Scientific Names	**Year**	2022	2020	2021	2022	2023	2020	2021	2022	2023	2022	2022
	Season	HF	LF	LF	HF	LF	LF	LF	LF	LF	LF	LF
	Efforts	6	4	10	9	10	5	8	5	14	6	5
	Abbre											
Anguilla bengalensis	ALAB											
Anguilla marmorata	AMAR											
Anguilla mossambica	AMOS											
Amphilius natalensis	ANAT			7			9					
Amphilius uranoscopus	AURA		14	7				5				
Enteromius afrohamiltoni	BFRI											1
Enteromius annectens	BANN								1	16	3	
Enteromius anoplus	BANO											
Enteromius crocodilensis	BARG											
Enteromius eutaenia	BEUT		3	93	7		4		2			
Brycinus imberi	BIMB											
Labeobarbus marequensis	BMAR		1	16	14			8	38	2		
Enteromius paludinosus	BPAU											
Labeobarbus polylepis	BPOL			17	2							
Enteromius radiatus	BRAD									21	45	
Enteromius toppini	BTOP											
Enteromius trimaculatus	BTRI				1				24	12		
Enteromius unitaeniatus	BUNI											
Enteromius viviparus	BVIV					1			3	54	15	

Sites		X31A Sabie	X31C Mac Marites		X31D Sabie	X31G Marite	X31K Sabie			X32H Sand	X33B Sabie	X33D Sabie
Scientific Names	Year	2022	2020	2021	2022	2023	2020	2021	2022	2023	2022	2022
	Season	HF	LF	LF	HF	LF	LF	LF	LF	LF	LF	LF
	Efforts	6	4	10	9	10	5	8	5	14	6	5
	Abbre											
Chiloglanis anoterus	CANO	15		24					21	1		
Chiloglanis bifurcus	CBIF											
Clarias gariepinus	CGAR				1				5	6	5	
Chiloglanis paratus	CPAR		24						14	51	1	7
Chiloglanis pretoriae	CPRE					2			14			
Chiloglanis swierstrai	CSWI						36		4	3	4	
Gambusia affinis	GAFF							7				2
Glossogobius callidus	GCAL									4		
Glossogobius giuris	GGIU						1					14
Hydrocynus vittatus	HVIT										3	
Labeo congoro	LCON											4
Labeo cylindricus	LCYL							5		4		6
Labeo molybdinus	LMOL				1		3		75	3		
Labeo rosae	LROS							4				
Labeo ruddi	LRUD											
Micralestes acutidens	MACU						8		22	18		1
Mesobola brevianalis	MBRE							1	4	1		
Marcusenius macrolepidotus	MMAC			2					2	11	2	
Micropterus salmoides	MSAL											
Oreochromis mossambicus	OMOS							3	3	19	22	
Oreochromis niloticus	ONIL											

Sites		X31A Sabie	X31C Mac Marites		X31D Sabie	X31G Marite	X31K Sabie			X32H Sand	X33B Sabie	X33D Sabie
Scientific Names	**Year**	2022	2020	2021	2022	2023	2020	2021	2022	2023	2022	2022
	Season	HF	LF	LF	HF	LF	LF	LF	LF	LF	LF	LF
	Efforts	6	4	10	9	10	5	8	5	14	6	5
	Abbre											
Opsaridium peringueyi	OPER		1	6				4	15			
Petrocephalus wesselsi	PCAT									1		
Pseudocrenilabrus philander	PPHI						2		13			
Schilbe intermedius	SINT									2		
Serranochromis meridianus	SMER									1		
Synodontis zambezensis	SZAM									3		
Tilapia rendalli	TREN							11	5		33	
Tilapia sparrmanii	TSPA						5		19			4
Labeobarbus nelspruitensis	VNEL		1									
Xiphophorus helleri	XHEL											
FRAI Assessment			72,4	68,6	68,6	74,4	67,5	74,3	75,3	75,2	70,8	67,6
FRAI Ecological Category			C	C	C	C	C	C	C	C	C	C
Total Abundance			15	44	172	26	3	68	48	284	233	133
Species Richness			1	6	8	6	2	8	9	19	20	10

In the Sabie Catchment the dominant fish category that was collected was rheophilic (fastflow-loving species). On average, fish species were collected between 300-600 mm of depth with some individuals collected in habitats with a depth of more than a metre (1000 mm) (Figure 3-19A). Specific species like *Synodontis intermedius* (SINT), *Hydrocynus vittatus* (HVIT) and *Serranochromis meridianus* (SMER) were only collected in habitats with depths more than 800 mm. In contrast, species like *Enteromius afrohamiltoni* (BFRI), *Gambusia affinis* (GAFF), *Mesobola brevianalis* (MBRE) and *Petrocephalus wesselsi* (PWES) were only collected in habitats with a depth less than 600 mm. The majority of the fish were collected between 0-0.4 m/s velocity habitats with some individuals collected at a maximum velocity of 1.4 m/s (Figure 3-19B). A lot of the species were collected in pool habitats with specific species like *Synodontis intermedius* (SINT), *Hydrocynus vittatus* (HVIT), *Opsaridium peringueyi* (OPER) and *Serranochromis meridianus* (SMER) that were only collected in habitats with a velocity of more than 0.4 m/s (Figure 3-19B).

A)



B)

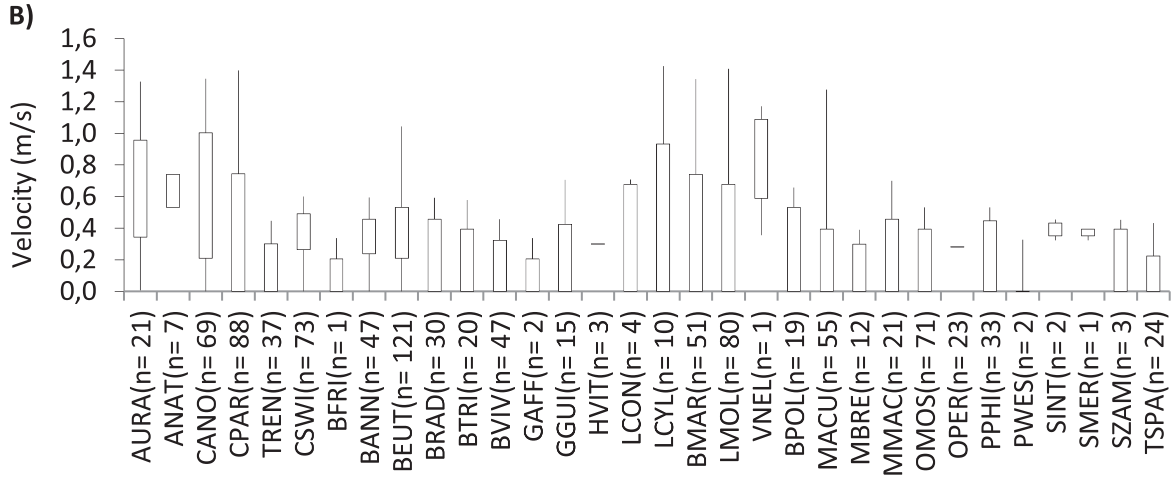


Figure 3-19: The A) Depth and B) Velocity ranges from different habitats where fish species in the Sabie Catchment were collected.

3.6.2.1.3.4 Crocodile Catchment

During the surveys from March 2020 to October 2023, 171 sampling efforts (Table 3-34) were carried out, resulting in the abundance of 2575 fish from 16 sites in the Crocodile Catchment. Thirty-four of the expected 49 different species and three alien invasive species were collected during the surveys. X22B

Crocodile was the site with the highest abundance of fish (n=569) during the 2020 survey and X23B Noordkaap was the site with the lowest abundance of fish (n=9). X24F Crocodile (n=17 in 2020), X22K Crocodile (n=15) and X24C Nsikazi (n=13) were the sites with the highest species richness. X23B Noordkaap (n=3) had the lowest fish species richness.

Labeobarbus marequensis (16 sites), *Pseudocrenilabrus philander* (15 sites) and *Enteromius trimaculatus* (14 sites) were collected at most of the sites. *Micralestes acutidens* (n=673), *Enteromius viviparus* (n= 317), and *Labeobarbus marequensis* (n=255) were the most abundant fish species caught during the survey. *Labeo congoro* (n=1), and *Petrocephalus wesselsi* (n=1) were the least abundant fish species caught.

The invasive species caught were *Micropterus salmoides* (three sites n=6), *Xiphophorus helleri* (one site n= 5) and *Cyprinus carpio* (one site n=2). Fifteen catchment scale migrators (*Anguilla bengalensis, Anguilla mossambica and Anguilla marmorata*) were found at X24F Crocodile but were expected at all of the sites, during the survey. *Oreochromis mossambicus* (IUCN category Vulnerable), *Anguilla bengalensis labiata, Anguilla mossambica* (IUCN category Near Threatened), and *Chiloglanis bifurcus* (IUCN category Critically Endangered), were the only species with the IUCN category above least concerned that were sampled during the survey. Other species with critically endangered (Kneria sp. 'South Africa', *Chetia brevis*) were not collected.

The FRAI scores obtained indicate that there is a noticeable change in the fish community structure of the Crocodile Catchment (Table 3-34). Over the study period, X21K Elands was in a Class B/C but deteriorated to a Class C during the other two sampling events. Twenty of the sampling events were in a moderately modified class (Class C), two sites were in class C/D (X23E Queens and X23H Kaap) and two sites were in class D (X23B Noordkaap and X23F Suidkaap). During the present study, the main impacts that caused changes to fish communities, included barriers, poor water quality, altered flows, sedimentation, and overexploitation. The sites close to Barberton were the most impacted.

Table 3-34: *Species richness and abundance of fishes obtained from sites in the Crocodile Catchment during the 2020, 2021, 2022 and 2023 surveys. The Ecological status of fish communities is also included.*

	X21B Crocodile	X21E Crocodile	X21G Elands	X21K Elands			X22B Houtbosloop	X22B Crocodile		X22F Nels	X22H White River	X22K Crocodile			X23B Noordkaap	X23E Queens	X23F Suidkaap	X23H Kaap	X24C Nsikazi		X24F Crocodile				X24H Mbyamiti
Year	23	22	22	20	21	22	23	20	23	22	23	20	21	22	22	22	22	22	20	21	20	21	22	23	21
Season	LF	LF	HF	HF	LF	HF	LF	LF	LF	HF	LF	LF	HF	HF	HF	HF	HF	HF	HF	HF	LF	LF	LF	HF	HF
Efforts	7	1	8	6	6	14	10	6	11	3	3	13	6	7	5	5	8	10	1	3	4	1	1	28	4
Anguilla bengalensis								1													1				
Anguilla marmorata																					2	1			
Anguilla mossambica		1										2									5	3			
Amphilius natalensis																									
Amphilius uranoscopus			16	2	2	14						2	1												
Enteromius afrohamiltoni																									
Enteromius annectens																									
Enteromius anoplus		3																							
Enteromius crocodilensis		5	13	14	4	17	8	36		16															
Enteromius eutaenia													2	5			5			8					
Brycinus imberi																									
Labeobarbus marequensis							1	11	51		7	11	23	25		29	5	22	1	16	1	34	4	14	
Enteromius paludinosus													37	1											
Labeobarbus polylepis			33	1		2															1				

	X21B Crocodile	X21E Crocodile	X21G Elands	X21K Elands			X22B Houtbosloop	X22B Crocodile		X22F Nels	X22H White River	X22K Crocodile			X23B Noordkaap	X23E Queens	X23F Suidkaap	X23H Kaap	X24C Nsikazi		X24F Crocodile				X24H Mbyamiti
Year	23	22	22	20	21	22	23	20	23	22	23	20	21	22	22	22	22	22	20	21	20	21	22	23	21
Season	LF	LF	HF	HF	LF	HF	LF	LF	LF	HF	LF	LF	HF	HF	HF	HF	HF	HF	HF	HF	LF	LF	LF	HF	HF
Efforts	7	1	8	6	6	14	10	6	11	3	3	13	6	7	5	5	8	10	1	3	4	1	1	28	4
Enteromius radiatus																				18					
Enteromius toppini							2																		
Enteromius trimaculatus								14		1			1	44		4	1	5	4	21	14	2	7	14	48
Enteromius unitaeniatus	4																		1		1	5			
Enteromius viviparus		2												59			1		3	21	94	14	26	4	93
Chiloglanis anoterus																							2		
Chiloglanis bifurcus																									
Clarias gariepinus				1		1																			
Chiloglanis paratus	1			1	1			35		1	6	1	2							8	17	6			1
Chiloglanis pretoriae													1								2	3	2	37	5
Chiloglanis swierstrai	16		29	1	2	27	13		3			1	2				1			2					
Gambusia affinis																				4				2	
Glossogobius callidus																									
Glossogobius giuris																									
Hydrocynus vittatus																						1		28	
Labeo congoro																					5	2			
Labeo cylindricus																		1							
Labeo molybdinus																					9	6	2		

	X21B Crocodile	X21E Crocodile	X21G Elands	X21K Elands			X22B Houtbosloop	X22B Crocodile		X22F Nels	X22H White River	X22K Crocodile			X23B Noordkaap	X23E Queens	X23F Suidkaap	X23H Kaap	X24C Nsikazi		X24F Crocodile				X24H Mbyamiti
Year	**23**	**22**	**22**	**20**	**21**	**22**	**23**	**20**	**23**	**22**	**23**	**20**	**21**	**22**	**22**	**22**	**22**	**22**	**20**	**21**	**20**	**21**	**22**	**23**	**21**
Season	**LF**	**LF**	**HF**	**HF**	**LF**	**HF**	**LF**	**LF**	**LF**	**HF**	**LF**	**LF**	**HF**	**HF**	**HF**	**HF**	**HF**	**HF**	**HF**	**HF**	**LF**	**LF**	**LF**	**HF**	**HF**
Efforts	**7**	**1**	**8**	**6**	**6**	**14**	**10**	**6**	**11**	**3**	**3**	**13**	**6**	**7**	**5**	**5**	**8**	**10**	**1**	**3**	**4**	**1**	**1**	**28**	**4**
Labeo rosae								5			1	2	3					4	1		28	15	1	17	
Labeo ruddi																									51
Micralestes acutidens																									
Mesobola brevianalis				17	2	5	3	457	4				4	9				6	72	75	14	5			
Marcusenius macrolepidotus																									
Micropterus salmoides											12	1		2											
Oreochromis mossambicus											2				3			1							
Oreochromis niloticus			1											42	5	1	9	4		34	5	2	1	14	5
Opsaridium peringueyi																									
Petrocephalus wesselsi												1	5	73						1					
Pseudocrenilabrus philander																					1				
Schilbe intermedius		5		5	7	8		5	1		1	8	3	2		5	8			1			1	2	
Serranochromis meridianus																									
Synodontis zambezensis																									
Tilapia rendalli																									
Tilapia sparrmanii													1						2	4	34	2		71	
Labeobarbus nelspruitensis	2			5	7			5		1	3		3	1	1		4								

	X21B Crocodile	X21E Crocodile	X21G Elands	X21K Elands			X22B Houtbosloop	X22B Crocodile		X22F Nels	X22H White River	X22K Crocodile			X23B Noordkaap	X23E Queens	X23F Suidkaap	X23H Kaap	X24C Nsikazi		X24F Crocodile				X24H Mbyamiti
Year	**23**	**22**	**22**	**20**	**21**	**22**	**23**	**20**	**23**	**22**	**23**	**20**	**21**	**22**	**22**	**22**	**22**	**22**	**20**	**21**	**20**	**21**	**22**	**23**	**21**
Season	**LF**	**LF**	**HF**	**HF**	**LF**	**HF**	**LF**	**LF**	**LF**	**HF**	**LF**	**LF**	**HF**	**HF**	**HF**	**HF**	**HF**	**HF**	**HF**	**HF**	**LF**	**LF**	**LF**	**HF**	**HF**
Efforts	**7**	**1**	**8**	**6**	**6**	**14**	**10**	**6**	**11**	**3**	**3**	**13**	**6**	**7**	**5**	**5**	**8**	**10**	**1**	**3**	**4**	**1**	**1**	**28**	**4**
Xiphophorus helleri																									
FRAI Assessment	72,3	70,8	69,2	78,1	74,5	71	67,7	73,7	72,5	67,5	69,9	72,8	74,8	74,8	52,2	61,1	57,2	59,1	71,4	70,4	68,8	69,6	68,7	70,2	71,5
FRAI Ecological Category	C	C	C	BC	C	C	C	C	C	C	C	C	C	C	D	CD	D	CD	C	C	C	C	C	C	C
Total Abundance	23	16	92	47	25	74	27	569	59	19	32	32	90	263	9	39	34	43	84	213	234	101	44	203	203
Species Richness	4	5	5	9	7	7	5	9	4	4	7	10	15	11	3	4	8	7	7	13	17	15	8	10	6

In the Crocodile Catchment the dominant fish category that was collected was rheophilic (fastflow-loving species). On average, fish species were collected between 220-500 mm of depth with some individuals collected in habitats with a depth of more than a metre (1000 mm) (Figure 3-20A). Specific species like Anguillids (AMAR, AMOS) were collected in shallow habitats (< 420 mm) while *Anguilla bengalensis* (ALAB) was collected in habitats only more than 370 mm. Various Enteromius species (BRAD, BUNI) and Chiloglanis species (CPAR, CPRE, CSWI) were also collected in the shallower habitats. The majority of the fish were collected between 0-0.5 m/s velocity habitats with some individuals collected at a maximum velocity of 1.5 m/s (Figure 3-20B). A lot of the species were collected in pool, or slow-flowing habitats with specific species like *Anguilla marmorata* (AMAR), *Enteromius anoplus* (BANO), *Hydrocynus vittatus* (HVIT) and *Micropterus salmoides* (MSAL) were collected in deep pool-like habitats with barely perceptible flows (can't see that water is flowing).

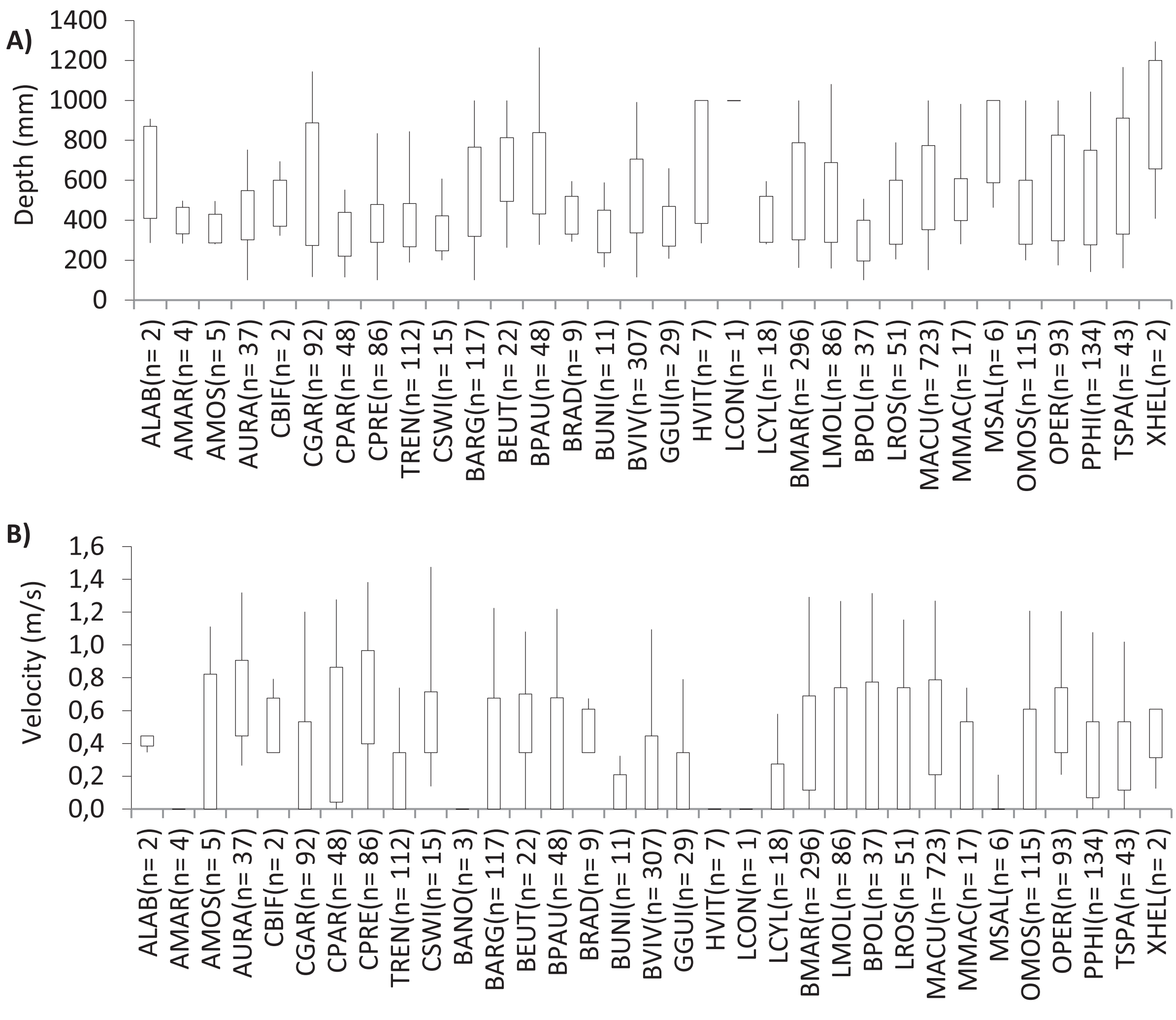


Figure 3-20: The A) Depth and B) Velocity ranges from different habitats where fish species in the Crocodile Catchment were collected.

3.6.2.1.3.5 Komati Catchment

During the surveys from November 2022 to June 2023, 66 sampling efforts (Table 3-35) were carried out, resulting in the abundance of 197 fish from 9 sites in the Komati Catchment. Twenty-three of the expected 43 different species and one alien invasive species (*Serranochromis robustus*) were collected during the surveys. X11F Komati was the site with the highest abundance of fish (n=48) during the 2021 survey and X11J Gladdespruit was the site with the lowest abundance of fish (n=2) during the 2022 survey. X14D Lomati (n=12), X13J Komati (n=5) and X11F Komati (n= 5) were the sites with the highest species richness. X11B Boesmanspruit (n=1) had the lowest fish species richness.

Labeobarbus marequensis (7 sites) and *Chiloglanis pretoriae* (6 sites) were collected at most of the sites. *Chiloglanis pretoriae* (n=87), *Labeobarbus marequensis* (n=22) and *Enteromius viviparus* (n= 21) were the most abundant fish species caught during the survey. Most of the other species had low abundances caught throughout the surveys.

No catchment scale migrators (*Anguilla bengalensis, A. mossambica and A. marmorata*) were found although they were expected at most of the sites, during the survey. *Oreochromis mossambicus* (IUCN category Vulnerable) and *Chiloglanis bifurcus* (IUCN category Critically Endangered), were the only species with the IUCN category above least concerned that were sampled during the survey. Other species with critically endangered (Kneria sp. 'South Africa', *Chetia brevis*) were not collected.

The FRAI scores obtained indicate that there is a noticeable change in the fish community structure of the Komati Catchment (Table 3-35). Over the catchment and sampling period, all the sites were in a moderately modified (Class C) state. During the present study, the main impacts that caused changes to fish communities, included barriers, poor water quality, altered flows, sedimentation and overexploitation.

Table 3-35: Species richness and abundance of fishes obtained from sites in the Komati Catchment during the 2020 to 2023 surveys. The Ecological status of fish communities is also included.

Sites		X11B Boesmanspruit	X11D Klein komati	X11F Komati		X11J Gladdespruit		X12K Komati	X13J Komati	X13K Komati	X14D Lomati	X14H Lomati
Scientific Names	Year	2023	2023	2020	2021	2022	2023	2020	2023	2023	2023	2022
	Season	LF	LF	LF	HF	HF	LF	LF	LF	LF	LF	LF
	Efforts	6	10	4	9	2	2	3	7	11	8	4
	Abbre	2023	2023	2020	2021	2022	2023	2020	2023	2023	2023	2022
Anguilla bengalensis	ALAB											
Anguilla marmorata	AMAR											
Anguilla mossambica	AMOS											
Amphilius natalensis	ANAT											
Amphilius uranoscopus	AURA			2	4			2			3	
Enteromius afrohamiltoni	BFRI											
Enteromius annectens	BANN											
Enteromius anoplus	BANO		2									
Enteromius crocodilensis	BARG			1	1							
Enteromius eutaenia	BEUT										5	
Brycinus imberi	BIMB											
Labeobarbus marequensis	BMAR	3				1	3	4	1		8	2
Enteromius paludinosus	BPAU										2	
Labeobarbus polylepis	BPOL			1	2							
Enteromius radiatus	BRAD										1	
Enteromius toppini	BTOP											
Enteromius trimaculatus	BTRI								2		4	
Enteromius unitaeniatus	BUNI											
Enteromius viviparus	BVIV								21			
Chiloglanis anoterus	CANO										1	
Chiloglanis bifurcus	CBIF										1	
Clarias gariepinus	CGAR						1					
Chiloglanis paratus	CPAR											
Chiloglanis pretoriae	CPRE		3	29	38			11			3	3

Sites		X11B Boesmanspruit	X11D Klein komati	X11F Komati		X11J Gladdespruit		X12K Komati	X13J Komati	X13K Komati	X14D Lomati	X14H Lomati
Scientific Names	Year	2023	2023	2020	2021	2022	2023	2020	2023	2023	2023	2022
	Season	LF	LF	LF	HF	HF	LF	LF	LF	LF	LF	LF
	Efforts	6	10	4	9	2	2	3	7	11	8	4
	Abbre	2023	2023	2020	2021	2022	2023	2020	2023	2023	2023	2022
Chiloglanis swierstrai	CSWI											
Gambusia affinis	GAFF											
Glossogobius callidus	GCAL											
Glossogobius giuris	GGIU									9		
Hydrocynus vittatus	HVIT											
Labeo congoro	LCON											
Labeo cylindricus	LCYL											2
Labeo molybdinus	LMOL								1			2
Labeo rosae	LROS											
Labeo ruddi	LRUD											
Micralestes acutidens	MACU											3
Mesobola brevianalis	MBRE											
Marcusenius macrolepidotus	MMAC											
Micropterus salmoides	MSAL											
Oreochromis mossambicus	OMOS										1	
Oreochromis niloticus	ONIL											
Opsaridium peringueyi	OPER										1	
Petrocephalus wesselsi	PCAT											
Pseudocrenilabrus philander	PPHI					1	3					
Schilbe intermedius	SINT											
Serranochromis robustus	SROB								1			
Synodontis zambezensis	SZAM											
Tilapia rendalli	TREN									1		
Tilapia sparrmanii	TSPA			3	3						1	
Labeobarbus nelspruitensis	VNEL											
Xiphophorus helleri	XHEL											

Sites		X11B Boesmanspruit	X11D Klein komati	X11F Komati		X11J Gladdespruit		X12K Komati	X13J Komati	X13K Komati	X14D Lomati	X14H Lomati
Scientific Names	Year	2023	2023	2020	2021	2022	2023	2020	2023	2023	2023	2022
	Season	LF	LF	LF	HF	HF	LF	LF	LF	LF	LF	LF
	Efforts	6	10	4	9	2	2	3	7	11	8	4
	Abbre	2023	2023	2020	2021	2022	2023	2020	2023	2023	2023	2022
FRAI Assessment		70,3	66,1	72	71,9	66,9	66,8	67,2	65	68,1	67,6	67,5
FRAI Ecological Category		C	C	C	C	C	C	C	C	C	C	C
Total Abundance		3	5	36	48	2	7	17	26	10	31	12
Species Richness		1	2	5	5	2	3	3	5	2	12	5

In the Komati Catchment the dominant fish category that was collected was rheophilic (fastflow-loving species). On average, fish species were collected between 200-500 mm of depth with some individuals collected in habitats with a depth of a metre (1000 mm) (Figure 3-21A). Specific species like P*seudocrenilabrus philander* (PPHI) had the greatest depth occurrence range, while species like *Chiloglanis bifurcus* (CBIF), *Enteromius anoplus* (BANO) and *Opsaridium peringueyi* (OPER) were only collected in shallow habitats (< 300 mm). Most of the species had narrow ranges of collection at specific depths (Figure 3-21A). The majority of the fish were collected between 0.1-0.7 m/s velocity habitats with some individuals collected at a maximum velocity of 1.4 m/s (Figure 3-21B). A lot of the species were collected across a broad range of velocities. Specific species were only collected in habitats with velocities less than 0.3 m/s. Some habitats that were sampled for fish unfortunately had no velocities measured.

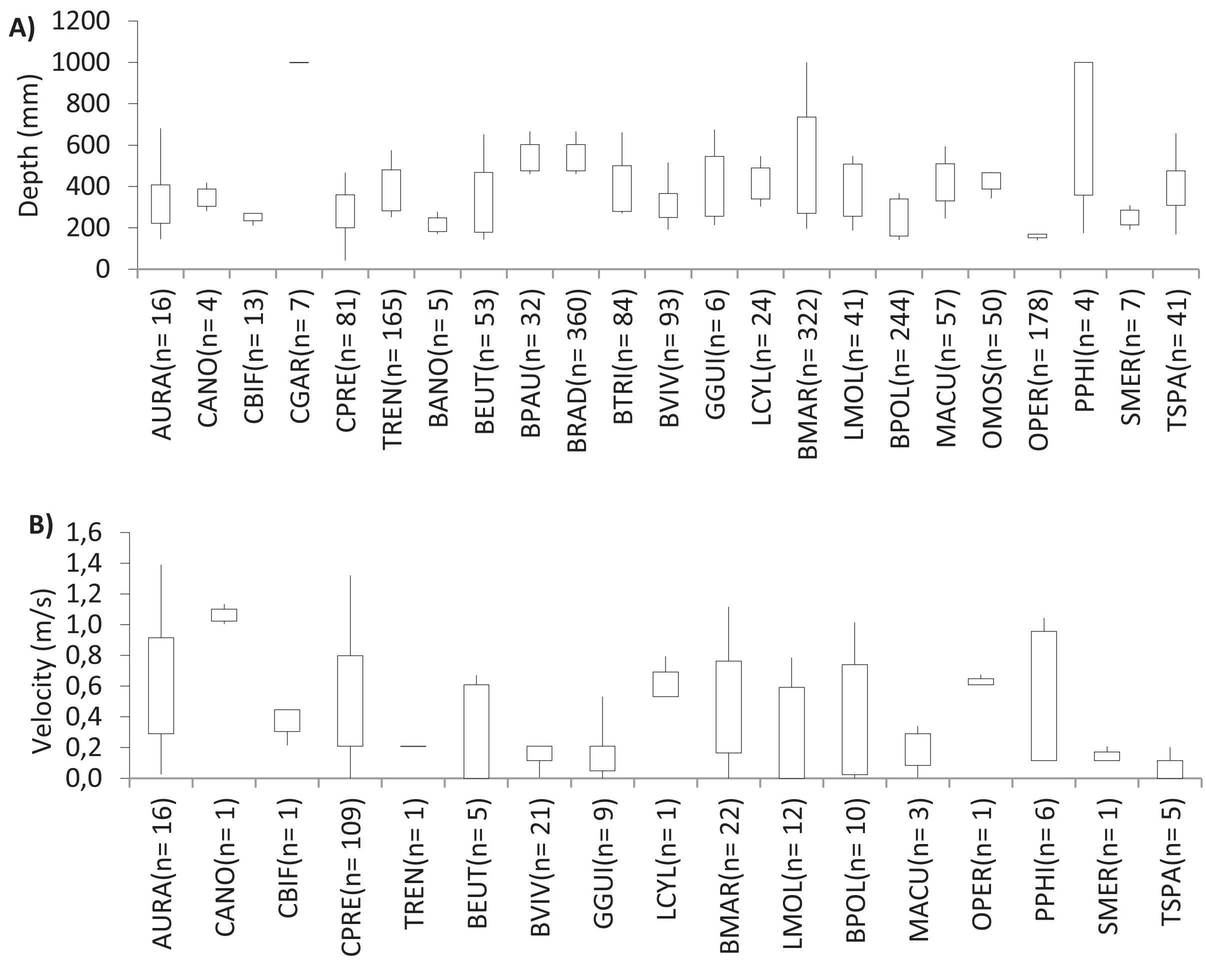


Figure 3-21: The A) Depth and B) Velocity ranges from different habitats where fish species in the Komati Catchment were collected.

3.6.2.1.3.6 Incomati Catchment

During the surveys from June 2022 to October 2022, 26 sampling efforts (Table 3-36) were carried out, resulting in the abundance of 883 fish from one river site, floodplain and the estuary in the Incomati Catchment. Thirty-nine of the expected 70 different fish species and potentially one alien invasive species (*Oreochromis niloticus n=21)* were collected during the surveys.

Glossogobius giuris (n=8), *Hydrocynus vittatus* (n=6), and *Brycinus imberi* (n=6) were the most abundant fish species caught at X13L Incomati. *Oreochromis mossambicus* (n= 59), *Enteromius radiatus* (n=39) and *Labeo congoro* (n=29) were the most abundant fish caught in the Y1-4 Floodplain.

Possible *O. mossambicus* and *Oreochromis niloticus* hybrids were also recorded (1 site, n= 21). Twenty catchment scale migrators (*Anguilla mossambica and Anguilla marmorata*) were found at Y1-4 Floodplain but were expected at all of the sites. *Oreochromis mossambicus* (IUCN category Vulnerable) and *Anguilla mossambica* (IUCN category Near Threatened) were the only species with the IUCN category above least concerned that were sampled during the survey.

The FRAI scores obtained indicate that there is a noticeable change in the fish community structure of the Incomati Catchment (Table 3-36). Over the study period, both X13L Incomati and Y1-4 Floodplain were in a moderately modified class (Class C). During the present study, the main impacts that caused changes to fish communities, included barriers, poor water quality, altered flows, sedimentation and overexploitation.

Table 3-36: Species richness and abundance of fishes obtained from sites in the Incomati Catchment during the 2022 surveys. The Ecological status of fish communities is also included.

Sites		**X13L Incomati**	**Y1-4 Floodplain**
Scientific Names	**Year**	**2022**	**2022**
	Season	**LF**	**LF**
	Efforts	**4**	**6**
	Abbre		
Anguilla bengalensis	ALAB		
Anguilla marmorata	AMAR		12
Anguilla mossambica	AMOS		8
Amphilius natalensis	ANAT		
Amphilius uranoscopus	AURA		
Enteromius afrohamiltoni	BFRI		
Enteromius annectens	BANN		5
Enteromius anoplus	BANO		
Enteromius crocodilensis	BARG		26
Enteromius eutaenia	BEUT		
Brycinus imberi	BIMB	6	9
Labeobarbus marequensis	BMAR		
Enteromius paludinosus	BPAU		
Labeobarbus polylepis	BPOL		
Enteromius radiatus	BRAD		34
Enteromius toppini	BTOP		
Enteromius trimaculatus	BTRI		
Enteromius unitaeniatus	BUNI		
Enteromius viviparus	BVIV		
Chiloglanis anoterus	CANO		
Chiloglanis bifurcus	CBIF		
Clarias gariepinus	CGAR		3
Chiloglanis paratus	CPAR		

Sites		X13L Incomati	Y1-4 Floodplain
Scientific Names	Year	2022	2022
	Season	LF	LF
	Efforts	4	6
	Abbre		
Chiloglanis pretoriae	CPRE		
Chiloglanis swierstrai	CSWI		
Gambusia affinis	GAFF		
Glossogobius callidus	GCAL		4
Glossogobius giuris	GGIU	8	11
Hydrocynus vittatus	HVIT	6	1
Labeo congoro	LCON	1	29
Labeo cylindricus	LCYL		
Labeo molybdinus	LMOL		
Labeo rosae	LROS	1	3
Labeo ruddi	LRUD		
Micralestes acutidens	MACU		
Mesobola brevianalis	MBRE		1
Marcusenius macrolepidotus	MMAC		1
Micropterus salmoides	MSAL		
Oreochromis mossambicus	OMOS	5	59
Oreochromis niloticus	ONIL		21
Opsaridium peringueyi	OPER		
Petrocephalus wesselsi	PCAT		
Pseudocrenilabrus philander	PPHI		1
Schilbe intermedius	SINT		4
Serranochromis meridianus	SMER		
Synodontis zambezensis	SZAM		
Tilapia rendalli	TREN		8
Tilapia sparrmanii	TSPA		9
Labeobarbus nelspruitensis	VNEL		
Xiphophorus helleri	XHEL		
FRAI Assessment		**64.7**	**70.6**
FRAI Ecological Category		**C**	**C**
Total Abundance		**27**	**249**
Species Richness		**6**	**20**

In the Incomati Catchment the dominant fish category that was collected was limnophilic (pool-loving species). On average, fish species were collected between 500-1000 mm (Figure 3-22A). Specific species like *Clarias gariepinus* (CGAR), *Enteromius annectens* (BANN) and *Pseudocrenilabrus philander* (PPHI) were collected only at depths less than 600 mm. The majority of the fish were collected between 0-0.3 m/s velocity (Figure 3-22B). Species were collected from the same area of habitats, while unfortunately some areas had no velocities measured.

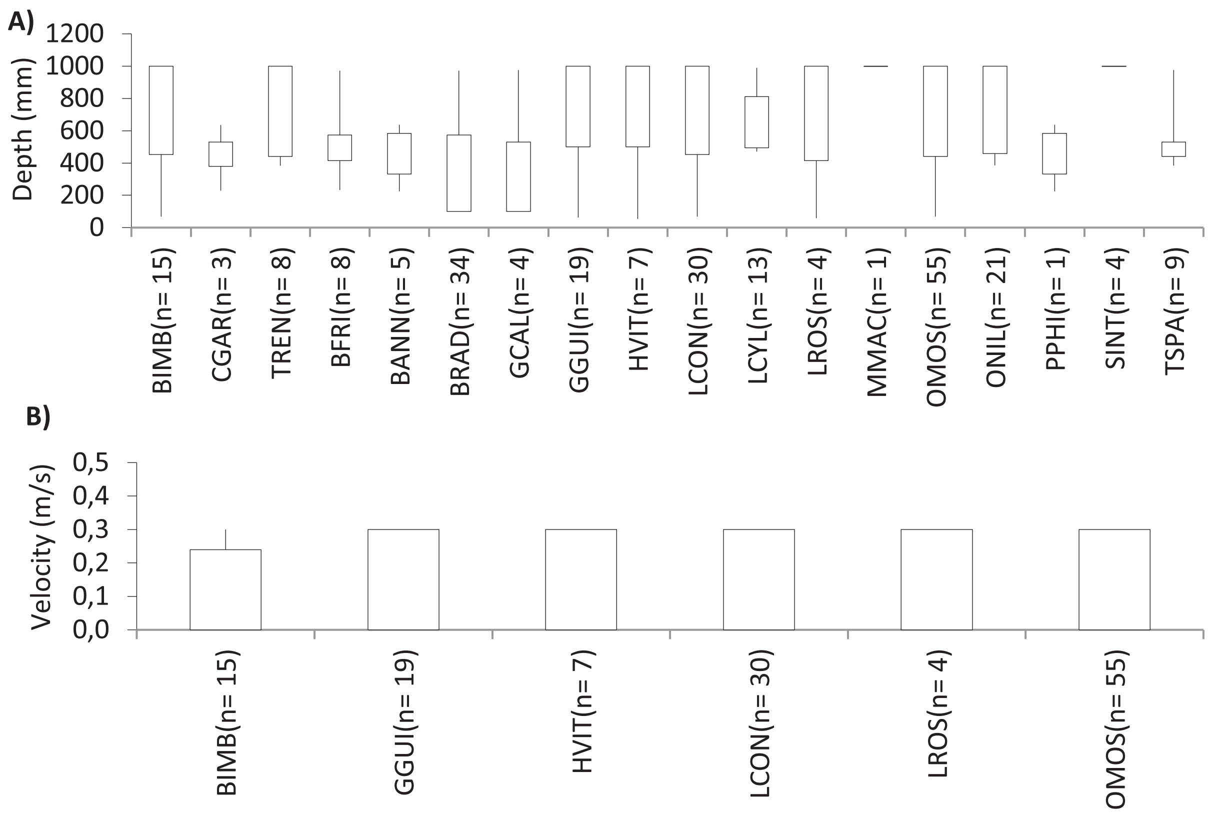


Figure 3-22: The A) Depth and B) Velocity ranges from different habitats where fish species in the Incomati Catchment were collected.

3.6.2.1.3.7 Estuary

Ambassis natalensis (n=173) and *Oreochromis mossambicus* (n=163) were the most abundant fish caught in the Y1-4 Estuary (Table 3-37).

Table 3-37: Species richness and abundance of fishes obtained from sites in the Incomati Estuary during the 2022 surveys.

Sites		Y1-4 Estuary				
Scientific Names	Year	31/05/2022	2/06/2022	23/08/2022	24/08/2022	27/08/2022
	Site	Top	Middle	Top	Middle	Middle/mouth
	Season	LF	LF	LF	LF	LF
	Efforts	3	3	1	2	7
Acanthopagrus berda		1			2	
Ambassis natalensis		1	3	4	2	163
Amblyrhynchotes honckenii						9
Caranx herberi					1	
Caranx sexfaciatus					1	
Clarias gariepinus		2				
Enteromius paludinosus			3			
Gilchristella aestuaria						36
Glossogobius guiris		3			1	35
Hypophthalmichthys molitrix		1				
Largo Spp			1		1	
Leiognathus equula		1	3	6	18	11
Oreochromis mossambicus		119	8	1	25	10
Pegusa nasuta		1			4	4
Platycephalus indicus					1	8
Rhabdosargus holubi						8
Schilbe intermedians		3			1	
Silago sihama					8	35
Synodontis zambesienses		2	1			
Terapon jarbua						59
Total Abundance		**134**	**19**	**11**	**65**	**378**
Species Richness		**10**	**6**	**3**	**12**	**11**

3.6.2.1.3.8 Redundancy Analyses

Inter river catchment comparisons for all sampling efforts and fish communities were overall significantly different from one another (F = 15.23; *p* = 0.002) (Figure 3-23). A total of 70.3% of the total variation was presented in this analysis with 52% explained on axis 1 and 18.3% explained on axis 2.

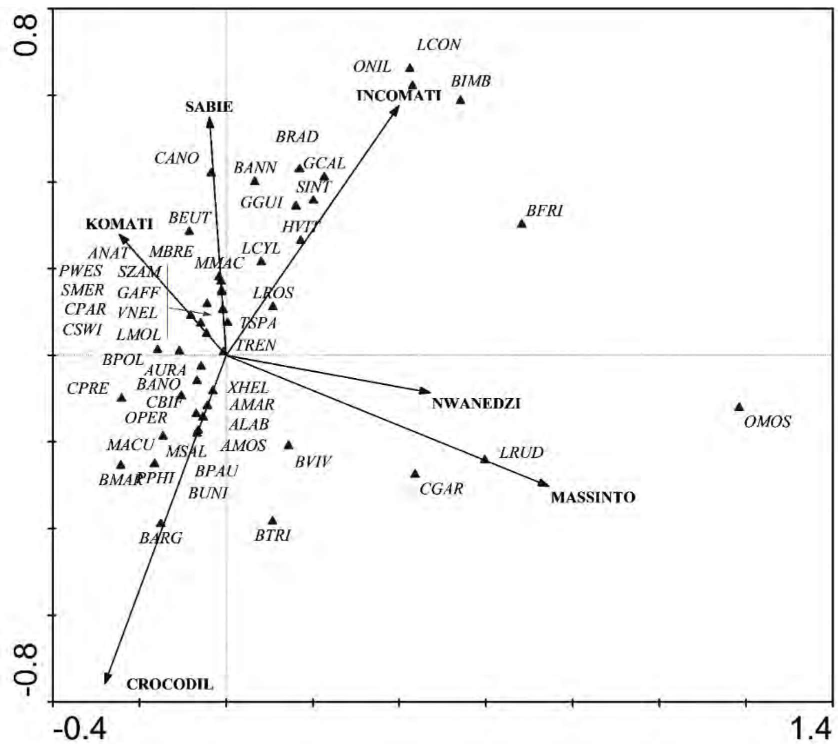


Figure 3-23: Redundancy analysis biplot based on the fish communities among the different main river catchments for all the sampling efforts. A total of 70.3% of the total variation were presented in this analysis with 52% explained on axis 1 and 18.3% explained on axis 2.

Intra-river catchment analyses for each of the regions in the main river catchments for all sampling efforts and fish communities were significant (F = 24.46, p = 0.002) (Figure 3-24). The river regions within each main catchment that accounted for the greatest variation in the analyses and were significant were: the site in the Uanetza Catchment (X40A), the site in the Massintonto Catchment (X40D), five sites/regions in the Sabie Catchment (X31C, X31K, X32G, X33B, X33D), seven sites/regions in the Crocodile Catchment (X24C, X22K, X24F, X24H, X22B, X21K, X21G), one site/region in the Komati Catchment (X11F) and the floodplain region in the Incomati Catchment (Y1_4). A total variation of 41.2% is presented by this analysis with 25.1% explained on axis 1 and 16.1% explained on axis 2.

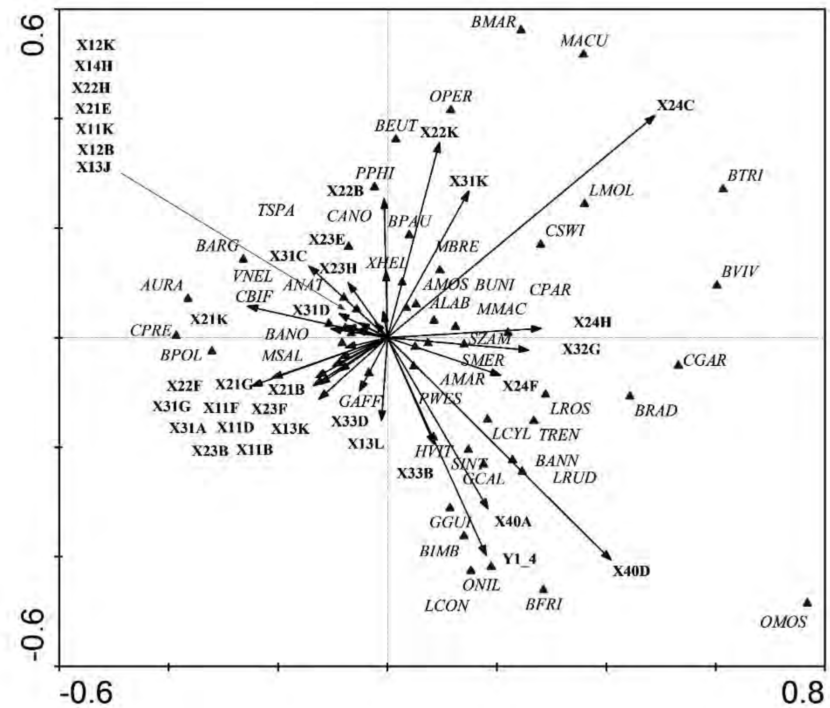


Figure 3-24: Redundancy analysis biplot based on the Intra-river catchment analyses for each of the regions in the main river catchments for all sampling efforts and fish communities. A total of 42.2% of the total variation were presented in this analysis with 25.1% explained on axis 1 and 16.1% explained on axis 2.

Velocity-depth relationships were a significant (F = 5.59, p = 0.01) driver of fish communities in the Incomati Catchment for all fish communities sampled (Figure 3-25). A total variation of 83% was shown with 55.2% explained on axis 1 and 24.8% explained on axis 2.

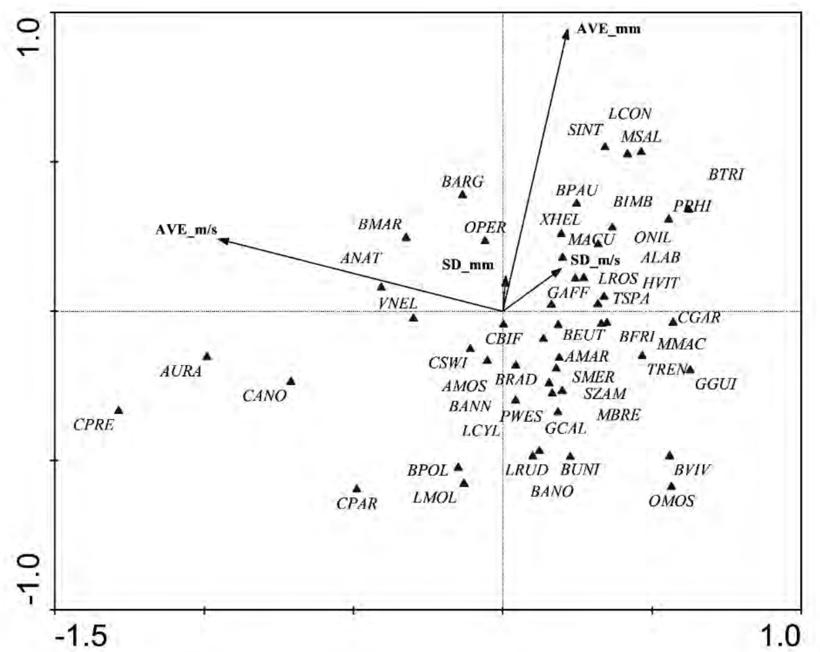


Figure 3-25: Redundancy analysis biplot based on the Velocity-Depth analyses for all sampling efforts and fish communities. A total of 83% of the total variation were presented in this analysis with 55.2% explained on axis 1 and 24.8% explained on axis 2.

Water quality was a significant (F = 5.40, p = 0.02) driver of fish communities in the Incomati Catchment for all fish communities sampled (Figure 3-26). Electrical conductivity (EC) (F = 5.18, p = 0.002) and water temperature (TEMP)(F = 4.15, p = 0.002) accounted for the greatest variation in the analyses. A total variation of 85.7% was shown with 48.1% explained on axis 1 and 37.6% explained on axis 2.

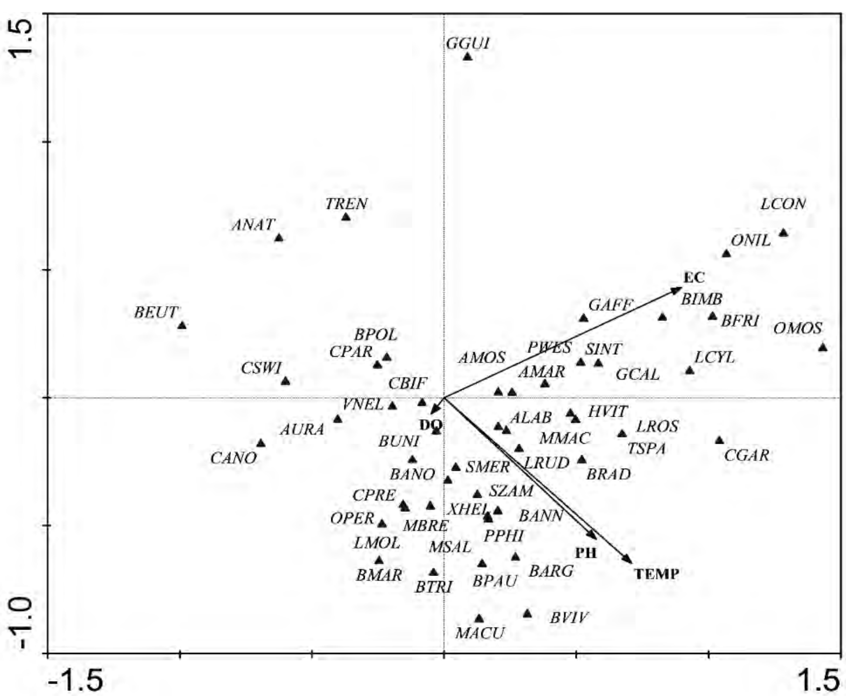


Figure 3-26: Redundancy analysis biplot based on the Water quality analyses for all sampling efforts and fish communities. A total of 85.7% of the total variation were presented in this analysis with 48.1% explained on axis 1 and 37.6% explained on axis 2.

Substrate diversity was a significant (F = 8.9, p = 0.01) driver of fish communities in the Incomati Catchment for all fish communities sampled (Figure 3-27). Sand (F = 5.4, p = 0.002), Mud (F = 5.33, p = 0.002), Cobbles (F = 2.27, p = 0.008), Bedrock (F = 2.95, p = 0.004), and Gravel (F = 1.9, p = 0.042) substrates accounted for the greatest variability in the analyses. A total variation of 63.9% was shown with 43.5% explained on axis 1 and 20.4% explained on axis 2.

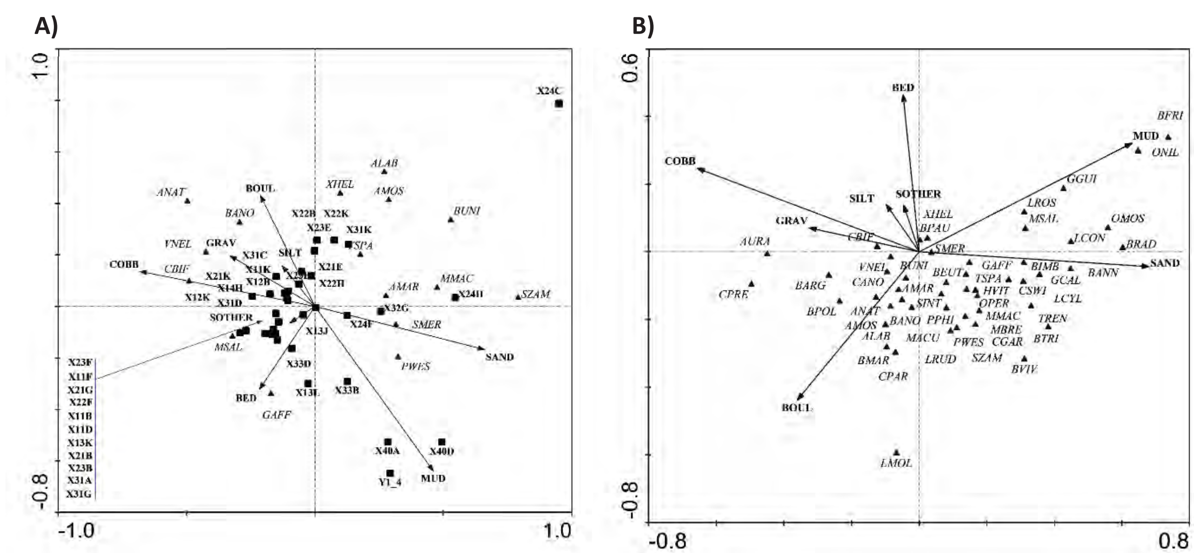


Figure 3-27: Redundancy analysis biplot based on the Substrate diversity analyses for all sampling efforts and fish communities. A total of 63.9% of the total variation were presented in this analysis with 43.5% explained on axis 1 and 20.4% explained on axis 2. A) Illustrate associations between fish species, river region and substrate diversity, B) illustrate association between fish species and substrate diversity.

Cover features was a significant (F = 8.9, p = 0.01) driver of fish communities in the Incomati Catchment for all fish communities sampled (Figure 3-28). Roots (F = 5.27, *p* = 0.002), Aquatic vegetation (F = 4.43, p = 0.002), Substrate as cover (F = 3.55, p = 0.002), Marginal vegetation (F = 3.29, *p* = 0.004), and Depth column (F = 1.89, p = 0.024) features accounted for the greatest variability in the analyses. A total variation of 63.9% was shown with 43.5% explained on axis 1 and 20.4% explained on axis 2.

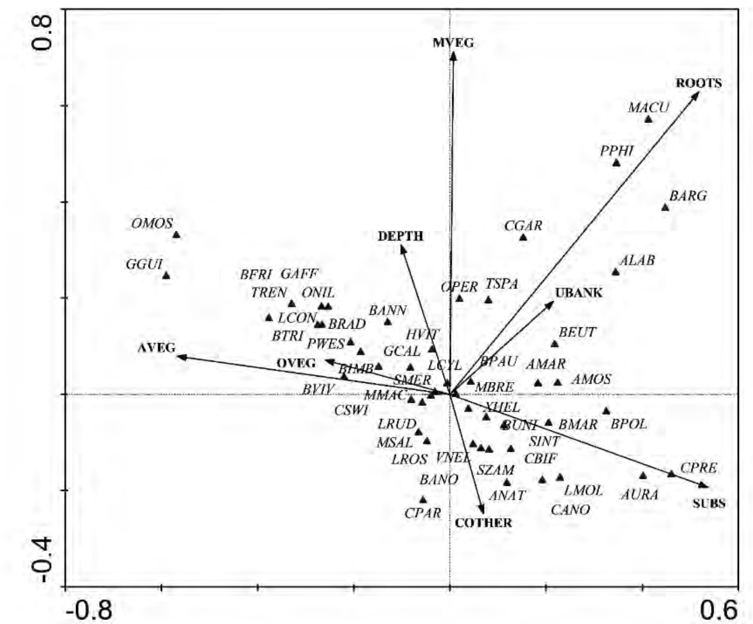


Figure 3-28: Redundancy analysis biplot based on the Cover features analyses for all sampling efforts and fish communities. A total of 63.9% of the total variation were presented in this analysis with 43.5% explained on axis 1 and 20.4% explained on axis 2.

3.6.2.1.4 Fish discussion

The fish communities of the Incomati Catchment vary considerably and are declining at a considerable rate. Only 45 of the expected 52 freshwater species were collected with more species being added to the International Union for Conservation of Nature (IUCN) Red list (IUCN, 2021). Unfortunately, no communities considered in the study are in a natural or pristine condition with most occurring in a moderately modified condition. Most of these fish communities are in a declining trend and are moderately affected by multiple stressors in the catchment with limited consideration of sustainability and/or conservation. The absence of many of the ecologically important fishes that have local and/or international conservation status is concerning.

3.6.2.1.4.1 Fish communities and Fish Respond Assessment Index

Less than half of the expected species were not collected for each site. The X24F Crocodile River site had the highest species richness with 20 species collected out of an expected 37 for that reach of the river (54%). Anguillid eel species (*Anguilla mossambica, A. bengalensis, A. marmorata*) were only collected in the Crocodile and Incomati River Catchments, demonstrating that connectivity is largely intact. The representation of eels as important parts of the Crocodile River is unique as the Sabie River Catchment and Komati River Catchment have impassable barriers in their lower reaches, preventing the inward migration.

Considering the wellbeing of the fish communities in the Incomati Catchment using the Fish Respond Assessment Index it illustrates that all fish communities are in a moderately modified (Class C) state with specific sites performing better (X21K Elands in 2020) or worse (X23F Suidkaap and X23B Noordkaap in 2022). In comparison to studies done by Kleynhans *et al*. (2015a, 2015b) and Roux *et al*. (2016) within the Incomati Catchment, our data corresponds, and no severe deviations were observed. When the FRAI outcomes for each site are compared to the Resource Quality Objectives (RQOs) for the catchment (DWS, 2014), specific sites are not meeting the set-out criteria. For example fish communities in the IUA X2-1 (X21B Crocodile EWR C2 site) should be maintained in a class B category, especially to support *Amphillius uranoscopus and Chiloglanis pretoria* species (DWS, 2014). From our assessment, the site is in a category C class with no *A. uranoscopus* collected. Additionally, for the IUA X3-2 (X31D Sabie) and IUA X3-9 (X32H Sand) the RQO is set-out for fish communities to be maintained at a class B category (DWS, 2014) with species richness of 26 and 35 respectively. A total of six species were collected in the Sabie River (X31D) and 18 species in the Sand River (X32H) (Table 3-33). A total of 11 site (not all RQOs were available) were below the set-out maintenance RQO category (DWS, 2014). Some of the limitations of the FRAI assessment is that it is only a rapid assessment, the tolerances and preferences of species are opinions-based, and the impact of alien and extra-limital freshwater fish species are only negative (habitat and predacious behaviour) and are not recognised for their potential of being good indicators of ecosystem health (Molony, 2001; Kennard *et al*., 2005).

3.6.2.1.4.2 Redundancy analyses

The fish communities differed significantly between the different main catchments within the Incomati Catchment. The Uanetza (Nwanedzi) and Massintonto River Catchments had the lowest association with various fish species. These are seasonal rivers and fish usually occupy these rivers to escape from stressors like floods that occur in the main river stems. Fish also utilises these rivers for breeding purposes before adults return to the main stem and juveniles grow and escape larger predators (Henning *et al*., 2007). The Sabie River Catchment had high associations with rheophilic fish species (CPAR, CSWI, CANO) and larger growing tigerfish (HVIT) and yellowfish (BMAR) (Figure 3-23). The Sabie River sites fish communities were significantly different from one another, although they had a high association between sites and observed fish communities (Figure 3-24). The distribution of fishes in the Crocodile River Catchment had a significant difference between other catchments (Figure 3-23). The distribution of many species, *Chiloglanis bifurcus* (CBIF) and *Enteromius crocodilenses* (BARG) for example had a strong association with the Crocodile River Catchment and its sites (Figure 3-23).The distribution ranges of these species (especially *C. bifurcus*) are extremely limited and account for some the variability in the communities observed. The Crocodile River Catchment also had a high association with alien invasive species as three of the four observed alien invasive species were observed in the catchment. The Crocodile River is characterised by many large-scale migratory fishes including the Anguillid eels (Anguilla spp.) that were unique to this community, and some water quality and/or habitat specialists that occurred such as *Opsaridium peringueyi* (Figure 3-23 and Figure 3-24). The Komati River Catchment differed significantly from the other catchments although it had a high association to similar fish species as the Crocodile and Sabie River Catchments (Figure 3-23). The Sabie River Catchment has more expected species compared to the Komati River Catchment (Kleynhans *et al*., 2015a). The confluence between these rivers to the Incomati River is not far (less than 60 km) allows to the repopulation of species between catchments. Inter-river catchment comparisons also illustrate that the sites of the Komati River Catchment have high association between each other (Figure 3-24). The Komati River Catchment had a lower-than-expected species richness that could have accounted for the sites having high associations to each other. The Incomati River Catchment had a higher association between the fish species collected in the Uanetza and Massintonto River Catchments (Figure 3-23 and Figure 3-24). The Incomati Catchment had lots of limnophillic species like *O. Mossambicus* and invasive

O. niloticus species that corresponds to the species collected in the Uanetza and Massintonto Rivers. The Incomati Catchment has lots of local communities depending on the fish resources either to sell or to eat that could have led to the decline in specialist species. Anguillid eels are also targeted along their outward migration in the Incomati floodplain to sell as live stock for international eel farms (Dlamini *et al*., 2023 in press, observational data).

The velocity-depth relationship between species indicated that both are a main driver of habitat flow determination and that the majority of species collected in the study area preferred or associated themselves more to habitats that were deeper (> 0.3 m) and with slower flow (Figure 3-25). Slow deeper habitats allow fish species to have more space to escape predators, exhort less energy while swimming and be ensured that the habitat will have sufficient water supply throughout the season (Harvey and Steward, 1991). In this study rheophilic species like *Labeobarbus marequensis* (BMAR), *O. peringueyi* (OPER)*, C. pretoriae* (CPRE) and *A. uranoscopus* (AURA)) had a positive association for fast velocities. These rheophilic species including *C. bifurcus*, *C. anoterus*, *E. eutenia* and *A. natalensis* are moderately to completely intolerant to no-flow conditions and have a high preference for fast-deep and fast-shallow habitats (Kleynhans *et al*., 2007). Fast flowing habitats (deep and shallow) have velocities greater than 0.3 m/s (Kleynhans, 2007) and all mentioned flow intolerant species were collected at 0.3 m/s or higher (Figure 3-25). A reduction in the flow regime will cause a decline in the abundances of these species in a community (Evans *et al*., 2021; Lange *et al*., 2018). Barrier (dam or weir) construction across the Incomati Catchment poses a major problem in terms of flow modifications as barriers reduced the timing, duration, and quantity of available flows. Flow reductions will lead to the loss of rheophilic species and non-/semirheophilic species will take their place (Evans *et al*., 2021) as well as forming conditions favouring invasive species.

The water quality parameters also affected fish communities significantly within the river catchments of the Incomati. Water temperature and electrical conductivity (EC) contribute significantly to the structuring of the fish communities of the Incomati Catchment (Figure 3-26). These variables are used as a proxy for the condition of the water (Walser and Bart, 1999; Thompson, Brandes and Kney, 2012). Agricultural activities, sedimentation and effluent discharge increase the EC of the system and negatively influences the fish community structures (Thompson, Brandes and Kney, 2012). Water quality is an important environmental driver for fish communities as many species are sensitive to changes and are not able to adapt (Wepener *et al*., 2011). Water quality sensitive species (OPER, MBRE, BMAR, BANO, MSAL) group together with no specific preference toward any water quality environmental drivers (Figure 3-26) while non-sensitive/tolerant species (TREN, CGAR, BEUT) are scattered across the analyses (Figure 3-26). Altered water quality conditions will see fish community shifts towards more tolerant species compositions, e.g. *E. crocodilensis, C. gariepinus, E. brevipinnis, O. mossambicus* and *P. philander* as well as the introduction of invasive species.

The substrate type and cover features act together to form the habitat environmental drivers as some substrate types can act as cover features for fish (Kleynhans, 2007)(Figure 3-27 and Figure 3-28). The habitat environmental drivers (substrates and cover features) significantly influenced the fish community composition of the Incomati Catchment. For the substrate variables, Sand, Mud, Cobbles, Bedrock and Gravel contributed the greatest variation (Figure 3-27A and B) and for the cover features, Roots, Aquatic vegetation (AVEG), Substrate as cover (SUBS), Marginal vegetation (MVEG) and Depth column (DEPTH) contributed the greatest variation in fish community composition (Figure 3-28). The majority of the fish species in the Incomati Catchment had a high association for sand and boulder substrates although boulder substrate had no significant contribution in the analyses (Figure 3-27B). The X24C Nsikazi site in the Crocodile River Catchment was an outlier with no association to any substrate structures (Figure 3-27A). The site was dominated by gravel and cobble rocks. These substrate structures are important as they act as spawning substrates for Cyprinid species, and play an important role for biological processes, competition, and predation avoidance. With the high sedimentation loads, sand mining and dam construction throughout the Incomati Catchment (Roux *et al*., 2016) these substrate types experience silting and species will lose these available habitats (Evans *et al*., 2021; Kleynhans and Louw, 2007). Some of the higher catchment sites sampled, had sedimentation loads due to either plantation, erosion (roads), barriers or sand mining. The substrate and cover features work in conjunction with the depth-velocity classes that fish species uses for their habitat preferences.

3.6.2.1.4.3 Estuary

A total of 20 fish species were collected in the estuary. Estuaries are important transitional zones between the salt and freshwater. Specific species also uses estuaries for breeding purposes. This study included the estuary sampling to determine the utilization of the estuary by marine stragglers and other freshwater species. No comparable historical data was available to make conclusions regarding the condition of the estuary. More information on resource usages at the Incomati estuary is needed as lots of local community members were observed fishing and possibly overutilising the estuary and its resources (see Section 3.6.2.4 on Ecosystem services).

3.6.2.1.5 Fish conclusion

This study provides an evaluation of the current ecological wellbeing of sites throughout the Incomati Catchment. It demonstrates the possible effects that environmental drivers have on the fish community composition and the ecological wellbeing of the different river systems. Fish communities in the Incomati are in a moderately stable but altered state with changes in many of the environmental stressors leading to the reduction in fish community compositions. Species like *C. gariepinus, S. intermedius, P. philander, O. mossambicus* and *T. sparmanii* (and all the invasive species) will dominate fish community compositions across the catchment if degradation of environmental variables and river system conditions continue. Importantly, although the FRAI outcomes demonstrate that the ecological wellbeing of fish communities is in an acceptable state, the FRAI is a rapid assessment method that does not address the population status of any species. Additional monitoring of important genetically unique *L. polylepis*, locally endemic *E. crocodilensis* and critically endangered *C. bifurcus* and Kneria spp fish species are in need to protect and improve IUCN ratings. Connectivity management between river regions and river systems are needed to restore the connectivity for long distance and regional migrators.

Results from the FRAI and multivariate analyses illustrate that fish communities throughout the Incomati Catchment are in a stable state but many drivers including habitat alterations, flow modifications and poor water quality are affecting the community compositions of the rivers. The declining trend in the wellbeing of fish communities throughout the catchment should be considered and conservation intervention should be prioritised. Management objectives should implement separate strategies for each river system due to the different anthropogenic environmental drivers. Sites with high sedimentation loads, barrier construction and water abstraction for irrigation need management and monitoring prioritisation to minimise the changes of reduced flows and substrate availability in the catchment. A recommendation is to start evaluating the purposes of barriers at sites and remove it if the purpose is no longer served. This will result in multiple positive outcomes as native migratory species will have new habitats, sedimentation will move out (exposing habitats) and water quality parameter will improve (Winter, 1990; Hill *et al*., 1994; Duvail *et al*., 2017).

The only way of ensuring water security is to manage water resources under worst case future scenarios (Vörösmarty *et al*., 2010). Aquatic ecosystem management has failed to evolve from binary presence/absence type monitoring towards more dynamic ecosystem process-based techniques. These techniques have the capacity to manage ecological functionality in the absence of sufficient flows. There is a need to evolve the capacity of water management authorities so that they can deal with changing environments and increasing stressors.

3.6.2.2 MACRO- AND MICRO-INVERTEBRATES

3.6.2.2.1 Background

The life cycles of all species are linked to the environmental conditions they evolved with or adapted to (Bosch *et al.*, 2014). The extraordinary evolutionary success of aquatic macroinvertebrates is evident in their presence in different freshwater ecosystems across the globe (Huryn*et al.*, 2008). Wallace & Anderson (1995) grouped four broad interacting factors influencing habitat utilisation:

- physiological constraints (e.g. water & salt balance, oxygen acquisition, temperature)
- trophic considerations (e.g. food)
- physical constraints (e.g. coping with habitat or habits)
- biotic interactions (e.g. predation, competition)

Many interacting biotic and abiotic drivers in stream systems drive biotic patterns (Dallas, 2007). In a study assessing drivers of macroinvertebrate community structure (family level), Dalu *et al.* (2017) highlighted canopy cover, channel width, substrate embeddedness, phosphate concentration, pH, salinity, and turbidity as the most influential. Water temperature variability was shown to be a critical driver influencing aquatic macroinvertebrate community composition in a study on streams in the Eastern and Western Cape. The study held true the hypothesis "that water temperature predictability provides an indication of structure and functional predictability and seasonal turnover in macroinvertebrate communities…." (Eady *et al.*, 2013). Communities responds to changes at family level, so it stands to reason that responses on a species level would be more pronounced. The "perpetually imperfect state of knowledge of aquatic insect taxonomy, pressing environmental issues, intriguing theoretical problems, …" should provide strong incentives for species level identification (Cummins *et al.*, 2008). With the focus on the use of family indices in southern Africa, our knowledge on the distribution of aquatic insects on a species level, linked with their environmental requirements through their different life stages, and adaptations are limited. Some studies however do still provide more detailed insight into species ecology.

A detailed study at 31 sites over four different sampling periods (Apr 1966, Jul 1966, Oct 1966, and Jan 1967) on the distribution of Ephemeroptera (mayflies) in the Incomati Basin (up to Komatipoort) (Matthew, 1968) was regularly referenced in this study. At these 31 sites Matthew (1968) measured depths, velocity, in situ parameters, and recorded habitat type for species sampled and identified, with abundances recorded.

The aim of this study was:

- to determine which invertebrate taxa are present in the different available biotopes (flow, depth, substrate, hydraulic biotopes, vegetation);
- to determine aquatic invertebrate abundances within quantifiable biotopes to better understand habitat preference to the lowest possible classification (i.e. genus or species level); and
- to determine present stream conditions using existing classification tools.

Additional information used to determine environmental conditions associated with specific macroinvertebrates included:

- SASS data collected in mostly the upper portions of the Incomati basin since 1998[1]
- Available information on the Freshwater Biodiversity Information System database
- Data collected for this survey by Lomarie Jansen van Rensburg, and
- Sources summerised in Table 3-40.

There are multiple challenges selecting indicator taxa or taxon (Hilty & Merenlender, 2000):

- Baseline information: knowing and understanding the biology, taxonomy, and tolerance of a taxa's measurable characteristics, and/or whether observed changes in taxa are due to natural ecosystem changes (e.g. seasonal) or human induced (e.g. pollution).
- Location information: taxa with limited mobility are less likely to avoid disturbance, but cosmopolitan distribution assist with cross-comparisons.
- Niche and life history attributes: taxon with low variability genetically and ecologically.
- Other factors include cost effectiveness, ease of detection and mensuration, ability to detect and quantify changes, inadequate sample size, and lack of statistical power.

No taxa fit these criteria, but Matthew (1968) recorded some species (e.g. *Prosopistoma crassi, P. mccaffertyi, Ephoron sylvatica*) during his surveys in 1966 and 1967 that are now rarely encountered or not at all. Abundances and community structure for especially Baetidae from the Matthew (1968) survey also changed when comparing to current data, but whether the cause is environmental or due to sampling frequency and effort is unclear and mostly speculative. The same applies to:

- Palaemonidae: *Macrobrachium lepidactylus*[2] (Taylor, 1990),
- Tricorythidae: *Tricorythus* sp. (Goetsch & Palmer, 1997)[3]
- Thiaridae: *Melanoides tuberculata* and *M. victoriae* [4](Oberholzer & Van Eeden, 1967; De Kock *et al.*, 2002; De Kock & Wolmarans, 2009),
- Iridinae: *Chambardia petersi* and *C. wahlbergi* (De Kock & Wolmarans 2012),
- Unionidae: *Unio caffer* (Oberholzer & Van Eeden, 1967; De Kock *et al.*, 2002; De Kock & Wolmarans, 2010).

The reason for the presence or absence of a species (preferably all species) is always the fundamental question that needs to be investigated to improve research outputs and our understanding of complex ecosystems. Tables 4-1 and 4-2 attempts to summarise some of the known, listed as indicators under the different subheadings.

3.6.2.2.2 Taxa Selected as Indicators

Variables measured during this study at some of the sites[5] were velocity, depth*, in situ* water quality, water chemistry, substrate and hydraulic biotope types, and discharge during sampling. Measured and documented responses to the two master drivers, flow (velocity) and water temperature are listed, and some data on preferences to combination of water temperature, elevation, and electrical conductivity presented.

[1] Collected by Gerhard J Diedericks.
[2] Speculation that barriers (i.e. Corumanu Dam) prevents migration and therefore affects life history.
[3] Decreasing in abundance and in some streams-rivers with high electrical conductivity not encountered. Linked to increases in sodium sulphate levels (Goetsch & Palmer, 1997; Zokufa et al., 2001).
[4] Water temperature, sensitivity to specific pollutants, barriers to fish movement (Lydeard et al., 2004; Wang et al., 2016)
[5] Time: (a) sampling permit delayed by MTPA; (b) timing of surveys (very high flows) because of permit delays; (c) time and finances allocated for macroinvertebrate sample analysis in laboratory (budget constraints).

3.6.2.2.2.1 Flow Indicators

The functioning of stream-river ecosystems is naturally linked to flood and drought disturbances, which in turn regulate and structure stream communities (Lytle, 2008). From a broad perspective (taxonomic orders), aquatic taxa requiring gill respiration as larvae/nymphs and arial adult (imago) stages are not capable of suddenly exiting their aquatic habitats to avoid sudden flood or drought events. These taxa (e.g. Ephemeroptera, Plecoptera, Trichoptera, Odonata, Megaloptera and some Diptera) have therfore evolved to synchronise emergence as adults with expected disturbance periods (i.e. floods in summer, drought early spring). In turn, taxa representing the orders Hemiptera and Coleoptera can as adults rapidly escape from sudden flood events (Lytle, 2008). For this reason, only taxa representing those who evolved to time their emegence over a larger timescale were considered for flow indicators. Taxa that can burrow or survive in the hyporheic zone were also not included.

Table 3-38: List of the velocity preferences of some aquatic macroinvertebrate species. An asterisk (*) indicate source as Matthew (1968).

<table>
<tr><th>Order</th><th>Species</th><th>Stagnant
(< 0.1 m/s)</th><th>Slow
(0.1-0.3 m/s)</th><th>Medium
(0.3-0.6 m/s)</th><th>Fast
(> 0.6 m/s)</th></tr>
<tr><td rowspan="2">Diptera</td><td>Athericidae</td><td></td><td colspan="2">0.25-0.49</td><td></td></tr>
<tr><td>Empididae</td><td></td><td></td><td colspan="2">0.4-0.8</td></tr>
<tr><td rowspan="19">Ephemeroptera</td><td>Baetidae: Acanthiops varius*</td><td></td><td></td><td></td><td>0.9-1.4</td></tr>
<tr><td>Baetidae: Afroptilum parvum*</td><td></td><td></td><td colspan="2">0.5-0.9</td></tr>
<tr><td>Baetidae: Centroptilis bifasciata*</td><td></td><td></td><td colspan="2">0.4-0.9</td></tr>
<tr><td>Baetidae: Dabulamanzi indusii*</td><td></td><td></td><td></td><td>> 0.9</td></tr>
<tr><td>Baetidae: Dabulamanzi media*</td><td></td><td colspan="2">0.2-0.5</td><td></td></tr>
<tr><td>Baetidae: Demoreptus natalensis*</td><td></td><td></td><td colspan="2">0.5-1.4</td></tr>
<tr><td>Dicercomyzidae: Dicercomyzon</td><td colspan="3">0-0.4</td><td></td></tr>
<tr><td>Heptageniidae: Afronurus barnardi*</td><td colspan="2">0-0.2</td><td></td><td></td></tr>
<tr><td>Heptageniidae: Afronurus peringueyi*</td><td></td><td colspan="2">0.2-0.5</td><td></td></tr>
<tr><td>Heptageniidae: Notonurus[6] njalensis*</td><td colspan="3">0-0.4</td><td></td></tr>
<tr><td>Leptophlebiidae: Euthraulus elegans*</td><td></td><td colspan="3">0.2-0.9</td></tr>
<tr><td>Machadorythidae: Machadorythus maculatus</td><td colspan="3">0-0.5</td><td></td></tr>
<tr><td>Oligoneuridae: Elassoneuria trimeniana*</td><td></td><td></td><td colspan="2">0.3-1.4</td></tr>
<tr><td>Oligoneuridae: Oligoneuropsis lawrencei*</td><td></td><td></td><td colspan="2">0.5-0.9</td></tr>
<tr><td>Polymitarcidae: Ephoron savignyi*</td><td></td><td></td><td colspan="2">0.5-0.9</td></tr>
<tr><td>Prosopistomatidae: Prosopistoma crassi*</td><td></td><td colspan="2">0.2-0.5</td><td></td></tr>
<tr><td>Prosopistomatidae: Prosopistoma mccaffertyi*</td><td></td><td></td><td colspan="2">0.5-0.9</td></tr>
<tr><td>Trichorythidae: Tricorythus “highveld”*</td><td></td><td></td><td colspan="2">0.5-1.4</td></tr>
<tr><td>Trichorythidae: Tricorythus “lowveld”*</td><td></td><td></td><td colspan="2">0.5-1.4</td></tr>
<tr><td rowspan="6">Odonata</td><td>Aeshnidae: Pinheyschna subpupillata</td><td></td><td colspan="3">0.1-0.8</td></tr>
<tr><td>Chlorocyphidae: Platycypha</td><td colspan="2">0-0.25</td><td></td><td></td></tr>
<tr><td>Gomphidae: Paragomphus cognatus</td><td></td><td colspan="2">0.2-0.45</td><td></td></tr>
<tr><td>Libellulidae: Zygonoides fuelleborni</td><td></td><td colspan="3">0.12-1.1</td></tr>
<tr><td>Libellulidae: Zygonyx natalensis</td><td></td><td colspan="3">0.3-1.1</td></tr>
<tr><td>Libellulidae: Zygonyx torridus</td><td></td><td colspan="3">0.3-1.1</td></tr>
<tr><td>Plecoptera</td><td>Perlidae: Neoperla</td><td></td><td colspan="3">0.1-0.9</td></tr>
<tr><td rowspan="4">Trichoptera</td><td>Hydropsychidae: Hydropsyche longifurca</td><td colspan="4">0.03-0.9</td></tr>
<tr><td>Hydropsychidae: Macrostemum</td><td></td><td colspan="3">0.21-0.9</td></tr>
<tr><td>Hydroptilidae: Hydrotila</td><td></td><td colspan="2">0.12-0.4</td><td></td></tr>
<tr><td>Philopotamidae: Chimarra</td><td colspan="4">0.09-0.9</td></tr>
</table>

[6] Previously genus *Compsoneuria*.

3.6.2.2.2.2 Water Temperature

Water temperature, linked to shading, elevation, depth, and climate is considered an important driver of community structure (Dallas, 2008; Eady *et al.*, 2013). Within the life cycles of species water temperature is closely linked to egg development, growth, emergence, metabolism, and more (Dallas, 2008, Rivers-Moore *et al.*, 2012; Dallas & Rivers-Moore, 2019). In Ephemeroptera, several studies supported the view that water temperature is the most important driver of community structure (Ramulifho *et al.*, 2020). With ecological data limited, information was gathered from *in situ* (spot) data[7] collected over different times of day and seasons, and some published in resources accessed.

[7] *In situ* temperature spot data does not consider temperature predictability and variability. Also, most data limited to where collected.

Table 3-39: Perceived species average water temperature preferences based on field observations, distribution records, and the WRC Dallas (2009) report and Dallas & Rivers-Moore (2012). Average water temperature categories are based on (Rivers-Moore et al., 2004)

<table>
<tr><th rowspan="3">Order</th><th rowspan="3">Species</th><th colspan="5">Termal preference</th></tr>
<tr><th>Cold</th><th>Cold-Cool</th><th>Cool</th><th>Cool-Warm</th><th>Warm</th></tr>
<tr><th>(<19°C)</th><th>(19-21°C)</th><th>(21-23°C)</th><th>(23-25°C)</th><th>(>25°C)</th></tr>
<tr><td rowspan="3">Bivalva</td><td>Iridinidae: Chambardia petersi</td><td></td><td></td><td colspan="2">21 - 25[93%]</td><td></td></tr>
<tr><td>Iridinidae: Chambardia wahlbergi</td><td colspan="4">15 - 25[98%]</td><td></td></tr>
<tr><td>Unionidae: Unio caffer</td><td colspan="4">10 - 25[98%]</td><td></td></tr>
<tr><td>Decapoda</td><td>Athyidae: Cardinia</td><td colspan="5">10.3 – 35.0</td></tr>
<tr><td rowspan="25">Ephemeroptera</td><td>Baetidae: Acanthiops varius</td><td colspan="2">RHLA CTmax – 34.1°C</td><td></td><td></td><td></td></tr>
<tr><td>Baetidae: Afroptilym parvum</td><td colspan="2">RHLA</td><td></td><td></td><td></td></tr>
<tr><td>Baetidae: Baetis harrisoni</td><td colspan="5">BODI</td></tr>
<tr><td>Baetidae: Centroptiloides bifasciata</td><td></td><td></td><td colspan="3">BODI</td></tr>
<tr><td>Baetidae: Crassabwa flava</td><td></td><td></td><td></td><td></td><td>OLL</td></tr>
<tr><td>Baetidae: Dabulamanzia indusii</td><td colspan="2">MHLA</td><td></td><td></td><td></td></tr>
<tr><td>Baetidae: Dabulamanzia media</td><td colspan="2">MHLA</td><td></td><td></td><td></td></tr>
<tr><td>Baetidae: Demoreptus natalensis</td><td colspan="2">MHLA</td><td></td><td></td><td></td></tr>
<tr><td>Baetidae: Procloeon africanum</td><td></td><td></td><td></td><td colspan="2">RLLA</td></tr>
<tr><td>Baetidae: Pseudocloeon glaucum</td><td></td><td></td><td></td><td colspan="2">DLLA</td></tr>
<tr><td>Baetidae: Pseudocloeon maculosa</td><td colspan="2">RHLA</td><td></td><td></td><td></td></tr>
<tr><td>Baetidae: Pseudocloeon vinosum</td><td colspan="2">MHLA</td><td></td><td></td><td></td></tr>
<tr><td>Heptageniidae: Afronurus barnardi</td><td colspan="2">RHLA CTmax – 32.5°C</td><td></td><td></td><td></td></tr>
<tr><td>Heptageniidae: Afronurus peringueyi</td><td colspan="5">3.9 – 30.0</td></tr>
<tr><td>Heptageniidae: Afronurus scotti</td><td colspan="2">RHLA</td><td></td><td></td><td></td></tr>
<tr><td>Leptophlebiidae: Adenophlebia sylvatica</td><td colspan="2">RHLA</td><td></td><td></td><td></td></tr>
<tr><td>Leptophlebiidae: Adenophlebiodes bicolor</td><td></td><td></td><td></td><td colspan="2">OLL</td></tr>
<tr><td>Machadorythidae: Machadorythus maculatus</td><td></td><td></td><td colspan="3">OLL</td></tr>
<tr><td>Oligoneuridae: Elassoneura trimeniana</td><td></td><td></td><td colspan="3">OLL</td></tr>
<tr><td>Oligoneuridae: Oligoneuropsis lawrencei</td><td colspan="3">RHLA</td><td></td><td></td></tr>
<tr><td>Polymitarcidae: Ephoron savignyi</td><td colspan="2">RHLA</td><td></td><td></td><td></td></tr>
<tr><td>Prosopistomatidae: Prosopistoma crassi</td><td></td><td colspan="3">MR</td><td></td></tr>
<tr><td>Prosopistomatidae: Prosopistoma mccaffertyi</td><td></td><td></td><td></td><td colspan="2">OLL</td></tr>
<tr><td>Tricorythidae: Trycorythus "headwaters"</td><td colspan="3">MHLA</td><td></td><td></td></tr>
<tr><td>Tricorythidae: Trycorythus "lowveld"</td><td></td><td></td><td colspan="3">OLL</td></tr>
<tr><td rowspan="3">Gastropoda</td><td>Thiaridae: Melanoides tuberculata</td><td></td><td colspan="3">21.0 - 25.0[98%]</td><td></td></tr>
<tr><td>Thiaridae: Melanoides victoriae</td><td colspan="2">16 - 20</td><td></td><td></td><td></td></tr>
<tr><td>Thiaridae: Tarebia granifera</td><td></td><td></td><td></td><td colspan="2">OLL</td></tr>
<tr><td rowspan="4">Odonata</td><td>Aeshnidae: Pinheyschna subpupillata</td><td colspan="4">6.7 - 24.7(n=387)</td><td></td></tr>
<tr><td>Aeshnidae:Anax speratus</td><td colspan="5">10.4 - 29.3(n=104)</td></tr>
<tr><td>Gomphidae: Paragomphus cognatus</td><td colspan="3">6.6 - 22.6[13.2](n=538)</td><td></td><td></td></tr>
<tr><td>Libellulidae: Zygonoides fuelleborni</td><td colspan="5">15.6 - 31.2(n=169)</td></tr>
<tr><td>Plecoptera</td><td>Perlidae: Neoperla</td><td colspan="5">3.9 – 28.0</td></tr>
<tr><td>Trichoptera</td><td>Lepidostomatidae: Lepidostoma</td><td colspan="3">6.0 - 22.5[16.0](n=1194)</td><td></td><td></td></tr>
</table>

BODI = based on distribution; Ctmax = critical thermal maxima; DLLA = dominant low-lying areas; MHLA = mainly high lying areas; MR = middle reaches; OLL = only low-lying areas; RHLA = restricted to high lying areas; RLLA = restricted to low lying areas; [x] = average; (n=xx) = number of records.

Table 3-40: A list of additional information used to guide preferences of aquatic macroinvertebrates to flow, physical- and chemical habitat within the Incomati system.

Order	Family	Genus	Species	Area	Topic	Reference
Ephemeroptera	Baetidae	*Centroptiloides*	*bifasciata*	Southern Africa	Distribution with ecological observations.	Agnew, 1962
Odonata	Gomphidae	*Paragomphus*	*cognatus*	Eastern Cape	Habitat selection in relation to substrate particle size.	Keetch & Moran, 1966
Mollusca	Various			Kruger National Park	Distribution	Oberholzer & Van Eeden (1967)
Ephemeroptera	Various	Various	Various	Incomati system	Distribution within catchment.	Matthew (1968)
Trichoptera	Hydropsychidae	*Cheumatopsyche*		South Africa	Life history alternatives	Scott *et al.* (1988)
Crustaceae	Palaemonidae	*Macrobrachium*		Eastern flowing rivers, South Africa	Ecology & genetic variation	Taylor (1990)
Ephemeroptera Trichoptera	Tricorythidae Philopotamidae	*Tricorythus* *Chimarra*	"lowveld"	Kruger National Park	Salinity tolerance	Goetsch & Palmer (1997)
Ephemeroptera	Tricorythidae	*Tricorythus*	"highveld"	Sabie River – Mpumalanga; Buffalo River – E Cape	Tolerance to complex saline kraft & textile effluents	Zokufa *et al.* (2001)
Various				South Africa	Toxicity database	Palmer *et al.* (2004)
Trichoptera	Various	Various	Various	South Africa	Regional biogeographical differences.	De Moor (2006)
Mollusca	Various	Various	Various	Kruger National Park	Distribution & habitats	De Kock *et al.* (2002)
Gastropoda	Thiaridae	*Melanoides*	*uberculate victoriae*	South Africa	Distribution & habitats	De Kock & Wolmarans (2009)
Pelecypoda	Unionidae	*Unio*	*caffer*	South Africa	Distribution & habitats	De Kock & Wolmarans (2010)
Pelecypoda	Iridinidae	*Chambardia*	*petersi wahlbergi*	South Africa	Distribution & habitats	De Kock & Wolmarans (2012)
Various				South Africa	Critical thermal maxima	Dallas & Rivers-Moore (2012)

3.6.2.2.2.3 Electrical Conductivity

Even though electrical conductivity (EC) measurements of < 500 µS/cm are still considered low, the preference of some species still appear to be absent from levels > 500 µS/cm (Table 3-41 and Table 3-41). The continuous absence or low numbers of Ephemeroptera: Tricorythidae: *Tricorythus* sp. in the Elands River downstream from the Sappi Ngodwana Pulp and Paper Mill, and other portions of the Incomati basin where Matthew (1968) previously encountered the family over different seasons is a concern.

Table 3-41: Summary of in situ electrical conductivity measurements[8] associated with the presence of the aquatic nymphs of three Odonata species and one Ephemeroptera.

Species	No.	Electrical Conductivity (µS/cm)									
		0 - 100	100 - 200	200 - 300	300 - 400	400 - 500	500 - 600	600 - 700	700 - 800	800 - 900	900 - 1 000
Aeshnidae: *Pinheyschna subpupillata*	n = 384	0%	74%	20%	5%	1%	0%	0%	0%	0%	0%
Gomphidae: *Paragomphus cognatus*	n = 556	58%	23%	19%	0%	0%	0%	0%	0%	0%	0%
Libellulidae: *Zygonoides fuelleborni*	n = 171	0%	27%	35%	4%	23%	1%	4%	1%	4%	4%
Tricorythidae: *Tricorythus* "headwater"	n = 21 196	64%	28%	6%	1%	0%	0%	0%	0%	0%	0%

Table 3-42. Records of some of the environmental conditions Tricorythus species encountered in headwater streams of the Incomati basin.

Tricorythidae: *Tricorythus* "headwater"		**Elevation (m a.s.l.)**									
	n = 22 382	0 - 300	300 - 600	**600 - 900**	**900 - 1200**	**1200 - 1500**	**1500 - 1800**	**1800 - 2100**	**2100 - 2400**	2400 - 2700	2700 - 3000
				2%	17%	38%	29%	7%	5%		
		Velocity (m/s)									
		Stagnant	Slow	Medium			Fast			Very fast	
		0 - 0.15	0.15 - 0.3	0.3 - 0.45	**0.45 - 0.6**	**0.6 - 0.75**	**0.75 - 0.9**	**0.9 - 1.05**	**1.05 - 1.2**	**1.2 - 1.35**	**1.35 - 1.5**
								0.5 - 1.4 (limited data)			
		Water Temperature (°C)									
	n = 21 430	0 - 4.3	4.3 - 8.6	**8.6 - 12.9**	**12.9 - 17.2**	**17.2 - 21.5**	**21.5 - 25.8**	**25.8 - 30.1**	30.1 - 34.4	34.4 - 38.7	38.7 - 43.0
				1%	27%	36%	31%	5%			
		Electrical Conductivity (µS/cm)									
	n = 21 196	**0 - 100**	**100 - 200**	**200 - 300**	**300 - 400**	400 - 500	500 - 600	600 - 700	700 - 800	800 - 900	900 - 100
		64%	28%	6%	1%						
		pH									
	n = 21 521	0 - 1.4	1.4 - 2.8	2.8 - 4.2	4.2 - 5.6	5.6 - 7.0	**7.0 - 8.4**	**8.4 - 9.8**	**9.8 - 11.2**	11.2 - 12.6	12.6 - 14.0
							14%	79%	7%		

Table 3-43 provides an overview of aquatic macroinvertebrate indicator taxa considered, and taxa recommended for consideration, with some of the data collected during this survey, and others from sources listed in section 3.6.2.2.1. With this study, sample size to environmental data is low (time & budget constraints).

[8] Personal data (Gerhard J Diedericks).

Table 3-43: Aquatic macroinvertebrate indicator taxa considered during the macroinvertebrate assessment, and taxa recommended for consideration

SPECIES		FLOW	WQ		SUBS				FLOODPLAIN	TROPHIC	SOURCE(S)
		(m/s)	Temp. (°C)	EC	Stones	Veg	Sand-Mud-Silt	Detritus			
Bivalva											
Iridinidae	*Chambardia petersi*										De Kock & Wolmarans (2012)
Iridinidae	*Chambardia wahlbergi*		15-25								
Unionidae	*Coelature framesi*										
Unionidae	*Unio caffer*		10-25				Sand				De Kock & Wolmarans (2010)
Coleoptera											
Elmidae	(Imago & larvae)	0-1.1	21-25								
Psephenidae	*Afrobrianax* sp.	0.1-0.9			Cobble						Velocity-TS
Odonata											
Aeshnidae	*Pinheyschna subpupillata*	0.1-0.8									

3.6.2.2.3 Macroinvertebrate Results

3.6.2.2.3.1 Present Ecological Status

Sits were categorised into classes applying the MIRAI model to existing data (Thirion, 2008). The results are presented for each site in Table 3-44, and briefly discussed.

Based on classes obtained from MIRAI and recommended categories for the Komati and Crocodile catchment sites, the system is currently mostly in better condition than what is recommended. Based on changes when comparing MIRAI results to previous data, conditions predominantly improved slightly or were similar at most sites sampled (Table 3-44). In the Sabie catchment, there are some sites on streams indicating slight deterioration (e.g. Mac Mac), but overall improvement.

Table 3-44: List of sites selected with PES indicated, and change compared to Recommended Class (REC) and previous data (if available) indicated by arrows as improved of deterioration.

CATCHMENT	IUA	Class	REC	CODE	RIVER	Description	n	PES	Change from previous	
									from previous	from REC
Incomati	Y1-4	2	B/C	Estuary	Incomati	Incomati Estuary	*			
	Y1-4	2	B/C	Flood	Incomati	Incomati Floodplain	1	C	NA	↘
Komati	X1-1	2	B/C	X11B	Boesmanspruit	Boesmanspruit	2	C	→	↘
	X1-3	2	C	X11D	Klein Komati	Klein Komati (possible new site)	7	B	↗	↑
	X1-3	2	C	X11F	Komati	Komati at EWR-K1	4	B/C	↗	↗
	X1-4	3	D	X11J	Gladdespruit	Gladdespruit	2	C	→	↑
	X1-6	1	D	X12K	Komati	Komati at EWR-K2	12	B/C	↗	↑
	X1-11	2	D	X13D	Komati	Komati River at Silingani	18	C	→	↑
	X1-9	3	D	X13J	Komati	Komati weir below Eswatini	2	B/C	↗	↑
	X1-10	3	D	X13K	Komati	Lower Komati River	11	C	→	↗
	Y1-2	3	C/D	X13L	Incomati	Incomati in Mozambique	1	C	NA	↗
	X1-7	2	C	X14D	Lomati	Lomati	2	B/C	↗	↗
	X1-8	3	C	X14H	Lomati	Lomati River at Kleindoringkop	11	B	↗	↑
Crocodile	X2-1	2	B	X21B	Crocodile	Crocodile at EWR-C2	12	B	↗	→
	X2-2	2	B/C	X21E	Crocodile	Crocodile at EWR-C3	5	B	→	↗
	X2-3	1	B	X21G	Elands	Elands River at Emgwenya	4	C	→	↓
	X2-4	1	B	X21G	Elands	Elands River at Nsinini	4	B/C	↗	↘
	X2-5	1	C	X21K	Elands	Elands River at Roodewal	16	C	→	→
	X2-7	1	C	X22A	Houtbosloop	Houtbosloop	2	B/C	↘	↗
	X2-6	2	C	X22B	Crocodile	Rivulets	3	C	↘	→
	X2-8	2	C/D	X22F	Nels	Nels at UMP	1	C	NA	↘
	X2-8	2	D	X22H	White River	Lower White River	2	C	→	→
	X2-9	2	C	X22K	Crocodile	Crocodile at Kanyamazane	9	C	→	→
	X2-10N	2	C	X23B	Noordkaap	Noordkaap	2	B/C	↗	↗
	X2-10Q	2	B/C	X23FQ	Queens	Queens	2	C	→	↘
	X2-10S	2	C	X23FS	Suidkaap	Suidkaap	2	B/C	↗	↗
	X2-10K	2	C	X23H	Kaap	Kaap River at Honeybird	3	C	→	→
	X2-12	2	B	X24C	Nsikazi	Nsikazi	1	D	NA	↓
	X2-13	1	C	X24F	Crocodile	Crocodile at Van Graan	2	D	→	↓
	X2-13	1	B	X24H	Mbyamiti	Mbyamiti	-			
Sabie-Sand	X3-1	1	B	X31A	Sabie	Sabie River at Merry pebbles	11	B	→	→
	X3-2	1	B	X31C	Mac-Mac	MacMac/Mac Mac/4	3	B/C	↘	↘
	X3-2	1	B	X31D	Sabie	Sabie at EWR-S (Aand-de-Vliet)	2	C	↘	↓
	X3-2	1	B/C	X31G	Marite	Marite/Marite/5	2	B/C	→	→
	X3-3	3	B	X31K	Sabie	Sabie/KNP/3 (Skekurukwane)	12	B/C	→	↘
	X3-8	2	B	X32H	Sand	Sand River at Exeter	2	B	↗	→
	X3-9	1	B	X32J	Sand	Sand at EWR-S8	-			
	X3-6	1	B	X33B	Sabie	Sabie River at Lower Sabie		C	→	↓
	Y1-5	2	C/D	X33D	Sabie	Sabie River in Mozambique	2	C	→	↗
	X4-1U	1	B	X40B	Uanetza	Uanetza KNP seasonal	-			
	Y1-1	1	C	X40BM	Uanetza	Uanetza in Mozambique	-			
	X4-1M	1	B	X40D	Massintonto	Massintonto KNP seasonal	-			
	Y1-3	1	C	X40DM	Massintonto	Massintonto in Mozambique	-			

3.6.2.2.4 Macroinvertebrate discussion

Stream conditions fluctuate considerably during different sampling events, linked to natural seasonal variations affecting multiple drivers. Sites sampled during very high flow events for example, could have lower SASS scores, but the cause is not necessarily due to impairment. Poor results could be linked to access to suitable wadable habitats during high flows, while elevated scores could be because of better access to more wadable habitats during low flows. High taxa diversity could also be because of high organic material, nutrient and/or ion availability (food sources), which could be to the detriment of taxa with a preference for oligotrophic conditions. When taxa diversity increases and specific taxa are absent from a sample, the effect on MIRAI results are limited.

When comparing current data to Oberholzer & Van Eeden (1967), Matthew (1968), Taylor (1990), De Kock *et al.* (2002), and De Kock & Wolmarans (2009) on species present and species abundance, there are changes in species composition and community structure. These changes are currently masked in a family-based index approach. Examples are:

- the absence of Tricorythidae: *Tricorythus* sp. in systems where they were previously abundant
- the absence or rare encounters of Prosopistomatidae: *Prosopistoma* sp.
- the slow disapearance of Palaemonidae: *Macrobrachium* sp. from the system.
- The dominance of Thiaridae: *Tarebia granifera* in the lower portions of the system, and the rare encounters of *Melanoides tuberculata* and *M. victoriae*.

Research questions should focus on the potential reasons rather than categorising river classes, since the changes in the river ecosystem driving the absence of lower abundance of specific species indicates potentially larger problems. The application of eDNA could assist in confirming presence-absence, especially for those species less often encountered through SASS sampling (e.g. Irininidae, Unionidae, Thiaridae: *Melanoides*), or those believed to be declining in certain reaches (e.g. Tricorythidae: *Tricorythus* sp., Prosopistomatidae: *Prosopistoma* sp., Palaemonidae: *Macrobrachium* sp.).

Long term chemical data suggests that there are increased ion concentrations (EC), and nutrients in these aquatic ecosystems (Griffin *et al.*, 2014). Available data suggests that some species are more sensitive to changes in water quality and water temperature than others (Eady *et al.*, 2013; Goetsch & Palmer, 1997; Ramulifho *et al.*, 2020; Wang *et al.*, 2016; Zokufa *et al.*, 2001). Knowing more about the preferred environmental conditions for species would assist in providing more concrete guidelines to industries discharging waste waters, which would ultimately improve conditions for the receiving rivers and streams.

3.6.2.3 RIPARIAN VEGETATION

3.6.2.3.1 In Situ Data Collection

In situ data collection was conducted with the use of cross-section transects perpendicular to flow. Cross-section locations were determined by on-site geomorphologist and riparian vegetation specialists. As far as possible, sites were placed across single or less complicated channels, perpendicular to flow and included vegetation species that represented flow-dependant community compositions (woody and non-woody).

Cross-sections were surveyed using a Leica TCR403 Power total station (Figure 3-29). Intervals of recorded points along transects depended upon the variation of topography and vegetation composition along transects. During the setup process, permanent markers (benchmarks) were created in order to ensure future replication of transects. Benchmarks were created in the form of steel pegs inserted into the ground, pegs inserted into the base of large trees or drilled markers on large boulders, bedrock or infrastructure.

Figure 3-29: Survey setup – Leica Tcr403 power total station on tripod.

3.6.2.3.2 Biotic data collected:

Vegetation: Plant species were identified along cross-sections along with individual height and abundance (if woody classification) and cover percentage (if non-woody classification). The elevation of individual plants was recorded along transects with the use of a Leica TCR403 Power total station so that the relative elevation of the individual could be linked to water level and discharge values.

3.6.2.3.3 Driver / abiotic data collected:

Elevation: Elevation was recorded for each point along transects with the use of the Leica TCR403 Power total station. Elevation values translate to relative elevation according to the lowest recorded point along transects (Figure 3-30 shows an example).

Discharge: Discharge was measured using the OTT MF Pro handheld device and a SonTek, M9 River Surveyor. The MF Pro handheld device was utilised by default unless conditions were unfavourable (unwadable or unsafe) to do so. The accuracy of the M9 River Surveyor was limited when water depth was < 0.3 m. Under conditions where channel depth ranged < 0.3 m and > 1 m, channels were divided into sections and assessed with both the MF Pro and River Surveyor. Total discharges calculated by the separate devices were then added together in order to determine the total discharge. The correct usage of a SonTek, M9 River Surveyor includes a minimum of 4-6 runs, perpendicular to flow in order to determine the most accurate calculation of total discharge for a site or section. Preferably, runs were recorded in pairs, including the recording of discharge from Left to Right bank and then again from Right to Left bank (or visa-versa). Once the minimum number of runs were recorded, an average of the total discharge was utilised as the accepted discharge value.

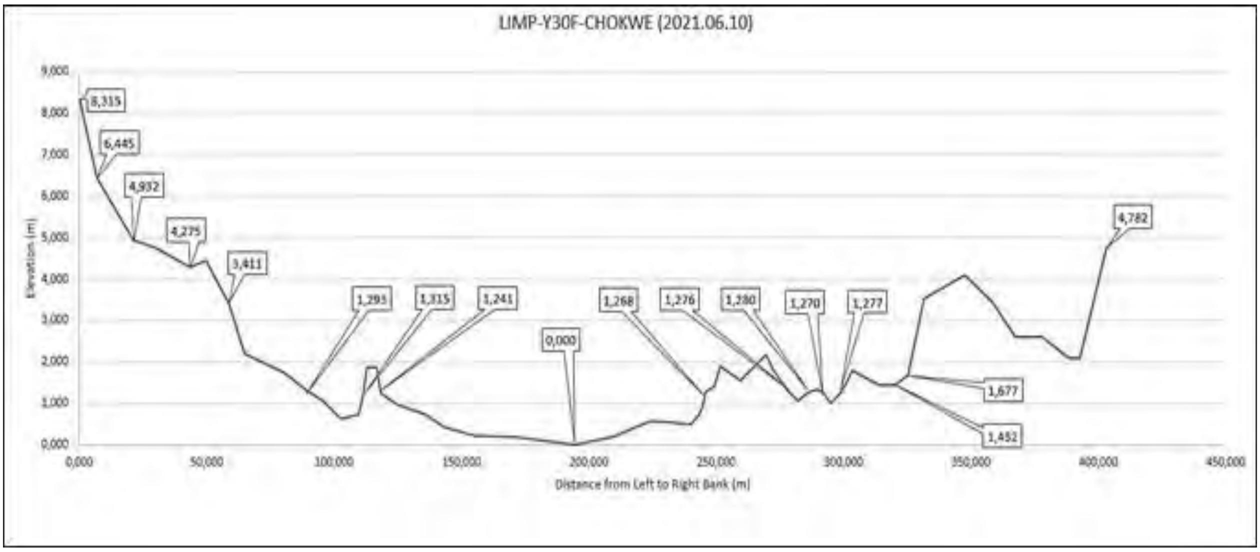


Figure 3-30: Example of cross-section profile with elevation.

3.6.2.3.4 Present Ecological State:

The riparian vegetation was assessed to determine a PES for both the riparian zone as a whole as well as for each of the sub-zones within the riparian zone. These sub-zones include the aquatic (where present), marginal, lower and upper zones, including the macro-channel bank (MCB), various flood features, such as benches, flood channels and backwaters, and a floodplain if it exists (Table 3-45). This is important since riparian vegetation distribution and species composition differs on different sub-zones, which has implications for flow requirements and flow-related impacts. These sub-zones form the basis of the overall assessment. Note, other zones or pertinent features that facilitate vegetation zonation may be prevalent at a site and should be named and assessed as the others. The PES of the riparian zone is then assessed using the Riparian Vegetation Response Assessment Index (VEGRAI) level 4 (Kleynhans *et al.*, 2007; with modifications).

Table 3-45: Description of generic riparian vegetation sub-zones.

	Marginal / Lower zone	Flood features / Upper zone	MCB
Alternative descriptions	Active features Wet bank	Seasonal features Wet bank	Ephemeral features Dry bank
Extends from	Water level at low flow	Marginal zone	Flood features
Extends to	Features that are hydrologically activated for the greater part of the year	Usually a marked increase in lateral elevation.	Usually a marked decrease in lateral elevation
Characterized by	See above	Geomorphic features that are hydrological activated on a seasonal basis. May have different species than marginal zone	Geomorphic features that are hydrological activated on an ephemeral basis. Presence of riparian and terrestrial species Terrestrial species with increased stature

Since all VEGRAI assessments are relative to the natural unmodified conditions (reference state) it is necessary and important to define and describe the reference state for each site. This is done (in part) before going into the field using historic aerial imagery, present and historic species distributions, general vegetation descriptions of the area, any anecdotal data available, knowledge of the area and comparison of the site characteristics to other comparable sections of river that might be in a better state. Armed with this information the reference (and present state) is quantified on site whereby the assessor reconstructs and quantifies the reference state from the present state by understanding how visible impacts have caused the vegetation to change and respond.

Impacts to riparian vegetation at the site are then described and rated. It is important to distinguish between a visible/known impact (such as flow manipulation) and a response of riparian vegetation to said impact. If there is no response by riparian vegetation the impact is noted but not rated since it has no visible/known effect. This is often the case with water quality for example. Ratings of impacts are as follows: No Impact = 0; Small impact = 1; Moderate impact = 2; large Impact = 3; Serious impact = 4; Critical impact = 5.

Once the riparian zone and sub-zones have been delineated, the reference and present states have been described and quantified (aerial cover is used) and a species checklist for the site has been compiled, the VEGRAI metrics are rated and qualified.

Table 3-46 outlines metrics that are assessed.

Table 3-46: Metrics that are rated in VEGRAI 4 (with modification).

Vegetation Components	Level 3	Level 4	Modification
Woody	Cover	Cover	Cover
	Abundance	Abundance	Abundance
	Species composition	Species composition	Species composition
		Recruitment	Recruitment

Vegetation Components	Level 3	Level 4	Modification
		Population structure	Population structure
			Vertical structure
Non-woody (grasses, sedges, dicot herbs)	Cover	Cover	Cover
	Species composition	Species composition	Abundance
			Species composition
Specialized category (e.g. reeds, Palmiet)			Cover
			Abundance

The determination of the reference condition relies on historic data or information as well as an understanding of the greater ecological context of the site and the impacts affecting it. The process of reconstructing reference condition for riparian or wetland vegetation involves the collection and assessment of all available sources of historic data and information and includes the following:

- Historic, and therefore expected distribution of vegetation Biomes, Bioregions and Types (Mucina & Rutherford, 2006, SANBI, 2018).
- Current and historic plant species distribution patterns (SANBI, 2009), especially of known riparian and wetland species.
- Past reports or assessments, although these may be of limited value in terms of historic time covered.
- Anecdotal information from any available source, be it published (e.g. Skead, 2009) or by interview with people who have a long-term experience of the site. This includes photographs that provide context, especially if they are dated.
- Acquisition of historic aerial photographs for time comparisons of change at the site.
- Comparison of current satellite coverages with historic aerial photographs and between timelines within the dataset, e.g. exploring Google Earth coverages across all available time frames.
- Assessment of on-site impacts and applying specialist understanding of what vegetation may be like in the absence of said impacts.

3.6.2.3.5 Flow Requirements:

The basis for determining the e-flows for riparian vegetation is to survey key riparian indicator sub-populations at the same time, and as close to as possible, as the hydraulic profile of the transect/s at the site. This enables accurate placement of the upper and lower limits of chosen sub-populations onto the profile. It is then a simple matter to use the rating curve or look-up tables for each transect to determine the flows at which sub-populations become activated (activation discharge – water level is at the lower limit of the sub-population, inundation at 0%) or inundated, or to calculate proportions of sub-population inundation. Similarly, this can be done for sub-zones or features within the riparian zone. This approach takes its roots from the Building Block Methodology (BBM, King *et al.*, 2008), which is a holistic approach that requires identification of a single predetermined condition, usually the present state. A single flow regime is then determined to facilitate the maintenance of the present state. From there flows may be adjusted to facilitate the maintenance of a different state, the recommended ecological category for example. Table 3-47 outlines generic indicators frequently used to determine environmental flow for riparian vegetation, and Table 3-48 their general responses to flow.

Table 3-47: Generic riparian zone indicators that are frequently used to determine environmental flows.

Indicator	Reasons for selection as indicator
Algae	Algae provide food for instream fauna (fish and invertebrates) and affect habitat quality.
Aquatic vegetation	Aquatic vegetation provide habitat, including protection and breeding sites, and food for fish and invertebrates.
Marginal zone graminoids	This guild includes grasses, sedges and reeds and is important for bank stabilisation, habitat creation for aquatic fauna (both inundated instream and overhanging vegetation) and for food (seeds, fruits, rotting leaf material).
Marginal zone woody vegetation	Marginal zone trees are important for bank stabilization, flood attenuation and provide overhanging shelter to instream fauna, particularly fish.
Lower zone / Seasonal feature graminoids	Like marginal zone graminoids this guild includes grasses, sedges and reeds growing in the lower zone. Non-woody vegetation in this zone is important for bank stabilization, grazing for animals and birds, and food and habitat for fish spawning during flooding.
Lower zone / Seasonal feature woody vegetation	Lower zone trees are important for bank stabilization, flood attenuation and the provision of food and habitat (including nesting sites) for riparian fauna.
Seasonal feature graminoids	This guild includes grasses, sedges and reeds and is important for bank stabilisation, habitat creation and for food (seeds, fruits, rotting leaf material).
Seasonal feature woody vegetation	Seasonal feature trees and shrubs are important for bank and sediment stabilization, flood attenuation and provide shelter and nesting sites for riparian fauna.
Flood feature graminoids	This guild includes grasses, sedges and post flood non-woody pioneers and is important for bank / sediment stabilisation and habitat creation.
Upper zone / Flood feature trees – riparian	Same function as lower zone trees but often more extensive in area and density and hence importance is elevated.
Upper zone trees – terrestrial	Terrestrialisation of the riparian zone occurs naturally to some extent but is kept at bay by the correct flooding regime, which affords the competitive edge to riparian trees. This indicator may be used as an integrity check for riparian zone structure and function.
Flood feature woody vegetation	Flood feature trees and shrubs are important for bank and sediment stabilization, flood attenuation and provide shelter and nesting sites for riparian fauna.
Terrestrial woody vegetation	These are woody species that are terrestrial and not considered riparian. Their presence in the riparian zone should be transient and may indicate potential; terrestrialisation

Table 3-48: General responses to flow by generic indicators.

Indicator	Definition	Predicted change	References
Algae	Aquatic, filamentous or benthic, green or brown.	Algae is favoured by reduced water depth and velocity. Higher flows and floods tend to scour the indicator.	Dallas and Day (2004).
Marginal zone graminoids	Grasses, sedges or reeds growing in the marginal zone	Winter base flows are important for survival while summer base flows for growth and reproduction. Small floods and freshets produce growth response and maintain reproductive success. Moderate to large floods will scour the indicator. Limited by water requirements and maximum rooting depths.	Canadell *et al.* (1996).
Marginal zone trees	Trees or shrubs growing in the marginal zone.	Winter base flows are important for survival while summer base flows for growth and reproduction. Small floods and freshets produce growth response and maintain reproductive success. Moderate to large floods will scour the indicator. Limited by water requirements and maximum rooting depths.	Canadell *et al.* (1996).
Lower zone / Seasonal feature graminoids	Grasses, sedges or reeds growing in the lower zone	Winter base flows are important for survival while summer base flows for growth and reproduction. Small to moderate floods produce growth response and maintain reproductive success. Large floods will scour the indicator and zero flow will cause desiccation stress. Limited by water requirements and maximum rooting depths.	Canadell *et al.* (1996).
Lower zone / Seasonal feature woody vegetation	Trees or shrubs growing in the lower zone.	Winter base flows are important for survival while summer base flows for growth and reproduction. Small to moderate floods produce growth response and maintain reproductive success. Large floods will scour the indicator and zero flow will cause desiccation stress. Limited by water requirements and maximum rooting depths.	Canadell *et al.* (1996).
Upper zone trees – riparian	Trees or shrubs growing in the upper zone that are by definition riparian.	Depth to soil moisture should not exceed 4-4.5 m. Zero flows may result in desiccation stress. Large floods are important for the maintenance of species diversity and recruiting opportunities.	Friedman and Lee (2002). Lite and Stromberg (2005). Leenhouts *et al.* (2005).

Indicator	Definition	Predicted change	References
Upper zone trees – terrestrial	Trees or shrubs growing in the upper zone that are by definition terrestrial.	Terrestrialisation of the upper zone occurs naturally, but the correct flooding regime is required to retard the process and maintain riparian species. Large floods provide riparian species with the competitive advantage.	Friedman and Lee (2002).

It is critical however, that the assessor understands the characteristics (such as phenology, reproductive strategies, survival techniques, growth requirements, rooting depths, etc.) and flow requirements (summer and winter, base flow, and flooding) of the indicator species used. Incorrect interpretation of requirements of riparian species will render the method of little use. In addition, it is imperative that a holistic view of the riparian zone be taken. For example, when setting flows for upper zone species, marginal zone species may (usually) be detrimentally affected, but these dynamics maintain the overall structure and functioning of the riparian zone in the long term.

The flow regime that is determined consists of different components, i.e. base flows (discharge and seasonality) and floods (seasonality, frequency, timing, duration, magnitude). Indicator sub-populations (that are surveyed onto the profile), together with hydraulics are used to determine base flow requirements for the wet and dry season. As a general guide, the dry season base flow should facilitate survival of marginal and lower zone vegetation while the wet season base flow should facilitate growth, reproduction, and recruitment. For high flows and floods there are multiple functions for different flows. Different class floods (usually class 1 to 5 but could be more or less) are determined and defined according to each of the sub-population requirements, and for the riparian zone as a whole. General flood functions are applied to each sub-population with specific considerations. Table 3-49 provides a general guideline for flood function and determination.

The following aims apply to all flood classes:

- To maintain existing vegetation composition in the riparian zone by maintaining the important components of natural variability in flow fluctuations.
- To stimulate reproduction and recruitment and maintain a range of size classes of dominant riparian species in perennial channels.
- To discourage encroachment of additional alien and terrestrial species in the riparian zone by periodic flooding.
- To maintain overall species and habitat heterogeneity in the riparian zone and prevention of dominance to the point of biodiversity loss.
- To prevent encroachment of the marginal zone vegetation towards the channel.

Table 3-49: General guideline of criteria to consider for flood determination.

Flood Class	Frequency	Seasonality	Rationale
I	usually from 3-6 event per year but depends on type of river (perennial, seasonal, ephemeral)	growing season (spring to summer)	Required to inundate marginal zone vegetation. Prevents establishment of terrestrial or alien species in the marginal zone. Provides recruitment opportunities in the marginal and lower zones. Stimulates growth and reproduction. Prevents encroachment of marginal zone vegetation towards the channel. Required during growing season (spread over several months).
II	usually from 2 event per year but depends on type of river (perennial, seasonal, ephemeral)	summer	Required to flood marginal zone and lower portion of lower zone. Prevents establishment of terrestrial or alien species in marginal and lower zones. Stimulates growth and reproduction. Prevents encroachment of marginal zone vegetation towards the channel. Required during mid to late summer.
III	An annual flood	late summer	Required to inundate lower zone vegetation and activate upper zone vegetation. Similar functions to above in these zones. Maintain heterogeneity in the marginal zone.
IV	A flood that occurs every second or third year	late summer	Required to inundate lower portion of the upper zone. Similar functions to above. Scour marginal and lower zones, maintain vegetation patchiness and heterogeneity.
V	An infrequent flood that occurs every 5 years or less.	late summer	Required to inundate upper zone macro channel and some portion of the MCB. Similar functions to above. Scour marginal, lower and upper zones, maintain vegetation patchiness and heterogeneity.

3.6.2.3.5.1 Deriving CPTs:

The best way to describe the methodology of deriving CPTs is by way of an example. The flow requirements for the X24F Crocodile River site are shown in Table 3-50 and the CPT derived from these flows in Table 3-51. The low flow requirement for riparian vegetation at this site is 5.1 m^3/s in the dry season and 14.4 m^3/s in the wet season. As long as seasonality remains intact there is therefore a low probability of risk to the vegetation if low flows remain between 5 and 14 m^3/s. This is transferred to Table 3-51 which shows a 90% probability of Zero risk to vegetation between 3.8 (close enough to 5 m^3/s) and 14.7 m^3/s. Beyond these preferred flows the probability of Zero risk decreases and the probability of higher risk increases. Similarly, the high flow requirements for vegetation are from 25 m^3/s (within-year floods) to 140 m^3/s (yearly flood; Table 3-50) and again, as long as seasonality remains intact the risk profile (Table 3-51 HF) shows a 90% probability of Zero risk to vegetation from high flows between 32.2 and 144.3 m^3/s. Beyond these high flows the probability of higher risk to vegetation increases.

Table 3-50: High and low flow requirements for riparian vegetation at the Crocodile River site X24F Crocodile.

Low Flows	Units	Discharge	Rip Veg Motivation
Dry Season	m^3/s	5.1	The dry season base flow needs to provide enough soil moisture (but not unduly inundate) to ensure survival and persistence during dormancy. The discharge is calculated at 0.3 m below the lowest limit of marginal zone vegetation, in this case *Phragmites mauritianus*. Stream permanency is important for persistence of the riparian vegetation. Once stream permanency declines below 10% population density will decline and once stream permanency declines below 20% MCB tree species will likely lose their competitive ability and be replaced by other hardy drought tolerant or terrestrial species (Lite & Stromberg, 2007, modified; Leenhouts *et al.*, 2005). This also links to terrestrial trees on the MCB which will increase as riparian trees decline due to loss of stream permanency. Depth to soil moisture should not exceed 4-4.5 m. Zero flows may result in desiccation stress or death. Depth to ground water important for longer term survival.
	Percentile	50th	
	Months	Dry season	
Wet Season	m^3/s	14.4	For wet season base flow, inundation and activation is important during the growing season to ensure sustained productivity and reproduction. Discharge is calculated at an elevation that inundates a portion of the marginal zone vegetation, but not as much as within-year floods.
	Percentile	50th	
	Months	Wet season	
Freshets/ Floods	**Units**	**Discharge**	**Rip Veg Motivation**
Class 1	m^3/s	25	These within-year freshets are required to inundate marginal zone vegetation, mostly reeds (*Phragmites mauritianus*) and sedges (*Cyperus sexangularis*). These floods facilitate and sustain a growth response by marginal zone graminoids, replenish soil moisture, deposit sediments and nutrients and ensure reproductive success. This event will help prevent encroachment towards the channel over time but also establishes the zone.
	daily average/ peak	peak	
	Number of days	6	
	Months	4 within-year floods in the wet season	
Class 2	m^3/s	140	This event inundates the flood features, such as benches or bars as well as the woody and non-woody flood feature vegetation component. While some scour may remove small portions of indicator, these floods facilitate and sustain a growth response, replenish soil moisture, deposit sediments and nutrients and ensure reproductive success.
	daily average/ peak	peak	
	Number of days	5	
	Months	annual flood (wettest month)	
Class 3	m^3/s	440	These events are set to flood terrestrial vegetation (*Dichrostachys cinerea*) which helps prevent terrestrialisation of the riparian zone. While some scour may remove portions of riparian vegetation, these floods also facilitate and sustain a growth response, replenish soil moisture, deposit sediments and nutrients and ensure reproductive success.
	daily average/ peak	peak	
	Number of days	4	
	Months	1:2/3 flood	
Class 4	m^3/s	2060	These infrequent events flood portions of riparian woody vegetation growing along the banks, in this case *Spirostachys africana*. Some scour or death due to inundation stress likely but also promotes growth and reproduction and recharges soils moisture important to all phreatophytes. Provides recruiting opportunities, and limits terrestrialisation.
	daily average/ peak	peak	
	Number of days	3	
	Months	1:5 flood	

Table 3-51: Derived CPT from flow requirements for the Crocodile River site X24F Crocodile for high flows (VEG_ECO_DEP_HF) and low flows (VEG_ECO_DEP_LF).

Discharge (m³/s)	VEG_ECO_DEP_HF				VEG_ECO_DEP_LF			
	Zero	Low	Med	High	Zero	Low	Med	High
0	0	0	0	100	0	0	0	100
0.4	10	20	30	40	10	20	30	40
0.8	10	20	30	40	10	20	30	40
1.2	10	20	30	40	30	40	20	10
1.6	10	20	30	40	30	40	20	10
2	15	30	30	25	60	32	7	1
2.4	15	30	30	25	60	32	7	1
2.8	15	30	30	25	75	20	5	0
3.2	25	50	20	5	75	20	5	0
3.8	25	50	20	5	90	10	0	0
8.4	50	40	9	1	90	10	0	0
14.7	75	20	5	0	90	10	0	0
22.6	75	20	5	0	75	20	5	0
32.2	90	10	0	0	75	20	5	0
43.5	90	10	0	0	60	32	7	1
56.3	90	10	0	0	60	32	7	1
70.7	90	10	0	0	45	45	9	1
86.8	90	10	0	0	45	45	9	1
104.4	90	10	0	0	45	45	9	1
123.5	90	10	0	0	45	45	9	1
144.3	90	10	0	0	45	45	9	1
166.5	75	20	5	1	45	45	9	1
190.4	75	20	5	1	30	40	20	10
215.7	75	20	5	1	30	40	20	10
242.6	75	20	5	1	30	40	20	10
271.1	75	20	5	1	30	40	20	10
301	60	32	7	1	30	40	20	10
332.5	60	32	7	1	30	40	20	10
365.5	60	32	7	1	15	30	35	20
400	60	32	7	1	15	30	35	20
436	45	45	9	1	15	30	35	20
473.4	45	45	9	1	15	30	35	20
512.4	45	45	9	1	15	30	35	20

3.6.2.3.6 Riparian vegetation results

The PES assessment (category and score) and derived activation discharges is show below for each site that was assessed.

3.6.2.3.6.1 PES & Activation Discharge

3.6.2.3.6.1.1 Nels River (X22F NELS)

The channel morphology could be described as single channelled with in-stream bedrock outcroppings. The marginal zone was primarily dominated by bedrock substrates with some coarse sands overlain in sections with reduced velocities. In-stream leigh-bars were sparsely to heavily vegetated with non-woody *Phragmites mauritianus* and woody *Breonadia salicina* which dominated the non-woody and woody components within this zone. (Figure 3-31). Other riparian species observed within the marginal zone included *Cyperus exaltatus, Ludwigia octovalvis, Verbena bonariensis, Annona senegalensis, Bridelia micrantha, Melinis repense, Melia azedarach* and *Catharanthus roseus.* Impacts affecting this zone included effluent discharges from upstream sources, water extraction activities and pollution in the form of litter within the marginal zone. The left bank of the river was dominated by exposed bedrock substrates that provided reduced surface area for riparian vegetation anchorage which the right bank was dominated by coarse sands, sands and fine sands farther up the banks with interspersed exposed bedrock outcroppings. The lower and upper zones were dominated by heavily vegetation woody trees which primarily included the species *Breonadia salicina, Annona senegalensis* and *Bridelia micrantha*. The macro-channel banks transitioned into a combination of woody trees and shrubs however human infrastructure such as bridges and tarred roads affected vegetation compositions. Major disturbances within these zones included pollution in the form of litter, human footpaths, and infrastructure such as roads, bridges and water pollution in the form of effluent discharges originating from open pipes feeding the pollution directly into the river as was deduced by the foul odours at the site. Alien species identified at the site included *Ageratum conyzoides, Verbena bonariensis, Melia azedarach* and *Catharanthus roseus.*

The present ecological state has an overall PES score of 68.5% (category C, which is moderately modified from reference conditions; Table 3-52 outlines a summary of the PES ratings, score and ecological category of zones, and provides most notable reasons for the perturbation and Table 3-53 lists the intensity and extent of impacts). The activation discharge measurement for indicators is shown in Table 3-54 and these will be used to derive flow requirements (base and flood) for the vegetation component of the site.

Figure 3-31: Site photographs (left; looking US-top and downstream-bottom) and an indication of site placement on satellite imagery (right; Bing ©) for the Nels River (X22F NELS).

Table 3-52: PES score and category with the main reasons for the score for the Nels River (X22F NELS).

LEVEL 4 ASSESSMENT	Nels River (X22F NELS)					07 November 2022
RIPARIAN VEGETATION EC METRIC GROUP	CALCULATED RATING	WEIGHTED RATING	CONFIDENCE	RANK	WEIGHT	Notes:
Macro channel valley	71.7	21.6	3.8	1.0	30.2	Weighted according to extent
Macro channel bank	67.1	46.9	3.4	2.0	69.8	Weighted according to extent
LEVEL 4 VEGRAI (%)						68.5
VEGRAI Ecological Category						C
AVERAGE CONFIDENCE						3.6

	Sub-zone	
	Macro channel valley	**Macro channel bank**
VEGRAI % (Zone)	71.7	67.1
EC (Zone)	**C**	**C**
Confidence (Zone)	3.8	3.4

Main cause of PES:

Woody were most dominant, followed by reeds. Only real impact with response by veg. was low densities of aliens and nutrient input from upstream sewerage likely resulted in more abundant reeds. Reeds weren't considered as there were none in non-marginal zones (a lot of bedrock further up, especially on left bank. Non-woody plants were negatively affected by pipes draining sewerage (leading from under roads) and responded by proliferous growth and increased invasives at those specific areas. Also, invasives seemed to increase around areas with pollution and disturbances by well-used foot paths. Effects however were limited to specific areas. Under dense woody vegetation there was minimal alterations (big old Matumi trees).

Table 3-53: Intensity and extent of impacts on riparian vegetation at the Nels River (X22F NELS).

IMPACTS	INTENSITY	EXTENT	NOTES
	Marginal zone		
Vegetation Removal	0.5	0.5	No obvious signs vegetation removal by anthropogenic influence.
Alien Species Invasion	1.5	1.5	Low to moderate abundances and densities of invasive plants within this zone.
Water Quantity	2	5	Observed water extraction activities both at the sites and upstream of the site however limited observable impacts on the riparian vegetation within this zone.
Water Quality	4	5	High impacts of water quality on the environment at the site. This was apparent through observed in-stream litter, odours of effluent discharges and discoloured water.
Erosion	0.5	0.5	Minimal observed impacts of erosion, primarily due to bedrock substrates within the in-stream environment and along the marginal zones.
	Non-marginal (incl. Flood bench, MCB, floodplain)		

IMPACTS	INTENSITY	EXTENT	NOTES
Vegetation Removal	3.5	3	Vegetation removal due to anthropogenic infrastructure such as roads and bridges. In addition to the above, removal by human traffic through footpaths and vehicles accessing the river to extract water also resulted in additional removal in isolated areas.
Alien Species Invasion	1.5	1.5	Some invasive plants were observed, however they existed in low abundances and densities.
Water Quantity	1	5	Despite the extensive water abstraction activities, limited impacts on the vegetation were observed.
Water Quality	3	3	Moderate to high impacts by water quality in isolated areas from pipes used to drain effluent directly into the river and run-off from pipes from paved roads.
Erosion	4	4	Erosion was observed in isolated areas due to vehicles accessing the river for water abstraction purposes in addition to footpaths by human traffic resulted in exposed and disturbed soils.

Table 3-54: Activation discharge measurements (m^3/s) for indicator species / guilds at the Nels River site (X22F NELS).

Indicator Species / Guild	Activation Discharge (m^3/s)		
	Average	Min	Max
Breonadia salicina	3.6	2.9	4.9
Melia azedarach	6.2	6.2	6.2
Syzygium cordatum	4.1	1.9	6.2

3.6.2.3.6.1.2 Crocodile River (X22F CROC)

The river is a single channelled with deep pools and shallow rapids farther upstream. Geomorphological features within the marginal (and in-stream) zone included bedrock outcroppings with coarse sands within the deep pools and a combination of gravel, cobbles, and some boulders within the shallow rapid habitats. The left bank consisted of steep banks dominated by compacted silts and sands while the right banks had more gradual gradients and consisted of silts, fine sands and coarse sands with bedrock outcroppings. The in-stream vegetation was dominated by the alien aquatic Eichhornia crassipes. The marginal zone was dominated by *Phragmites mauritianus, Commelina erecta, Ageratum conyzoides, Cyperus sexangularis, Cyperus dives* and *Ludwigia octovalis.* Impacts within this zone included water extraction activities from a nearby pumphouse, effluent discharges from an upstream sewerage treatment facility and large quantities of the invasive aquatic plant *Eichhornia crassipes* (Figure 3-32). The lower, upper and macro-channel bank zones were dominated by coarse sands, sands and fine sands to a lesser degree. The upper and macro-channel banks on the right bank were dominated by bedrock and boulder outcroppings with interspersed coarse sands and gravels. The vegetation within the lower zone was primarily dominated by grass cover with interspersed *Cyperus sexangularis, C. dives* and *Ludwigia octovalis* as the dominant species. The upper and macro-channel bank zones were dominated by a large woody component which consisted of a variety of species, including *Ficus sycamorus, Gymnosporia buxifolia, Philenoptera violaceae, Sclerocarya birrea, Combretum erythrophyllum, Ziziphus mucronata, Ricinus communis, Melia azedarach, Terminalia sericea* and *Albizia versicolor*. Other non-woody plants observed within these zones included *Ageratum conyzoides, Asparagus sp., Solanum incanum, Solanum mauritianum* and *Persicaria decipiens.* Impacts within the lower zone included pollution in the form of litter and low impacts by invasive plants. Impacts observed within the upper zone included low impacts by pollution in the form of litter, human footpaths, and some evidence of small open fires. The macro-channel bank zone was impacted by two-tracks from vehicles on both banks and a train track and pumphouse located on the right bank. Dominant invasive plants observed included *Ageratum conyzoides, Melia azedarach* and *Ricinus communis.*

The present ecological state has an overall PES score of 62.6% (category C, which is moderately modified from reference conditions; Table 3-55 outlines a summary of the PES ratings, score and ecological category of zones, and provides most notable reasons for the perturbation and Table 3-56 lists the intensity and extent of impacts). The activation discharge measurement for indicators is shown in Table 3-57 and these will be used to derive flow requirements (base and flood) for the vegetation component of the site.

Figure 3-32: Site photographs (left; looking US-top and downstream-bottom) and an indication of site placement on satellite imagery (right; Bing ©) for the Crocodile River (X22F CROC).

Table 3-55: PES score and category with the main reasons for the score for the Crocodile River (X22F CROC).

LEVEL 4 ASSESSMENT	**Crocodile River (X22F CROC)**					**07 November 2022**
Riparian Vegetation EC Metric Group	**Calculated Rating**	**Weighted Rating**	**Confidence**	**Rank**	**Weight**	**Notes:**
Macro channel valley	64.6	15.5	3.6	1.0	24.0	Weighted according to extent
Macro channel bank	62.0	47.1	3.8	2.0	76.0	Weighted according to extent
LEVEL 4 VEGRAI (%)						62.6
VEGRAI Ecological Category						**C**
AVERAGE CONFIDENCE						3.7
	Sub-zone					

LEVEL 4 ASSESSMENT	Crocodile River (X22F CROC)					07 November 2022
Riparian Vegetation EC Metric Group	**Calculated Rating**	**Weighted Rating**	**Confidence**	**Rank**	**Weight**	**Notes:**
	Macro channel valley			**Macro channel bank**		
VEGRAI % (Zone)	64.6			62.0		
EC (Zone)	**C**			**C/D**		
Confidence (Zone)	3.6			3.8		
Main cause of PES:						
Very low densities of woodies in marginal zones. Some woody exotics but very few. Reeds very abundant and dense in some areas, likely due to effluent input from upstream sewerage treatment facility. Quite a few aliens, especially in the water (hyacinth) which were a dense mat in some sheltered areas. Also, a moderate amount of non-woody aliens. Higher densities of woody aliens (*M. azedarach and Rucinus* were prolific in places) but overall, not such a massive impact at the site. Moderate overall. Some removal due to roads, pumphouse and train track but only on right bank and small amount of roads on left bank. Some foot paths and open fires but with low impact. Reeds only limited to marginal and lower zones.						

Table 3-56: Intensity and extent of impacts on riparian vegetation at the Crocodile River (X22F CROC).

IMPACTS	INTENSITY	EXTENT	NOTES
	Marginal zone		
Vegetation Removal	0.5	0.5	No observable signs of vegetation removal within the marginal zone.
Alien Species Invasion	4	3	High abundances of invasive aquatic (*Eichhornia crassipes*) in downstream areas. Some invasive plants along the margins of the river however these existed in low densities and abundances.
Water Quantity	0.5	0.5	No observed sign of alterations to water quantity.
Water Quality	3	5	Upstream effluent discharges from Kanyamazane sewerage treatment facility resulted in reduced water quality. These impacts were observed through the high densities of E. crassipes which took advantage of the increased nutrient levels. Foul odour in isolated, low velocity marginal areas and physical pollution in the rivers also indicated compromised water quality.
Erosion	0.5	0.5	No observed sign of erosion by anthropogenic influence within this zone.
	Non-marginal (incl. Flood bench, MCB)		
Vegetation Removal	3.5	2.5	Removal of vegetation in the upper and macro-channel bank zones due to vehicle tracks, pumphouse and train tracks.
Alien Species Invasion	2.5	2.5	Some invasive plants were observed within the lower, upper and macro-channel bank zones, however these existed in low to moderate abundances and densities.
Water Quantity	0.5	0.5	No observed impact on environment by water quantity alterations.
Water Quality	0.5	0.5	No observed impact on environment by water quality alterations.
Erosion	1.5	1.5	Some erosion observed due to vehicle tracks however the impacts were limited to isolated areas and grasses had established in most areas which provided soil anchorage.

Table 3-57: Activation discharge measurements (m³/s) for indicator species / guilds at the Crocodile River (X22F CROC).

Indicator Species / Guild	Activation Discharge (m³/s)		
	Average	Min	Max
Melia azedarach	40.9	34.5	44.3
Ageratum conyzoides	11.5	10.8	11.9
Albizia versicolor	30.9	30.9	30.9
Albizia versicolour	112.7	112.7	112.7
Breonadia salicina	12.3	11.9	13.1
Celtis africana	53.8	50.8	55.3
Combretum erythrophyllum	103.4	103.4	103.4
Commelina erecta	10.4	6.0	18.3
Cyperus denudatus	10.8	10.8	10.8
Cyperus dives	18.3	18.3	18.3
Eichhornia crassipes	5.6	3.0	8.7
Ficus sycamorus	72.4	72.4	72.4
Gymnosporia buxifolia	122.9	103.4	129.1
Ischaemum fasciculatum	9.7	8.7	10.8
Ludwigia octovalvis	12.0	6.0	18.3
Persicaria decipiens	15.4	9.7	21.1
Philenoptera violacea	127.4	125.7	129.1
Phragmites mauritianus	27.6	24.2	32.7
Phyllanthus reticulatus	80.4	75.0	83.1
Sclerocarya birrea	112.7	112.7	112.7
Tithonia diversifolia	30.6	27.4	32.7
Verbena bonariensis	25.8	25.8	25.8

3.6.2.3.6.1.3 Elands at Nsinini (X21K ELANDS)

The Elands River at Nsinini was a single channel at the location of the site, however was also multi-channelled farther upstream with vegetated in-stream bars which consisted of a combination of coarse sands, gravels and cobbles. The site was primarily dominated by gravels and cobbles with interspersed coarse sands and some scattered boulders. The in-stream substrates consisted of coarse sands, gravels and cobbles with some exposed bedrock (Figure 3-33). The vegetation compositions differed quite significantly along left and right banks. The left bank consisted of heavily vegetated woody trees that were overhanging the water in many sections while the right bank consisted of grasses and herbs with a small proportion of scattered trees. The left bank consisted of a steep gradient while the right bank consisted of a low to moderate gradient from the water's edge. Dominant species within this zone included *Phytolacca dioica, Amaranthus sp. Verbena bonariensis, Combretum erythrophyllum, Salix mucronata, Phragmites mauritianus, Phragmites australis, Sesbania punicea* and *Persicaria longiseta*. Impacts observed within this zone included hydraulic disturbances by a low bridge which resulted in deep pools developing upstream of the bridge.

The lower zone was dominated by gravels, cobbles and coarse sands to a lesser degree. The upper and macro-channel bank zones were dominated by finer substrates interspersed with coarse sands. Once again, there were distinct differences between the left and right banks where the left bank was dominated by forestry activities that extended from transition with the lower and upper zone to many kilometres laterally and longitudinally from the river. The plantation consisted of a combination of

Pinus sp. and Eucalyptus sp. The right bank was dominated by herbaceous plants in the lower zone and grasses with scattered trees and shrubs in the upper and macro-channel bank zones. Dominant species within these zones *included Phytolacca dioica, Acacia mearnsii, Vachellia karoo, Solanum mauritianum, Solanum incanum, diospyros lycioides, Combretum erythrophyllum, Pseudognaphalium luteo-album, Ipomoea purpurea, Sesbania punicea, Solanum sisymbrifolium, Senecio inaequidens* and *Melilotus albus*. Impacts affecting these zones included hydraulic influences which resulted in erosional action in selected areas and intensive, removal and erosion due to heavily used dirt tracks from residents and forestry vehicles and extensive forestry activities on the left bank of the river that extended from the upper zone.

The present ecological state has an overall PES score of 50.2% (category D, which is largely modified from reference conditions; Table 3-58 outlines a summary of the PES ratings, score and ecological category of zones, and provides most notable reasons for the perturbation and Table 3-59 lists the intensity and extent of impacts). The activation discharge measurement for indicators is shown in Table 3-60 and these will be used to derive flow requirements (base and flood) for the vegetation component of the site.

Figure 3-33: Site photographs (left; looking US-top and downstream-bottom) and an indication of site placement on satellite imagery (right; Bing ©) for the Elands River (X21K ELANDS).

Table 3-58: PES score and category with the main reasons for the score for the Elands River (X21K ELANDS).

LEVEL 4 ASSESSMENT	Elands at Nsinini (X21K ELANDS)					08 November 2022
Riparian Vegetation EC Metric Group	**Calculated Rating**	**Weighted Rating**	**Confidence**	**Rank**	**Weight**	**Notes:**
Macro channel valley	69.2	15.4	3.4	1.0	22.2	Weighted according to extent
Macro channel bank	44.8	34.9	3.7	2.0	77.8	Weighted according to extent
LEVEL 4 VEGRAI (%)						50.2
VEGRAI Ecological Category						D
AVERAGE CONFIDENCE						3.6

	Sub-zone	
	Macro channel valley	**Macro channel bank**
VEGRAI % (Zone)	69.2	44.8
EC (Zone)	**C**	**D**
Confidence (Zone)	3.4	3.7

Main cause of PES:

Some woody aliens, high densities of non-woody aliens. Also, low bridge affected water quantities and left to erosion in places which affected mostly the non-woody plants. Forestry on the left bank was the major impactor to all plants as well as high non-woody densities of small herbs which were also present in relatively high abundances. Additionally, a well-used road caused erosion and removal. I would agree with a D score as the right side of the bank was in relatively good condition except for the herbaceous invasives.

Table 3-59: Intensity and extent of impacts on riparian vegetation at the Elands River (X21K ELANDS).

IMPACTS	INTENSITY	EXTENT	NOTES
	Marginal zone		
Vegetation Removal	0.5	0.5	Minimal observed impact of vegetation removal within this zone.
Alien Species Invasion	2	2	Some invasive plants observed within this zone, however they were observed in low abundances.
Water Quantity	3.5	3.5	Local alterations to water quantity due to low bridge upstream of site which resulted in water backing-up in upstream areas, resulting in unnatural deep, slow-flowing pools.
Water Quality	0.5	0.5	No observed impact by water quality.
Erosion	2.5	2.5	Some erosion observed as a result of low bridge and resultant hydraulic disturbances. In addition to the bridge, affects from heavily utilised dirt track's influence extended into marginal zone at bridge crossing.
	Non-marginal (incl. Flood bench, MCB)		

IMPACTS	INTENSITY	EXTENT	NOTES
Vegetation Removal	4.5	4	Removal of vegetation intensive especially on the left bank due to Pinus and Eucalyptus plantations. In addition to the plantations, removal was also evident due to heavily utilised dirt tracks due to resident and forestry vehicle traffic.
Alien Species Invasion	4.5	4	High abundances and species densities of invasive plants at the site. Plantations were dominant on the left bank and invasive herbaceous species in high species densities and abundances on the right bank, specifically within the lower zone and transitions to upper zones. Some woody invasive were present on the right bank however these existed in low abundances.
Water Quantity	0.5	5	No observable evidence of water quantity alterations.
Water Quality	0.5	5	No observable evidence of water quality alterations.
Erosion	3.5	2	Moderate to high erosion in isolated areas due to heavily utilised dirt tracks and influence from low bridge.

Table 3-60:. Activation discharge measurements (m^3/s) for indicator species / guilds at the Elands River site (X21K ELANDS).

Indicator Species / Guild	Activation Discharge (m^3/s)		
	Average	Min	Max
Argemone ochroleuca	4.6	3.4	4.8
Combretum erythrophyllum	5.6	2.7	7.6
Diospyros lycioides	7.5	5.4	9.7
Diospyros whyteana	9.3	9.3	9.3
Eucalyptus glandis	9.7	9.7	9.7
Heliochrysum sp.	3.2	3.2	3.2
Heliotropium amplexicaule	9.5	9.0	9.7
Hyparrhenia hirta	5.1	4.8	5.4
Lippia javanica	5.7	5.4	6.0
Melinis repens	5.4	5.4	5.4
Schkuhria pinnata	4.9	4.8	5.1
Searsia chirindensis	7.3	7.3	7.3
Solanum incanum	7.8	7.6	7.9
Solanum mauritianum	5.1	4.8	5.4

3.6.2.3.6.1.4 Elands at SAPPI (X21E ELANDS)

Local geomorphology at the Elands River site, near SAPPI could be described as a single channel dominated by in-stream gravels, cobbles and some boulders with little to no finer substrates due to high velocity flows. Marginal substrates that were sheltered by dense stands of *Arundo donax* and *Phragmites mauritianus* consisted of silts, fine sands and sands with some coarse sands interspersed (Figure 3-34). Dominant riparian vegetation within this zone were almost exclusively limited to dense stands of *A. donax* and *P. mauritianus* with some woody *Salix mucronata* interspersed in isolated pockets. Impacts experienced within this zone included high densities of the invasive *A. donax* which competed for space with the indigenous *P. mauritianus*.

Geomorphological features within the lower zone could be described as finer substrates such as silts, fine sands and sands with some interspersed coarse sands. The upper zone consisted of mainly sands, coarse sands and some fine gravels. The upper zone consisted of gravels and coarse sands with some sands and finally the macro-channel bank zones (especially on the right bank) consisted of interspersed bedrock and boulder outcroppings with gravels, cobbles and coarse sands. The riparian vegetation differed considerably from left to right bank. The lower zone on the left bank consisted of a dominant herbaceous layer with scattered trees and shrubs, most of which consisted of native plant species and the upper and macro-channel bank consisted of a dense stand of trees at the sites and downstream of the sites and the upstream areas consisted of open grassland-dominated areas with scattered large trees (mostly *Vachellia* species). The right bank consisted of a large herbaceous component in the lower zone with few scattered trees. The upper and macro-channel bank zones on the right bank (at the site and upstream of the site) consisted a herbaceous-dominated component with few scattered trees while farther downstream consisted of a dense stand of Pinus plantation. The undergrowth of the Pinus plantation included some indigenous and invasive plant species. Dominant species within these zones included *Verbena bonariensis, Lantana camara, Bidens pilosa, Solanum mauritianum, Arundo donax, Phragmites mauritianus, Senecio inaequidens, Tecoma stans, Solanum pseudocapsicum, Asparagus sp., Momordica charantia, Melis repens, Pseudognaphalium luteoalbum, Richardia brasiliensis, Oenothera rosea, Centella asiatica, Imperata cylindrica, Commelina erecta, Heliotropium amplexicaule, Rumex crispus, Salix mucronata, Lippia javanica, Sida rhombifolia, Momordica balsamina, Commelina africana, Physalis peruviana, Eragrostis sp., Cliffortia strobilifera, Ranunculus multifidus, Pulicaria scabra, Lobelia flaccida, Cyperus denudatus, Passiflora subpeltata and Thunbergia alata.* Observed impacts within this zone included *Pinus* plantation that resulted in complete transformation of habitat and species compositions within certain sections of the site, high densities of invasive herbaceous, reed and shrub species and erosional and removal of plants for dirt tracks that extended the lower, upper and macro-channel bank zones. Dominant invasive plants observed at the site included *Verbena bonariensis, Lantana camara, Bidens pilosa, Solanum mauritianum, Tecoma stans, Momordica charantia, Richardia brasiliensis, Oenothera rosea, Centella asiatica, Arundo donax, Sida rhombifolia, Passiflora subpeltata, Solanum pseudocapsicum* and *Thunbergia alata.*

The present ecological state has an overall PES score of 44.0% (category D, which is largely modified from reference conditions; Table 3-61 outlines a summary of the PES ratings, score and ecological category of zones, and provides most notable reasons for the perturbation and

Table 3-62 lists the intensity and extent of impacts). The activation discharge measurement for indicators along 3 different transects is shown in Table 3-63, Table 3-64 and

Table 3-65, and these will be used to derive flow requirements (base and flood) for the vegetation component of the site.

Figure 3-34: Site photographs (left; looking US-top and downstream-bottom) and an indication of site placement on satellite imagery (right; Bing ©) for the Elands River (X21E ELANDS).

Table 3-61: PES score and category with the main reasons for the score for the Elands River (X21E ELANDS).

LEVEL 4 ASSESSMENT	Elands at SAPPI (X21E ELANDS)					09 November 2022
Riparian Vegetation EC Metric Group	**Calculated Rating**	**Weighted Rating**	**Confidence**	**Rank**	**Weight**	**Notes:**
Macro channel valley	42.3	6.9	3.3	1.0	16.3	Weighted according to extent
Macro channel bank	44.3	37.1	3.5	2.0	83.7	Weighted according to extent
LEVEL 4 VEGRAI (%)						44.0
VEGRAI Ecological Category						**D**
AVERAGE CONFIDENCE						3.4

	Sub-zone	
	Macro channel valley	**Macro channel bank**
VEGRAI % (Zone)	42.3	44.3
EC (Zone)	**D**	**D**
Confidence (Zone)	3.3	3.5

Main cause of PES:

No impact observed on woodies in the marginal – only *Salix mucronata* was seen here and in healthy densities. Intense invasive of *Arundo donax* which was mostly out-competing *P. mauritianus*. Some alien herbs seen in this zone, but their impacts were insignificant as in such low densities. Pine plantations on downstream reaches of the right bank affected plants. Also, there were quite a few non-woody herbs in other areas, but I'd say it was a low to moderate invasion.

Table 3-62: Intensity and extent of impacts on riparian vegetation at the Elands River (X21E ELANDS).

IMPACTS	INTENSITY	EXTENT	NOTES
	Marginal zone		
Vegetation Removal	0.5	0.5	No observed removal of vegetation within this zone.
Alien Species Invasion	4.5	4	Dense stands of invasive *Arundo donax* that competed for habitat with the indigenous reed *Phragmites mauritianus*.
Water Quantity	0.5	5	No observed disturbance by water quantity within this zone.
Water Quality	0.5	5	No observed disturbance by water quality within this zone.
Erosion	0.5	0.5	No observed disturbance by erosion within this zone.
	Non-marginal (incl. Flood bench, MCB)		
Vegetation Removal	4	3.5	Removal within selected areas due to plantations that completed transformed specific areas at the site however this was limited to the downstream areas on the right bank. Removal was also evident due to dirt tracks that extended into the lower, upper and macro-channel bank zones also on the right bank only. There was no evidence of removal on the left bank at the site except for farther upstream nearby a bridge where the habitat had been altered in a small area around the immediate vicinity of the bridge.
Alien Species Invasion	4.5	4	High densities of herbaceous species, reeds and woody Pinus species present at the site. Overall the site was heavily impacted by invasive plants with the greatest impact observed within the plantations where even the undergrowth consisted of majority invasive species (Momordica and Lantana camara dominating this area).
Water Quantity	0.5	5	No observed disturbance by water quantity within these zones.
Water Quality	0.5	5	No observed disturbance by water quality within these zones.
Erosion	3	2	Erosion was evident in selected areas where dirt tracks were utilised and maintained by forestry trucks.

Table 3-63: Activation discharge measurements (m^3/s) for indicator species / guilds at the Elands River along cross-section 1 (X21E ELANDS).

Indicator Species / Guild	Activation Discharge (m^3/s)		
	Average	Min	Max
Ageratum conyzoides	8.5	8.5	8.5
Arundo donax	2.1	0.5	5.1
Asparagus sp.	24.3	14.1	34.5
Centella asiatica	52.2	48.4	53.4
Commelina erecta	3.0	1.0	5.1
Cyperus denudatus	7.4	6.1	9.8
Eragrostis sp.	36.8	20.7	48.4
Heliotropium amplexicaule	20.5	14.1	24.4

Indicator Species / Guild	Activation Discharge (m³/s)		
	Average	Min	Max
Hyparrhenia hirta	140.5	96.9	169.2
Imperata cylindrica	24.2	8.5	48.4
Lantana camara	133.1	48.4	161.3
Lobelia flaccida	11.9	9.8	14.1
Melia azedarach	31.4	28.3	34.5
Persicaria lapathifolia	5.1	5.1	5.1
Phragmites mauritianus	12.8	0.5	34.5
Pseudognaphalium luteoalbum	8.5	8.5	8.5
Pulicaria scabra	9.6	5.1	14.1
Ranunculus multifidus	6.1	6.1	6.1
Richardia brasiliensis	122.8	84.3	161.3
Salix mucronata	2.4	2.4	2.4
Solanum incanum	50.9	48.4	53.4
Vachellia sieberiana	20.5	14.1	24.4
Verbena bonariensis	12.9	6.1	53.4

Table 3-64: Activation discharge measurements (m³/s) for indicator species / guilds at the Elands River along cross-section 2 (X21E ELANDS).

Indicator Species / Guild	Activation Discharge (m³/s)		
	Average	Min	Max
Arundo donax	5.1	0.9	10.6
Asparagus sp.	78.9	10.6	152.4
Centella asiatica	76.9	12.3	94.6
Cliffortia strobilifera	10.9	5.1	12.3
Combretum erythrophyllum	19.1	16.0	22.2
Commelina erecta	6.9	3.0	12.3
Cyperus denudatus	12.3	12.3	12.3
Eragrostis sp.	71.2	56.2	86.2
Hyparrhenia hirta	181.7	20.0	318.1
Imperata cylindrica	52.3	10.6	90.4
Lantana camara	36.7	16.0	78.2
Melia azedarach	148.0	24.5	318.1
Melinis repens	37.5	37.5	37.5
Phragmites mauritianus	12.1	0.1	56.2
Pseudognaphalium luteoalbum	12.3	12.3	12.3
Ranunculus multifidus	12.3	12.3	12.3
Richardia brasiliensis	136.8	136.8	136.8
Rumex crispus	9.9	9.1	10.6
Solanum incanum	83.3	78.2	94.6

Indicator Species / Guild	Activation Discharge (m^3/s)		
	Average	Min	Max
Vachellia sp.	53.6	16.0	78.2
Verbena bonariensis	29.5	10.6	56.2

Table 3-65: Activation discharge measurements (m^3/s) for indicator species / guilds at the Elands River along cross-section 3 (X21E ELANDS).

Indicator Species / Guild	Activation Discharge (m^3/s)		
	Average	Min	Max
Ageratum conyzoides	12.9	12.9	12.9
Arundo donax	1.2	0.5	2.8
Asparagus sp.	43.1	22.7	63.6
Centella asiatica	11.2	7.7	15.9
Cliffortia strobilifera	6.3	2.8	11.5
Cyperus denudatus	8.4	5.5	12.9
Lantana camara	43.8	12.9	74.8
Lippia javanica	30.3	30.3	30.3
Momordica balsamina	70.0	50.6	74.8
Momordica charantia	66.3	66.3	66.3
Passiflora subpeltata	80.7	74.8	86.7
Phragmites mauritianus	9.1	0.5	66.3
Physalis peruviana	13.7	11.5	15.9
Pinus sp.	73.3	55.6	86.7
Pulicaria scabra	9.2	5.5	12.9
Ranunculus multifidus	8.9	5.5	12.9
Richardia brasiliensis	41.1	41.1	41.1
Salix mucronata	5.2	0.5	5.5
Sida rhombifolia	34.5	34.5	34.5
Solanum mauritianum	60.9	60.9	60.9
Tecoma stans	49.0	34.5	63.6
Thunbergia alata	80.7	74.8	86.7
Verbena bonariensis	9.8	5.5	34.5

3.6.2.3.6.1.5 Noordkaap River (X23B NOORDKAAP)

The Noordkaap River site could be described as a single channel with a densely vegetated reed component (*Phragmites mauritianus*; Figure 3-35). Other dominant species observed within this zone included *Pericardial decipiens, Salix mucronata, Cyperus albostriatus, Tecoma stans, Ranunculus baurii* and *Campuloclinium macrocephalum*. Impacts observed at the site included dumping by local communities withing the water and along the margins of the river, low impact by invasive plants and animal paths by local livestock (goats and cows).

The lower, upper and macro-channel bank zones were relatively uniform on the left bank with coarse sands dominating a grassland-dominated habitat with scattered large trees (*Vachellia nilotica* and *Vachellia sieberiana*). The grassland-dominated system is likely a modified states because of intensive and extensive livestock activities in the area as fenced-off areas on the right bank (also where local communities have established residences) contain a variety of herbaceous plants, shrubs and a wider variety of trees. The right bank could be described as a gradual gradient landscape with compact silts and fine sands likely due to heavy human traffic in the area from local communities living along the banks of the river with local agricultural activities, informal housing, and pollution in the form of litter and sewerage. Dominant species observed within these zones included *Vachellia nilotica, Vachellia sieberiana, Eragrostis superbe, Sida sp. Verbena bonariensis, Solanum incanum, Cynodon dactylon, Ranunculus multifidus, Argemone ochroleuca, Zinnia peruviana, Bidens pilosa, Cyperus sexangularis* and *Parthenium hysterophorus.* Observed dominant invasive plants at the site included *Campuloclinium macrocephalum, Tecoma stans, Verbena brasiliensis, Solanum sisymbrifolim, Argemone ochroleuca, Zinnia peruviana, Bidens pilosa* and *Parthenium hysterophorus.*

The present ecological state has an overall PES score of 48.3% (category D, which is largely modified from reference conditions; Table 3-66 outlines a summary of the PES ratings, score and ecological category of zones, and provides most notable reasons for the perturbation and Table 3-67 lists the intensity and extent of impacts). The activation discharge measurement for indicators is shown in Table 3-68 and these will be used to derive flow requirements (base and flood) for the vegetation component of the site.

Figure 3-35: Site photographs (left; looking US-top and downstream-bottom) and an indication of site placement on satellite imagery (right; Bing ©) for the Noordkaap River (X23B NOORDKAAP).

Table 3-66: PES score and category with the main reasons for the score for the Noordkaap River (X23B NOORDKAAP).

LEVEL 4 ASSESSMENT	Noordkaap River (X23B NOORDKAAP)					28 November 2022
Riparian Vegetation EC Metric Group	**Calculated Rating**	**Weighted Rating**	**Confidence**	**Rank**	**Weight**	**Notes:**
Macro channel valley	77.9	11.1	3.5	1.0	14.3	Weighted according to extent
Macro channel bank	43.3	37.1	3.8	2.0	85.7	Weighted according to extent
LEVEL 4 VEGRAI (%)						48.3
VEGRAI Ecological Category						D
AVERAGE CONFIDENCE						3.6
	Sub-zone					
	Macro channel valley			**Macro channel bank**		
VEGRAI % (Zone)	77.9			43.3		
EC (Zone)	**B/C**			**D**		
Confidence (Zone)	3.5			3.8		
Main cause of PES:						
Very dense reed cover with some non-woody and some woody. Litter and erosion were noted in some areas, both inside the water and within the marginal areas. Some woody aliens and some non-woody invasives, however in low densities compared to reeds. Dense reeds were only limited to marginal areas. Some woody and non-woody invasives but most significant impact was transformation of habitat by cattle and goats on the left bank and transformation, litter, trampling and rural infrastructure on the right bank. Overall, the upper and MCB was moderately to heavily transformed at this site due to human and livestock influence.						

Table 3-67: Intensity and extent of impacts on riparian vegetation at the Noordkaap River (X23B NOORDKAAP).

IMPACTS	INTENSITY	EXTENT	NOTES
	Marginal zone		
Vegetation Removal	1.5	0.5	Some removal of vegetation in selected areas due to dumping activities within the marginal zone as well as trampling by humans and livestock to access small dumpsite and to access the water.
Alien Species Invasion	1	1	Very low densities of invasive plants within this zone.
Water Quantity	0.5	5	No observed disturbances to water quantity at the site.
Water Quality	2.5	5	Water quality compromised at low to moderate degrees in isolated areas due to local dumping and effluent input from local communities living alongside the river.
Erosion	1	0.5	Small amounts of erosion due to local dumping and footpaths however these are relatively low impact.
	Non-marginal (incl. Flood bench, MCB)		
Vegetation Removal	4	5	Removal and alterations to species compositions on both banks. Left bank affected by intensive livestock activities which have altered vegetation compositions to maintain grasslands at unnatural densities and removed most shrubs and small trees. Only large trees remains (likely due to goats). Right bank affected by infrastructure (rural houses, footpaths, fences, etc.) by local communities living along the banks of the river.

IMPACTS	INTENSITY	EXTENT	NOTES
Alien Species Invasion	1.5	1	Low impact by invasive plants located in sparse abundances within these zones.
Water Quantity	0.5	5	No observed impact by alterations to water quantity.
Water Quality	2.5	1	Observed out-houses and litter likely results in run-off from local communities established on the right bank of the river.
Erosion	3	3	Erosion due to local communities footpaths, dirt tracks and rural infrastructure but limited only on the right bank. Evidence of livestock paths and resultant erosion on the left bank but most of the potential erosion on these paths are mitigated by sparse grass cover along paths.

Table 3-68: Activation discharge measurements (m³/s) for indicator species / guilds at the Noordkaap River (X23B NOORDKAAP).

Indicator Species / Guild	Activation Discharge (m³/s)		
	Average	Min	Max
Argemone ochroleuca	1.6	1.3	1.8
Commelina erecta	0.5	0.5	0.5
Cyperus albostriatus	1.9	0.7	2.8
Cyperus sexangularis	1.0	0.7	2.0
Nicotiana glauca	1.7	1.5	1.9
Parthenium hysterophorus	2.0	0.8	2.9
Persicaria decipiens	0.5	0.5	0.5
Phragmites mauritianus	1.0	0.5	2.6
Ranunculus baurii	0.7	0.0	0.9
Ranunculus multifidus	0.8	0.7	0.9
Schkuhria pinnata	2.0	1.2	2.6
Schoenoplectus brachyceras	0.7	0.7	0.7
Sida rhombifolia	2.0	1.8	2.2
Solanum incanum	2.6	1.3	5.9
Solanum sisymbriifolium	1.3	1.3	1.3
Striga asiatica	0.7	0.7	0.7
Vachellia nilotica	2.3	1.6	2.9
Verbena bonariensis	1.8	1.7	1.8
Ximenia caffra	4.3	4.3	4.3
Zinnia peruviana	2.8	2.8	2.8
Ziziphus mucronata	2.2	2.2	2.2

3.6.2.3.6.1.6 Suidkaap River (X23F SUIDKAAP)

The Suidkaap River was single channelled with a dense reed component which mostly comprised of the invasive species *Arundo donax* (Figure 3-36). The left bank consisted of a dense stand of *A. donax* with a grassy component and a gradual slope of mostly coarse sands with some sands and fine sands while the right bank consisted of a steep cut bank with exposed roots that seem to have been exposed to scouring along the banks, a large woody tree component at the site and a dense reed component further downstream of the site. Dominant species within this zone included *A. donax, Combretum erythrophyllum, Morus alba, Cyperus sexangularis* and some aquatic *Ceratophyllum demersum*. Impacts observed within this zone included scouring to the right bank and high densities of invasive species.

The lower, upper, and macro-channel banks of the left and right bank differed somewhat. The left banks consisted of *A. donax* extending into the lower and all the upper zones then followed by a tree component. The zones had a gradual to steep gradient dominated by coarse sands. The right bank consisted of a relatively flat area with a dense woody component in the lower zones, a depression containing *A. donax* and *Phragmites mauritianus* in what seemed to be a floodplain and then another tree component past the reeds. Impacts within these zones included some human infrastructure from a small picnic site where *Morus alba* had been planted for shade that had spread to the surrounding areas. The picnic site had eroded, exposed soils from human use and a the surrounding areas had a moderate to high invasive plant component. Dominant species within these zones included *A. donax, M. alba, P. mauritianus, C. erythrophyllum, Melia azedarach, Vachellia sp.* and *Ziziphus mucronata.* Dominant invasive plants identified at the site included *A. donax, M. alba, M. azedarach* and *Solanum sisymbrifolium*.

The present ecological state has an overall PES score of 49.0% (category D, which is largely modified from reference conditions. Table 3-69 outlines a summary of the PES ratings, score and ecological category of zones, and provides most notable reasons for the perturbation and Table 3-70 lists the intensity and extent of impacts). The activation discharge measurement for indicators is shown in Table 3-71 and these will be used to derive flow requirements (base and flood) for the vegetation component of the site.

Figure 3-36: Site photographs (left; looking across the channel) and an indication of site placement on satellite imagery (right; Bing ©) for the Suidkaap River (X23F SUIDKAAP).

Table 3-69: PES score and category with the main reasons for the score for the Suidkaap River (X23F SUIDKAAP).

LEVEL 4 ASSESSMENT	Suidkaap River (X23F SUIDKAAP)					10 November 2022
RIPARIAN VEGETATION EC METRIC GROUP	CALCULATED RATING	WEIGHTED RATING	CONFIDENCE	RANK	WEIGHT	Notes:
Macro channel valley	50.5	26.2	3.2	1.0	52.0	Weighted according to extent
Macro channel bank	47.4	22.7	3.2	2.0	48.0	Weighted according to extent
LEVEL 4 VEGRAI (%)						49.0
VEGRAI Ecological Category						D
AVERAGE CONFIDENCE						3.2

	Sub-zone	
	Macro channel valley	**Macro channel bank**
VEGRAI % (Zone)	50.5	47.4
EC (Zone)	**D**	**D**
Confidence (Zone)	3.2	3.2

Main cause of PES:

Grass planted directly on margin on left bank affected plant compositions, *Morus alba* competed with native woodies on the right bank and *A. donax* the only reed species present at most locations, especially on the left bank. Some herbaceous invasives also present. Picnic area cleared all native plants and planted Morus alba. M. alba and other invasives also competed with other native plants.

Table 3-70: Intensity and extent of impacts on riparian vegetation at the Suidkaap River X23F SUIDKAAP).

IMPACTS	INTENSITY	EXTENT	NOTES
	Marginal zone		
Vegetation Removal	3	3	Some removal of vegetation for artificially planted grasses along the margins of the river for public usage in association with the nearby picnic site.
Alien Species Invasion	4.5	4	High densities of invasive plants within this zone extending almost the entire zone of both reed components and some marginal woody invasives.
Water Quantity	1	5	Scouring of the right bank was evident however it is likely that this was due to recent heavy rains from natural events.
Water Quality	0.5	5	No observed evidence of water quality alterations within this zone.
Erosion	0.5	0.5	No observed disturbances by erosion noted within this zone.
	Non-marginal (incl. Flood bench, MCB)		
Vegetation Removal	3	1.5	Removal of a section of vegetation for the development of a small picnic site where indigenous vegetation was replaced by woody invasives Morus alba to provide a shaded area for the picnic area.

IMPACTS	INTENSITY	EXTENT	NOTES
Alien Species Invasion	4	4.5	High invasive species component within these zones.
Water Quantity	0.5	5	No observed disturbance by water quantity.
Water Quality	0.5	5	No observed disturbance by water quality.
Erosion	2.5	1.5	Some erosion observed within the small, isolated area of the picnic site however outside of that area erosional action seemed minimal.

Table 3-71: Activation discharge measurements (m^3/s) for indicator species / guilds at the Suidkaap River (X23F SUIDKAAP).

Indicator Species / Guild	Activation Discharge (m^3/s)		
	Average	Min	Max
Arundo donax	15.3	8.2	37.2
Combretum erythrophyllum	19.7	11.3	33.6
Cyperus sexangularis	9.7	9.7	9.7
Ehretia rigida	59.4	54.3	64.5
Flueggea virosa	54.3	54.3	54.3
Gymnosporia buxifolia	39.4	24.5	54.3
Lantana camara	26.7	26.7	26.7
Morus alba	12.1	12.1	12.1
Phragmites mauritianus	2.6	1.7	3.1
Solanum incanum	31.8	30.1	33.6
Vachellia sp.	33.6	33.6	33.6

3.6.2.3.6.1.7 Queens River at Barberton (X23E QUEENS)

The Queens River was a single channel with a dense reed component (*Phragmite mauritianus* and *Typha capensis*; Figure 3-37). The in-stream substrates were dominated by coarse sands with some bedrock outcroppings. Other species observed within this zone included *Lantana camara, Hibiscus sp., Combretum erythrophyllum, Commelina erecta, Pulicaria scabra, Melia azedarach, Megathyrsus maximus* and *Cyperus alternifolius*. The banks at the site differed somewhat – the left bank was dominated by the *P. mauritianus* and *T. capensis* while the right bank was dominated by small herbs and large woody trees. Impacts noted within this zone included some hydraulic influence from the downstream bridge column which would have affected hydraulic behaviour, however the effects seemed minor and pollution from upstream activities (town of Barberton) which likely resulted in increased nutrient levels, contributing to the dense reed component along the banks of the river.

The lower, upper, and macro-channel bank zones possessed relatively steep gradients, however, less so on the left bank where the reed cover extended into the lower and some of the upper zone. The substrates were predominantly sands, fine sands, and some coarse sands. A densely vegetated woody component existed in the upper zones with a large variety of herbaceous plants in the understory. Dominant species within this zone included *Annona senegalensis, Ziziphus mucronata, Tribulus terrestris, Euphorbia hirta, Cenchrus ciliaris, Schkuhria pinnata, Parthenium hysterophorus, Solanum incanum, Tridax procumbens, Campuloclinium macrocephalum, Eragrostis superba, Vachellia siberiana, Flueggea virosa, Morus alba, Verbea bonariensis* and *Lantana camara.* Dominant invasive plants observed at the site included *Parthenium hysterophorus , Campuloclinium macrocephalum, Morus alba, Lantana camara* and *Verbena bonariensis.*

The present ecological state has an overall PES score of 72.6% (category C, which is moderately modified from reference conditions; Table 3-72 outlines a summary of the PES ratings, score and ecological category of zones, and provides most notable reasons for the perturbation and Table 3-73 lists the intensity and extent of impacts). The activation discharge measurement for indicators is shown in Table 3-74 and these will be used to derive flow requirements (base and flood) for the vegetation component of the site.

Figure 3-37: Site photographs (left; looking US) and an indication of site placement on satellite imagery (right; Bing ©) for the Queens River (X23E QUEENS).

Table 3-72: PES score and category with the main reasons for the score for the Queens River (X23E QUEENS).

LEVEL 4 ASSESSMENT	Queens River at Barberton (X23E QUEENS)					30 November 2022
Riparian Vegetation EC Metric Group	**Calculated Rating**	**Weighted Rating**	**Confidence**	**Rank**	**Weight**	**Notes:**
Macro channel valley	62.4	12.5	3.3	1.0	20.0	Weighted according to extent
Macro channel bank	75.2	60.1	3.3	2.0	80.0	Weighted according to extent
LEVEL 4 VEGRAI (%)						72.6
VEGRAI Ecological Category						**C**
AVERAGE CONFIDENCE						3.3
	Sub-zone					
	Macro channel valley			**Macro channel bank**		
VEGRAI % (Zone)	62.4			75.2		
EC (Zone)	**C**			**C**		
Confidence (Zone)	3.3			3.3		
Main cause of PES:						
Some *Arundo donax* competing for resources with *P. mauritianus* and some non-woody invasives in this zone. Few woody plants and relatively low impact. Some non-woody invasive herbs competing with natives, *A. donax* amongst *P. mauritianus* and low densities of woody invasive. Evidence of footpaths in the area but low usage and mostly overgrown. Also, some litter however low impact and isolated to one area.						

Table 3-73: Intensity and extent of impacts on riparian vegetation at the Queens River (X23E QUEENS).

IMPACTS	INTENSITY	EXTENT	NOTES
	Marginal zone		
Vegetation Removal	0.5	0.5	No observed evidence of vegetation removal in this zone.
Alien Species Invasion	2	1	Some invasive plants were observed within this zone, however they existed in low densities.
Water Quantity	2	5	Some evidence of hydraulic influence from the downstream bridge, however the affects were low within this zone.
Water Quality	2	5	Further studies will likely be required to substantiate this claim, however upstream influences from the town of Barberton very likely have affected nutrient contents at the site which would have likely resulted in increased aerial cover percentage of the reed component within this zone.
Erosion	0.5	0.5	No observed influence of erosion within this zone.
	Non-marginal (incl. Flood bench, MCB, floodplain)		
Vegetation Removal	1.5	1	Some removal limited to the left bank only within the macro-channel bank of a residential building that replaced native vegetation with lawns however this is limited to a relatively small area.
Alien Species Invasion	2.5	2.5	Some invasive plants were observed at the site in low to moderate abundances however species densities were relatively high which would have affected native species via competition for space and resources.
Water Quantity	0.5	5	No observed influence by water quantity within these zones.
Water Quality	0.5	5	No observed influence by water quality within these zones.
Erosion	1	1	Minimal observed evidence of erosion within these zones. The area was well vegetated, and the soils minimally disturbed by human influence. Several small footpaths were evident, but most were already overgrown.

Table 3-74: Activation discharge measurements (m^3/s) for indicator species / guilds at the Queens River (X23E QUEENS).

Indicator Species / Guild	Activation Discharge (m^3/s)		
	Average	Min	Max
Acalypha villicaulis	8.4	3.2	13.1
Annona senegalensis	4.6	3.0	5.6
Asparagus densiflorus	13.1	13.1	13.1
Combretum erythrophyllum	5.0	4.6	5.3
Commelina erecta	4.2	0.4	11.8
Cyperus alternifolius	2.5	1.8	3.2
Cyperus dives	1.8	1.8	1.8
Lantana camara	13.7	13.1	14.4
Megathyrsus maximus	5.2	4.6	5.6

Indicator Species / Guild	Activation Discharge (m³/s)		
	Average	Min	Max
Melia azedarach	13.1	11.8	14.4
Phragmites mauritianus	1.8	0.4	3.2
Ranunculus multifidus	2.0	1.8	2.5
Saccharum officinarum	5.3	5.0	5.6
Solanum incanum	5.6	5.6	5.6
Typha capensis	2.3	1.8	3.0
Urochloa mosambicensis	7.9	5.3	11.8
Verbesina encelioides	2.9	1.8	4.6

3.6.2.3.6.1.8 Gladdespruit River (X11K GLADDESPRUIT)

The Gladdesprut River was a single channel consisting of a dense reed cover (*Phragmites mauritianus*) with scattered semi-aquatic and marginal herbs (*Rumex crispus, Commelina erecta, C. africana* and *Centella asiatica)* with sparsely scattered marginal trees (*Combretum erythrophyllum and Salix mucronata*; Figure 3-38). The geomorphology within the zone could be described as bedrock and boulders in-stream covered by a thin layer of coarse sands and silts, fine sands, and sands within the marginal zones. There were minimal impacts noted within this zone. The only notable impact was from that of a low bridge which likely affected in-stream substrate compositions and affected local hydraulics upstream and downstream of the structure.

The lower, upper and macro-channel banks geomorphologies were fairly consistent with fine gravels on course and fine sands with some interspersed cobbles. The vegetation within the lower zone could be described as heavily wooded while the upper and macro-channel bank zones were dominated by a grass layer with a high species density of herbaceous plants and some scattered woody trees (mostly *Vachellia* species). Dominant species at the site included *Eragrostis superbe, Richardia brasiliensis, Triumfetta sonderi, Lippia javanica, Pearsonia sessilifolia, Solanum sisymbrifolium, Crinum macowanii, Solanum incanum, Rumex crispus, Lantana camara, Solanum americanum, Ranunculus multifidus, Combretum erythrophyllum, Heliotropium ovalifolium, Bidens pilosa, Diospyros lycioides, Cyperus esculentus, Thunbergia sp., Cyperus cristatus, Imperata cylindrica, Ocimum obovatum, Hypoxis rigidula, Verbena bonariensis, Megathyrsus maximus, Vachellia karoo, Coccinia adoensis, Thunbergia atriplicifolia, Albuca virens, Hilliardiella elaeagnoides, Melia azedarach, Eragrostis capensis, Gomphrena celosioides, Acalypha villicaulis, Commelina erecta, Commelina africanum, Cucumis zeyheri, Asparagus densiflorus, Melinis repens, Oxalis obliquifolia, Sporobolus sp., Schkuhria pinnata, Paspalum sp., Parthenium hysterophorus* , *Centella asiatica* and *Salix mucronata.* Minimal impacts were observed within these zones – the limited impacts that were observed included some removal and erosion due to a nearby dirt track on both left and right banks and low densities of invasive plants. Invasive species that were observed at the site included *Richardia brasiliensis, Solanum sisymbrifolium, Lantana camara, Bidens pilosa, Verbena bonariensis, Melia azedarach, Gomphrena celosioides, Parthenium hysterophorus* and *Centella asiatica.*

The present ecological state has an overall PES score of 79.8% (category B/C, which is marginally modified from reference conditions; Table 3-75 outlines a summary of the PES ratings, score and ecological category of zones, and provides most notable reasons for the perturbation and Table 3-76 lists the intensity and extent of impacts). The activation discharge measurement for indicators is shown in Table 3-77 and these will be used to derive flow requirements (base and flood) for the vegetation component of the site.

Figure 3-38: Site photographs (left; looking across the channel) and an indication of site placement on satellite imagery (right; Bing ©) for the Gladdespruit River (X11K GLADDESPRUIT).

Table 3-75: PES score and category with the main reasons for the score for the Gladdespruit River (X11K GLADDESPRUIT).

LEVEL 4 ASSESSMENT	Gladdespruit River (X11K GLADDESPRUIT)					29 November 2022
Riparian Vegetation EC Metric Group	**Calculated Rating**	**Weighted Rating**	**Confidence**	**Rank**	**Weight**	**Notes:**
Macro channel valley	85.2	20.5	3.7	1.0	24.0	Weighted according to extent
Macro channel bank	78.1	59.4	4.0	2.0	76.0	Weighted according to extent
LEVEL 4 VEGRAI (%)						79.8
VEGRAI Ecological Category						**B/C**
AVERAGE CONFIDENCE						3.8
	Sub-zone					
	Macro channel valley			**Macro channel bank**		
VEGRAI % (Zone)	85.2			78.1		
EC (Zone)	**B**			**B/C**		
Confidence (Zone)	3.7			4.0		
Main cause of PES:						
Overall, the site was in quite good condition. Very high native species diversity (one of the longest species lists), low disturbances of any type. A small amount of litter and dirt tracks on both banks only. Especially very limited disturbances in marginal zones. Only noted disturbance was removal and erosion due to roads which ran parallel with both banks. Otherwise, minimal disturbances. Great species diversities and compositions.						

Table 3-76: Intensity and extent of impacts on riparian vegetation at the Gladdespruit River (X11K GLADDESPRUIT).

IMPACTS	INTENSITY	EXTENT	NOTES
	Marginal zone		
Vegetation Removal	0.5	0.5	No observed removal of vegetation within this zone.
Alien Species Invasion	1	1	Some invasive plants were observed within this zone however they were observed at low densities and low species abundances.
Water Quantity	0.5	5	No observed impact by water quantity alterations.
Water Quality	0.5	5	No observed impact by water quality alterations.
Erosion	0.5	0.5	No observed erosion by anthropogenic influence within this zone.
	Non-marginal (incl. Flood bench, MCB)		
Vegetation Removal	2	1	Some removal of vegetation for nearby dirt tracks but these were limited to specific areas and had a relatively low impact.
Alien Species Invasion	2	2	Some invasive plants were observed within this zone however they were observed at low densities and low species abundances.
Water Quantity	0.5	5	No observed impact by water quantity alterations.
Water Quality	0.5	5	No observed impact by water quality alterations.
Erosion	2	1	Low erosional impact due to nearby dirt tracks however the impact was low overall.

Table 3-77: Activation discharge measurements (m^3/s) for indicator species / guilds at the Gladdespruit River (X 11K GLADDESPRUIT).

Indicator Species / Guild	Activation Discharge (m^3/s)		
	Average	Min	Max
Acalypha villicaulis	4.6	3.8	5.7
Asparagus densiflorus	6.2	3.8	8.7
Bidens pilosa	3.0	3.0	3.0
Centella asiatica	4.5	4.5	4.5
Coccinia adoensis	3.2	3.2	3.2
Combretum erythrophyllum	3.5	2.9	4.1
Commelina africana	2.5	2.4	2.6
Cyperus esculentus	4.6	2.9	9.3
Fimbristylis dichotoma	4.5	4.5	4.5
Hilliardiella elaeagnoides	5.6	4.5	6.7
Imperata cylindrica	4.6	3.8	5.7
Lippia javanica	7.3	4.5	9.3
Megathyrsus maximus	5.8	4.1	7.4
Ocimum sp.	6.7	6.7	6.7
Oxalis obliquifolia	5.8	4.5	6.7
Parthenium hysterophorus	4.9	4.1	5.7
Paspalum sp.	8.9	8.5	9.3
Phragmites mauritianus	2.6	1.7	4.0

Indicator Species / Guild	Activation Discharge (m^3/s)		
	Average	Min	Max
Ranunculus multifidus	2.7	2.4	2.9
Rumex crispus	2.5	2.1	2.7
Schkuhria pinnata	4.5	3.3	5.7
Solanum incanum	6.0	4.1	9.3
Solanum sisymbriifolium	3.6	3.2	4.1
Sporobolus africanus	5.9	5.9	5.9
Triumfetta sonderi	8.7	8.7	8.7
Vachellia karoo	5.5	5.5	5.5

3.6.2.3.6.1.9 Kaap River at Honeybird (X23G KAAP)

The Kaap River at Honeybird was a single channel that was deeply incised bedrock-dominated system (Figure 3-39). The marginal zones were sparsely vegetated due to the substrates. Some specialized species persisted despite the harsh conditions. These included *Breonadia salicina, Ficus ingense, Ficus glumosa, Persicaria desipiens, Ludwigia octovalvis, Phragmites australis, P. mauritianus* and *Morella serrata*. No visible anthropogenically sourced impacts were observed within this zone.

The lower zone consisted of a steep gradient that was also primarily dominated by a bedrock component. The upper zone consisted of a more gradual gradients with bedrock underlying substrates overlain with fine sands, sands and coarse sands in some places with many bedrock outcroppings. The macro-channel bank possessed a gradual to steep gradient at places and dominant substrates were fine sands, sands and silts. These zones possessed a high diversity of indigenous plant species with both high abundances and diversities. Some invasive plants were observed but in low abundances and diversities. Some of the most dominant species observed at these sites included *Ludwigia octovalvis, F. glumosa, F. ingense, Combretum imberbe, Fleuggea virosa, Crinum macowanii, Bauhinia galpinii, Jasminum flaminense, Bridelia mollis, Peltophorum africanum, Megathyrsus maximus, Ficus albutifolia, B. salicina, Dichrostachys cineria* and *Sclerocarya birrea*. Impacts observed within this zone included the presence of invasive plants, despite the low densities that were observed at the site, some of the species have the potential to harm the ecology of an ecosystem if left unchecked. An additional impact observed was that of a dirt track utilised by residential vehicles and trucks which was moderately utilised. Invasive species were identified at the site, however they existed in low abundances. Some of the species included *Ricinus communis, Solanum mauritianum, Richardia brasiliensis, Tithonia diversifolia, Bidens piloa, Parthenium hysterophorus, Sesbania punicea* and *Ageratum conyzoides.*

The present ecological state has an overall PES score of 60.0% (category C/D, which is moderately to largely modified from reference conditions; Table 3-78 outlines a summary of the PES ratings, score and ecological category of zones, and provides most notable reasons for the perturbation and Table 3-79 lists the intensity and extent of impacts). The activation discharge measurement for indicators along 3 transects is shown in Table 3-80, Table 3-81 and Table 3-82, and these will be used to derive flow requirements (base and flood) for the vegetation component of the site.

Figure 3-39: Site photographs (left; looking US-top and downstream-bottom) and an indication of site placement on satellite imagery (right; Bing ©) for the Kaap River (X23G KAAP).

Table 3-78: PES score and category with the main reasons for the score for the Kaap River (X23G KAAP).

LEVEL 4 ASSESSMENT	Kaap River at Honeybird (X23G KAAP)					2022/11/11-12
Riparian Vegetation EC Metric Group	**Calculated Rating**	**Weighted Rating**	**Confidence**	**Rank**	**Weight**	**Notes:**
Macro channel valley	66.7	20.1	3.3	1.0	30.2	Weighted according to extent
Macro channel bank	57.1	39.9	3.5	2.0	69.8	Weighted according to extent
LEVEL 4 VEGRAI (%)						60.0
VEGRAI Ecological Category						**C/D**
AVERAGE CONFIDENCE						3.4
	Sub-zone					
	Macro channel valley			**Macro channel bank**		
VEGRAI % (Zone)	66.7			57.1		
EC (Zone)	**C**			**D**		
Confidence (Zone)	3.3			3.5		
Main cause of PES:						
Overall, the site was in quite good condition. There were low densities of invasive plants but some species that had the potential to become problematic. In the marginal zone the only disturbance was low densities of invasive herbs. Woody was most dominant due to substrate composition. Low to moderate invasive plants. Removal and erosion due to a heavily utilised dirt track.						

Table 3-79: Intensity and extent of impacts on riparian vegetation at the Kaap River (X23G KAAP).

IMPACTS	INTENSITY	EXTENT	NOTES
	Marginal zone		
Vegetation Removal	0.5	0.5	No observed removal of vegetation within this zone.
Alien Species Invasion	1.5	1	Some invasive plants were observed within this zone however the conditions were not favourable therefore they existed in very low abundances.
Water Quantity	0.5	5	No observed impact by water quantity.
Water Quality	0.5	5	No observed impact by water quality.
Erosion	0.5	5	No observed impact by erosion, likely due to the bedrock components.
	Non-marginal (incl. Flood bench, MCB)		
Vegetation Removal	1.5	1	Some vegetation removal limited to the moderately utilised dirt track at the site.
Alien Species Invasion	2	2	Some invasive plants were observed in low abundances however some of the species are known for their aggressive behaviour therefore if left unchecked have the potential to significantly alter the environment.
Water Quantity	0.5	5	No observed impact by water quantity.
Water Quality	0.5	5	No observed impact by water quality.
Erosion	1.5	1	Some erosion due to the presence of the dirt track and the fact that the track was regularly used by large trucks which affected sediment movement and erosion potential.

Table 3-80: Activation discharge measurements (m^3/s) for indicator species / guilds at the Kaap River at Honeybird cross-section 1 (X23G KAAP).

Indicator Species / Guild	Activation Discharge (m^3/s)		
	Average	Min	Max
Ageratum conyzoides	44.8	44.8	44.8
Arundo donax	35.8	28.2	43.4
Breonadia salicina	28.2	28.2	28.2
Breonadia salicina	22.2	12.4	28.2
Cyperus sexangularis	20.8	12.4	35.5
Euphorbia cyathophora	45.4	39.3	49.0
Ficus sycamorus	53.5	52.0	55.0
Heart-shaped creeper	46.5	35.5	55.0
Ipomoea sp.	31.3	27.1	35.5
Jasminum fluminense	26.0	26.0	26.0
Melia azedarach	49.0	49.0	49.0
Phragmites australis	45.8	44.8	49.0
Phragmites mauritianus	14.8	12.4	17.7
Phragmites mauritianus	35.8	28.2	43.4
Pinus sp.	15.0	15.0	15.0
Pulicaria scabra	32.2	17.7	44.8
Senegalia nigrescens	43.4	43.4	43.4

Indicator Species / Guild	Activation Discharge (m^3/s)		
	Average	Min	Max
Sesbania punicea	30.3	15.9	44.8
Solanum mauritianum	28.2	28.2	28.2
Tithonia diversifolia	49.0	49.0	49.0

Table 3-81: Activation discharge measurements (m^3/s) for indicator species / guilds at the Kaap River at Honeybird cross-section 2 (X23G KAAP).

Indicator Species / Guild	Activation Discharge (m^3/s)		
	Average	Min	Max
Albizia versicolor	22.2	22.2	22.2
Bidens pilosa	34.6	34.6	34.6
Breonadia salicina	26.0	12.3	36.6
Chamaecrista mimosoides	33.7	33.7	33.7
Cyperus sexangularis	30.2	27.3	34.6
Euphorbia cyathophora	38.0	33.7	41.5
Ficus glumosa	41.5	41.5	41.5
Gymnosporia buxifolia	24.3	22.2	26.5
Ipomea sp.	33.1	26.5	39.5
Jasminum fluminense	35.3	33.7	37.5
Megathyrsus maximus	27.3	26.5	28.2
Melia azedarach	34.4	26.5	41.5
Round-heart creeper	41.5	41.5	41.5
Serrated woody, spiral	31.2	26.5	41.5
Sesbania punicea	34.6	34.6	34.6
Tithonia diversifolia	39.1	31.8	41.5

Table 3-82: Activation discharge measurements (m^3/s) for indicator species / guilds at the Kaap River at Honeybird cross-section 3 (X23G KAAP).

Indicator Species / Guild	Activation Discharge (m^3/s)		
	Average	Min	Max
Bauhinia galpinii	36.5	36.5	36.5
Bidens pilosa	3.4	3.4	3.4
Breonadia salicina	14.8	3.4	26.1
Bridelia mollis	12.3	12.3	12.3
Combretum imberbe	21.8	21.8	21.8
Crinum macowanii	37.3	37.3	37.3
Dichrostachys cinerea	25.4	14.6	33.2
Ficus glumosa	30.0	30.0	30.0

Indicator Species / Guild	Activation Discharge (m^3/s)		
	Average	Min	Max
Ficus ingense	19.7	19.7	19.7
Flueggea virosa	31.5	31.5	31.5
Jasminum fluminense	10.8	9.5	12.3
Melia azedarach	10.6	10.6	10.6
Morella serrata	2.7	0.8	6.6
Peltophorum africanum	23.9	23.9	23.9
Senegalia nigrescens	12.3	12.3	12.3
Senegalia sp.	10.6	10.6	10.6

3.6.2.3.6.1.10 Sabie River at Merry Pebbles (X31A SABIE)

The Sabie River at Merry Pebbles was located downstream of a high bridge and a low bridge that resulted in a deep, slow pool upstream of the bridge and reduced velocities downstream of the bridge. The resultant effects of the bridge affected sediment depositions with finer substrates upstream of the low bridge (silts, fine sands, sands and coarse sands) and almost exclusively gravels and cobbles downstream of the bridge within the in-stream environment (Figure 3-40). The marginal zones consisted of silts and fine sands with some coarse sand and sands in some areas. The left bank was heavily modified due to the invasive tree that looked to have been propagated for aesthetic appeal many years back (*Quercus acutissima*). The large trees seemed to have altered the soil composition or outcompeted native species for sunlight as very few species (other than seedlings and saplings of *Q. acutissima* were able to grow within a few metres of any tree. The right bank however consisted of a higher diversity of native plants than those located on the left bank. The right bank also differed morphologically from the left in that it consisted of a steep bank (approximately 2 m in places) while the left bank consisted of a very gradual gradient in comparison. This is likely due to hydraulic influence of the sharp bend downstream of the site. Dominant species within this zone included *Centella asiatica, Q. acutissima (primarily sapplings and juvenile plants), Desmodium sp., Nasturtium officinale* and *Impatiens hochstetteri.*

The left and right banks of the river differed significantly due to the *Q. acutissima* plantation. The lower, upper and macro-channel banks on the left bank were almost completely devoid of anything except *Q. acutissima* while the right bank consisted of a relatively high species diversity in comparison. Substrates were similar on both banks with silts and fine sands dominating, overlain with fine gravels in some areas. Dominant species within these zones included *Ranunculus multifidus, Cyperus alternifolius, Verbena sp., Pulicaria scabra, Callistemon viminalis, Nasturtium officinale, Colocasia esculenta, Sambucus nigra, Impatiens hochstetteri, Solanum pseudocapsicum* and *Tradescantia fluminensis*. The site had a high species diversity and high abundances of invasive plants. These included *C. asiatica, Desmodium sp., Verbena sp., C. viminalis, N. officinale, C. esculenta, S. nigra* and *T. fluminensis.*

The present ecological state has an overall PES score of 48.5% (category D, which is largely modified from reference conditions; Table 3-83 outlines a summary of the PES ratings, score and ecological category of zones, and provides most notable reasons for the perturbation and Table 3-84 lists the intensity and extent of impacts). The activation discharge measurement for indicators is shown in Table 3-85 and these will be used to derive flow requirements (base and flood) for the vegetation component of the site.

Figure 3-40: Site photographs (left; looking US-top and downstream-bottom) and an indication of site placement on satellite imagery (right; Bing ©) for the Sabie River (X31A SABIE).

Table 3-83: PES score and category with the main reasons for the score for the Sabie River (X31A SABIE).

LEVEL 4 ASSESSMENT	Sabie River at Merry Pebbles (X31A SABIE)					14 November 2022
RIPARIAN VEGETATION EC METRIC GROUP	CALCULATED RATING	WEIGHTED RATING	CONFIDENCE	RANK	WEIGHT	Notes:
Macro channel valley	61.9	16.3	3.3	1.0	26.3	Weighted according to extent
Macro channel bank	43.7	32.2	3.3	2.0	73.7	Weighted according to extent
LEVEL 4 VEGRAI (%)						48.5
VEGRAI Ecological Category						D
AVERAGE CONFIDENCE						3.3
	Sub-zone					
	Macro channel valley			**Macro channel bank**		
VEGRAI % (Zone)	61.9			43.7		
EC (Zone)	**C/D**			**D**		
Confidence (Zone)	3.3			3.3		
Main cause of PES:						
Reeds only growing further away from *Q. acuttisima*, indicating the soils might not be suitable anymore closer to them. Most were on the opposite bank to the large trees. Some invasive non-woodies. Reeds observed only on opposite bank (in non-marginal zones) from *Q.acuttisima*. Plant structure almost completely transformed on the left bank and some woody and non-woody invasives on the right bank. Overall site is moderately to highly impacted.						

Table 3-84: Intensity and extent of impacts on riparian vegetation at the Sabie River (X31A SABIE).

IMPACTS	INTENSITY	EXTENT	NOTES
	Marginal zone		
Vegetation Removal	3	2	Small amount of removal for the placement of a road and bridge, however large amounts of removal for the propagation of *Q. acutissima*, however these effects were more prominent within the non-marginal zones.
Alien Species Invasion	3	3	High degrees of invasive plants in comparison to present native species.
Water Quantity	3.5	5	Water quantity altered both upstream and downstream of low bridge where deep pools formed unnaturally due to hydraulic influence and scouring and reduced flows below the bridge.
Water Quality	2.5	5	Upstream effluent input from a sewerage treatment works within the town of Sabie affected environment. Evident through the high levels of in-stream algae.
Erosion	3	4	Erosion and sediment deposition alterations due to low bridge with moderately to high impact on local hydraulic conditions.
	Non-marginal (incl. Flood bench, MCB)		
Vegetation Removal	4	3.5	Removal of native species for the propagation of large stands of *Q. acutissima* as well as some removal for moderately utilised roads to access surrounding areas and an administrative building in the upper and macro-channel bank upstream of the site on the left bank.
Alien Species Invasion	4.5	3.5	High impact of invasive plants within these zones however the left bank was impacted most severely with the right bank consisting of herbaceous and woody invasives amongst indigenous vegetation but in high abundances.
Water Quantity	2	5	Some impact on water quantity as it is visibly evident that water levels are restricted due to upstream low bridge.
Water Quality	0.5	5	No apparent impact of water quality within these zones.
Erosion	4	2	Erosion potential high on the left bank where bare, exposed soils exists under *Q. acutissima* plantations which seem to grow to the exclusion of any other species. It is likely that they excrete an enzyme into the soils which affect the soil chemistry to remove any potential competition.

Table 3-85: Activation discharge measurements (m^3/s) for indicator species / guilds at the Sabie River (X31A SABIE).

Indicator Species / Guild	Activation Discharge (m^3/s)		
	Average	Min	Max
Cyperus alternifolius	16.2	2.7	28.5
Melaleuca viminalis	8.9	8.9	8.9
Quercus acutissima	13.9	4.5	32.1
Schoenoplectus sp.	2.7	2.7	2.7
Solanum pseudocapsicum	26.8	26.8	26.8
Verbena bonariensis	11.4	11.4	11.4

3.6.2.3.6.1.11 Sabie River at Skurukwane (X31M SABIE)

The Sabie River at Skurukwane within the Kruger National Park could be described as multiple braided channels dominated by coarse sands within some channels and gravels and cobbles within other, shallow, fast-flowing channels (Figure 3-41). The marginal zones were dominated by a dense reed component (*Phragmites mauritianus*) with some sedges and herbs in other areas (*Ageratum conyzoides* and *Cyperus sp*.). There was no notable impact within this zone, likely due to the site's location within a nature reserve.

The lower zones were similar to the marginal zones in description and vegetation – dominated by coarse sands and some fine sands and most areas dominated by a dense reed component and others a herbaceous component with some small shrubs. The upper and macro-channel bank zones were dominated by fine sands and sands with scattered boulders, a dense grass component, some shrubs and scattered large trees. Dominant species noted within these zones *included Breonadia salicina, Combretum hereroense, Combretum imberbe, Cymbopogon plurinodis, Dichrostachys cinerea, Euclea divinorum, Flueggea virosa, Grewia flavescens, Gymnosporia senegalensis, Lippia javanica, Philenoptera violacaea, Sclerocarya birrea, Senna didymbotrya, Trichelia emetica, Vachellia sp.* and *Ziziphus mucronata*. Impacts noted within this zone were limited to a dirt track that passed through the macro-channel bank on the right bank. This led to increased erosion potential and some vegetation removal. One two invasive species were observed at this site. They included *A. conyzoides* and *S. didymbotrya*.

The present ecological state has an overall PES score of 81.5% (category B/C, which is slightly to moderately modified from reference conditions; Table 3-86 outlines a summary of the PES ratings, score and ecological category of zones, and provides most notable reasons for the perturbation and Table 3-87 lists the intensity and extent of impacts). The activation discharge measurement for indicators is shown in Table 3-88 and these will be used to derive flow requirements (base and flood) for the vegetation component of the site.

Figure 3-41: Site photographs (left; looking US-top and downstream-bottom) and an indication of site placement on satellite imagery (right; Bing ©) for the Sabie River (X31M SABIE).

Table 3-86: PES score and category with the main reasons for the score for the Sabie River (X31M SABIE).

LEVEL 4 ASSESSMENT	**Sabie River at Skurukwane (X31M SABIE)**					**08 August 2022**
Riparian Vegetation EC Metric Group	**Calculated Rating**	**Weighted Rating**	**Confidence**	**Rank**	**Weight**	**Notes:**
Macro channel valley	86.0	11.8	4.0	1.0	13.7	Weighted according to extent
Macro channel floor	80.7	69.6	4.0	2.0	86.3	Weighted according to extent
LEVEL 4 VEGRAI (%)						81.5
VEGRAI Ecological Category						**B/C**
AVERAGE CONFIDENCE						4.0
	Sub-zone					
	Macro channel valley			**Macro channel floor**		
VEGRAI % (Zone)	86.0			80.7		
EC (Zone)	**B**			**B/C**		
Confidence (Zone)	4.0			4.0		
Main cause of PES:						
Site located within KNP therefore very little to fault it on. Small dirt road resulted in erosion and removal on right bank but otherwise was in very good condition. Low invasive species diversities and abundances.						

Table 3-87: Intensity and extent of impacts on riparian vegetation at the Sabie River (X31M SABIE).

IMPACTS	INTENSITY	EXTENT	NOTES
	Marginal zone		
Vegetation Removal	0.5	0.5	No observed impact by removal.
Alien Species Invasion	1	0.5	Some invasive plants were observed at the site, however they existed in very low densities.
Water Quantity	0.5	5	No observed impact by water quantity.
Water Quality	0.5	5	No observed impact by water quality.
Erosion	0.5	0.5	No observed impact by erosion.
	Non-marginal (incl. Flood bench, MCB)		
Vegetation Removal	1.5	1	Some vegetation removal limited only to a dirt track passing through the macro-channel bank on the right bank of the river.
Alien Species Invasion	2	1	Some invasive plants were observed at the site, however they existed in very low densities.
Water Quantity	0.5	5	No observed impact by water quantity.
Water Quality	0.5	5	No observed impact by water quality.
Erosion	1.5	1	Some erosion was observed; however this was limited only to a dirt track passing through the macro-channel bank on the right bank of the river.

Table 3-88:. Activation discharge measurements (m^3/s) for indicator species / guilds at the Sabie River site (X31M SABIE).

Indicator Species / Guild	Activation Discharge (m^3/s)		
	Average	Min	Max
Ageratum conyzoides	5.83	23.34	23.34
Breonadia salicina	4.78	14.33	14.33
Combretum hereroense	28.24	56.48	56.48
Combretum imberbe	29.69	59.38	59.38
Cymbopogon plurinodis	26.17	418.70	418.70
Dichrostachys cinerea	23.48	46.96	46.96
Euclea divinorum	23.28	232.84	232.84
Flueggea virosa	29.78	268.04	268.04
Grewia flavescens	27.04	27.04	27.04
Gymnosporia senegalensis	16.90	118.32	118.32
Lippia javanica	25.82	77.47	77.47
Philenoptera violacea	20.02	40.04	40.04
Phragmites australis	4.47	13.42	13.42
Sclerocarya birrea	24.64	49.28	49.28
Senegalia nigrescens	26.90	80.69	80.69
Senna didymobotrya	8.08	64.67	64.67
Trichilia emetica	20.78	187.01	187.01
Vachellia sp.	24.67	24.67	24.67
Ziziphus mucronata	21.82	65.47	65.47

3.6.2.3.6.1.12 Sabie River at Lower Sabie (X33B SABIE)

The Sabie River, located downstream of the Sabie Bridge within Kruger National Park was a braided channel primarily dominated by coarse sands and in-stream vegetated sand bars. The in-stream substrates consisted of predominantly coarse sands with intermittent bedrock outcropping. Vegetated sand bars consisted of coarse sands anchored with underlying bedrock geologies and the native reed *Phragmites mauritians* which was persistent at the site especially within the marginal and lower zones. Impacts noted within this zone were minimal and limited to some hydraulic influence from an upstream bridge (Figure 3-42).

The lower zones consisted of primarily coarse sands with some fine sands and bedrock outcroppings on a relatively flat gradient. Species that dominated this zone included *P. mauritianus, Centella asiatica, Argemone ochroleuca, A. mexicana, Verbena brasiliensis, cynodon dactylon, Schoenoplectus brachyceras* and *Ageratum conyzoides.* The upper and macro-channel bank zones consisted of gradual to steep gradient that were dominated by coarse sands with some fine sands. These zones were dominated by low shrubs and some tall trees. Dominant species included *Lippia javanica, Spirostachys africana, Flueggea virosa, C. dactylon, Sida rhombifolia, Euphorbia hirta, Parthemium hysterophorus, Philenoptera violaceae, gardenia volkansii, Eragrostis superba, Grewia vilosa, Schkuhria pinnata, Gomphrena celosioides, Senna obtusifolia, Portulaca oleracea, Gymnosporia buxifoli* and *Indigofera tinctoria*. Impacts noted within this zone were minimal and limited to a tarred road within the macro-channel bank. Dominant invasive species identified at the site included *A. ochroleuca, A. mexicana, V. brasiliensis, G. celosioides, Senna obtusifolia, P. oleracea, A. conyzoides, S. pinnata* and *T. procumbens.*

The present ecological state has an overall PES score of 83.7% (category B, which is near natural; Table 3-89 outlines a summary of the PES ratings, score and ecological category of zones, and provides most notable reasons for the perturbation and Table 3-90 lists the intensity and extent of impacts). The activation discharge measurement for indicators is shown for three transects in Table 3-91, Table 3-92 and Table 3-93 respectively and these will be used to derive flow requirements (base and flood) for the vegetation component of the site.

Figure 3-42:. Site photographs (left; looking across the channel) and an indication of site placement on satellite imagery (right; Bing ©) for the Sabie River (X33B SABIE).

Table 3-89:. PES score and category with the main reasons for the score for the Sabie River (X33B SABIE).

LEVEL 4 ASSESSMENT	Sabie River at Lower Sabie (X33B SABIE)					16 November 2022
RIPARIAN VEGETATION EC METRIC GROUP	CALCULATED RATING	WEIGHTED RATING	CONFIDENCE	RANK	WEIGHT	Notes:
Macro channel valley	83.3	34.0	4.0	1.0	40.8	Weighted according to extent
Macro channel bank	83.9	49.7	4.0	2.0	59.2	Weighted according to extent
LEVEL 4 VEGRAI (%)						83.7
VEGRAI Ecological Category						B
AVERAGE CONFIDENCE						4.0
	Sub-zone					
	Macro channel valley			**Macro channel bank**		
VEGRAI % (Zone)	83.3			83.9		
EC (Zone)	**B**			**B**		
Confidence (Zone)	4.0			4.0		
Main cause of PES:						
Site located in KNP, very low human impact overall. High species diversity and invasives were in relatively low abundances.						

Table 3-90: Intensity and extent of impacts on riparian vegetation at the Sabie River (X33B SABIE).

IMPACTS	INTENSITY	EXTENT	NOTES
	Marginal zone		
Vegetation Removal	0.5	0.5	No visible signs of vegetation removal within this zone.
Alien Species Invasion	1	1	Some invasive species were observed within this zone, however they existed in very low densities.
Water Quantity	1.5	5	Some effects were observed from an upstream bridge, however their effects at this distance from the bridge were minimal.
Water Quality	0.5	5	No observed impacts by water quality.
Erosion	0.5	0.5	No observed impacts by erosion within this zone.
	Non-marginal (incl. Flood bench, MCB)		
Vegetation Removal	1	1	Some removal of vegetation due to the existence of a tarred road, however their effects were limited only to the macro-channel bank on the right bank of the river.
Alien Species Invasion	2	2	Some invasive species were observed within this zone, however they existed in very low densities.
Water Quantity	0.5	5	No observed impacts by water quantity.
Water Quality	0.5	5	No observed impacts by water quality.
Erosion	0.5	0.5	No observed impacts by erosion as the road was tarred.

Table 3-91: Activation discharge measurements (m^3/s) for indicator species / guilds at the Lower Sabie, cross-section 1 (X33B SABIE).

Indicator Species / Guild	Activation Discharge (m^3/s)		
	Average	Min	Max
Cyperus sexangularis	18.8	13.1	22.1
Dichrostachys cinerea	67.2	42.7	101.1
Euclea divinorum	59.1	59.1	59.1
Flueggea virosa	64.6	16.0	113.1
Gymnosporia senegalensis	42.2	27.5	65.8
Ischaemum fasciculatum	21.6	19.0	24.2
Lippia javanica	33.2	33.2	33.2
Megathyrsus maximus	21.6	21.1	22.1
Phragmite mauritianus	10.1	5.4	14.1
Kigelia africana	124.3	124.3	124.3

Table 3-92: Activation discharge measurements (m^3/s) for indicator species / guilds at the Lower Sabie, cross-section 2 (X33B SABIE).

Indicator Species / Guild	Activation Discharge (m^3/s)		
	Average	Min	Max
Ageratum conyzoides	23.6	13.4	33.9
Argemone mexicana	19.6	19.6	19.6
Combretum imberbe	157.7	157.7	157.7
Commelina erecta	6.3	4.5	8.0
Cyperus sexangularis	27.6	21.3	33.9
Dichrostachys cinerea	118.0	80.4	157.7
Euclea divinorum	100.9	100.9	100.9
Flueggea virosa	80.4	80.4	80.4
Grewia flavescens	137.0	137.0	137.0
Gymnosporia senegalensis	42.0	33.9	50.2
Lippia javanica	85.4	33.9	137.0
Nuxia oppositifolia	22.9	22.9	22.9
Philenoptera violacea	112.9	33.9	191.9
Phragmite mauritianus	14.3	4.5	30.1
Spirostachys africana	137.0	137.0	137.0

Table 3-93: Activation discharge measurements (m^3/s) for indicator species / guilds at the Lower Sabie, cross-section 3 (X33B SABIE).

Indicator Species / Guild	Activation Discharge (m^3/s)		
	Average	Min	Max
Centella asiatica	14.7	11.8	18.5
Commelina erecta	8.8	8.4	9.2
Commelina sp.	8.2	5.5	14.6
Cymbopogon caesius	25.1	25.1	25.1
Cynodon dactylon	18.7	10.9	26.2
Cyperus sexangularis	24.2	13.6	34.8
Dichrostachys cinerea	49.8	48.4	51.3
Diospyros mespiliformus	73.9	60.2	90.0
Eragrostis superba	49.9	34.8	64.9
Flueggea virosa	32.0	18.5	42.8
Gomphrena celosioides	17.1	13.6	20.6
Grewia flavescens	71.3	71.3	71.3
Gymnosporia senegalensis	21.7	21.7	21.7
Ischaemum fasciculatum	10.7	6.9	20.6
Lippia javanica	29.9	19.6	48.4
Ludwigia stolonifera	5.5	5.5	5.5
Megathyrsus maximus	63.1	19.6	83.1
Parthenium hysterophorus	25.2	13.6	83.1
Phragmites mauritianus	12.7	5.5	21.7
Phragmites mauritianus	6.2	6.2	6.2
Richardia brasiliensis	20.6	20.6	20.6
Schoenoplectus brachyceras	14.2	10.9	17.5
Sida rhombifolia	42.2	11.8	83.1
Spirostachys africana	21.7	21.7	21.7
Themeda triandra	39.4	18.5	60.2
Vachellia sp.	60.2	60.2	60.2
Verbena bonariensis	19.6	19.6	19.6

3.6.2.3.6.1.13 Lomati River (X14H LOMATI)

The Lomati River was primarily single-channelled, however small streams were diverted at points, creating small backchannels (Figure 3-43). The in-stream conditions were primarily bedrock-dominated with silts, fine sands and some sands and coarse sands in isolated areas. The left bank was primarily dominated by large woody trees with some reeds (*Phragmites mauritianus*) up and downstream of the site while the right bank was predominantly dominated by a dense reed component (*P. mauritianus*) with scattered large trees. Impacts noted were erosion of exposed soils in the understory of large trees on left bank, likely due to large flooding events resulting in scouring of sediments and exposing roots of large trees. Dominant species within this zone included *P. mauritianus, Lantana camara, Ranunculus multifidus, Centella asiatica, Eichhornia crassipes, Ludwigia octovalis, Salvinia molesta, Combretum erythrophyllum* and *Breonadia salicina.*

The lower zone consisted of a gradual gradient dominated by silt and fine substrates with fine gravels in some areas. The left bank consisted of a dense stand of woody trees including *B. salicina, C. erythrophyllum, F. sycamorus, Albizia versicolor, L. camara, Diospyros mespiliformis with a limited understory containing some herbaceaous species, most of which were invasive species; Commelina erecta, Chromolaena odorata, Sphagneticola trilobata, Parthenium hysterophorus, Richardia brasiliensis, lepidium bonariensis, Ranunculus multifidus, Ageratum conyzoides* and *Centella asiatica*. The upper and macro-channel bank zones consisted of a dense woody cover with a limited understory, including additional species such as *Peltophorum africanum, Flueggea virosa* and *Psidium guajava*. The right bank consisted of a dense reed component into the upper zone while the macro-channel bank and floodplain was converted into intensive agricultural lands. Dominant invasive species noted at the site included *L. camara, C. odorata, S. trilobata, P. hysterophorus, P. guajava, R. brasiliensis, L. bonariensis, C. asiatica, A. conyzoides* and *Salvinia molesta.*

The present ecological state has an overall PES score of 63.9% (category C, which is moderately modified from reference conditions; Table 3-94 outlines a summary of the PES ratings, score and ecological category of zones, and provides most notable reasons for the perturbation and Table 3-95 lists the intensity and extent of impacts). The activation discharge measurement for indicators is shown in Table 3-96 and these will be used to derive flow requirements (base and flood) for the vegetation component of the site.

Figure 3-43: Site photographs (left; looking US-top and downstream-bottom) and an indication of site placement on satellite imagery (right; Bing ©) for the Lomati River (X14H LOMATI).

Table 3-94: PES score and category with the main reasons for the score for the Lomati River (X14H LOMATI).

LEVEL 4 ASSESSMENT	Lomati River (X14H LOMATI)					18 November 2022
RIPARIAN VEGETATION EC METRIC GROUP	**CALCULATED RATING**	**WEIGHTED RATING**	**CONFIDENCE**	**RANK**	**WEIGHT**	**Notes:**
Macro channel valley	80.3	22.6	3.7	1.0	28.2	Weighted according to extent
Macro channel bank	57.5	41.3	3.7	2.0	71.8	Weighted according to extent
LEVEL 4 VEGRAI (%)						63.9
VEGRAI Ecological Category						C
AVERAGE CONFIDENCE						3.7

	Sub-zone	
	Macro channel valley	**Macro channel bank**
VEGRAI % (Zone)	80.3	57.5
EC (Zone)	**B/C**	**C/D**
Confidence (Zone)	3.7	3.7

Main cause of PES:

Large woody trees had exposed roots due to erosion, however sediment scouring could have occurred during natural events as they were within the marginal zone. Some non-woody invasives however in low abundances. Agricultural practices on the right bank completely transformed all vegetation withing the MCB and floodplain area. A small field on the left bank was transformed and grassed for a pumphouse and some disturbance for a small path and fence on the left bank as well. Other than these specific areas, the site was in good condition.

Table 3-95: Intensity and extent of impacts on riparian vegetation at the Lomati River (X14H LOMATI).

IMPACTS	INTENSITY	EXTENT	NOTES
	Marginal zone		
Vegetation Removal	0.5	0.5	No observed removal of vegetation within this zone.
Alien Species Invasion	2	1	High species diversity of invasive species however they persisted in low densities.
Water Quantity	2	5	A large water pump was operating upstream of the sites which looked to be extracting water directly from the river for agricultural purposes. This likely affected water quantity at the site.
Water Quality	1.5	5	No observed evidence of water quality compromises on the vegetation but it is highly likely that the adjacent agricultural practices would have affected water and soil chemistry through runoff.
Erosion	1.5	1	Scouring of sediments within the marginal zones was evident through exposed roots, however these scouring events could have originated from natural flooding events.
	Non-marginal (incl. Flood bench, MCB)		
Vegetation Removal	3	2	Removal of vegetation for the establishment of agricultural lands, however this was limited to the right

IMPACTS	INTENSITY	EXTENT	NOTES
			bank and only existed in the macro-channel bank and floodplains.
Alien Species Invasion	3	1.5	A high diversity of invasive plants was observed at the site, however they existed in low densities within the understory primarily on the left bank.
Water Quantity	0.5	5	No observed impact by water quantity within these zones.
Water Quality	0.5	5	No observed impact by water quality within these zones.
Erosion	1.5	1	Some evidence of erosion within the exposed soils of the understory of the tree canopy, however there is limited evidence indicating the erosion is a result of anthropogenic activities.

Table 3-96: Activation discharge measurements (m^3/s) for indicator species / guilds at the Lomati River (X14H LOMATI).

Indicator Species / Guild	Activation Discharge (m^3/s)		
	Average	Min	Max
Ageratum conyzoides	4.1	3.8	4.3
Breonadia salicina	15.0	15.0	15.0
Combretum erythrophyllum	8.5	4.3	20.4
Eichhornia crassipes	1.5	0.9	2.1
Flueggea virosa	27.5	27.5	27.5
Indigofera sp.	7.6	7.6	7.6
Jasminum fluminense	27.5	27.5	27.5
Kraussia floribunda	4.3	4.3	4.3
Ludwigia octovalis	3.2	2.1	4.3
Phragmites mauritianus	4.6	0.9	25.4
Psidium guajava	15.6	3.8	27.5
Salix mucronata	13.4	13.4	13.4
Sphagneticola trilobata	13.8	3.8	27.5
Vachellia sp.	4.3	4.3	4.3

3.6.2.3.6.1.14 Komati River (X13K KOMATI)

The Komati River site is located approximately 3 km from the border with Mozambique and is a braided, bedrock-dominated system with a prominent reed component. In-stream substrates were dominated by bedrock with silts and fine sands overlain in some areas and coarse sands in others. Heavily vegetated leigh-bars persisted throughout the site, anchored by the native *Phragmites mauritianus* (Figure 3-44). Impacts affecting this site included the hydraulic manipulation by a low bridge approximately 400 m downstream of the site that resulted in unnatural deep pools and scoured sediments downstream of the bridge. The bridge was a popular fishing spot for locals and utilised by pods of hippopotamus and likely also crocodiles.

The lower zones were dominated by a reed component (*P. mauritianus*) while the upper and macro-channel bank zones predominantly consisted of woody shrubs and some herbs. The substrates on the left banks of the non-marginal zones were dominated by a large bedrock-component while the right banks of the river consisted of predominantly coarse sands with some fine sands and sands. Dominant species within these zones included *Dichrostachys cinerea, Lippia javanica, Parthenium hysterophorus, Ziziphus mucronata, Achillea sp., Ocimum americanum, Commelina erecta, Gomphrena celosioides, Indigofera tinctoria, Jasminum sp., Ruellia patula, Conyza bonariensis, Phyllanthus reticulatusm Sclerocarya birrea, Gymnosporia buxifolia, Ludwigia octovalvis, Vachellia xanthophloea, Morella serrata* and *Rhynchosia caribaea.* Dominant invasive plants identified at the site included *P. hysterophorus, G. celosiodes* and *C. bonariensis.*

The present ecological state has an overall PES score of 81.9% (category B/C, which is slightly to moderately modified from reference conditions; Table 3-97 outlines a summary of the PES ratings, score and ecological category of zones, and provides most notable reasons for the perturbation and Table 3-98 lists the intensity and extent of impacts). The activation discharge measurement for indicators was not measured due to equipment failure.

Figure 3-44: Site photographs (left; looking US-top and downstream-bottom) and an indication of site placement on satellite imagery (right; Bing ©) for the Komati River (X13K KOMATI).

Table 3-97: PES score and category with the main reasons for the score for the Komati River (X13K KOMATI).

LEVEL 4 ASSESSMENT	Komati River (X13K KOMATI)					19 November 2022
Riparian Vegetation EC Metric Group	Calculated Rating	Weighted Rating	Confidence	Rank	Weight	Notes:
Macro channel valley	82.6	32.2	4.0	1.0	38.9	Weighted according to extent
Macro channel bank	81.5	49.8	4.0	2.0	61.1	Weighted according to extent
LEVEL 4 VEGRAI (%)						81.9
VEGRAI Ecological Category						B/C
AVERAGE CONFIDENCE						4.0
	Sub-zone					
	Macro channel valley			**Macro channel bank**		
VEGRAI % (Zone)	82.6			81.5		
EC (Zone)	**B**			**B/C**		

LEVEL 4 ASSESSMENT	Komati River (X13K KOMATI)					19 November 2022
Riparian Vegetation EC Metric Group	Calculated Rating	Weighted Rating	Confidence	Rank	Weight	Notes:
Confidence (Zone)	4.0			4.0		
Main cause of PES:						
Very low densities of woodies within this zone and no observed impacts on them. No real impact within the marginal zone except perhaps the increased water quantity from back-up from downstream bridge but that seems to have been there for a long while, so the vegetation has already adapted to the 'new' norm. No observed evidence of disturbance to woody plants. A good species diversity and no or few observed woody invasives						

Table 3-98: Intensity and extent of impacts on riparian vegetation at the Komati River (X13K KOMATI).

IMPACTS	INTENSITY	EXTENT	NOTES
	Marginal zone		
Vegetation Removal	0.5	0.5	No observed removal of vegetation within this zone.
Alien Species Invasion	1	1	Some invasive plants observed within this zone, however they existed in very low densities.
Water Quantity	2.5	5	Water quantity altered due to downstream low bridge that resulted in deep, slow-flowing pools and resulted in the backing-up of water, the effects of which could be seen approximately 500 m upstream of the bridge via satellite imagery.
Water Quality	1.5	5	Some pollution in the form of dump sites, scattered litter along the banks and litter within the water areas with reduced velocities. Likely resulting from the activities of the nearby communities and town situated upstream and parallel to the site on both sites of the river.
Erosion	0.5	0.5	No observed evidence of erosion within this zone.
	Non-marginal (incl. Flood bench, MCB)		
Vegetation Removal	1	0.5	Some removal due to dirt track that ran parallel with the river on the left bank, however their impacts and extent were limited and low.
Alien Species Invasion	2	1.5	Some invasive plants were identified at the site, however they existed in low densities.
Water Quantity	1.5	5	Alterations to water quantity were evident due to the downstream low bridge which affected local hydraulics.
Water Quality	0.5	5	Impacts by water quality were not apparent within the non-marginal zones, however pollution by litter and small dump sites likely affected the health of the system.
Erosion	1	1	Limited disturbance by erosion due to dirt tracks within the upper and macro-channel bank zones at the site.

3.6.2.3.6.1.15 Crocodile River at Van Graan (X24F CROC)

The Crocodile River, downstream of Van Graan Weir within the Kruger National Park could be described as a bedrock-dominated system with braided channels and in-stream vegetated leigh and sand bars (Figure 3-45). The in-stream environment consisted of primarily bedrock outcroppings with coarse sands overlaying low velocity, sheltered sections and within sheltered, deeper pools. Shallow rapids were dominated by bedrock with overlain gravels and cobbles. Grasses and sedges dominated the marginal zones (primarily *Cyperus sexangularis* and *Schoenoplectus brachyceras*) with some in-stream aquatic plants dominated by *Potamogeton crispus*. Impacts within this zone included the hydraulic influence of the weir, which was regularly opened and closed, resulting in scouring of sediments within the direct vicinity of the weir especially. This in turn resulted in the uprooting of marginal vegetation and steeper gradients along the banks of the river. The influence was mostly noted on the right bank of the river nearby the weir.

The lower zone of the left bank consisted of a relatively steep gradient dominated by underlying bedrock with fine sands, sands and coarse sands overlaying the bedrock, anchored by a dominant grassy component (*Cynodon dactylon* and *Ishaemum faciculatum*). The right bank consisted of a gradual gradient with seasonal back pools. The dominant substrates were coarse sands and some fine sands and sands with the occasional bedrock outcropping. The area consisted of a large grass component in combination with *C. sexangularis* and *S. brachyceras* and low densities of the native reed *Phragmites mauritianus.* The upper and macro-channel banks of both banks consisted of shrubs and large trees. Dominant species observed here included *Combretum hereroense, Flueggea virosa, Diospyros mespiliformus, Gymnosporia buxifolia, Ficus sycamorus, Combretum microphyllum* and *Combretum imberbe.* Few alien species were noted at this site. Some included *Centella asiatica, Eichhornia crassipes* and *Ageratum conyzoides* located within the marginal and lower zones.

The present ecological state has an overall PES score of 63.7% (category C, which is moderately modified from reference conditions; Table 3-99 outlines a summary of the PES ratings, score and ecological category of zones, and provides most notable reasons for the perturbation and Table 3-100 lists the intensity and extent of impacts). The activation discharge measurement for indicators is shown in Table 3-101 and these will be used to derive flow requirements (base and flood) for the vegetation component of the site.

Figure 3-45: Site photographs (left; looking US-top and downstream-bottom) and an indication of site placement on satellite imagery (right; Bing ©) for the Crocodile River (X24F CROCODILE).

Table 3-99: PES score and category with the main reasons for the score for the Crocodile River (X24F CROCODILE).

LEVEL 4 ASSESSMENT	Crocodile River at Van Graan (X24F CROC)					03 November 2022
Riparian Vegetation EC Metric Group	Calculated Rating	Weighted Rating	Confidence	Rank	Weight	Notes:
Macro channel valley	63.8	37.9	3.5	1.0	59.4	Weighted according to extent
Macro channel bank	63.5	25.8	3.3	2.0	40.6	Weighted according to extent
LEVEL 4 VEGRAI (%)						63.7
VEGRAI Ecological Category						C
AVERAGE CONFIDENCE						3.4
	Sub-zone					
	Macro channel valley			**Macro channel bank**		
VEGRAI % (Zone)	63.8			63.5		
EC (Zone)	C			C		
Confidence (Zone)	3.5			3.3		
Main cause of PES:						
There were no woody plants in the marginal or lower zones at this site. The only started in the upper zones, much further back. Likely due to regular flushing from weir which is opened to the max regularly throughout the year. Impacts on reeds include erosion and scouring by disturbances from regularly opening weir. Alien hyacinth in water numerous in sheltered areas. Some low abundances of alien herbs in marginal areas. Reeds only in selected, small pockets where there was enough shelter against flows or were further up the bank. Plants affected by agriculture, fences and roads but limited only to MCB on right bank. Small amount of non-woody aliens affecting non-woody component, also MCB on right bank resulted in their removal and replacement by agriculture. Overall low woody densities.						

Table 3-100: Intensity and extent of impacts on riparian vegetation at the Crocodile River (X24F CROCODILE).

IMPACTS	INTENSITY	EXTENT	NOTES
	Marginal zone		
Vegetation Removal	2	1.5	Some evidence of vegetation removal due to scouring from the weir being opened and closed on a regular basis.
Alien Species Invasion	3	2	Moderate densities of Eichhornia crassipes within the in-stream environment but these were limited to low velocity areas such as upstream of the weir.
Water Quantity	4	5	Water quantity restricted moderate to high downstream of the weir, resulting in scouring and altered environment, including species compositions.
Water Quality	0.5	5	No observed evidence of water quality alterations within this zone.
Erosion	3	3	Erosion due to scouring along banks as a result of weir manipulation in response to farmers requesting flows and management responding by opening the weir without regard of possible impacts on the environment.
	Non-marginal (incl. Flood bench, MCB)		

IMPACTS	INTENSITY	EXTENT	NOTES
Vegetation Removal	3.5	2.5	Some vegetation removal for a pumphouse building situated on the right bank of the river, upstream of the weir as well as dirt tracks and agricultural plantations within macro-channel bank zones and floodplains on the right bank.
Alien Species Invasion	3	2.5	Low densities of invasive plants within the lower and upper zones but high intensity of agricultural plantation within the macro-channel banks and floodplains on the right bank.
Water Quantity	0.5	5	No observed evidence of water quantity alterations within the non-marginal zones.
Water Quality	0.5	5	No observed evidence of water quality alterations within the non-marginal zones.
Erosion	3	2	Erosion potential moderate on the right bank due to pumphouse infrastructure, dirt tracks and agriculture on the right bank.

Table 3-101: Activation discharge measurements (m^3/s) for indicator species / guilds at the Crocodile River site (X24F CROCODILE).

Indicator Species / Guild	Activation Discharge (m^3/s)		
	Average	Min	Max
Centella asiatica	7.5	7.5	7.5
Combretum hereroense	26.4	26.4	26.4
Combretum microphyllum	26.3	25.6	26.9
Cyperus denudatus	3.7	3.7	3.7
Cyperus sexangularis	7.5	7.5	7.5
Diospyros mespiliformus	26.0	25.6	26.4
Eichhornia crassipes	3.5	3.3	3.7
Flueggea virosa	18.4	12.3	26.4
Gymnosporia buxifolia	22.7	14.0	26.4
Phragmites mauritianus	7.8	6.6	9.3
Schoenoplectus brachyceras	4.9	3.7	5.5

3.6.2.3.6.1.16 Lower Komati River in Mozambique (above Sabie confluence)

The marginal zone was comprised mostly of dense reedbeds (Phragmites australis) overhanging the channel with medium to large fig trees (*Ficus Sycomorus*) scattered within and some Grewia shrubs on the Left Bank. The Right Bank was less steep with unconsolidated sand bars, mostly colonised by reeds, scattered sedges and some aquatic species with recruiting riparian trees (notably *Faidherbia albida* saplings and young adults). Mostly riparian forest and thicket, cleared in places on the RB and extensively cleared on the LB, with signs of alien species invasion and terrestrialisation. Steep cut banks mostly on the LB with tall tree, many alien or terrestrial, and an undulating floodplain on the RB with tall tree and shrub (Figure 3-46).

The present ecological state has an overall PES score of 62.0% (category C/D, which is moderately to largely modified from reference conditions; Table 3-102 outlines a summary of the PES ratings, score and ecological category of zones, and provides most notable reasons for the perturbation and Table

3-103 lists the intensity and extent of impacts). The activation discharge measurement for indicators is shown in Table 3-104 and these will be used to derive flow requirements (base and flood) for the vegetation component of the site.

Figure 3-46: Site photographs (left; looking US-top and downstream-bottom) and an indication of site placement on satellite imagery (right; Bing ©) for the Komati River ((KOMATI in MOZ above Sabie confluence).

Table 3-102: PES score and category with the main reasons for the score the Komati River ((KOMATI in MOZ above Sabie confluence).

LEVEL 4 ASSESSMENT	Komati River in Moz (above Sabie confluence)					01 June 2022
RIPARIAN VEGETATION EC METRIC GROUP	**CALCULATED RATING**	**WEIGHTED RATING**	**CONFIDENCE**	**RANK**	**WEIGHT**	**Notes:**
Macro channel valley	61.9	16.9	3.0	1.0	27.3	Weighted according to extent
Macro channel bank	62.0	45.1	3.0	2.0	72.7	Weighted according to extent
LEVEL 4 VEGRAI (%)						62.0
VEGRAI Ecological Category						**C/D**
AVERAGE CONFIDENCE						3.0
	Sub-zone					
	Macro channel valley			**Macro channel bank**		
VEGRAI % (Zone)	61.9			62.0		
EC (Zone)	**C/D**			**C**		
Confidence (Zone)	3.0			3.0		
Main cause of PES:						
The main causes for the PES score are alien plant species and high impacts by high density of people including wood removal, erosion and vegetation clearing for roads and access points.						

Table 3-103: Intensity and extent of impacts on riparian vegetation at the Komati River ((KOMATI in MOZ above Sabie confluence).

IMPACTS	INTENSITY	EXTENT	NOTES
	Marginal zone		
Vegetation Removal	1.5	2	Localised sand mining and clearing at points of entry.
Alien Species Invasion	1	2	Periwinkle, *Persicaria lapathifolia*.
Water Quantity	0	5	No discernible response.
Water Quality	0	5	No discernible response.
Erosion	3	3	Left Bank cut at points of entry.
	Non-marginal (incl. Flood bench, MCB, floodplain)		
Vegetation Removal	3	3	Physical clearing, high density people and roads, select wood removal.
Alien Species Invasion	2	3	Mainly *Eucalyptus camaldulensis* and *Cassurina*.
Water Quantity	0	5	None.
Water Quality	0	5	None.
Erosion	3	3	Cut banks, roads and entry points.

Table 3-104: Activation discharge measurements (m^3/s) for indicator species / guilds at the Komati River ((KOMATI in MOZ above Sabie confluence).

Indicator Species / Guild	Activation Discharge (m^3/s)		
	Average	Min	Max
Commelina diffusa	6.0	3.8	8.1
Cynodon dactylon	11.4	11.4	11.4
Cyperus sexangularus	23.6	23.6	23.6
Dichrostachys cinerea	81.8	72.6	90.9
Eucalyptus camaldulensis	30.2	30.2	30.2
Faidherbia albida	3.8	3.8	3.8
Ficus caprifolium	2.2	1.9	2.5
Ficus sycamorus	23.6	23.6	23.6
Grewia flavescence	8.1	8.1	8.1
Megathyrsus maximus	92.1	23.6	199.4
Phragmites mauritianus	5.3	1.4	20.5
Pluchea dioscoridis	3.8	3.8	3.8
Senna didymobotrya	11.4	11.4	11.4
Vachellia tortillis	199.4	199.4	199.4
Ziziphus macrunata	40.4	8.1	72.6

3.6.2.3.6.1.17 Sabie River in Mozambique (DS Curumano Dam)

The marginal zone was comprised mostly of dense reedbeds (Phragmites australis) overhanging the channel with medium to large fig trees (Ficus Sycomorus) scattered within. Eddies, in places catered for marginal zone grasses (*Leersia hexandra*) and forbs (*Typha capensis, Commelina* sp) and were dominated aby aquatic species (*Ceratophyllum demersum*) some of which were alien (*Lemna gibba, Pistia stratiotes*). It is likely that a natural flow regime (without regulation or peaking) would have resulted in a more species rich community with more habitat diversity and less dense reeds (Figure 3-47).

Dominated by a mix of woody (riparian and terrestrial) and non-woody vegetation (mainly terrestrial grasses but also reeds on lower features). Riparian trees included *Ficus sycomorus*, some of which were senescing on the floodplain, *Faidherbia albida, Flugea virosa* and terrestrialisation of flood features by *Dichrostachys cinerea*. The channel has been confined by manual elevation of banks to form extended levees that reduces flooding of the floodplain, and the floodplain is extensively and severely cleared for agriculture.

The present ecological state has an overall PES score of 61.5% (category C/D, which is moderately to largely modified from reference conditions; Table 3-105 outlines a summary of the PES ratings, score and ecological category of zones, and provides most notable reasons for the perturbation and Table 3-106 lists the intensity and extent of impacts). The activation discharge measurement for indicators is shown in Table 3-107 and these will be used to derive flow requirements (base and flood) for the vegetation component of the site.

Figure 3-47: Site photographs (left; looking US-top and downstream-bottom) and an indication of site placement on satellite imagery (right; Bing ©) for the Sabie River (SABIE in MOZAMBIQUE).

Table 3-105: PES score and category with the main reasons for the score for the Sabie River (SABIE in MOZAMBIQUE).

LEVEL 4 ASSESSMENT	Sabie River in Moz					31 May 2022
RIPARIAN VEGETATION EC METRIC GROUP	CALCULATED RATING	WEIGHTED RATING	CONFIDENCE	RANK	WEIGHT	Notes:
Macro channel valley	59.3	17.9	3.2	1.0	30.2	Weighted according to extent
Macro channel bank	62.5	43.6	3.2	2.0	69.8	Weighted according to extent
LEVEL 4 VEGRAI (%)						61.5
VEGRAI Ecological Category						C/D
AVERAGE CONFIDENCE						3.2
	Sub-zone					
	Macro channel valley			**Macro channel bank**		
VEGRAI % (Zone)	59.3			62.5		
EC (Zone)	**C/D**			**C**		
Confidence (Zone)	3.2			3.2		
Main cause of PES:						
The main causes for the PES score are alien plant species including aquatic, marginal zone and perennial woody species, altered flow regime from bi-daily peaking and flood regulation, and clearing of the floodplain for agricultural activities.						

Table 3-106: Intensity and extent of impacts on riparian vegetation at the Sabie River (SABIE in MOZAMBIQUE).

IMPACTS	INTENSITY	EXTENT	NOTES
	Marginal zone		
Vegetation Removal	0.5	0.5	Minimal removal from access points.
Alien Species Invasion	2.5	3	Alien cover up to 10%. Mainly Water Lettuce.
Water Quantity	2.5	5	Bi-daily peaking from upstream Curumano Dam.
Water Quality	1	5	Appears minimal, some algae in the water column.
Erosion	0.5	5	Negligible, some eddy areas due to peaking.
	Non-marginal (incl. Flood bench, MCB, floodplain)		
Vegetation Removal	3.5	4	Clearing for pump station and access; clearing of floodplain for agriculture
Alien Species Invasion	4	4	Mainly Eucalyptus camaldulensis.
Water Quantity	2.5	3	Bi-daily peaking from upstream Curumano Dam. Reduced floodplain flooding due to construction of elevated banks / berms.
Water Quality	0	5	No impact observed
Erosion	1.5	2.5	Localised to pumphouse and access points.

Table 3-107: Activation discharge measurements (m^3/s) for indicator species / guilds at the Sabie River (SABIE in MOZAMBIQUE).

Indicator Species / Guild	Activation Discharge (m^3/s)		
	Average	Min	Max
Ceratophyllum demersum	0.4	0.4	0.4
Combretum microphyllum	45.5	45.5	45.5
Commelina diffusa	22.8	22.8	22.8
Dichrostachys cinerea	35.9	35.9	35.9
Ficus caprifolium	17.0	17.0	17.0
Ficus sycomorus	23.4	8.5	38.2
Flueggea virosa	60.4	35.9	90.0
Lantana camara	38.2	38.2	38.2
Leersia hexandra	0.0	0.0	0.0
Lemna gibba	1.3	0.4	2.1
Megathyrsus maximus	40.4	18.9	90.0
Phragmites australis	15.9	3.2	29.1
Typha capensis	1.1	0.0	2.1
Ipomoea sp.	27.7	8.5	45.5
Pistia stratiotes	0.6	0.0	2.1

3.6.2.3.6.1.18 Incomati Floodplain (Riverine section within floodplain)

The marginal zone was comprised mostly of dense reedbeds (Phragmites australis) overhanging the channel with medium to large fig trees (*Ficus Sycomorus*) scattered within. Eddies, in places catered for marginal zone grasses (*Leersia hexandra*) and forbs (*Typha capensis, Commelina* sp) and were dominated aby aquatic species (*Ceratophyllum demersum, Trapa natans*) some of which were alien (*Lemna gibba, Pistia stratiotes*). Backwater areas comprised similar aquatic and emergent species.

Floodplain areas restricted by constructed tall berms which also serve as roads for access by people and livestock. High density of people (fishing and boating) and livestock, with extensive trampling and grazing pressure. Vegetation comprised of mostly grasses to sparse floodplain and flood benches with scattered clumps of shrubs and localised tall trees (Figure 3-48).

The present ecological state has an overall PES score of 54.3% (category D, which is largely modified from reference conditions; Table 3-108 outlines a summary of the PES ratings, score and ecological category of zones, and provides most notable reasons for the perturbation and Table 3-109 lists the intensity and extent of impacts). The activation discharge measurement for indicators is shown in Table 3-110 and these will be used to derive flow requirements (base and flood) for the vegetation component of the site.

Figure 3-48: Site photographs (left; looking US-top and downstream-bottom) and an indication of site placement on satellite imagery (right; Bing ©) for the Komati River (river section within floodplain).

Table 3-108: PES score and category with the main reasons for the score for the Komati River (river section within floodplain).

LEVEL 4 ASSESSMENT	Incomati within Floodplain					04 June 2022
RIPARIAN VEGETATION EC METRIC GROUP	CALCULATED RATING	WEIGHTED RATING	CONFIDENCE	RANK	WEIGHT	Notes:
Macro channel valley	64.8	9.3	3.0	1.0	14.3	Weighted according to extent
Macro channel bank	52.5	45.0	3.0	2.0	85.7	Weighted according to extent
LEVEL 4 VEGRAI (%)						54.3
VEGRAI Ecological Category						D
AVERAGE CONFIDENCE						3.0
	Sub-zone					
	Macro channel valley			**Macro channel bank**		
VEGRAI % (Zone)	64.8			52.5		
EC (Zone)	**C**			**D**		
Confidence (Zone)	3.0			3.0		
Main cause of PES:						
The main causes for the PES score are alien plant species including aquatic, marginal zone and perennial woody species, and physical activities such as trampling grazing and clearing, high densities of people and livestock and constant boating and fishing.						

Table 3-109: Intensity and extent of impacts on riparian vegetation at the Komati River (river section within floodplain).

IMPACTS	INTENSITY	EXTENT	NOTES
	Macro channel valley		
Vegetation Removal	1	4	Cutting of reeds and sedges, extensive grazing
Alien Species Invasion	2.5	3	*Pistia stratifolia, Xanthium stromarium*
Water Quantity	0	5	No impacts noted

IMPACTS	INTENSITY	EXTENT	NOTES
Water Quality	0	5	No impacts noted
Erosion	1	1	Pathways and access paths / points for fishing and cattle.
	Macro channel bank		
Vegetation Removal	2.5	3	Removal of wood and reeds, clearing of pathways and access points and extensive grazing.
Alien Species Invasion	3	3	*Xanthium stromarium* and *Senna* sp mainly.
Water Quantity	0	5	No impact observed
Water Quality	0	5	No impact observed
Erosion	1	2	Roads and pathways and extended berms.

Table 3-110: Activation discharge measurements (m^3/s) for indicator species / guilds at the Komati River (river section within floodplain).

Indicator Species / Guild	Activation Discharge (m^3/s)		
	Average	Min	Max
Carex sp.1	15.9	15.9	15.9
Combretum microphyllum	76.4	76.4	76.4
Commelina diffusa	18.8	15.9	21.7
Cynodon dactylon	53.2	26.5	65.1
Echinochloa pyramidalis	23.6	15.9	31.5
Echinochloa sp.	23.7	15.9	31.5
Ficus caprifolium	28.1	28.1	28.1
Ficus sycomorus	90.7	90.7	90.7
Flueggea virosa	62.9	62.9	62.9
Gymnosporia senegalensis	65.6	58.6	74.1
Hibiscus sp.	60.8	60.8	60.8
Megathyrsus maximus	77.6	76.4	78.7
Persicaria lapathifolia	23.3	23.3	23.3
Phragmites australis	13.7	0.2	40.6
Pluchea dioscoridis	25.8	21.7	29.8
Schoenoplectus corymbosus	20.2	18.7	21.7
Senna didymobotrya	18.7	18.7	18.7
Setaria sphacelata	46.4	46.4	46.4
Terrestrial Grasses	95.6	95.6	95.6
Vachellia tortilis	78.7	78.7	78.7
Vachillia xanthophloea	62.5	46.4	78.7

3.6.2.3.6.2 Vegetation Flow Requirements

The flow requirements derived from cross sectional surveys, and which were used to derive CPTs for riparian vegetation are listed below.

Uanetza catchment

The flow requirements for the X40B Uanetza site derived from cross sectional surveys are provided in Table 3-111.

Table 3-111: High and low flow requirements for riparian vegetation at the X40B Uanetza River site.

Flows	Units	Discharge	Rip Veg Motivation
X40B Uanetza in SA			
Low Flow – Dry Season	m^3/s		Insufficient vegetation data to determine meaningful flows.
	Percentile	50th	
	Months	Sep	
Low Flow – Wet Season	m^3/s		
	Percentile	50th	
	Months	Feb	
Freshets / Floods – Class 1	m^3/s	15	Low confidence based on profile, not vegetation.
	daily average/ peak	peak	
	Number of days	6	
	Months	4 within-year floods in the wet season	
Freshets / Floods – Class 2	m^3/s	26	Low confidence based on profile, not vegetation.
	daily average/ peak	peak	
	Number of days	5	
	Months	annual flood (wettest month)	

Massintonto catchment

The flow requirements for the X40D Massintonto site derived from cross sectional surveys are provided in Table 3-112.

Table 3-112: High and low flow requirements for riparian vegetation at the X40D Massintonto site.

Flows	Units	Discharge	Rip Veg Motivation
X40D Massintonto in SA			
Low Flow – Dry Season	m^3/s	0.01	A minimum flow to ensure survival of aquatic vegetation.
	Percentile	50th	
	Months	Sep	
Low Flow – Wet Season	m^3/s	0.27	Maximum flow for all aquatic vegetation and activates herbaceous species.
	Percentile	50th	
	Months	Feb	
Freshets / Floods – Class 1	m^3/s	1.9	Flood all reeds.
	daily average/ peak	peak	
	Number of days	6	
	Months	4 within-year floods in the wet season	
Freshets / Floods – Class 2	m^3/s	10	Activates riparian shrubs.
	daily average/ peak	peak	
	Number of days	5	
	Months	annual flood (wettest month)	

Sabie catchment

The flow requirements for sites within the Sabie catchment derived from cross sectional surveys are provided in Table 3-113.

Table 3-113: High and low flow requirements for riparian vegetation at sites within the Sabie catchment.

Flows	Units	Discharge	Rip Veg Motivation
X31A Sabie			
Low Flow – Dry Season	m^3/s	0.5	Low confidence estimate of maintenance flow for marginal vegetation. Stream permanency is important for persistence of the riparian vegetation. Stream permanency to remain at 100%.
	Percentile	50th	
	Months	Sep	
Low Flow – Wet Season	m^3/s	2.05	Activates marginal zone vegetation.
	Percentile	50th	
	Months	Feb	
Freshets / Floods – Class 1	m^3/s	4.5	Activates trees on bench, low confidence.
	daily average/ peak	peak	
	Number of days	6	
	Months	4 within-year floods in the wet season	
Freshets / Floods – Class 2	m^3/s	13	Flood trees (represented by alien species, so low confidence)
	daily average/ peak	peak	
	Number of days	5	
	Months	annual flood (wettest month)	
X31K Sabie			
Low Flow – Dry Season	m^3/s	2.36	The dry season base flow needs to provide enough soil moisture (but not unduly inundate) to ensure survival and persistence during dormancy. The discharge is calculated at 0.5 m below the lowest limit of marginal zone vegetation, in this case *Phragmites mauritianus* and *Ludwigia adscendence*. Stream permanency is important for persistence of the riparian vegetation. Stream permanency to remain at 100%.
	Percentile	50th	
	Months	Sep	
Low Flow – Wet Season	m^3/s	6	For wet season base flow, inundation and activation is important during the growing season to ensure sustained productivity and reproduction. Discharge is calculated at an elevation that inundates a portion of the marginal zone vegetation, but not as much as within-year floods.
	Percentile	50th	
	Months	Feb	
Freshets / Floods – Class 1	m^3/s	25	These within-year freshets are required to inundate marginal zone vegetation, mostly reeds (*Phragmites mauritianus*) and sedges (*Cyperus dives*) but also *Breonadia salicina* saplings. These floods facilitate and sustain a growth response by marginal zone graminoids, replenish soil moisture, deposit sediments and
	daily average/ peak	peak	
	Number of days	4	

Flows	Units	Discharge	Rip Veg Motivation
	Months	4 within-year floods in the wet season	nutrients and ensure reproductive success. This event will help prevent encroachment towards the channel over time but also establishes the zone.
Freshets / Floods – Class 2	m^3/s	50	This event inundates the flood features, such as benches or bars as well as the woody and non-woody flood feature vegetation components, mainly *Cyperus dives, Syzygium cordatum and Nuxia oppositifolia*. While some scour may remove small portions of indicator, these floods facilitate and sustain a growth response, replenish soil moisture, deposit sediments and nutrients and ensure reproductive success.
	daily average/ peak	peak	
	Number of days	5	
	Months	annual flood (wettest month)	
Freshets / Floods – Class 3	m^3/s	85	These events are set to flood terrestrial vegetation which helps prevent terrestrialisation of the riparian zone and the upper limits of flood feature riparian vegetation (*Nuxia oppositifolia*). While some scour may remove portions of riparian vegetation, these floods also facilitate and sustain a growth response, replenish soil moisture, deposit sediments and nutrients and ensure reproductive success.
	daily average/ peak	peak	
	Number of days	4	
	Months	1:2/3 flood	
Freshets / Floods – Class 4	m^3/s	120	These infrequent events flood portions of riparian woody vegetation growing along the banks. Some scour or death due to inundation stress likely but also promotes growth and reproduction and recharges soils moisture important to all phreatophytes. Provides recruiting opportunities, and limits terrestrialisation.
	daily average/ peak	peak	
	Number of days	3	
	Months	1:5 flood	
X33B Sabie			
Low Flow – Dry Season	m^3/s	4.47	The dry season base flow needs to provide enough soil moisture (but not unduly inundate) to ensure survival and persistence during dormancy. The discharge is calculated at 0.3 m below the lowest limit of marginal zone vegetation, in this case *Phragmites mauritianus*. Stream permanency is important for persistence of the riparian vegetation. Stream permanency to remain at 100%.
	Percentile	50^{th}	
	Months	Sep	
Low Flow – Wet Season	m^3/s	14.48	For wet season base flow, inundation and activation is important during the growing season to ensure sustained productivity and reproduction. Discharge is calculated at an elevation that inundates a portion of the marginal zone vegetation, but not as much as within-year floods.
	Percentile	50^{th}	
	Months	Feb	

Flows	Units	Discharge	Rip Veg Motivation
Freshets / Floods – Class 1	m³/s	75	These within-year freshets are required to inundate marginal zone vegetation, mostly reeds (*Phragmites mauritianus*) and sedges *(Cyperus sexangularis*). These floods facilitate and sustain a growth response by marginal zone graminoids, replenish soil moisture, deposit sediments and nutrients and ensure reproductive success. This event will help prevent encroachment towards the channel over time but also establishes the zone.
	daily average/ peak	peak	
	Number of days	6	
	Months	4 within-year floods in the wet season	
Freshets / Floods – Class 2	m³/s	126	This event inundates the flood features, such as benches or bars as well as the woody and non-woody flood feature vegetation component. While some scour may remove small portions of indicator, these floods facilitate and sustain a growth response, replenish soil moisture, deposit sediments and nutrients and ensure reproductive success.
	daily average/ peak	peak	
	Number of days	5	
	Months	annual flood (wettest month)	
Freshets / Floods – Class 3	m³/s	350	These events are set to flood terrestrial vegetation (*Dichrostachys cinerea*) which helps prevent terrestrialisation of the riparian zone. While some scour may remove portions of riparian vegetation, these floods also facilitate and sustain a growth response, replenish soil moisture, deposit sediments and nutrients and ensure reproductive success.
	daily average/ peak	peak	
	Number of days	4	
	Months	1:2/3 flood	
Freshets / Floods – Class 4	m³/s	1500	These infrequent events flood portions of riparian woody vegetation growing along the banks, in this case *Spirostachys africana*. Some scour or death due to inundation stress likely but also promotes growth and reproduction and recharges soils moisture important to all phreatophytes. Provides recruiting opportunities, and limits terrestrialisation.
	daily average/ peak	peak	
	Number of days	3	
	Months	1:5 flood	
X33D Sabie			
Low Flow – Dry Season	m³/s	2.59	Maintain and activate marginal zone vegetation (*Phragmites australis*). Stream permanency is important for persistence of the riparian vegetation. Stream permanency to remain at 100%.
	Percentile	50th	
	Months	Sep	
Low Flow – Wet Season	m³/s	19.4	Inundate a proportion of the marginal zone vegetation.
	Percentile	50th	
	Months	Feb	
Freshets / Floods – Class 1	m³/s	60	Floods the reed population and the flood bench.
	daily average/ peak	peak	
	Number of days	6	

Flows	Units	Discharge	Rip Veg Motivation
	Months	4 within-year floods in the wet season	
Freshets / Floods – Class 2	m^3/s	100	Annual flood to inundate upper flood bench (*Megathyrsus maximus*).
	daily average/ peak	peak	
	Number of days	5	
	Months	annual flood (wettest month)	
Freshets / Floods – Class 3	m^3/s	170	Floods into terrestrial species and prevents terrestrialisation.
	daily average/ peak	peak	
	Number of days	4	
	Months	1:2/3 flood	

Komati catchment

The flow requirements for sites within the Komati catchment derived from cross sectional surveys are provided in Table 3-114. Data for riparian vegetation for the X13J Komati site is absent due to equipment failure.

Table 3-114: High and low flow requirements for riparian vegetation at sites within the Komati catchment.

Flows	Units	Discharge	Rip Veg Motivation
X21G Elands			
Low Flow – Dry Season	m^3/s	0.5	Activates marginal zone vegetation and floods a small proportion of reeds. Stream permanency is important for persistence of the riparian vegetation. Stream permanency to remain at 100%.
	Percentile	50^{th}	
	Months	Sep	
Low Flow – Wet Season	m^3/s	2.72	Floods broadleaf marginal zone vegetation.
	Percentile	50^{th}	
	Months	Feb	
Freshets / Floods – Class 1	m^3/s	7.6	Activates riparian trees on flood features.
	daily average/ peak	peak	
	Number of days	6	
	Months	4 within-year floods in the wet season	
Freshets / Floods – Class 2	m^3/s	10	Inundates riparian trees on flood features and prevents terrestrialisation.
	daily average/ peak	peak	
	Number of days	5	
	Months	annual flood (wettest month)	
X21K Elands			
Low Flow – Dry Season	m^3/s	1.03	The dry season base flow needs to provide enough soil moisture (but not unduly inundate) to ensure survival and persistence during dormancy. The discharge is calculated at 0.3 m below the lowest limit of marginal zone vegetation. Stream permanency is important for persistence of the riparian vegetation. Stream permanency to remain at 100%.
	Percentile	50^{th}	
	Months	Sep	
Low Flow – Wet Season	m^3/s	3.71	For wet season base flow, inundation and activation is important during the growing season to ensure sustained productivity and reproduction. Discharge is calculated at an elevation that inundates a portion of
	Percentile	50^{th}	
	Months	Feb	

Flows	Units	Discharge	Rip Veg Motivation
			the marginal zone vegetation, but not as much as within-year floods.
Freshets / Floods – Class 1	m^3/s	8-10	These within-year freshets are required to inundate marginal zone vegetation, mostly reeds (*Phragmites mauritianus*) and sedges (*Cyperus* sp) but also *Salix mucronata*. These floods facilitate and sustain a growth response by marginal zone graminoids, replenish soil moisture, deposit sediments and nutrients and ensure reproductive success. This event will help prevent encroachment towards the channel over time but also establishes the zone.
	daily average/ peak	peak	
	Number of days	4	
	Months	4 within-year floods in the wet season	
Freshets / Floods – Class 2	m^3/s	66	This event inundates the flood features, such as benches or bars as well as the woody and non-woody flood feature vegetation components, mainly *Combretum erythrophyllum*. While some scour may remove small portions of indicator, these floods facilitate and sustain a growth response, replenish soil moisture, deposit sediments and nutrients and ensure reproductive success.
	daily average/ peak	peak	
	Number of days	5	
	Months	annual flood (wettest month)	
Freshets / Floods – Class 3	m^3/s	185	These events are set to flood terrestrial vegetation which helps prevent terrestrialisation of the riparian zone and the upper limits of flood feature riparian vegetation. While some scour may remove portions of riparian vegetation, these floods also facilitate and sustain a growth response, replenish soil moisture, deposit sediments and nutrients and ensure reproductive success.
	daily average/ peak	peak	
	Number of days	4	
	Months	1:2/3 flood	
Freshets / Floods – Class 4	m^3/s	320	These infrequent events flood portions of riparian woody vegetation growing along the banks. Some scour or death due to inundation stress likely but also promotes growth and reproduction and recharges soils moisture important to all phreatophytes. Provides recruiting opportunities, and limits terrestrialisation.
	daily average/ peak	peak	
	Number of days	3	
	Months	1:5 flood	
X22B Crocodile			
Low Flow – Dry Season	m^3/s	3.89	Low confidence assessment: flows required to maintain reeds. Stream permanency is important for persistence of the riparian vegetation. Stream permanency to remain at 100%.
	Percentile	50^{th}	
	Months	Sep	
Low Flow – Wet Season	m^3/s	7.83	Low confidence assessment: flows required to maintain and flood a small portion of reeds.
	Percentile	50^{th}	
	Months	Feb	
Freshets / Floods –	m^3/s	15	

Flows	Units	Discharge	Rip Veg Motivation
Class 1	daily average/ peak	peak	Low confidence assessment: This is the discharge required to flood the flood bench and reeds.
	Number of days	6	
	Months	4 within-year floods in the wet season	
Freshets / Floods – Class 2	m³/s	30	Low confidence assessment: This is the discharge required to activate bank riparian tree species.
	daily average/ peak	peak	
	Number of days	5	
	Months	annual flood (wettest month)	
X22F Nels			
Low Flow – Dry Season	m³/s		There were insufficient data to set dry season base flows, but stream permanency is important for persistence of the riparian vegetation and should remain at 100%.
	Percentile	50th	
	Months	Sep	
Low Flow – Wet Season	m³/s		There were insufficient data to set wet season base flows.
	Percentile	50th	
	Months	Feb	
Freshets / Floods – Class 1	m³/s	4.1	Low confidence assessment: This is the discharge required to reach the lowest limit of *Breonadia salicina*.
	daily average/ peak	peak	
	Number of days	6	
	Months	4 within-year floods in the wet season	
Freshets / Floods – Class 2	m³/s	17	Low confidence assessment: This is the discharge required to inundate approximately 50% of the *Breonadia salicina* population.
	daily average/ peak	peak	
	Number of days	5	
	Months	annual flood (wettest month)	
Freshets / Floods – Class 3	m³/s	30	Low confidence assessment: This is the discharge required to flood the *Breonadia salicina* population.
	daily average/ peak	peak	
	Number of days	4	
	Months	1:2/3 flood	
X22H White River			
Low Flow – Dry Season	m³/s		There were insufficient data to set dry season base flows, but stream permanency is important for persistence of the riparian vegetation and should remain at 100%.
	Percentile	50th	
	Months	Sep	
Low Flow – Wet Season	m³/s	1.6	Low confidence: flows required to maintain water ferns.
	Percentile	50th	
	Months	Feb	
Freshets / Floods – Class 1	m³/s	3.9	Low confidence assessment: This is the discharge required to flood some of the reeds.
	daily average/ peak	peak	
	Number of days	6	
	Months	4 within-year floods in the wet season	
Freshets / Floods – Class 2	m³/s	7.2	Low confidence assessment: This is the discharge required to flood the reeds and forbs.
	daily average/ peak	peak	
	Number of days	5	
	Months	annual flood (wettest month)	
X22K Crocodile			
Low Flow – Dry Season	m³/s	4.45	Ensures survival of marginal zone grasses and sedges. Stream permanency is important for persistence of the riparian vegetation. Stream permanency to remain at 100%.
	Percentile	50th	
	Months	Sep	
Low Flow – Wet Season	m³/s	14.65	Maintains marginal zone grasses and sedges in the growing period.
	Percentile	50th	

Flows	Units	Discharge	Rip Veg Motivation
	Months	Feb	
Freshets / Floods – Class 1	m³/s	25	Activates *Breonadia salicina*, floods marginal zone grasses and sedges.
	daily average/ peak	peak	
	Number of days	6	
	Months	4 within-year floods in the wet season	
Freshets / Floods – Class 2	m³/s	86	Activates reed population (*Phragmites mauritianus*).
	daily average/ peak	peak	
	Number of days	5	
	Months	annual flood (wettest month)	
Freshets / Floods – Class 3	m³/s	146	Inundates (floods) 100% of the reed population.
	daily average/ peak	peak	
	Number of days	4	
	Months	1:2/3 flood	
Class 4	m³/s	300	Activates bank riparian trees (*Celtis africana*).
	daily average/ peak	peak	
	Number of days	3	
	Months	1:5 flood	
X23B Noordkaap			
Low Flow – Dry Season	m³/s	0.38	Activation of marginal zone reeds, grasses and *Berula*. Stream permanency is important for persistence of the riparian vegetation. Stream permanency to remain at 100%.
	Percentile	50th	
	Months	Sep	
Low Flow – Wet Season	m³/s	1.1	Floods a proportion of marginal zone reeds and grasses.
	Percentile	50th	
	Months	Feb	
Freshets / Floods – Class 1	m³/s	3.5	Floods about 100% of marginal zone grasses, reeds and broadleaf vegetation.
	daily average/ peak	peak	
	Number of days	6	
	Months	4 within-year floods in the wet season	
Freshets / Floods – Class 2	m³/s	6.5	Floods 100% of reeds and sedges.
	daily average/ peak	peak	
	Number of days	5	
	Months	annual flood (wettest month)	
X23E Queens			
Low Flow – Dry Season	m³/s	0.12	Maintains reeds at 20 cm below lowest limit. Stream permanency is important for persistence of the riparian vegetation. Stream permanency to remain at 100%.
	Percentile	50th	
	Months	Sep	
Low Flow – Wet Season	m³/s	0.55	Activates reeds.
	Percentile	50th	
	Months	Feb	
Freshets / Floods – Class 1	m³/s	1.45	Inundates some reeds and activates grasses.
	daily average/ peak	peak	
	Number of days	6	
	Months	4 within-year floods in the wet season	
Freshets / Floods – Class 2	m³/s	8.8	Floods portion of reeds and flood bench.
	daily average/ peak	peak	

Flows	Units	Discharge	Rip Veg Motivation
	Number of days	5	
	Months	annual flood (wettest month)	
X23F Suidkaap			
Low Flow – Dry Season	m³/s	0.72	Maintenance of reeds. Stream permanency is important for persistence of the riparian vegetation. Stream permanency to remain at 100%.
	Percentile	50th	
	Months	Sep	
Low Flow – Wet Season	m³/s	2.86	Inundation of reeds.
	Percentile	50th	
	Months	Feb	
Freshets / Floods – Class 1	m³/s	9.6	Floods the reeds and the flood bench.
	daily average/ peak	peak	
	Number of days	6	
	Months	4 within-year floods in the wet season	
Freshets / Floods – Class 2	m³/s	21	Activates and maintains riparian trees (*Combretum erythrophyllum*).
	daily average/ peak	peak	
	Number of days	5	
	Months	annual flood (wettest month)	
	Units	Discharge	
X23G Kaap			
Low Flow – Dry Season	m³/s	0.8	The dry season base flow needs to provide enough soil moisture (but not unduly inundate) to ensure survival and persistence during dormancy. The discharge is calculated at 0.3 m below the lowest limit of marginal zone vegetation. Stream permanency is important for persistence of the riparian vegetation. Stream permanency to remain at 100%.
	Percentile	50th	
	Months	Sep	
Low Flow – Wet Season	m³/s	3.39	For wet season base flow, inundation and activation is important during the growing season to ensure sustained productivity and reproduction. Discharge is calculated at an elevation that inundates a portion of the marginal zone vegetation, but not as much as within-year floods.
	Percentile	50th	
	Months	Feb	
Freshets / Floods – Class 1	m³/s	31	These within-year freshets are required to inundate marginal zone vegetation, mostly reeds (*Phragmites mauritianus*) and sedges (*Cyperus* sp) but also *Breonadia salicina*. These floods facilitate and sustain a growth response by marginal zone graminoids, replenish soil moisture, deposit sediments and nutrients and ensure reproductive success. This event will help prevent encroachment towards the channel over time but also establishes the zone.
	daily average/ peak	peak	
	Number of days	4	
	Months	4 within-year floods in the wet season	
Freshets / Floods – Class 2	m³/s	118	This event inundates the flood features, such as benches or bars as well as the woody and non-woody flood feature vegetation components.
	daily average/ peak	peak	

Flows	Units	Discharge	Rip Veg Motivation
	Number of days	5	While some scour may remove small portions of indicator, these floods facilitate and sustain a growth response, replenish soil moisture, deposit sediments and nutrients and ensure reproductive success.
	Months	annual flood (wettest month)	
Freshets / Floods – Class 3	m^3/s	164	These events are set to flood terrestrial vegetation which helps prevent terrestrialisation of the riparian zone and the upper limits of flood feature riparian vegetation. While some scour may remove portions of riparian vegetation, these floods also facilitate and sustain a growth response, replenish soil moisture, deposit sediments and nutrients and ensure reproductive success.
	daily average/ peak	peak	
	Number of days	4	
	Months	1:2/3 flood	
Freshets / Floods – Class 4	m^3/s	70-90	These infrequent events flood portions of riparian woody vegetation growing along the banks. Some scour or death due to inundation stress likely but also promotes growth and reproduction and recharges soils moisture important to all phreatophytes. Provides recruiting opportunities, and limits terrestrialisation.
	daily average/ peak	peak	
	Number of days	3	
	Months	1:5 flood	
X24F Crocodile			
Low Flow – Dry Season	m^3/s	5.1	The dry season base flow needs to provide enough soil moisture (but not unduly inundate) to ensure survival and persistence during dormancy. The discharge is calculated at 0.3 m below the lowest limit of marginal zone vegetation, in this case *Phragmites mauritianus*. Stream permanency is important for persistence of the riparian vegetation. Stream permanency to remain at 100%.
	Percentile	50^{th}	
	Months	Sep	
Low Flow – Wet Season	m^3/s	14.4	For wet season base flow, inundation and activation is important during the growing season to ensure sustained productivity and reproduction. Discharge is calculated at an elevation that inundates a portion of the marginal zone vegetation, but not as much as within-year floods.
	Percentile	50^{th}	
	Months	Feb	
Freshets / Floods – Class 1	m^3/s	25	These within-year freshets are required to inundate marginal zone vegetation, mostly reeds (*Phragmites mauritianus*) and sedges (*Cyperus sexangularis*). These floods facilitate and sustain a growth response by marginal zone graminoids, replenish
	daily average/ peak	peak	
	Number of days	6	

Flows	Units	Discharge	Rip Veg Motivation
	Months	4 within-year floods in the wet season	soil moisture, deposit sediments and nutrients and ensure reproductive success. This event will help prevent encroachment towards the channel over time but also establishes the zone.
Freshets / Floods – Class 2	m^3/s	140	This event inundates the flood features, such as benches or bars as well as the woody and non-woody flood feature vegetation component. While some scour may remove small portions of indicator, these floods facilitate and sustain a growth response, replenish soil moisture, deposit sediments and nutrients and ensure reproductive success.
	daily average/ peak	peak	
	Number of days	5	
	Months	annual flood (wettest month)	
Freshets / Floods – Class 3	m^3/s	440	These events are set to flood terrestrial vegetation (*Dichrostachys cinerea*) which helps prevent terrestrialisation of the riparian zone. While some scour may remove portions of riparian vegetation, these floods also facilitate and sustain a growth response, replenish soil moisture, deposit sediments and nutrients and ensure reproductive success.
	daily average/ peak	peak	
	Number of days	4	
	Months	1:2/3 flood	
Freshets / Floods – Class 4	m^3/s	2060	These infrequent events flood portions of riparian woody vegetation growing along the banks, in this case *Spirostachys africana*. Some scour or death due to inundation stress likely but also promotes growth and reproduction and recharges soils moisture important to all phreatophytes. Provides recruiting opportunities, and limits terrestrialisation.
	daily average/ peak	peak	
	Number of days	3	
	Months	1:5 flood	
X11K Gladdespruit			
Low Flow – Dry Season	m^3/s	0.3	Maintains reeds at 30 cm below lowest limit of population. Stream permanency is important for persistence of the riparian vegetation. Stream permanency to remain at 100%.
	Percentile	50th	
	Months	Sep	
Low Flow – Wet Season	m^3/s	2.11	Activates and floods a proportion of marginal zone vegetation.
	Percentile	50th	
	Months	Feb	
Freshets / Floods – Class 1	m^3/s	4	Floods the reeds.
	daily average/ peak	peak	
	Number of days	6	
	Months	4 within-year floods in the wet season	
Freshets / Floods – Class 2	m^3/s	5.5	Activates terrestrial species (*Vachellia karroo*)
	daily average/ peak	peak	
	Number of days	5	
	Months	annual flood (wettest month)	
Freshets / Floods – Class 3	m^3/s	10	Prevents terrestrialisation.
	daily average/ peak	peak	
	Number of days	4	

Flows	Units	Discharge	Rip Veg Motivation
	Months	1:2/3 flood	
X14H Lomati			
Low Flow – Dry Season	m³/s	1.13	Activates marginal zone vegetation and floods a small proportion of reeds. Stream permanency is important for persistence of the riparian vegetation. Stream permanency to remain at 100%.
	Percentile	50th	
	Months	Sep	
Low Flow – Wet Season	m³/s	3.97	Floods broadleaf marginal zone vegetation.
	Percentile	50th	
	Months	Feb	
Freshets / Floods – Class 1	m³/s	31	Activates riparian trees on flood features.
	daily average/ peak	peak	
	Number of days	6	
	Months	4 within-year floods in the wet season	
Freshets / Floods – Class 2	m³/s	66	Inundates riparian trees on flood features.
	daily average/ peak	peak	
	Number of days	5	
	Months	annual flood (wettest month)	
Freshets / Floods – Class 3	m³/s	114	Prevents terrestrialisation.
	daily average/ peak	peak	
	Number of days	4	
	Months	1:2/3 flood	

Incomati catchment

The flow requirements for the Y40A Incomati site derived from cross sectional surveys are provided in Table 3-115.

Table 3-115: High and low flow requirements for riparian vegetation at the Y40A Incomati site.

Flows	Units	Discharge	Rip Veg Motivation
Y40A Incomati			
Low Flow – Dry Season	m³/s	2.36	The dry season base flow needs to provide enough soil moisture (but not unduly inundate) to ensure survival and persistence during dormancy. The discharge is calculated at 0.3 m below the lowest limit of marginal zone vegetation. Stream permanency to remain at 100%.
	Percentile	50th	
	Months	September	
Low Flow – Wet Season	m³/s	22	For wet season base flow, inundation and activation is important during the growing season to ensure sustained productivity and reproduction. Discharge is calculated at an elevation that inundates a portion of the marginal zone vegetation, but not as much as within-year floods.
	Percentile	50th	
	Months	Feb	
Freshets / Floods – Class 1	m³/s	39	These within-year freshets are required to inundate marginal zone vegetation. These floods facilitate and sustain a growth response by marginal zone graminoids, replenish soil moisture, deposit sediments and nutrients and ensure reproductive success. This event will help prevent encroachment towards the channel over time but also establishes the zone.
	daily average/ peak	peak	
	Number of days	4	
	Months	4 within-year floods in the wet season	
Freshets / Floods – Class 2	m³/s	70	This event inundates the flood features, such as benches or bars as well as the woody and non-woody flood feature vegetation components. While some scour may remove small portions of indicator, these floods facilitate and sustain a growth response, replenish soil moisture,
	daily average/ peak	peak	
	Number of days	5	
	Months	annual flood (wettest month)	

Flows	Units	Discharge	Rip Veg Motivation
			deposit sediments and nutrients and ensure reproductive success.
Freshets / Floods – Class 3	m³/s	137	These events are set to flood terrestrial vegetation which helps prevent terrestrialisation of the riparian zone and the upper limits of flood feature riparian vegetation. While some scour may remove portions of riparian vegetation, these floods also facilitate and sustain a growth response, replenish soil moisture, deposit sediments and nutrients and ensure reproductive success.
	daily average/ peak	peak	
	Number of days	4	
	Months	1:2/3 flood	
Freshets / Floods – Class 4	m³/s	294	These infrequent events flood portions of riparian woody vegetation growing along the banks. Some scour or death due to inundation stress likely but also promotes growth and reproduction and recharges soils moisture important to all phreatophytes. Provides recruiting opportunities, and limits terrestrialisation.
	daily average/ peak	peak	
	Number of days	3	
	Months	1:5 flood	

3.6.2.4 ECOSYSTEM SERVICES

3.6.2.4.1 Introduction

The Incomati River Basin is important for both ecological and socio-economic benefits to the population living in the Basin. One of the main aims of the study is to develop a socio-ecological risk assessment framework for the water resources and communities of the Incomati Basin and identify multiple stressors and their synergistic effects on the well-being of the rivers and linked ecosystems and ecosystem services in the basin. To meet this aim, it is important to describe water-related ecosystem services based on social surveys that took place in different parts of the basin. This is important to understand how communities in the basin use and benefit from ecosystem services that the rivers of the Incomati Basin provide. This section presents the description and occurrence of ecosystem services in the Incomati River Basin as well as examples of how people in the basin benefit from the flow-related ecosystem services. Water-related ecosystem services categories that contribute directly to the livelihoods of communities and the environment in different sub-catchments of the Incomati River Basin were identified between 2022 and 2023. The study took place in different parts of the Komati River, upstream of the Sabie in South Africa, Crocodile River, Elands River, Incomati estuary (Macanete), lower Sabie (downstream of the Corumana dam) and around the Incomati Flood plains.

3.6.2.4.2 Methodology

Direct observations, interviews, and focus groups with local community members and water users in the basin were conducted. A total of 496 participants from South Africa (n=271) and Mozambique (n=225) took part in the study. Of these participants, 86% were males and 24% were females with age ranges between 18-67 years old. Ecosystem Services are spatial thus to be able to determine the water-related ecosystem services for local communities in the Incomati Basin, a community-based participatory mapping approach was used. Participatory mapping was carried out with members of different communities sampled in different parts of the Incomati Basin which represent the views of local members. The mapping exercise helped to identify key ecosystems and features in the landscape, which are of importance to the local communities and their contribution towards livelihoods and wellbeing.

During the mapping processes shared ideas of what is important (places, attributes or goods and services) to local communities were identified throughout the process. The located areas for ecosystem services and areas of livelihoods in the catchment were hand-drawn, each group produced a map of the area and associated ecosystem services in the Lower Komati River. Since most of the participants were not familiar with reading maps, they drew the map of the river as they understood it on paper provided and located areas where they derive ecosystem services and areas of social value based on their judgment. This is known as cognitive mapping, which is based on the principle that drawing a locality allows an individual to learn, store, recall, use, and manipulate information about an area. According to Wheeldon and Faubert (2009), cognitive mapping helps to better frame participants' experiences and spatially locate important parts of an area.

3.6.2.4.3 Limitations of the Report

The report has been limited to the determination of ecosystem services and their contribution to livelihoods based on social surveys and observations. The report has been limited by the following factors:

Water users/local communities' consultation to obtain on-the-ground information on what ecosystem services are in the Incomati River Basin was constrained, as in some sites full stakeholder surveys could not take place, because of limited funds. Thus, in some parts of the basin, selected key informants (government departments, individuals living close to the rivers) provided data that was also verified with existing literature sources. The selected key informants were representatives, and they might have not fully represented the diversity of ecosystem and water users in the Incomati basin to describe ecosystem services provided by the different risk regions and sub-basins of the river basin. Thus, the information presented in this report provides a snapshot of flow-related ecosystem services and not a full representation of the situation across the basin. However, their key knowledge about the basin was regarded as useful in obtaining information on flow-related ecosystem services, which was considered sufficient for the study. Secondly, no attempts were made to estimate the value of ecosystem services, this was not necessary for the implementation of the study.

The group discussions and interviews were biased towards male participants as they comprised 86% of participants compared to 24% were females. However, an effort to include females was made during the recruitment of informant interviews. However, since there was no quantification of the ecosystem services, the representation of ecosystem services was not hugely affected.

3.6.2.4.4 Ecosystem services in different sites along the Incomati Basin

3.6.2.4.4.1 Uanetza catchment

Uanetza in Mozambique

Riparian livestock grazing was common on the site. Since this is a non-perennial river, there was no water available water at the Uanetza site.

3.6.2.4.4.2 Massintonto catchment

X40D Massintonto

The site is along a non-perennial river that dries out at low flow. However, during the low flow season communities dug deep holes to get water for their household activities and also for the livestock.

3.6.2.4.4.3 Sabie catchment

Sabie River at Lower Sabie

The site is along the Sabie River, downstream of the Sabie Bridge and upstream of the Lower Sabie rest camp within Kruger National Park. The main ecosystem services on this site are regulatory, supporting, and cultural services. Since the site is in a protected area, biodiversity conservation is as important as the area's aesthetic value. Biodiversity conservation is central to the functioning of ecosystems in this site and to the delivery of all other ecosystem services (regulatory, cultural, supporting). Along the river in this site, there is a tarred access road for tourists, the site attracts a range of diverse user groups including sightseers and walkers who are attracted to the river's flow and riparian aesthetic appeal. Few invasive plant species were observed in the site. The site is along one of the birding spots in the Kruger National Park. Large raptors were observed along the Sabie nesting along the river. Downstream of the site outside of the KNP, were picnic spots with views over the river. The KNP conservation areas in Sabie are home to different wildlife species whose continued survival is linked to the flows of rivers in the basin and are important for eco-tourism inside and outside of the park and sustaining riparian vegetation that completes the ecosystem.

Mbyamiti

One of the seasonal rivers in the Kruger National Park the Mbyamiti Camp is situated on the bank of the Mbyamiti River, one of Kruger's most popular camps. The river flow is important for the maintenance of the Mbyamiti camp's tourist' aesthetics as the camp offers luxurious lodging. Tourist roads follow some parts of the river in a scenic way at times, which are important aesthetics for game viewing. The river route is known for its aesthetics and tourists occasionally photograph waterbirds where the road crosses the river at the Mbyamiti weir. According to tourists, several water birds, e.g. storks have been identified at the site.

The Sabie River at Merry Pebbles

The Sabie River at Merry Pebbles is downstream of a high bridge and a low bridge that resulted in a deep, low-velocity pool upstream of the lower bridge which are important parts for tourist aesthetics. The site is important for intrinsic and biodiversity values as there is tourism, camping, river tubing and conservation of aquatic biodiversity (cultural ecosystem services). Other major ecosystem services in this area include supporting services (nutrient and water cycling).

Upper Sabie at EWR-S1

The upper section of the river passes the Marite township and Hazyview town. The river extent comprises open terrain and farmland. Since the site is within a forested area, with restricted access to local communities, the site is more important for supporting services (nutrient cycling) and river flow for the forest as a streamflow reduction activity. Given the nature of the site the cultural services, representing the recreational and aesthetic value associated with the area are important, with low importance of provisioning services as the site's legal access to provisioning services is low.

Mac-Mac at EWR-4

The site is at a picnic site between pine plantations, where forestry is a consumptive user(provision) and carbon storage from plantation dead leaves and plants (regulating). The site has a waterfall, a major tourist attraction in the area. Thus, flow is important to maintain the aesthetics and natural purifying process and dilution of pollutants downstream where there are no reticulated settlements as the community mostly dumps waste in the river.

Sabie River at Hazyview

The site is within Hazyview town and is used for water abstraction and aesthetics for guests at Kruger Hotel. The site has lots of riparian vegetation which helps in the absorption and dilution of pollutants from the nearest town.

Marite at EWR-S5

The site is within informal settlements at Shabalala Village and is used for subsistence fishing, small-scale agriculture, and cultural services. The river flow also helps the natural purifying process and dilution of pollutants downstream. The river can naturally purify and dilute pollutants downstream of the site.

Sabie River at Skhrukwane

The site is in the Kruger National Park; and is important for the maintenance of aquatic and riparian biodiversity and the area's aesthetics (cultural ecosystem service). The riparian zone has lots of reeds that trap solid water pollution coming through from outside Kruger National Park.

Sabie/KNP/3

The site is within Kruger National Park a protected area. Water flow is regarded as important for the maintenance of the area's aesthetics and control of nutrient and water cycle.

Sabie River in Mozambique

The site is below the Sabie town in Mozambique where there are lots of agricultural activities. People use the site for subsistence fishing and for cultural rituals. River flow in this site is important for the natural purifying process and dilution of pollutants downstream and for cultural cleansing rituals.

3.6.2.4.4.4 Crocodile catchment

Crocodile River at Van Graan

The site is within Kruger National Park, a protected area, downstream of Van Graan Weir. River flow is regarded as an important attribute in this site for the maintenance of biodiversity in the protected areas. Other main ecosystem services in this site are provisioning services (water for sugar cane irrigation and cash crops, water supply to municipality and communities); and regulatory. The Van Graan dam is largely designed for the supply of water for irrigation (provisioning) and regulating services through flood control in the areas downstream. The site also provides riparian and marginal vegetation mainly composed of *Cyperus sexangularis* and *Schoenoplectus brachyceras* which are mostly used for craft and skin treatment in traditional medicine. Livestock grazing downstream was also observed downstream of the site, *Cynodon dactylon was the most preferred species for livestock grazing. Stands of the native phragmites* observed at the site provide food and shelter resources for some water birds. The site is also most important for supporting services for the life cycle of various fish species in the river which depend on the natural variability in the river flow.

Elands River at Nsinini

The site was observed to be more important for provisioning, recreational, cultural and supporting services. The site was also observed to be important for recreation as guests frequented the site for fly fishing. Water from this site is also used in the trout farm. Several riparian plants in the area are important for medicinal use, this includes the *Acacia mearnsii De Wild*. (Fabaceae) commonly used to treat microbial infections. *Combretum erythrophyllum* (umvubu) is also commonly used to treat venereal diseases, make crafts, cattle troughs, and grain mortars from wood. The site is also within forested areas which are known as streamflow reduction activities which can lower water levels which can be detrimental to water flow in the river. Main human activities that have an impact include disturbances from the low bridge which results in deep pools that local people visit for cultural and religious rituals.

Nels @UMP (X22F NELS)

The river flows through the industrial section of Mbombela before its confluence with the Crocodile River. The pollution from the industries threatens the water quality of the Nels River and communities throughout the basin. The site is characterized by domestic water use which includes washing laundry and cultural activities. Small-scale fisheries (provisioning) are prevalent in the area using handmade rods. The site is also used for cultural rituals, especially along the pool areas close to the bridges. Major solid waste was observed at the site and effluent discharges directly into the river were observed at the site. Thus, at this site flow is important for the natural purifying processes of pollutants through dilution, sedimentation, filtration, physical and chemical immobilization, and uptake of pollutants from the industrial area by vegetation and aquatic organisms. The indigenous *Phragmites mauritianus* and *Breonadia salicina* were most observed riparian plants on the site. These riparian plants in the area are known to offer regulatory services which include the trapping, breakdown, and transforming pollutants from the closest industries in the area which is important to improve the aesthetic value of the area as the site is also used for picnics.

Rivulets-Crocodile River

Commercial irrigation is most common for citrus crops along the reach, some crops are planted close to the edge of the river. People also rely on riparian plant species that dominate the riparian zone for herbs and cattle crazing. Parts of the river have slow-flowing pool areas with rapids and riffles used for cultural cleansing by communities. Water flow in this site is important for regulatory services to maintain water quality and transform nutrient pollutants from the nearest citrus fields. The site used to be known for large-scale yellow fish, which was one of the majorly preferred fish species in the area. Downstream of the site are tourist areas which makes it important for provisioning services.

Lower White River

The site is downstream of wastewater treatment works and given the high levels of potential pollution from the WWTW, water quality and biota communities are threatened. Thus, the maintenance of optimal flow allows for natural purification, dilution, sedimentation, and physical and chemical immobilization of contaminants. The site is at a gauging weir. No fishing activities were observed although the site is near informal settlements with a high possibility of fishing. The site was mostly dominated by reeds *Phragmites mauritianus* which are important to control flooding and filter pollutants. Several water bird species were observed in the site. Upstream of the site residents from the nearest township harvest reeds to make mats and baskets.

Noordkaap

Solid waste pollution was observed in this part of the river, which threatens communities' use of the river. Thus, regulatory ecosystem services through the purification of pollutants and uptake by riparian and marginal plant communities which includes the most dominant reed *Phragmites mauritianus* is one of the major ecosystem services in the site. The site is near informal communities with livestock grazing along the riparian zone. Local communities, abstract water from the river for their small scale farming gardens. Small-scale fisheries and harvesting of the reed are also prevalent activities in the area.

Queens River at Barberton

The site is mostly used for irrigating small-scale farming (provisioning). The site has dense reeds and a bridge downstream where people practice spiritual and cultural activities. Since the site is downstream of Barberton town, the dominant reeds *Phragmites mauritianus* and river flow help in the control of pollution from Barberton town. One of the common plants in the riparian zone *Annona senegalensis (Annonaceae)* known as mamense is harvested by locals for food, cattle are also known to graze on this plant. The Queens River is also dominated by recreation and tourism largely for river adventure camps and hiking trails (Figure 3-49), considered one of the most scenic trails in the region as the trail route traverses over river crossings and pools.

Figure 3-49: Queens River hiking trail site photograph

Nsikazi

Nsikazi is a seasonal river in Kruger National Park (KNP) between Kaapmuiden and Numbi which makes it important for aesthetic value for tourists. Downstream outside of Kruger Park, the Nsikazi River is close to community villages, Mjejane Nature Reserve and Marloth Park in the Marlothi Conservancy area. Thus, even outside of KNP the site has a high potential for tourism and conservancy. The Nsikazi River has been identified as an important ecological corridor to be conserved which has been threatened by sand mining through the removal of riparian vegetation around the river.

Crocodile at EWR-C2

The site is close to several irrigated agricultural activities in the area which rely on the river for irrigation water (provision service). The use of the site's water has a positive economic impact on the country's GDP mainly due to the required commercial irrigation water which impacts the sugar industry. There is also potential runoff from the agricultural fields which also has the potential to pollute the river, thus adequate river flow can control nutrient pollutants (supporting services).

Crocodile-Lower Creek/Kaap

The site is downstream of agricultural activities and mining which abstract water for irrigation and processing (provisioning service), and changes in flow have potential economic consequences. Upstream land use includes mainly urban sprawl and rural subsistence farming, with associated impacts on water quality and physical habitat. Flow from this site can also manage pollutants from small-scale agricultural activities and mining(regulating).

Elands

The site is between the Waterval Boven and Machadodorp formal settlements, with generally higher population densities. Utilisation of the river for provisioning, cultural use ecosystem services tends to be higher here as populations make often use. However, the population densities are such that resources tend to be under pressure. The site is next to a weir just below a large mining area. The main abstraction is for domestic water use, industrial and mining activity, SAPPI Pulp and Paper factory, forestation, and subsistence fields irrigation (provisioning service). Changes in flow have a potential impact on the economy and livelihoods.

Elands River at Roodewal

The site is below the Ngodwana SAPPI mill which uses river water for processing (provision) and sampling was below the water abstraction point for SAPPI. Subsistence farming by local communities is common in the area. The site is dominated by reeds and riparian regions have pine plantations that are a streamflow reduction activity. The river passes through the different industrial sections of the Sappi mill which use the water in the industrial processes. Several people use the bridge that crosses the river.

Houtbosloop

The site is just before the confluence with the Crocodile River. The river passes through citrus plantations and water is abstracted for irrigation, making provisioning ecosystem service (water supply) more important. Since the irrigated agricultural fields are dependent on the provisioning aspect of the river, any change in flow will affect field production.

Crocodile/KaNyamazane/4

The site is below the peri-urban area of Kanyamazane outside of Nelspruit. Lots of flow-related activities occurring here include fishing, sand mining, religious activities, and agriculture. River flow in this site is important for dilution of pollutants (regulating).

Crocodile at Kanyamazane

The site is close to an informal settlement that depends on the river for subsistence fishing, cultural rituals, and subsistence agriculture irrigation. River flow in this site is also important for the natural purifying process and dilution of pollutants from adjacent agricultural fields and solid waste disposal which is common in the area.

Suidkaap

The site is below the Barberton WWTW and a known picnic site which is common for its aesthetics. River flow in this site is also important for the natural purifying process and dilution of pollutants from adjacent agricultural fields, mines and instream solid waste disposal, as litter pollution was observed in the site.

Kaap River at Honeybird

The site is below a weir where water abstraction occurs and some fishing activity.

3.6.2.4.4.5 Komati catchment

Komati River

The site is along the Komati River, a few kilometres from the Lebombo border between South Africa and Mozambique. Upstream of the site is the Komatipoort town a peri-urban area. Main ecosystem services in the site include provisioning (water supply for sugarcane irrigation) with several rural communities who rely on the river for provisioning services (fish, craft fiber), cultural, recreational and tourism services. The most preferred fish species was *Oreochromis mossambicus.* People use deep, low-velocity pool areas for fishing, cultural and religious activities. The site is also important for livestock grazing as several livestock were observed grazing along the riparian zone. Several tourist resorts are nestled between the Komati and Crocodile Rivers and after the rivers' confluence, which makes the site important for aesthetic value. However, the use of the river by communities living around the river depends on the qualitative assessment of the river's health status based on the observed changes.

Komati at EWR-K1

The site is downstream of commercial irrigation and industry. Downstream of the site is a tourist lodge (Mt Komati River Lodge) which makes it important for the aesthetic value of the area. Local fishing is most common in this area. The site is upstream of the *Vygeboom Dam* which stores and regulates flood water from the Upper Komati and stabilizes river flow downstream of the dam. The dam is also used for recreational fishing which includes flyfishing. The area close to the site is also known for tourist attractions as people generally visit Badplaas resort and hot springs. Small-scale fisheries are common along the dam and close to the lower bridge with bass and carp as the most targeted fish species for household consumption.

Gladdespruit

Local communities predominantly abstract water for domestic use directly from the river, in this part of the basin. Fishing and irrigated commercial agriculture are most prevalent on this site. However, over the years there has been a reported decline in fish abundance at this site. Local communities also use the river site close to the low bridge for cultural activities. Dense reed (*Phragmites mauritianus*) was observed along the river's margins. Local communities use the site for small-scale fisheries and cultural rituals, especially around fast shallow, and slow shallow-flow habitats. *Oreochromis mossambicus* and *Clarias gariepinus* were the most abundant species and were targeted by fishers.

Komati at EWR-K2

The site is at Kromdraai downstream of the Vygeboom Dam which regulates floods from upstream of the Komati River. Subsistence agriculture is one of the major activities downstream of this site, where local communities abstract water to irrigate their household gardens. The river is also used to irrigate a commercial rose farm close to the site. Irrigated agriculture is one of the major water users in the sub-basin from upstream to downstream and water for agriculture irrigation offers direct and indirect beneficiaries through a combination of ecosystem services. Irrigation offers multiple linkages of ecosystem services including supporting services; maintenance of soil fertility and soil biodiversity; regulatory services; pollution regulation; and provisioning of water for irrigation. Communities from the Tjakastad area fish around the area for subsistence living.

Komati River at Silingani

The site is in the Middle Komati in Eswatini. Downstream of the site are irrigated sugar cane fields (Nyonyane). Communities are also in proximity to the site which uses the water for subsistence farming, fishing and cultural use. The site is close to the Maguga dam, which attenuates floods to the downstream communities and stores irrigation water. Whilst the dam may have been built for *hydroelectric power generation and irrigation, it also* supports other ecosystem services which include nature-based tourism that supports livelihoods, including spiritual and emotional fulfilment. The area close to Maguga is also preferred for recreational use, as it offers aesthetic appeal with its panoramic views of *Nyonyane* Mountain. River flow in this site is recognized as a powerful way of ensuring the continued supply of these vital ES, with human development and biodiversity at the core.

Lomati River at Kleindoringkop

The site is next to a large banana farm and banana processing warehouse which relies on the Lomati River for irrigation and processing water abstraction. The site is downstream of the Driekoppies Dam on the Lomati River, which was initially built to store irrigation water. The dam upstream also regulates flow and provides dilution to pollutant effects of sugar cane runoff downstream. Over the years the dam has also been used to abstract raw water to supply neighbouring communities. Riparian livestock grazing was observed at the site. The site is associated with urban sprawl and rural subsistence farming, with the associated use of river for subsistence fishing.

Komati weir below Eswatini

The site is close to the border between Eswatini and South Africa and is mostly used for subsistence fishing, sand mining and to supply irrigation water for commercial fruit plantations.

3.6.2.4.4.6 Incomati catchment

Incomati Estuary

The sites are commonly used for fishing activities. People daily put out nets and traps. The site has lots of mangrove areas. The estuary is also important for cultural activities and tourism accommodations along the estuary, making the river flow site important for the maintenance of the area's aesthetics. The estuary also plays a major role in the life cycles of the economically important shrimp, fish and shellfish species. The area is prone to malaria transmitted by Anopheline mosquitoes thus some aquatic invertebrates in the sites have been identified by traditional healers in the area to be effective at killing mosquito larvae. Plants like *Clematis viridiflora Bertol* are used by traditional healers for the treatment of malaria.

Incomati Floodplain

The site is associated with informal settlements and fishing activities. Flood plains and the river's riparian zone play a major regulating service to the river's ecosystem and linkage between land and water. Small-scale fishing and the use of rivers to transport people across sugar cane industries are most prevalent.

Based on the data collected ecosystem services in the Incomati Basin include provisioning, regulating, cultural and supporting services.

3.6.2.4.5 Provisioning

The provisioning ecosystem services identified in the basin include commercial and subsistence irrigation agriculture water, subsistence fishing, sand mining, grazing of livestock along riparian areas, harvesting of reed for household building and craft, and use of riverine plants for medicinal purposes.

3.6.2.4.5.1 Provisioning of water for commercial irrigation

The provisioning services were the most observed ecosystem services in the catchment because of their tangible nature. Abstraction of irrigation water for commercial agriculture is the most prevalent provision by the ecosystem in the Basin from the Lower Komati to the Lower Sabie catchment and the floodplains. More than 50% of the water from the entire Incomati Basin is abstracted for irrigation. The Incomati floodplains and Lower Komati provide fertile farmland and commercial sugar cane is grown in these floodplains. The main estates, Tongaat Hulett at Xinavane and Illovo Sugar at Maragra, are the main water users downstream of the Incomati Basin. Besides the commercial provisional use of the basin, there are also smallholdings, as well as local communities that also derive water supply from the basin.

The provisioning of water for irrigation within the Incomati River Basin is supported by natural and built infrastructure (dams), as most of the commercial farms have dams to store irrigation water in the upstream parts of the catchment. The Kwena Dam is the main reservoir of the Crocodile system, located upstream in the catchment. The dam is used to improve the assurance of supply of water for irrigation purposes in the catchment. Although water in the basin is mostly used for commercial irrigation, there are strategic water uses, that have priority, including water transfer to ESKOM plants in the Olifants catchment and to irrigation in the Umbeluzi in Eswatini from the Komati River.

The community surveys also reported that the high abstraction of irrigation water upstream of the basin leaves the downstream parts of the catchment mostly in Mozambique dry and the communities downstream of the basin vulnerable as they do not have sufficient coping mechanisms to cushion themselves against the threats of low flow. Thus, there have been efforts for surface water for irrigation and for households in the basin to be conjunctively used to sustain the water quantity and quality requirements of users in the catchment.

While water for agriculture irrigation is a provisioning ecosystem service, it can alter the structure and function of ecosystem processes, reducing regulating and cultural ecosystem services. These changes often include reducing biodiversity and changing the distribution of plants, smoothing out landscape heterogeneity, changing nutrient and biomass cycling and altering landscape and river ecosystems' interactions. This was most observed downstream of the basin in the Lower Komati which had increased alien plants and riparian area destruction from commercial agriculture irrigation.

3.6.2.4.5.2 Provisioning for subsistence agriculture and livelihoods

Besides using the Incomati River water for commercial irrigation, communities adjacent to river systems in the basin rely on the river for the provisioning of water for subsistence livelihoods like irrigated subsistence agriculture and for drinking through municipality supply. Subsistence irrigation water in the basin is supplied through irrigation schemes or individually in all the countries. In Mozambique, the irrigation water is supplied through schemes abstracting from the Corumana dam along the Sabie River which is also used to supply drinking water to people living in the Greater Maputo Metropolitan Area.

Observation from the field showed that, along the tributaries, communities irrigate their subsistence farms (vegetables). Most parts of the river basin where subsistence irrigation is common include Schoemansdal, Driekoppies, Hazyview communities. The river sites are also regarded as important for sand mining, fishing, swimming, handicraft reeds, cultural rituals, and traditional medicine.

In the Macaneta estuary local communities, fish, practice agriculture (mainly rainfed at the edges of the dunes), free-range livestock keeping and gather a variety of natural resources (e.g. reeds, wood for energy and construction, wild fruits, etc.). Most of these are collected for household consumption and livelihoods. Based on discussions it is estimated that around 50% of the fish from the Incomati estuary sell in Maputo Bay. Moreover, the health of mangrove systems is a vital element in the productivity of fishing and is dependent on the freshwater from the Incomati to the estuary for important feeding areas for juvenile fish.

3.6.2.4.5.3 Livestock riparian grazing

Livestock production in the basin is both socially and financially important to smallholder farmers in the basin. Based on observation, livestock mostly graze along the basin rivers' banks and riparian zones. In most parts of the catchment, the rivers' riparian zone provides forage. However, in some parts of the basin, the soils have become compacted, and some parts of the streambank are damaged, as livestock lingers around the riparian zone, especially during spring.

3.6.2.4.5.4 Fisheries

Subsistence fishing is another provisioning service that is common in the basin. In all parts of the basin subsistence fishing is a common feature. The local communities and fishers' livelihood and dependence on fisheries were studied. Results from the survey show that about 86% (N-194) of fishers in Mozambique, depend on fishing as their primary source of income and nutrition with an average of more than 10 years of fishing experience. The most preferred and targeted catch was Tilapia (*Oreochromis* (27%), catfish *Clarias* (26%) *Labeobarbus* (8%) tigerfish, and goby in both South Africa and Mozambique. Fishers' catches per day were highest in the Moaba area as they fish in the Corumana dam in the Lower Sabie River in Mozambique compared to all other areas under study. On average, fishers in the Corumana dam landed an estimated 30 kg of fish/day compared to an average of 8 kg in the Injaka dam in the upper Sabie River in South Africa over 5 fishing days per week. Fishers land an estimated 9.34 $kg.fisher^{-1}.d^{-1}$, over 5 fishing days per week dominated by Tilapia (*Oreochromis* (27%), catfish *Clarias* (26%) *Labeobarbus* (8%) tigerfish, goby, mullets, carp, silver robber, barbus. The

Macaneta community in Mozambique mostly rely on the Incomati estuary for fishing for freshwater estuarine fish depending on the season and targeted species. It is estimated that over 100 tonnes of fish are from the estuary. River flow is important for the health and productivity of mangrove systems and saltmarshes, especially for juvenile fish.

3.6.2.4.5.5 Handicraft plants, fuelwood and sand mining

The river systems along the Incomati Basin provide communities with fibre for handicrafts, (aquatic fibre to make grass mats and crafts) and household fuel. Participants identified reed harvesting as another tangible benefit they get from the river basin, especially in the Incomati Estuary. The use of aquatic reed has been a common activity in most communities in Africa. Most communities adjacent to rivers make use of aquatic fibre grass with 56% of the annual harvest sold and the rest used in their households (Mahlalela, 2014). In South Africa, more than half the households surveyed have used aquatic reed for weaving over the 10 past years (Shackleton and Shackleton, 2004). In the Incomati estuary local communities harvest fibre (Figure 3-50) which is used for house building and handicrafts sold in the Maputo market.

Figure 3-50: Fibre harvested at the Incomati estuary for house building and handicraft.

3.6.2.4.6 Regulating services

Regulating services are ecosystem services that regulate water flow, maintain biodiversity, nutrient recycling and bank stability. These services control runoff and pollutants which could be distractive to the functioning of the ecosystem. Regulating services offered by ecosystems are important for climate, human disease and natural disaster regulations. Regulating services are important through the protection of infrastructure that supports human well-being and livelihoods as they moderate the impact of disasters which may have devastating effects on vulnerable communities (Singh, Nair & Gupta, 2013).

3.6.2.4.6.1 Flow and water quality regulation

In the Incomati Basin, flood plains in Mozambique, wetlands and the river's riparian zone play a major regulating service to the river's ecosystems. The flood plains are made of relatively level alluvial sand or gravel adjacent to the river channel which also works as a sink that regulates flow. According to Marneweck and Batchelor (2002) floodplains regularly work as sinks for water overflows during floods and periods of high rainfall in the catchment. The most prominent floodplain system is in the lower part of the Incomati River. Most of the ecological services provided by the floodplain are important for the enhancement of water quality with the removal of phosphates as well as by removing nitrates and toxicants from neighbouring agriculture farms. In the flood plains, flooding is most prominent as it is in the downstream part of the catchment. Different kinds of flows that compose the flow regime of a river each contribute differently to the river's overall ecological maintenance. The key elements of natural flow regimes are flow variability, low flows (usually related to the dry season), high flows (associated with floods) and small floods, seasonally and inter-annually distributed. Riparian vegetation may filter some anthropogenic inputs before they enter systems, thus ameliorating these damages. Elevated loads of nutrients from commercial farms and suspended sediments from the sugar cane fields entering reservoirs lead to algal blooms and increased turbidity, increasing the costs of potable water supply. So, the floodplains and wetlands work as sinks for excess water and nutrients.

3.6.2.4.6.2 Flood attenuation services

The lower Incomati Basin is prone to floods and over the years there have been reports of flood damage, where loss of crops and damage to infrastructure has occurred, and sever floods like those experienced in 2000 resulted in the loss of lives. Based on local community interviews, over the years they have had to deal with flooding periods which have destroyed crops and properties.

The floodplains in the lower Sabie and Incomati flood plains areas in Xinavane in Mozambique allow for floods to pass through the river area if the floodplain development is minimized (Silva *et al.*, 2001). The floodplain area reduces the risk of floods by increasing the space in which floodwaters may discharge, hence lowering the high-water level. However, based on field observation, the river channel in the Lower Sabie has elevated banks that form extended levees that reduce flooding of the floodplain and in the floodplain, there has been subsistence agriculture by local communities.

In the Incomati Floodplain areas, local communities have built tall berms which also serve as roads for access by people and livestock. Some human activities take place along the site including small-scale fishing and boating to transport people across the river, and livestock grazing along the flood plains which has caused visible trampling. The livestock mostly feeds on the riparian and floodplain vegetation, which is mostly grasses, clumps of shrubs and localized tall trees.

3.6.2.4.7 Supporting services

The Incomati River basin's flow also plays a role in sustaining and supporting freshwater-dependent habitats, e.g. riparian zone and flood pans which are breeding grounds for biodiversity. The riparian zones play an important role as nursery areas for riparian vegetation. In Mozambique, the Incomati estuary is an important sanctuary for breeding colonies of aquatic birds and provides water and other ecological services to local populations. The estuary also plays a major role in the life cycles of the economically important shrimp, finfish and shellfish species.

Based on conversations with participants in the study, from different locations in Mozambique (Magude, Xinavane and Chobela), over the years they have observed that the wet season flow peak usually results in flooding which occurs every second year on average. This is a significant supporting service since the river requires a pulse of at least 600 Mm^3 for the water to overtop the riverbanks and inundate the floodplain, which is a natural condition for maintaining and sustaining essential ecological functioning. Floods of this magnitude flush the mouth of the estuary and deposit new sediments in the mangrove forests, where shrimps will breed, finding shelter and nutrients. A decrease in the frequency of seasonal flooding events also decreases the lateral and longitudinal connectivity of the floodplain and other habitats of the estuary, necessary to permit the natural dynamics of the river-estuary ecosystem. Based on fishers' observation, over the years the average inflow of fresh water into the estuary has decreased impacting the floodplain and estuary, leading to a major decrease in yield in key resources such as reeds, grasslands and mangroves which rely on freshwater. Based on conversations with the participants along the estuary, during the dry season the water is more saline, however during the flooding season the salinity is greatly reduced. In the Marracuene District, Maputo Province, local communities have, since the 1980s, noticed increasing saltwater intrusion up the estuary which has hindered their irrigated agriculture. Wetlands have more salt-tolerant grasslands (*Sporobolus*) and reedbeds (*Phragmites*), to salt marsh and mangroves in some areas with no vegetation.

3.6.2.4.8 Cultural

Different parts of the Incomati basin's ecosystems are recognized for their aesthetics, spiritual, educational, cultural and recreational values.

3.6.2.4.8.1 Spiritual and cultural use

In the Incomati estuary, according to participants, the traditional ceremony "Gwaza-Muthine" takes place annually and attracts over 30,000-40,000 people. The ceremony also known as "The Battle of Marracuene", is a celebration in remembrance of the anti-colonial resistance against the Portuguese colonial army in 1895. It celebrates the old kings of Marracuene who gave freedom to local people and pays homage to those who resisted colonial rule along with those who died in the historic Battle of Marracuene in 1895. Local leaders invite spirits and make traditional beer called *Canhu* to drink, and play traditional music. The president typically oversees the slaughter of a hippo from the estuary and the distribution of its meat for everyone. Since there are no more hippos in the estuary, goats are sacrificed.

Based on observation and group discussions, different parts of the river basin (Lower Komati, Estuary, Upper Sabie) are also used as a medium for cleansing, reaching, and communicating with higher beings as commonly done in the African culture. Water is regarded as a medium for communicating the sacrality of life and situating life within the spiritual. Central to the cultural and spiritual role of the river water is that some areas along the river are specifically reserved for chiefs (community leaders) to conduct sacred rituals and cultural cleansings for their communities. This was highlighted by community mapping Participant 1 in Group 3 from Magudu village, who stated that: *There used to be areas reserved for the area's chiefs to conduct rituals along the Komati River (Community mapping, Driekoppiesvillage, 19/09/2021).* Bernard (2003) states that in most African cultures, the spiritual cleansing in a river plays an important role in helping people feel a sense of security. The authors explain that these feelings of security and belonging are central to helping people feel that their lives are full of meaning and purpose. Writing about the Kowie River, Cock (2018) describes the river as an ultimate life-sustaining resource that is believed to spiritually cleanse people from misfortunes. The association between river water and life is consistent with the findings of Dandekar (2018), who highlight that rivers have enriched several cultures across the world, as the water not only brings people together but also uplifts the depths of the human spirit.

3.6.2.4.8.2 Education and research

The Incomati estuary is also used for research and educational purposes, in 2000, there have been early detection of water public health threats. Surveillances are conducted along the Incomati River and estuary in Marracuene District, Mozambique. Communities with scientists collected and analysed health data from the river where health risk assessment was also conducted. There are other opportunities to exchange traditional and scientific knowledge about the Macaneta wetlands: the launch of the Festival of the Incomati Estuary. There have been exhibitions hosted by the French National Research Institute for Sustainable Development (IRD), the University Eduardo Mondlane (UEM), the cooperative Repensar and the Marracuene District to highlight the importance of ecosystem conservation. This meeting also marked the start of the Festival do Estuário (Festival of the Estuary).

3.6.2.4.8.3 Ecotourism

In the Incomati River, there are predominately protected areas, thus the main ecosystem services are to maintain the area's aesthetics, riparian zone, and for tourist attraction. In the Kruger National Park, Crocodile and Sabie are important river systems that support the Kruger National Park ecosystem for ecotourism and to improve the park's aesthetics. Observation from sites in the Kruger National Park showed that the rivers' flow regimes are important to maintain the area's aesthetics which is an important feature for tourist attraction. Beyond tourism and aesthetic values, some parts of the Incomati basin are important for scientific research and education. Several studies to understand the biodiversity and ecosystems of the Incomati basin have taken place, in most parts of the basin. Scientists and students derive educational value and knowledge about the riverine ecosystems that exist and can be enjoyed by future generations in the basin.

Dams along the basin in South Africa and Eswatini have also become tourist and recreation attractions for water sports, angling or fishing. The Maguga and Driekoppies dams are some examples of dams along the Incomati Basin that are used not only for providing water supply but are now established tourist attractions, and allow freshwater angling activities, fishing competitions and water sports.

In Mozambique, Macaneta along the estuary offers several resorts and is a popular tourist destination for visitors and residents of southern Mozambique and South Africa. Moreover, there are also some residents at Macaneta living mainly off the aesthetics of the estuary. The estuary lies in peri-urban and outlying rural fringes of the national capitol (Maputo) in southern Mozambique (Macaneta). Tourism forms an important component of this trend. The village is also developing its tourism industry with lodges and hiking sports along the estuary. However, the industry is threatened by erosion and has had to be protected with a boulder revetment. This was raised by the community as their greatest concern for future tourism development. The erosion is most common during high rain season and high tides. The Incomati River mouth is diverted to the south by a long spit of sand extending about 12 km. On one of the very narrow sections of the spit, Macaneta Beach, a tourism development was built. During the floods of 2000, the river cut through the spit to the sea at Macaneta Beach. Furthermore, since the construction of the new road bridge across the Incomati River, the flow of tourists into the Macaneta area, for daily or weekly periods, has increased dramatically. The bridge that allows accessibility between Macaneta and Marracuene, also increased the tourist values of the areas. Over the years there has been increased building of new lodges and housing that are inevitably tapping into the groundwater resources of the floodplain and dunes.

3.6.2.4.9 Ecosystem services conclusion

Ecosystem services provided by the Incomati River Basin are important for communities living in adjacent to and distant from the basin. Main cities, industries (mining, processing), commercial agriculture, and other economically important activities benefit from the river's provisioning of water for domestic, processing and irrigation supply. Besides the obvious provisioning of water supply for economic development, the basin water flow also enhances the ecosystem's cultural value and supports the ecosystems supporting and regulating services. These ecosystem services interact with each other, as the abstraction of water (provisioning) can affect the river's supporting, regulating and cultural services. Thus, it is important to manage the provisioning services to enhance the other ecosystem services, so the basin can continuously provide the other ecosystem services. The maintenance of provisioning services is also important to manage and protect the aquatic ecosystems and its functioning.

3.6.3 ENVIRONMENTAL FLOWS FOR THE INCOMATI BASIN

The PROBFLO approach adopted in the study resulted in the provision of flow (volume, timing, duration and frequency) requirements aligned to flow-ecosystem (supporting service endpoints were used) relationships. This iterative process included using *independent flow requirements* for different ecosystem components used to generate an initial e-flow scenario, then running the PROBFLO risk models and adjusting the flow requirements to provide acceptable *integrated synergistic* flow requirements. The e-flow modelling process included the use of the following hydrological approaches for each site using specialist data provided and the iterative PROBFLO risk outputs:

- The Desktop Reserve Model (DRM) within the SPATSIM framework (Hughes, 1999) has been used to calculate the e-flows based on the long term monthly natural (reference) flows and using the ecological information for fish, macroinvertebrates, riparian vegetation and flows for the movement of sediments through the system for the selected percentiles.
- Initial monthly flow distributions (pre-defined distributions within SPATSIM) have been selected and adjusted to fit the flow characteristics of the reference flows as well as the ecological specifications. The distributions include information for the annual peak and low flow months, shape of low flow months, low and high flow assurance rules.
- The DRM was run in an iterative process and changes made to the model parameters until a good fit was obtained with the ecological requirements supplied by the ecologists for the selected months. These parameters were then used to interpolate flows for those months where no ecological data was available.

The above steps were used to quantify the baseflows and drought flow requirements at each of the sites. Only when these had been quantified, the freshet and flood requirements as provided by the ecologists were integrated and included to determine the final e-flows per site. Data available from gauging weirs in close vicinity of the selected sites have been used to provide guidance for the specification of freshets and floods in terms of timing (which months), frequency (how many per month) and duration (number of days).

The integrated floods and final e-flows as percentage of the natural Mean Annual Runoff (nMAR) per e-flow site are presented in Table 3-116 and Table 3-117 respectively. It should be noted that the e-flows for the OTH sites (Table 3-10) are based on fish requirements only, thus low confidence in the final results. The detailed output of the e-flows as timeseries and percentile tables are available electronically.

Table 3-116: Integrated freshet/ flood requirements as included in DRM for e-flow site.

	Class 1			Class 2			Class 3			Class 4		
	m^3/s	#day	Month	m^3/s	#day	Month	m^3/s	#day	Month	m^3/s	#day	Month
UANETZA CATCHMENT												
X40B Uanetza in SA	1	3	Dec, Jan, Mar, Apr	5	3	Mar, Apr	10	3	Feb			
Y40C Uanetza in Moz	1.0 (5.0)	3	Dec, Jan, Apr (Mar)	10	3	Feb						
MASSINTONTO CATCHMENT												
X40D Massintonto KNP	2	3	Dec, Jan, Apr	5	3	Mar	15	3	Feb			
Y40B Massintonto in Moz	2.0 (5.0)	3	Dec, Jan, Apr (Mar)	15	3	Feb						
SABIE CATCHMENT												
X31A Sabie	3	3	Nov	4.5	3	Dec, Jan, Mar, Apr	13	5	Feb			

	Class 1			Class 2			Class 3			Class 4		
	m³/s	#day	Month	m³/s	#day	Month	m³/s	#day	Month	m³/s	#day	Month
X31C Mac-Mac	2	10	Dec, Jan, Mar, Apr	5	8	Feb						
X31D Sabie	7	10	Dec, Jan, Mar, Apr	17	8	Feb						
X31G Marite	6	10	Dec, Jan, Mar, Apr	11	8	Feb						
X31K Sabie	15	10	Oct, Nov, Dec, Jan, Mar, Apr	25	8	Dec, Jan, Feb, Mar	85	5	Feb			
X32H Sand	3.7	5	Nov	6	5	Dec, Jan, Mar, Apr	11	3	Feb			
X32J Sand	3	10	Dec, Jan, Mar, Apr	6	8	Feb						
X33B Sabie	15	10	Nov, Dec, Jan, Apr	40	6	Jan, Feb, Mar	80	8	Feb, Mar	125	5	Feb
Y40F Sabie	30	6	Dec, Apr	60	6	Jan, Mar	100	4	Feb			
CROCODILE CATCHMENT												
X21B Crocodile	5	5	Dec, Jan, Mar, Apr	11	6	Feb						
X21E Crocodile	9	6	Nov, Dec, Jan, Mar, Apr	13	8	Feb						
X21F Elands	0.7	10	Nov, Dec, Jan, Mar, Apr	2.5	8	Feb						
X21G Elands	4.2	5	Oct, Nov, Dec, Jan, Mar, Apr	7.5	5	Dec, Jan, Feb, Mar	10	5	Feb			
X21K Elands	8	10	Oct, Nov, Dec, Mar, Apr, May	50 (30)	3 (5)	Jan (Mar)	100	4	Feb			

	Class 1			Class 2			Class 3			Class 4		
	m³/s	#day	Month	m³/s	#day	Month	m³/s	#day	Month	m³/s	#day	Month
X22A Houtbosloop	3 (4)	5 (7)	Nov, Apr (Dec, Jan, Mar)	7	8	Feb						
X22B Crocodile	15	6	Oct, Nov, Dec, Jan, Mar, Apr	25	5	Dec, Jan, Feb, Mar	50	5	Feb			
X22F Nels	4.8	6	Oct, Nov, Dec, Jan, Mar, Apr	8	3	Dec, Jan, Feb, Mar	17	5	Feb			
X22H White River	2.3	5	Oct, Nov	4	5	Dec, Jan, Feb, Mar, Apr	9	5	Feb, Mar			
X22K Crocodile	25	4	Oct, Nov, Dec	35	6	Jan, Feb, Mar, Apr	80	5	Feb			
X23B Noordkaap	1.7	3	Nov, Apr	3	5	Dec, Jan, Feb, Mar	6.5	5	Feb			
X23E Queens	1.5	4	Nov, Dec, Jan, Mar, Apr	6	5	Feb						
X23F Suidkaap	4	4	Nov, Apr	9.6	4	Dec, Jan, Mar	21	5	Feb			
X23G Kaap	5 (8)	10	Oct, Apr (Nov, Dec, Jan, Feb, Mar)	15	4	Jan, Mar	30	5	Feb			
X24C Nsikazi	2	10	Nov, Dec, Jan, Mar, Apr	4	8	Feb						
X24F Crocodile	16	5	Dec, Jan, Feb, Mar	25	10	Oct, Nov, Dec, Mar, Apr	60	3	Jan, Feb, Mar	140	5	Feb
X24G Mbyamiti	0.5	10	Dec, Jan, Mar, Apr	1	8	Feb						

KOMATI CATCHMENT

	Class 1			Class 2			Class 3			Class 4		
	m³/s	#day	Month	m³/s	#day	Month	m³/s	#day	Month	m³/s	#day	Month
X11B Boesmanspruit	2	10	Nov, Dec, Jan, Mar, Apr	8	8	Feb						
X11D Klein Komati	0.5	10	Nov, Dec, Jan, Mar, Apr	1.6	8	Feb						
X11F Komati	3.5	10	Nov, Dec, Jan, Mar, Apr	8	8	Feb						
X11J Gladdespruit	1.6	5	Nov, Dec, Apr	4	3	Jan, Mar	10	4	Feb			
X12K Komati	8	10	Nov, Dec, Jan, Mar, Apr	15	8	Feb						
X13B Komati	10	5	Oct, Apr	15	5	Nov, Dec, Jan, Mar	30	5	Feb			
X13J Komati	22	10	Nov, Dec, Jan, Mar, Apr	42	8	Jan, Feb, Mar	180	5	Feb			
X13K Komati	45	6	Nov, Dec, Mar, Apr	160	3	Jan	220	3	Feb			
X14D Lomati	5.8	8 (10)	Nov, Dec, Apr (Jan, Mar)	9	8	Feb						
X14H Lomati	8	5	Dec, Apr	20	3	Jan, Mar	60	5	Feb			
INCOMATI CATCHMENT												
Y40A Incomati	35	5	Nov, Dec, Jan, Mar, Apr	55	10	Dec, Jan, Feb, Mar	85	8	Feb, Mar	200	5	Feb

Table 3-117: E-flow requirement summary for the sites considered in the study.

SITE NAME	nMAR (MCM)	FINAL E-FLOW AS PERCENTAGE OF NMAR			
		BASE FLOW	DROUGHT FLOWS	HIGH FLOWS*	TOTAL E-FLOWS
UANETZA CATCHMENT					
X40B Uanetza	20.4	13.84	0.79	18.34	32.18
Y40C Uanetza	46.8	9.67	0.79	5.99	15.66
MASSINTONTO CATCHMENT					
X40D Massintonto	30.6	13.24	0.36	13.22	26.46
Y40B Massintonto	61.2	10.36	0.36	6.61	16.97
SABIE CATCHMENT					
X31A Sabie	98.1	39.77	15.63	6.04	45.81
X31C Mac-Mac	63.3	34.77	13.27	7.0	41.77
X31D Sabie	280.2	37.14	11.29	5.48	42.62
X31G Marite	157.2	24.25	8.79	7.74	31.99
X31K Sabie	541.8	27.60	18.20	14.04	41.64
X32H Sand	128.4	24.82	9.24	5.76	30.58
X32J Sand	142.4	23.70	9.21	4.37	28.07
X33B Sabie	744.7	38.84	16.45	16.02	54.86
Y40F Sabie	745.8	20.56	12.16	7.96	28.52
CROCODILE CATCHMENT					
X21B Crocodile	84.3	33.40	13.11	7.84	41.24
X21E Crocodile	211.6	29.95	12.08	6.61	36.56
X21F Elands	36.0	34.40	12.98	5.63	40.03
X21G Elands	81.5	36.50	18.49	16.37	52.87
X21K Elands	218.9	30.74	13.87	22.77	53.51
X22A Houtbosloop	68.9	22.43	14.14	9.01	31.44
X22B Crocodile	584.3	27.13	17.10	8.82	35.95
X22F Nels	129.9	20.10	10.93	10.78	30.88
X22H White River	50.4	15.24	7.94	17.30	32.54
X22K Crocodile	866.5	25.11	13.05	7.16	32.27
X23B Noordkaap	52.1	24.36	13.72	8.27	32.63
X23E Queens	29.5	23.77	13.27	8.79	32.56
X23F Suidkaap	105.3	24.35	13.24	10.42	34.77
X23G Kaap	181.2	19.19	12.29	14.99	34.18
X24C Nsikazi	54.6	32.11	12.73	9.0	41.11
X24F Crocodile	1 186.2	15.17	12.57	9.68	24.85
X24G Mbyamiti	16.5	12.47	0.90	6.29	18.76
KOMATI CATCHMENT					
X11B Boesmanspruit	62.8	17.77	6.49	9.58	27.35
X11D Klein Komati	81.4	13.15	6.67	1.71	14.86
X11F Komati	168.8	21.34	7.66	5.25	26.59
X11J Gladdespruit	80.8	13.60	9.20	5.01	15.61
X12K Komati	355.9	14.48	8.48	5.44	19.92
X13B Komati	859.5	11.75	2.29	2.62	14.37
X13J Komati	1 025.4	15.11	11.21	10.73	25.84

SITE NAME	nMAR (MCM)	FINAL E-FLOW AS PERCENTAGE OF NMAR			
		BASE FLOW	DROUGHT FLOWS	HIGH FLOWS*	TOTAL E-FLOWS
X13K Komati	1 376.7	13.93	9.43	7.29	21.22
X14D Lomati	111.2	21.31	13.86	9.44	30.75
X14H Lomati	264.3	15.35	9.05	8.25	23.60
INCOMATI CATCHMENT					
Y40A Incomati	2 615.5	16.15	11.24	7.47	23.62

* Please note that the actual floods as specified should be used and not only the percentage

Table 3-118: Summary of the present ecological state for biological components considered in the study aligned to the target ecological state for each component using A-F ecological categories where A = Natural, B= largely Natural, C = moderate modified, D = largely modified but still sustainable and F = critically modified and unsustainable.

SITE NAME	IUA	REC	FISH		INVERTEBRATE		VEGETATION	
			PES	TARGET	PES	TARGET	PES	TARGET
UANETZA CATCHMENT								
X40B Uanetza	X4-1U	B	C					
Y40C Uanetza	Y1-1	C						
X40D Massintonto	X4-1M	B	C					
Y40B Massintonto	Y1-3	C						
SABIE CATCHMENT								
X31A Sabie	X3-1	B	C		B		D	
X31C Mac-Mac	X3-2	B	C	B/C	B/C	A/B		A/B
X31D Sabie	X3-2	B	C	B	C	B		B
X31G Marite	X3-2	B/C	C	B/C	B/C	B/C		B/C
X31K Sabie	X3-3	B	C	B	B/C	B	B/C	A/B
X32H Sand	X3-8	B	C		B			
X32J Sand	X3-9	B	C	B		B		B
X33B Sabie	X3-6	B	C		C		B	
Y40F Sabie	Y1-5	C/D	C		C		C/D	
CROCODILE CATCHMENT								
X21B Crocodile	X2-1	B	C	B	B	B		A/B
X21E Crocodile	X2-2	B/C	C	B	B	C		C
X21F Elands	X2-3	B			C		D	
X21G Elands	X2-4	B	C		B/C			
X21K Elands	X2-5	C	C		C		D	
X22A Houtbosloop	X2-7	C	C		B/C			
X22B Crocodile	X2-6	C	C		C			
X22F Nels	X2-8	C/D	C		C		C	
X22H White River	X2-8	D	C		C			

SITE NAME	IUA	REC	FISH		INVERTEBRATE		VEGETATION	
			PES	TARGET	PES	TARGET	PES	TARGET
X22K Crocodile	X2-9	C	C	B	C	C	C	C
X23B Noordkaap	X2-10N	C	D		B/C		D	
X23E Queens	X2-10Q	B/C	C/D		C		C	
X23F Suidkaap	X2-10S	C	D		B/C		D	
X23G Kaap	X2-10K	C	C/D	C	C	B	C/D	C/D
X24C Nsikazi	X2-12	B	C		D			
X24F Crocodile	X2-13	C	C		D		C	
X24G Mbyamiti	X2-13	B	C					
KOMATI CATCHMENT								
X11B Boesmanspruit	X1-1	B/C	C		C			
X11D Klein Komati	X1-3	C	C		B			
X11F Komati	X1-3	C	C		B/C			
X11J Gladdespruit	X1-4	D	C	D	C	D	B/C	D
X12K Komati	X1-6	D	C		B/C			
X13B Komati	X1-11	D	C		C			
X13J Komati	X1-9	D	C	C/D	B/C	D		D
X13K Komati	X1-10	D	C		C		B/C	
X14D Lomati	X1-7	C	C		B/C			
X14H Lomati	X1-8	C	C	C	B	C	C	B/C
INCOMATI CATCHMENT								
Y40A Incomati	Y1-2	C/D	C		C		D	
Estuary Incomati	Y1-4	B/C						
Flood Incomati	Y1-4	B/C	C		C			

3.6.4 RISK OF FLOWS TO ECOSYSTEM SERVICES ASSESSMENT

The socio-ecological consequences of altered flows (and non-flow environmental variables) for each of the four scenarios ((i) natural, (ii) present day, (iii) e-flows and (iv) extended droughts observed in the flow record) are provided in this results and discussion section. The risk of multiple stressors have been provided for the ecosystem services ((i) provisioning, (ii) regulatory and (iii) cultural services that represent the social parts of the system and (iv) the supporting services that represent the ecological requirements of the system). The graphs and corresponding maps present the trends in the relative risk scores for the four scenarios (natural, present, e-flows and drought) for each risk region representing the sub-catchment areas of the Incomati Catchment. Detailed results are provided for each endpoint in Figure 3-51 to Figure 3-57 with graphs of probable risk. While the relative risk of the flow and non-flow stressors to the endpoints of the study have been determined using the RRA-BN approach, resulting in risk distributions for each endpoint or component of the socio-ecological system we have selected in the study to represent the whole system, we have used a Monte Carlo randomisation approach (1 000 iterations) to integrate the risk from endpoints per ecosystem service category presented in the Uncertainty Evaluation Section below (Section 3.7).

3.6.4.1 Supporting Services

The water resources within the Incomati Catchment provide supporting services through the maintenance of the river ecosystems represented through our evaluation of the risk to the fish, vegetation and invertebrate communities or components of the ecosystem. The holistic risk of the multiple stressors, including altered flows, water quality habitat and disturbance to wildlife including alien invasive species impacts for example, to the endpoints provided. These results include the risk distribution (probability/proportion (%) of zero, low moderate and high risk ranks) with the expected value or most likely risk rank score outcome expressed as a risk score (range 0-100, graphs and maps presented in the Annexure). Here the probability (%) of the high risk (failure of the endpoint or unacceptable condition) is presented with the moderate risk (representing threshold of potential concern) for the four scenarios considered in the assessment (NAT – natural, PRS – present, EFLOW – e-flow and DRGHT – drought) scenarios. The expected value or most likely risk rank score is an inversely proportional proposition of the state or condition of the endpoints. The results presented and the discussion as such considers the probable risk ranks, most likely risk rank score and probable state of the ecosystem are discussed interchangeably. Figure 3-51 to Figure 3-140 provide an example of the graphs and maps generated that illustrate the probable risk posed to the different services and endpoints within each risk region for each scenario (NAT – natural, PRS – present, EFLOW – e-flow and DRGHT – drought).

Results of the FISH-ECO-END endpoint are presented in Figure 3-51 to Figure 3-57 and in the Annexure Figure 7-1 to Figure 7-1 to Figure 7-7. Results include most likely or expected outcomes including risk rank ranges ranged from 24-42% for the natural (NAT) scenario, 26-75% for the present (PES) scenario, 27-75% for the e-flow (EFL) scenario and 27-75% for the drought (DRG) scenario. Under the natural scenario (for FISH-ECO-END) the highest risk rank is observed for the Mtsoli sub-catchment (in Crocodile River Catchment). Under the present scenario (for FISH-ECO-END) the highest risk ranges were observed in the Komati Catchment. Under the e-flow scenario (for FISH-ECO-END) the highest risk ranges were observed in the Komati and Crocodile Catchments. Under the drought scenario (for FISH-ECO-END) the highest risk rank ranges were observed in the Komati, Crocodile and Sabie Catchments. The results include general increasing proportional probability in high risk from natural to present, e-flows and drought. The risk between present and e-flows demonstrates when e-flow requirements required to meet the vision for the reach of river considered is: (i) comparable to the present state, e-flows would be comparable, (ii) requires improvement in states resulting in less risk and probable improvement in state and (iii) when the vision allows the sustainability threshold to meet the vision to relate to a sustainable but poorer condition that what is presently observed. Risk associated with the drought scenarios generally exceed the present and e-flows, however on occasion the risk to the drought scenario is better than the present and e-flows due to the history of flows for that site where observed drought flows were better than the present flows. The comparative probability of high risk to the fish endpoints for the:

- drought scenarios for X31G Marite River, X32H Sand River and X33B Sabie River, X22H White River, X23B Kaap River, X23E Queens River, X11B Boesmanspruit, X11D Komati River, X12K, X13B, X13J, X13K in the Komati River and X14D and X14H in the Lomati River.
- present scenarios to X22H White River, X23E Queens River, X12K, X13B, X13J, X13K in the Komati River and X14H in the Lomati River.

These high risks summaries are graphically presented to the fish of the rivers in Figure 3-57. These results include zero to very low risk as expected to the fish for the Natural State. Comparatively the present high risk in the Komati River sub-basin in general and the Kaap, and White River sub-basins of the Crocodile River sub-basin. The probable risk to the fish through e-flows again demonstrates high risk to the high risk rank in the Inkomati River sub-basin due to non-flow stressors. The high probabilities of high risk to the fish in the drought scenario is expected.

Risk to the INV-ECO-END endpoints are presented in Figure 3-58 to Figure 3-64 and in the Annexure Figure 7-8 to Figure 7-14. Results include risk rank ranges ranged from 23-54% for the natural (NAT) scenario, 53-75% for the present (PES) scenario, 40-75% for the e-flow (EFL) scenario and 39-75% for the drought (DRG) scenario. Under the natural scenario (for INV-ECO-END) the highest risk rank is observed for in Crocodile and Komati River Catchments. Under the present scenario (for INV-ECO-END) the highest risk ranges were observed in the Komati and Incomati Catchments. Under the e-flow scenario (for INV-ECO-END) the highest risk ranges were observed in the Komati Catchment. Under the drought scenario (for INV-ECO-END) the highest risk rank ranges were observed in the Komati and Crocodile Catchments. Similar summary trends of the Figure 3-64 demonstrate that the changes in risk from the Natural to present scenarios including the Komati River and parts of the Crocodile River (White River) and other tributaries of the upper Crocodile and Elands River, and lower Sabie River. For macro-invertebrates the e-flow scenarios will result in an improvement in risk to all high risk reaches of the catchment. Drought flow scenarios again result in a general worsening of the condition of the rivers, including higher risk to most sites in the basin.

For the VEG-ECO-END endpoint results are presented in Figure 3-65 to Figure 3-71 and in the Annexure Figure 7-15 to Figure 7-21. The risk rank ranges ranged from 20-50% for the natural (NAT) scenario, 31-75% for the present (PES) scenario, 31-75% for the e-flow (EFL) scenario and 30-75% for the drought (DRG) scenario (Figure 3-71). Under the natural scenario (for VEG-ECO-END) the highest risk rank is observed for in the Uanetza and Massintonto River Catchments. Under the present scenario (for VEG-ECO-END) the highest risk ranges were observed in the Komati and Crocodile Catchments. Under the e-flow scenario (for VEG-ECO-END) the highest risk ranges were observed in the Komati Catchment. Under the drought scenario (for VEG-ECO-END) the highest risk rank ranges were observed in the Komati and Crocodile Catchments. The summary of the high risks to the vegetation endpoint is presented in Figure 3-71. Trends differ from the instream components (fish and macroinvertebrates). Results include a considerable change in risk from natural to present for the upstream Komati River and Crocodile River with a very high risk in the lower Incomati Basin in Mozambique. The e-flow scenario includes the Sabie River and the Elands River. The drought scenarios again highlight the vulnerability of the lower Incomati Basin, upper reaches of the basin (Komati, Crocodile and Sabie Rivers) and middle reaches of the Komati and Crocodile Rivers.

3.6.4.1.1 FISH-ECO-END endpoint

The following figures below refer to the medium and high relative risk scores for the FISH-ECO-END endpoint under each scenario (Natural, Present, E-Flow and Drought) for the Uanetza Catchment (Figure 3-51), the Massintonto Catchment (Figure 3-52), Sabie Catchment (Figure 3-53), Crocodile Catchment (Figure 3-54), Komati Catchment (Figure 3-55) and the Incomati Catchment (Figure 3-56). Figure 3-57 refers to the map illustration of the relative risk scores to the FISH-ECO-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought).

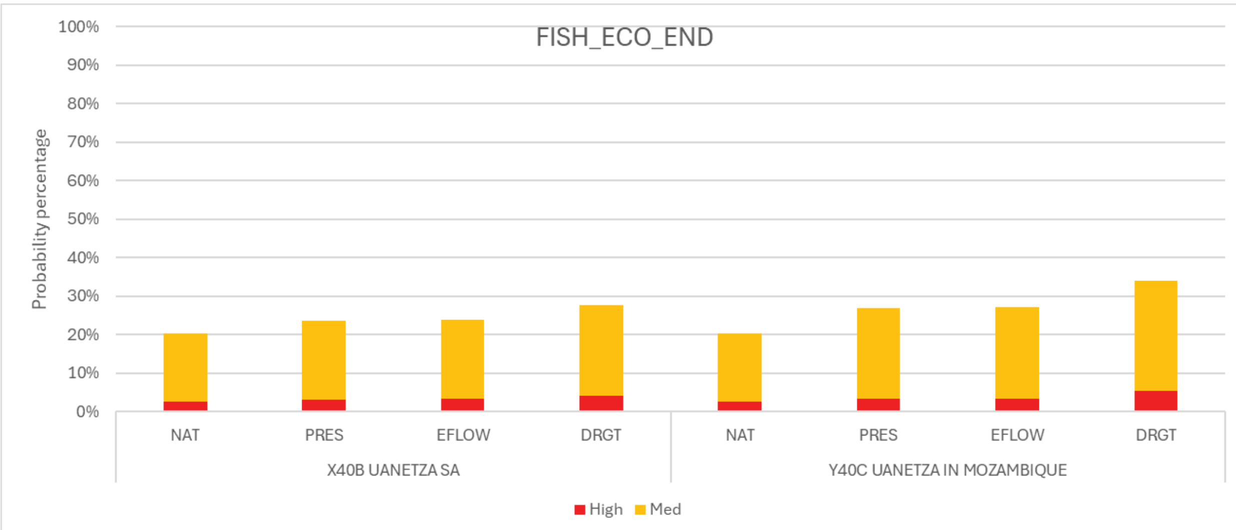


Figure 3-51: The medium and high relative risk scores for the FISH-ECO-END endpoint for the Uanetza catchment for each scenario (Natural, Present, E-Flow and Drought).

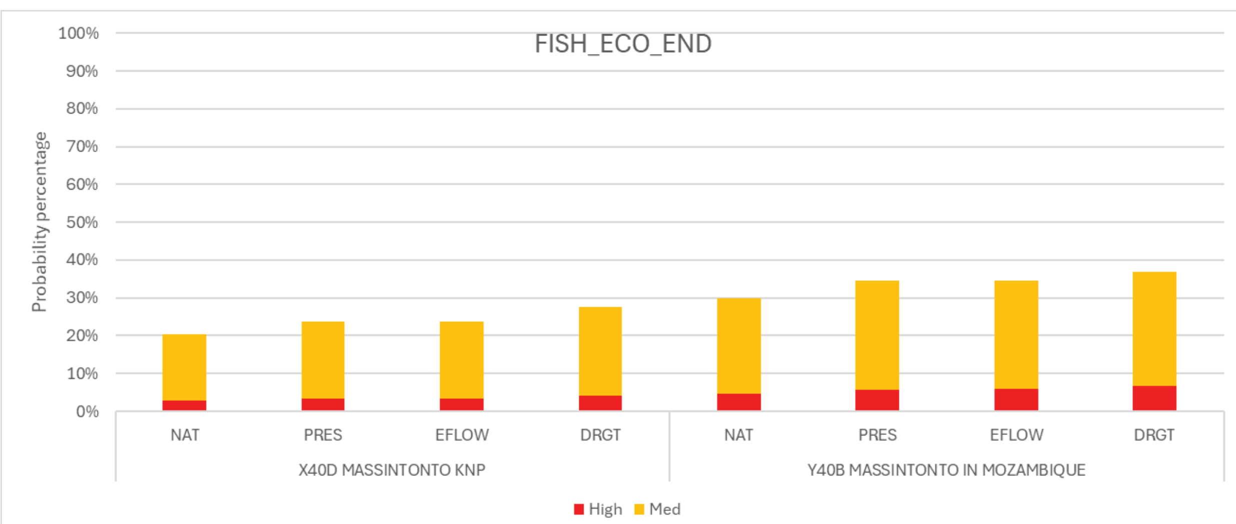


Figure 3-52: The medium and high relative risk scores for the FISH-ECO-END endpoint for the Massintonto catchment for each scenario (Natural, Present, E-Flow and Drought).

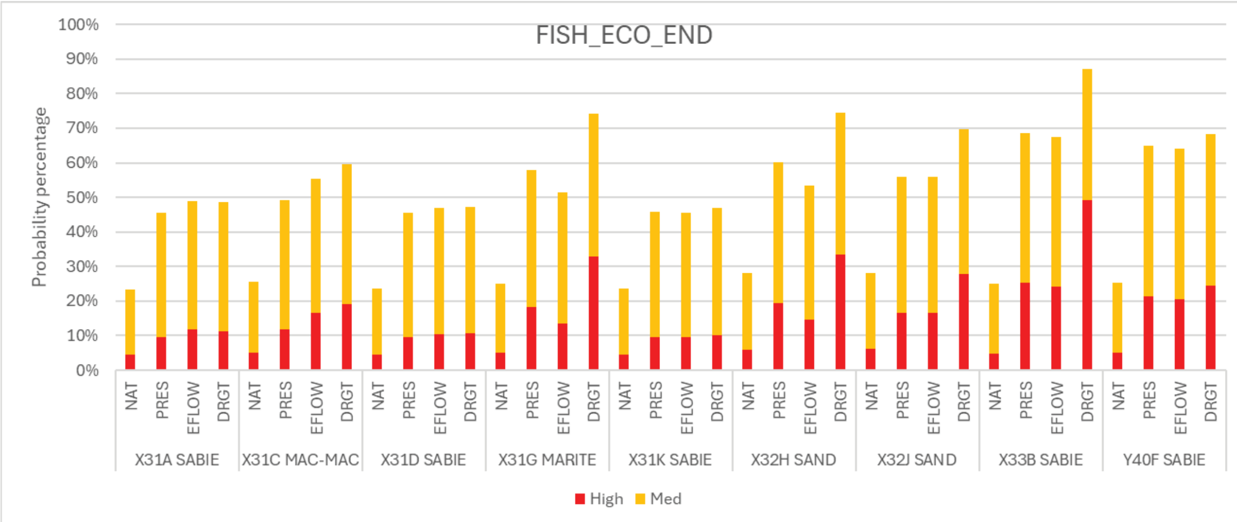


Figure 3-53: The medium and high relative risk scores for the FISH-ECO-END endpoint for the Sabie catchment for each scenario (Natural, Present, E-Flow and Drought).

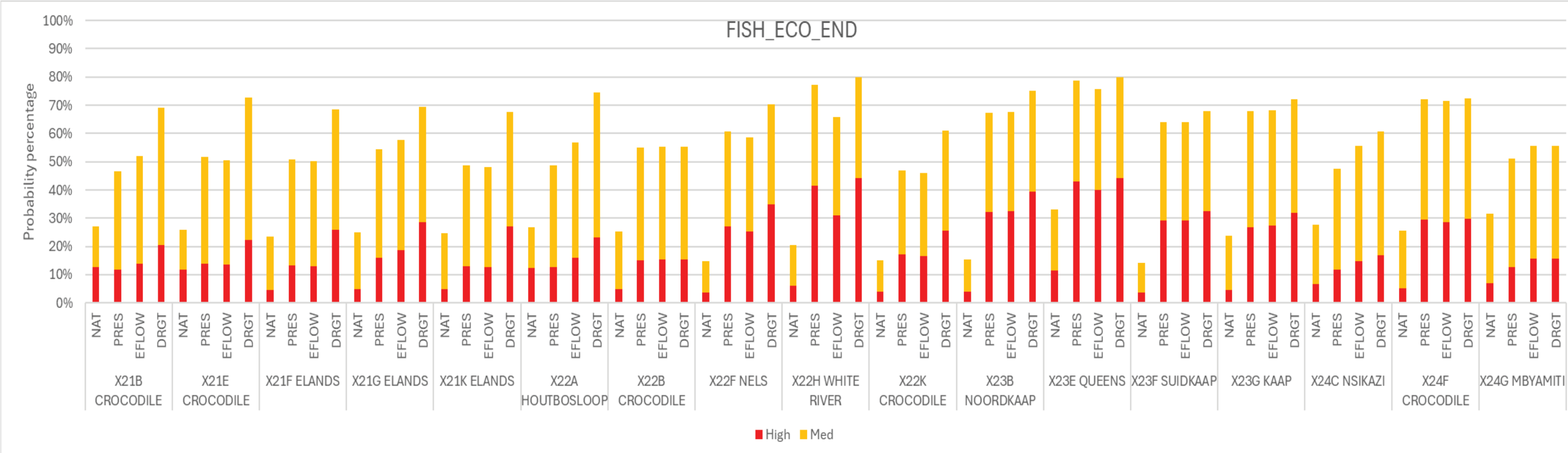


Figure 3-54: The medium and high relative risk scores for the FISH-ECO-END endpoint for the Crocodile catchment for each scenario (Natural, Present, E-Flow and Drought).

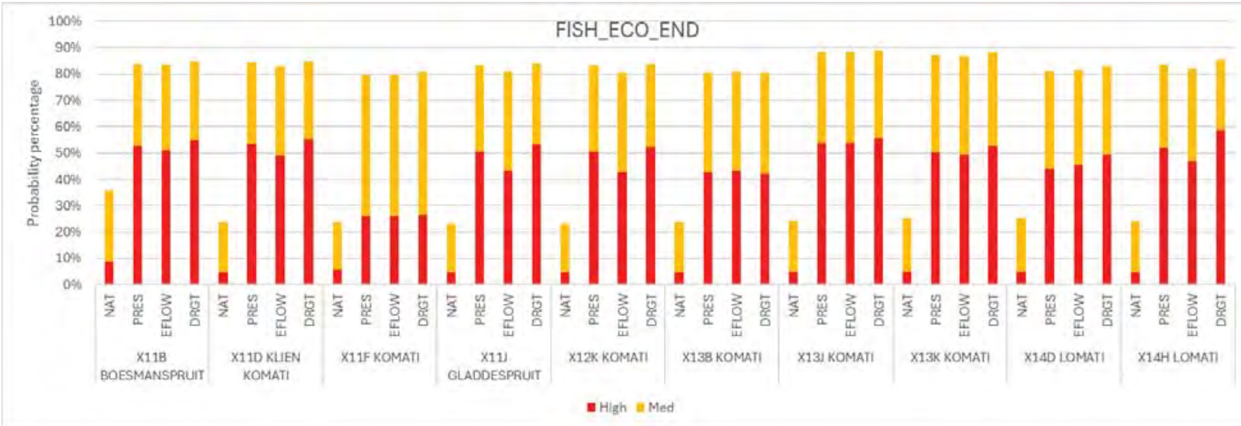


Figure 3-55: The medium and high relative risk scores for the FISH-ECO-END endpoint for the Komati catchment for each scenario (Natural, Present, E-Flow and Drought).

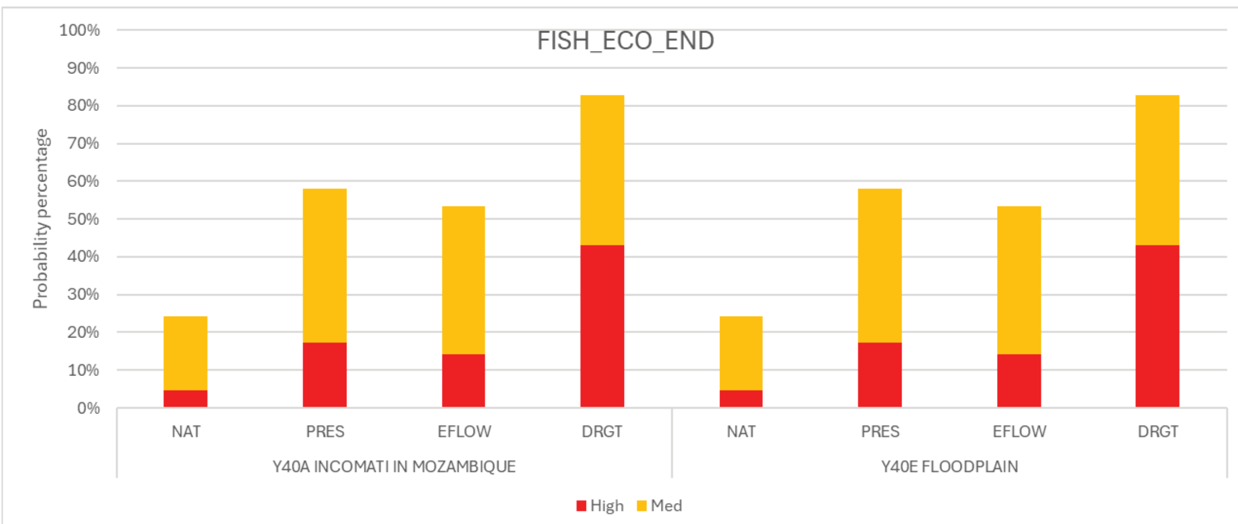


Figure 3-56: The medium and high relative risk scores for the FISH-ECO-END endpoint for the Incomati catchment for each scenario (Natural, Present, E-Flow and Drought).

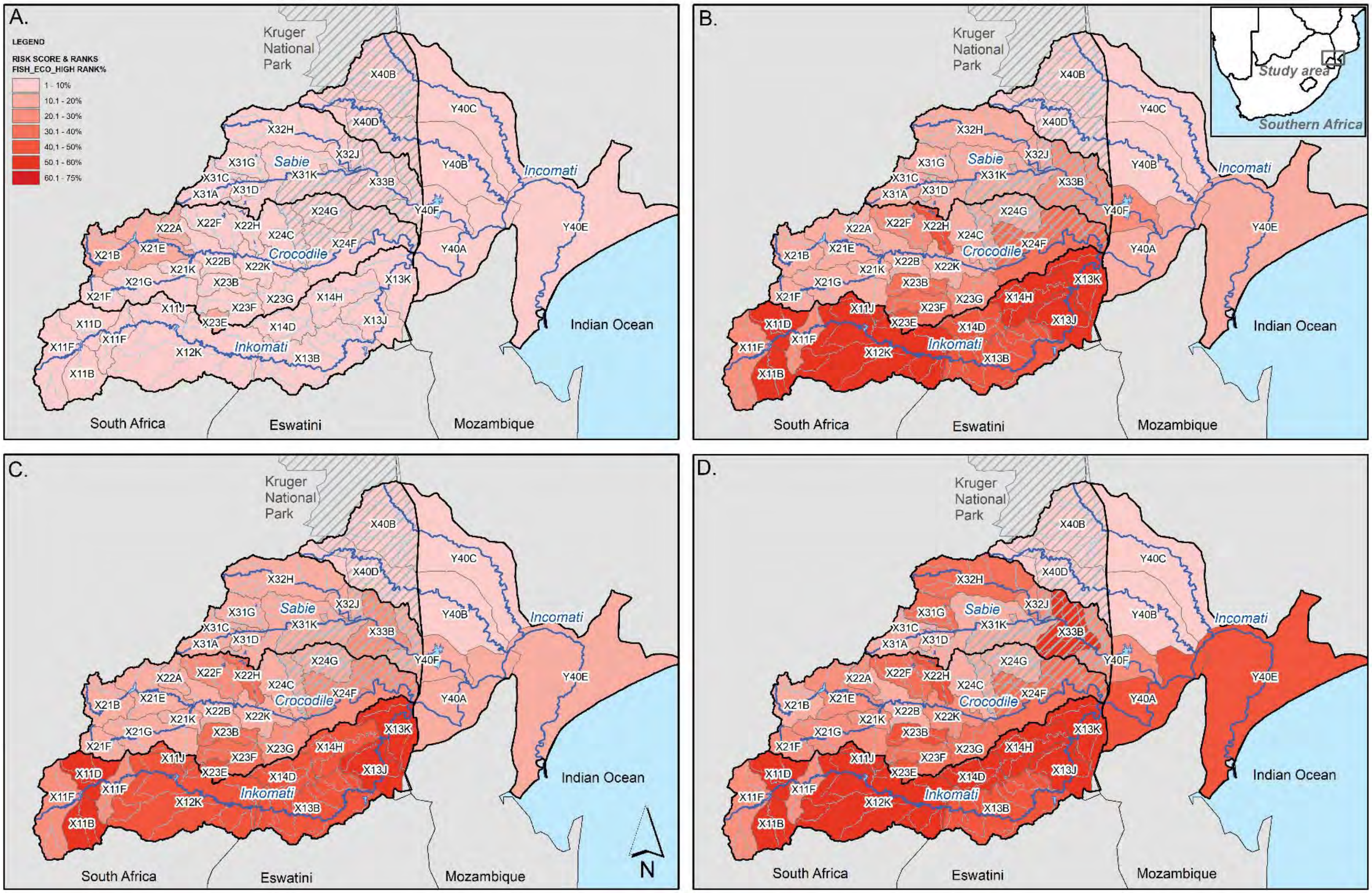


Figure 3-57: The high relative risk scores to FISH-ECO-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought).

3.6.4.1.2 INV-ECO-END endpoint

The following figures below refer to the medium and high relative risk scores for the INV-ECO-END endpoint under each scenario (Natural, Present, E-Flow and Drought) for the Uanetza Catchment (Figure 3-58), the Massintonto Catchment (Figure 3-59), Sabie Catchment (Figure 3-60), Crocodile Catchment (Figure 3-61), Komati Catchment (Figure 3-62) and the Incomati Catchment (Figure 3-63). Figure 3-64 refers to the map illustration of the relative risk scores to the INV-ECO-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought).

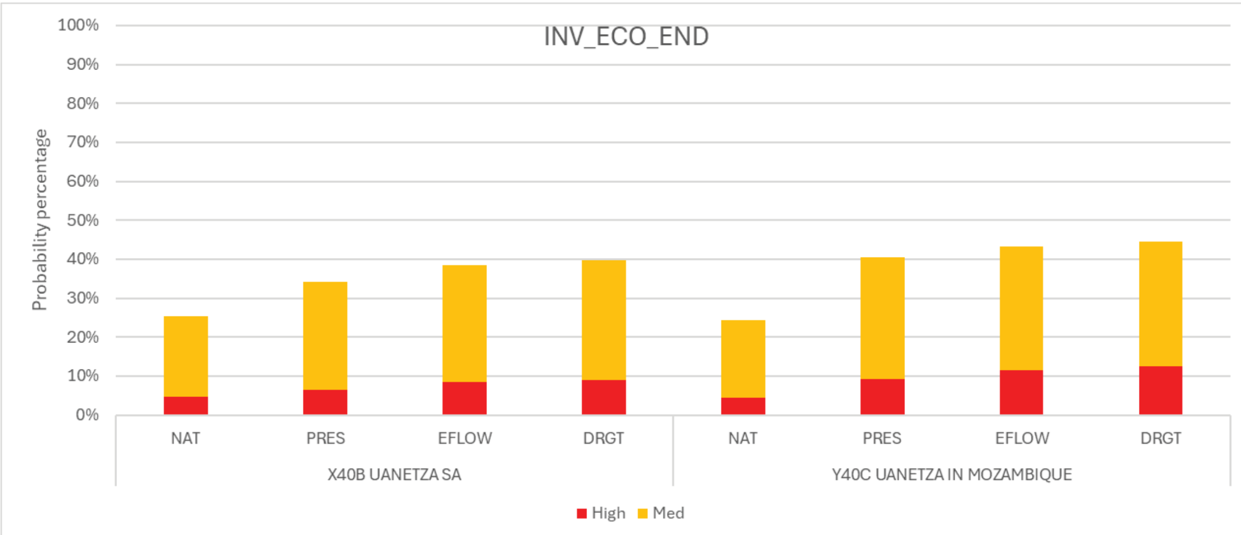


Figure 3-58: The medium and high relative risk scores for the INV-ECO-END endpoint for the Uanetza catchment for each scenario (Natural, Present, E-Flow and Drought).

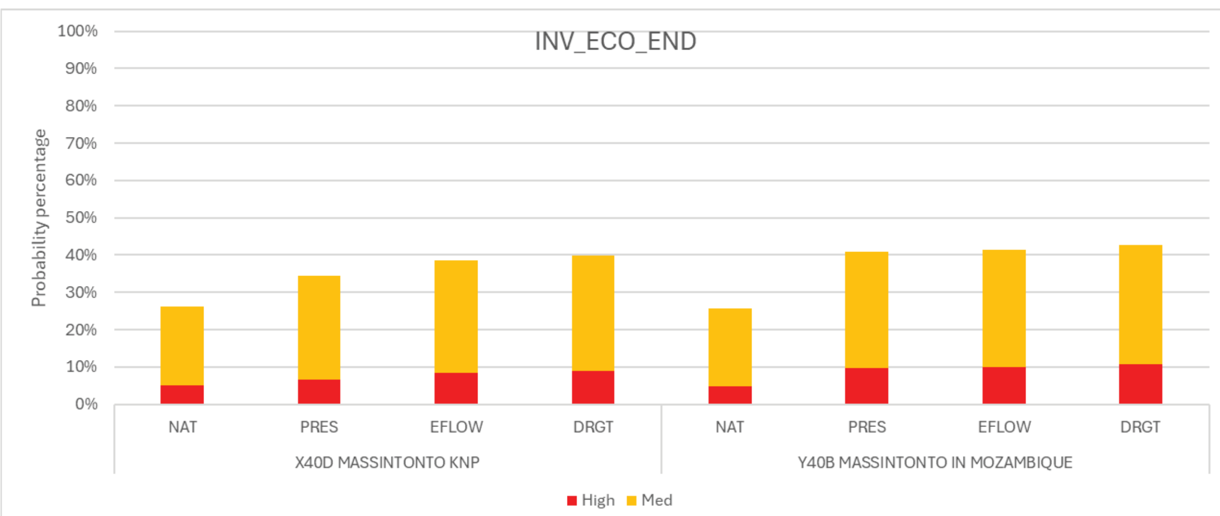


Figure 3-59: The medium and high relative risk scores for the INV-ECO-END endpoint for the Massintonto catchment for each scenario (Natural, Present, E-Flow and Drought).

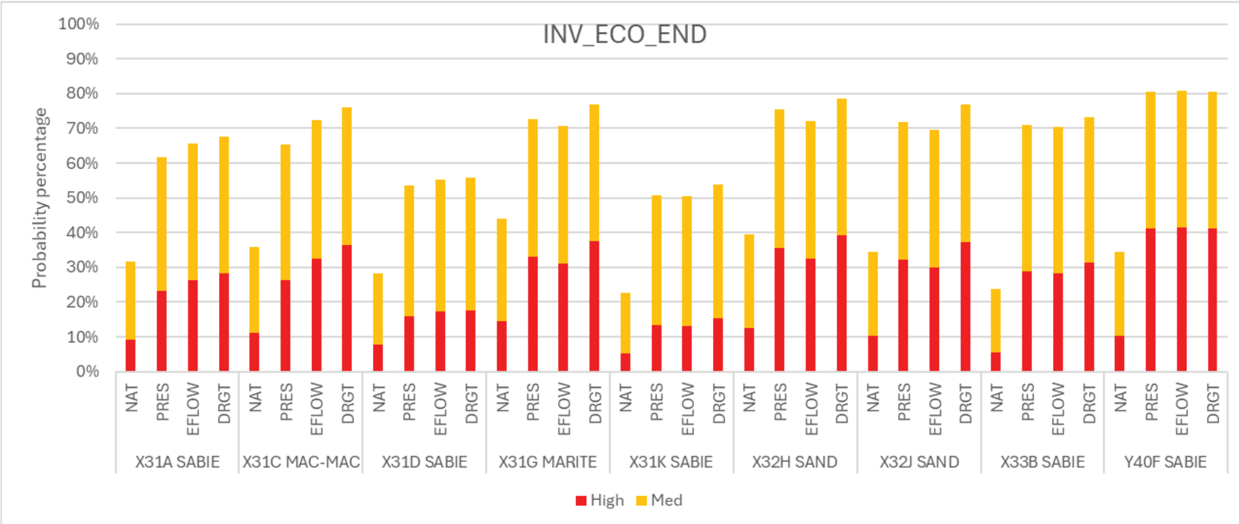


Figure 3-60: The medium and high relative risk scores for the INV-ECO-END endpoint for the Sabie catchment for each scenario (Natural, Present, E-Flow and Drought).

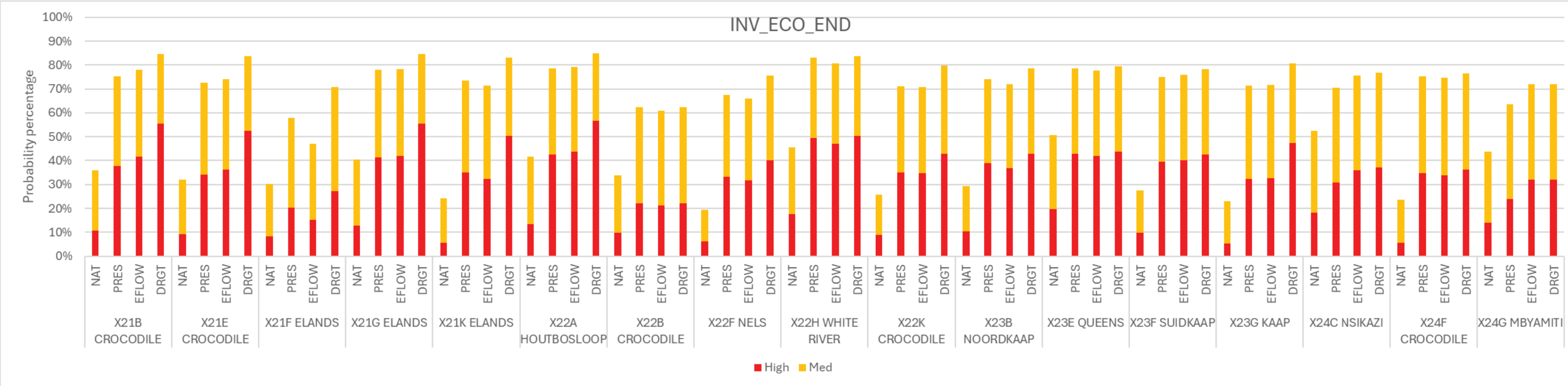


Figure 3-61: The medium and high relative risk scores for the INV-ECO-END endpoint for the Crocodile catchment for each scenario (Natural, Present, E-Flow and Drought).

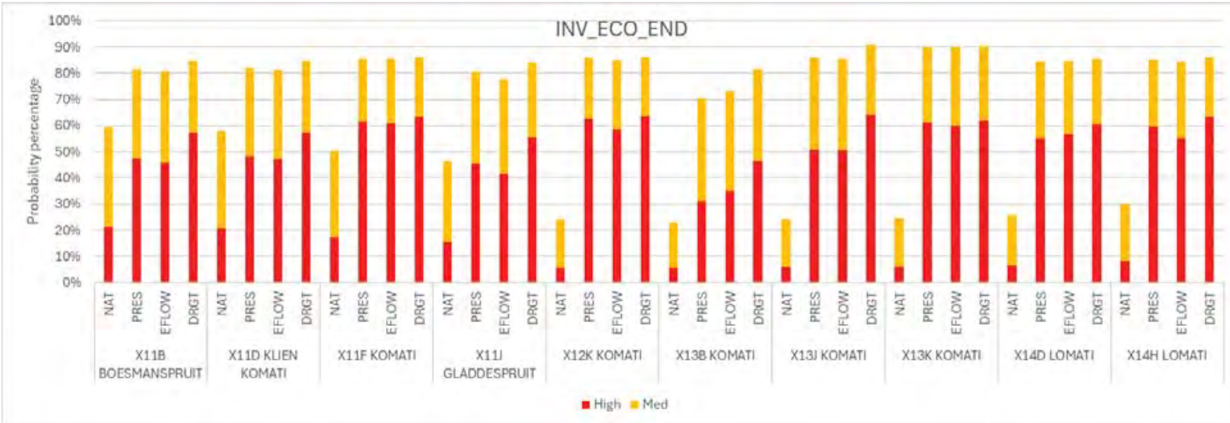


Figure 3-62: The medium and high relative risk scores for the INV-ECO-END endpoint for the Komati catchment for each scenario (Natural, Present, E-Flow and Drought).

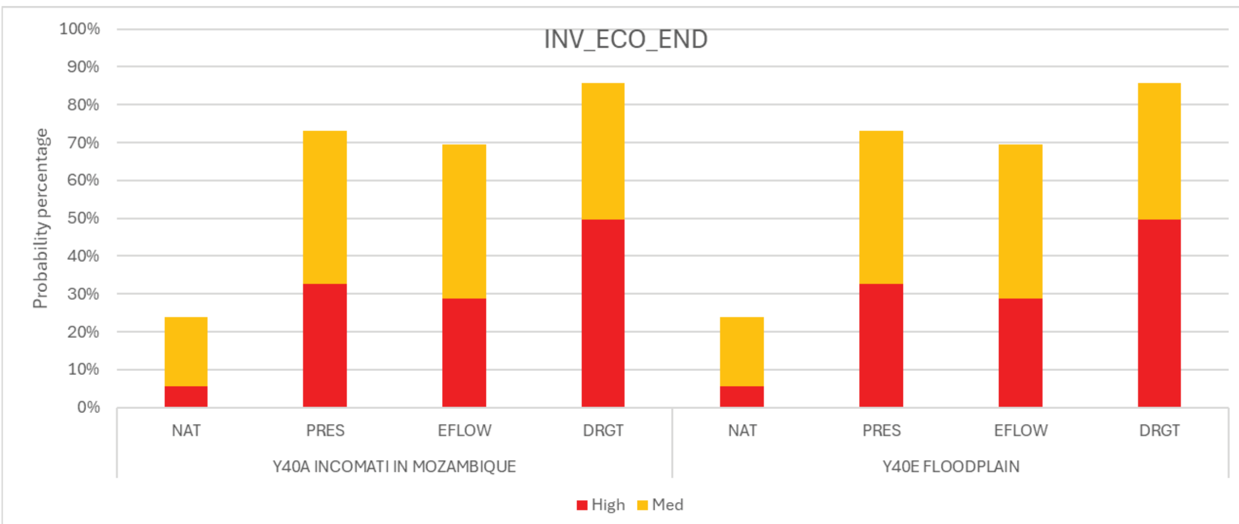


Figure 3-63: The medium and high relative risk scores for the INV-ECO-END endpoint for the Incomati catchment for each scenario (Natural, Present, E-Flow and Drought).

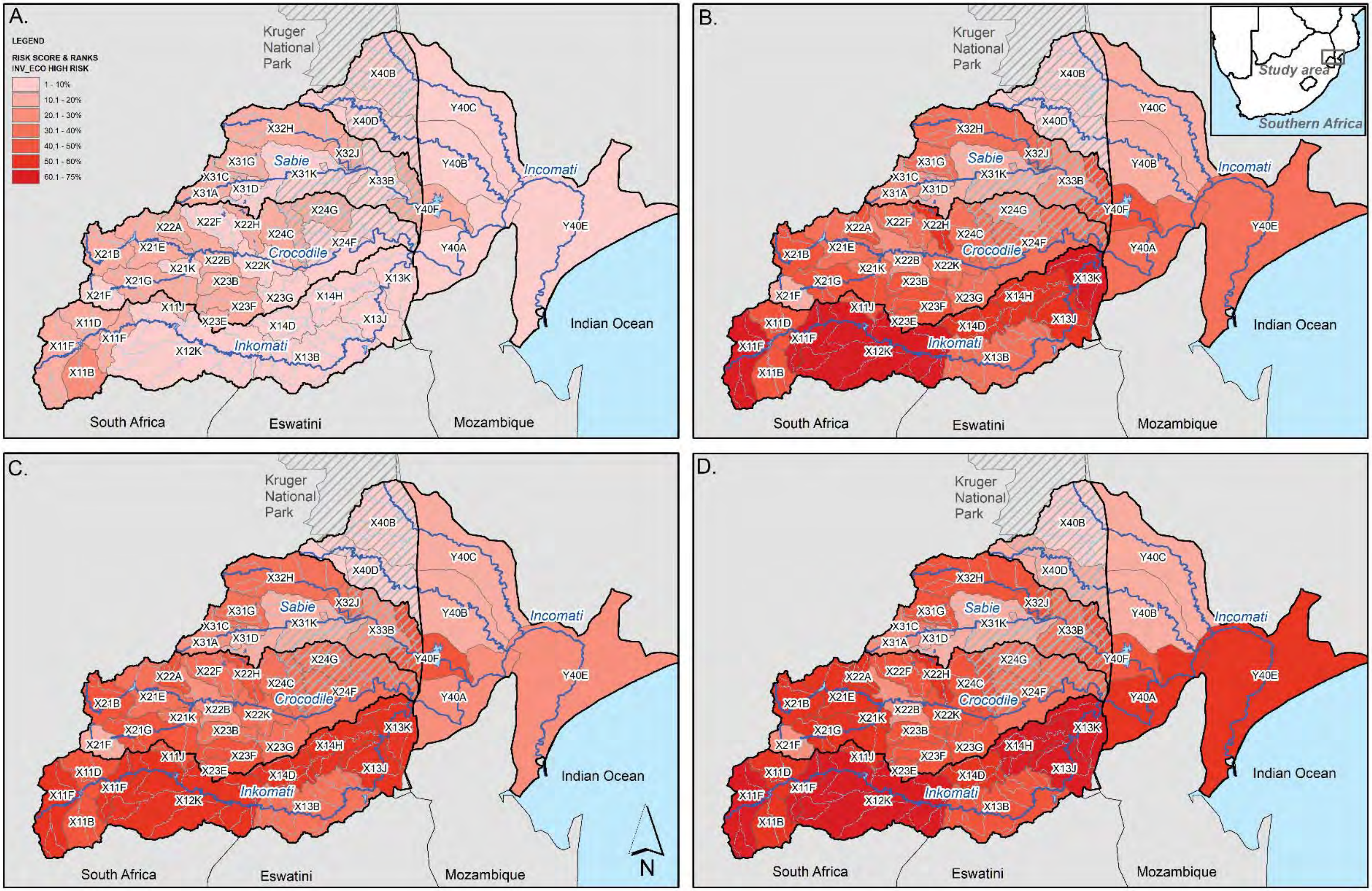


Figure 3-64: The high relative risk scores to INV-ECO-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought).

3.6.4.1.3 VEG-ECO-END endpoint

The following figures below refer to the medium and high relative risk scores for the VEG-ECO-END endpoint under each scenario (Natural, Present, E-Flow and Drought) for the Uanetza Catchment (Figure 3-65), the Massintonto Catchment (Figure 3-66), Sabie Catchment (Figure 3-67), Crocodile Catchment (Figure 3-68), Komati Catchment (Figure 3-69) and the Incomati Catchment (Figure 3-70). Figure 3-71 refers to the map illustration of the relative risk scores to the VEG-ECO-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought).

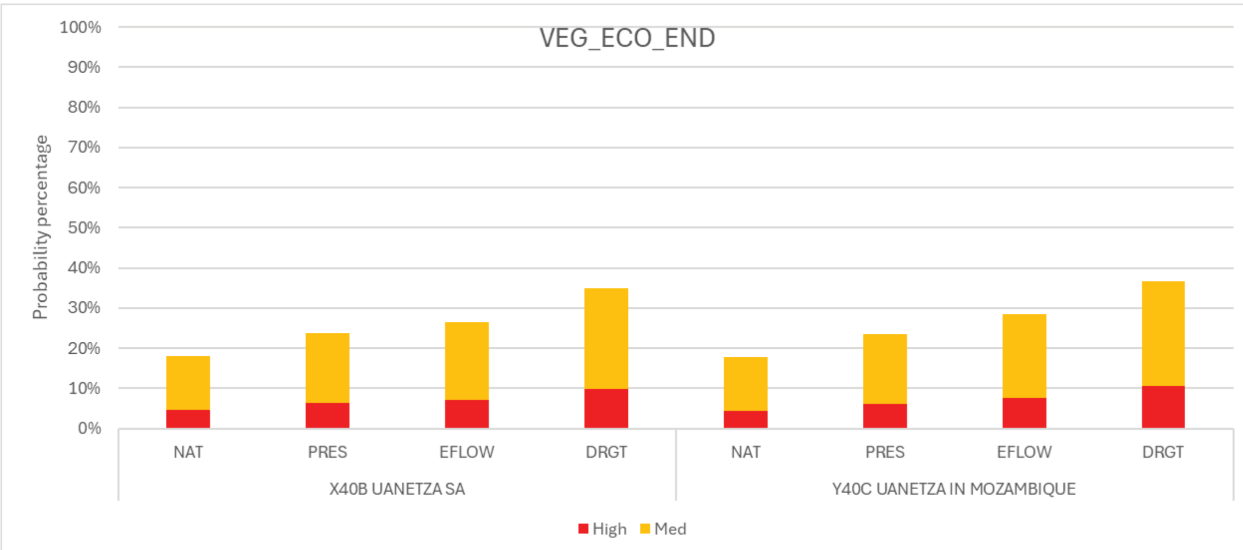


Figure 3-65: The medium and high relative risk scores for the VEG-ECO-END endpoint for the Uanetza catchment for each scenario (Natural, Present, E-Flow and Drought).

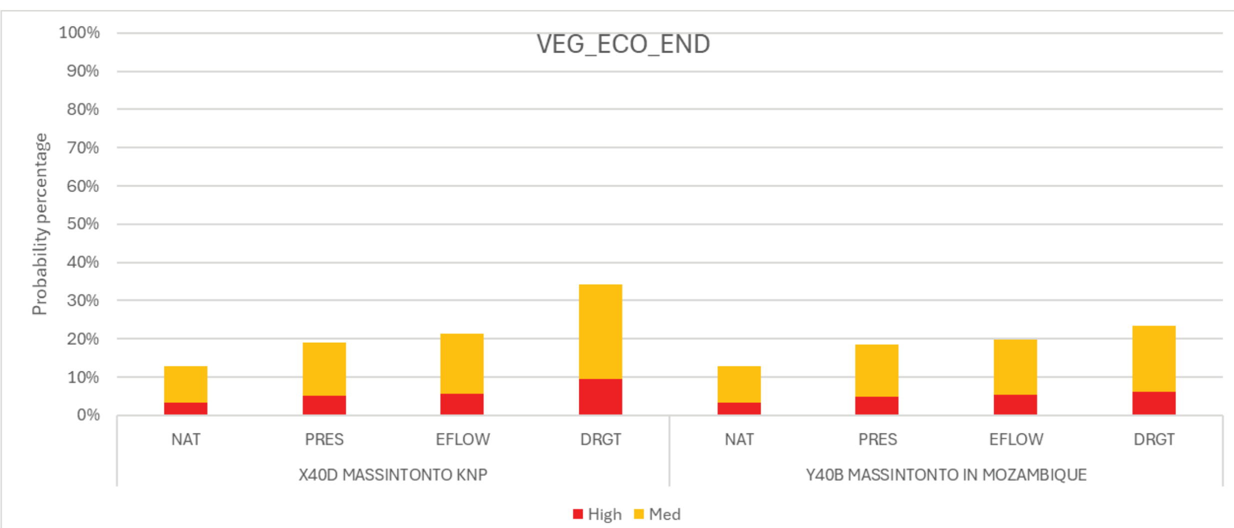


Figure 3-66: The medium and high relative risk scores for the VEG-ECO-END endpoint for the Massintonto catchment for each scenario (Natural, Present, E-Flow and Drought).

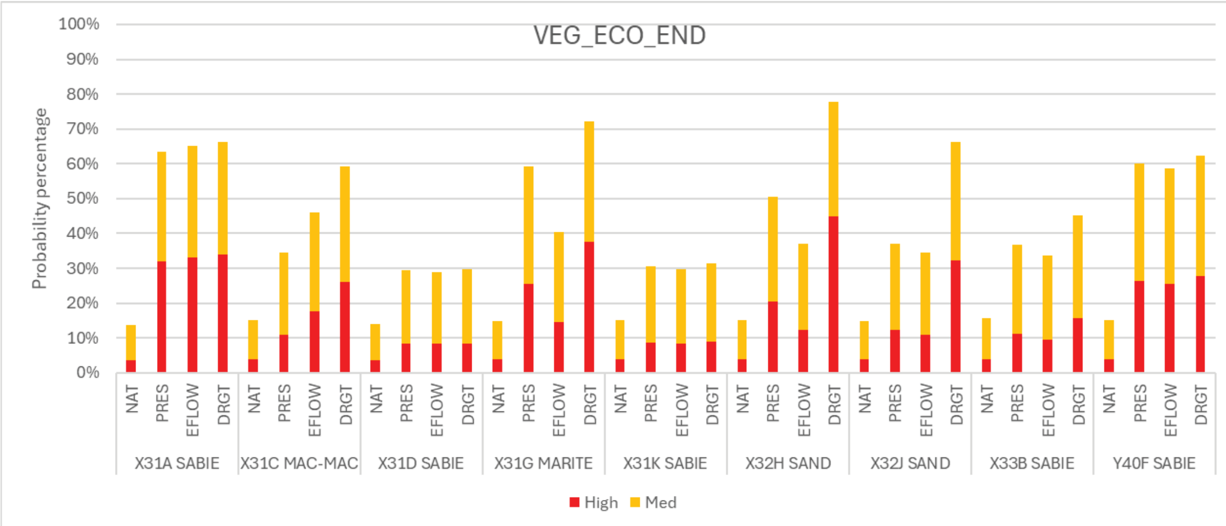


Figure 3-67: The medium and high relative risk scores for the VEG-ECO-END endpoint for the Sabie catchment for each scenario (Natural, Present, E-Flow and Drought).

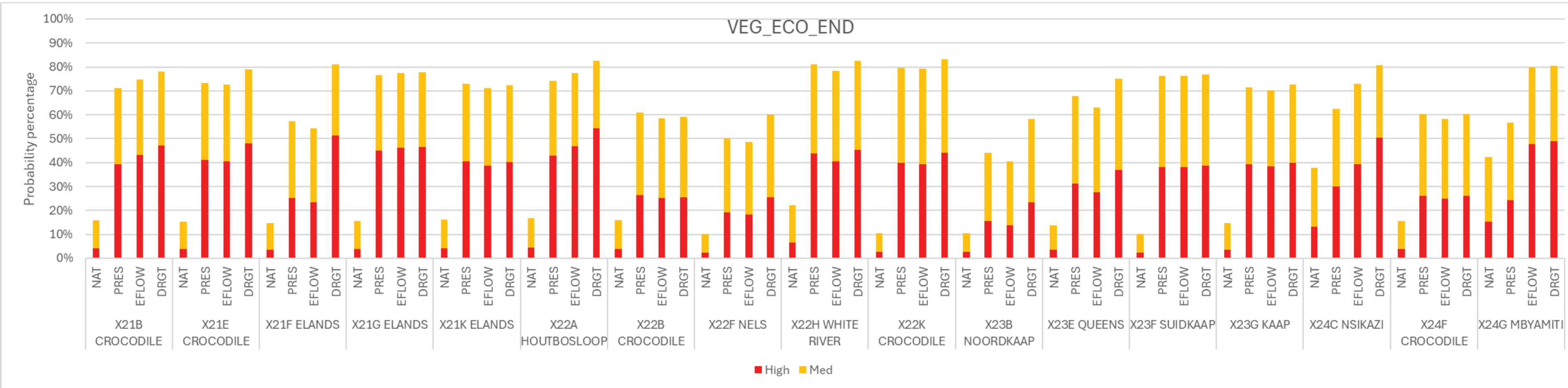


Figure 3-68: The medium and high relative risk scores for the VEG-ECO-END endpoint for the Crocodile catchment for each scenario (Natural, Present, E-Flow and Drought).

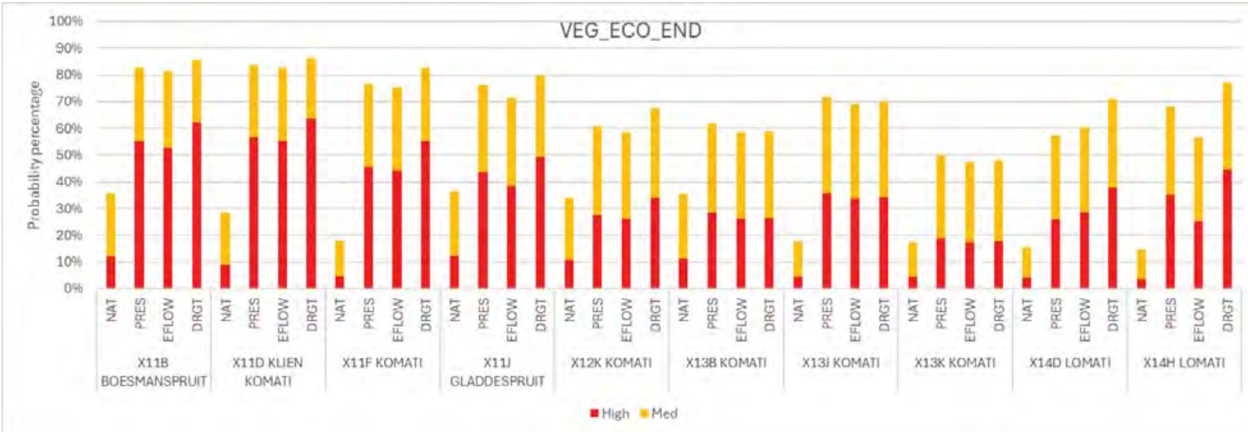


Figure 3-69: The medium and high relative risk scores for the VEG-ECO-END endpoint for the Komati catchment for each scenario (Natural, Present, E-Flow and Drought).

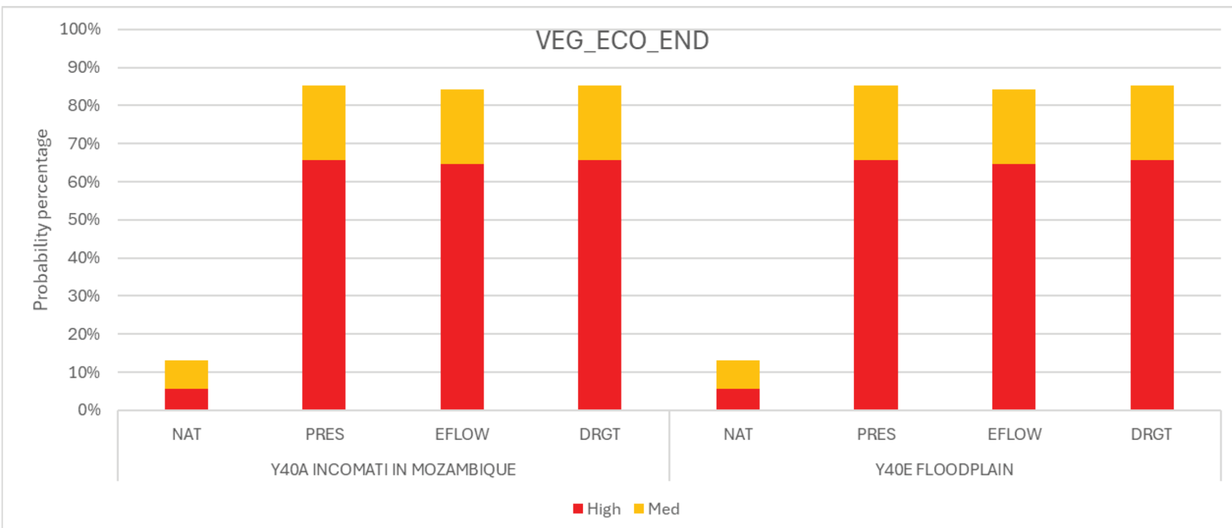


Figure 3-70: The medium and high relative risk scores for the VEG-ECO-END endpoint for the Incomati catchment for each scenario (Natural, Present, E-Flow and Drought).

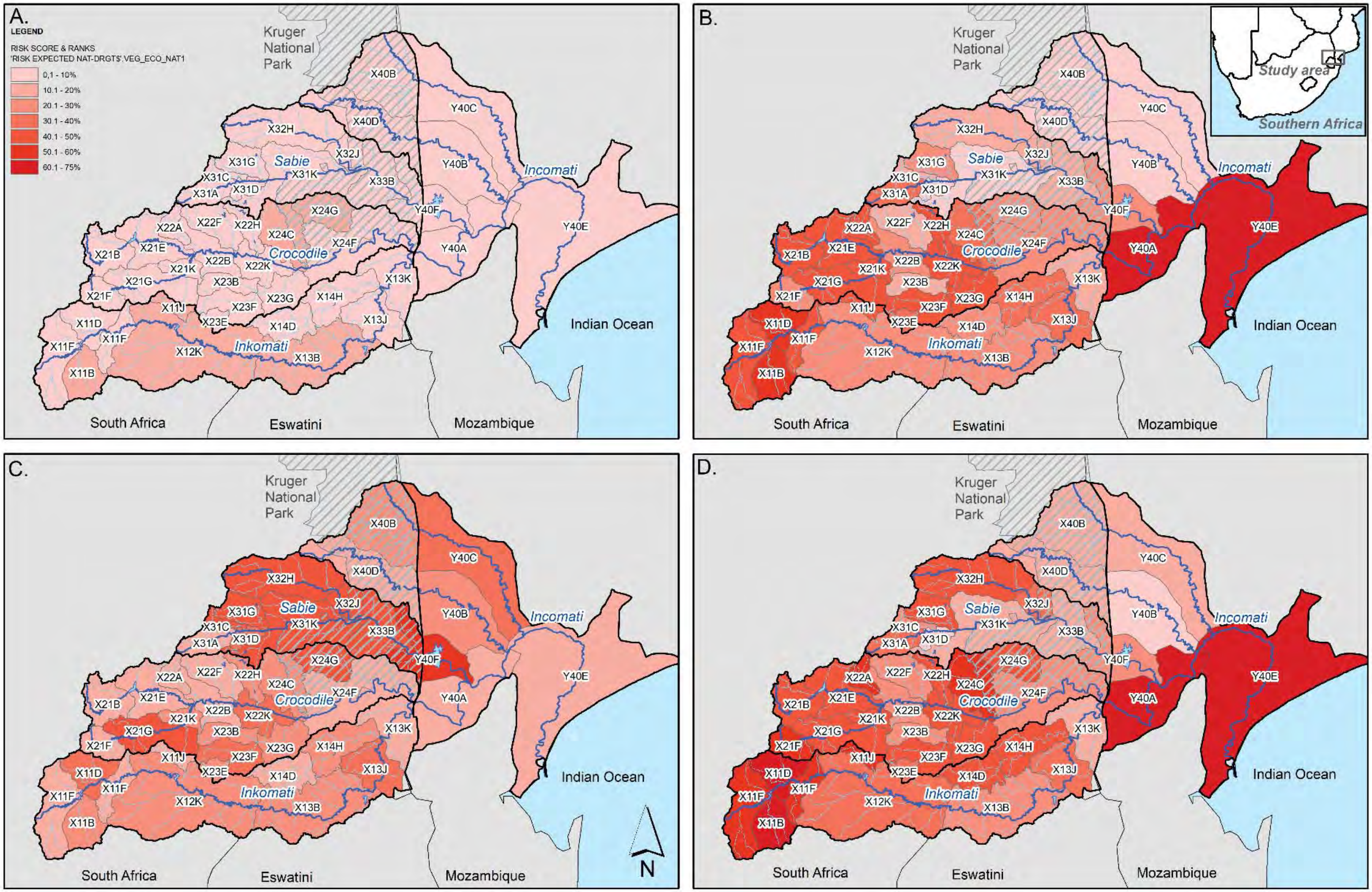


Figure 3-71: The high relative risk scores to VEG-ECO-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought).

3.6.4.2 Provisioning Services

For the SUB-FISH-END endpoint, the risk rank ranges ranged from 22-42% for the natural (NAT) scenario, 28-75% for the present (PES) scenario, 33-75% for the e-flow (EFL) scenario and 34-75% for the drought (DRG) scenario (Figure 3-78). Under the natural scenario (for SUB-FISH-END) the highest risk rank is observed in the Crocodile River Catchment. Under the present scenario (for SUB-FISH-END) the highest risk ranges were observed in the Komati Catchment. Under the e-flow scenario (for SUB-FISH-END) the highest risk ranges were observed in the Komati Catchment. Under the drought scenario (for SUB-FISH-END) the highest risk rank ranges were observed in the Komati Catchment.

For the SUB-VEG-END endpoint, the risk rank ranges ranged from 28-50% for the natural (NAT) scenario, 35-66% for the present (PES) scenario, 35-66% for the e-flow (EFL) scenario and 34-75% for the drought (DRG) scenario (Figure 3-85). Under the natural scenario (for SUB-VEG-END) the highest risk rank is observed for in Uanetza Catchment. Under the present scenario (for SUB-VEG-END) the highest risk ranges were observed in the Crocodile (Nels) and Komati (Klein Komati) Catchments. Under the e-flow scenario (for SUB-VEG-END) the highest risk ranges were observed in the Uanetza and Komati Catchments. Under the drought scenario (for SUB-VEG-END) the highest risk rank ranges were observed in Uanetza in Mozambique Catchment.

For the LIV-VEG-END endpoint, the risk rank ranges ranged from 24-42% for the natural (NAT) scenario, 41-75% for the present (PES) scenario, 39-75% for the e-flow (EFL) scenario and 41-75% for the drought (DRG) scenario (Figure 3-92). Under the natural scenario (for LIV-VEG-END) the highest risk rank is observed for in the Uanetza and Komati River Catchments. Under the present scenario (for LIV-VEG-END) the highest risk ranges were observed in the Sabie Catchment. Under the e-flow scenario (for LIV-VEG-END) the highest risk ranges were observed in the Sabie Catchment (KNP). Under the drought scenario (for LIV-VEG-END) the highest risk rank ranges were observed in the Uanetza (Mozambique), Sabie and Crocodile Catchments.

For the DOM-WAT-END endpoint, the risk rank ranges ranged from 55-66% for the natural (NAT) scenario, 25-66% for the present (PES) scenario, 31-66% for the e-flow (EFL) scenario and 28-66% for the drought (DRG) scenario (Figure 3-99). Under the natural scenario (for DOM-WAT-END) the highest risk rank is observed for in the Uanetza, Massintonto and Komati River Catchments. Under the present scenario (for DOM-WAT-END) the highest risk ranges were observed in the Crocodile and Komati Catchments. Under the e-flow scenario (for DOM-WAT-END) the highest risk ranges were observed in the Crocodile Catchment. Under the drought scenario (for DOM-WAT-END) the highest risk rank ranges were observed in the Uanetza (Mozambique) and Crocodile Catchments.

3.6.4.2.1 SUB-FISH-END endpoint

The following figures below refer to the medium and high relative risk scores for the SUB-FISH-END endpoint under each scenario (Natural, Present, E-Flow and Drought) for the Uanetza Catchment (Figure 3-72), the Massintonto Catchment (Figure 3-73), Sabie Catchment (Figure 3-74), Crocodile Catchment (Figure 3-75), Komati Catchment (Figure 3-76) and the Incomati Catchment (Figure 3-77). Figure 3-78 refers to the map illustration of the relative risk scores to the SUB-FISH-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought).

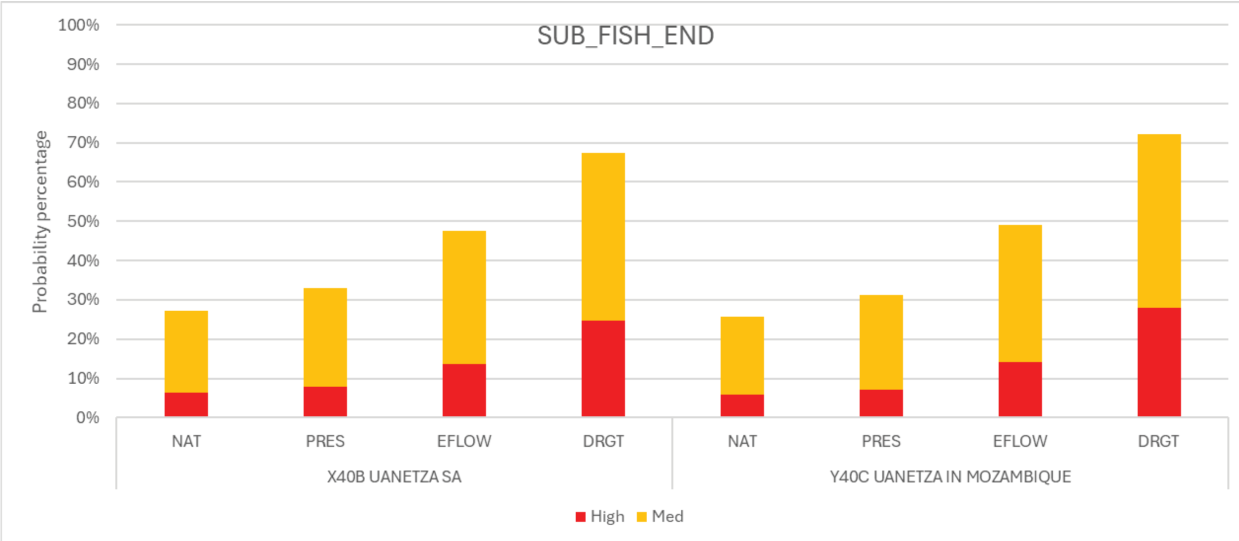


Figure 3-72: The medium and high relative risk scores for the SUB-FISH-END endpoint for the Uanetza catchment for each scenario (Natural, Present, E-Flow and Drought).

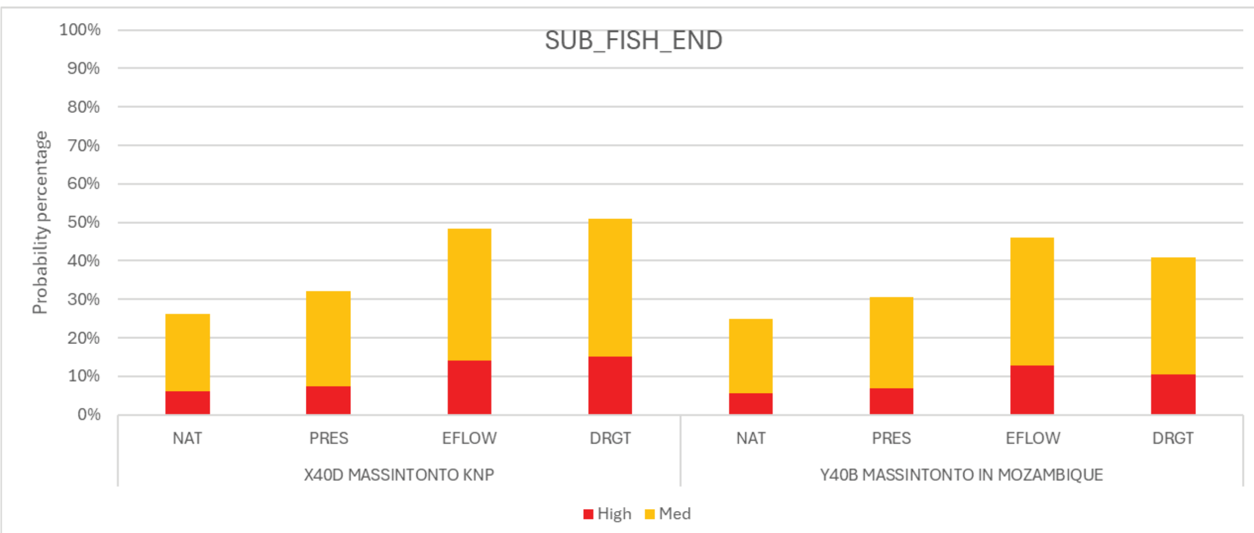


Figure 3-73: The medium and high relative risk scores for the SUB-FISH-END endpoint for the Massintonto catchment for each scenario (Natural, Present, E-Flow and Drought).

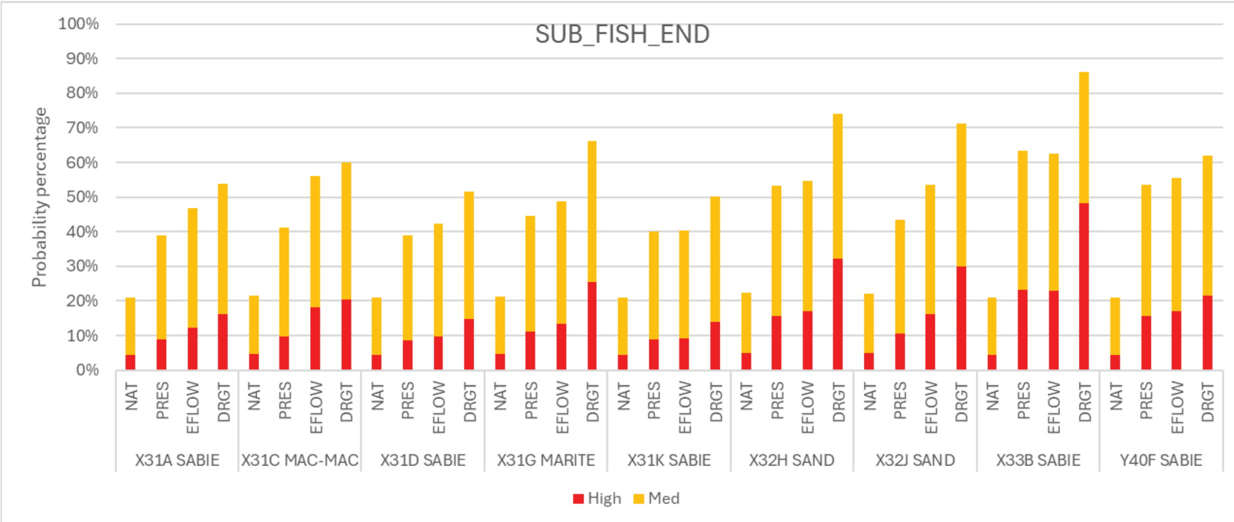


Figure 3-74: The medium and high relative risk scores for the SUB-FISH-END endpoint for the Sabi catchment for each scenario (Natural, Present, E-Flow and Drought).

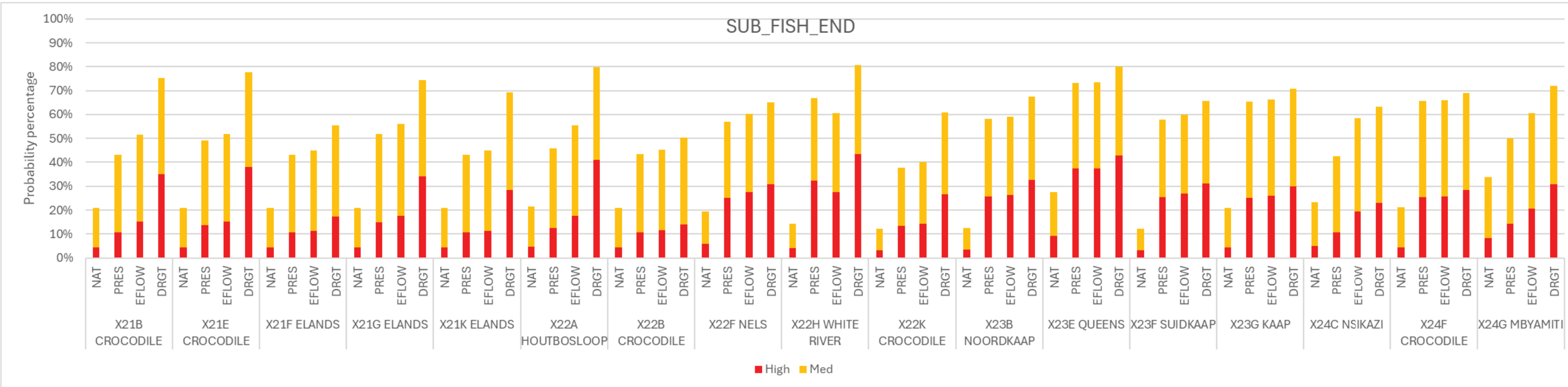


Figure 3-75: The medium and high relative risk scores for the SUB-FISH-END endpoint for the Crocodile catchment for each scenario (Natural, Present, E-Flow and Drought).

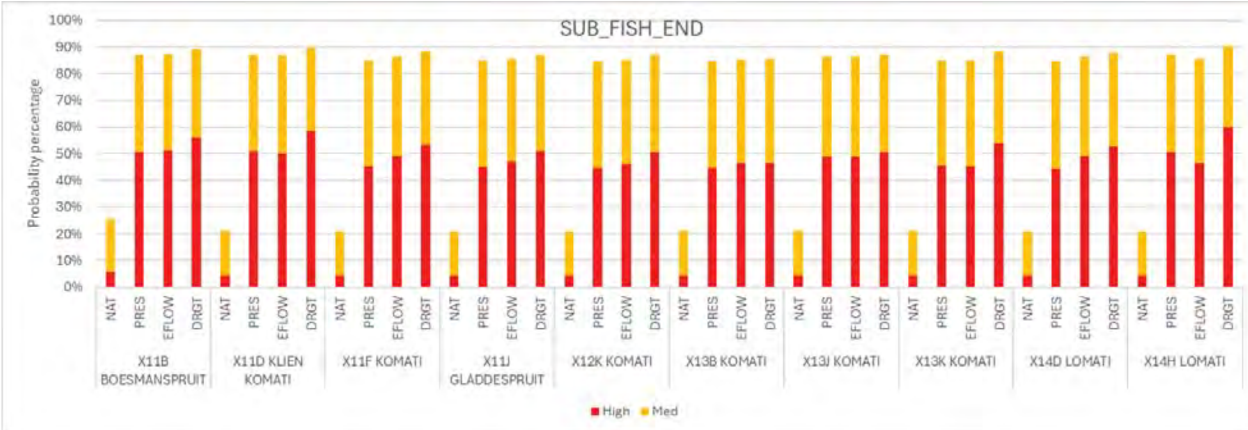


Figure 3-76: The medium and high relative risk scores for the SUB-FISH-END endpoint for the Komati catchment for each scenario (Natural, Present, E-Flow and Drought).

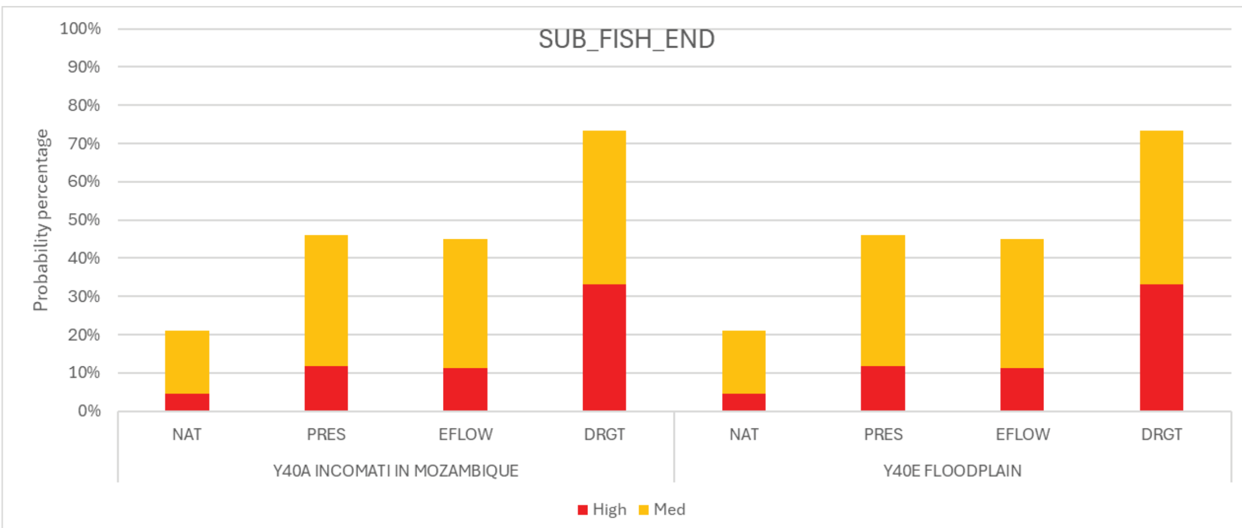


Figure 3-77: The medium and high relative risk scores for the SUB-FISH-END endpoint for the Incomati catchment for each scenario (Natural, Present, E-Flow and Drought).

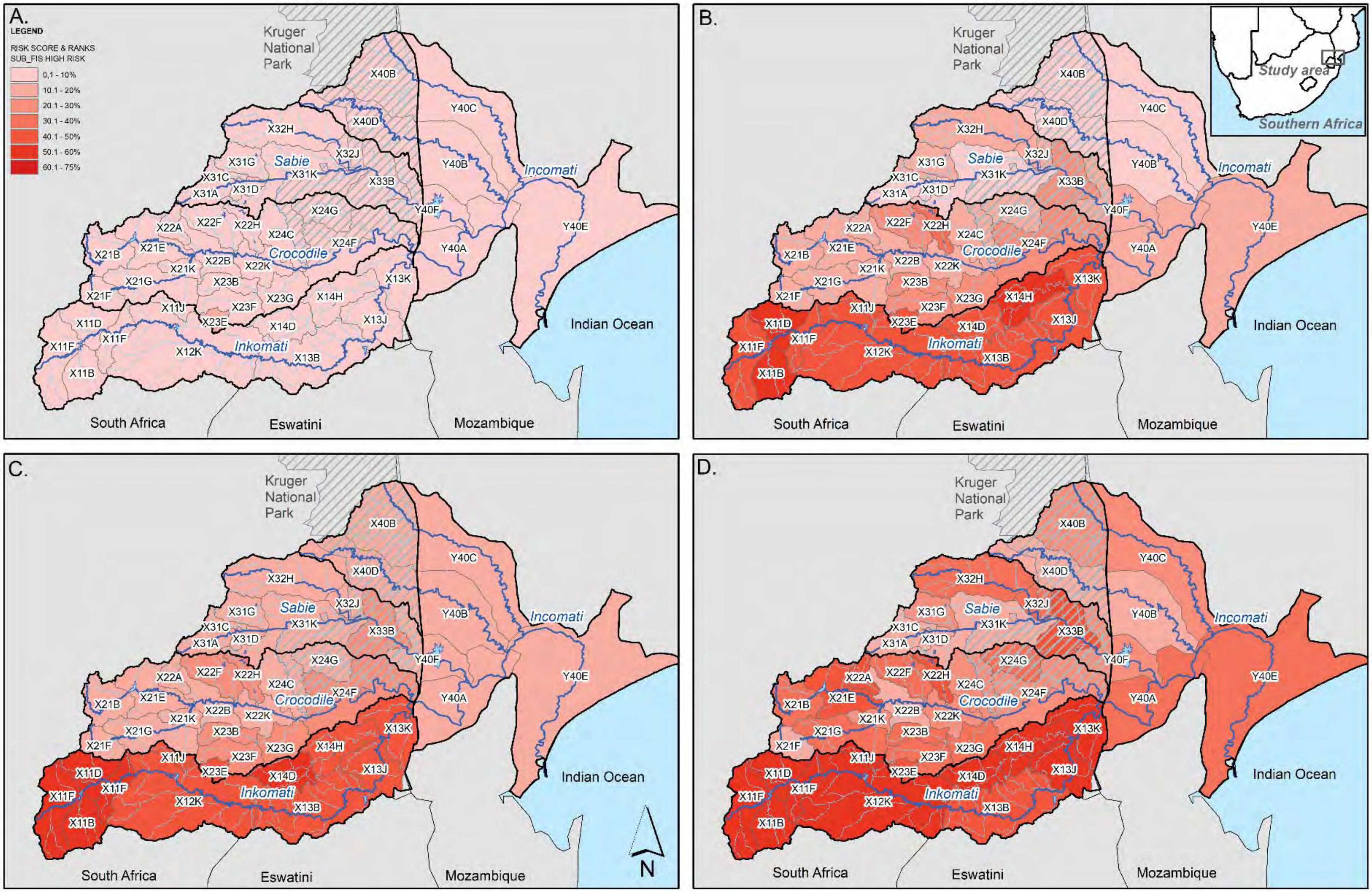


Figure 3-78: The high relative risk scores to SUB-FISH-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought).

3.6.4.2.2 SUB-VEG-END endpoint

The following figures below refer to the medium and high relative risk scores for the SUB-VEG-END endpoint under each scenario (Natural, Present, E-Flow and Drought) for the Uanetza Catchment (Figure 3-79), the Massintonto Catchment (Figure 3-80), Sabie Catchment (Figure 3-81), Crocodile Catchment (Figure 3-82), Komati Catchment (Figure 3-83) and the Incomati Catchment (Figure 3-84). Figure 3-85 refers to the map illustration of the relative risk scores to the SUB-VEG-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought).

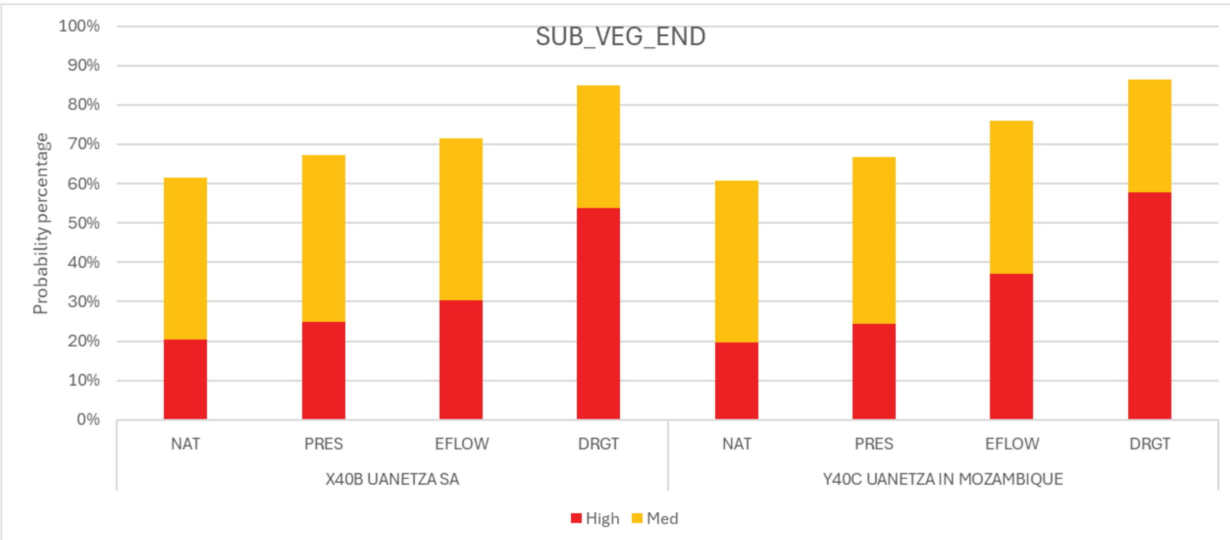


Figure 3-79: The medium and high relative risk scores for the SUB-VEG-END endpoint for the Uanetza catchment for each scenario (Natural, Present, E-Flow and Drought).

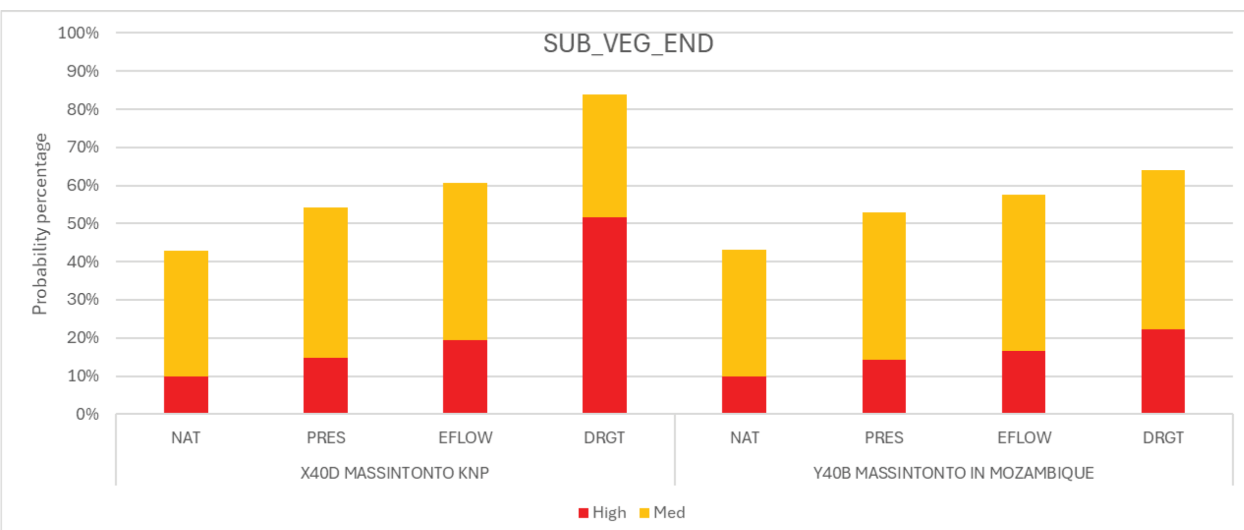


Figure 3-80: The medium and high relative risk scores for the SUB-VEG-END endpoint for the Massintonto catchment for each scenario (Natural, Present, E-Flow and Drought).

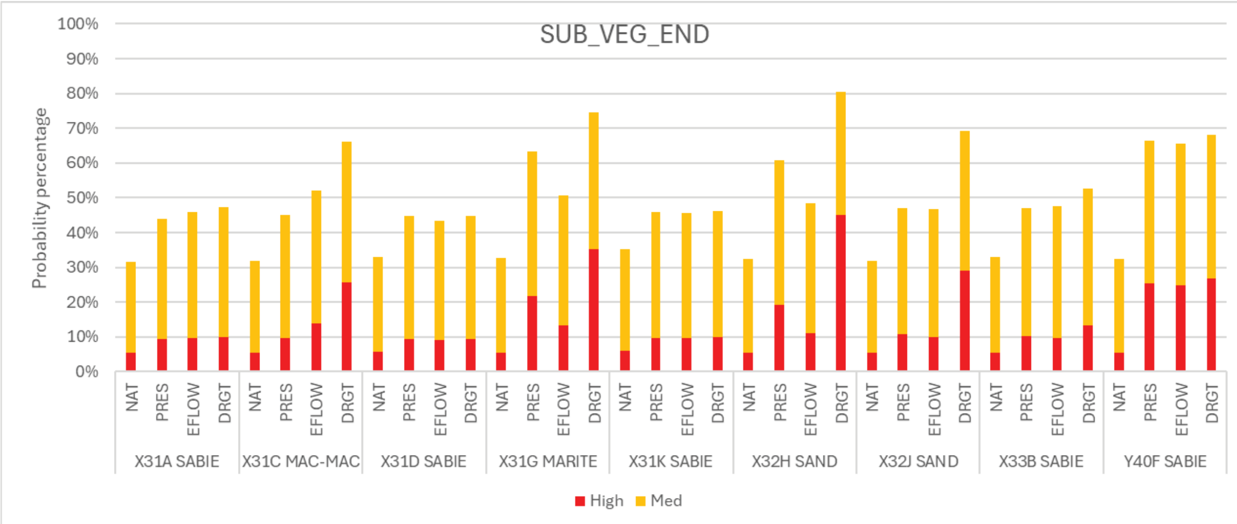


Figure 3-81: The medium and high relative risk scores for the SUB-VEG-END endpoint for the Sabie catchment for each scenario (Natural, Present, E-Flow and Drought).

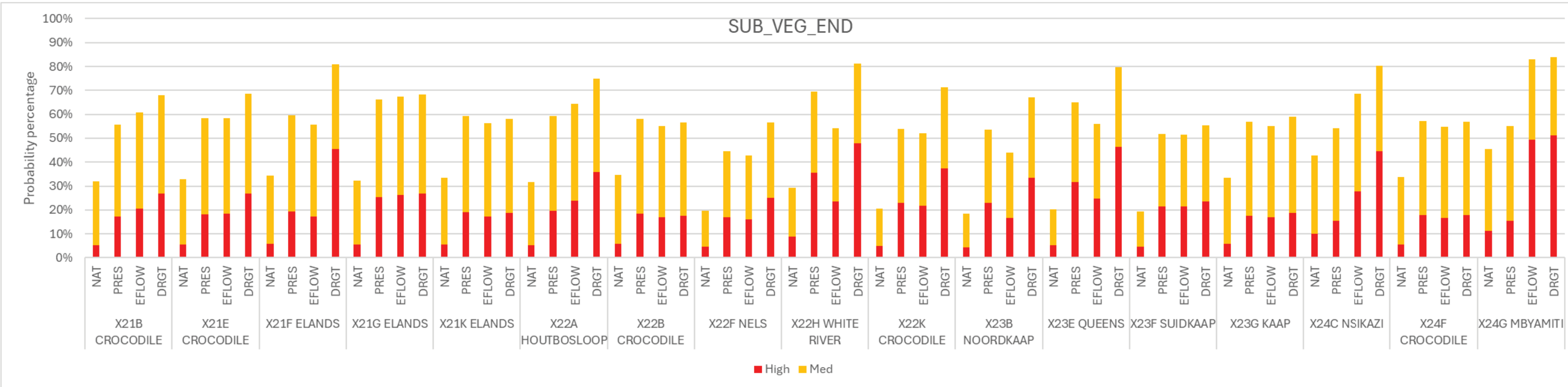


Figure 3-82: The medium and high relative risk scores for the SUB-VEG-END endpoint for the Crocodile catchment for each scenario (Natural, Present, E-Flow and Drought).

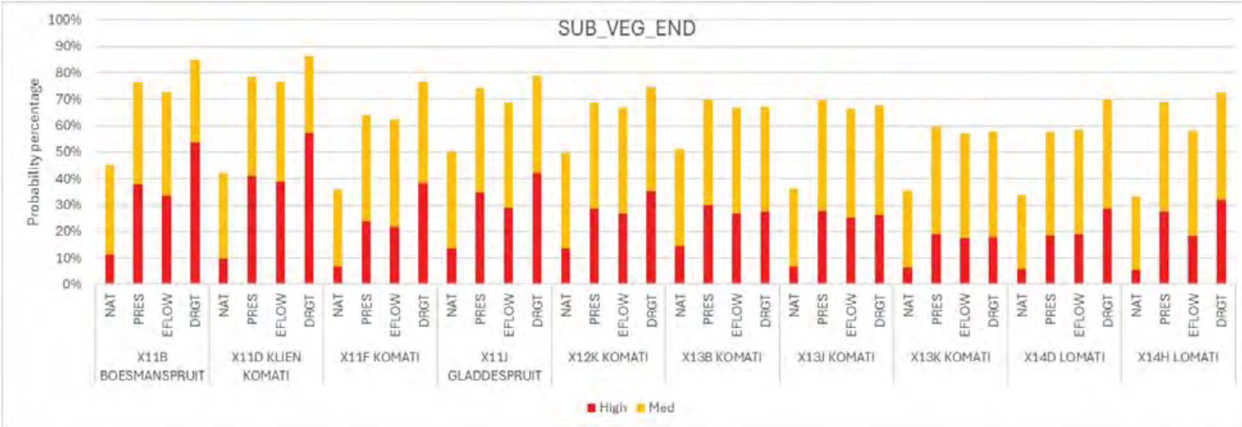


Figure 3-83: The medium and high relative risk scores for the SUB-VEG-END endpoint for the Komati catchment for each scenario (Natural, Present, E-Flow and Drought).

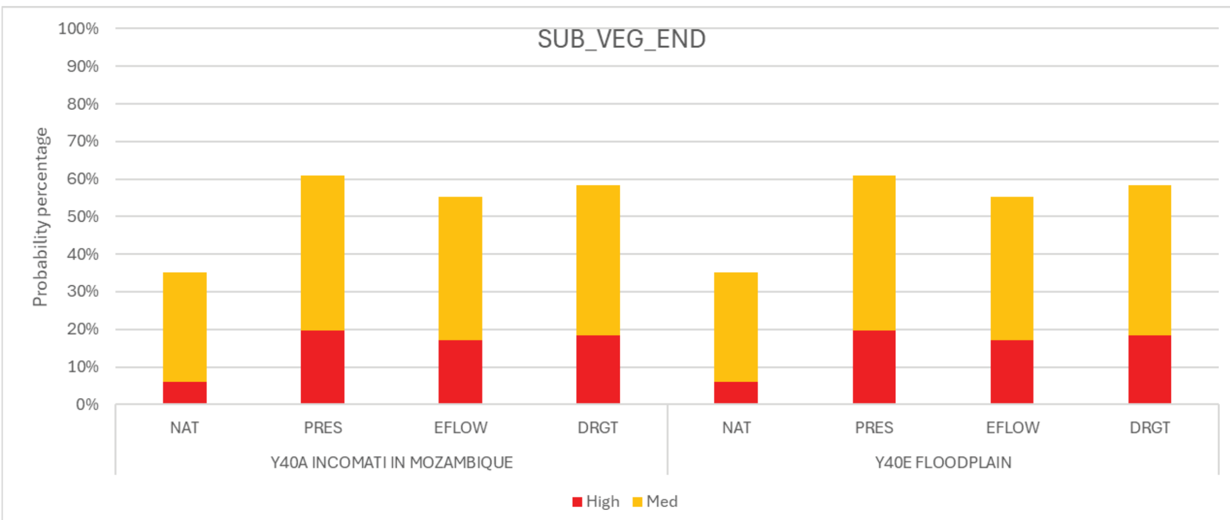


Figure 3-84: The medium and high relative risk scores for the SUB-VEG-END endpoint for the Incomati catchment for each scenario (Natural, Present, E-Flow and Drought).

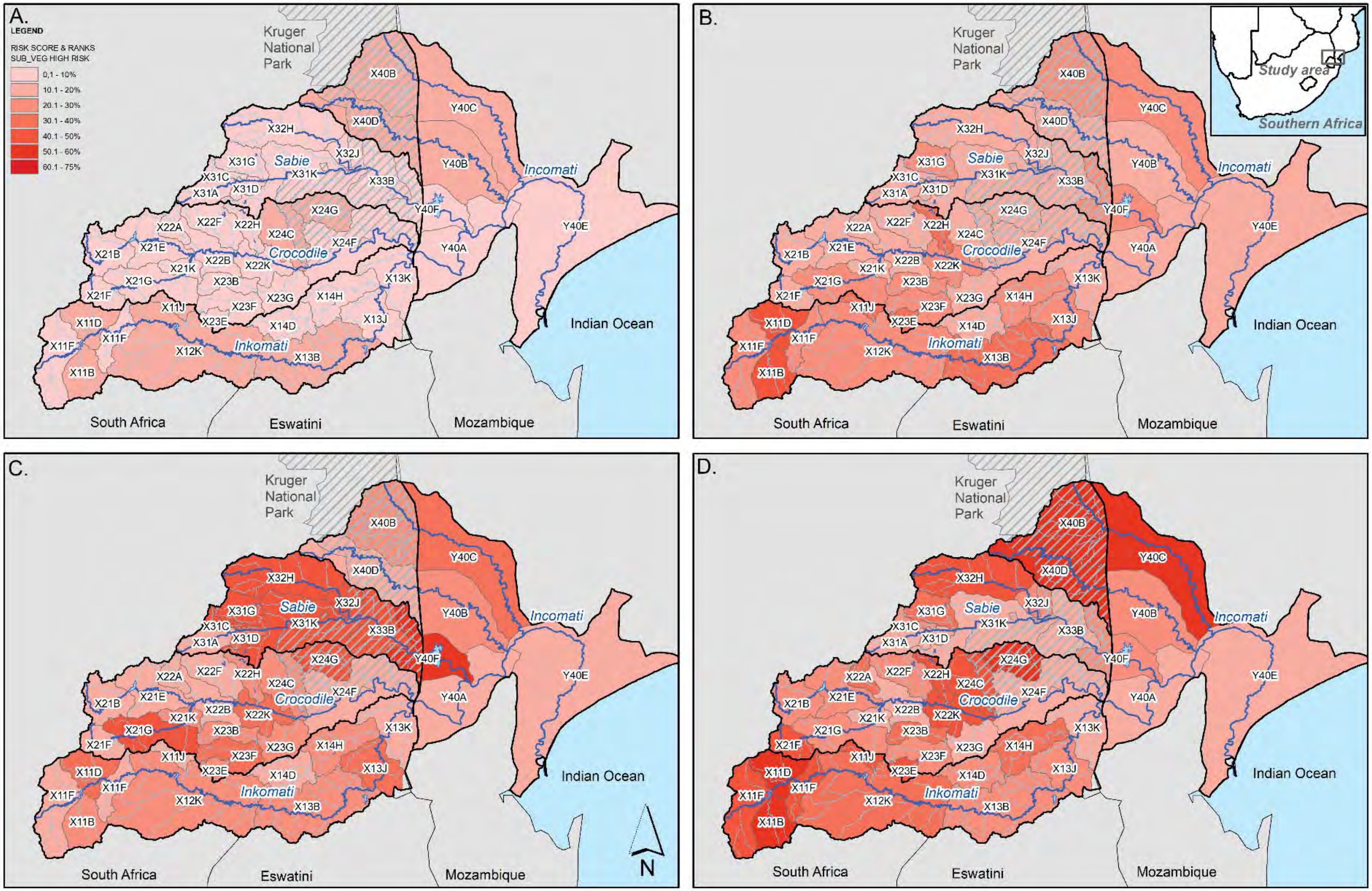


Figure 3-85: The high relative risk scores to SUB-VEG-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought).

3.6.4.2.3 LIV-VEG-END endpoint

The following figures below refer to the medium and high relative risk scores for the LIV-VEG-END endpoint under each scenario (Natural, Present, E-Flow and Drought) for the Uanetza Catchment (Figure 3-86), the Massintonto Catchment (Figure 3-87), Sabie Catchment (Figure 3-88), Crocodile Catchment (Figure 3-89), Komati Catchment (Figure 3-90) and the Incomati Catchment (Figure 3-91). Figure 3-92 refers to the map illustration of the relative risk scores to the LIV-VEG-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought).

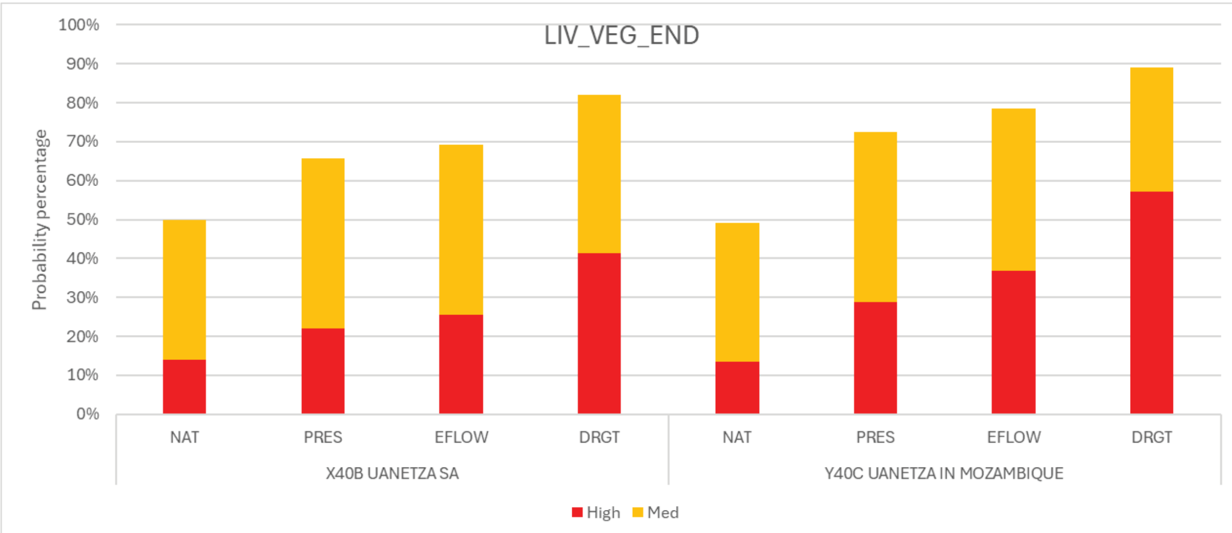


Figure 3-86: The medium and high relative risk scores for the LIV-VEG-END endpoint for the Uanetza catchment for each scenario (Natural, Present, E-Flow and Drought).

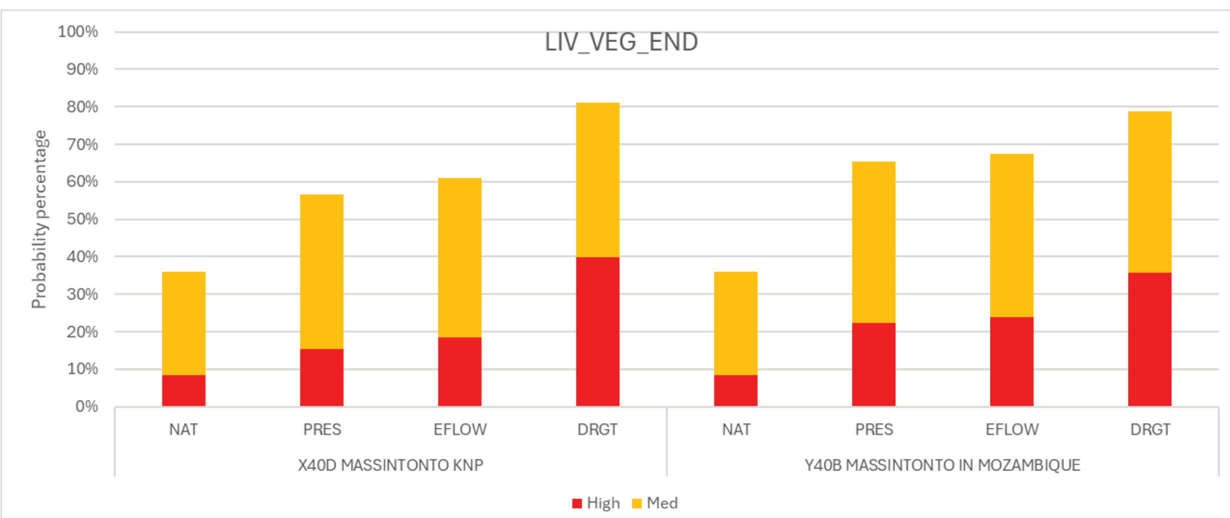


Figure 3-87: The medium and high relative risk scores for the LIV-VEG-END endpoint for the Massintonto catchment for each scenario (Natural, Present, E-Flow and Drought).

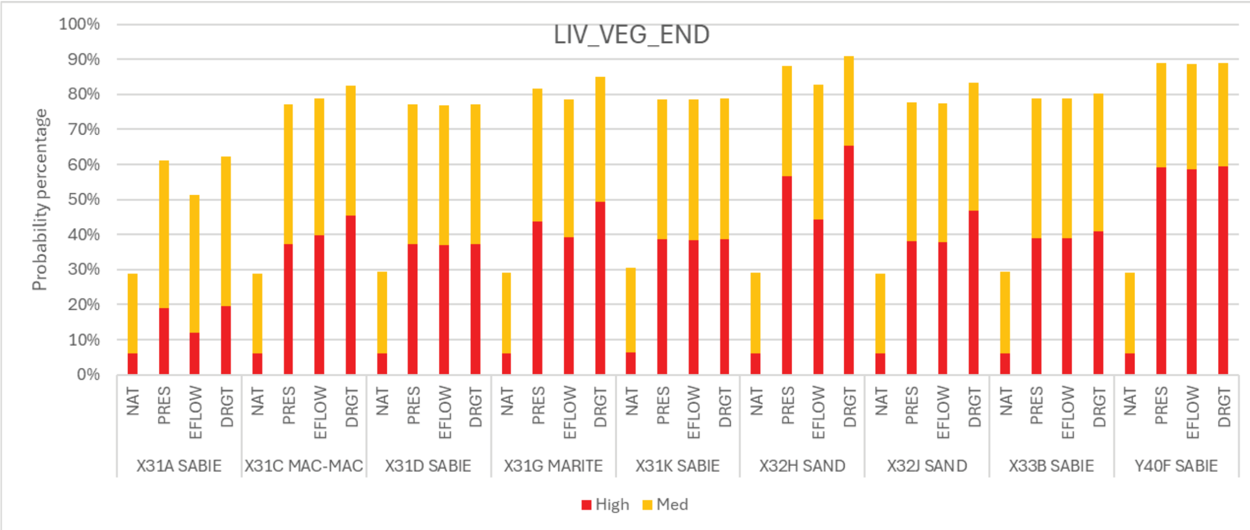


Figure 3-88: The medium and high relative risk scores for the LIV-VEG-END endpoint for the Sabie catchment for each scenario (Natural, Present, E-Flow and Drought).

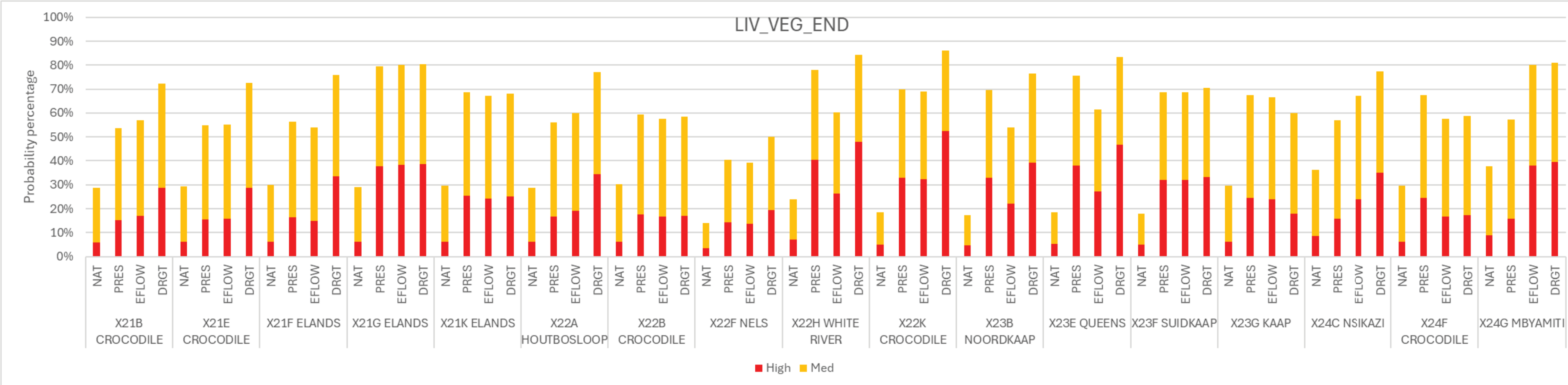


Figure 3-89: The medium and high relative risk scores for the LIV-VEG-END endpoint for the Crocodile catchment for each scenario (Natural, Present, E-Flow and Drought).

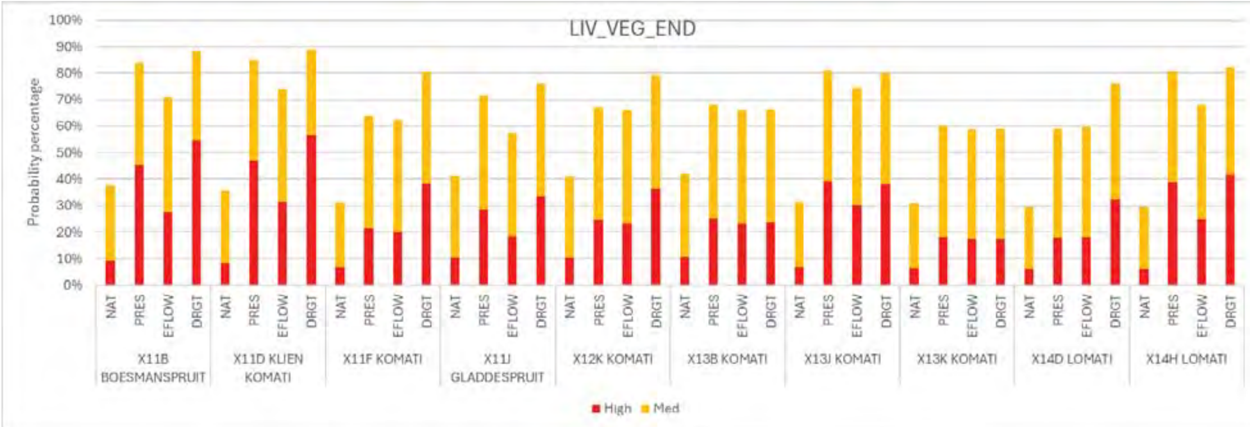


Figure 3-90: The medium and high relative risk scores for the LIV-VEG-END endpoint for the Komati catchment for each scenario (Natural, Present, E-Flow and Drought).

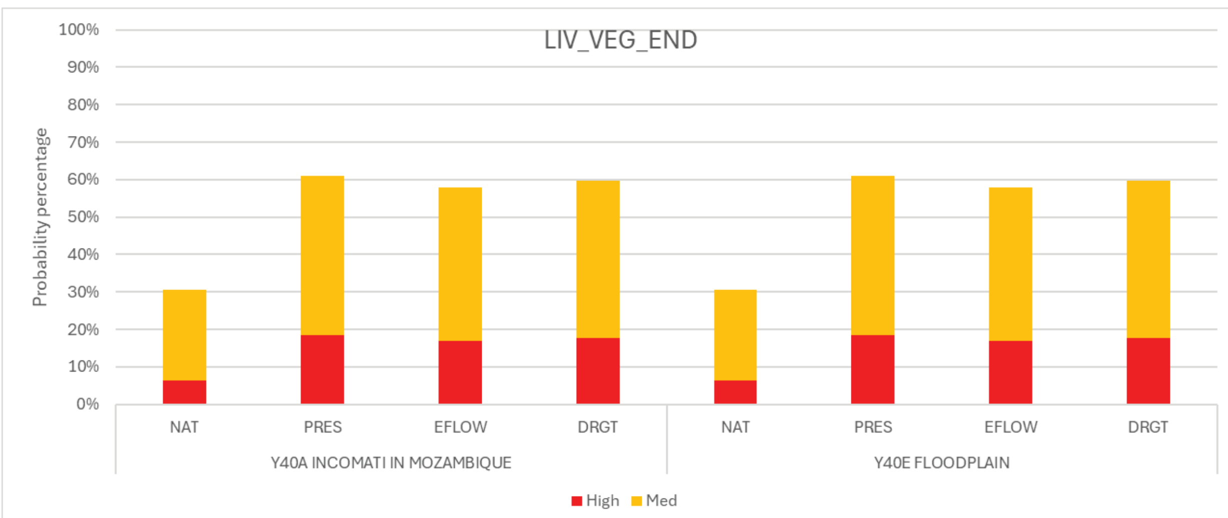


Figure 3-91: The medium and high relative risk scores for the LIV-VEG-END endpoint for the Incomati catchment for each scenario (Natural, Present, E-Flow and Drought).

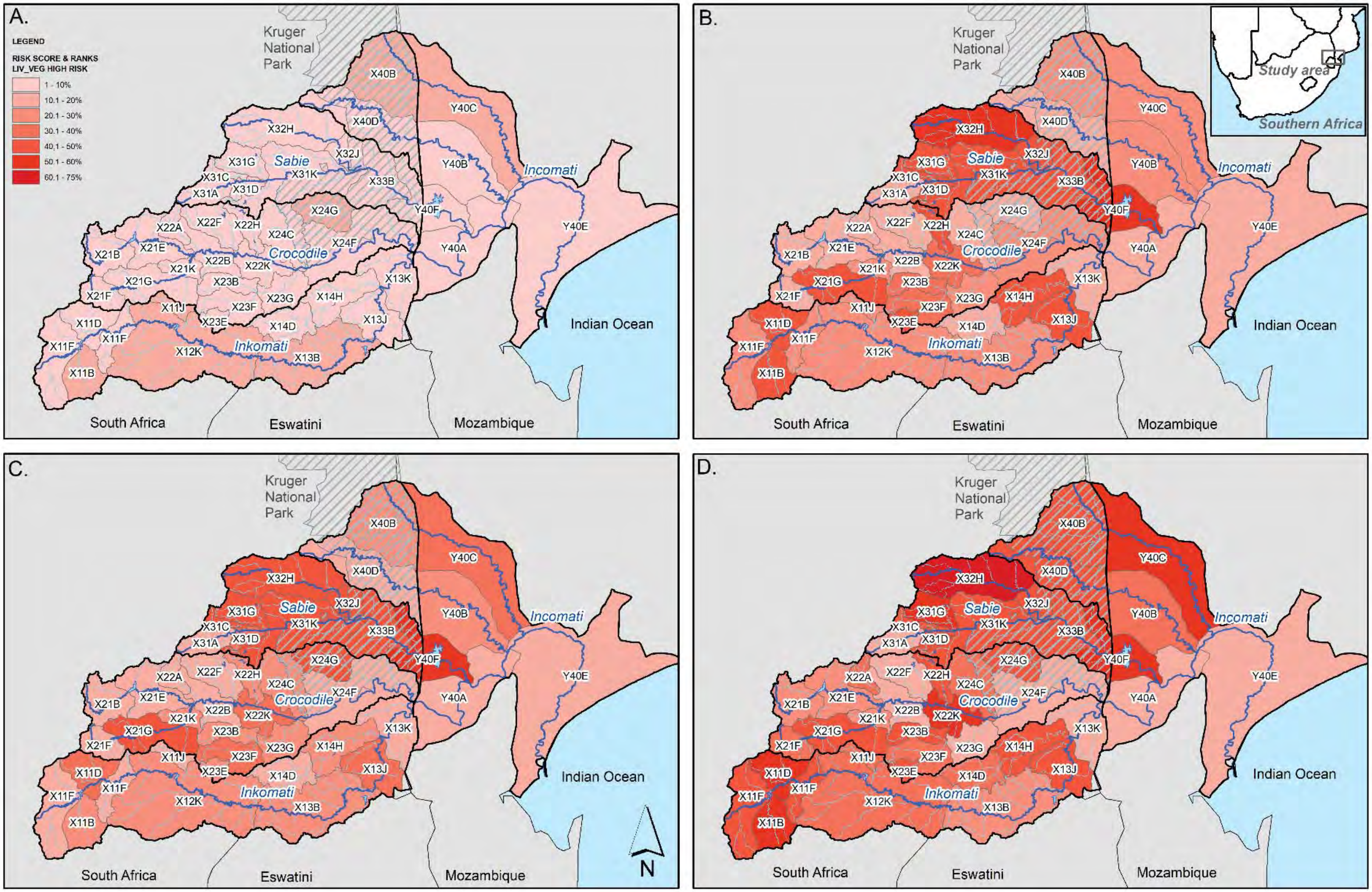


Figure 3-92: The high relative risk scores to LIV-VEG-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought)

3.6.4.2.4 DOM-WAT-END endpoint

The following figures below refer to the medium and high relative risk scores for the DOM-WAT-END endpoint under each scenario (Natural, Present, E-Flow and Drought) for the Uanetza Catchment (Figure 3-93), the Massintonto Catchment (Figure 3-94), Sabie Catchment (Figure 3-95), Crocodile Catchment (Figure 3-96), Komati Catchment (Figure 3-97) and the Incomati Catchment (Figure 3-98). Figure 3-99 refers to the map illustration of the relative risk scores to the DOM-WAT-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought).

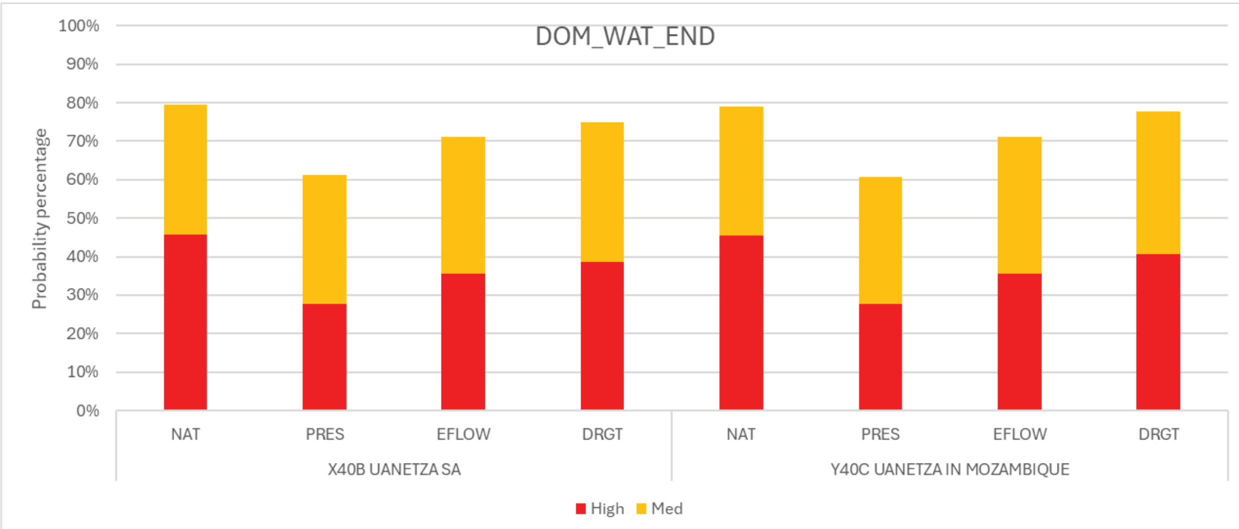


Figure 3-93: The medium and high relative risk scores for the DOM-WAT-END endpoint for the Uanetza catchment for each scenario (Natural, Present, E-Flow and Drought).

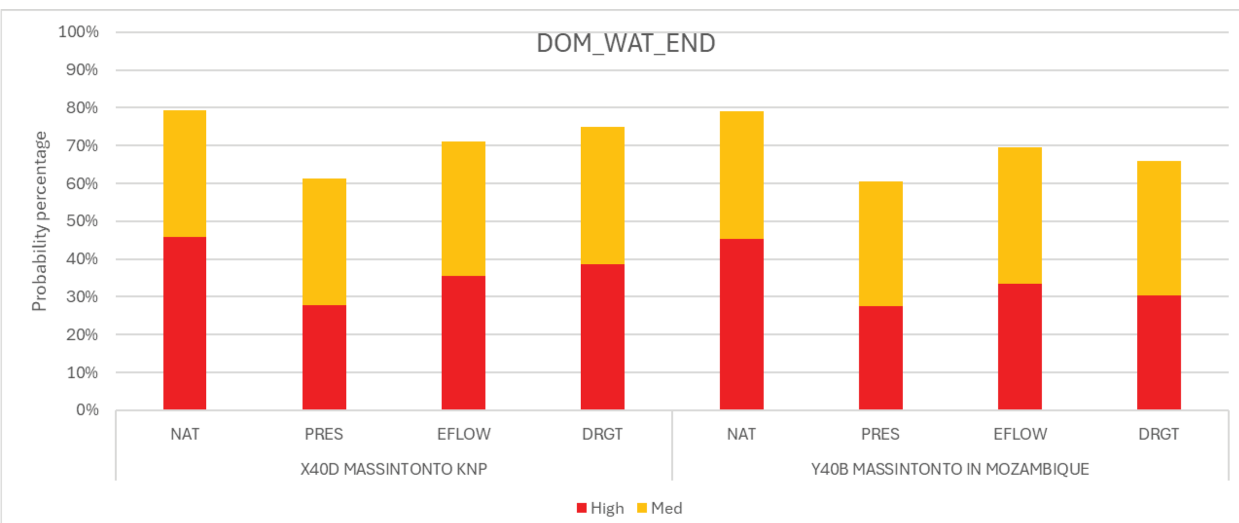


Figure 3-94: The medium and high relative risk scores for the DOM-WAT-END endpoint for the Massintonto catchment for each scenario (Natural, Present, E-Flow and Drought).

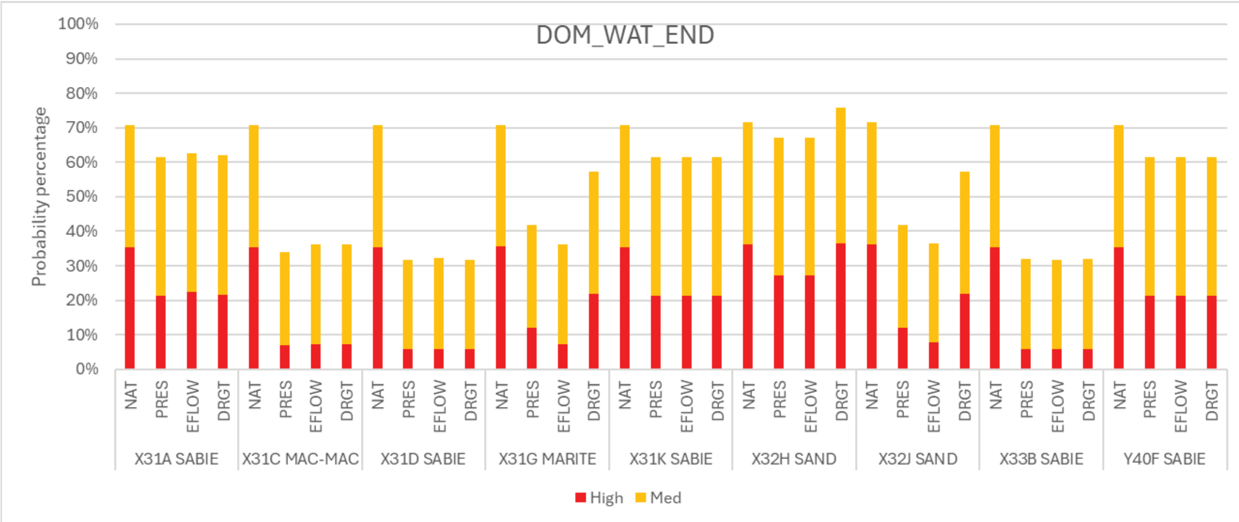


Figure 3-95: The medium and high relative risk scores for the DOM-WAT-END endpoint for the Sabie catchment for each scenario (Natural, Present, E-Flow and Drought).

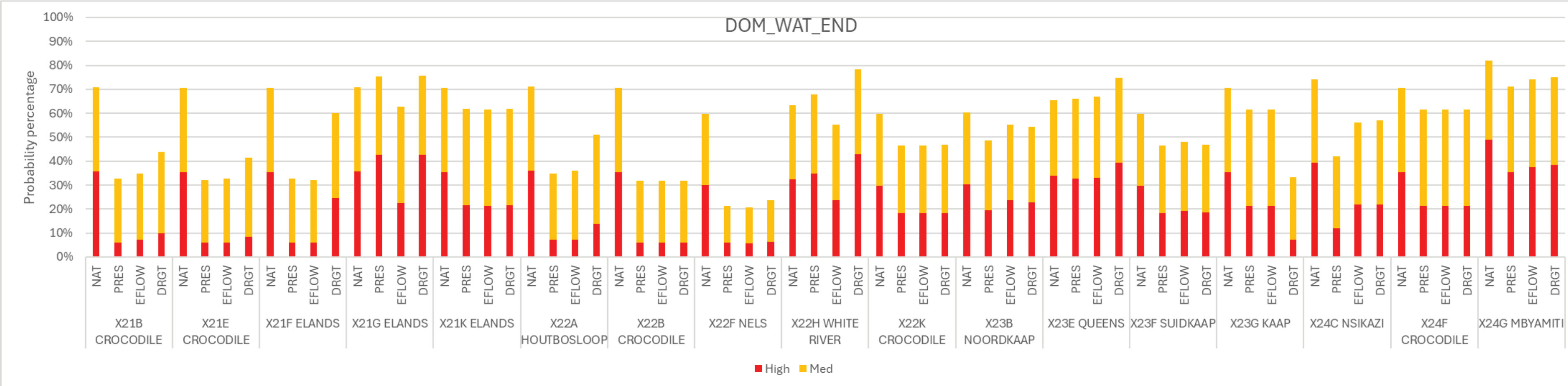


Figure 3-96: The medium and high relative risk scores for the DOM-WAT-END endpoint for the Crocodile catchment for each scenario (Natural, Present, E-Flow and Drought).

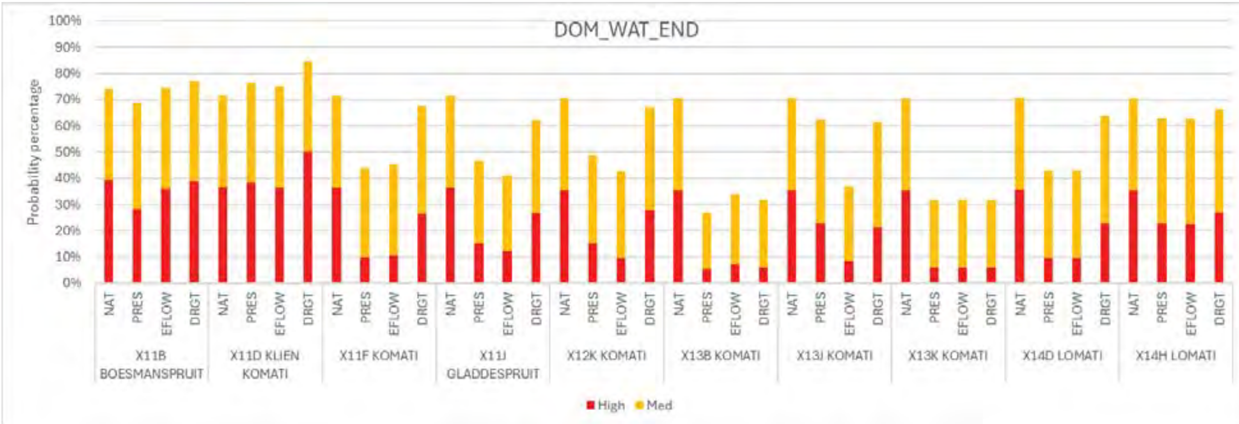


Figure 3-97: The medium and high relative risk scores for the DOM-WAT-END endpoint for the Komati catchment for each scenario (Natural, Present, E-Flow and Drought).

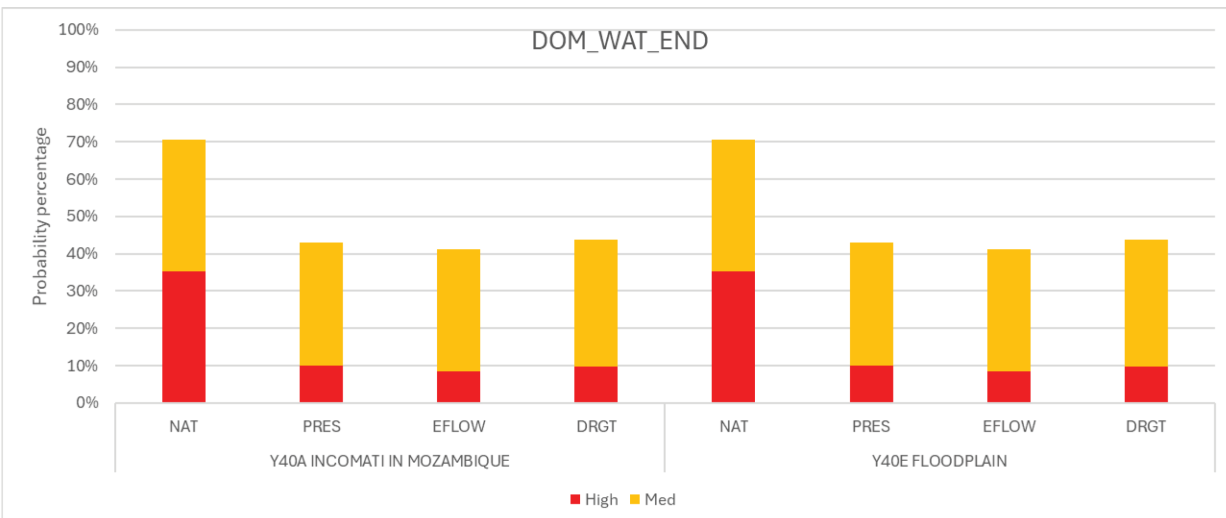


Figure 3-98: The medium and high relative risk scores for the DOM-WAT-END endpoint for the Incomati catchment for each scenario (Natural, Present, E-Flow and Drought).

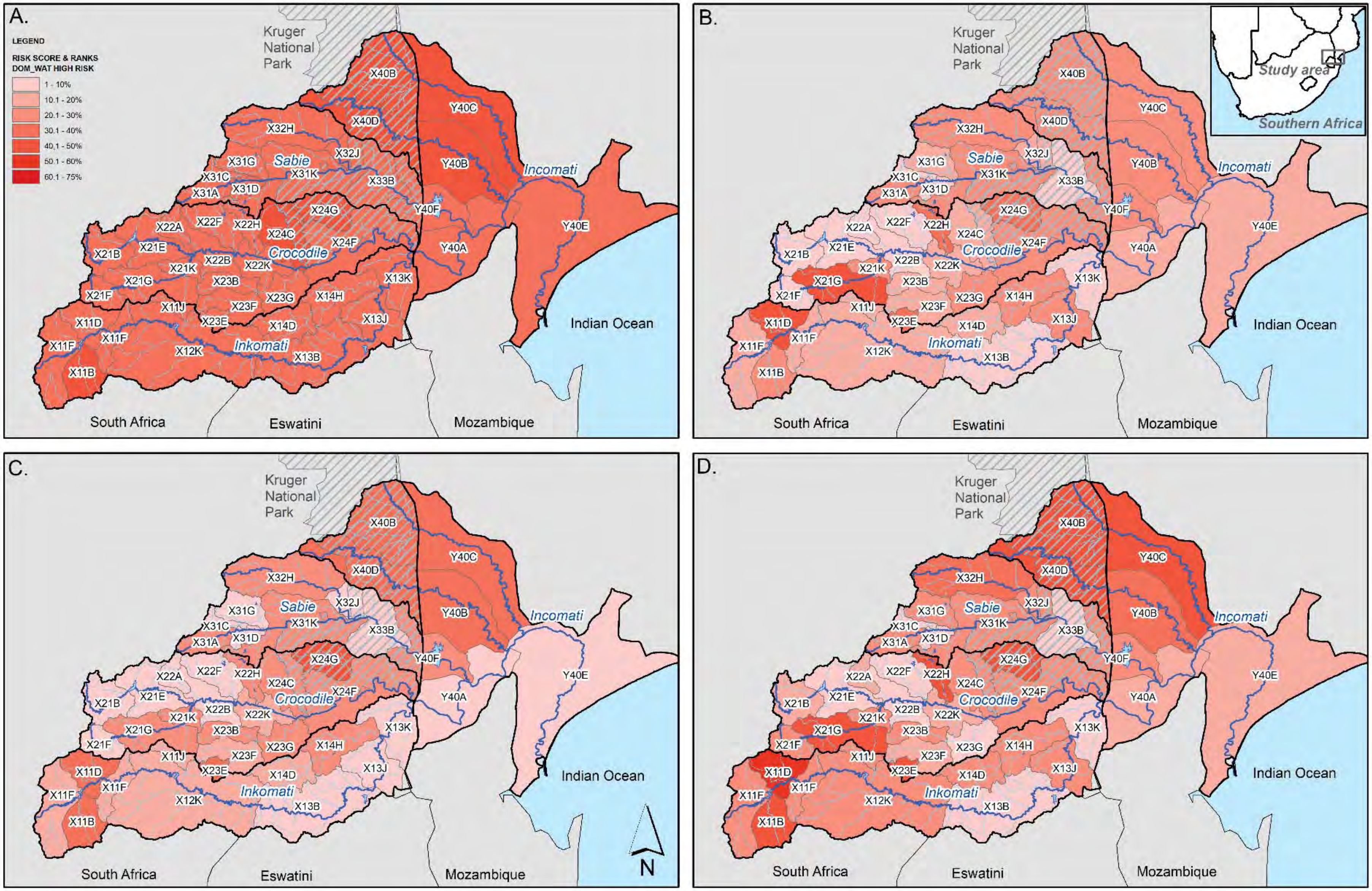


Figure 3-99: The high relative risk scores to DOM-WAT-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought).

3.6.4.3 Regulatory Services

3.6.4.3.1 FLO-ATT-END endpoint

The following figures below refer to the medium and high relative risk scores for the FLO-ATT-END endpoint under each scenario (Natural, Present, E-Flow and Drought) for the Uanetza Catchment (Figure 3-100), the Massintonto Catchment (Figure 3-101), Sabie Catchment (Figure 3-102), Crocodile Catchment (Figure 3-103), Komati Catchment (Figure 3-104) and the Incomati Catchment (Figure 3-105). Figure 3-106 refers to the map illustration of the relative risk scores to the FLO-ATT-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought).

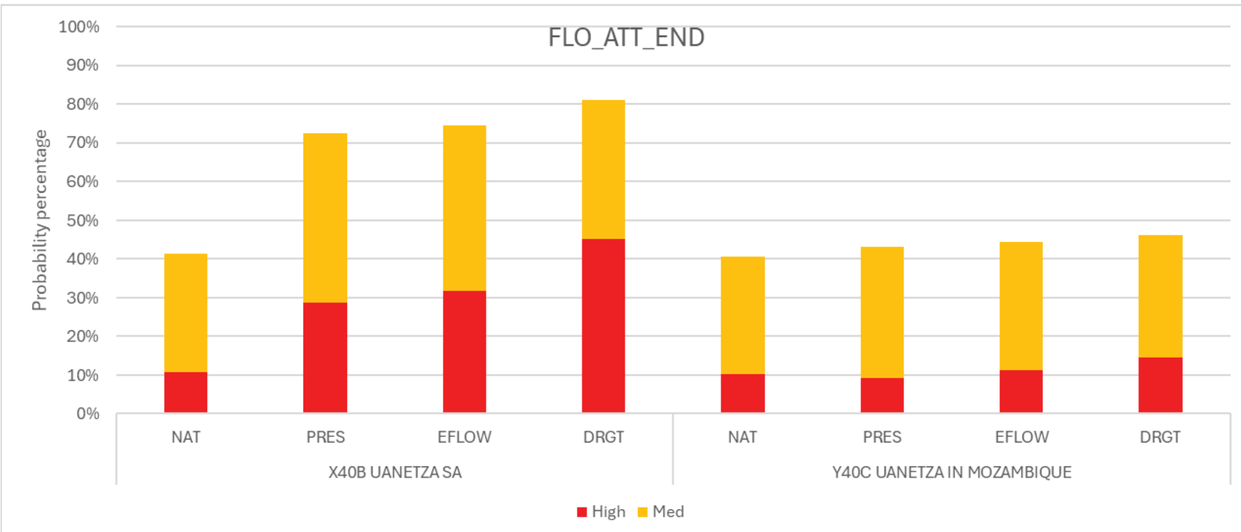


Figure 3-100: The medium and high relative risk scores for the FLO-ATT-END endpoint for the Uanetza catchment for each scenario (Natural, Present, E-Flow and Drought).

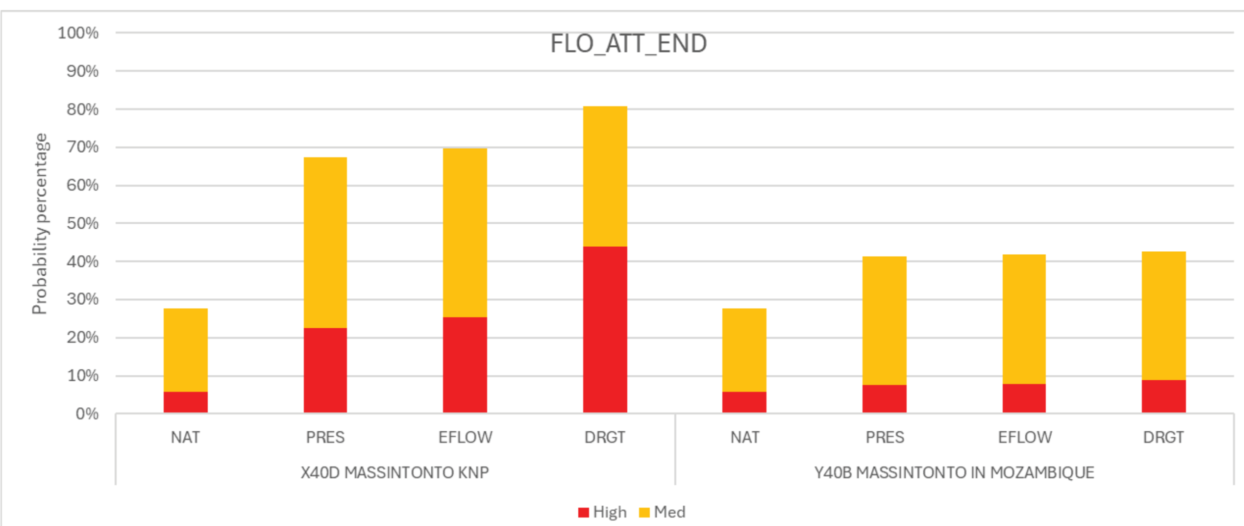


Figure 3-101: The medium and high relative risk scores for the FLO-ATT-END endpoint for the Massintonto catchment for each scenario (Natural, Present, E-Flow and Drought).

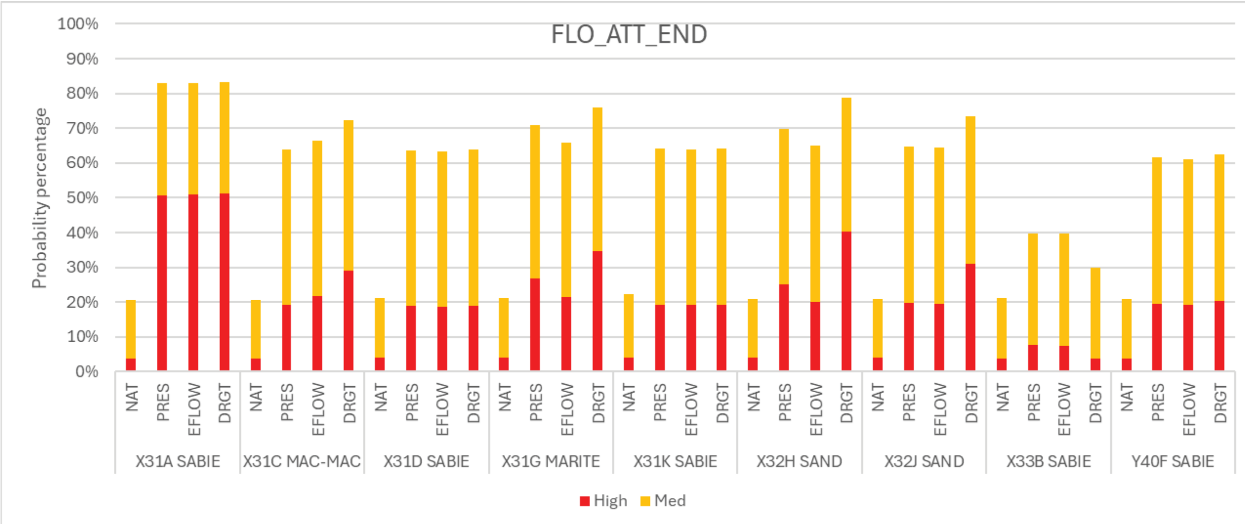


Figure 3-102: The medium and high relative risk scores for the FLO-ATT-END endpoint for the Sabie catchment for each scenario (Natural, Present, E-Flow and Drought).

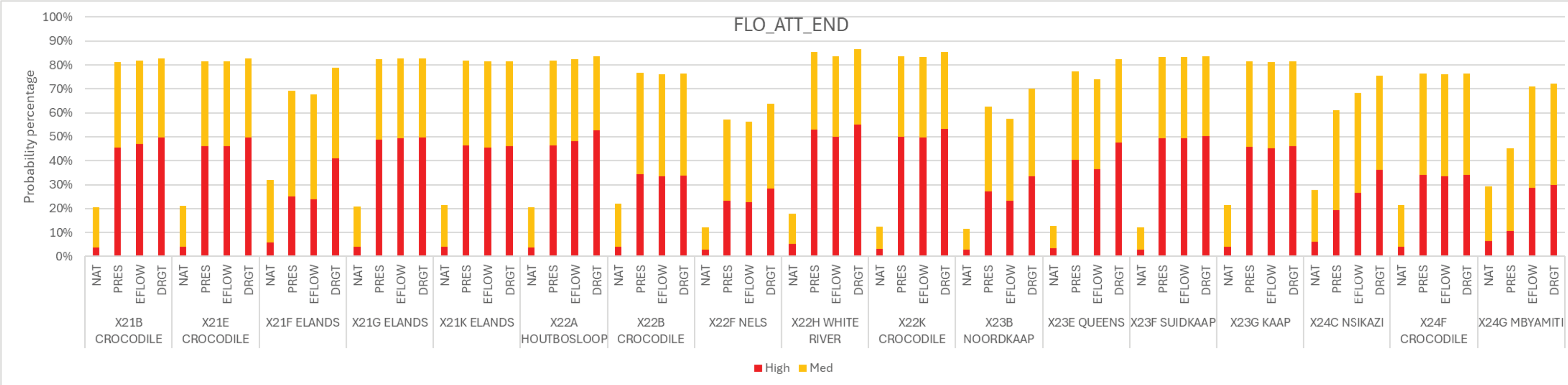


Figure 3-103: The medium and high relative risk scores for the FLO-ATT-END endpoint for the Crocodile catchment for each scenario (Natural, Present, E-Flow and Drought).

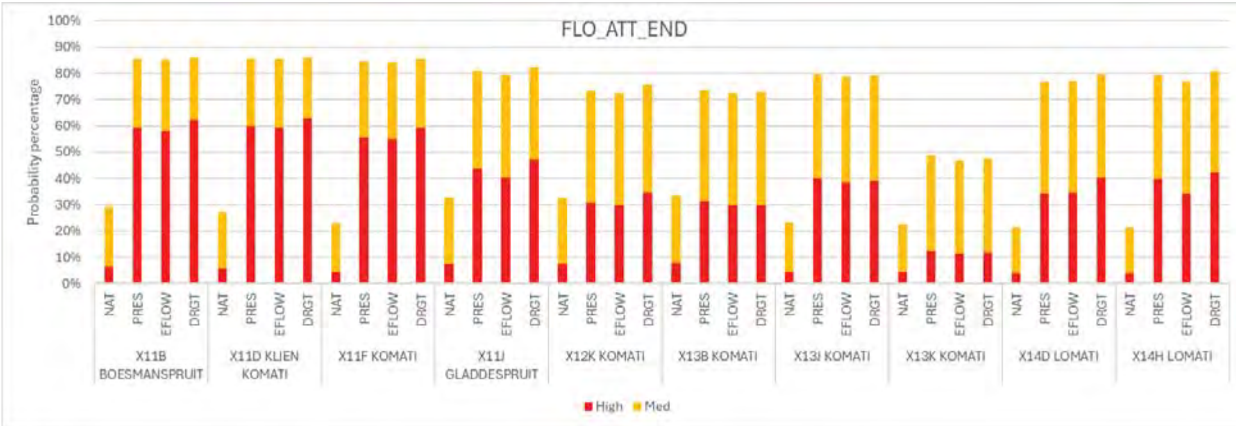


Figure 3-104: The medium and high relative risk scores for the FLO-ATT-END endpoint for the Komati catchment for each scenario (Natural, Present, E-Flow and Drought).

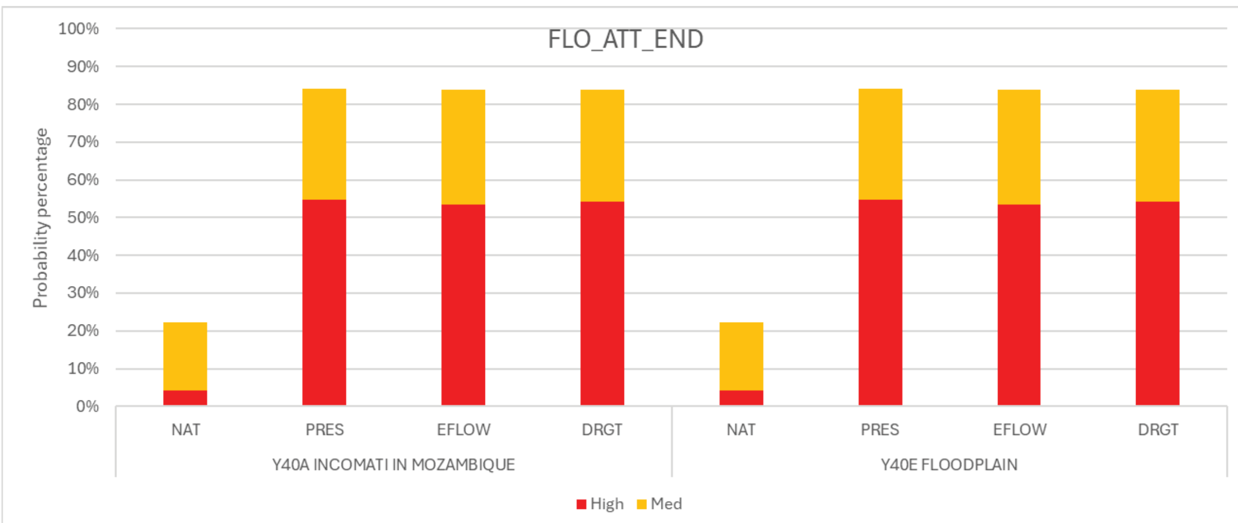


Figure 3-105: The medium and high relative risk scores for the FLO-ATT-END endpoint for the Incomati catchment for each scenario (Natural, Present, E-Flow and Drought).

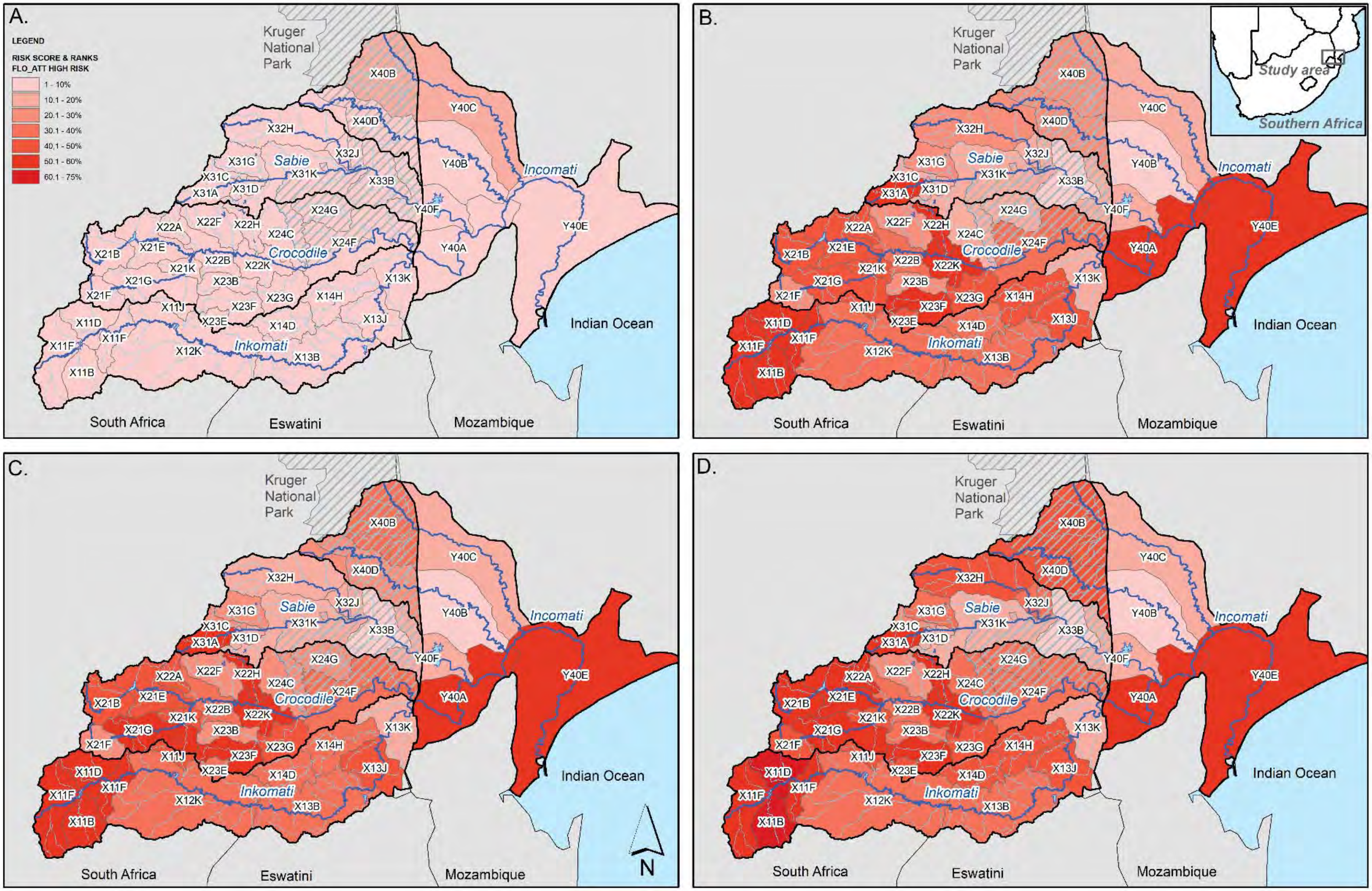


Figure 3-106: The high relative risk scores to FLO-ATT-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought).

3.6.4.3.2 RIV-ASS-END endpoint

The following figures below refer to the medium and high relative risk scores for the RIV-ASS-END endpoint under each scenario (Natural, Present, E-Flow and Drought) for the Uanetza Catchment (Figure 3-107), the Massintonto Catchment (Figure 3-108), Sabie Catchment (Figure 3-109), Crocodile Catchment (Figure 3-110), Komati Catchment (Figure 3-111) and the Incomati Catchment (Figure 3-112). Figure 3-113 refers to the map illustration of the relative risk scores to the RIV-ASS-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought).

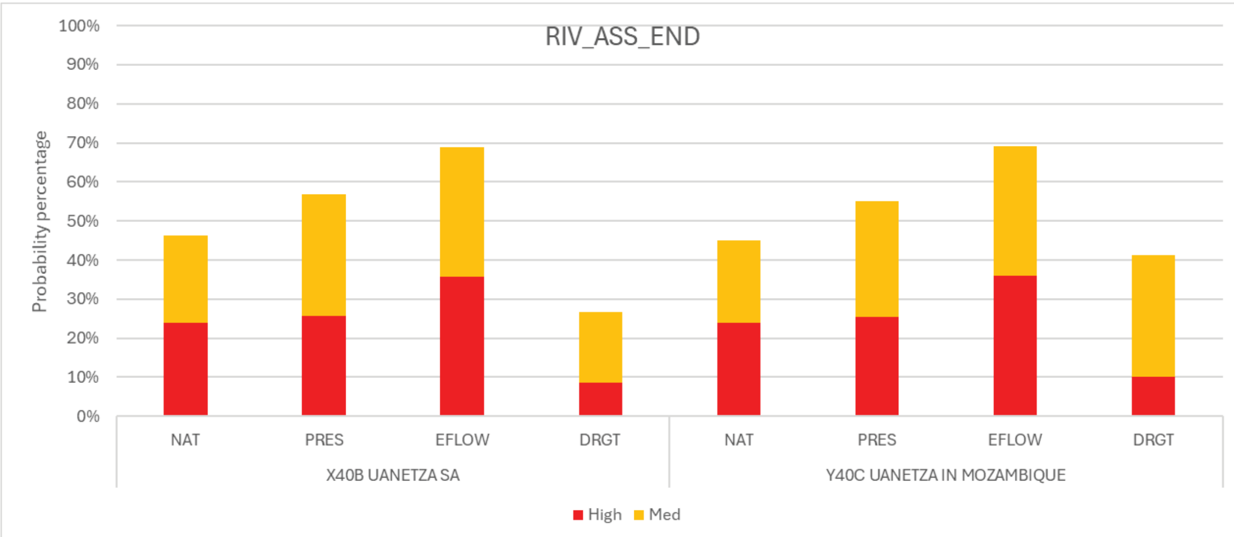


Figure 3-107: The medium and high relative risk scores for the RIV-ASS-END endpoint for the Uanetza catchment for each scenario (Natural, Present, E-Flow and Drought).

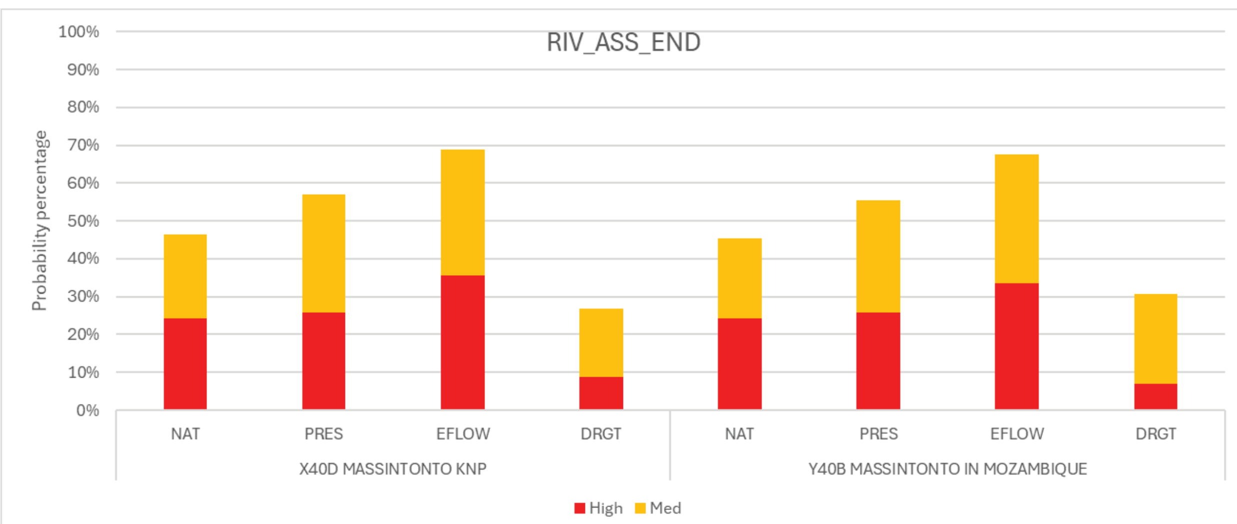


Figure 3-108: The medium and high relative risk scores for the RIV-ASS-END endpoint for the Massintonto catchment for each scenario (Natural, Present, E-Flow and Drought).

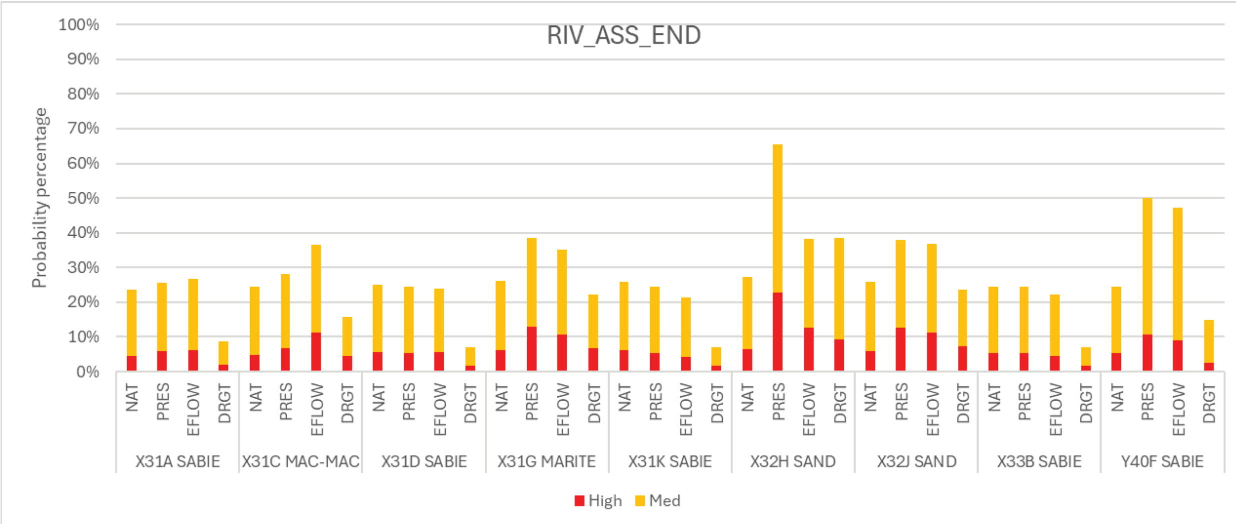


Figure 3-109: The medium and high relative risk scores for the RIV-ASS-END endpoint for the Sabie catchment for each scenario (Natural, Present, E-Flow and Drought).

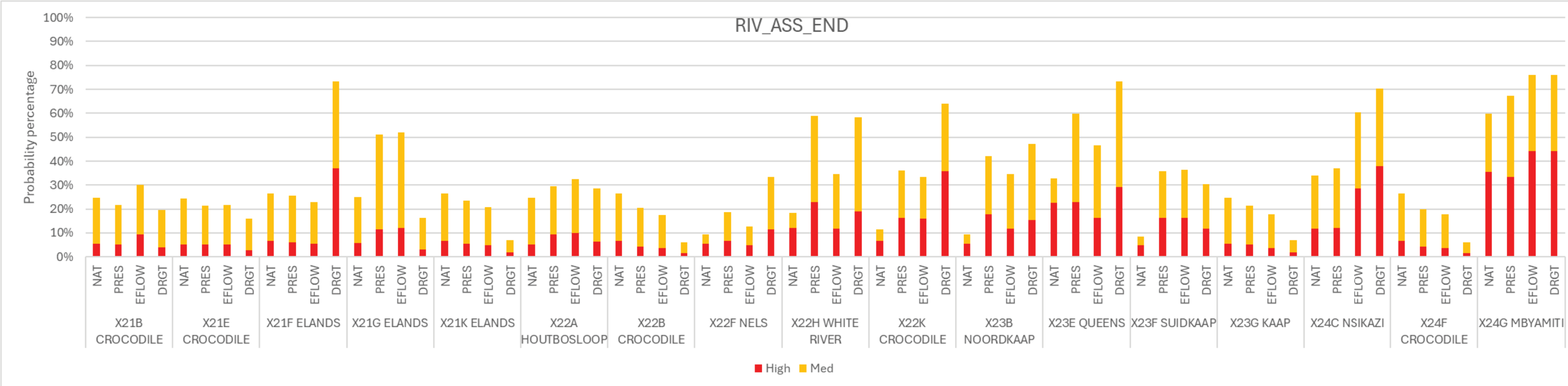


Figure 3-110: The medium and high relative risk scores for the RIV-ASS-END endpoint for the Crocodile catchment for each scenario (Natural, Present, E-Flow and Drought).

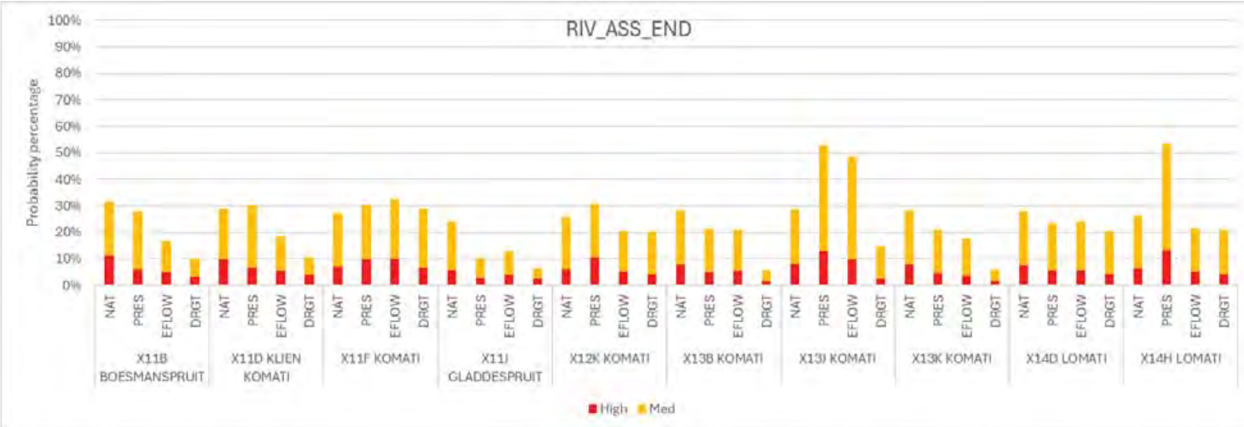


Figure 3-111: The medium and high relative risk scores for the RIV-ASS-END endpoint for the Komati catchment for each scenario (Natural, Present, E-Flow and Drought).

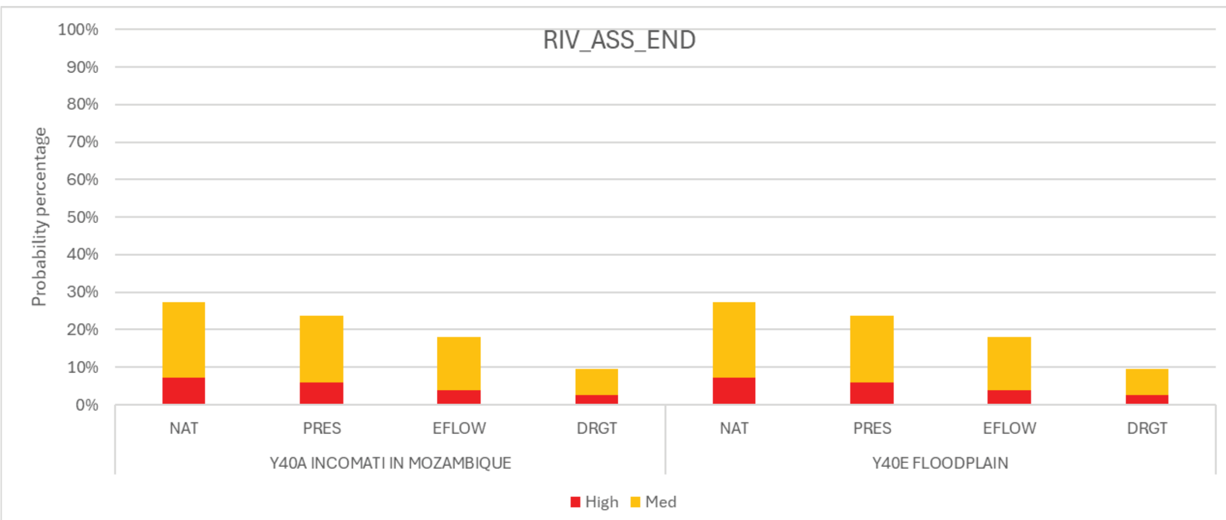


Figure 3-112: The medium and high relative risk scores for the RIV-ASS-END endpoint for the Incomati catchment for each scenario (Natural, Present, E-Flow and Drought).

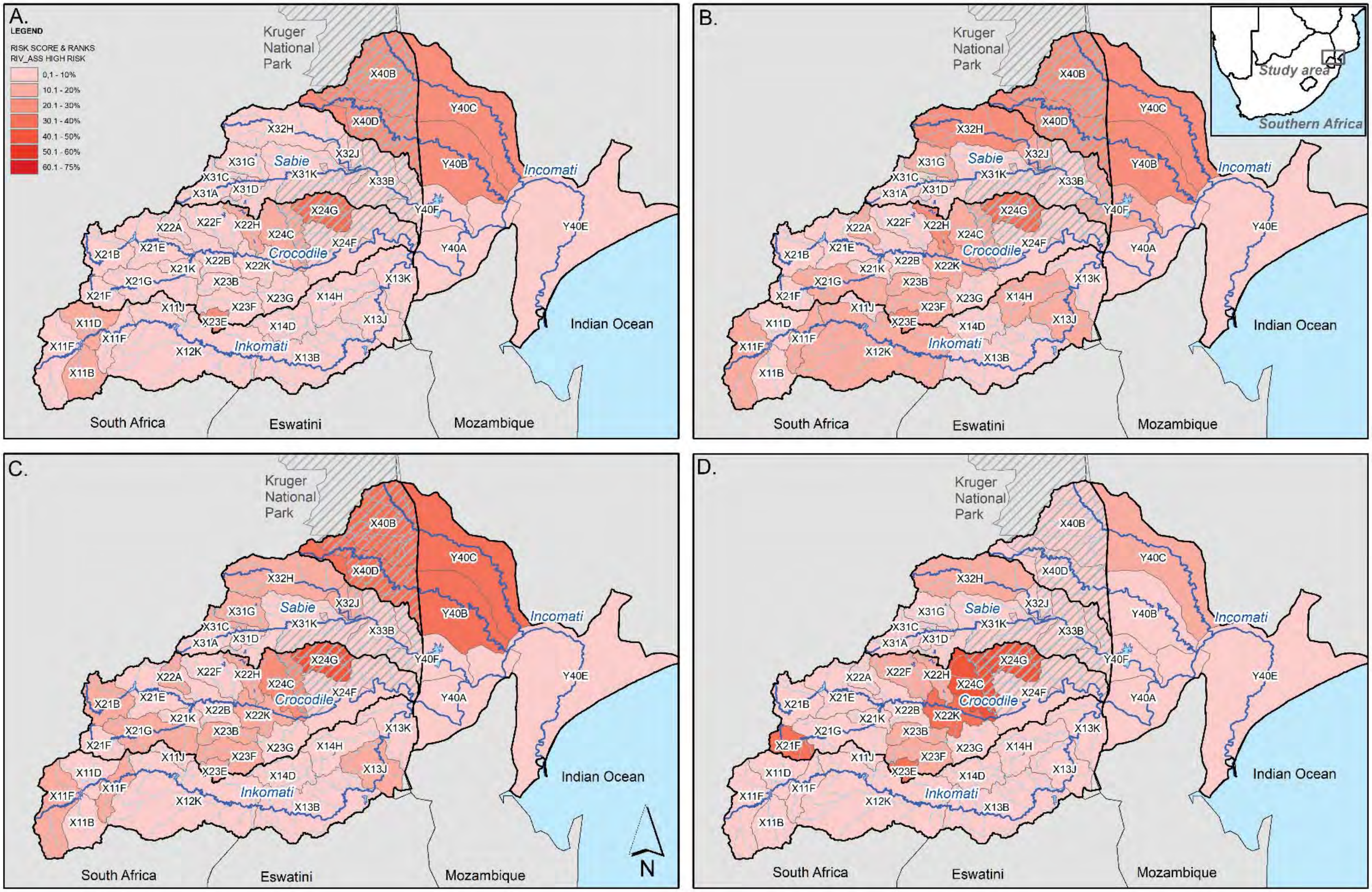


Figure 3-113: The high relative risk scores to RIV-ASS-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought).

3.6.4.3.3 WAT-DIS-END endpoint

The following figures below refer to the medium and high relative risk scores for the WAT-DIS-END endpoint under each scenario (Natural, Present, E-Flow and Drought) for the Uanetza Catchment (Figure 3-114), the Massintonto Catchment (Figure 3-115), Sabie Catchment (Figure 3-116), Crocodile Catchment (Figure 3-117), Komati Catchment (Figure 3-118) and the Incomati Catchment (Figure 3-119). Figure 3-120 refers to the map illustration of the relative risk scores to the WAT-DIS-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought).

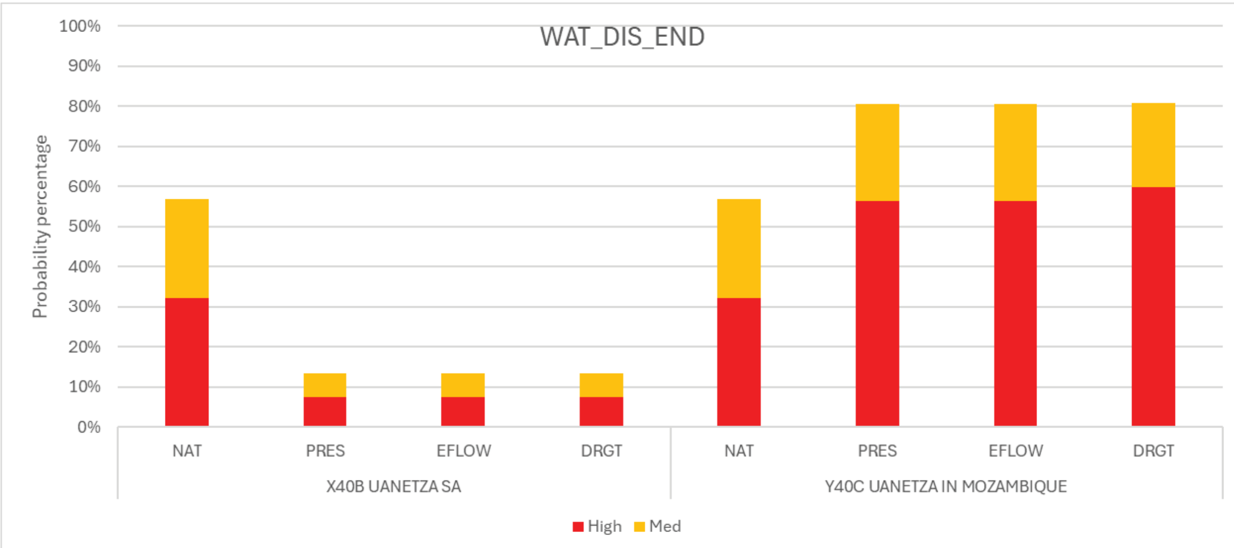


Figure 3-114: The medium and high relative risk scores for the WAT-DIS-END endpoint for the Uanetza catchment for each scenario (Natural, Present, E-Flow and Drought).

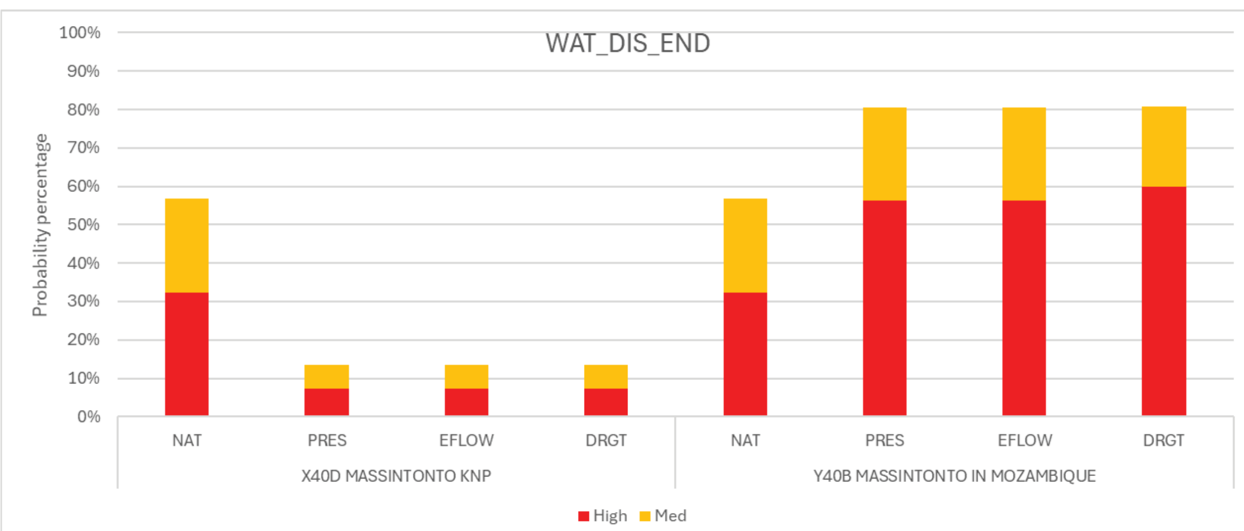


Figure 3-115: The medium and high relative risk scores for the WAT-DIS-END endpoint for the Massintonto catchment for each scenario (Natural, Present, E-Flow and Drought).

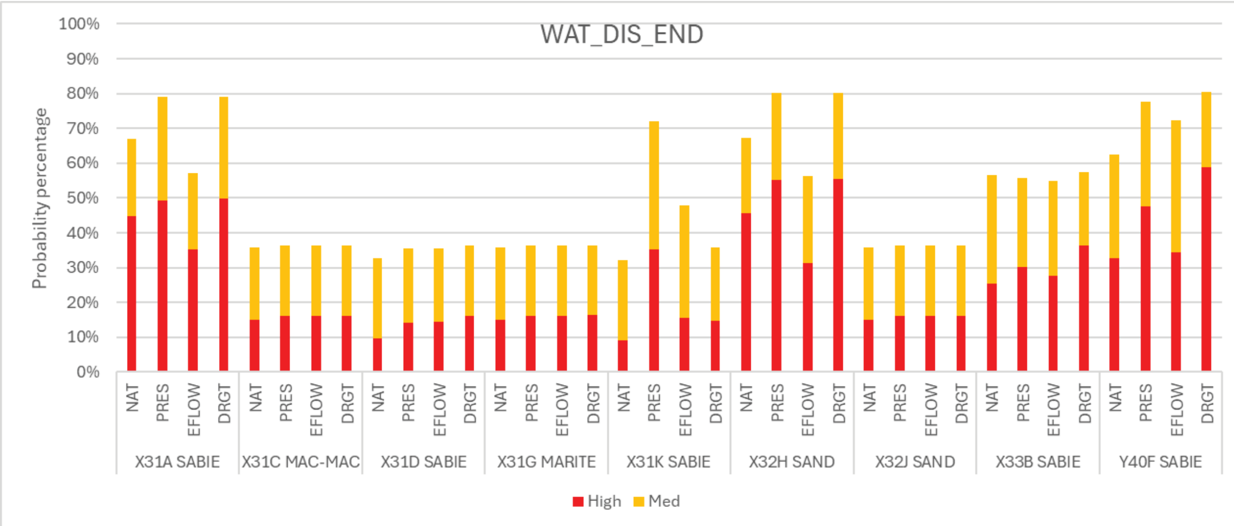


Figure 3-116: The medium and high relative risk scores for the WAT-DIS-END endpoint for the Sabie catchment for each scenario (Natural, Present, E-Flow and Drought).

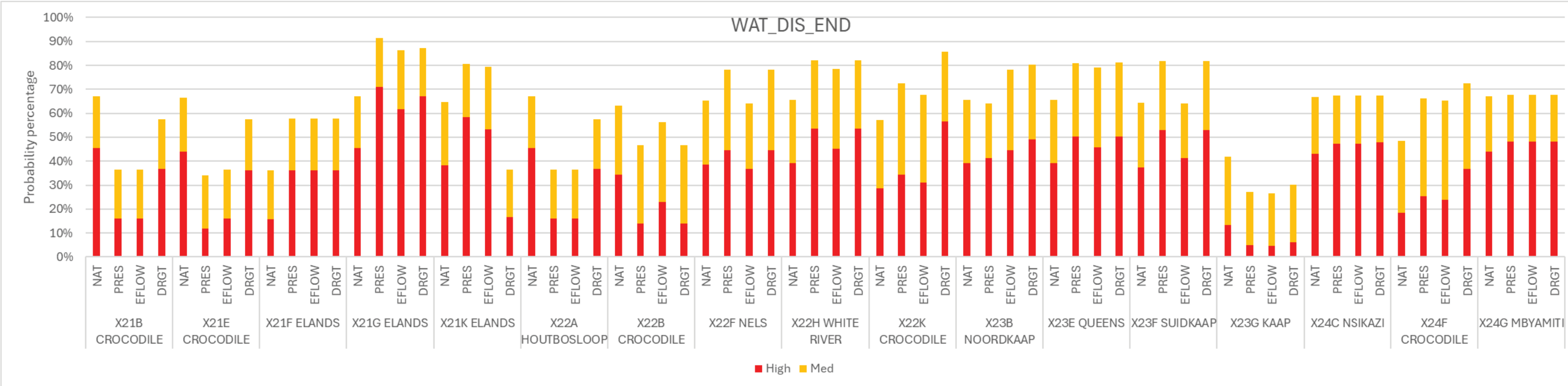


Figure 3-117: The medium and high relative risk scores for the WAT-DIS-END endpoint for the Crocodile catchment for each scenario (Natural, Present, E-Flow and Drought).

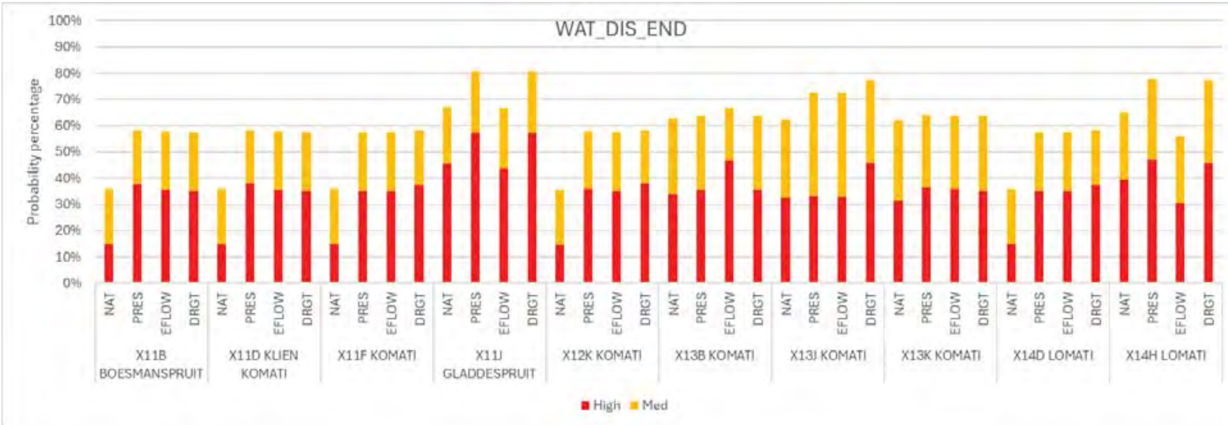


Figure 3-118: The medium and high relative risk scores for the WAT-DIS-END endpoint for the Komati catchment for each scenario (Natural, Present, E-Flow and Drought).

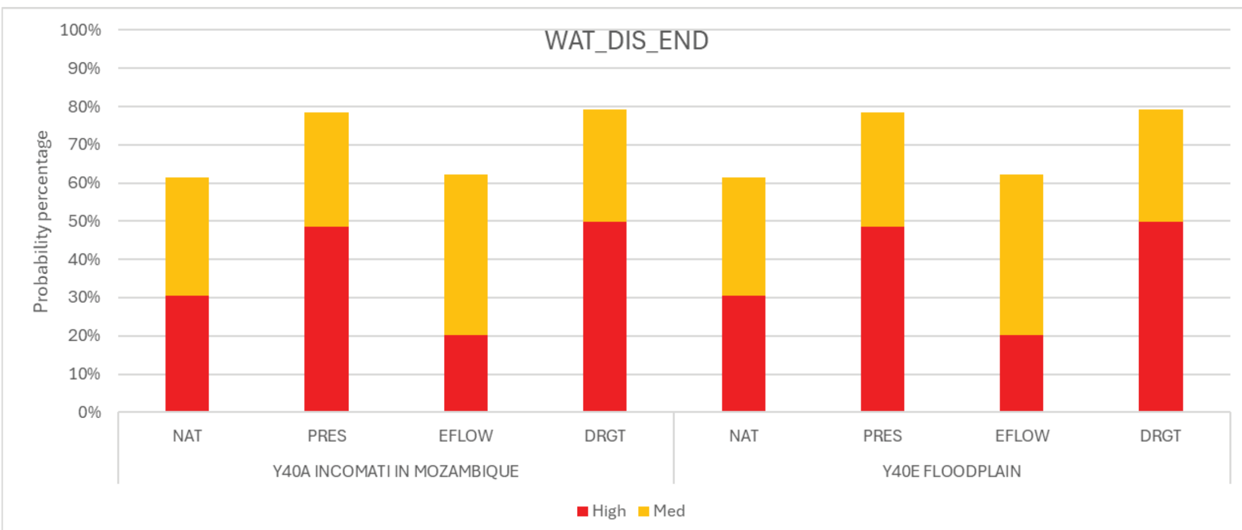


Figure 3-119: The medium and high relative risk scores for the WAT-DIS-END endpoint for the Incomati catchment for each scenario (Natural, Present, E-Flow and Drought).

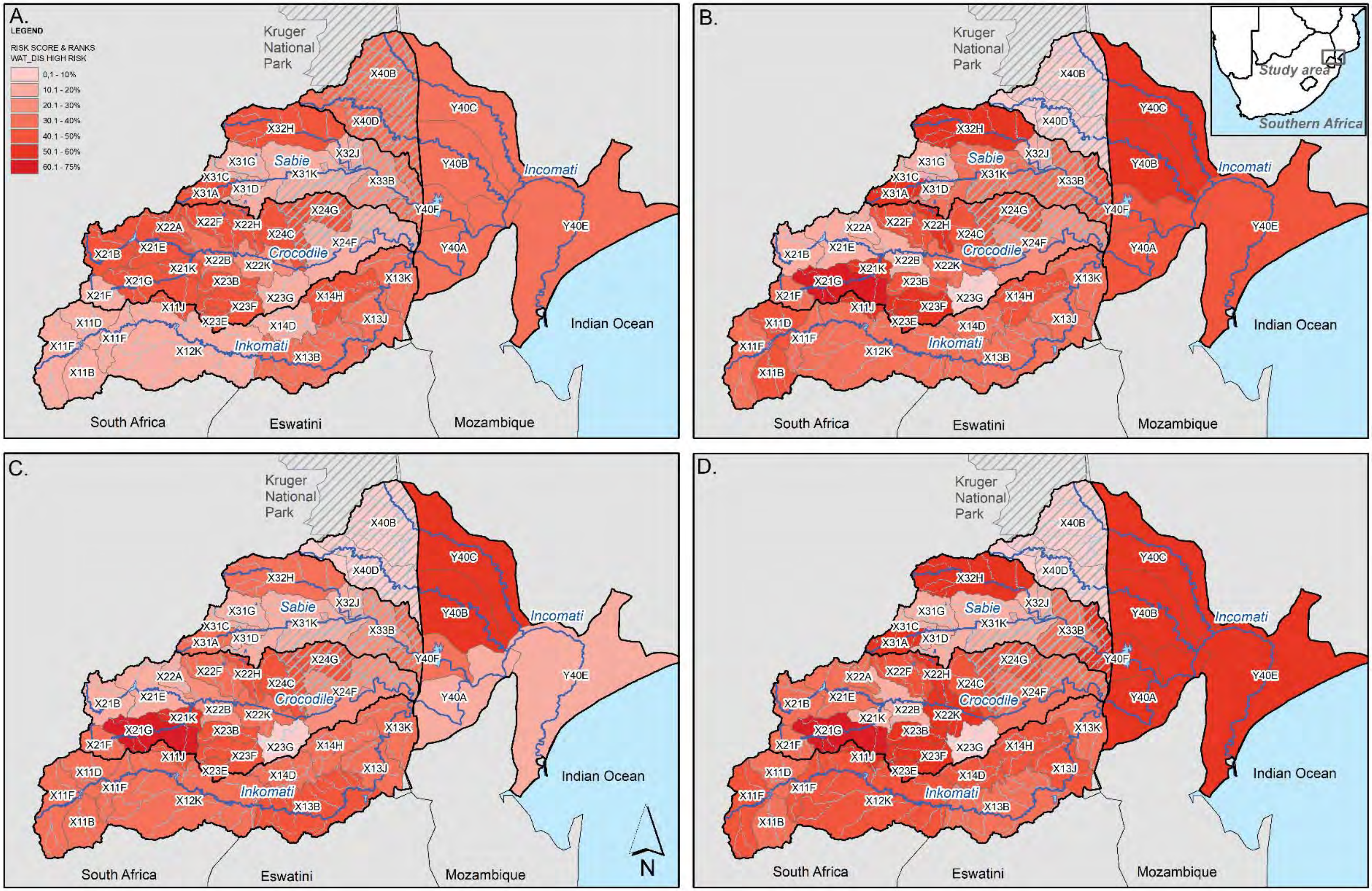


Figure 3-120: The high relative risk scores to WAT-DIS-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought).

3.6.4.3.4 RES-RES-END endpoint

The following figures below refer to the medium and high relative risk scores for the RES-RES-END endpoint under each scenario (Natural, Present, E-Flow and Drought) for the Uanetza Catchment (Figure 3-121), the Massintonto Catchment (Figure 3-122), Sabie Catchment (Figure 3-123), Crocodile Catchment (Figure 3-124), Komati Catchment (Figure 3-125) and the Incomati Catchment (Figure 3-126). Figure 3-127 refers to the map illustration of the relative risk scores to the RES-RES-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought).

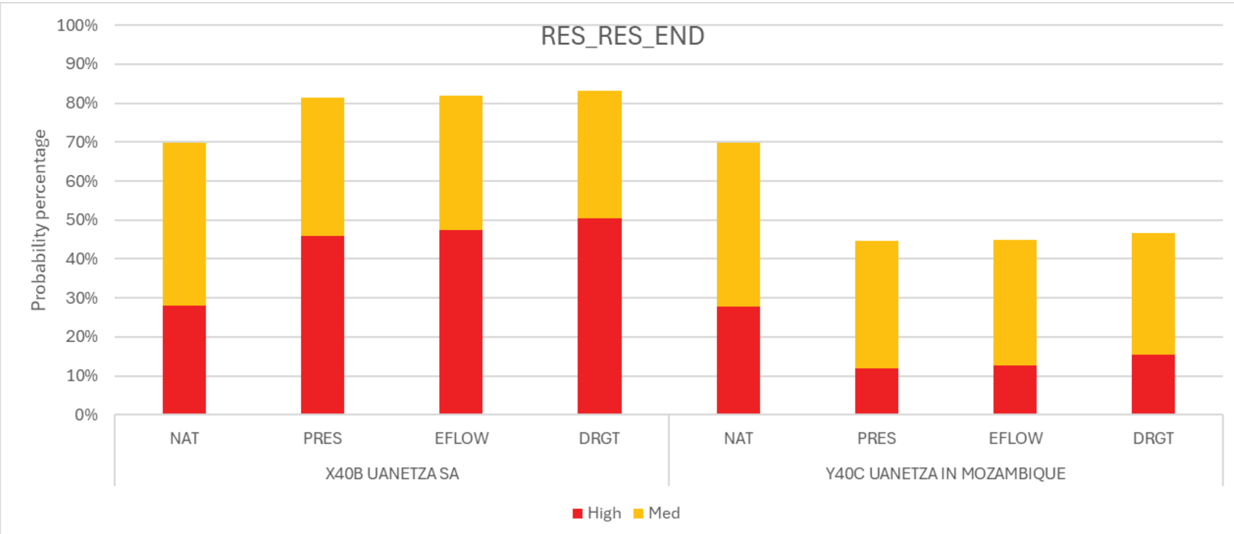


Figure 3-121: The medium and high relative risk scores for the RES-RES-END endpoint for the Uanetza catchment for each scenario (Natural, Present, E-Flow and Drought).

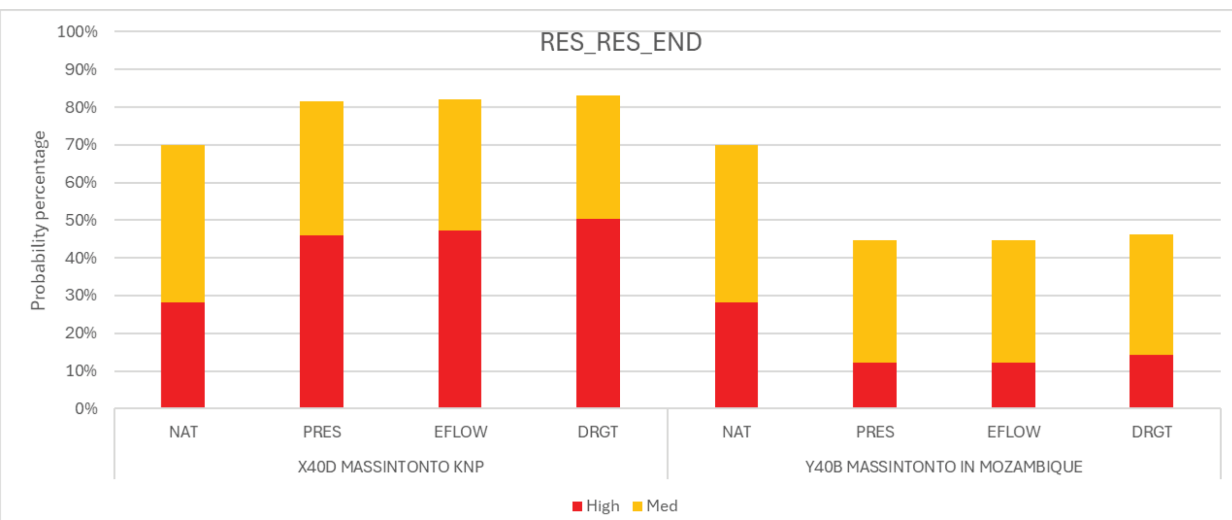


Figure 3-122: The medium and high relative risk scores for the RES-RES-END endpoint for the Massintonto catchment for each scenario (Natural, Present, E-Flow and Drought).

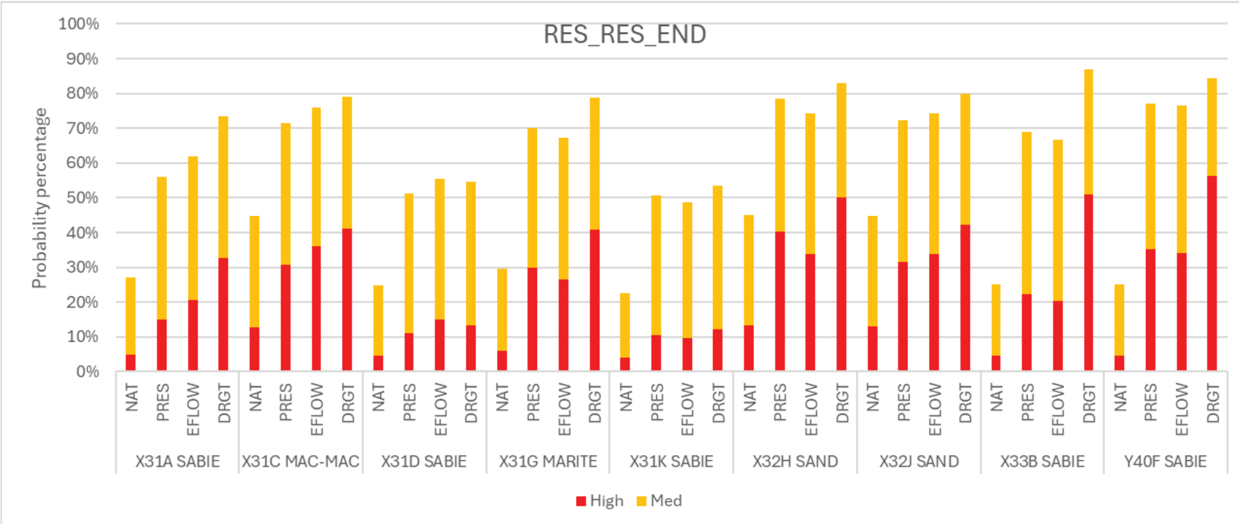


Figure 3-123: The medium and high relative risk scores for the RES-RES-END endpoint for the Sabie catchment for each scenario (Natural, Present, E-Flow and Drought).

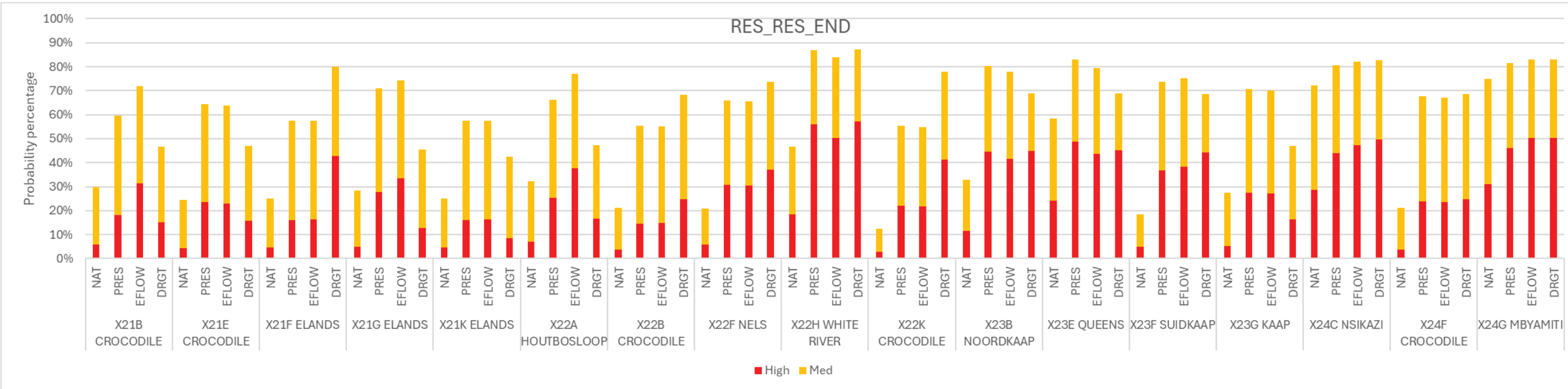


Figure 3-124: The medium and high relative risk scores for the RES-RES-END endpoint for the Crocodile catchment for each scenario (Natural, Present, E-Flow and Drought).

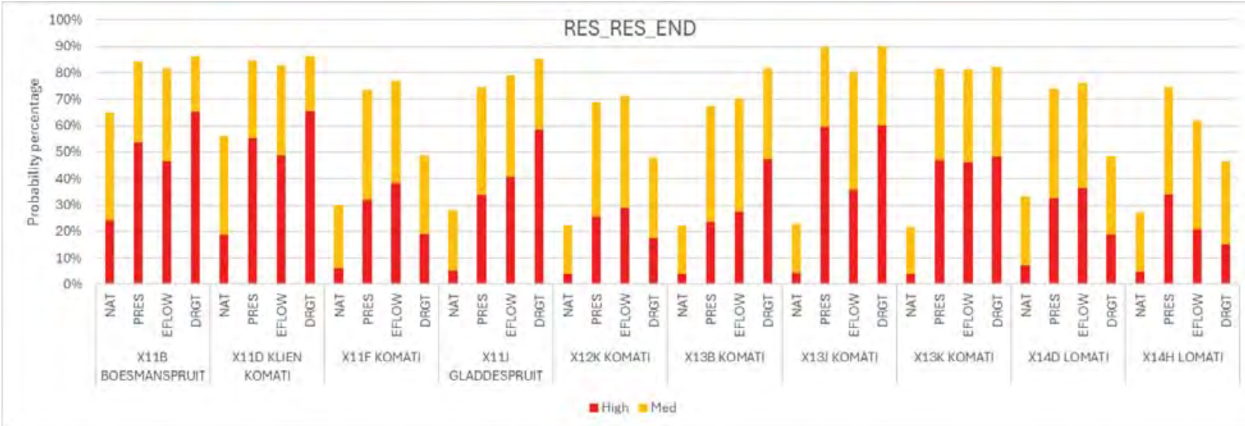


Figure 3-125: The medium and high relative risk scores for the RES-RES-END endpoint for the Komati catchment for each scenario (Natural, Present, E-Flow and Drought).

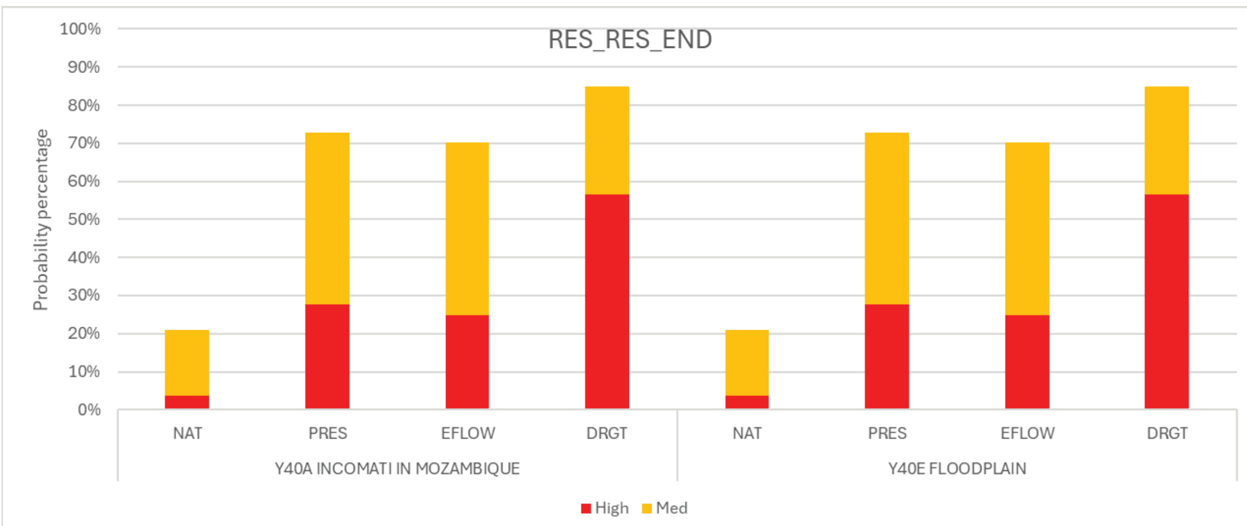


Figure 3-126: The medium and high relative risk scores for the RES-RES-END endpoint for the Incomati catchment for each scenario (Natural, Present, E-Flow and Drought).

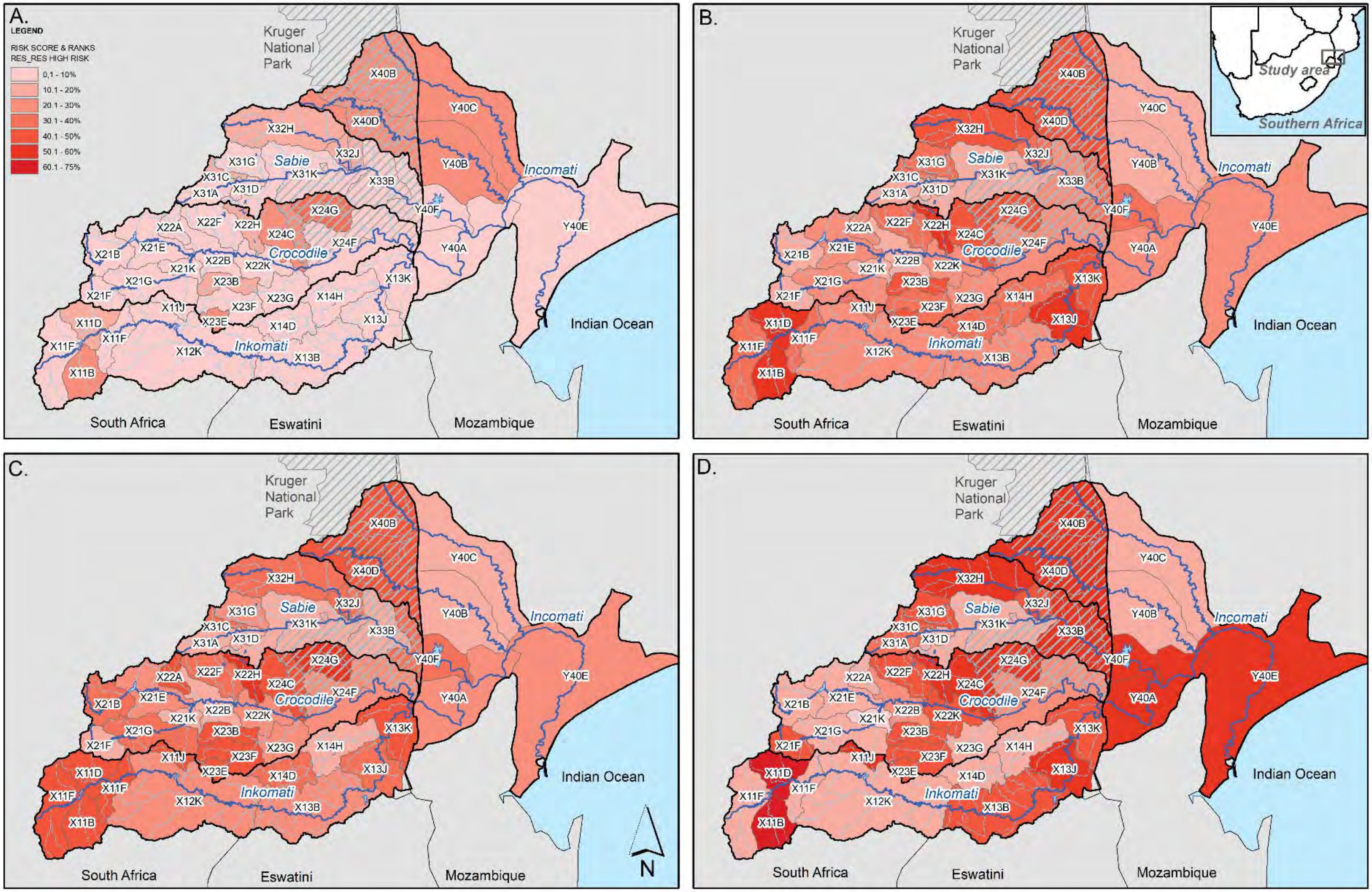


Figure 3-127: The high relative risk scores to RES-RES-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought).

3.6.4.4 Cultural Services

3.6.4.4.1 REC-SPIR-END endpoint

The following figures below refer to the medium and high relative risk scores for the REC-SPIR-END endpoint under each scenario (Natural, Present, E-Flow and Drought) for the Uanetza Catchment (Figure 3-128), the Massintonto Catchment (Figure 3-129), Sabie Catchment (Figure 3-130), Crocodile Catchment (Figure 3-131), Komati Catchment (Figure 3-132) and the Incomati Catchment (Figure 3-133). Figure 3-134 refers to the map illustration of the relative risk scores to the REC-SPIR-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought).

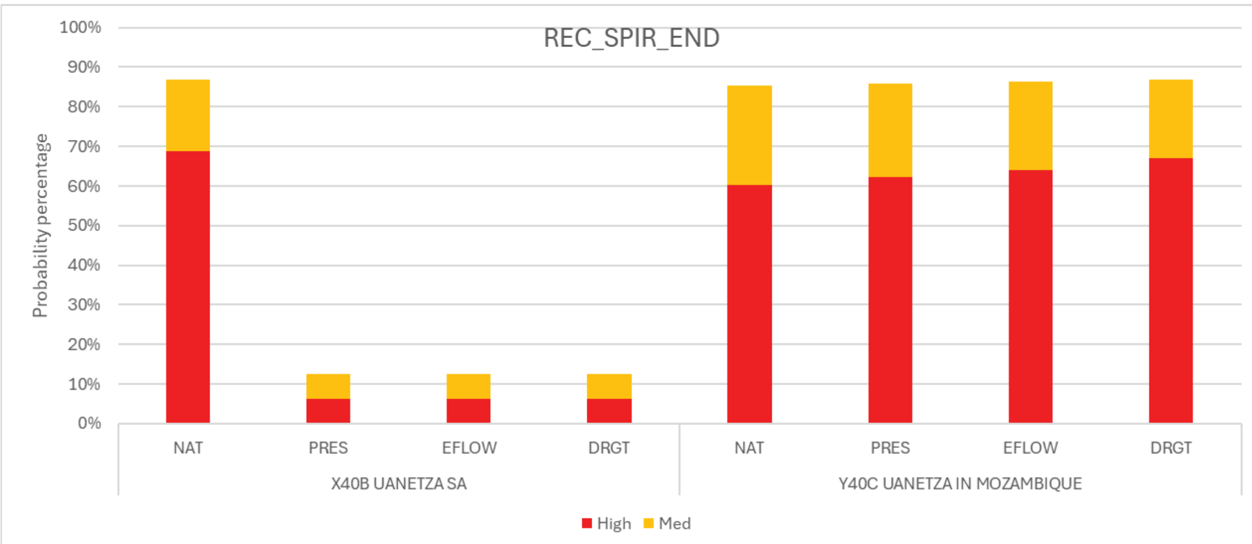


Figure 3-128: The medium and high relative risk scores for the REC-SPIR-END endpoint for the Uanetza catchment for each scenario (Natural, Present, E-Flow and Drought).

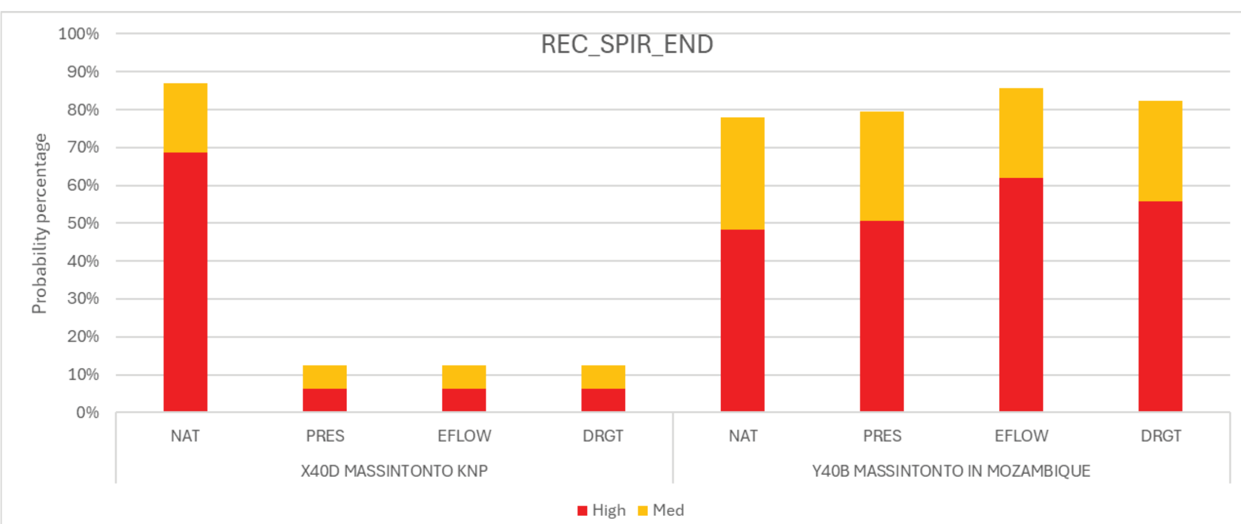


Figure 3-129: The medium and high relative risk scores for the REC-SPIR-END endpoint for the Massintonto catchment for each scenario (Natural, Present, E-Flow and Drought).

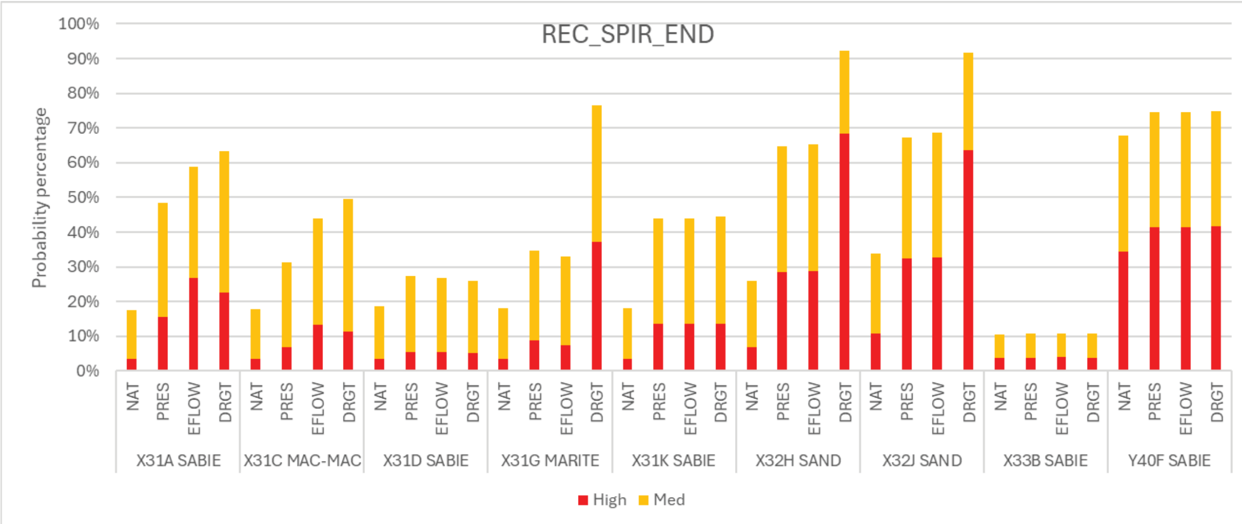


Figure 3-130: The medium and high relative risk scores for the REC-SPIR-END endpoint for the Sabie catchment for each scenario (Natural, Present, E-Flow and Drought).

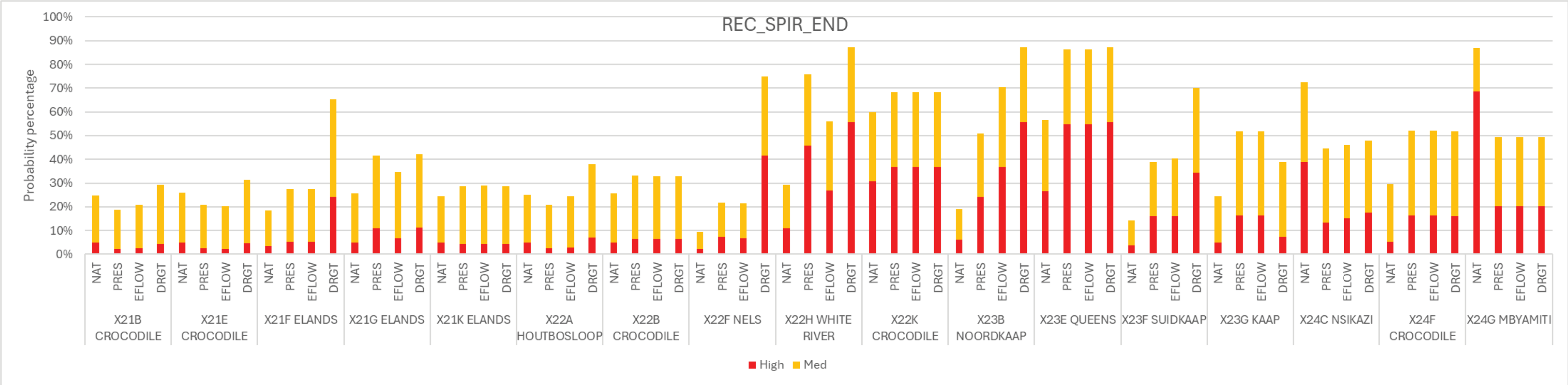


Figure 3-131: The medium and high relative risk scores for the REC-SPIR-END endpoint for the Crocodile catchment for each scenario (Natural, Present, E-Flow and Drought).

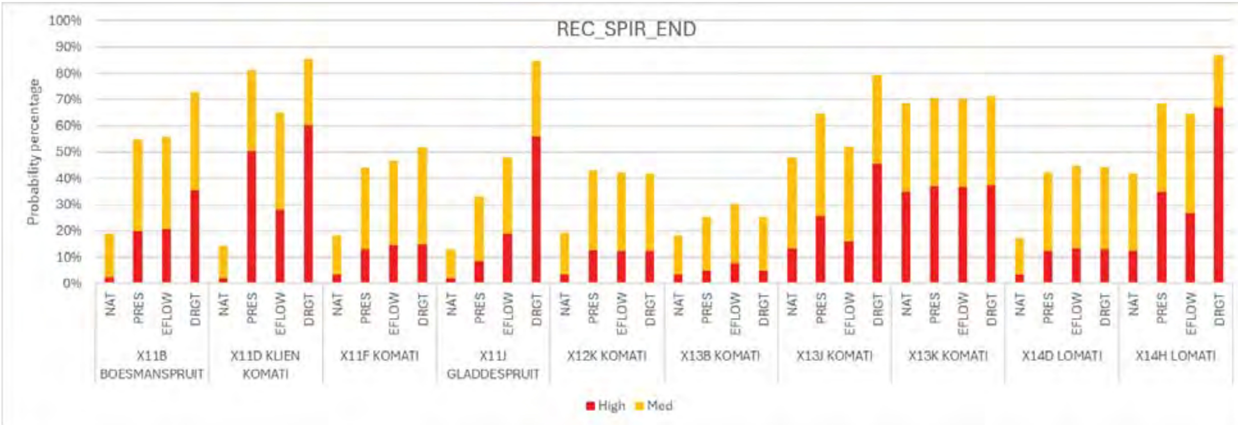


Figure 3-132: The medium and high relative risk scores for the REC-SPIR-END endpoint for the Komati catchment for each scenario (Natural, Present, E-Flow and Drought).

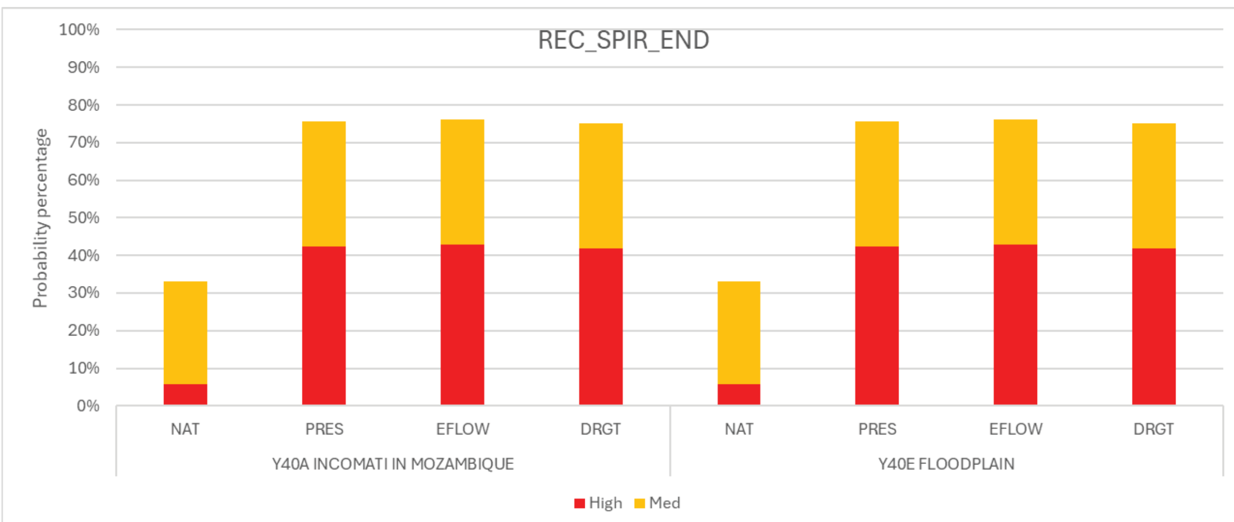


Figure 3-133: The medium and high relative risk scores for the REC-SPIR-END endpoint for the Incomati catchment for each scenario (Natural, Present, E-Flow and Drought).

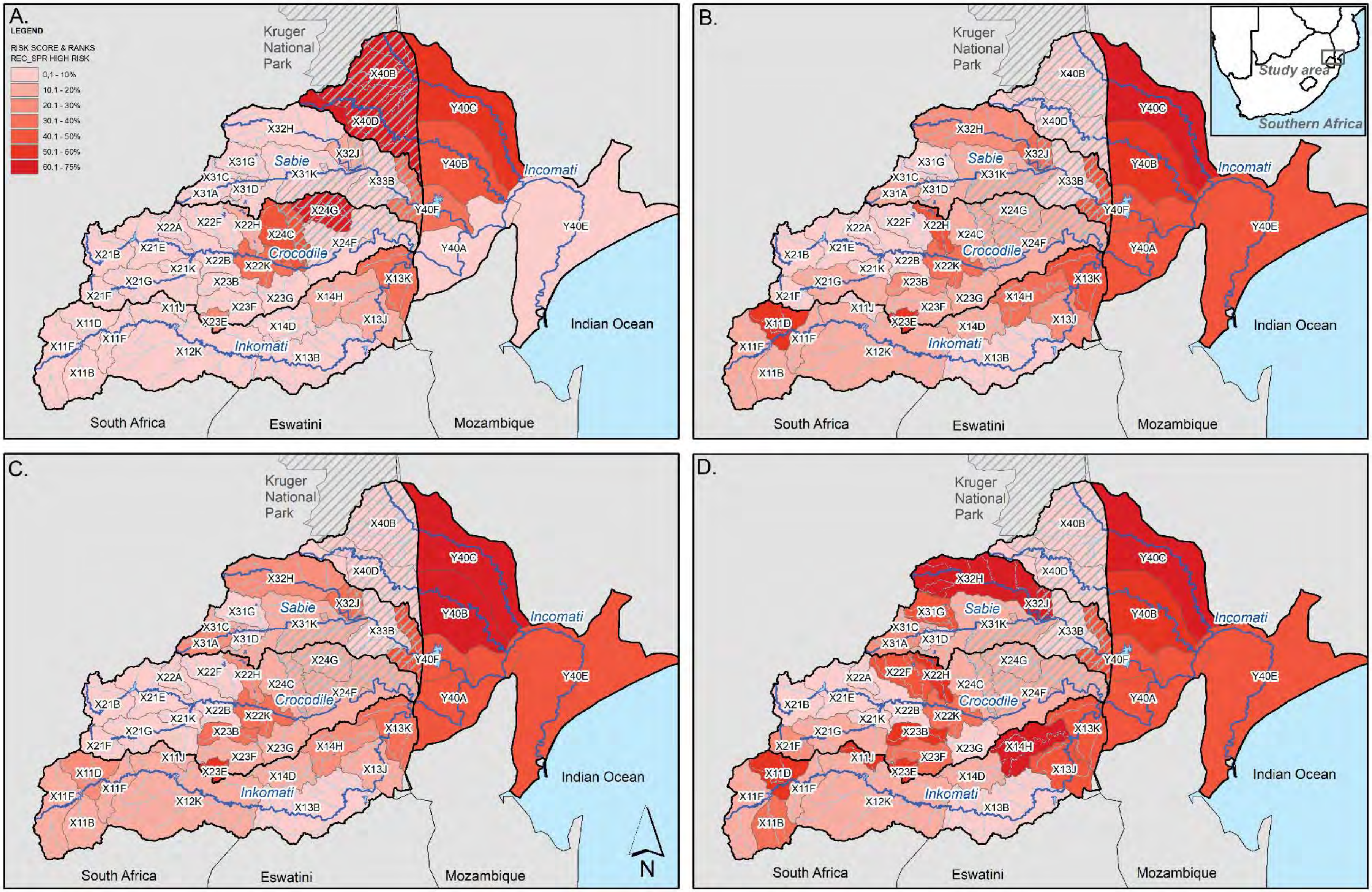


Figure 3-134: The high relative risk scores to REC-SPIR-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought).

3.6.4.4.2 TOURISM-END endpoint

The following figures below refer to the medium and high relative risk scores for the TOURISM-END endpoint under each scenario (Natural, Present, E-Flow and Drought) for the Uanetza Catchment (Figure 3-135), the Massintonto Catchment (Figure 3-136), Sabie Catchment (Figure 3-137), Crocodile Catchment (Figure 3-138), Komati Catchment (Figure 3-139) and the Incomati Catchment (Figure 3-140). Figure 3-141 refers to the map illustration of the relative risk scores to the TOURISM-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought).

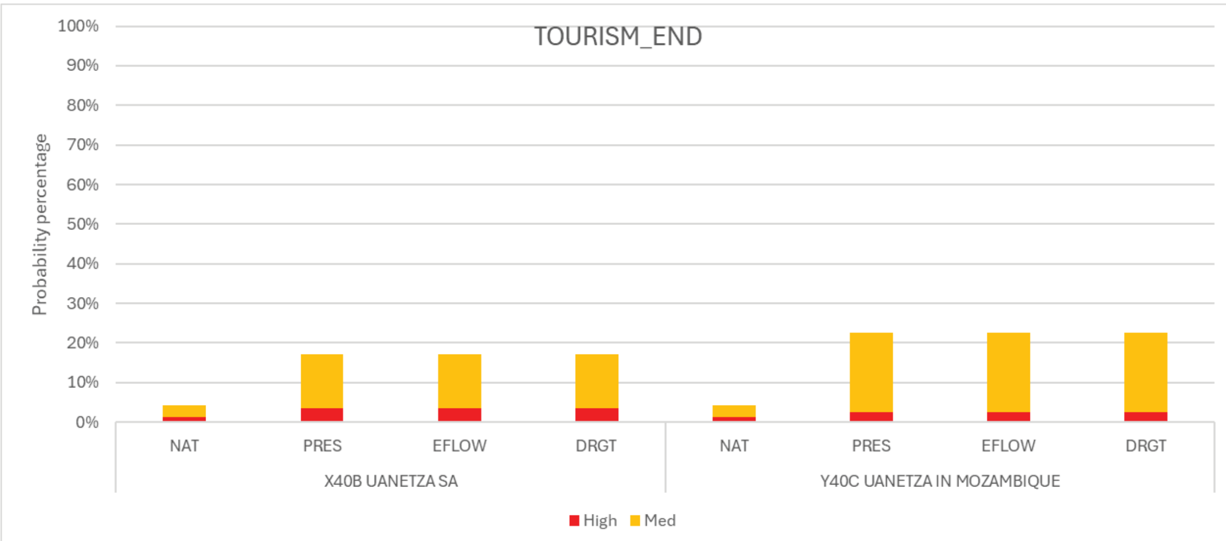


Figure 3-135: The medium and high relative risk scores for the TOURISM-END endpoint for the Uanetza catchment for each scenario (Natural, Present, E-Flow and Drought).

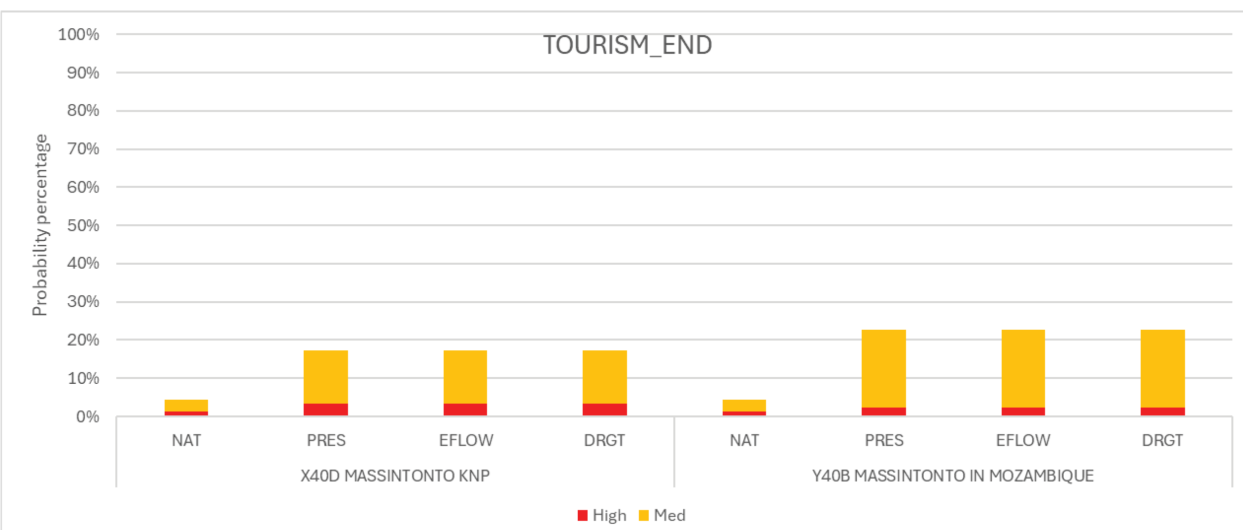


Figure 3-136: The medium and high relative risk scores for the TOURISM-END endpoint for the Massintonto catchment for each scenario (Natural, Present, E-Flow and Drought).

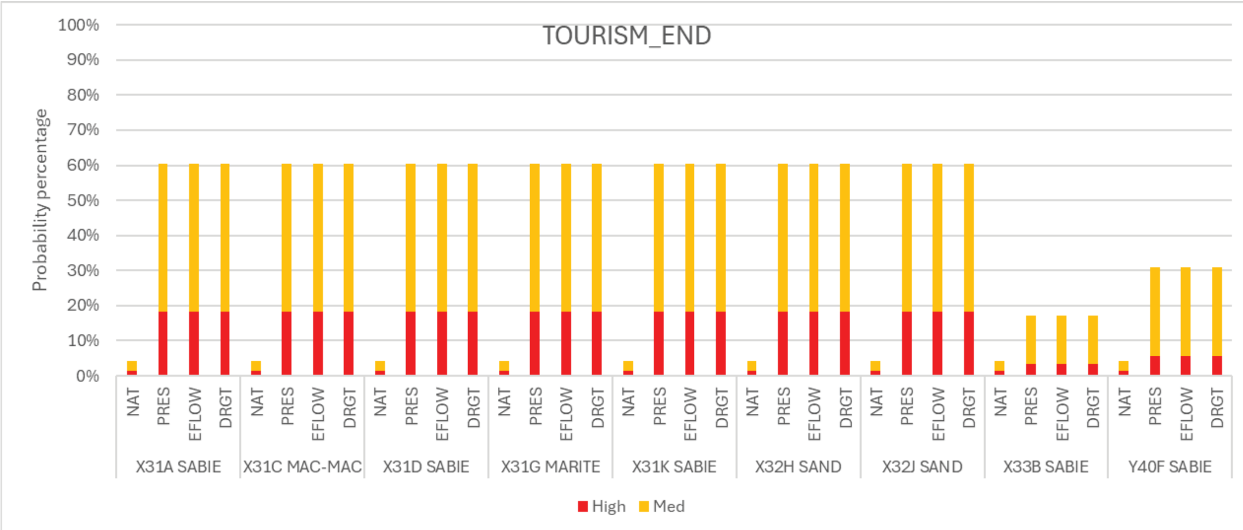


Figure 3-137: The medium and high relative risk scores for the TOURISM-END endpoint for the Sabie catchment for each scenario (Natural, Present, E-Flow and Drought).

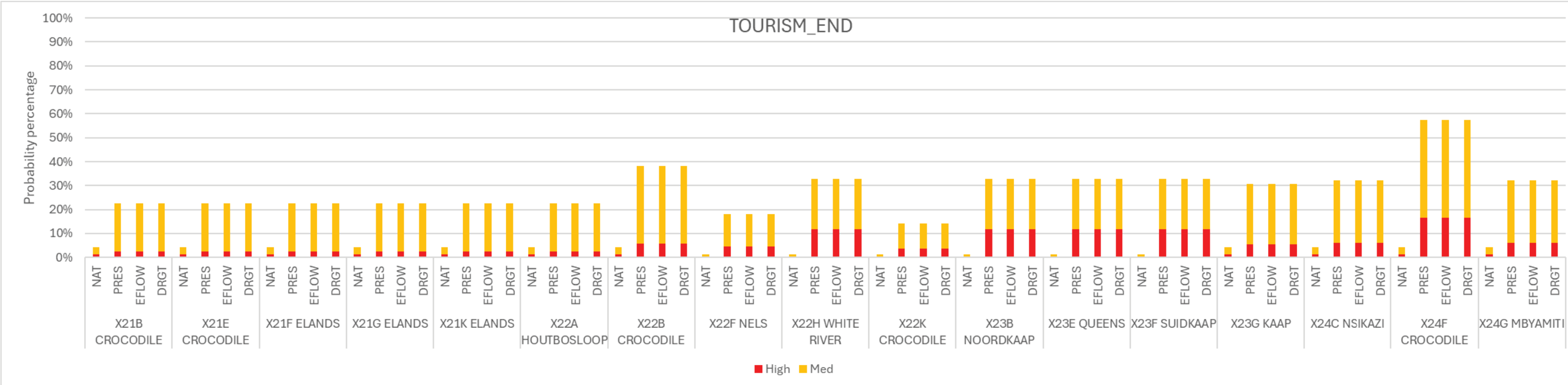


Figure 3-138: The medium and high relative risk scores for the TOURISM-END endpoint for the Crocodile catchment for each scenario (Natural, Present, E-Flow and Drought).

Figure 3-139: The medium and high relative risk scores for the TOURISM-END endpoint for the Komati catchment for each scenario (Natural, Present, E-Flow and Drought).

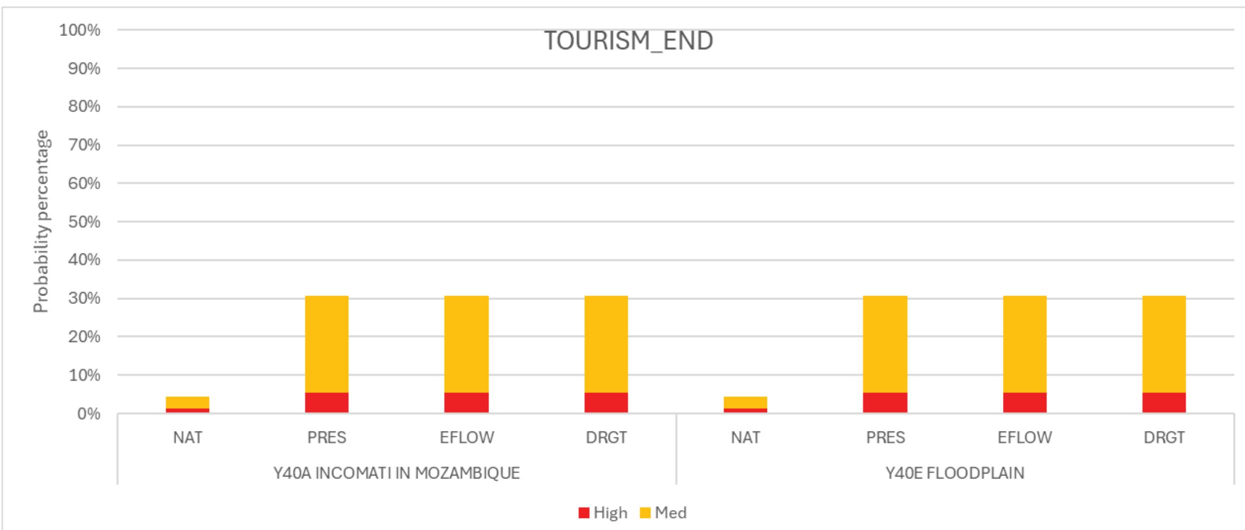


Figure 3-140: The medium and high relative risk scores for the TOURISM-END endpoint for the Incomati catchment for each scenario (Natural, Present, E-Flow and Drought).

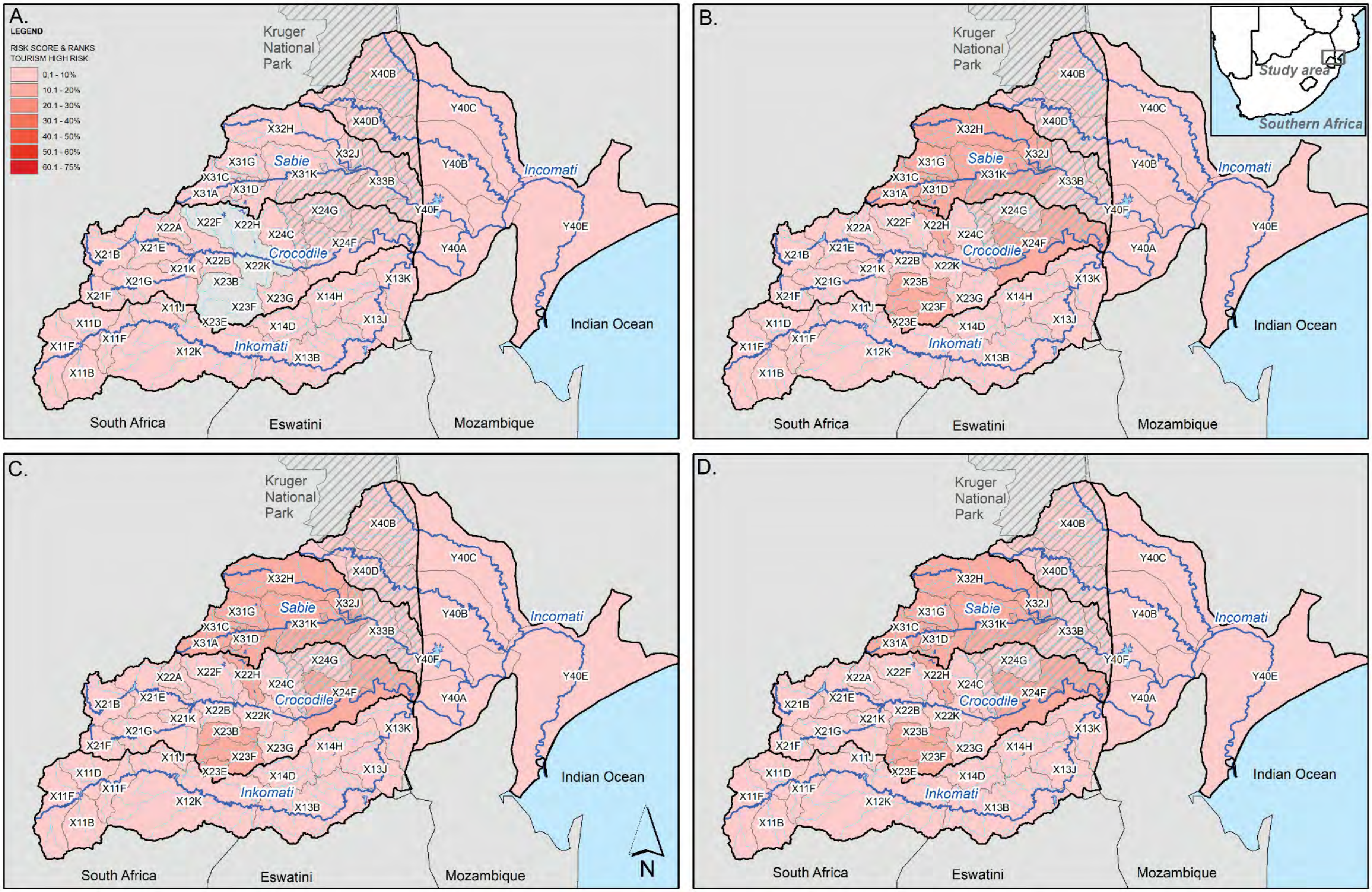


Figure 3-141: The high relative risk scores to TOURISM-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought).

3.7 STEP 7: UNCERTAINTY EVALUATION

Uncertainty associated with the availability and use of data, and the modelling process can influence the risk estimate. To reduce uncertainty in the study after implementing the RRM-BN model and the preliminary analyses, the model's structure, parametrization, and findings were evaluated by hydrology, hydraulic, water quality, ecology and social experts involved in the study. With their assistance the model was calibrated to best represent the risk of multiple stressors to natural pre-anthropogenic conditions for which some data is available, and to represent the risk to endpoints observed under PRS conditions that were evaluated in the study. The RRM-BN approach included the opportunity to incorporate uncertainty in the conditional probability tables where relationships between variables are represented as limited or high confidence, in the knowledge of the flow-ecosystem relationships using broad (low confidence with high SD) relationship profiles or high confidence (low SD) combinations. Uncertainty associated with available data specific to the reach of river being considered in the study, can be reduced though additional sampling and/or risk projection testing in monitoring and uncertainty reduction experimentation.

Additionally, the level of confidence for the other sites (Table 3-10) is lower as on some biophysical assessments were undertaken at these sites and the e-flow is solely based on the requirements for fish.

3.7.1 Sensitivity of findings

The "Sensitivity to findings" tool of Netica to evaluate the contribution of individual variables (nodes) to the risk outcomes (O'Brien *et al.*, 2018). An example of the results is provided in Table 3-119 for the FISH-ECO-ENDPOINT and the results for the remainder of the endpoints is provided in the supplementary data.

Table 3-119: Sensitivity of findings for the FISH-ECO-ENDPOINT for the natural, present, e-flow and drought scenarios.

Natural Scenario

Node	Variance Reduction	Percent	Mutual Info	Percent	Variance of beliefs
FISH_ECO_END	598.8	100	1.5868	100	0.4001
FISH_ECO_ENV	361.7	60.4	0.7048	44.4	0.1113
FISH_ECO_INS	80.65	13.5	0.1089	6.87	0.0126
FISH_ECO_BAR	48.49	8.1	0.0683	4.31	0.0076
NO_BAR_FISH	38.04	6.35	0.0503	3.17	0.0061
FISH_ECO_DTW	36.27	6.06	0.0554	3.49	0.0083
FISH_ECO_HAB	27.48	4.59	0.0330	2.08	0.0034
FISH_ECO_CUES	11.55	1.93	0.0145	0.912	0.0017
FISH_ECO_POT	10.96	1.83	0.0227	1.43	0.0045
FISH_ECO_GEOM	10.41	1.74	0.0123	0.772	0.0013
FISH_ECO_ALI	7.641	1.28	0.0131	0.827	0.0023
SUB_FISH_ENV	7.28	1.22	0.0107	0.674	0.0014
WQ_ECOSYSTEM	6.513	1.09	0.0081	0.508	0.0009
SUB_FISH_END	5.164	0.862	0.0072	0.453	0.0010
FISH_ECO_CUEQ	4.991	0.834	0.0061	0.385	0.0007
FISH_ECO_VD	4.923	0.822	0.0058	0.367	0.0006
FISH_ECO_SSUP	4.17	0.696	0.0049	0.311	0.0006
FISH_ECO_COV	4.07	0.68	0.0048	0.303	0.0005
LANDUSE_SSUP	2.592	0.433	0.0031	0.197	0.0004
FISH_ALIEN_PRED	1.958	0.327	0.0033	0.206	0.0006
SUB_VEG_RIP	1.924	0.321	0.0025	0.155	0.0004
VEG_ECO_INS	1.809	0.302	0.0023	0.147	0.0004
VEG_ECO_SSUP	1.744	0.291	0.0021	0.135	0.0003
RIV_ASS_SSUP	1.744	0.291	0.0021	0.135	0.0003
RES_RES_SSUP	1.744	0.291	0.0021	0.135	0.0003
SUB_VEG_SSUP	1.744	0.291	0.0021	0.135	0.0003
INV_ECO_SSUP	1.744	0.291	0.0021	0.135	0.0003
SUB_FISH_SSUP	1.744	0.291	0.0021	0.135	0.0003
LIV_VEG_RIP	1.31	0.219	0.0017	0.108	0.0003
SUB_VEG_EDMED	1.223	0.204	0.0016	0.0988	0.0002
FISH_ALIEN_COMP	1.063	0.177	0.0019	0.119	0.0004
SUB_VEG_WOOD	1.059	0.177	0.0014	0.0854	0.0002
RES_RES_STR	0.8835	0.148	0.0012	0.074	0.0002
LIV_VEG_END	0.8376	0.14	0.0011	0.0699	0.0002
INV_SUB	0.797	0.133	0.0010	0.0637	0.0002
INV_ECO_INS	0.7854	0.131	0.0011	0.0668	0.0002
SUB_VEG_SUPP	0.7501	0.125	0.0010	0.0616	0.0002
RES_RES_GEOM	0.7365	0.123	0.0009	0.0589	0.0001
SUB_FISH_GEOM	0.7283	0.122	0.0009	0.0584	0.0001
SUB_VEG_GEOM	0.7263	0.121	0.0009	0.0582	0.0001
VEG_ECO_GEOM	0.7169	0.12	0.0009	0.0575	0.0001
SUB_VEG_REED	0.6984	0.117	0.0009	0.0571	0.0001
FISH_ECO_VD_LF	0.6962	0.116	0.0008	0.0522	0.0001

Present Scenario

Node	Variance Reduction	Percent	Mutual Info	Percent	Variance of beliefs
FISH_ECO_END	627.8	100	1.85203	100	0.50105
FISH_ECO_ENV	278.1	44.3	0.71455	38.6	0.14465
FISH_ECO_POT	117	18.6	0.17052	9.21	0.02918
FISH_ECO_BAR	73.87	11.8	0.1228	6.63	0.01355
FISH_ECO_INS	52.06	8.29	0.08728	4.71	0.01155
NO_BAR_FISH	43.69	6.96	0.06625	3.58	0.00747
SUB_FISH_ENV	39.16	6.24	0.06241	3.37	0.00543
FISH_ECO_HAB	24.4	3.89	0.03422	1.85	0.00309
SUB_FISH_END	21.37	3.4	0.03173	1.71	0.00296
FISH_ECO_VD	8.104	1.29	0.0111	0.6	0.00108
FISH_ECO_GEOM	7.84	1.25	0.01069	0.577	0.00103
FISH_ECO_DTW	6.995	1.11	0.01044	0.564	0.00105
FISH_ECO_VD_LF	5.221	0.832	0.00709	0.383	0.00066
FISH_ECO_SSUP	4.591	0.731	0.00621	0.335	0.00055
FISH_ECO_CUES	3.624	0.577	0.00523	0.282	0.00063
WQ_ECOSYSTEM	2.717	0.433	0.0038	0.205	0.00041
FISH_ECO_CUEQ	2.705	0.431	0.00392	0.212	0.00048
LANDUSE_SSUP	2.418	0.385	0.00326	0.176	0.00029
FISH_ECO_ALI	2.099	0.334	0.00283	0.153	0.00017
DISCHARGE_HF	1.847	0.294	0.00268	0.145	0.00033
VEG_ECO_INS	1.766	0.281	0.00241	0.13	0.00021
SUB_VEG_RIP	1.565	0.249	0.00213	0.115	0.00019
REC_SPIR_VD	1.546	0.246	0.00224	0.121	0.00027
RES_RES_COV	1.471	0.234	0.00213	0.115	0.00025
INV_ECO_SSUP	1.333	0.212	0.00179	0.0969	0.00015
SUB_FISH_SSUP	1.333	0.212	0.00179	0.0969	0.00015
SUB_VEG_SSUP	1.333	0.212	0.00179	0.0969	0.00015
RES_RES_SSUP	1.333	0.212	0.00179	0.0969	0.00015
RIV_ASS_SSUP	1.333	0.212	0.00179	0.0969	0.00015
VEG_ECO_SSUP	1.333	0.212	0.00179	0.0969	0.00015
INV_ECO_INS	1.3	0.207	0.00177	0.0953	0.00015
FISH_ECO_VD_HF	1.281	0.204	0.00183	0.099	0.00022
LIV_VEG_RIP	1.197	0.191	0.00164	0.0884	0.00015
DISCHARGE_LF	1.119	0.178	0.00149	0.0807	0.00012
SUB_VEG_EDMED	1.073	0.171	0.00146	0.0789	0.00013
SUB_FISH_GEOM	1.033	0.165	0.00139	0.0751	0.00012
SUB_VEG_WOOD	1.026	0.163	0.0014	0.0756	0.00013
INV_SUB	1.018	0.162	0.00137	0.0741	0.00012
SUB_FISH_VD	0.9871	0.157	0.00144	0.078	0.00017
SUB_FISH_HAB	0.9763	0.156	0.00134	0.0724	0.00012
RES_RES_GEOM	0.9409	0.15	0.00127	0.0684	0.00011
SUB_VEG_GEOM	0.937	0.149	0.00126	0.0681	0.00011
VEG_ECO_GEOM	0.9339	0.149	0.00126	0.0679	0.00011
SUB_FISH_INST	0.8838	0.141	0.00122	0.0659	0.00011
SUB_VEG_REED	0.8804	0.14	0.0012	0.065	0.00011
SUB_VEG_SUPP	0.8724	0.139	0.00119	0.0641	0.00011
INV_ECO_HAB	0.8596	0.137	0.00117	0.0629	0.00010
LIV_VEG_END	0.7974	0.127	0.00109	0.0588	0.00010
FISH_ALIEN_PRED	0.7952	0.127	0.00105	0.0565	0.00007

E-flow Scenario

Node	Variance Reduction	Percent	Mutual Info	Percent	Variance of beliefs
FISH_ECO_END	634.6	100	1.8665	100	0.50647
FISH_ECO_ENV	290.3	45.7	0.7276	39	0.14797
FISH_ECO_POT	110	17.3	0.16094	8.62	0.02827
FISH_ECO_BAR	85.44	13.5	0.13953	7.48	0.01434
NO_BAR_FISH	50.56	7.97	0.07491	4.01	0.00795
FISH_ECO_INS	49.89	7.86	0.08197	4.39	0.01073
SUB_FISH_ENV	38.04	5.99	0.05942	3.18	0.00441
FISH_ECO_HAB	24.23	3.82	0.03385	1.81	0.00308
SUB_FISH_END	20.51	3.23	0.02979	1.6	0.00249
FISH_ECO_GEOM	11.58	1.82	0.01582	0.847	0.00146
FISH_ECO_DTW	7.768	1.22	0.01168	0.626	0.00108
FISH_ECO_SSUP	6.977	1.1	0.00946	0.507	0.00079
FISH_ECO_VD	5.619	0.885	0.00766	0.41	0.00075
LANDUSE_SSUP	3.657	0.576	0.00493	0.264	0.00042
FISH_ECO_VD_LF	3.47	0.547	0.00469	0.251	0.00044
WQ_ECOSYSTEM	3.26	0.514	0.0045	0.241	0.00046
FISH_ECO_CUES	3.152	0.497	0.00444	0.238	0.00048
VEG_ECO_INS	2.483	0.391	0.00336	0.18	0.00027
FISH_ECO_ALI	2.324	0.366	0.00318	0.17	0.00017
SUB_VEG_RIP	2.291	0.361	0.0031	0.166	0.00025
FISH_ECO_CUEQ	2.108	0.332	0.00297	0.159	0.00033
SUB_FISH_SSUP	2.006	0.316	0.00271	0.145	0.00022
RES_RES_SSUP	2.006	0.316	0.00271	0.145	0.00022
VEG_ECO_SSUP	2.006	0.316	0.00271	0.145	0.00022
INV_ECO_SSUP	2.006	0.316	0.00271	0.145	0.00022
RIV_ASS_SSUP	2.006	0.316	0.00271	0.145	0.00022
SUB_VEG_SSUP	2.006	0.316	0.00271	0.145	0.00022
INV_ECO_INS	1.796	0.283	0.00242	0.13	0.00019
LIV_VEG_RIP	1.627	0.256	0.00221	0.118	0.00018
SUB_VEG_EDMED	1.563	0.246	0.00212	0.113	0.00017
SUB_VEG_GEOM	1.554	0.245	0.0021	0.112	0.00017
VEG_ECO_GEOM	1.553	0.245	0.0021	0.112	0.00017
RES_RES_GEOM	1.549	0.244	0.00209	0.112	0.00017
SUB_VEG_WOOD	1.484	0.234	0.00201	0.108	0.00017
DISCHARGE_LF	1.266	0.2	0.00169	0.0907	0.00014
SUB_VEG_REED	1.263	0.199	0.00172	0.0919	0.00014
SUB_VEG_SUPP	1.261	0.199	0.00171	0.0914	0.00014
INV_SUB	1.162	0.183	0.00157	0.084	0.00012
INV_ECO_HAB	1.126	0.177	0.00152	0.0815	0.00012
LIV_VEG_END	1.078	0.17	0.00146	0.0781	0.00012
FISH_ECO_VD_HF	0.9854	0.155	0.00136	0.0727	0.00014
DISCHARGE_HF	0.9489	0.15	0.0013	0.0698	0.00013
FISH_ALIEN_PRED	0.8841	0.139	0.00117	0.0629	0.00007
SUB_VEG_END	0.8643	0.136	0.00117	0.0626	0.00010
RIV_ASS_GEOM	0.7831	0.123	0.00106	0.0565	0.00008
RES_RES_STR	0.702	0.111	0.00094	0.0505	0.00007
RES_RES_HAB	0.7012	0.111	0.00094	0.0505	0.00007
VEG_ECO_END	0.6905	0.109	0.00094	0.0502	0.00008
REC_SPIR_VD	0.6873	0.108	0.00094	0.0506	0.00009

Drought Scenario

Node	Variance Reduction	Percent	Mutual Info	Percent	Variance of beliefs
FISH_ECO_END	592.8	100	1.76665	100	0.4685
FISH_ECO_ENV	220	37.1	0.64341	36.4	0.1276
FISH_ECO_POT	149	25.1	0.21526	12.2	0.0330
FISH_ECO_INS	45.33	7.65	0.08516	4.82	0.0114
FISH_ECO_BAR	34.16	5.76	0.0648	3.67	0.0099
NO_BAR_FISH	20.19	3.41	0.03563	2.02	0.0055
SUB_FISH_ENV	11.52	1.94	0.02124	1.2	0.0029
FISH_ECO_HAB	9.326	1.57	0.01416	0.801	0.0016
SUB_FISH_END	6.111	1.03	0.01075	0.608	0.0016
FISH_ECO_CUES	5.103	0.861	0.0082	0.464	0.0011
FISH_ECO_DTW	4.451	0.751	0.00747	0.423	0.0012
FISH_ECO_CUEQ	4.155	0.701	0.00666	0.377	0.0009
FISH_ECO_VD	3.803	0.642	0.00569	0.322	0.0007
FISH_ECO_VD_LF	1.442	0.243	0.00214	0.121	0.0003
FISH_ECO_ALI	1.379	0.233	0.00212	0.12	0.0003
WQ_ECOSYSTEM	1.134	0.191	0.00191	0.108	0.0003
DISCHARGE_HF	0.9013	0.152	0.00143	0.0809	0.0002
FISH_ECO_GEOM	0.797	0.134	0.00118	0.0671	0.0002
FISH_ECO_VD_HF	0.7264	0.123	0.0011	0.0625	0.0001

3.7.2 Integrated risk to ecosystems

3.7.2.1 Supporting Services

The combined relative risk scores for the three supporting services for each scenario is represented in Figure 3-142A-D. As expected, the relative risk for the NAT scenario is zero too low for most risk regions (Figure 3-142A) but for the PRES scenario a moderate risk (58.41-75%) is predicted for most of the risk regions, especially those in the Komati catchment (Figure 3-142B). The relative risk predicted for the Uanetza, Massintonto and some of the Sabie catchment remained low. These results indicated that for the PRS scenario, the water resources of the Incomati basin are at a moderate risk of not being able to provide the supporting services to the associated aquatic ecosystems. Although most risk regions remained in a moderate risk for the EFLOW scenario, the risk reduced to 50.1-58.4% (Figure 3-142C). The X21F and X31G risk regions reduced to a low risk under e-flow conditions. The DRGHT scenario predicts that most risk regions will still remain in a moderate relative risk range but with more risk regions reflecting a 66.71-75% risk (Figure 3-142D). During DRGHT conditions, there is a higher moderate relative risk that the water resources will not be able to support the associated aquatic ecosystems which could result in complete failure of the aquatic ecosystem.

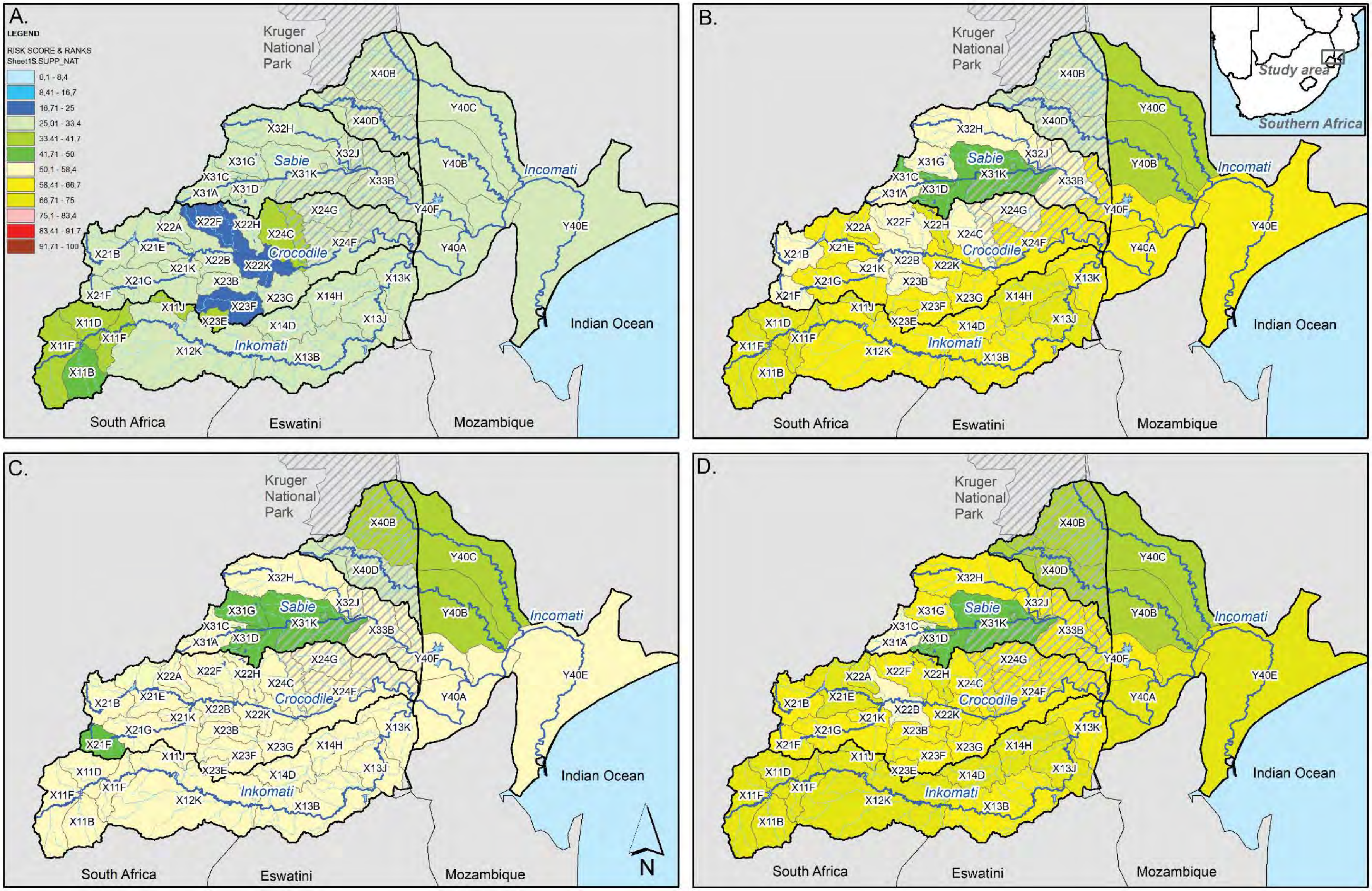


Figure 3-142: Relative risk scores to supporting services per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

3.7.2.2 Provisioning Services

The relative risk posed to the combined provisioning services endpoints indicated low relative risk for all risk regions under NAT conditions (Figure 3-143A). For the PRES scenario, most of the northern portion of the basin as well as the risk regions in Mozambique remain in a low risk range but the X32H and Y40F risk regions in the Sabie catchment, the southern portions of the Crocodile catchment as well as most of the Komati catchment reduce to a moderate relative risk (Figure 3-143B). The EFLOW scenario shows some interesting results as the Uanetza and Massitonto catchments reduce to a moderate risk whereas most of the Crocodile catchment improves to a low risk range (Figure 3-143C). The DRGHT scenario reflects an increase in the relative risk for most risk regions to a higher moderate relative risk that the water resources will not be able to support the provisioning services of the ecosystem (Figure 3-143D).

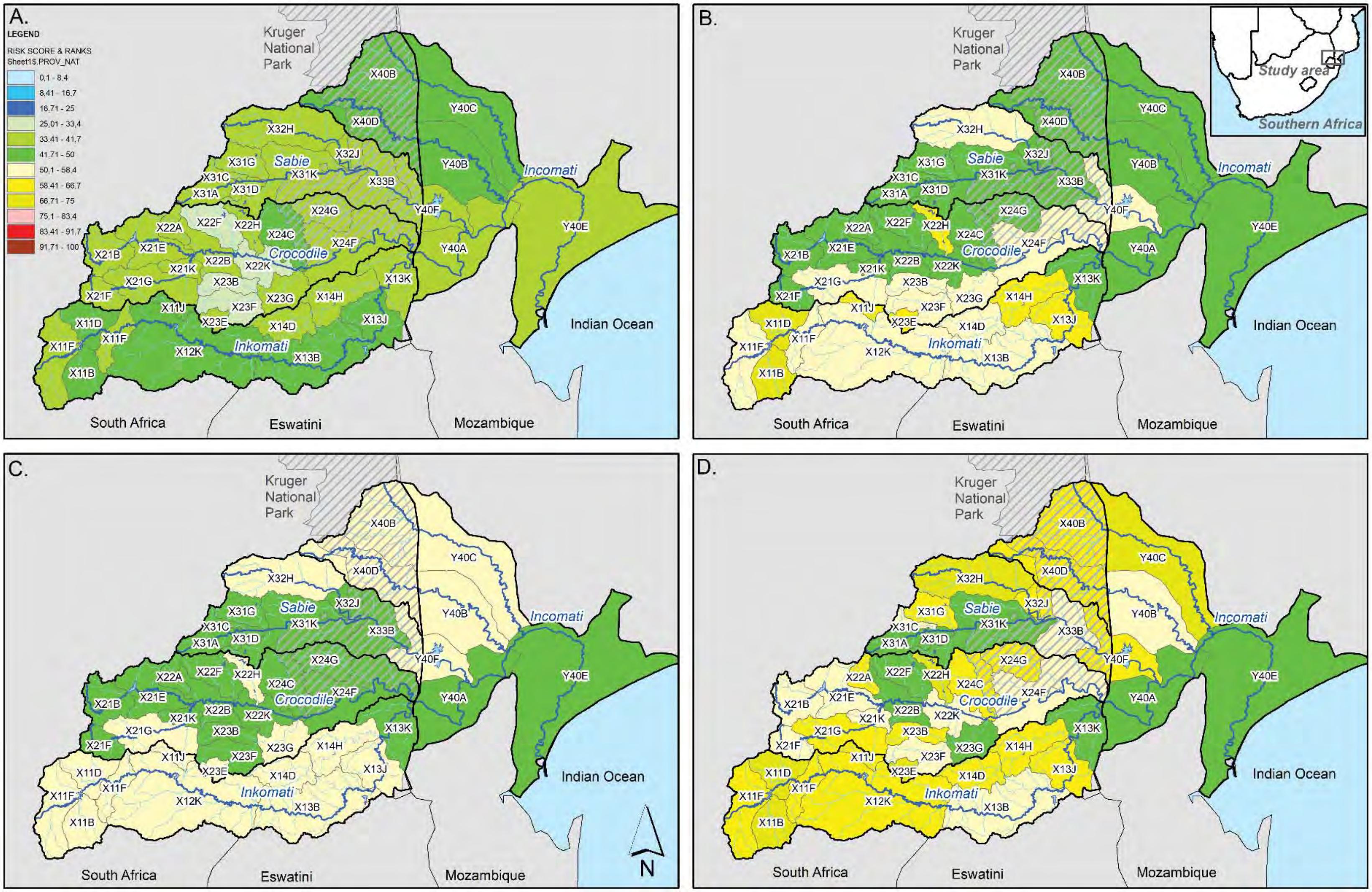


Figure 3-143: Relative risk scores to provisioning services per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed.

3.7.2.3 Regulatory Services

The proposed relative risk to the combined regulatory services indicates that for the NAT scenario, the risk regions are in a low relative risk category (Figure 3-144A). For the PRES scenario, most risk regions remain in a low relative risk range expect for the risk regions in Mozambique and some in the Crocodile and Komati catchments (Figure 3-144B). White River in risk region X22H has the highest relative risk and between 66.71 and 75%. The EFLOW scenario indicates a shift in the results as the risk to some risk regions reduce to a lower risk range, but other risk regions indicate greater risk (Figure 3-144C). The DRGHT scenario seems very similar to the PRS day scenario with a few risk regions within the Crocodile catchment recording a high risk but still within the moderate range (Figure 3-144D).

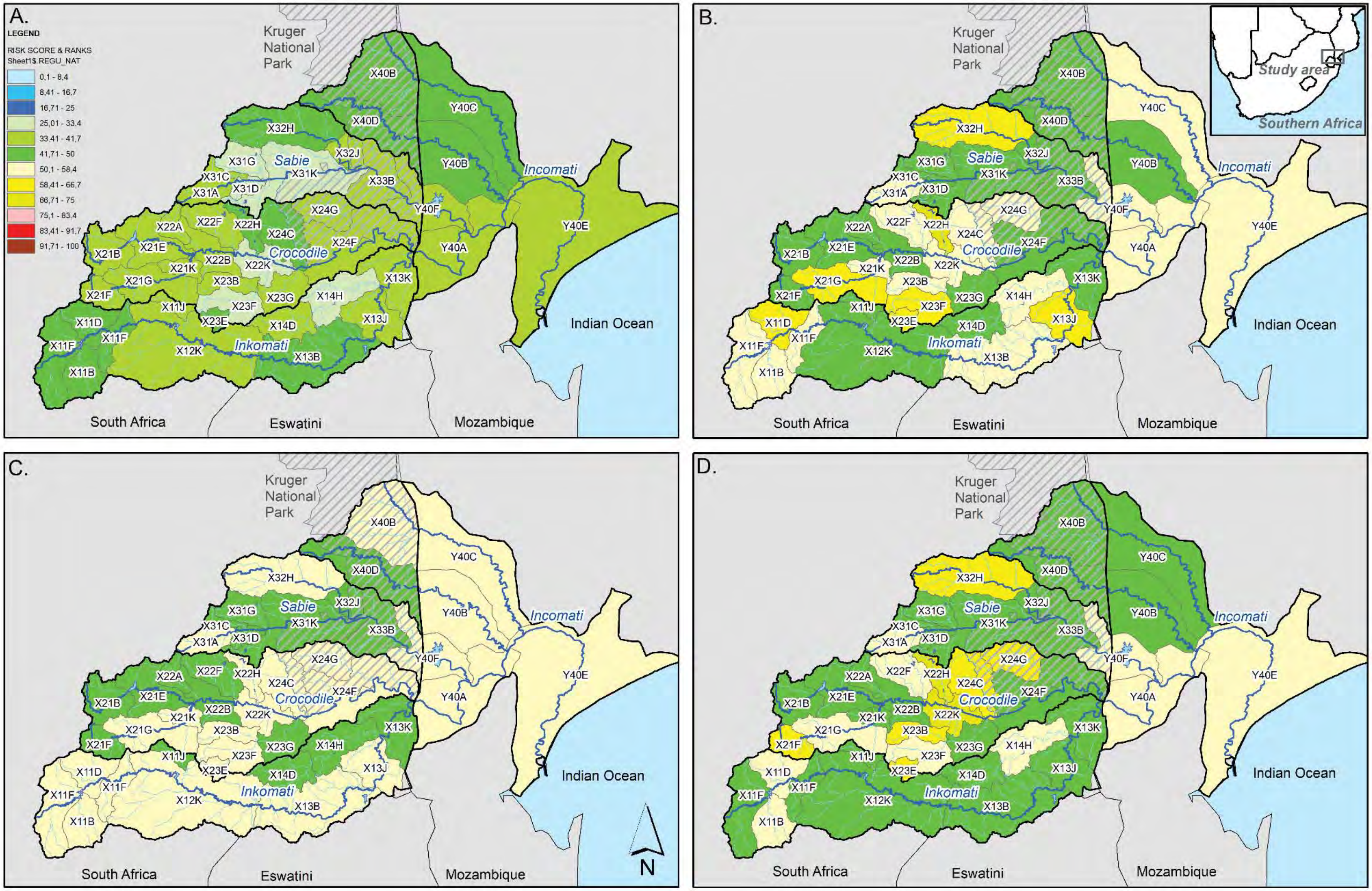


Figure 3-144: Relative risk scores to regulatory services per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed.

3.7.2.4 Cultural Services

The combined risk to the cultural services provided by the water resources within each risk region is represented in Figure 3-145A-D and shows that for the NAT scenario, there is zero to low risk for cultural services for all the risk regions. For the PRES scenario, most risk regions remain in a zero to low risk range with the exception of the X32J risk region in the KNP that show a moderate risk (Figure 3-145B). The EFLOW and DRGT scenarios (Figure 3-145C & D) reflects very similar results to the PRES scenario with the exception of the X31G and X32H risk regions in the Sabie catchment that also reflect moderate risk during the DRGT scenario.

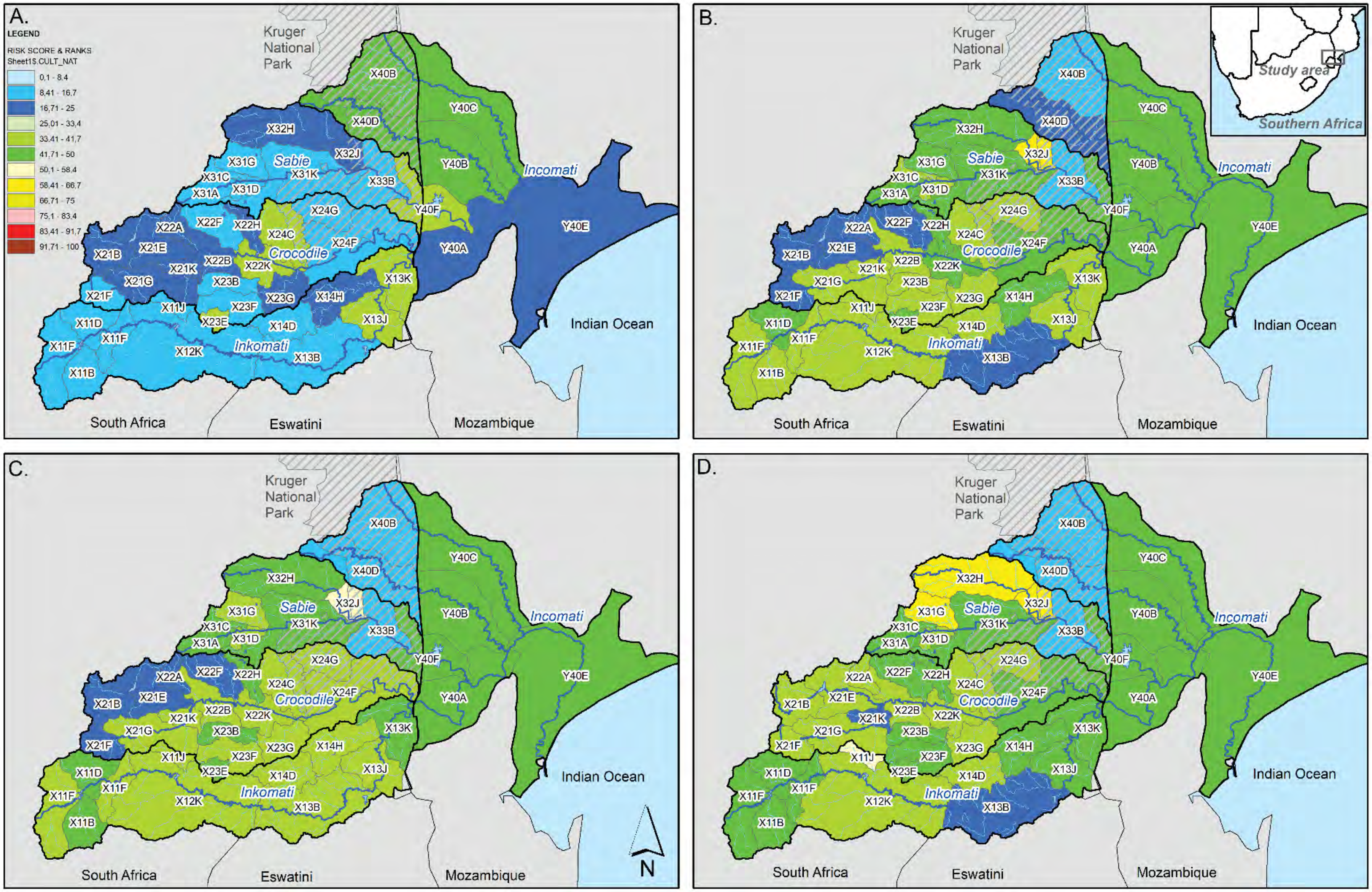


Figure 3-145: Relative risk scores to cultural services per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed.

4 IMPLEMENTATION

4.1 STEP 8: HYPOTHESES ESTABISHMENT

The regional scale ecological risk assessment can be applied in an adaptive manner and include functionality to identify the probably contributors (sources) responsible for stressors and ultimately risk identified in the study. In this study this functionality allowed for the establish a risk-based monitoring and adaptive management framework for the protection and allocation of water resources and trade-off consideration in the Incomati Basin, demonstrated in the Kaap River sub-basin (Objective 4). For the demonstration of the functionality of this approach the PROBFLO Process demonstrate was applied to a modified net applicable to the Kaap Sub-River basin (Figure 4-4). The approach includes the modification of the Bayesian Network to still allow for the determination of the risk to selected ecosystem service endpoints (here limited to supporting services). To identify potential sources or land use activities that may contribute to the risk new components of the model including nodes and associated conditional probabilities were added. The risk assessment application network (Figure 4-4) has been modified from the Incomati Risk assessment model (Figure 3-14) and includes detail input variables to describe probable water quality variables, flow variables and habitat variables to give detail to the assessment and allow for the identification of the probable sources contributing to the stressors.

The Bayesian Network mode used in the assessment consists of four components including model input variables established from the risk assessment used in the greater study (Figure 4-1). The input variables include major drivers that should be considered in the application model specifically designed to allow resource monitoring. Here the state of river connectivity (barriers), water quality variables (now including nutrients, system variables and toxicants), altered flows, sediment processes and the presence of and potential contributions of fishermen, recreational activities and alien fauna. The risk assessment model relationships used in the study have been included here to represent the causal *exposure* risk pathways linking model input variables to ecosystem components. Conditional probabilities have been established and used to represent relationships between model nodes/variables. The exposure relationships then integrate with potential variables that in this case include data from present ecological state monitoring into causal *effects* relationships to provide risk to the endpoints of the study. This model combined model stressor-ecosystem knowledge with input evidence that can be collected during ecosystem monitoring. We have aligned routine ecosystem monitoring approach outcomes (South African Ecoclassification methods) into the model as this data is routinely being collected through regional system monitoring (including the Ecostatus programme in South Africa). This application will allow direct linkages between the risk assessment outcomes including e-flows directly to ecosystem monitoring methods that will then identify and contribute to the management of sources of the stressors identified. This allows us to implement the risk assessment and monitor/manage users of water resources and/or sources of stressors. Here water quality, flow, habitat and other stressors are evaluated, the ecosystem health or status is determined and used to confirm, validate or update risk projections to provide a risk projection for present day conditions.

The next development is to identify important drivers of change of the ecosystem being evaluated. Here we add on new driver information to the model so that the potential contributors to altered water quality, quantity and habitat is evaluated automatically. In Figure 4-2 we describe how altered flows and habitat drivers are added into the implementation/monitoring models and then how the water quality component is included in detail (Figure 4-3).

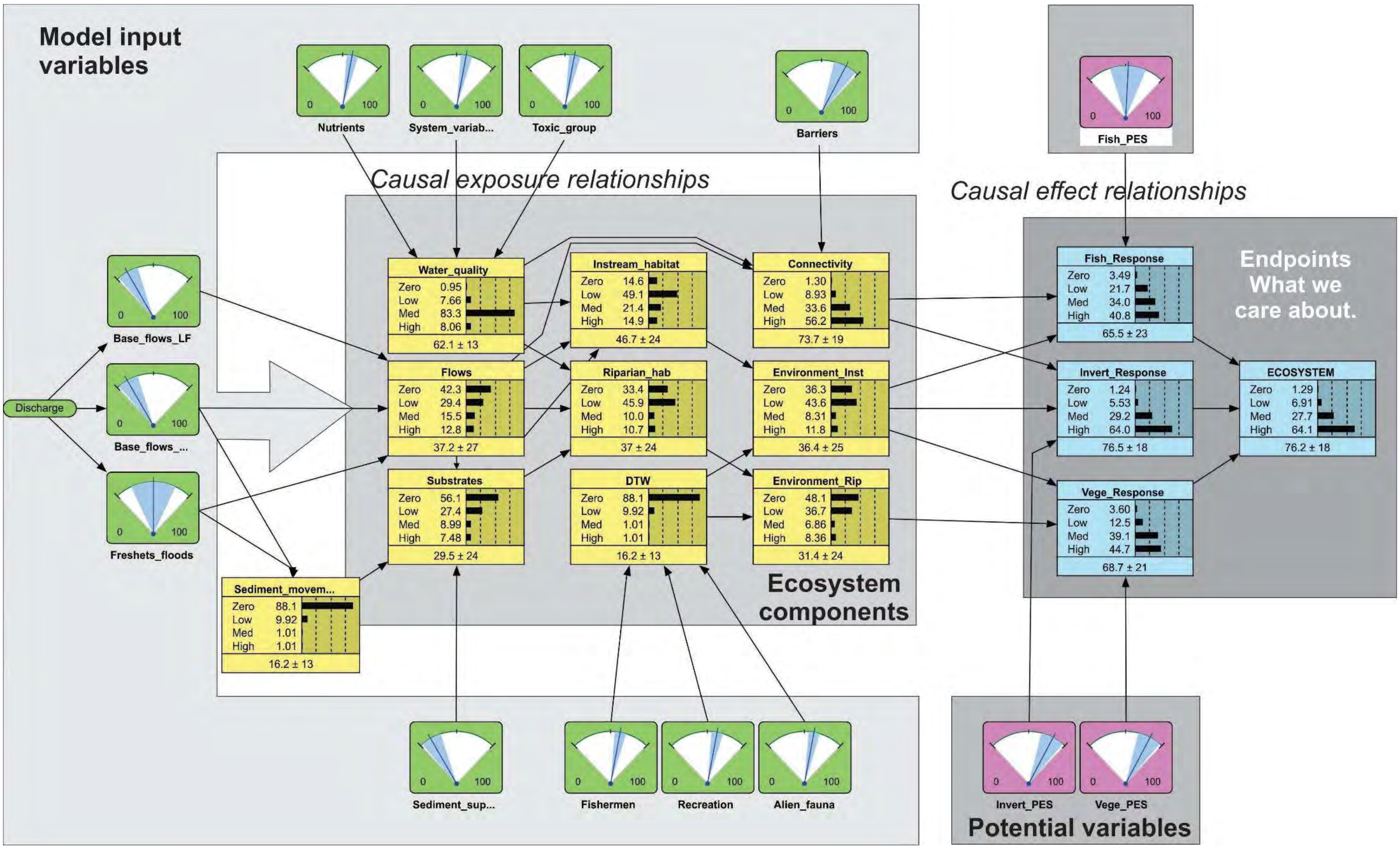


Figure 4-1: Schematic diagram to show parts of the modified Bayesian Networks designed to model the risk of altered flows, water quality and habitat to a river ecosystem. Risk components included and causal risk exposure and effect relationships included.

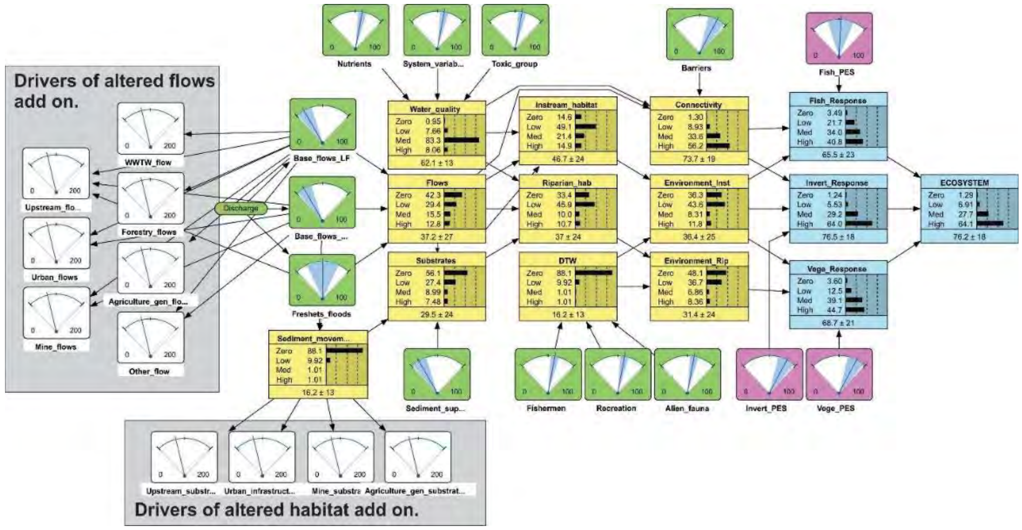


Figure 4-2: Schematic diagram to show parts of the modified Bayesian Networks designed to model the risk of altered flows, water quality and habitat to a river ecosystem. Highlighted areas demonstrate add-ons to model drivers of potential changes in flows and habitats.

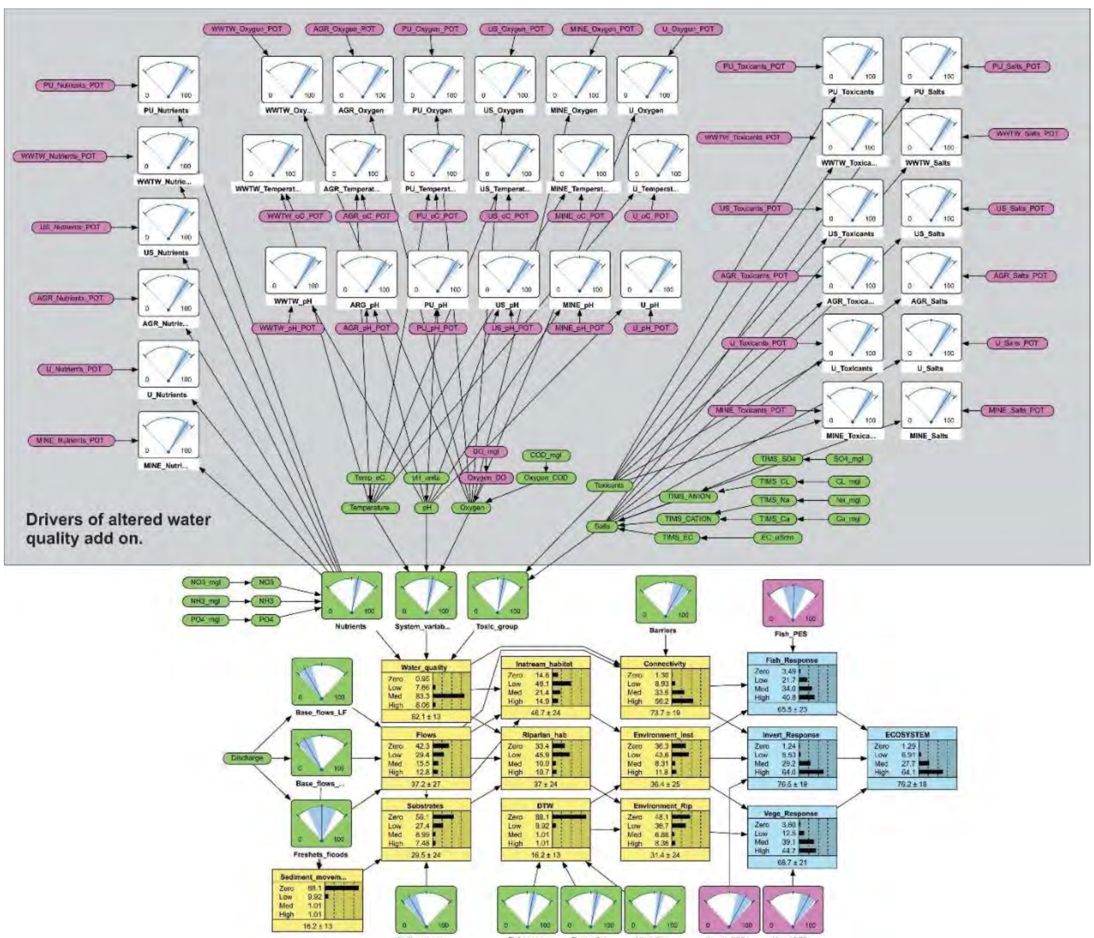


Figure 4-3: Schematic diagram to show parts of the modified Bayesian Networks designed to model the risk of altered flows, water quality and habitat to a river ecosystem. Highlighted areas demonstrate add-ons to model drivers of potential changes in water quality.

The final model presented in Figure 4-4 has been developed for this assessment and tested in the Kaap River sub-basin.

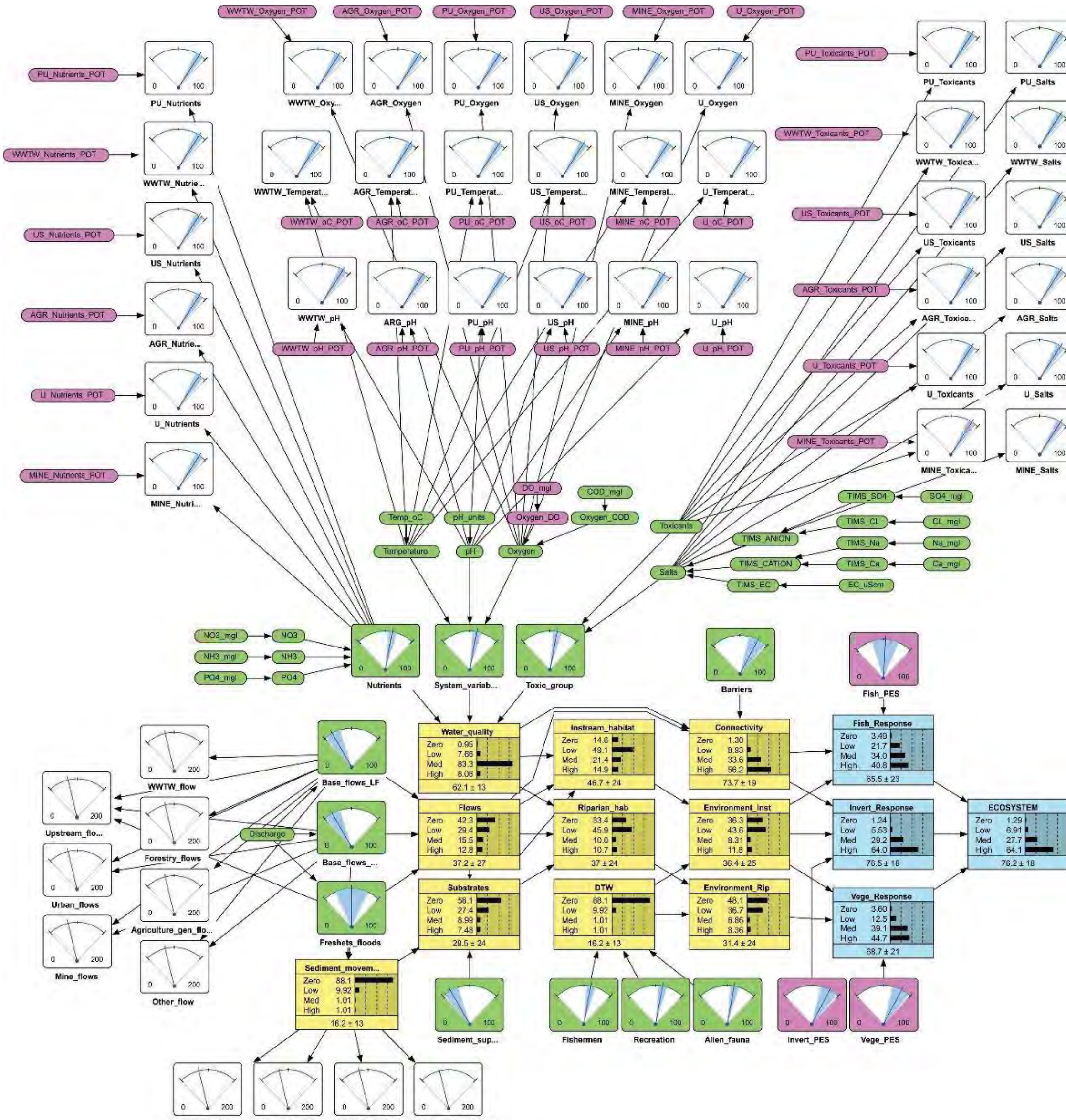


Figure 4-4: Schematic diagram to show parts of the modified Bayesian Networks designed to model the risk of altered flows, water quality and habitat to a river ecosystem. Highlighted areas demonstrate add-ons to model drivers of potential changes in water quality. All add-ons included.

4.2 STEP 9: TEST HYPOTHESES

The implementation of the adaptive risk management framework for the Kaap River sub-basin in the study was applied to the four sites considered in the study including the sub-basin X23B, X23E and X23G (Figure 4-5). The Kaap River catchment is located in the Mpumalanga province, South Africa and has an area of approximately 1640 km2 (Camacho Suarez *et al.*, 2015). Nelspruit and Barberton are the closest urban areas to the catchment with bushveld and grasslands being the predominant land cover. A large portion of the upstream region of the catchment is used for pine and eucalyptus plantations for paper and timber production (25%). Other land uses, mainly in the downstream region, include sugar cane, citrus trees and various cash crops resulting in irrigations requirements of approximately 56 mm per annum. The three main tributaries of the Kaap River are the Queens River, the upper Suidkaap River and the Noordkaap River with the highest average monthly flows per year occurring in February and the lowest in September. The Kaap River is an important contributor to flows into the Crocodile River which in turn flows into the Incomati transboundary river, shared by South Africa, Eswatini and Mozambique (Camacho Suarez *et al.*, 2015).

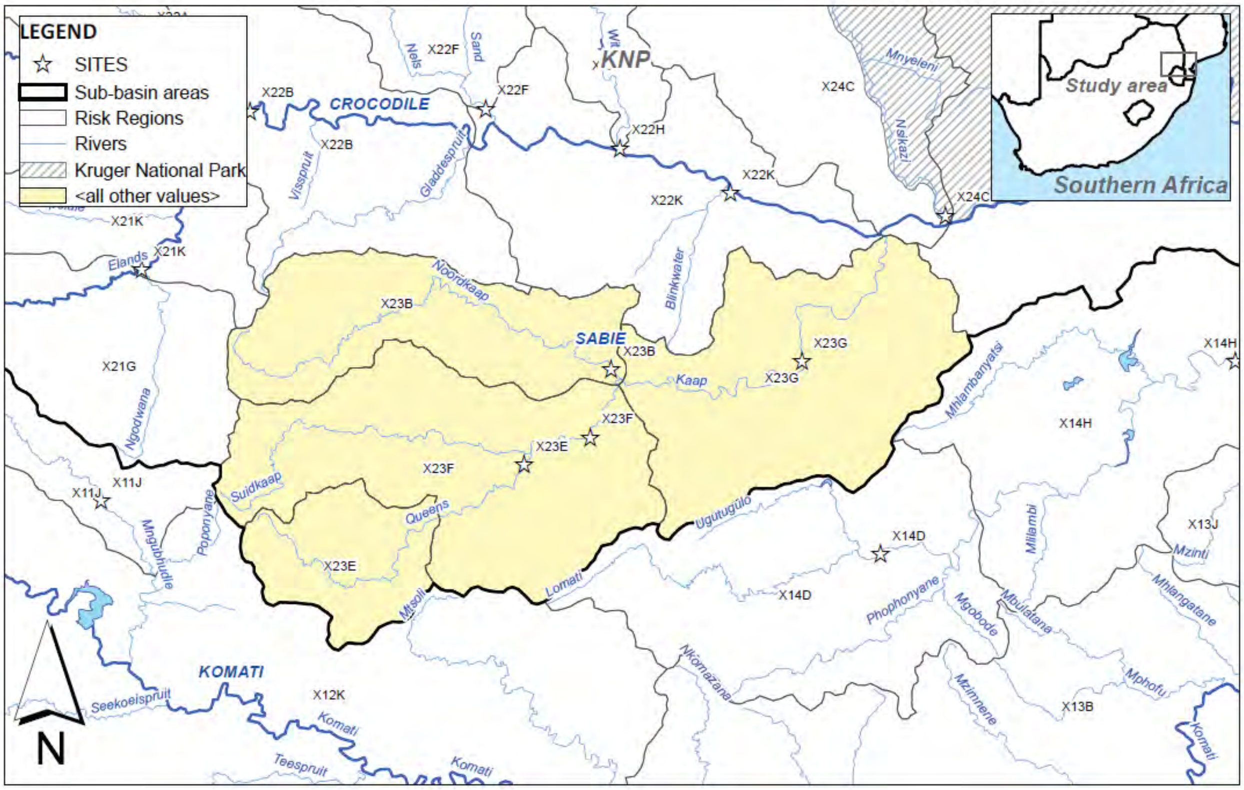


Figure 4-5: The Kaap River sub-basin considered for the implementation of the adaptive risk management framework for the study.

In 2016 The Department of Water and Sanitation (DWS) gazetted the classes of water resources and Resource Quality Objectives (RQOs) for the catchments of the Inkomati (DWS, 2016). According to this document, the Kaap Catchment as an Integrated Unit of Analysis is classified as a Class II indicating it requires moderate protection and moderate utilisation is permissible. The irrigation board of the Kaap River has provided initial flow requirement (triggers) that they are using which has been considered/implemented in this case study. These triggers include:

- Noord-Kaap River (X23B)
  - Low (drought) flow requirements: 0.14 m^3/s, (update 1 m^3/s).
  - Normal base flow requirements: 0.18 $m^{3/}s$, (update 1.8 m^3/s).
  - High base flow requirements: 0.22 $m^{3/}s$, (update 4.3 m^3/s).
  - Flood flow requirements: 0.25 m^3/s, (update 15 m^3/s).
- Suid-Kaap River (X23F)
  - Low (drought) flow requirements: 0.16 m3/s, (update 15.3 m^3/s).
  - Normal base flow requirements: 0.32 m^3/s, (update 15.3 m^3/s).
  - High base flow requirements: 0.41 m^3/s, (update 15.3 m^3/s).
  - Flood flow requirements: 0.5 m^3/s, (update 15.3 m^3/s).

- Queens River (X23E)
    - Low (drought) flow requirements: 0.12 m^3/s, (update 15.3 m^3/s).
    - Normal base flow requirements: 0.21 m^3/s, (update 15.3 m^3/s).
    - High base flow requirements: 0.27 m^3/s, (update 15.3 m^3/s).
    - Flood flow requirements: 0.3 m^3/s, (update 15.3 m^3/s).
- Kaap River (X23G)
    - Low (drought) flow requirements: 0.085 $m^3/$, (update 1 m^3/s).
    - Normal base flow requirements: 0.183 m^3/s, (update 1.8 m^3/s).
    - High base flow requirements: 0.225 m^3/s, (update 4.3 m^3/s).
    - Flood flow requirements: 0.250 m^3/s, (update 15.3 m^3/s).

Table 4-1 provides the target ecological category for the Noordkaap, Suidkaap, Queens and Kaap Rivers of which the Noordkaap, lower Suidkaap and Kaap Rivers should remain in at least moderately modified class (C category) and the upper Suidkaap and Queens Rivers in a largely natural class (B category). Further requirements provided for the Kaap River biophysical node include the following:

- The instream and riparian habitat as well as the fish should not be less than a moderately modified class (C category), the geomorphology and macro-invertebrates a largely natural class (B category) and the riparian vegetation a moderately modified to largely modified class (C/D category) (The irrigation board of the Kaap River has provided initial flow requirement (triggers) that they are using which has been considered/implemented in this case study. These triggers include:
    - Noord-Kaap River (X23B)
        - Low (drought) flow requirements: 0.14 m^3/s, (update 1 m^3/s).
        - Normal base flow requirements: 0.18 m^3/s, (update 1.8 m^3/s).
        - High base flow requirements: 0.22 m^3/s, (update 4.3 m^3/s).
        - Flood flow requirements: 0.25 m^3/s, (update 15 m^3/s).
    - Suid-Kaap River (X23F)
        - Low (drought) flow requirements: 0.16 m^3/s, (update 15.3 m^3/s).
        - Normal base flow requirements: 0.32 m^3/s, (update 15.3 m^3/s).
        - High base flow requirements: 0.41 m^3/s, (update 15.3 m^3/s).
        - Flood flow requirements: 0.5 m^3/s, (update 15.3 m^3/s).
    - Queens River (X23E)
        - Low (drought) flow requirements: 0.12 m^3/s, (update 15.3 m^3/s).
        - Normal base flow requirements: 0.21 $m^{3/}s$, (update 15.3 m^3/s).
        - High base flow requirements: 0.27 m^3/s, (update 15.3 m^3/s).
        - Flood flow requirements: 0.3 m^3/s, (update 15.3 m^3/s).
    - Kaap River (X23G)
        - Low (drought) flow requirements: 0.085 $m^3/$, (update 1 m^3/s).
        - Normal base flow requirements: 0.183 m^3/s, (update 1.8 m^3/s).
        - High base flow requirements: 0.225 m^3/s, (update 4.3 m^3/s).
        - Flood flow requirements: 0.250 m^3/s, (update 15.3 m^3/s).

The water quality has a target ecological category of largely natural (B category) with specific numerical RQOs for nutrients, salts and toxics provided in Table 4-2. The target ecological category for hydrology is moderately modified (C category) with specific RQOs provided in Table 4-3 including the natural Mean Annual Runoff in million cubic meters per annum (nMAR), flow required expressed as a percentage (%nMAR) of the nMAR for low and total flows as well as months (90% and 60%) where the flow should equal or exceed the indicated minimum values. Note these flows provided in the RQOs for the basin have been improved in this study. We have also provided flow requirements for the other sub-basins in the Kaap River Basin. The irrigation board of the Kaap River has provided initial flow requirement (triggers) that they are using which has been considered/implemented in this case study. These triggers include:

- Noord-Kaap River (X23B)
  - Low (drought) flow requirements: 0.14 m^3/s, (update 1 m^3/s).
  - Normal base flow requirements: 0.18 m^3/s, (update 1.8 m^3/s).
  - High base flow requirements: 0.22 m^3/s, (update 4.3 m^3/s).
  - Flood flow requirements: 0.25 m^3/s, (update 15 m^3/s).
- Suid-Kaap River (X23F)
  - Low (drought) flow requirements: 0.16 m^3/s, (update 15.3 m^3/s).
  - Normal base flow requirements: 0.32 m^3/s, (update 15.3 m^3/s).
  - High base flow requirements: 0.41 m^3/s, (update 15.3 m^3/s).
  - Flood flow requirements: 0.5 m^3/s, (update 15.3 m^3/s).
- Queens River (X23E)
  - Low (drought) flow requirements: 0.12 m^3/s, (update 15.3 m^3/s).
  - Normal base flow requirements: 0.21 m^3/s, (update 15.3 m^3/s).
  - High base flow requirements: 0.27 m^3/s, (update 15.3 m^3/s).
  - Flood flow requirements: 0.3 m^3/s, (update 15.3 m^3/s).
- Kaap River (X23G)
  - Low (drought) flow requirements: 0.085 $m^3/$, (update 1 m^3/s).
  - Normal base flow requirements: 0.183 m^3/s, (update 1.8 m^3/s).
  - High base flow requirements: 0.225 m^3/s, (update 4.3 m^3/s).
  - Flood flow requirements: 0.250 m^3/s, (update 15.3 m^3/s).

Table 4-1: The target ecological category for the biophysical nodes within the Kaap River Catchment and Resource Quality Objectives for the habitat and biota of the Kaap River biophysical node (DWS, 2016)

Biophysical node	River Name	Target EC
X23B-01052	Noordkaap	C – Moderately modified
X23C-01098	Suidkaap	B/C – Largely to moderately modified
X23F-01120	Suidkaap	C – Moderately modified
X23E-01154	Queens	B/C – Largely to moderately modified
EWR C7	Kaap	C – Moderately modified

Habitat and Biota RQOs

Biophysical node	Instream Habitat Integrity	Riparian Habitat Integrity	Geomorphology	Fish	Macro-invertebrates	Riparian Vegetation
EWR C7 Kaap River	C	C	B	C	B	C/D

Table 4-2: Resource Quality Objectives for water quality (ecological and user) for the Kaap River biophysical node (DWS, 2016)

Biophysical node	Target EC	Sub-Component	Narrative RQO	Numerical RQO
X23G-01057 EWR C7 Kaap River	B	Nutrients (phosphate and Total Inorganic Nitrogen)	Tolerable	50th percentile of the data must be less than 0.125 mg/L PO4-P (aquatic ecosystems: driver).
				50th percentile of the data must be < 4.0 mg/L TIN-N (aquatic ecosystems: driver)
		Electrical Conductivity (salts)	Acceptable	95th percentile of the data must be less than or equal to 200 mS/m (Aquatic ecosystems: driver).
		Toxics	Ideal	95th percentile of the data must be within the TWQR for toxics (1996a) or the upper limit of the A category in DWAF (2008).
				As levels: 95th percentile of the data must be less than 0.020 mg/L As (aquatic ecosystems: driver).
				Cn (free) levels: 95th percentile of the data must be less than 0.004 mg/L Cn (aquatic ecosystems: driver).

Table 4-3: Key hydrological Resource Quality Objectives for the Kaap River biophysical node (DWS, 2016)

Biophysical node	Target EC	nMAR (MCM)	Low Flows (%nMAR)	Total Flows (%nMAR)
X23G-01057 EWR C7 Kaap River	C	179.5	16.38	21.84
		Months	90% (m^3/s)	60% (m^3/s)
		Oct	0.19	0.45
		Nov	0.32	0.67
		Dec	0.47	0.89
		Jan	0.61	1.12
		Feb	0.86	1.53
		Mar	0.84	1.49
		Apr	0.82	1.42
		May	0.68	1.24
		June	0.61	1.13
		July	0.47	0.89
		Aug	0.29	0.62
		Sep	0.17	0.44

Our understanding of the land use activities in the area which contributed to the development of a list of sources to be included in the assessment was based on interviews with managers of the Kaap River sub-basin. These activities/users are indicated on a map of the study area in Figure 4-6 and Table 4-4.

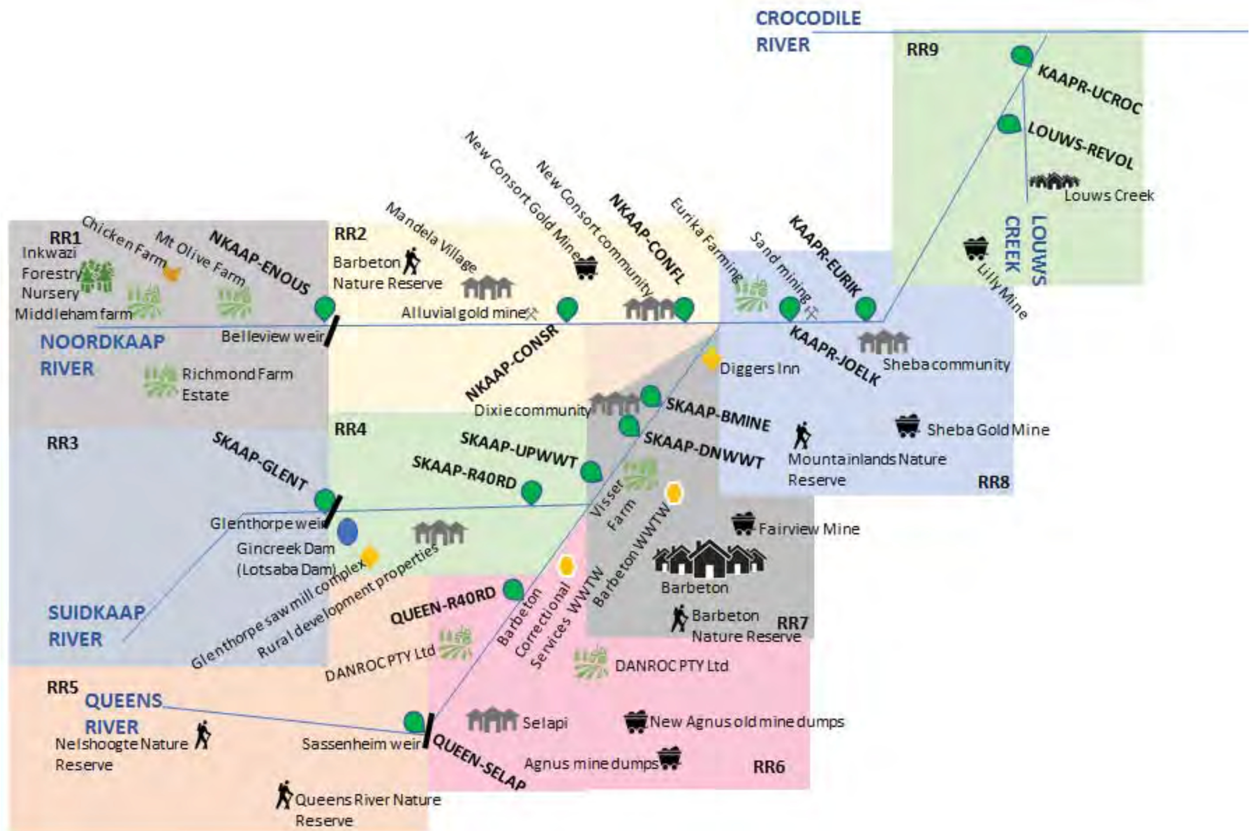


Figure 4-6: Location and nature of the land use activities in the Kaap River sub-basin.

Table 4-4: Name of major water resource users known to occur in the study area and considered in the study.

Sub-basin	Sample sites (see Annexure 2)	Activity/source
X23B (upper reaches)	X23B-NKAAP-ENOUS	Richmond farm estate
		Middleham farm
		Inkwazi forestry nursery
		Chicken farm
		Mount Olive Farm
		Belleview weir
X23B (lower reaches)	X23B-NKAAP-CONSR X23B-NKAAP-CONFL	New Consort gold mine
		Barberton nature reserve
		Alluvial gold mining
		New Consort community
		Mandela Village
X23F (upper reaches)	X23C-SKAAP-GLENT	Glenthorpe weir
X23F (lower reaches)	X23C-SKAAP-R40RD	Gincreek Dam (Lotsaba Dam)
		Glenthorpe sawmill complex
		Rural development properties
X23E upper reaches)	X23E-QUEEN-SELAP	Queens River Nature Reserve
		Nelshoogte Nature Reserve
		Sassenheim weir
X23E (upper reaches)	X23E-QUEEN-R40RD	Selapi
		DANRCO
		Agnus mine dumps
		Barberton correctional services WWTW
X23F (below confluence of Queens)	X23C-SKAAP-UPWWT X23C-SKAAP-DNWWT X23C-SKAAP-BMINE	Barberton town
		Barberton nature reserve
		Visser farm
		Fairview mine
		Dixie community
		Barberton WWTW
X23G (below confluence of Noord- and Suid-Kaap Rivers)	X23G-KAAPR-JOELK X23G-KAAPR-EURIK	Sheba gold mine
		Sand mining
		Mountainlands nature reserve
		Eurika farming
X23G (lower reaches)	X23G-KAAPR-UCROC X23-LOUWS-REVOL	Lilly mine
		Louw's Creek town

Following the assessment of the present ecological state of the Kaap sub-basin area was determined for the testing of the implementation of the risk assessment (see Annexure 2) and Figure 4-7. Rends in the results are comparable to the risk assessment outcomes (Figure 3-142) obtained in this study. This data was used to model the risk to the endpoints, the results of which are presented in Figure 4-8.

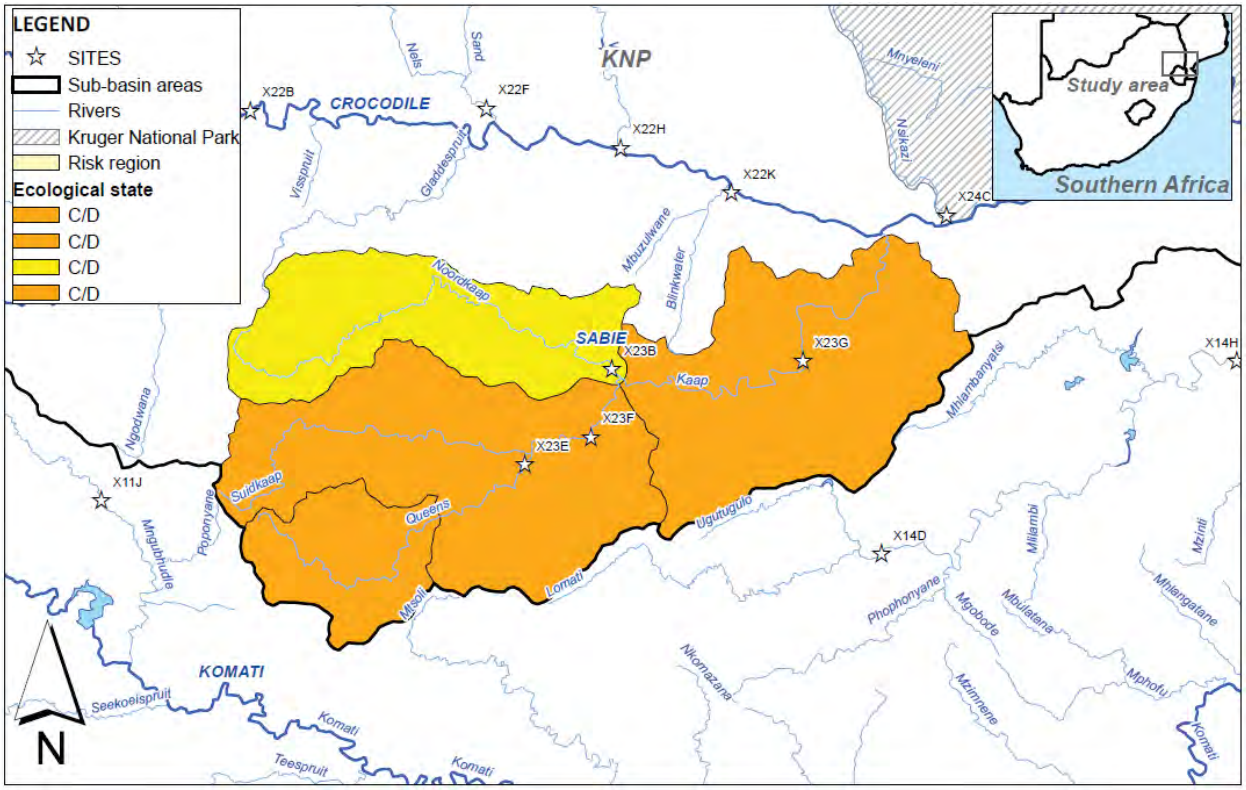


Figure 4-7: Outcomes of the present ecological state assessment of the Kaap River Catchment. Compare these results to the outcomes of the risk assessment (Figure 3-142).

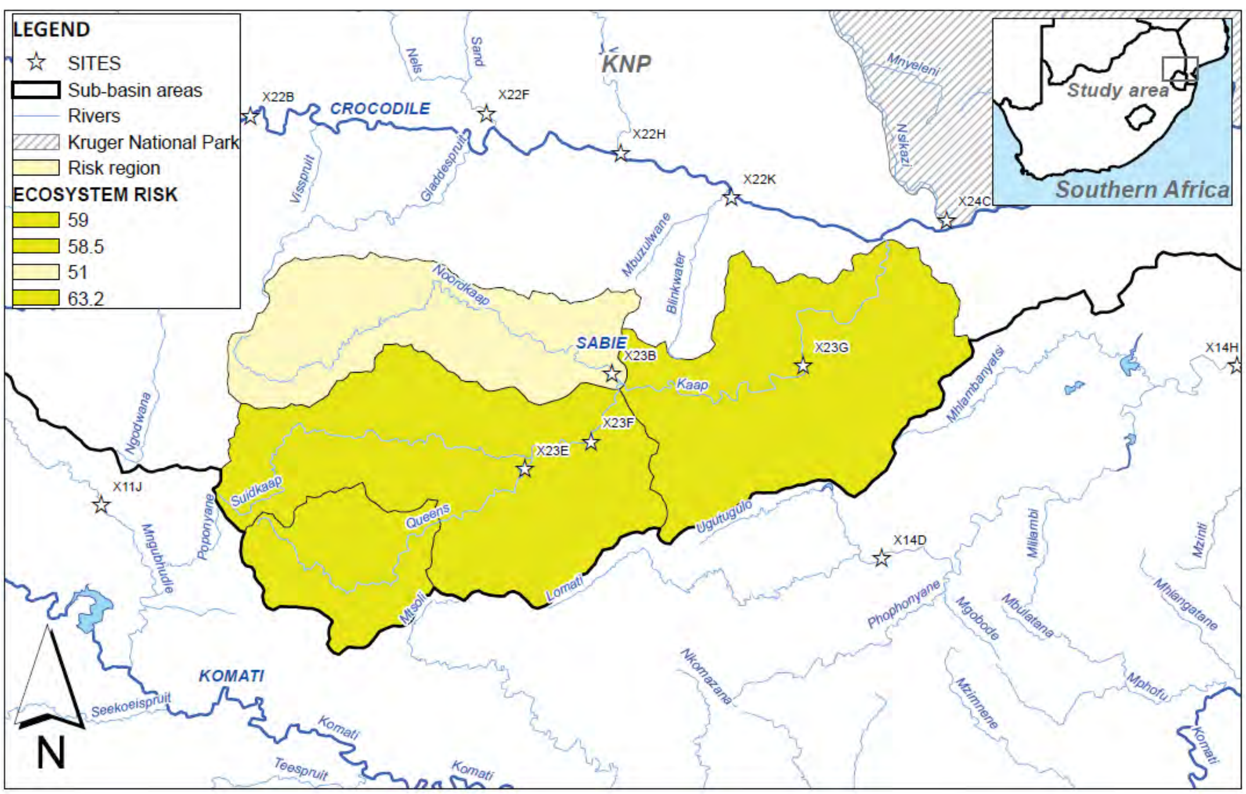


Figure 4-8: Outcomes of the risk assessment framework to demonstrate the implementation of the tool in the Kaap River sub-basin. Compare with Figure 3-142. All risk results in "moderate risk rank".

The implementation assessment can be used to provide risk score results that can be used to identify the driving variables of the (Figure 4-9). From this case study the risk assessment has identified the Waste Water Treatment Works (WWTW) and the urban centre in the Suidkaap River associated with Barbeton town as a major contributor to the risk in the study. The impact associated with these stressors has been identified in the Kaap River as well and represented in the study as an upstream impact. The cumulative impact from upstream sources has been identified as the greatest source of impact affecting the water resources of the Kaap River sub-basin. Apart from the WWTW and urban centre other impacts associated with barriers and alien invasive fauna have been identified throughout the study area and contribute to the cumulative impact in the Kaap River. The mines in the basin have also been identified to be contributing to the elevated risk in the Noordkaap, Suidkaap and Kaap Rivers. Forestry and Agricultural activities were also identified to contribute to the overall risk with a decreasing trend from upstream to downstream.

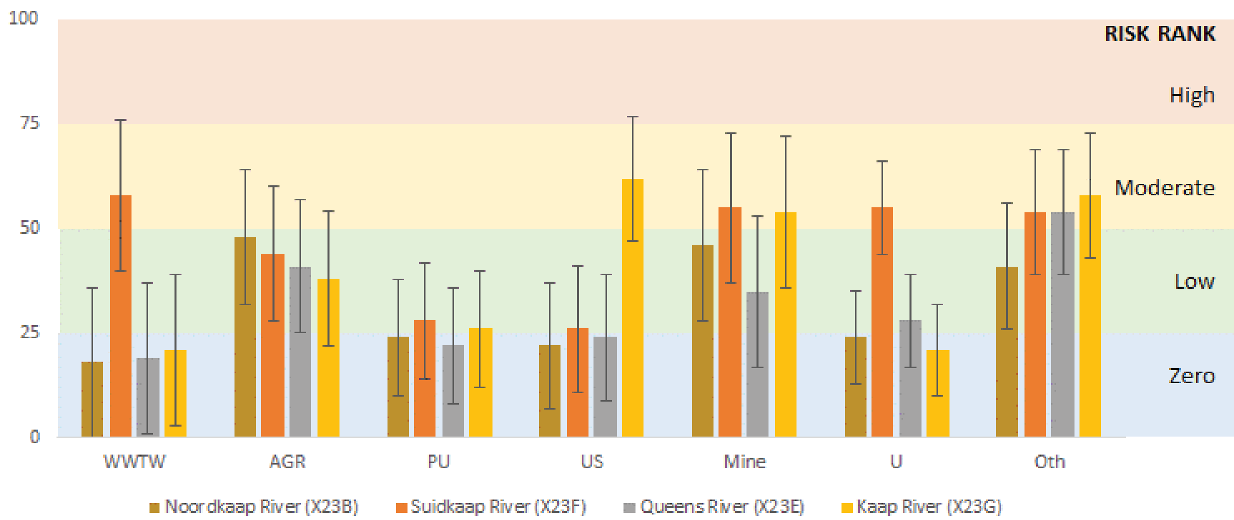


Figure 4-9: Graph of the risk of sources to the Kaap River sub-basin ecosystem for the Noordkaap (X23B), Suidkaap (X23F), Queens River (X23R) and the Kaap River (X23G).

This approach can in addition identify the nature of the stressors associated with the identified sources that are contributing to the moderate risk scores. In this case study the WWTW contribute to nutrient loading and increase in salinity of the Suidkaap River. Forestry and agriculture affects the flows, habitat and some contribution to the water quality risk in the study area. The upstream impacts in the Kaap River include upstream impacts associated with altered flows, water quality and habitats. Mines in the Suidkaap and Kaap Rivers in particular affect the water quality of the study area. The Urban centre of Barbeton affects water quality and habitat of the Suidkaap River and the other stressors include alien invasive species, barriers and overharvesting of fish in the study area. These results have been generated by the risk assessment automatically. These results direct the water resource managers of the Kaap River to identify the drivers of the risk derived in the study.

4.3 STEP 10: COMMUNICATION

Rivers are dynamic and contain ecological and social components that are important. These socio-ecological systems of rivers are difficult to represent and difficult to manage effectively. Water resource use is often excessive resulting in social and ecological impacts. The regional scale ecological risk assessment approach has been developed into a tools (including for example PROBFLO) to contribute to the understanding of how multiple stressors affect ecosystems and to the management of these systems on regional scales. In this study a regional scale ecological risk assessment of the Incomati Basin was undertaken. The risk assessment approach has been used to model the socio-ecological system of the rivers in the Incomati Basin. The models are evidence driven and require an understanding of the state of a range of environmental variables of the rivers and how the chemical and physical attributes of the rivers interact with the biological and social aspects of the rivers we care about. In the study 41 sub-catchment areas of the Incomati Basin were delineated, and risk models for each of the 41 sub-basins were developed and used to generate the risk of multiple stressors in the study. The 41 sub-basin areas or risk regions include sampling sites where chemical, physical, biological and social evidence was obtained for the risk assessment. The risk assessment models were applied to supporting services and other ecosystem services (provisioning, cultural and regulatory services) in the study. The supporting services represent the key attributes of the ecosystem including the fish, macro-invertebrates and riparian vegetation. The risk assessment to the supporting services were used to generate the environmental flow requirements for the 41 reaches in the study area. The risk to the supporting, provisioning, regulatory and cultural services were considered in the study to demonstrate the relative risk of risk regions/sub-basin areas throughout the Incomati Basin using the natural, present day, environmental flows and drought scenarios.

The results of the risk assessment include the likely risk scores aligned to zero, low, moderate and high risk along a continuum from 0 to 100. The risk scores are validated, robust and inversely proportional to the state or health of the rivers being considered. In addition, the risk assessment provides information on the probability of high risk (unsustainable/failure of that socio-ecological attribute) to each endpoint for each scenario considered in the study. The results generally demonstrate a trend between the natural scenario and present-day scenarios for each variable considered. The environmental flow requirements established in the study are aligned to the vision for the sustainable balance between the use and protection of the resource. The risk to the social and ecological endpoints associated with the e-flow requirements are on occasion better than present, showing that recovery of the system will occur if the e-flows are implemented. On other occasions the present state of the resource is better than the e-flow requirement risk outcomes, this suggests use of the resource can increase. The drought scenario generally demonstrates how risk will increase if an extended drought occurs, possibly aligned to a climate change scenario for the region.

The risk assessment outcomes of the study are provided on a regional scale (41 sub-basins in the catchment) and available for stakeholders to identify areas that have been developed beyond the threshold of sustainability. The outcomes also provide environmental flow on a comprehensive scale throughout the basin. The risk assessment also provides users with information on the probable socio-ecological consequences of not providing environmental flows and/or managing water resource use in the region. Finally in the study demonstrated how this approach can be implemented and contribute to the development of a monitoring/implementation tool and allow stakeholders to identify and manage the drivers or sources of risk.

5 CONCLUSION

This risk assessment has been completed using available and collected social and ecological evidence with multiple partners from the Incomati Basin over a three year period. We have aligned available information, improved our understanding of the hydrology of the basin, and provided new data to fill in gaps in our understanding. In the study we have identified and described resource users, the nature of their resource use and threat of their synergistic activities to the ecological and social attributes of the rivers of the basin that we care about. We have identified physical, chemical stressors and the impacts of river connectivity loss and disturbance to wildlife impacts from alien invasive fauna and flora in the basin. We have characterised our aquatic biodiversity and how our ecosystems and the people who depend on these ecosystems; have, are and may be affected my multiple stressors. We have provided a framework for stakeholders that has provided e-flow and associated non-flow drivers of change needed to achieve a holistic sustainable balance between the use and protection of water resources in the basin. This framework allows stakeholders to identify stressors, evaluate their impact/s and address excessive use and abuse of our water resources. We finally have developed a framework that allows stakeholders to consider other regulators and their water resource management, to allow stakeholders of the shared resource to work together to share and manage resources across the basin. This framework is adaptable and can be used in an iterative manner with machine learning capabilities from implementation monitoring to grow and improve projections for improved application in the future.

6 REFERENCES

Allan, J.D., 2004. Landscapes and Riverscapes: The Influence of Land-use on Stream Ecosystems. *Annual Review of Ecological and Evolutionary Systems*, 35, 257-284.

Allan, J.D., Abell, R., Hogan, Z.E.B., Revenga, C., Taylor, B.W., Welcomme, R.L. and Winemiller, K., 2005. Overfishing of inland waters. *BioScience*, 55: 1041-1051.

Anderson, A. J., 2005. Engaging disadvantaged communities: Lessons from the Incomati CMA establishment process. In International Workshop on "African Water Laws: Plural Legislative Framework for Rural Water Management in Africa". Johannesburg, South Africa.

Ansara-Ross, T.M., Wepener, V., Van Den Brink, P.J. and Ross, M.J., 2008. Probabilistic risk assessment of the environmental impacts of pesticides in the Crocodile (west) Marico catchment, North-West Province. *Water SA*, 34, 637-644.

Anzecc, A., 2000. Australian and New Zealand guidelines for fresh and marine water quality. Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, Canberra, 1, pp.1-314.Ashton, P.J., 2010. The demise of the Nile crocodile (Crocodylus niloticus) as a keystone species for aquatic ecosystem conservation in South Africa: The case of the Olifants River. Aquatic Conservation: Marine and Freshwater Ecosystems, 20: 489-493.

Ayre, K.K. and Landis, W.G., 2012. A Bayesian approach to landscape ecological risk assessment applied to the Upper Grande Ronde Watershed, Oregon. *Human and Ecological Risk Assessment: An International Journal*, 18(5), pp.946-970.

Basson, M. S. and Rossouw, J. D., 2003. Incomati water management area-Overview of water resources availability and utilisation. Department of Water Affairs and Forestry, DWAF Report No. P WMA, 5(000), 00.

Bernard, P., 2003. Ecological Implications of Water Spirit Beliefs in Southern Africa: The Need to Protect Knowledge, Nature, and Resource rights. USDA Forest Service Proceedings RMRS , Volume 27, 148-154.

Birkhead, A., 2010. The role of ecohydraulics in the South African Reserve, in: James, C., King, J. (Eds.), Ecohydraulics for South African Rivers – a Review and Guide. Water Research Commission TT453/10, Pretoria, South Africa, pp. 159-218.

Bok, A., Kotze, P., Heath, R. and Rossouw, J., 2007. Guidelines for the planning, design and operation of fishways in South Africa.

Borsuk, M.E., Stow, C.A. and Reckhow, K.H., 2004. A Bayesian network of eutrophication models for synthesis, prediction, and uncertainty analysis. *Ecological Modelling*, 173(2-3), pp.219-239.

Bosch, T. C., Adamska, M., Augustin, R., Domazet-Loso, T., Foret, S., Fraune, S., Miller, D. J., 2014. How do environmental factors influence life cycles and development? An experimental framework for early-diverging metazoans. *Bioessays*, 36(12),

Branco, P., Amaral, S. D., Ferreira, M. T. and Santos, J. M., 2017. Do small barriers affect the movement of freshwater fish by increasing residency? *Science of the Total Environment*, *581*, 486-494.

Brown, J. and Woodhouse, P., 2004. Pioneering redistributive regulatory reform. A study of implementation of a catchment management agency for the Incomati Water Management Area, South Africa (No. 1649-2016-135867).

Canadell, J., Jackson, R.B., Ehleringer, J.B., Mooney, H.A., Sala, O.E. and Schulze, E.D., 1996. Maximum rooting depth of vegetation types at the global scale. *Oecologia*, 108, pp.583-595.

Chibwe, T., Bourblanc, M., Kirsten, J. F., Mutondo, J., Farolfi, S, and Dinar, A., 2012. Reform process and performance analysis in water governance and management: A case of study of Incomati Water Management Area in South Africa.

Chikozho, C., 2005. Policy and institutional dimensions of integrated river basin management: Broadening stakeholder participatory processes in the Incomati River Basin of South Africa and the Pangani River Basin of Tanzania.

Cock, J., 2018. Writing the Ancestral River-A biography of the Kowie River. (1st edition) Wits University Press. Johannesburg, South Africa.

Colnar, A.M. and Landis, W.G., 2007. Conceptual model development for invasive species and a regional risk assessment case study: The European green crab, Carcinus Maenas, at Cherry Point, Washington, USA. *Human and Ecological Risk Assessment*, 13: 120-155.

Colvin, J., F. Ballim, S. Chimbuya, M. Everard, J. Goss, G. Klarenberg, S. Ndlovu, D. Ncala, and D. Weston., 2008. Building capacity for co-operative governance as a basis for integrated water resource managing in the Incomati and Mvoti catchments, South Africa. *Water Sa* 34, no. 6: 681-689.

Cummins, K. W., Merritt, R. W. and Berg, M. B., 2008. Ecology and distribution of aquatic insects. In R. W. Merrit, K. W. Cummins, & M. B. Berg (Eds.), An Introduction to the Aquatic Insects of North America. (4th ed., pp. 105-122). Dubuque, Iowa, United States: Kendall/Hunt Publishing Company.

Dabrowski, J.M. and De Klerk, L.P., 2013. An assessment of the impact of different land use activities on water quality in the upper Olifants River Catchment. *Water SA*, 39: 231-245.

Daily, G.C., 2000. Management objectives for the protection of ecosystem services. *Environmental Science and Pollution Research*, 3: 333-339.

Dallas, H.F. and Day, J.A. 2004. The Effect of water quality variables on aquatic ecosystems: A review. Water Research Commission, Report No. TT 224/04.

Dallas, H., 2008. Water temperature and riverine ecosystems: An overview of knowledge and approaches for assessing biotic responses, with special reference to South Africa. *Water SA*, 34(3), 393-404.

Dallas, H. F., 2007. The effect of biotope-specific sampling for aquatic macroinvertebrates on reference site classification and the identification of environmental predictors in Mpumalanga, South Africa. *African Journal of Aquatic Science*, 32, 165-173.

Dallas, H. F. and Rivers-Moore, N. A., 2019. Environmental water temperature guidelines for perennial rivers in South Africa. Volume 2: A technical manual for setting water temperature guidelines. WRC Report No. TT 799/2/19. Water Research Commission.

Dalu, T., Wasserman, R. J., Tonkin, J. D., Mwedzi, T., Magoro, M. L. and Weyl, O. L., 2017. Water or sediment? Partitioning the role of water column and sediment chemistry as drivers of macroinvertebrate communities in an austral South African stream. *Science of the Total Environment*, 607-608, 317-325.

Dandekar, P., 2018. Free-Flowing Rivers Sustaining Livelihoods, Cultures and Ecosystems, California: International River. International Rivers. Oakland CA.

Darwall, W., Smith, K., Allen, D., Seddon, M., Reid, G., Clausnitzer, V. and Kalkman, V., 2009. Freshwater Biodiversity: A Hidden Resource Under Threat.

Darwall, W. R., Smith, K., Allen, D., Holland, R., Harrison, I. and Brooks, E. G., 2011. The diversity of life in African freshwaters: Underwater, under threat. An analysis of the status and distribution of freshwater species throughout mainland Africa. In *IUCN, Gland, Switzerland and Cambridge, UK*.

Das, S.K. and Chakrabarty, D., 2007. The use of fish community structure as a measure of ecological degradation: A case study in two tropical rivers of India. *BioSystems*, 9: 188-196.

Dayaram, A., Harris, L. R., Grobler, B. A., Van der Merwe, S., Rebelo, A. G., Powrie, L. W. and Skowno, A. L., 2019. Vegetation Map of South Africa, Lesotho and Swaziland 2018: A description of changes since 2006. *Bothalia-African Biodiversity & Conservation*, 49(1), 1-11.

De Kock, K. N. and Wolmarans, C. T., 2010. Verspreiding en habitats van Unio caffer Krauss, 1848 (Bivalvia: Unionoida: Unionidae) in Suid Afrika gebaseer op die rekords in die databasis van die Nasionale Varswaterslakversameling. *Suid-Afrikaanse Tydskrif vir Natuurwetenskap en Tegnologie*, 29(4), pp. 173-185.

De Kock, K. N. and Wolmarans, C. T., 2012. Die verspreiding en habitat van Chambardia wahlbergi en Chambardia petersi (Bivalvia: Iridinidae) in Suid-Afrika. *Suid-Afrikaanse Tydskrif vir Natuurwetenskap and Tegnologie*, 13(1), 8.

De Kock, K. N. and Wolmarans, C. T., 2009. Distribution and habitats of Melanoides tuberculata (Müller, 1774) and M. victoriae (Dohrn, 1865) (Mollusca: Prosobranchia: Thiaridae) in South Africa. *Water SA*, 35(5), 713-720.

De Kock, K. N., Wolmarans, C. T. and Du Preez, L. H., 2002. Freshwater mollusc diversity in the Kruger National Park: a comparison between a period of prolonged drought and a period of exceptionally high rainfall. *Koedoe*, 45(2).

De Lange, W. J., Wise, R. M., Forsyth, G. G. and Nahman, A., 2010. Integrating socio-economic and biophysical data to support water allocations within river basins: An example from the Incomati Water Management Area in South Africa. *Environmental modelling & software*, 25(1), 43-50.

Denby, K, Movik S, Mehta L and Van Koppen B. 2016. The 'trickle down' of IWRM: A case study of local-level realities in the Incomati Water Management Area, South Africa.

Department of Water and Sanitation (DWS) 2014. 'A Desktop Assessment of the Present Ecological State, Ecological Importance and Ecological Sensitivity per Sub Quaternary Reaches for Secondary Catchments in South Africa', Compiled by RQS-RDM. Department of Water and Sanitation, Pretoria, South Africa.

Department of Water and Sanitation 2016. Classes of Water Resources and Resources Quality Objectives for the Catchments of the Incomati. Act No 1616 of 2016. As of the National Water Act 108 of 1998. Government Gazette. Republic of South Africa.

Department of Water and Sanitation 2019. Reserve Determination of Water Resources for the Incomati Catchment. Act No 998 of 2019. As of the National Water Act 108 of 1998. Government Gazette. Republic of South Africa.

Dickens, C. and O'Brien, G. C., (In Press) Water quality, water quality indicators, water quality standards. In: Encyclopedia of the UN Sustainable Development Goals. edited by Prof. Dr. Dr. h. c. Walter Leal Filho, Assist. Prof. Dr. Pinar Gökçin Özuyar, Dr. Anabela Marisa Azul, Prof. Luciana Londero Brandli, Prof. Tony Wall. I Springer reference. In Press

Dickens, C., Smakhtin, V., McCartney, M., O'Brien, G. and Dahir, L., 2019. Defining and Quantifying National-Level Targets, Indicators and Benchmarks for Management of Natural Resources to Achieve the Sustainable Development Goals. *Sustainability*, 11(2), 462.'

Diedericks, G., Simaika, J. and Roux, F., 2013. A Survey of Adult Odonata Along the Crocodile-Incomati River Main Stem from Source to Ocean. *Report to the Mpumalanga parks and tourism Agency*, 56.

Dlamini V., O'Brien G., (in-press) The contribution of WIO Anguillid eel fisheries to local fisheries' livelihood, local economy and cultural aspects in different parts of the Incomati Basin in South Africa and Mozambique. *Ecosystems and People*

Du Plessis, A., 2019. Current Water Quality Risk Areas for Limpopo, Olifants and the Incomati-Usuthu WMAs. In Water as an Inescapable Risk (pp. 183-212). Springer, Cham.

Dudgeon, D., 2010. Prospects for sustaining freshwater biodiversity in the 21st century: Linking ecosystem structure and function. *Current Opinion in Environmental Sustainability*, *2*, 422-430

Dudgeon, D., Arthington, A.H., Gessner, M.O., Kawabata, Z.I., Knowler, D.J., Lévêque, C., Naiman, R.J., Prieur-Richard, A.H., Soto, D., Stiassny, M.L.J. and Sullivan, C.A., 2006. Freshwater biodiversity: Importance, threats, status and conservation challenges. *Biological Reviews of the Cambridge Philosophical Society*, 81: 163-182.

Dupon, J.F., 1986. The effects of mining on the environment of high islands: a case study of nickel mining in New Caledonia. Noumea, New Caledonia: South Pacific Regional Environment Programme, South Pacific Commission.

Duvail, S., Hamerlynck, O., Paron, P., Hervé, D., Nyingi, W. D. and Leone, M., 2017. The changing hydro-ecological dynamics of rivers and deltas of the Western Indian Ocean: Anthropogenic and environmental drivers, local adaptation and policy response. *Comptes Rendus – Geoscience*, 349: 269-279.

Department of Water and Sanitation. 2016. *Water Quality Management Policies and Strategies for South Africa* (Issue 1).

Department of Water and Sanitation (DWS), 2017. Reserve Determination of Water Resources in the Inkomati Catchment in Terms of Section 16(1) AND (2) Of the National Water Act, 1998 (ACT NO. 36 of 1998). No. 41237.

Eady, B. R., Rivers-Moore, N. A. and Hill, T. R., 2013. Relationship between water temperature predictability and aquatic macroinvertebrate assemblages in two South African streams. *African Journal of Aquatic Sciences*, 38(2), 163-174.

Environmental Performance Index, 2020. Global metrics for the environment: Ranking country performance on sustainability issues. In Yale University.

Evans, W., Downs, C.T., Burnett, M.J. and O'Brien, G.C., 2022. Assessing fish community response to water quality and habitat stressors in KwaZulu-Natal, South Africa. *African Journal of Aquatic Science*, 47(1), pp.47-65.

Fausch, K.D., Lyons, J., Karr, J.R. and Angermeier, P.L., 1990. Fish Communities as Indicators of Environmental degradation. *American Fisheries Society Symposium*, 8,123-144.

Fouché, P.S.O. 2009. 'Aspects of the ecology and biology of the Lowveld largescale yellowfish (*Labeobarbus marequensis*, Smith 1843) in the Luvuvhu River, Limpopo River system, South Africa', Department of Biodiversity, PhD, p. 299.

Friedman, J.M. and Lee, V.J., 2002. Extreme floods, channel change, and riparian forests along ephemeral streams. *Ecological monographs*, 72(3), pp.409-425.

Frissell, C.A., Liss, W.J., Warren, C.E. and Hurley, M.D., 1986. A hierarchical framework for stream habitat classification: viewing streams in a watershed context. *Environmental management*, 10, pp.199-214.

Goetsch, P.-A. and Palmer, C. G., 1997. Salinity Tolerances of Selected Macroinvertebrates of the Sabie River, Kruger National Park, South Africa. *Archives of Environmental Contamination and Toxicity*, 32-41.

Gordon, N., McMahon, T., Finlayson, B., Gippel, C. and Nathan, R., 2004. Stream Hydrology: An Introduction for Ecologists, 2nd ed. John Wiley & Sons Ltd, Chichester.

Griffin, N. J., Palmer, C. G. and Scherman, P.A., 2014. Critical Analysis of Environmental Water Quality in South Africa: Historic and current trends. WRC Report No. 2184/1/14. Pretoria: Water Research Commission.

Hallowes, J., Frezgi, M., Jonker, V. and Manley, R., 2010. Tripartite Permanent Technical Committee (TPTC) between Mozambique , South Africa and Swaziland.

Harvey, B.C. and Stewart, A.J., 1991. Fish size and habitat depth relationships in headwater streams. *Oecologia*, 87: 336-342.

Hellegers, P. J. G. J., Soppe, R., Perry, C. J. and Bastiaanssen, W. G. M., 2009. Combining remote sensing and economic analysis to support decisions that affect water productivity. *Irrigation Science*, 27(3), 243-251.

Henning, J.A., Gresswell, R.E. and Fleming, I.A., 2007. Use of seasonal freshwater wetlands by fishes in a temperate river floodplain. *Journal of Fish Biology*, 71: 476-492.

Hill, M., Long, E. and Hardin, S., 1994. Effects of dam removal on Dead Lake, Chipola River, Florida.

Hilty, J., & Merenlender, A., 2000. Faunal indicator taxa selection for monitoring ecosystem health. *Biological Conservation*, 92(2), 185-197.

Hines, E. and Landis, W., 2014. Regional risk assessment of the Puyallup River Watershed and the evaluation of low impact development in meeting management goals, *Integr. Environ*.

Hirschowitz, P., Birkhead, A. and James, C., 2007. Hydraulic Modelling for Ecological Studies for South African Rivers (No. WRC Report No. 1508/1/07). Pretoria, South Africa.

Holmlund, C.M. and Hammer, M., 1999. Ecosystem services generated by fish populations. *Ecological Economics*, 29: 253-268.

Hooper, D.U., Chapin, F.S., Ewel, J.J., Hector, A., Inchausti, P., Lavorel, S., Lawton, J.H., Lodge, D.M., Loreau, M., Naeem, S. and Schmid, B., 2005. Effects of biodiversity on ecosystem functioning: a consensus of current knowledge. *Ecological Monographs*, 75: 3-35.

Hughes, D.A. and Munster, F., 1999. A decision support system for an initial "low confidence" estimate of the quantity component of the Reserve for rivers. Unpublished Report, Institute for Water Research, Rhodes University. pp. 32.

Huryn, A. D., Wallace, J. B. and Anderson, N. H., 2008. Habitat, Life History, Secondary Production, and Behavioral Adaptations of Aquatic Insects. In R. W. Merrit, K. W. Cummins, & M. B. Berg (Eds.), An Introduction to the Aquatic Insects of North America (4th ed., pp. 55-104). United States of America: Kendall/Hunt Publishing Company.

International Union for Conservation of Nature. 2021. The IUCN Red List of Threatened Species. Version 2021-1.

Jackson, M.C., Woodford, D.J. and Weyl, O.L.F., 2016. Linking key environmental stressors with the delivery of provisioning ecosystem services in the freshwaters of southern Africa. *Geo: Geography and Environment*, 3: 1-12.

Jewitt, G.P.W. and Görgens, A.H.M., 2000a. Scale and model interfaces in the context of integrated water resources management for the rivers of the Kruger National Park (Vol. 627, p. 184). Pretoria: Water Research Commission.

Jewitt, GPW* and Gorgens, A., 2000b. Facilitation of interdisciplinary collaboration in research: lessons from a Kruger National Park Rivers Research Programme project. South African Journal of Science, 96(8), pp.410-414.Jumani, S., Deitch, M. J., Kaplan, D. Anderson, E. P., Krishnaswamy, J., Lecours, V., & Whiles, M. R. (2019). River fragmentation and flow alteration metrics: A review of methods and directions for future research. Environmental Research Letters, 15.

Keetch, D. P. and Moran, V. C., 1966. Observations on the biology of nymphs of *Paragomphus cognatus* (Rambur) (Odonata: Gomphidae). I. Habitat selection in relation to substrate particle size. Proceedings of The Royal Entomological Society of London. *Series A. General Entomology*, 41(7-9), 116-122.

Kennard, M.J., Arthington, A.H., Pusey, B.J. and Harch, B.D., 2005. Are alien fish a reliable indicator of river health? *Freshwater Biology*, 50: 174-193.

Kleynhans, C.J. and Louw, M.D., 2008. River Ecoclassification: Manual for Ecostatus Determination (Version 2)—Module A: EcoClassification and EcoStatus Determination. Water Research Commission (WRC) Report no. TT, 329(08).

Kleynhans, C. J., C. Thirion, F. Roux, A. Hoffmann, H. Marais, and G. Diedericks., 2013. "Ecostatus of the crocodile river catchment, Incomati River system." South Africa: Mpumalanga tourism agency: 126.

Kleynhans, C. and Louw, M., 2012. River reach demarcation, delineation and site suitability. Appendix A: Comprehensive Reserve determination study for selected water resources (rivers, groundwater and wetlands) in the Incomati Water Management Area, Mpumalanga. Sabie and Crocodile systems: resource unit delineation (No. 26/8, p. 006). Report.

Kleynhans, C.J., 1986. The distribution , status and conservation of some fish species of the Transvaal. South *African Journal of Wildlife Research*, 16, 135-140.

Kleynhans, C.J., 2007. Module D: Fish Response Assessment Index in River ecoclassification: Manual for ecostatus Determination (version 2). Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC report No. TT 330.

Kleynhans, C.J. and Louw, M.D., 2007. Module A: EcoClassification and EcoStatus determination. River EcoClassification: Manual for EcoStatus Determination (version 2) Water Research Commission Report No. TT, 333(08).

Kleynhans, C.J., Thirion, C., Roux, F., Hoffmann, A. and Diedericks, G.J., 2015a. Ecostatus of the Komati River catchment, Incomati River systems.

Kleynhans, C.J., Thirion, C., Roux, F., Hoffmann, A., Marais, H. and Diedericks, G.J., 2015b. Ecostatus of the Crocodile River Catchment , Incomati River System (Issue November).

Komar, P., 1996. Entrainment of sediments from deposits of mixed grain sizes and densities., in: Carling, P., Dawson, M. (Eds.), Advances in Fluvial Dynamics and Stratigraphy. John Wiley, Chichester, pp. 127-182.

Kotze, I. M., Reyers, B., Schonegevel, L. Y., Nel, J. L. and Roux, D., 2006. A conservation vision for the freshwater biodiversity of the Olifants, Incomati and Usutu-Mhlathuze Water Management Areas: final report. CSIR Report Number CSIR/NRE/ECO/ER/2006/0199/C CSIR, Stellenbosch.

Kotze, P., Mackenzie, J., Deacon, A., Louw, M. and Macfadyan, S., 2013. Review and update of the Desktop Present Ecological Status (PES) and Ecological Importance (EI) and Ecological Sensitivity (ES) of South African Rivers according to the Sub-Quaternary (SQ) Catchments: INCOMATI (X) WMA. WRC PROJECT, (K5/2041).

Lamouroux, N., Souchon, Y. and Herouin, E., 1995. Predicting Velocity Frequency Distributions in Stream Reaches. *Water Resour. Res*. 31, 2367-2375.

Landis, W., 2004. Regional scale ecological risk assessment: using the relative risk model.

Lange, K., Bruder, A., Matthaei, C., Brodersen, J. and Paterson, R., 2018. Multiple-stressor effects on freshwater fish: Importance of taxonomy and life stage. *Fish and Fisheries*, 19, 974-983.

Leenhouts, J.M., Stromberg, J.C., Scott, R.L., Lite, S.J., Dixon, M., Rychener, T., Makings, E., Williams, D.G., Goodrich, D.C., Cable, W.L. and Levick, L.R., 2005. Hydrologic requirements of and consumptive ground-water use by riparian vegetation along the San Pedro River, Arizona (No. 2005-5163). US Geological Survey.

LeMarie, M., Van der Zaag, P., Menting, G., Baquete, E. and Schotanus, D., 2006. The use of remote sensing for monitoring environmental indicators: the case of the Incomati estuary, Mozambique. *Physics and Chemistry of the Earth*, Parts A/B/C, 31(15-16), 857-863.

Lite, S.J. and Stromberg, J.C., 2005. Surface water and ground-water thresholds for maintaining Populus-Salix forests, San Pedro River, Arizona. *Biological conservation*, 125(2), pp.153-167.

Lydeard, C., Cowie, R. H., Ponder, W. F., Bogan, A. E., Bouchert, P., Clark, S. A. and Thompson, F. G., 2004. The global decline of molluscs. *BioScience*, 54(4), 321-330.

Lynch, A. J., Baumgartner, L. J., Boys, C. A., Conallin, J., Cowx, I. G., Finlayson, C. M., Franklin, P. A., Hogan, Z., Koehn, J. D., McCartney, M. P., O'Brien, G. C., Phouthavong, K., Silva, L. G. M., Tob, C. A., Valbo-Jørgensen, J., Vi Vu, A., Whiting, L., Wibowo, A. and Duncan, P., 2019. Speaking the same language: can the sustainable development goals translate the needs of inland fisheries into irrigation decisions?. *Marine and Freshwater Research*.

Lytle, D.A. and Poff, N.L., 2004. Adaptation to natural flow regimes. *Trends in ecology & evolution*, 19(2), pp.94-100.

Lytle, D. A., 2008. Life-history and behavioral adaptations to flow regime in aquatic insects. In J. Lancaster, & R. A. Briers, Aquatic Insects: challenges to populations (pp. 122-138).

Macaringue, D., 2014. The potential of micro-hydropower generation in the Incomati River Catchment in Mozambique (Doctoral dissertation).

Mahlalela, L.S., 2014. Economic valuation and natural resource rent as tools for wetland conservation in Swaziland: the case of Lawuba wetland. Doctoral dissertation, University of Pretoria. South Africa.

Marcot, B.G., Holthausen, R.S., Raphael, M.G., Rowland, M.M. and Wisdom, M.J., 2001. Using Bayesian belief networks to evaluate fish and wildlife population viability under land management alternatives from an environmental impact statement. *Forest ecology and management*, 153(1-3), pp.29-42.

Marcot, B.G., Steventon, J.D., Sutherland, G.D. and McCann, R.K., 2006. Guidelines for developing and updating Bayesian belief networks applied to ecological modeling and conservation. *Canadian Journal of Forest Research*, 36(12), pp.3063-3074.

Marneweck, G. C. and Batchelor, A., 2002. Ecological and economic evaluation of wetlands in the upper Olifants River catchment. *Wetland inventory and classification* (1162/1), 02.

Matthew, J., 1968. 'n Ondersoek na die verspreiding van sekere Ephemeroptera (Insecta) in die Komatirivierstelsel, Oos-Transvaal. MSc Thesis , Dierkunde. Potchefstroom: Universiteit van Potchefstroom.

Millennium Ecosystem Assessment (MEA), 2005. Ecosystems and Human WellBeing: Synthesis. Island Press, Washington, DC

Mehta, L., Alba, R., Bolding, A., Denby, K., Derman, B., Hove, T. and Van Koppen, B., 2014. The politics of IWRM in Southern Africa. *International Journal of Water Resources Development,* 30(3), 528-542.

Molony, B., 2001. Environmental requirements and tolerances of Rainbow trout (*Oncorhynchus mykiss*) and Brown trout (Salmo trutta) with special reference to Western Australia : A review. *Fish. Res. Rep. West. Aust*., 130: 1-28.

Mucina, L. and Rutherford, M.C., 2006. The vegetation of South Africa, Lesotho and Swaziland (pp. viii+-807).

Nel, J., Colvin, C., Le Maitre, D., Smith, J. and Haines, I. 2013. South Africa's strategic water source areas. WWF South Africa, Cape Town.

O'Brien, G. C., Dickens, C., Hines, E., Wepener, V., Stassen, R., Quayle, L., Fouchy, K., MacKenzie, J., Graham, P. M., Landis, W. G., 2018. A regional-scale ecological risk framework for environmental flow evaluations. *Hydrol. Earth Syst. Sci.* 22: 957-975.

O'Brien, G.C., Dickens, C., Baker, C., Stassen, R. and Van Weert, F., 2020. Sustainable floodplains: Linking e-flows to floodplain management, ecosystems, and livelihoods in the Sahel of North Africa. *Sustainability* (Switzerland), 12: 1-32.

O'Brien, G., Smit, N.J. and Wepener, V., 2021. Regional scale risk to the ecological sustainability and ecosystem services of an African floodplain system. *Risk analysis*, 41(10), pp.1925-1952.

O'Brien, G. C. and Wepener, V., 2012. Regional-Scale Risk Assessment methodology using the Relative Risk Model (RRM) for surface freshwater aquatic ecosystems in South Africa. *Water SA*. 38(2):155-166

O'Brien, G. C., Smit, N. J. and Wepener, V., 2014. Conservation of fishes in the Elands River, Mpumalanga, South Africa: Past, present and future. *Koedoe*; 56(1).

O'Brien, G. C., Burnett, M. and Petersen, R., 2018b. Tigerfish (*Hydrocynus vittatus*) of the Sabie River. In K. Brink, P. Gough, J. Royte, P.P. Schollema, and H. Wanningen (Eds.), From Sea to Source 2.0. Protection and Restoration of Fish Migration in Rivers Worldwide (pp. 308-309). World Fish Migration Foundation.

O'Brien, G.C., Burnett, M. Petersen, R., 2018a. Rivers of Kruger National Park in a sea of dams. In K. Brink, P. Gough, J. Royte, P.P. Schollema, and H. Wanningen (Eds.), From Sea to Source 2.0. Protection and Restoration of Fish Migration in Rivers Worldwide (pp. 38-39). World Fish Migration Foundation.

O'Brien, G.C., Ross, M., Hanzen, C., Dlamini, V., Petersen, R., Diedericks, G.J. and Burnett, M.J., 2019. River connectivity and fish migration considerations in the management of multiple stressors in South Africa. Marine and Freshwater Research, 70: 1254-1264.

Oberholzer, G. and Van Eeden, J. A., 1967. The Freshwater Molluscs of the Kruger National Park. Potchefstroom: Institute for Zoological Research.

O'Brien, G. C., Dickens, C., Hines, E., Wepener, V., Stassen, R., Quayle, L., Fouchy, K., MacKenzie, J., Graham, P. M. and Landis, W. G., 2018. A regional-scale ecological risk framework for environmental flow evaluations, *Hydrol. Earth Syst. Sci*., 22, 957-975.

O'Brien, G.C., Swemmer, R. and Wepener, V., 2009. Ecological integrity assessment of the fish assemblages of the Matigulu / Nyoni and Umvoti estuaries , KwaZulu-Natal , South Africa. *African Journal of Aquatic Sciences*, 34: 293-302.

Saraiva Okello, A. M. L., Masih, I., Uhlenbrook, S., Jewitt, G. P. W., Van Der Zaag, P. and Riddell, E., 2015. Drivers of spatial and temporal variability of streamflow in the Incomati River basin. *Hydrology and Earth System Sciences*, *19*, 657-673.

Oliveira, A.G., Gomes, L.C., Latini, J.D. and Agostinho, A.A., 2014. Implications of using a variety of fishing strategies and sampling techniques across different biotopes to determine fish species composition and diversity. *Natureza & Conservação*, 12: 112-117.

Pollino, C. A., Woodberry, O., Nicholson, A., Korb, K. and Hart, B. T., 2007. Parameterisation and evaluation of a Bayesian network for use in an ecological risk assessment, ,

Ramoelo, A., Munyati, C., Lück-Vogel, M., Le Maitre, D. C. and Van Aardt, J., 2007. Land degradation mapping for modelling of ecosystem benefit flows in the Incomati catchment using remote sensing.

Ramulifho, P. A., Foord, S. H. and Rivers-Moore, N. A., 2020. The role of hydro-environmental factors in Mayfly (Ephemeroptera, Insecta) community structure: Identifying threshold responses. *Ecology and Evolution*, 10, 6919-6928.

Rapport, D.J., 1989. What constitutes ecosystem health? In: McKenzie, D.H. and McDonald, V.J. eds. Ecological Indicators. Boston, MA: Springer.

Riddell, E., G. Jewitt, K. Chetty, A. Saraiva Okello, B. Jackson, A. Lamba, S. Gokoo, P. Naidoo, T. Vather, and S. Thornton-Dibb., 2014. A management tool for the Incomati Basin with focus on improved hydrological understanding for risk-based operational water management.

Rivers-Moore, N. A., Dallas, H. F. and Ross-Gillespie, V., 2012. Life history does matter in assessing potential ecological impacts of thermal changes on aquatic macroinvertebrates. *River Research and Applications*, 29(9), 1100-1109.

Rivers-Moore, N. A., Jewitt, G. P., Weeks, D. C. and O'Keeffe, J. H., 2004. Water Temperature and Fish Distribution in the Sabie River System: Towards the development of an adaptive management tool. WRC Report No. 1065/1/04. Pretoria: Water Research Commission.

Rodríguez, J., Douglas, B.T., Bennett, E., Cumming, G., Cork, S., Agard, J., Dobson, A., Peterson, G., 2005. Trade-Offs Across Space, Time, and Ecosystem Services. *Ecology and Society*. 11.

Rodríguez, J.R., Douglas, B.T., Elena, J., Bennett, M., Cumming, G.S., Cork, S.J., Agard, J., Dobson, A.P. and Peterson, G.P., 2006. Trade-offs across Space, Time, and Ecosystem Services. *Ecology and Society*, 11.

Rogers, K. H. and Luton, R., 2016. Building an Adaptive and Stakeholder-Centred Catchment Management Agency in the Incomati/Usuthu River Catchment.

Rogers, K., Sihlophe, N., Sherwill, T., Arendse, L., Van Wilgen, B., Zeka, S. and Van Wyk, E., 2007. Stakeholder connectedness and participatory water resource management in South Africa. *Water Sa*, 33(4), 505-512.

Roux, D. J., Kevin, M. and Hill, L., 2010. Learning Strategy Framework for the Incomati Catchment Management Agency. Pretoria: Water Research Commission.

Roux, F., Diedericks, G.J., Kleynhans, C.J., Thirion, C., Hoffmann, A. and Selepe, M., 2016. Ecostatus of the Sabie-Sand river catchment. *Journal of Chemical Information and Modeling*, 53, 1-30.

Rowlston, B., Jordanova, A., Birkhead, A., 2008. , in: King, J., Tharme, R., De Villiers, M. (Eds.), Environmental Flow Assessments for Rivers: Manual for the Building Block Methodology. Pretoria, South Africa.

Rowntree, K.M., Wadeson, R.A. and O'keeffe, J., 1999. The development of a geomorphological classification system for the longitudinal zonation of south african rivers. *South African Geographical Journal*, 82: 163-172.

Rowntree, K.M., 2013. Geomorphological Driver Assessment Index in River EcoClassification: Manual for EcoStatus Determination (version 2) (Water Research Commission Report No. TT 551/13). Pretoria, South Africa.

Rowntree, K.M., Wadeson, R.A. and O'keeffe, J., 2000. 'The development of a geomorphological classification system for the longitudinal zonation of South African rivers', *South African Geographical Journal*, 82(3), pp. 163-172.

South African National Biodiversity Institute, 2009. South African National Biodiversity Assessment 2009. South African National Biodiversity Institute, Pretoria. South Africa.

Saraiva Okello, A.M. L., Masih, I., Uhlenbrook, S., Jewitt, G.P.W., Van Der Zaag, P. and Riddell, E., 2015. Drivers of spatial and temporal variability of streamflow in the Incomati River basin. *Hydrology and Earth System Sciences*, 19: 657-673.

Sawunyama, T. 2013. Small farm dam capacity estimations from simple geometric relationships in support of the water use verification process in the Incomati Water Management Area. *IAHS-AISH publication*, 362, 57-63.

Sawunyama, T. and Slaughter, A., 2018. Application of the Water Quality Systems Assessment Model (WQSAM) to the Crocodile River Catchment in Mpumalanga, South Africa for integrated management of water quality.

Schreiner, B., Mtsweni, A., Buthelezi, A. and Pegram, G., 2010. An Institutional Framework for Stakeholder Consultation in Trans-boundary River Basin Management.

Shackleton, C. and Shackleton, S., 2004. The importance of non-timber forest products in rural livelihood security and as safety nets: A review of evidence from South Africa. *South African Journal of Science*, 100(11):658-664.

Silva, A.T., Lucas, M.C., Castro-Santos, T., Katopodis, C., Baumgartner, L.J., Thiem, J.D., Aarestrup, K., Pompeu, P.S., O'Brien, G.C., Braun, D.C., Burnett, N.J., Zhu, D.Z., Fjeldstad, H.P., Forseth, T., Rajaratnam, N., Williams, J.G. and Cooke, S.J., 2018. The future of fish passage science, engineering, and practice. *Fish and Fisheries*, 19: 340-362.

Singh, S., Nair, S. S. and Gupta, A. K., 2013. Ecosystem services for disaster risk reduction: a case study of wetland in East Delhi Region, India. *Global Journal of Human Social Science, Geography, Geo-Sciences, Environmental Disaster Management*, 13(4), 1-12.

Skead, C.J., 2009. Historical plant incidence in southern Africa: a collection of early travel records in southern Africa (pp. xii+-378).

Skelton, P.H., Cambray, J.A., Lombard, A. and Benn, G.A., 1995. Patterns of distribution and conservation status of freshwater fishes in South Africa. *South African Journal of Zoology*, 30: 71-81.

Sleeter, B.M., Loveland, T., Domke, G., Herold, N., Wickham, J. and Wood, N. 2018. Land cover and land-use change. In: Reidmiller, DR; Avery, CW; Easterling, DR; Kunkel, KE; Lewis, KLM; Maycock, TK; Stewart, BC, eds. 2018. Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II. Washington, DC: US Global Change Research Program. 202-231.

Smakhtin, V. U., 2001. Estimating continuous monthly baseflow time series and their possible applications in the context of the ecological reserve. *Water SA* Vol. 27 No. 2.

Soko M. and Gyedu-Ababio T., 2019. Pollution Status of Incomati River Estuary Based on Meiofauna Analyses (Free-living Nematodes) in Maputo, Mozambique. Journal of Water Resources and Ocean Science, 8(5), pp.63-76.

Soko, M.I. and Gyedu-Ababio, T., 2015. The Spatial and Temporal Variations of Ichythyofauna and Water Quality in the Crocodile River (East), Mpumalanga, South Africa. *Journal of Water Resource and Protection*, 7: 152-170.

South African National Biodiversity Institute, 2018. South African National Biodiversity Assessment 2018. South African National Biodiversity Institute, Pretoria. South Africa.

Stankiewicz, J. and De Wit, M. J., 2006. A proposed drainage evolution model for Central Africa—Did the Congo flow east?. *Journal of African Earth Sciences*, 44(1), 75-84.

Taylor, L. R., 1990. The Ecology of and Genetic Variation in Selected Species of the Freshwater Prawn Genus Macrobrachium. Rand Afrikaans University, Department of Zoology, Faculty Natural Sciences. Johannesburg: Unpublished.

Ter Braak, C.J., 1994. Canonical community ordination. Part I: Basic theory and linear methods. Ecoscience, 1(2), pp.127-140.

Thirion, C., 2008. Module E: Volume 1 – Macroinvertebrate Response Assessment Index (MIRAI). WRC Report No. TT 332/08. Pretoria: Water Research Commission.

Thompson, M., Brandes, D. and Kney, A., 2012. Using electronic conductivity and hardness data for rapid assessment of stream water quality. *Journal of Environmental Management*, 104, 152-157.

Van den Brink, P., Van den Brink, N. and Ter Braak, C. J. F., 2003. Multivariate analysis of ecotoxicological data using ordination: Demonstrations of utility on the basis of various examples. *Australasian Journal of Ecotoxicology*, *9*, 141-156.

Van Straalen, N.M. and Van Rijn, J.P., 1998. Ecotoxicological risk assessment of soil fauna recovery from pesticide application. *Reviews of environmental contamination and toxicology: continuation of residue reviews,* pp.83-141.

Van Wyk, A. E., 1996. Biodiversity of the Maputaland centre. In The biodiversity of African plants (pp. 198-207). Springer, Dordrecht.

Vezi, M., Downs, C., Wepener, V. and O'Brien, G. C., 2019. Application of the relative risk model for evaluation of ecological risk in selected river dominated estuaries in KwaZulu-Natal, South Africa. *Ocean & Coastal Management*.

Vörösmarty, C.J., McIntyre, P.B., Gessner, M.O., Dudgeon, D., Prusevich, A., Green, P., Glidden, S., Bunn, S.E., Sullivan, C.A., Liermann, C.R. and Davies, P.M., 2010. Global threats to human water security and river biodiversity. *Nature*, 467: 555-561.

Wade, M., O'Brien, G. C., Wepener, V., & Jewitt, G., 2020. Risk Assessment of Water Quantity and Quality Stressors to Balance the Use and Protection of Vulnerable Water Resources. *Integrated Environmental Assessment and Management*, *17*, 110-130.

Wallace, J. B. and Anderson, N. H., 1995. Habitat, life history, and behavioral adaptations of aquatic insects. In R. W. Merritt, & K. W. Cummins (Eds.), An Introduction to the Aquatic Insects of North America (3rd ed., pp. 41-73). Dubuque, Iowa, United States of America: Kendall/Hunt Publishing Company.

Walser, C. and Bart, H., 1999. Influence of agriculture on in-stream habitat and fish community structure in Piedmont watersheds of the Chattahoochee River System. *Ecology of Freshwater Fish*, 8, 237-246.

Wang, N., Ivey, C. D., Ingersoll, C. G., Brumbaugh, W. G., Alvarez, D., Hammer, E. J. and Barnhart, M. C., 2016. Acute sensitivity of a broad range of freshwater mussels to chemicals with different modes of toxic action. *Environmental Toxicity and Chemistry*, 35(1), 115-127.

Wepener, V., Van Dyk, C., Bervoets, L., O'Brien, G.C., Covacic, A. and Cloete, Y., 2011. An assessment of the influence of multiple stressors on the Vaal River, South Africa. *Physics and Chemistry of the Earth.* 36, 949-962.

Wessels, P. and Rooseboom, A., 2009. Flow-gauging structures in South African rivers Part 1: An overview. *Water SA*, 35(1).

Wheeldon, J. and Faubert, J., 2009. Framing experience: Concept maps, mind maps, and data collection in qualitative research. *International journal of qualitative methods*, 8(3), 68-83.

Wilkinson, M. J., Magagula, T. K. and Hassan, R. M., 2015. Piloting a method to evaluate the implementation of integrated water resource management in the Incomati River Basin. *Water SA*, 41(5), 633-642.

Williams, C. R., Leaner, J. J., Nel, J. M. and Somerset, V. S., 2010. Mercury concentrations in water resources potentially impacted by coal-fired power stations and artisanal gold mining in Mpumalanga, South Africa. *Journal of Science*.

Winter, B., 1990. A brief review of dam removal efforts in Washington, Oregon, Idaho, and California. U.S.

Withers, P.J., Neal, C., Jarvie, H.P. and Doody, D.G., 2014. Agriculture and eutrophication: where do we go from here?. *Sustainability*, 6(9), pp.5853-5875.

Woodborne, S., Huchzermeyer, K.D.A., Govender, D., Pienaar, D.J., Hall, G., Myburgh, J.G., Deacon, A.R., Venter, J. and Lübcker, N., 2012. Ecosystem change and the Olifants River crocodile mass mortality events. *Ecosphere*, 3: 1-17.

Zaimes, G.N., Gounaridis, D. and Symenonakis, E., 2019. Assessing the impact of dams on riparian and deltaic vegetation using remotely-sensed vegetation indices and Random Forests modelling. *Ecological indicators*, 103, pp.630-641.

Zhang, U., Liu, X., Qin, B., Shi, K., Deng, J. & Zhou, Y., 2016. Aquatic vegetation in response to increased eutrophication and degraded light climate in Eastern Lake Taihu: Implications for lake ecological restoration. China: Scientific Reports.

Zhao, T., Grenouillet, G., Pool, T., Tudesque, L. and Cucherousset, J., 2016. Environmental determinants of fish community structure in gravel pit lakes. *Ecology of Freshwater Fish*, 25: 412-421.

Zokufa, W. T., Scherman, P.-A. and Palmer, C. G., 2001. Tolerance of selected riverine indigenous macroinvertebrates from the Sabie River (Mpumalanga) and Buffalo River (Eastern Cape), to complex saline kraft and textile effluents. Pretoria: Water Research Commission, WRC Report No. 783/1/01.

7 ANNEXURE 1

7.1 Supporting Services

7.1.1 FISH-ECO-END endpoint

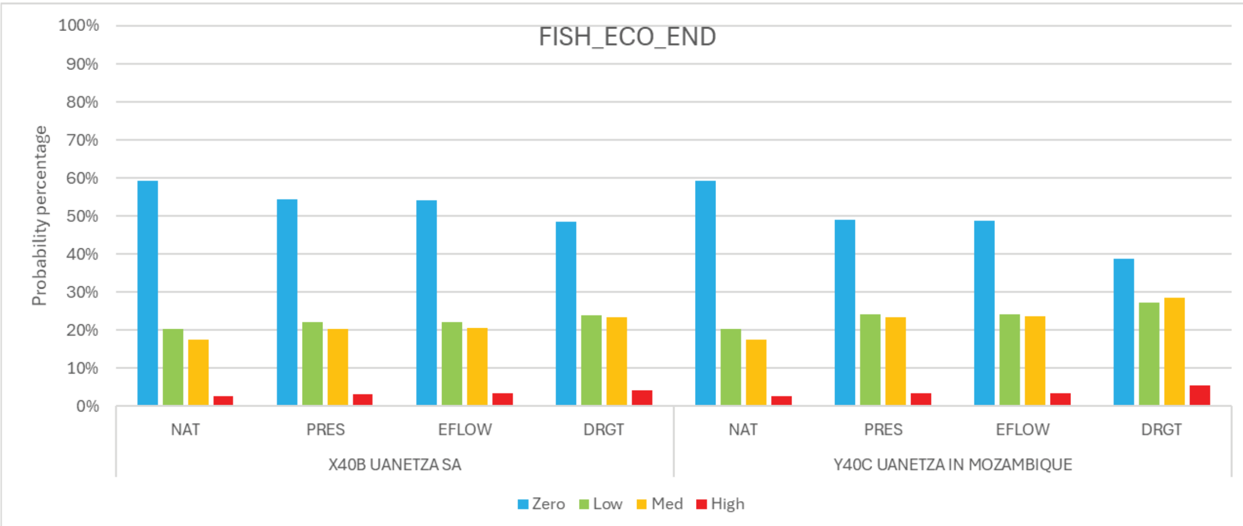


Figure 7-1: Relative risk scores to FISH-ECO-END for the Uanetza catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

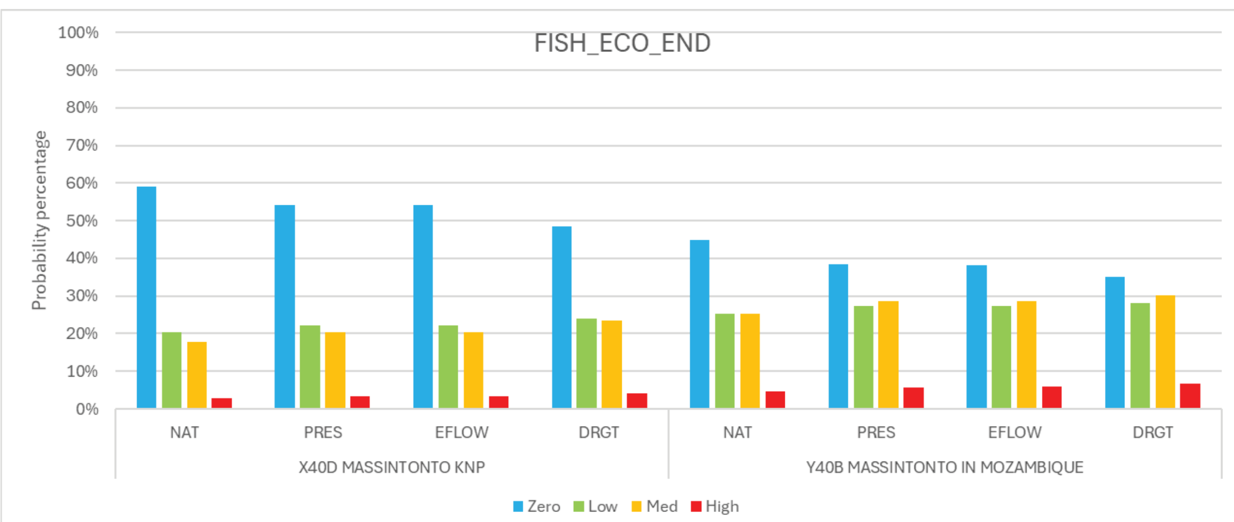


Figure 7-2: Relative risk scores to FISH-ECO-END for the Massintonto catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

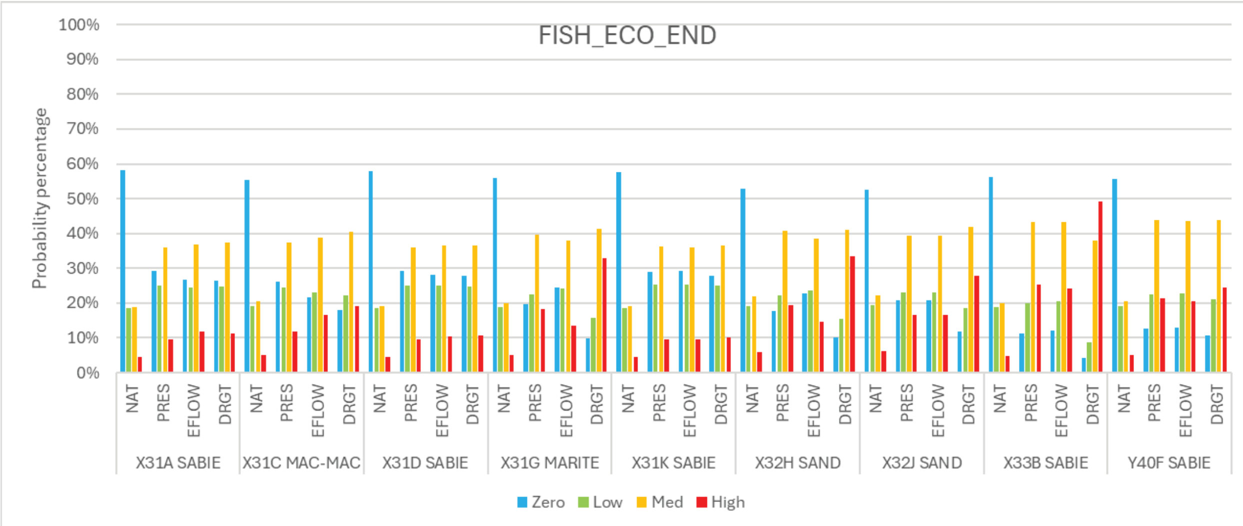


Figure 7-3: Relative risk scores to FISH-ECO-END for the Sabie catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

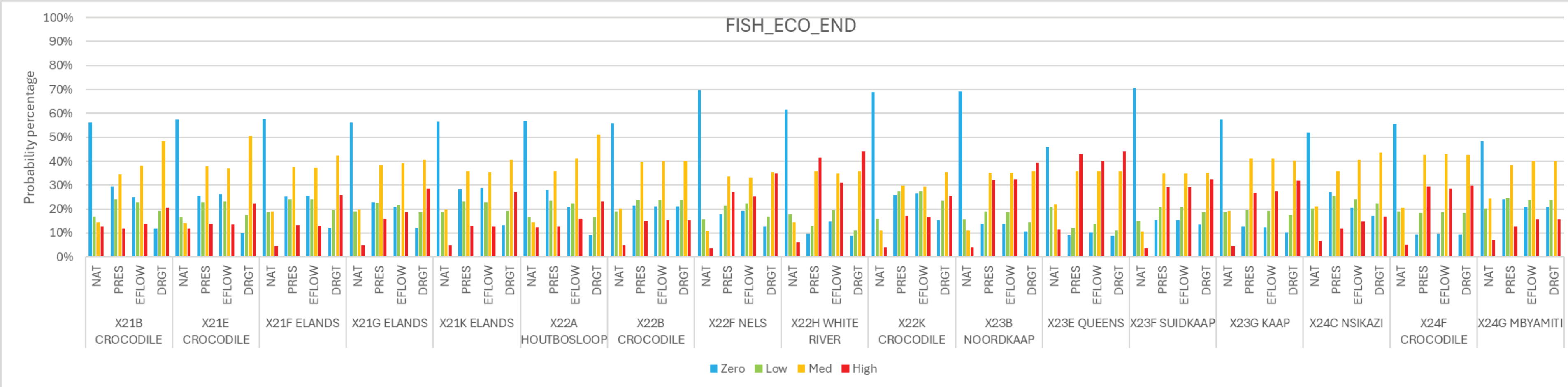


Figure 7-4: Relative risk scores to FISH-ECO-END for the Crocodile catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

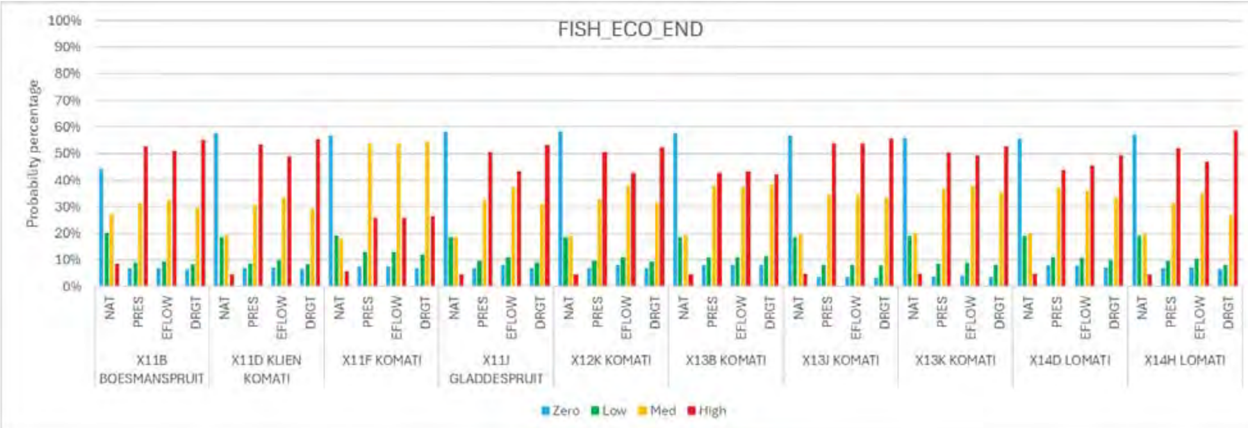


Figure 7-5: Relative risk scores to FISH-ECO-END for the Komati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

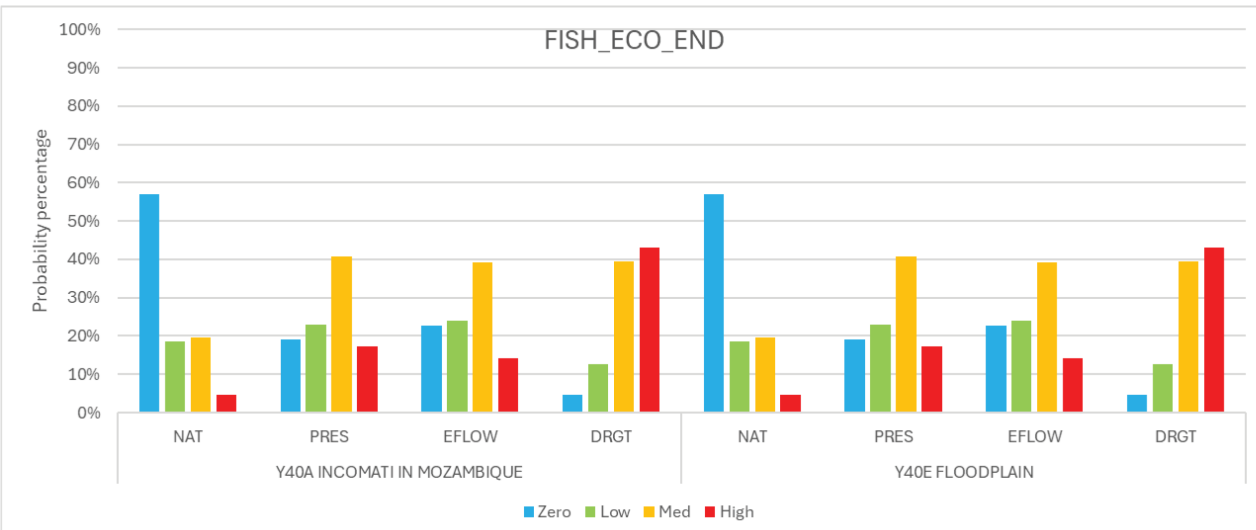


Figure 7-6: Relative risk scores to FISH-ECO-END for the Incomati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

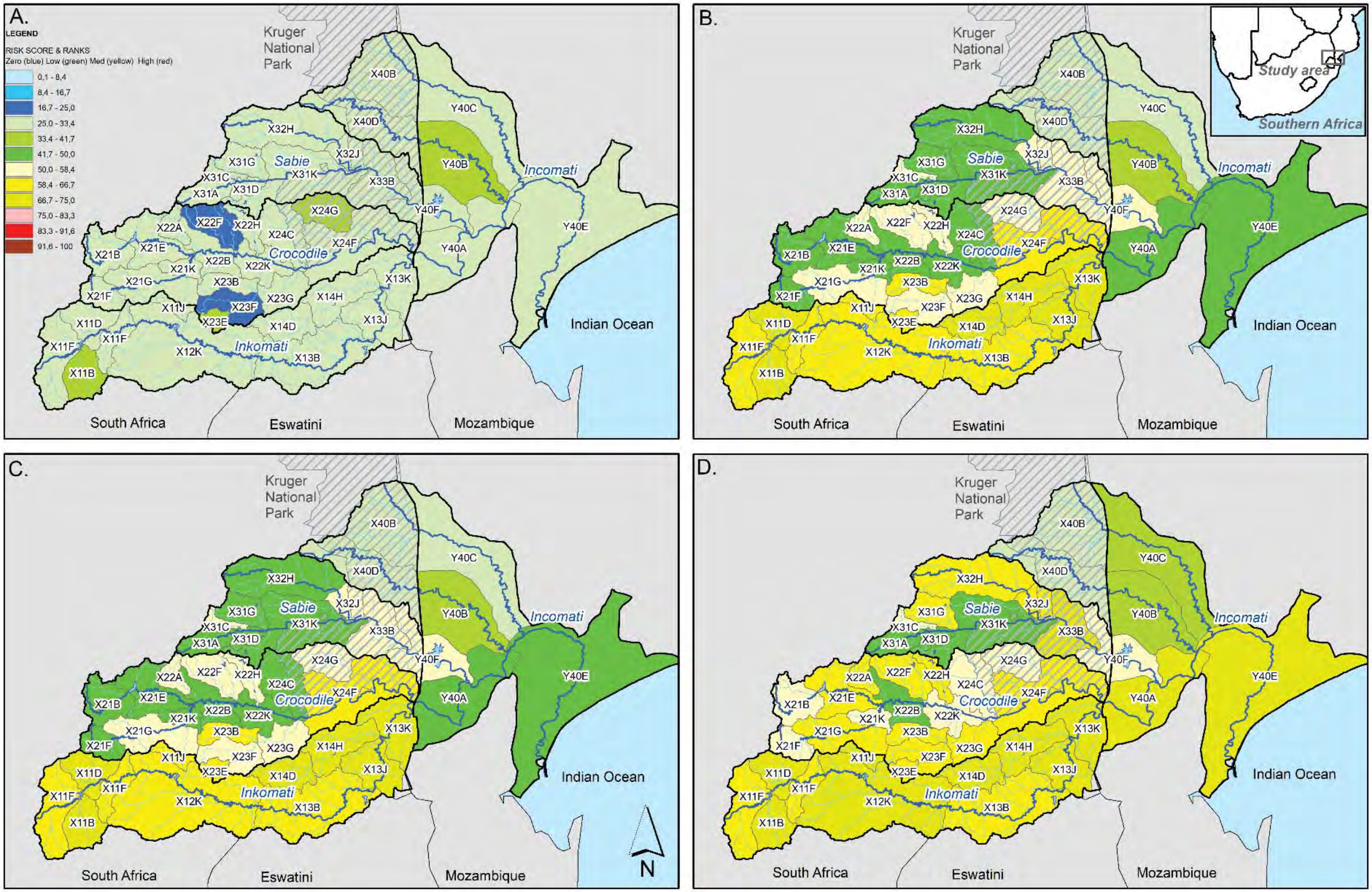


Figure 7-7: Relative risk scores to FISH-ECO-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed.

7.1.2 INV-ECO-END endpoint

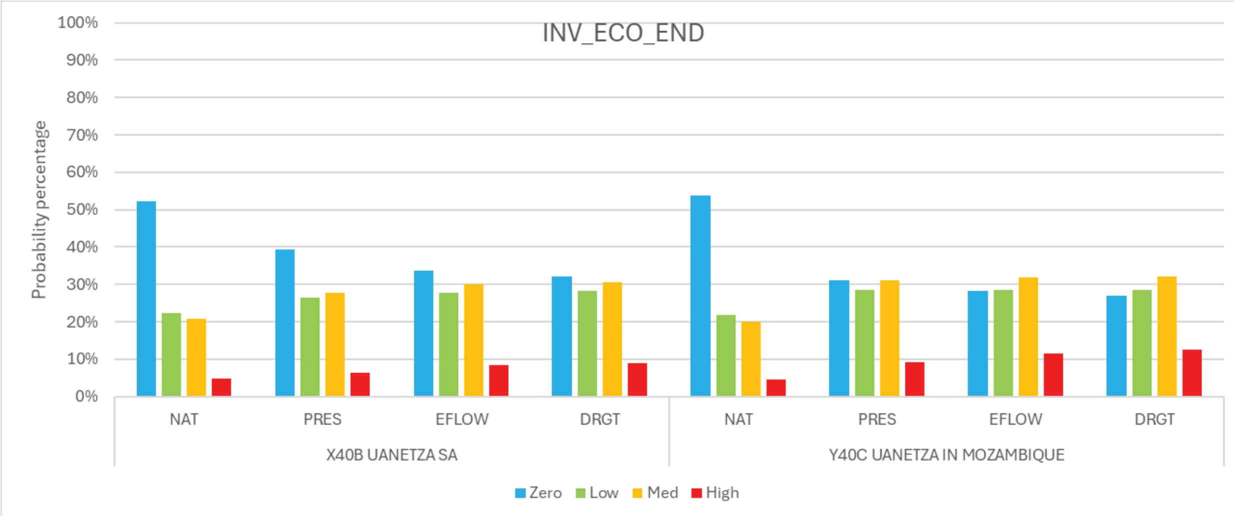


Figure 7-8: Relative risk scores to INV-ECO-END for the Uanetza catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

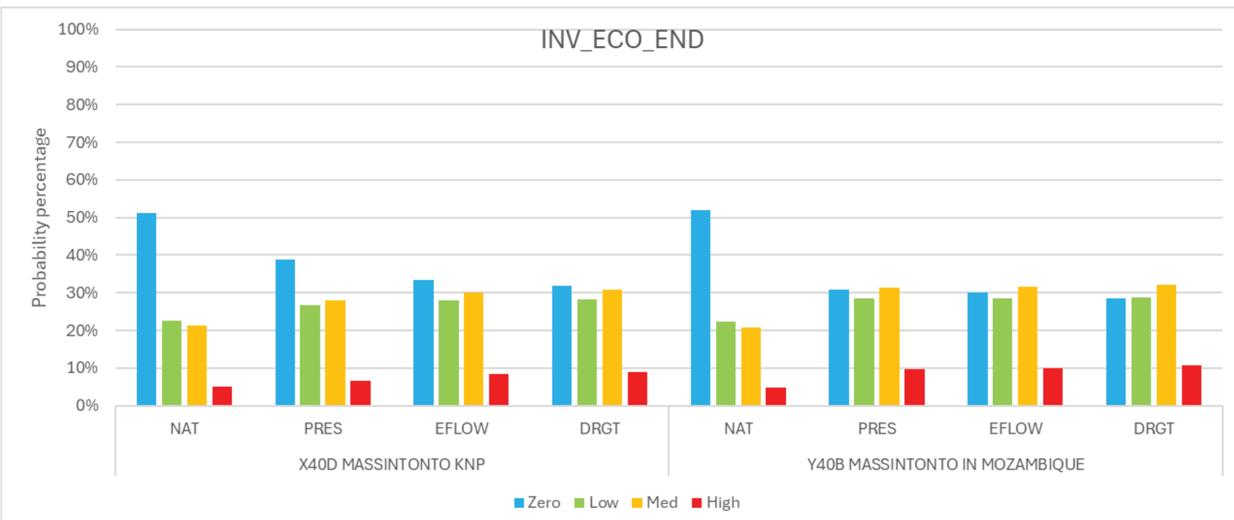


Figure 7-9: Relative risk scores to INV-ECO-END for the Massintonto catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

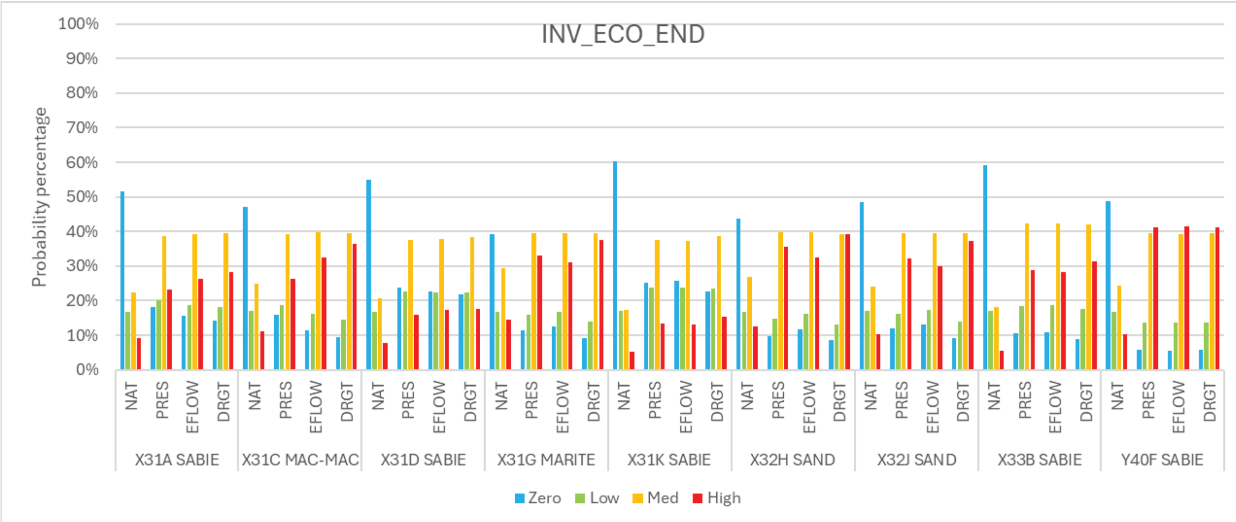


Figure 7-10: Relative risk scores to INV-ECO-END for the Sabie catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

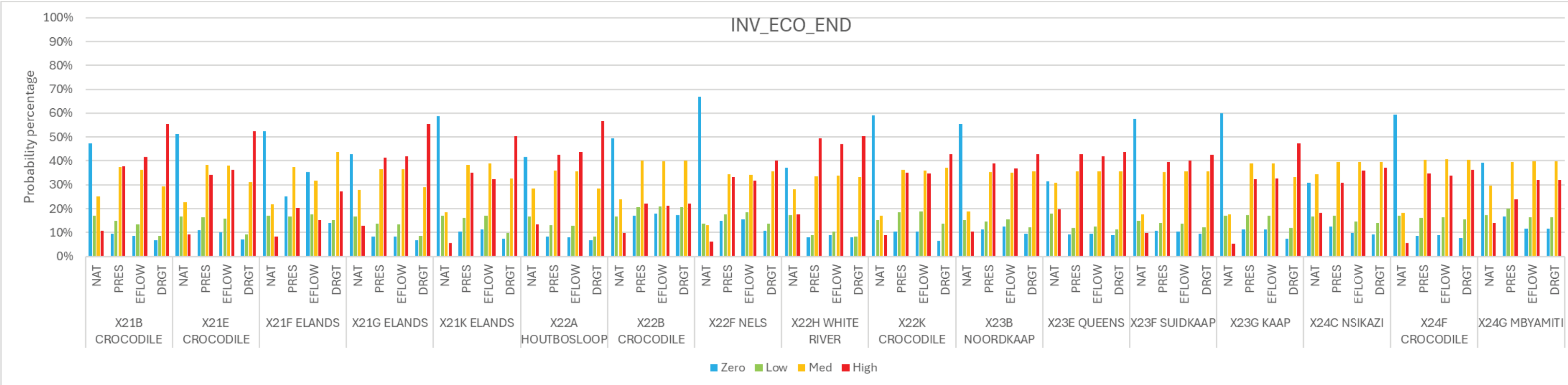


Figure 7-11: Relative risk scores to INV-ECO-END for the Crocodile catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

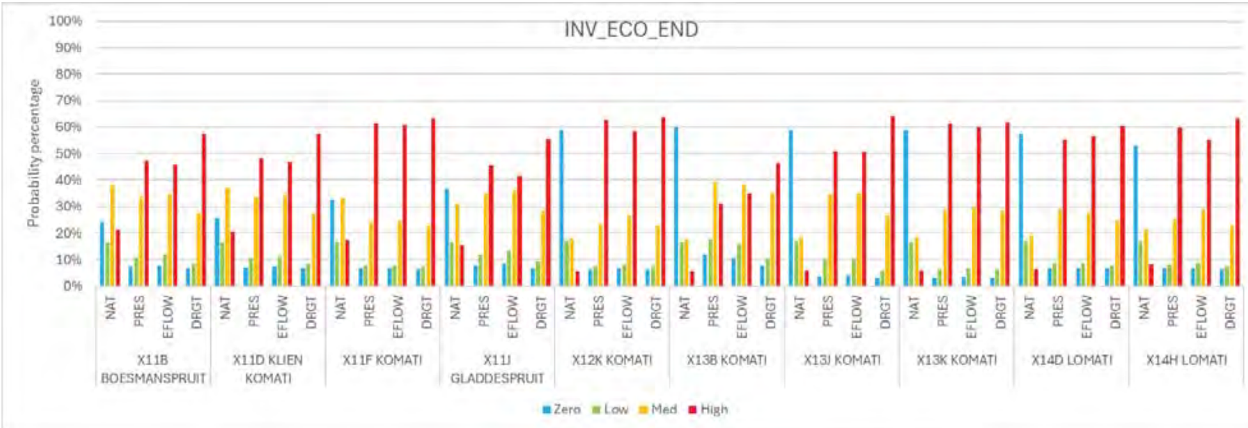


Figure 7-12: Relative risk scores to INV-ECO-END for the Komati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

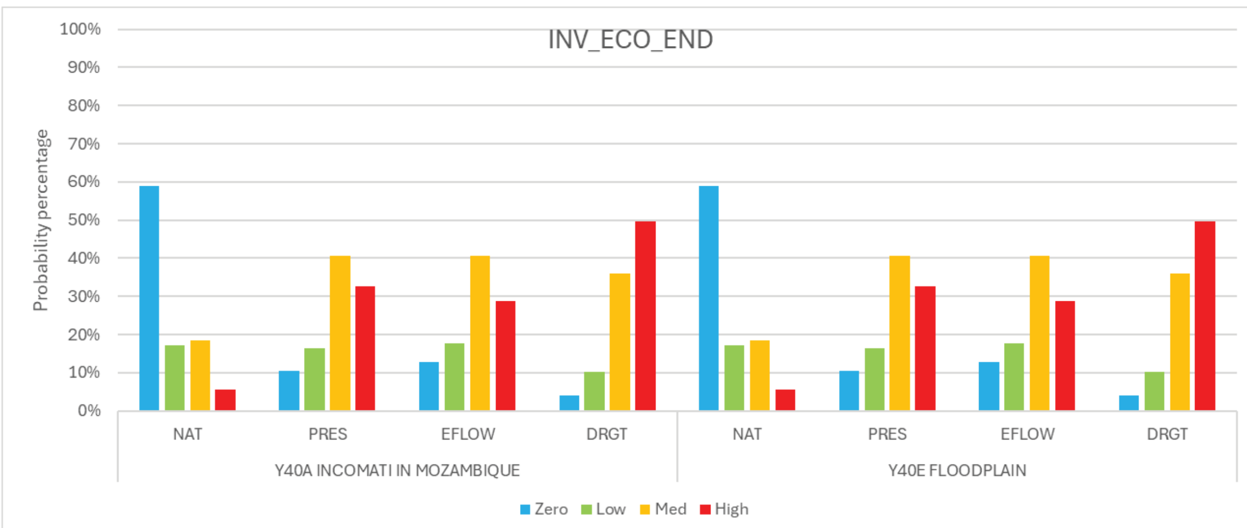


Figure 7-13: Relative risk scores to INV-ECO-END for the Incomati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

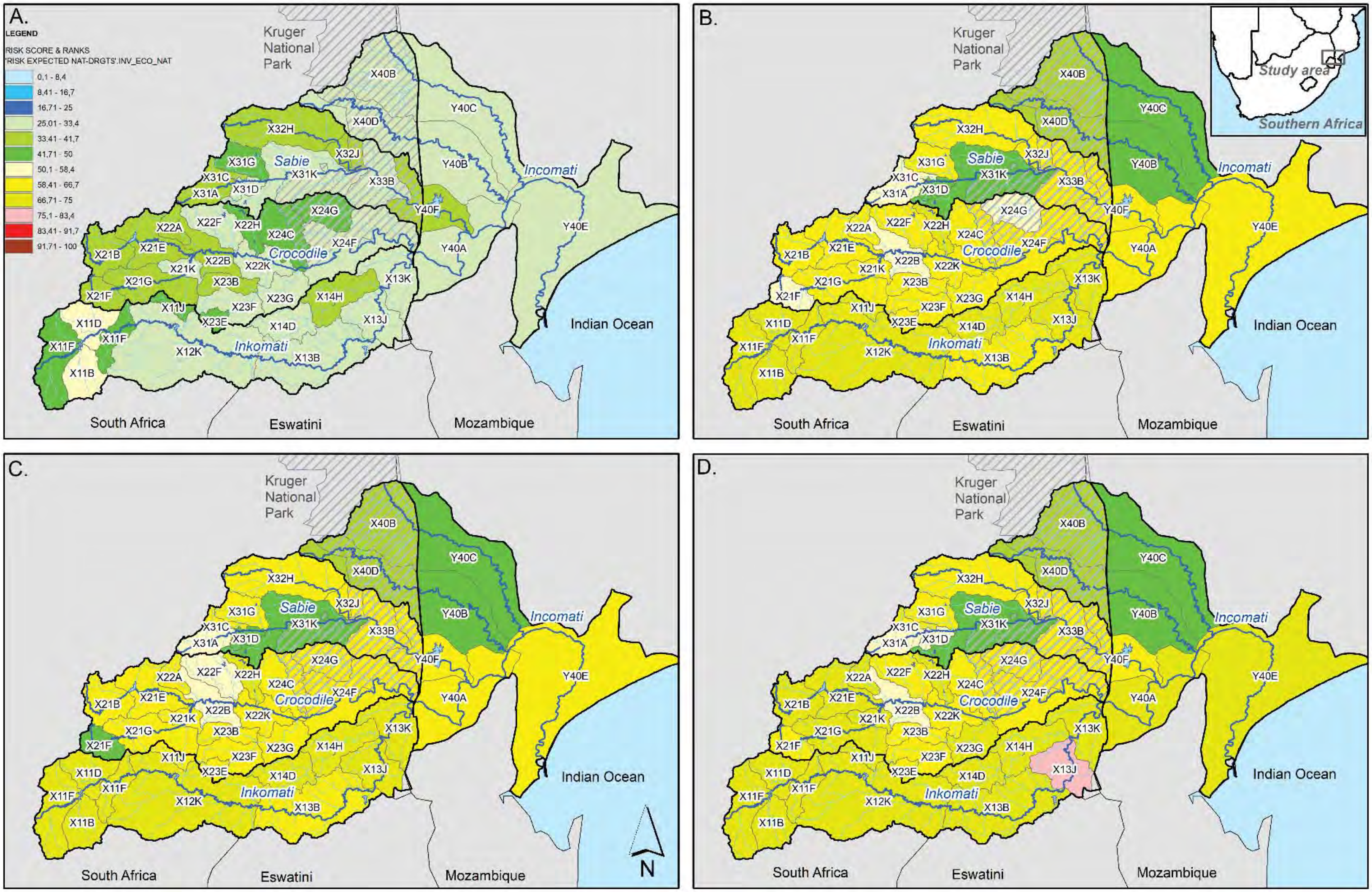


Figure 7-14: Relative risk scores to INV-ECO-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed.

7.1.3 VEG-ECO-END endpoint

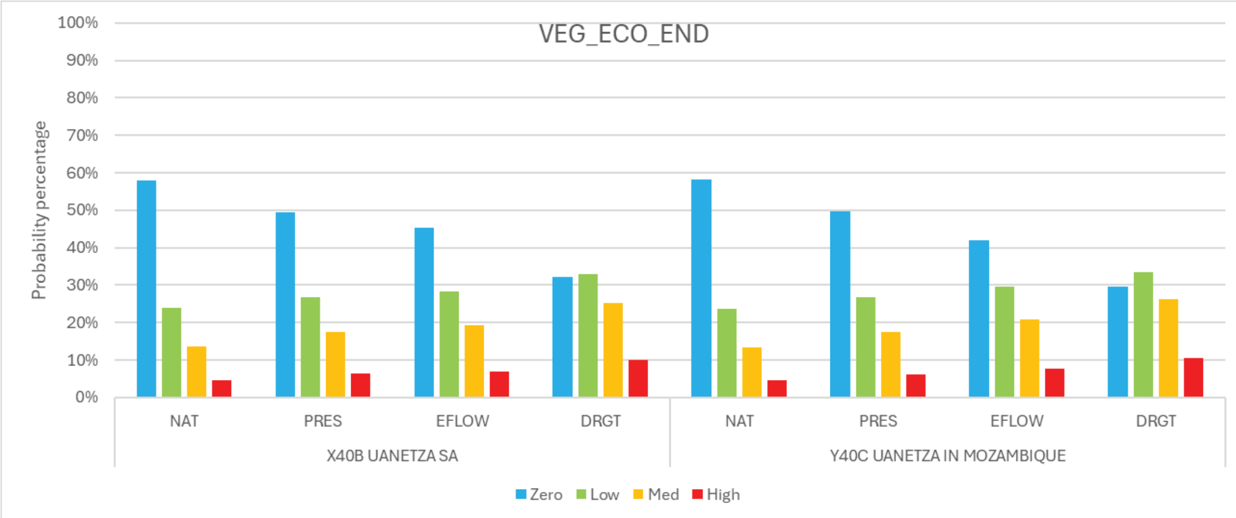


Figure 7-15: Relative risk scores to VEG-ECO-END for the Uanetza catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

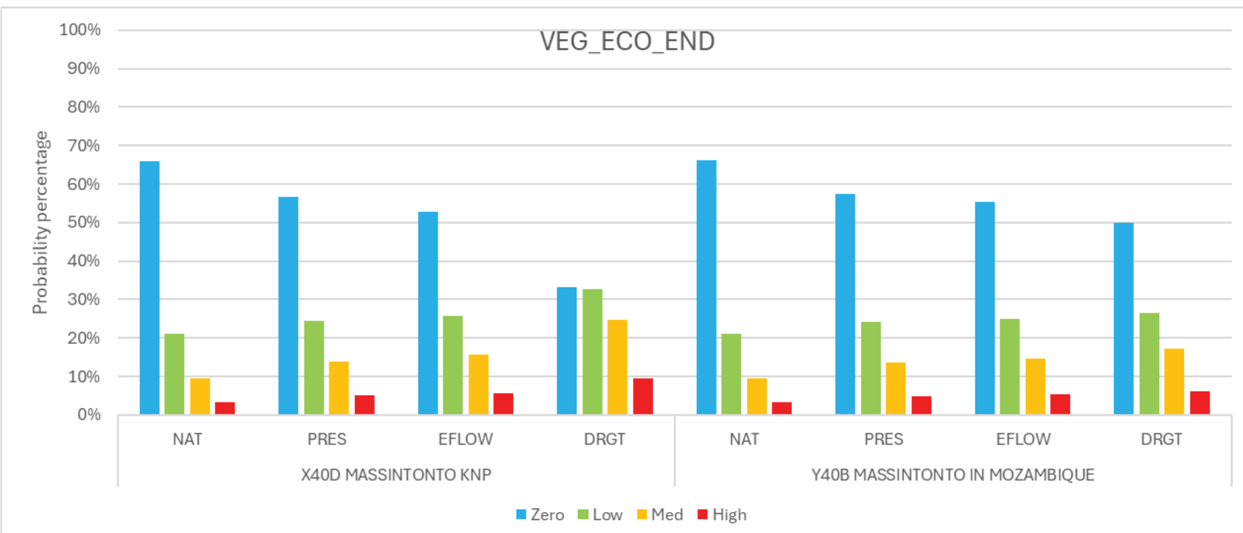


Figure 7-16: Relative risk scores to VEG-ECO-END for the Massintonto catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

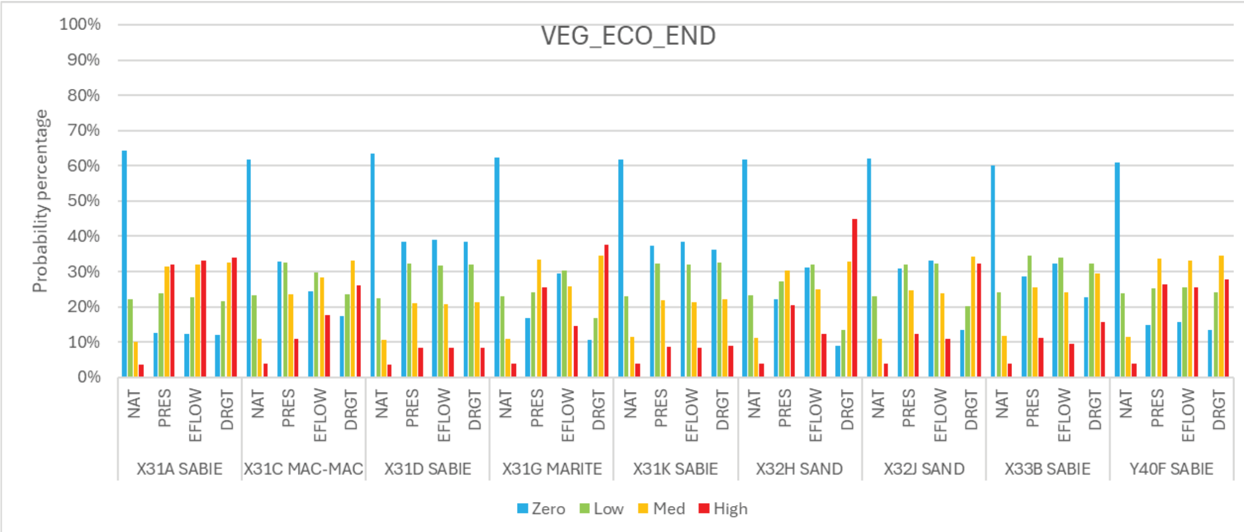


Figure 7-17: Relative risk scores to VEG-ECO-END for the Sabie catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

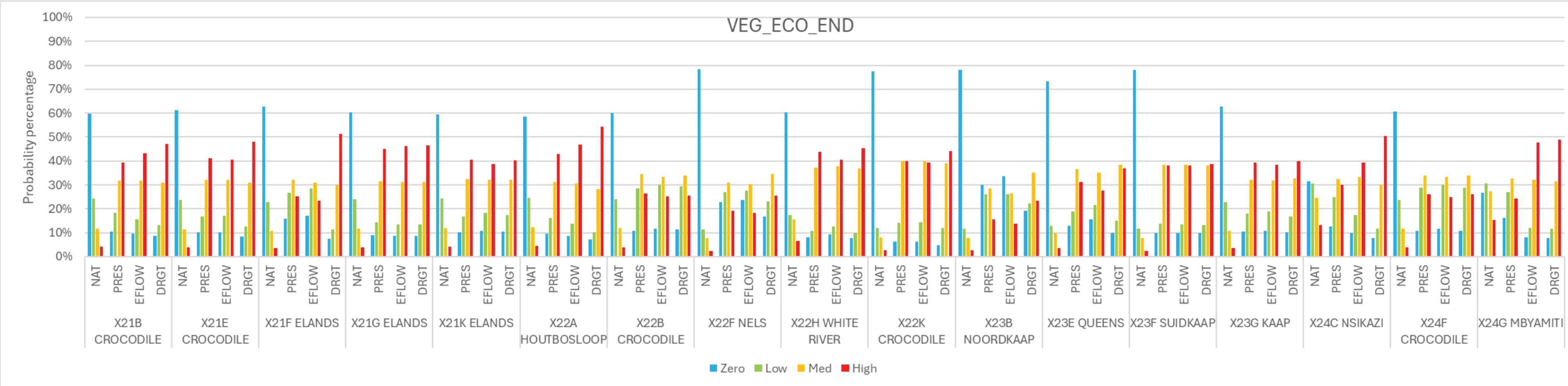


Figure 7-18: Relative risk scores to VEG-ECO-END for the Crocodile catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

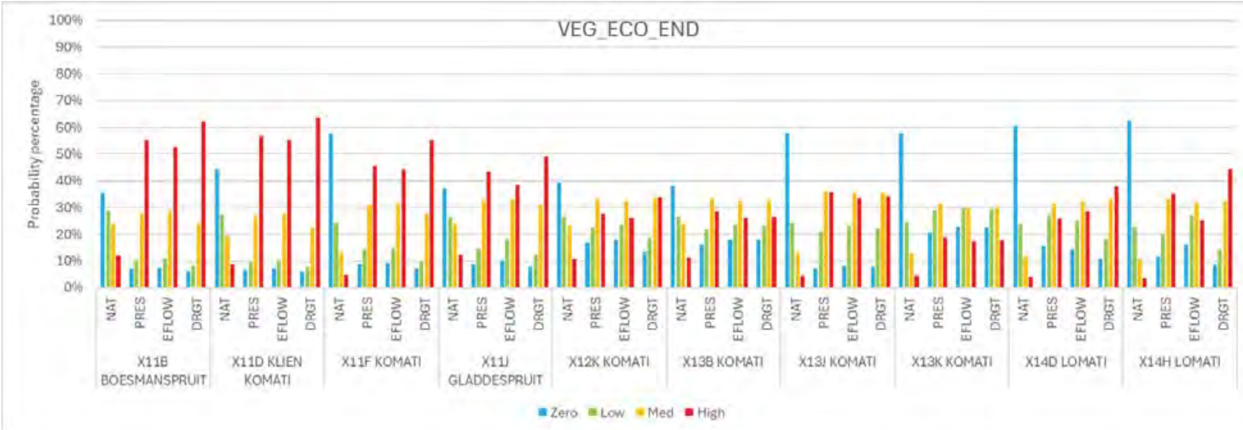


Figure 7-19: Relative risk scores to VEG-ECO-END for the Komati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

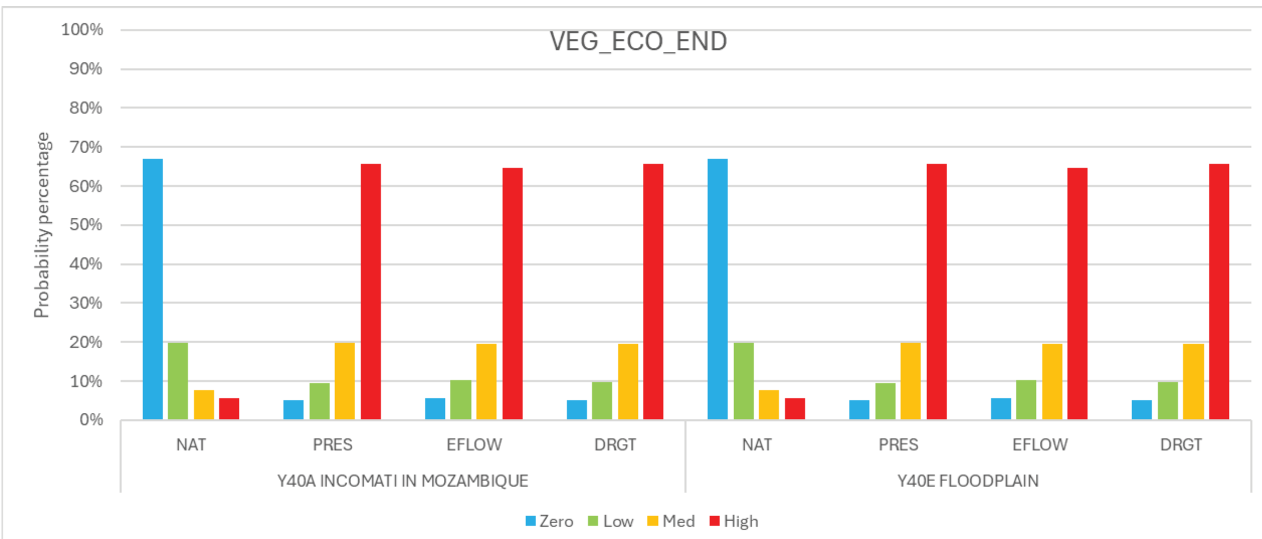


Figure 7-20: Relative risk scores to VEG-ECO-END for the Incomati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

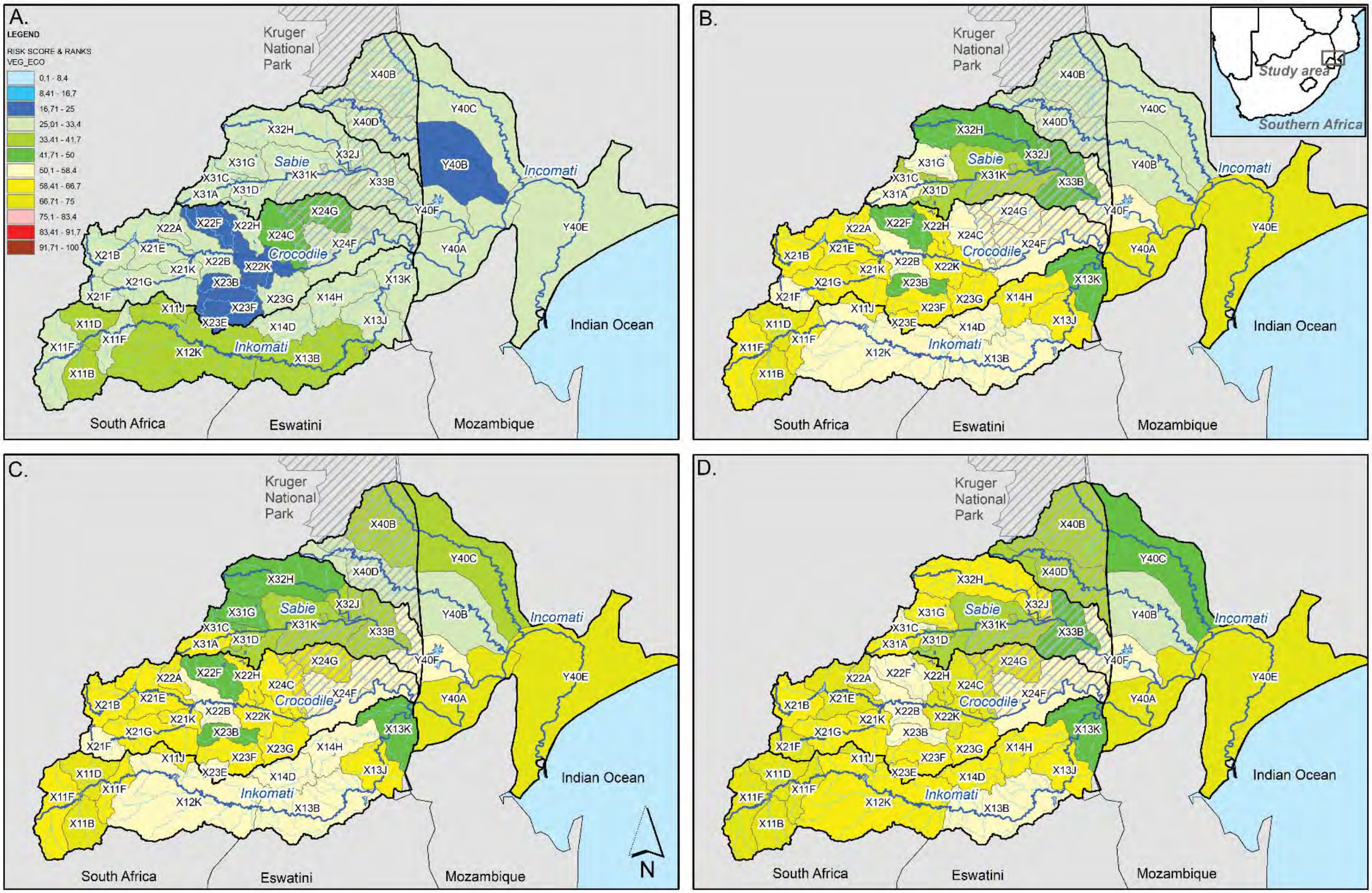


Figure 7-21: Relative risk scores to VEG-ECO-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed.

7.2 Provisioning Services

7.2.1 SUB-FISH-END endpoint

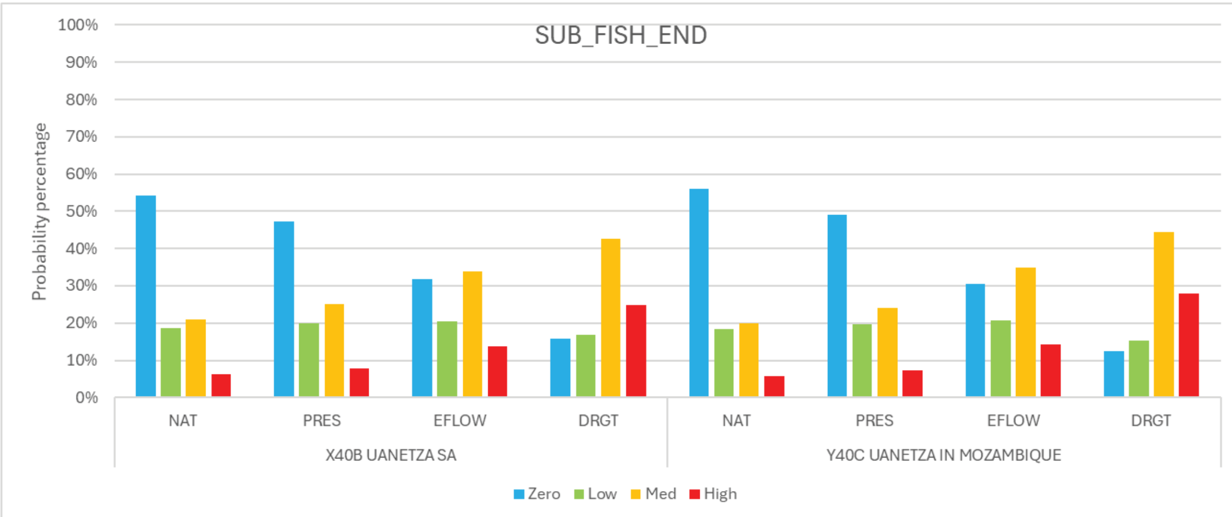


Figure 7-22: Relative risk scores to SUB-FISH-END for the Uanetza catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

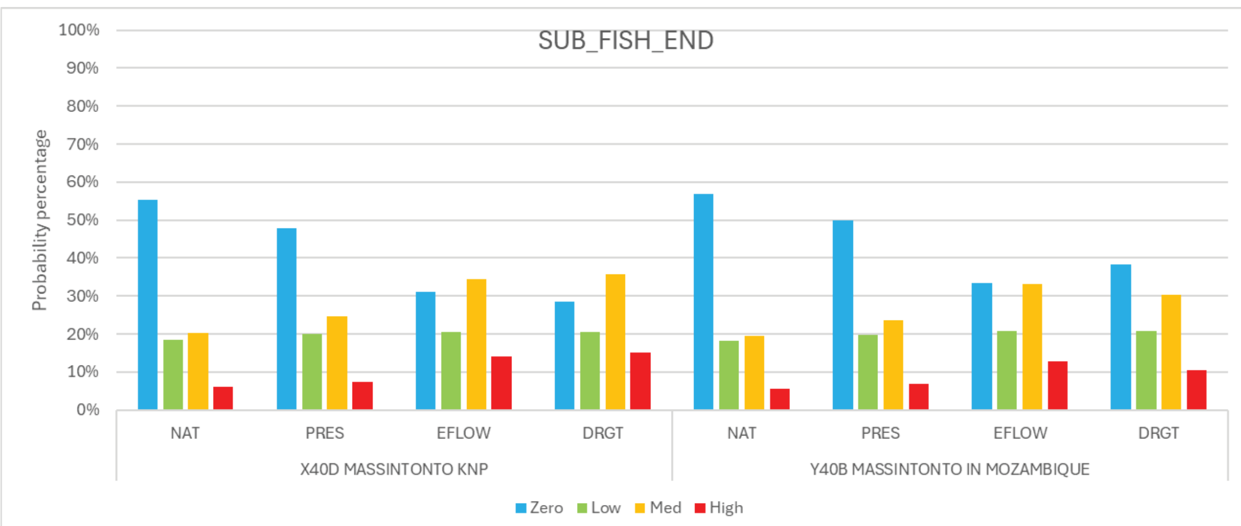


Figure 7-23: Relative risk scores to SUB-FISH-END for the Massintonto catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

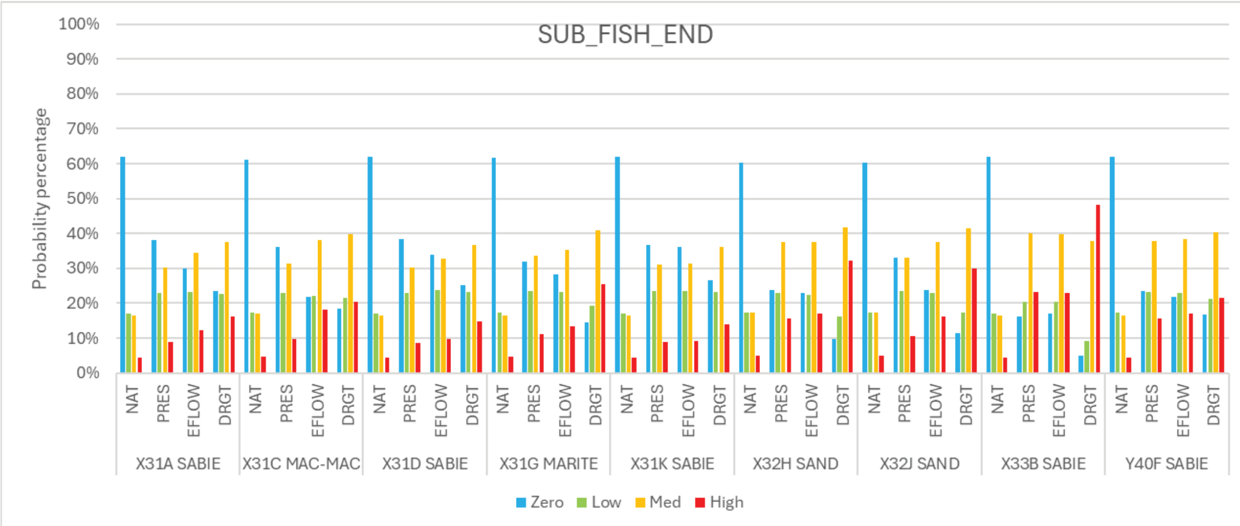


Figure 7-24: Relative risk scores to SUB-FISH-END for the Sabie catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

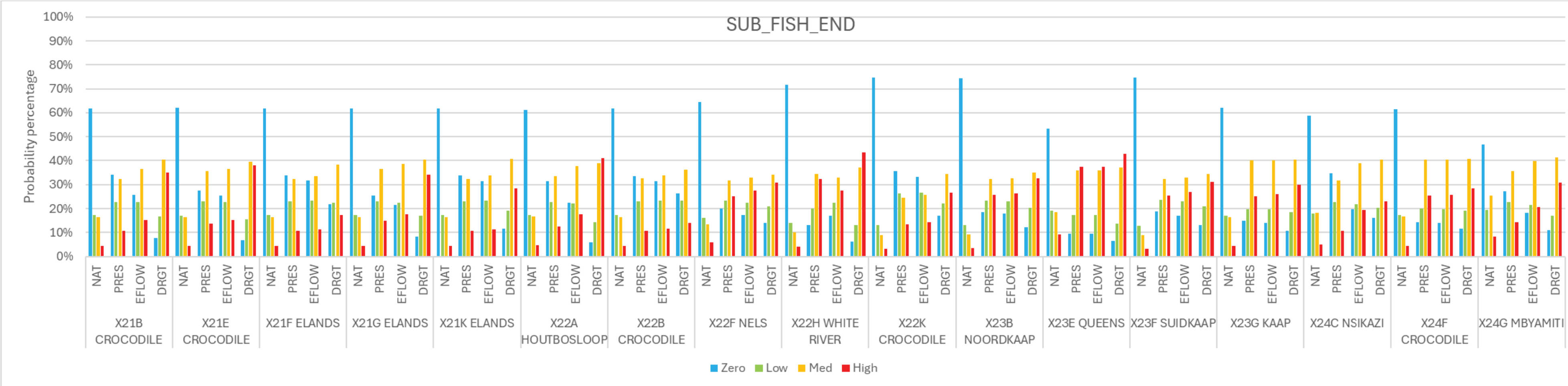


Figure 7-25: Relative risk scores to SUB-FISH-END for the Crocodile catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

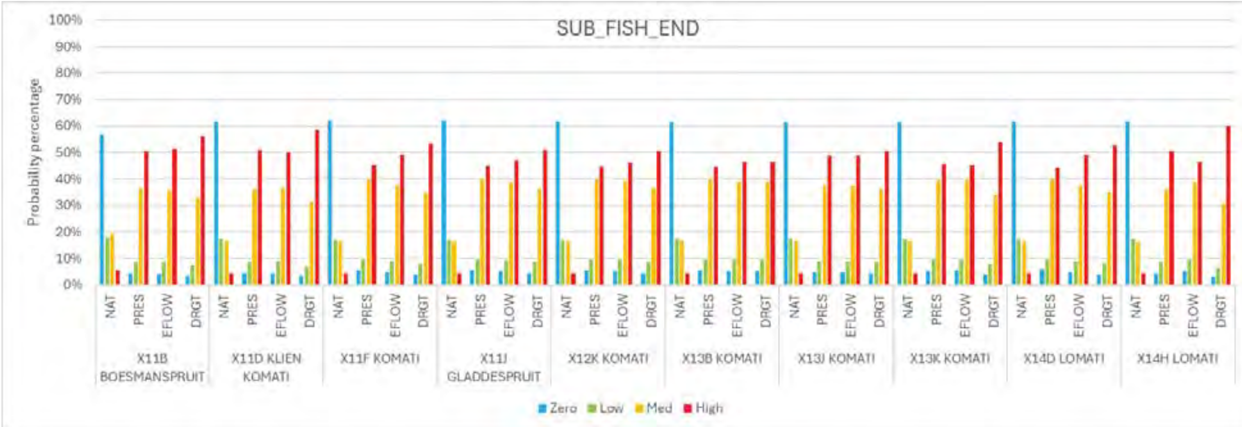


Figure 7-26: Relative risk scores to SUB-FISH-END for the Komati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

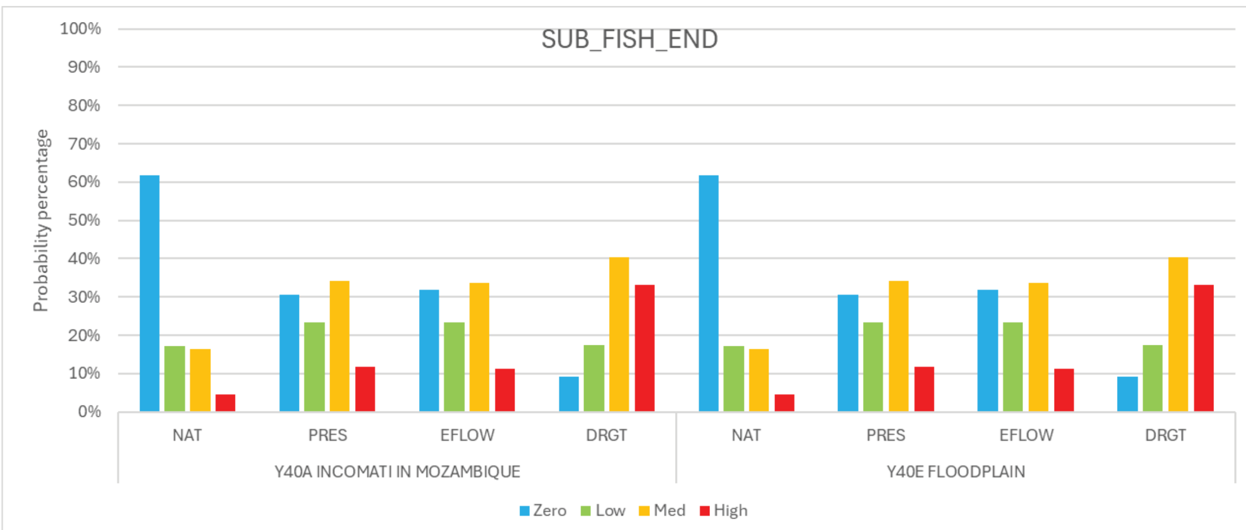


Figure 7-27: Relative risk scores to SUB-FISH-END for the Incomati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

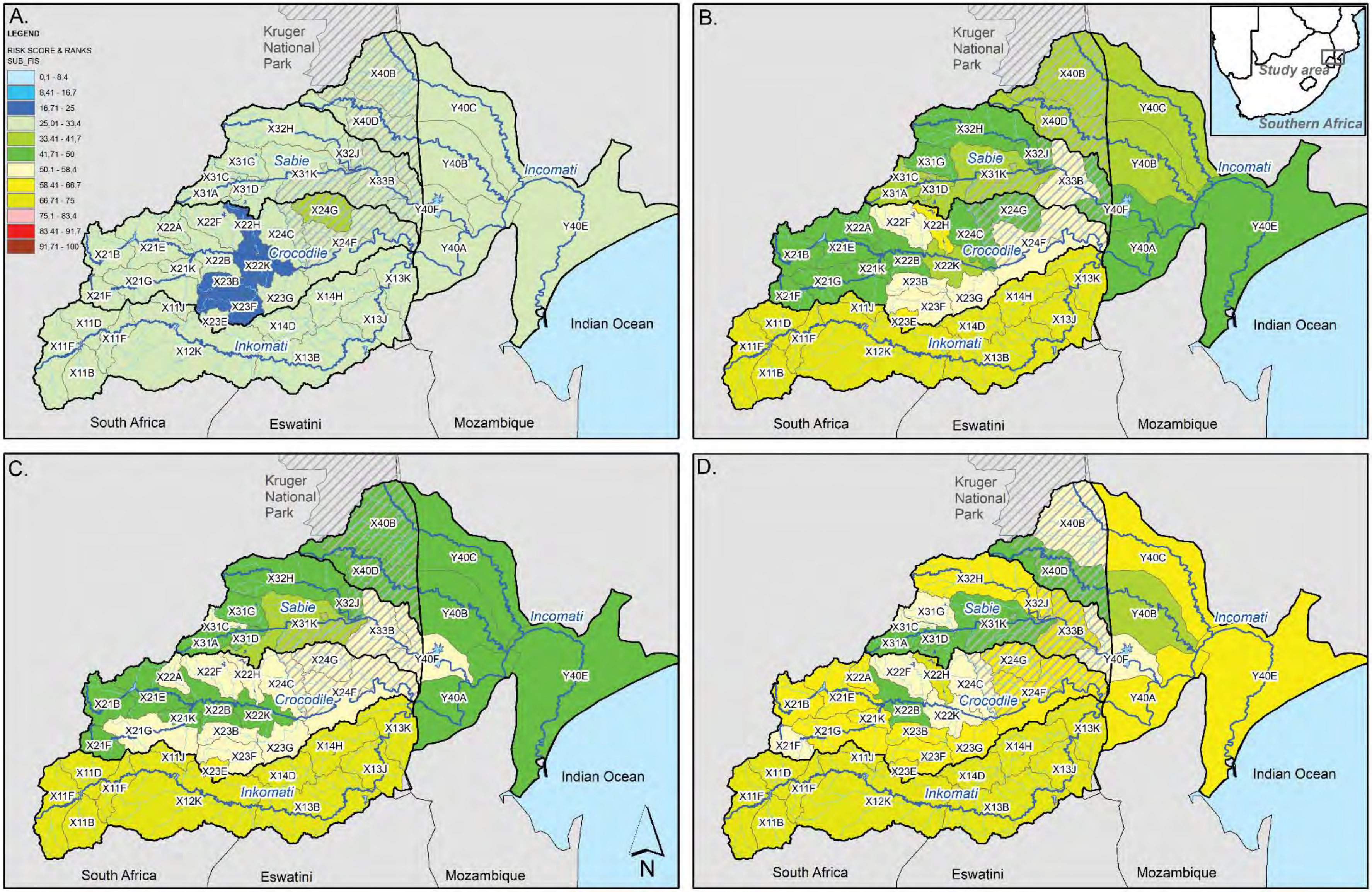


Figure 7-28: Relative risk scores to SUB-FISH-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

7.2.2 SUB-VEG-END endpoint

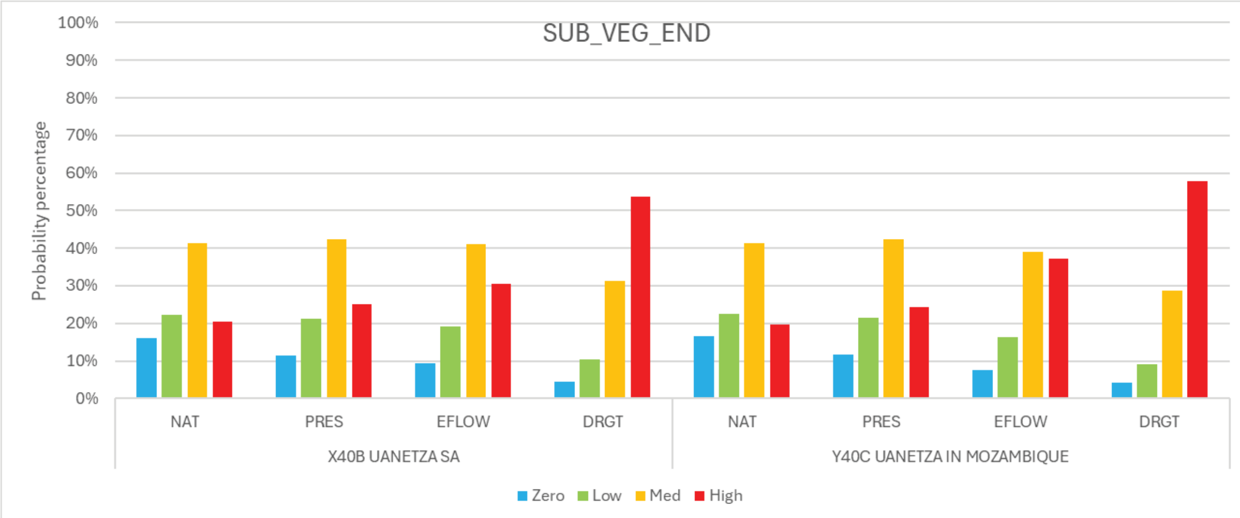


Figure 7-29: Relative risk scores to SUB-VEG-END for the Uanetza catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

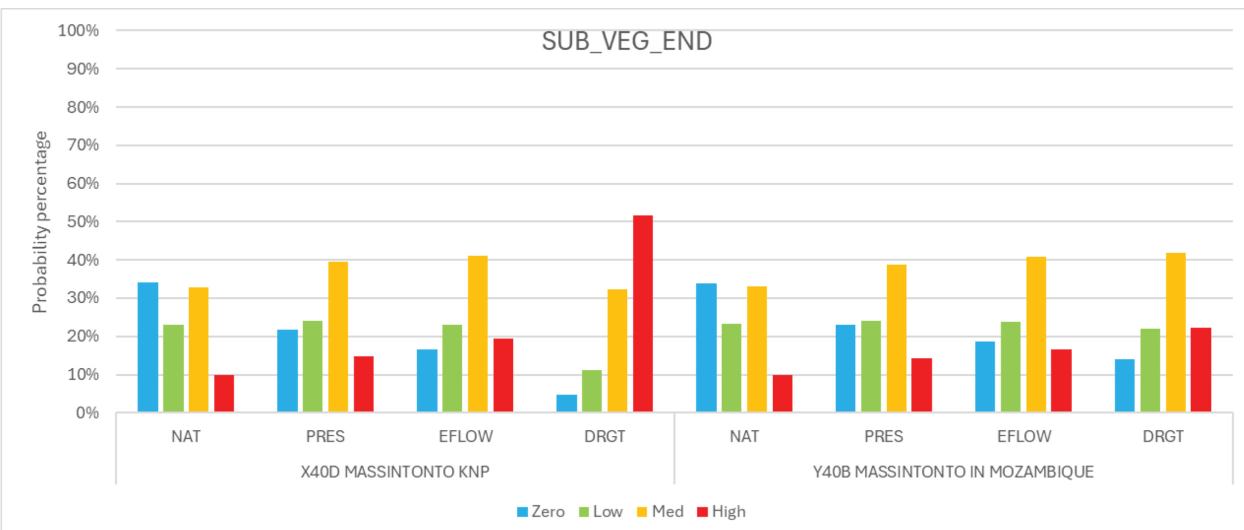


Figure 7-30: Relative risk scores to SUB-VEG-END for the Massintonto catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

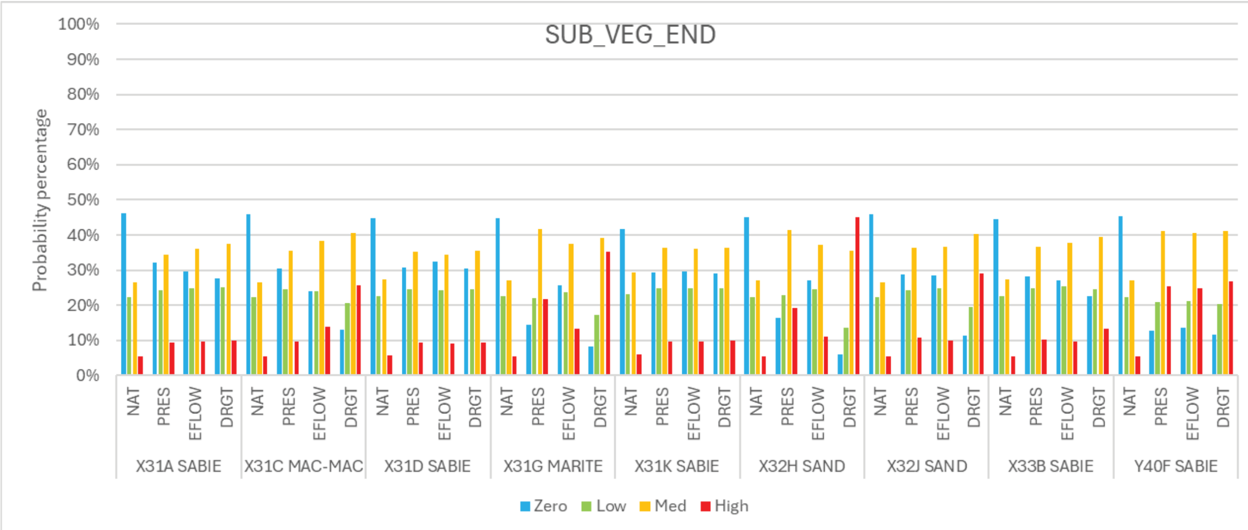


Figure 7-31: Relative risk scores to SUB-VEG-END for the Sabie catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

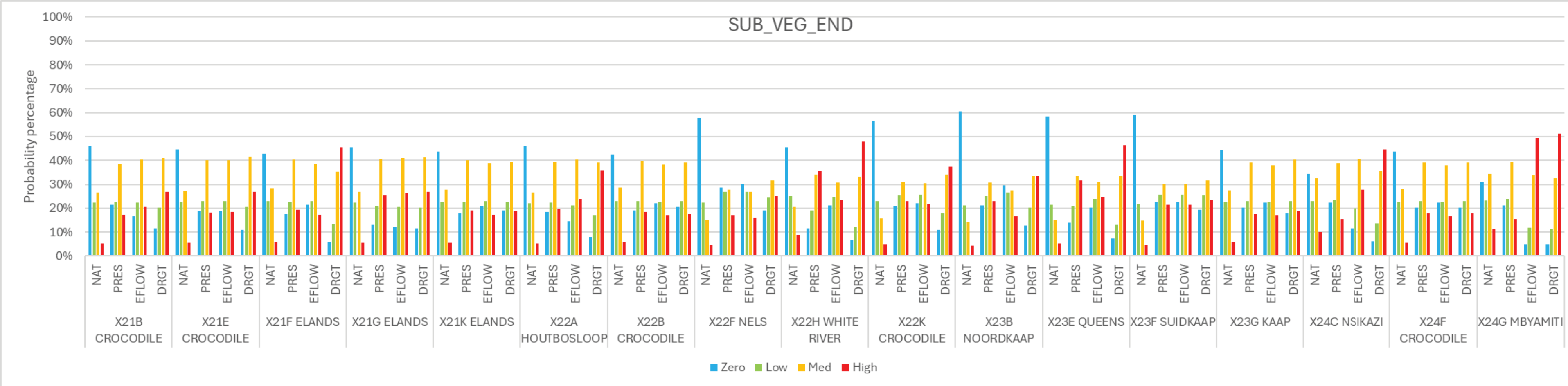


Figure 7-32: Relative risk scores to SUB-VEG-END for the Crocodile catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

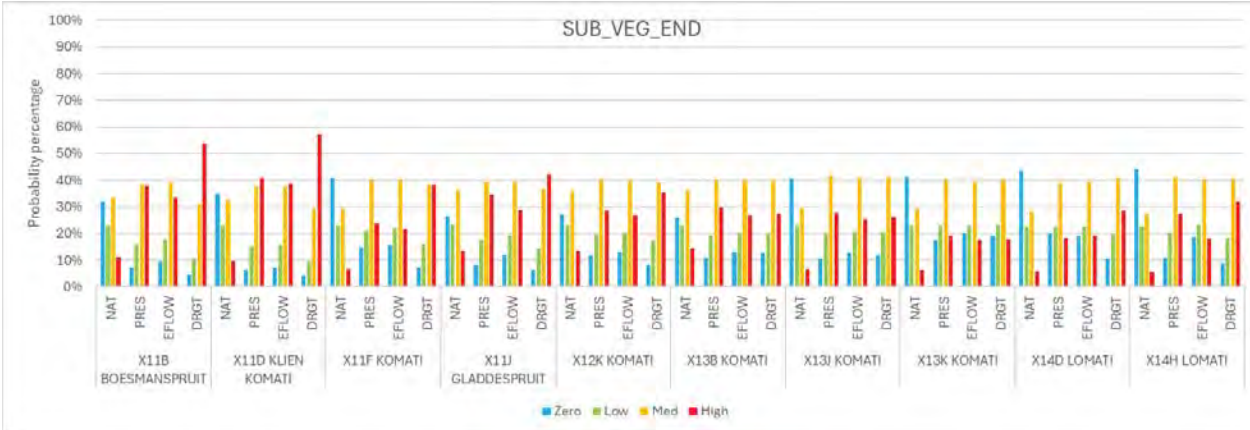


Figure 7-33: Relative risk scores to SUB-VEG-END for the Komati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

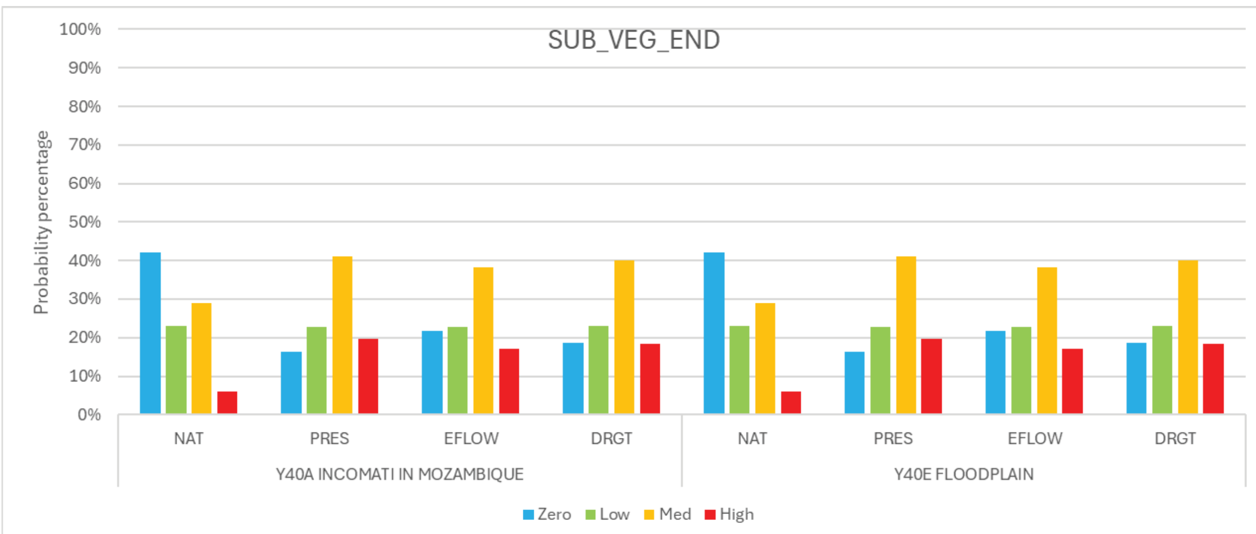


Figure 7-34: Relative risk scores to SUB-VEG-END for the Incomati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

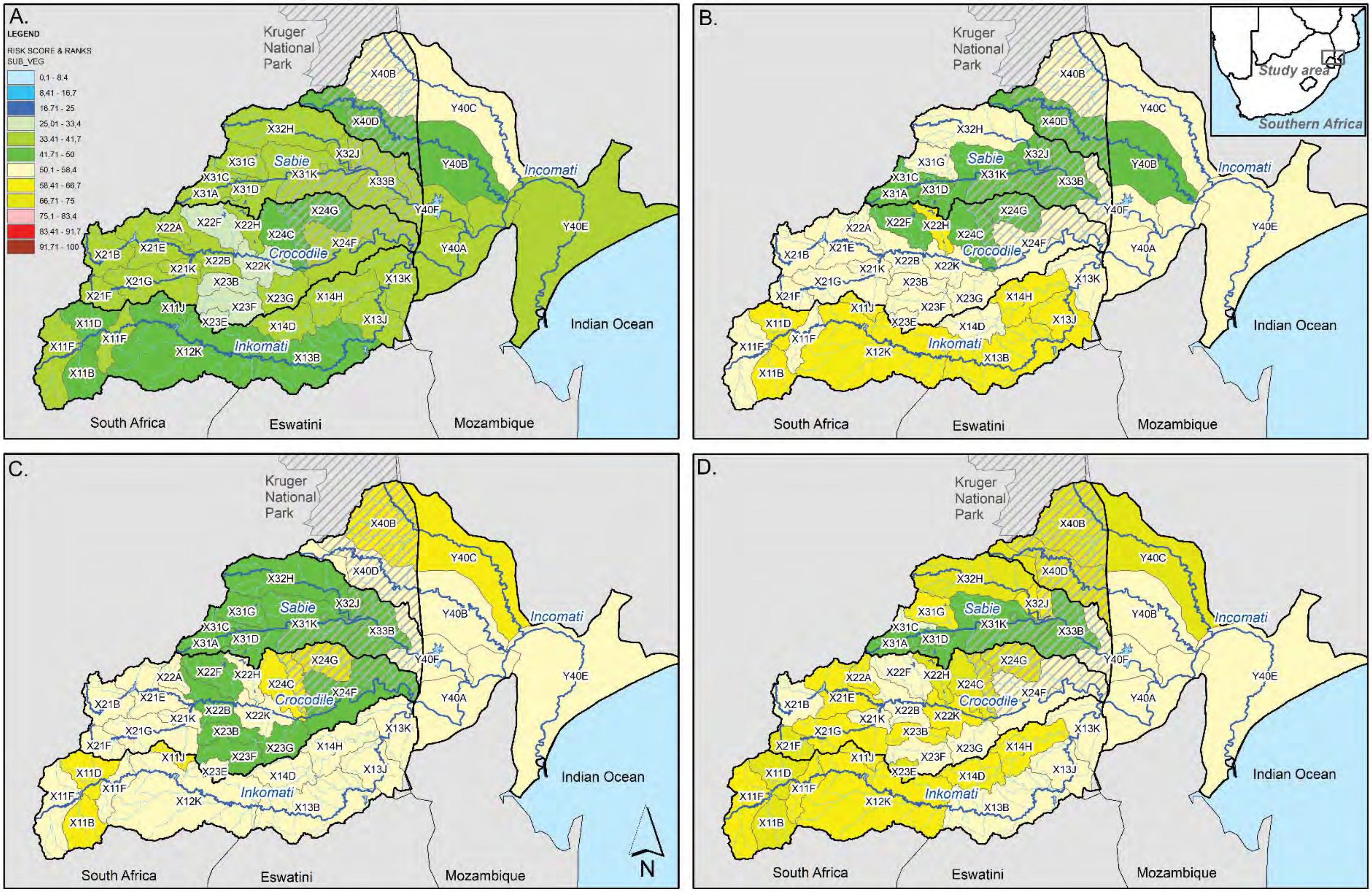


Figure 7-35: Relative risk scores to SUB-VEG-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

7.2.3 LIV-VEG-END endpoint

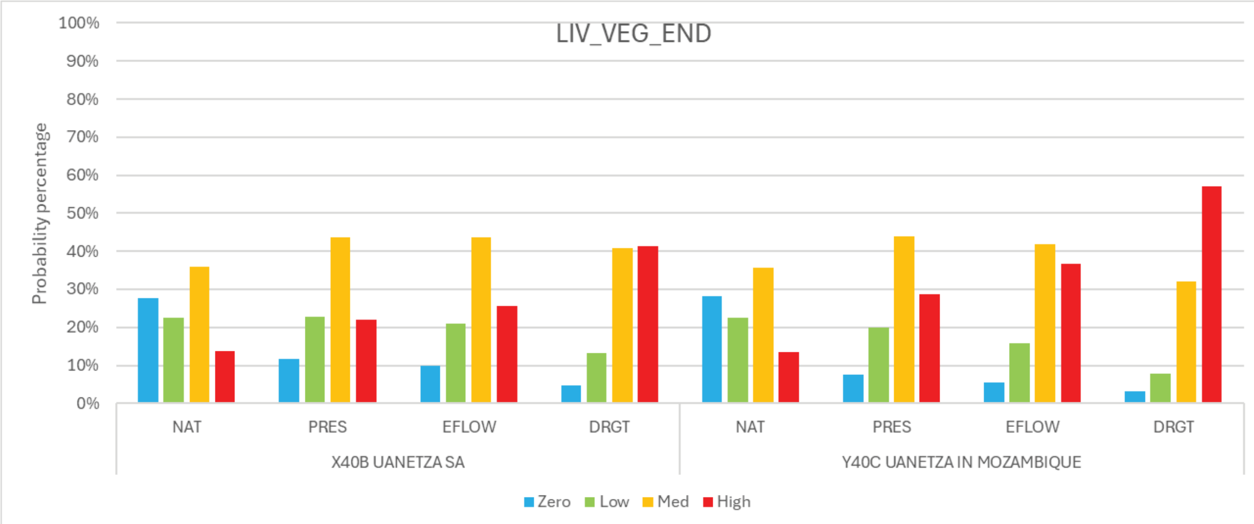


Figure 7-36: Relative risk scores to LIV-VEG-END for the Uanetza catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

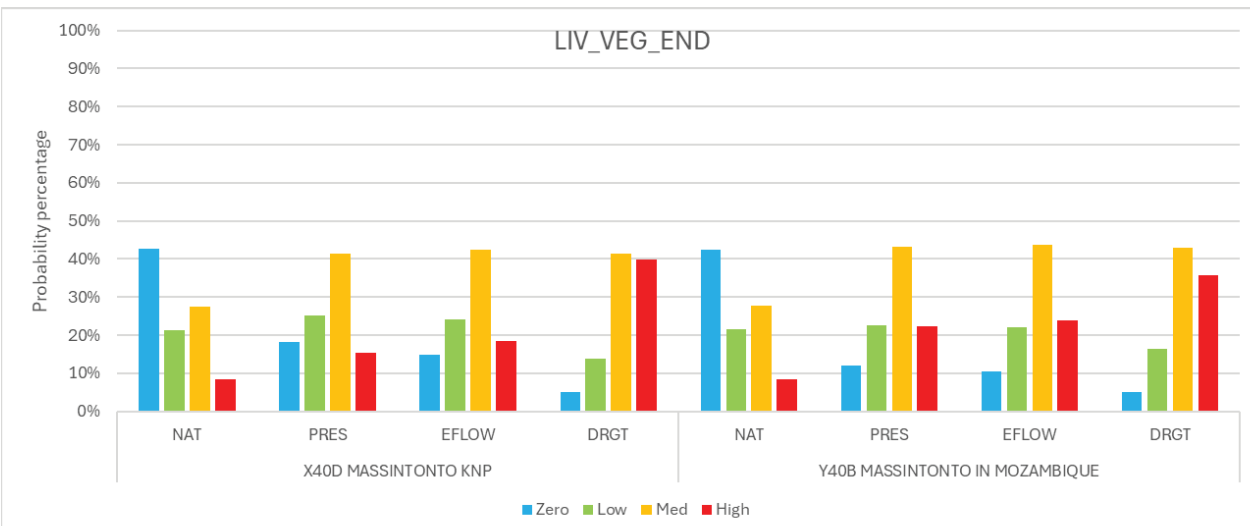


Figure 7-37: Relative risk scores to LIV-VEG-END for the Massintonto catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

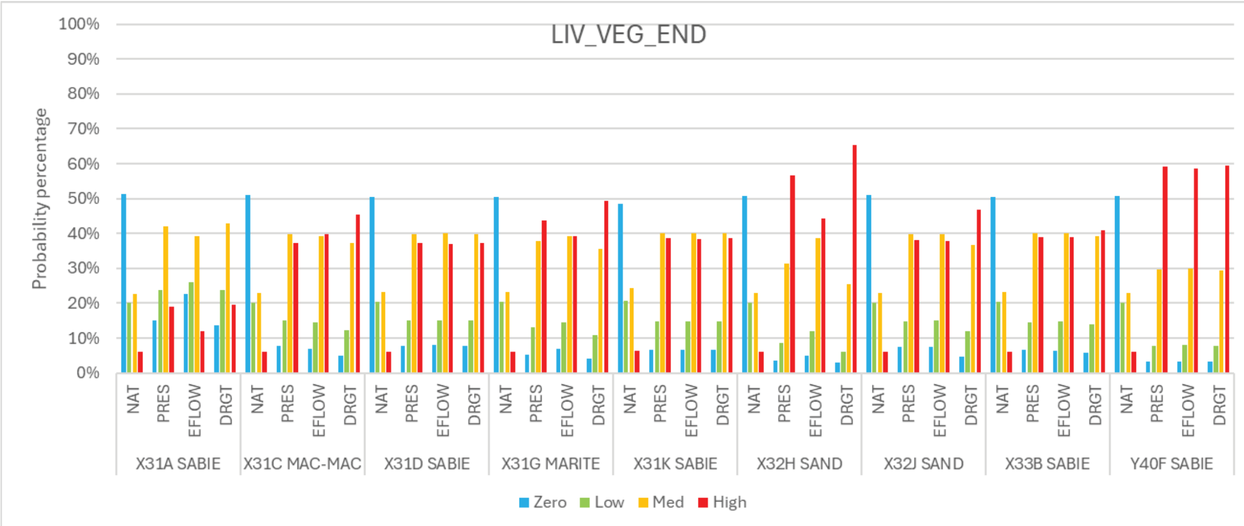


Figure 7-38: Relative risk scores to LIV-VEG-END for the Sabie catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

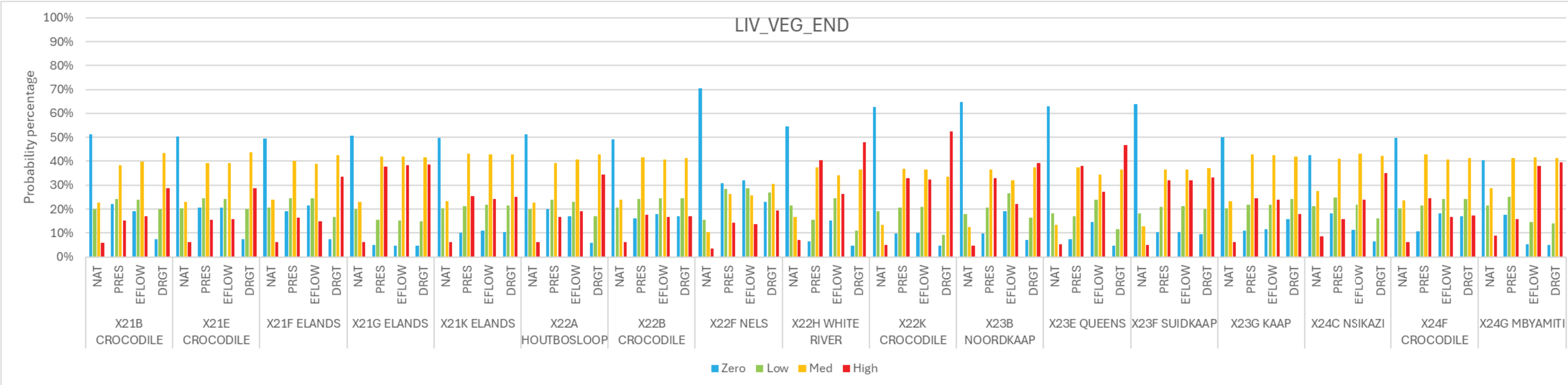


Figure 7-39: Relative risk scores to LIV-VEG-END for the Crocodile catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

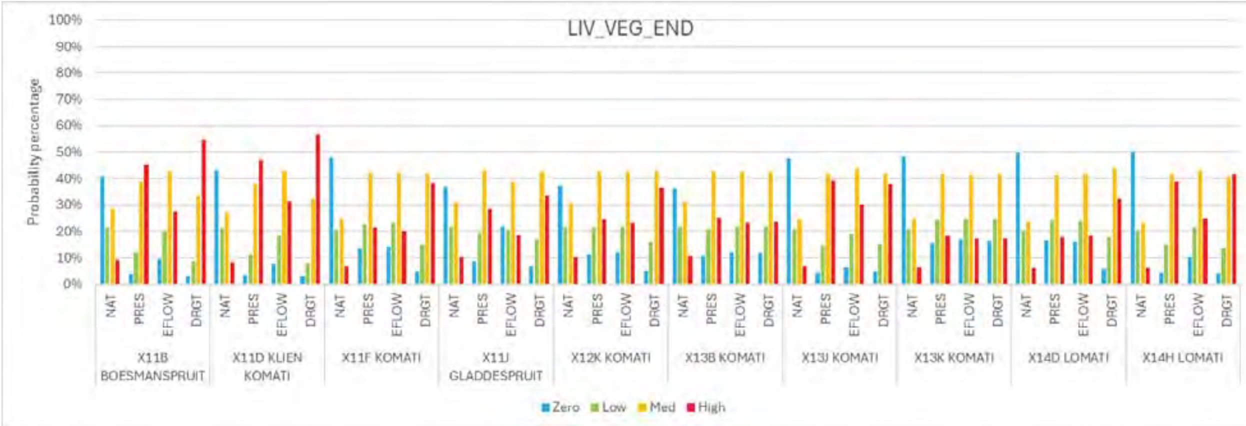


Figure 7-40: Relative risk scores to LIV-VEG-END for the Komati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

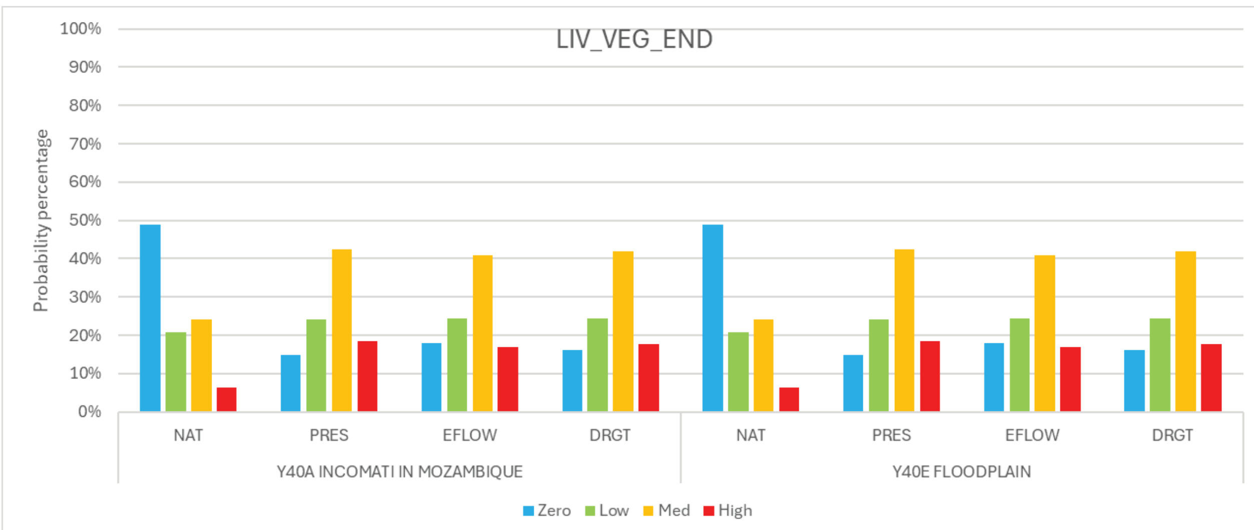


Figure 7-41: Relative risk scores to LIV-VEG-END for the Incomati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

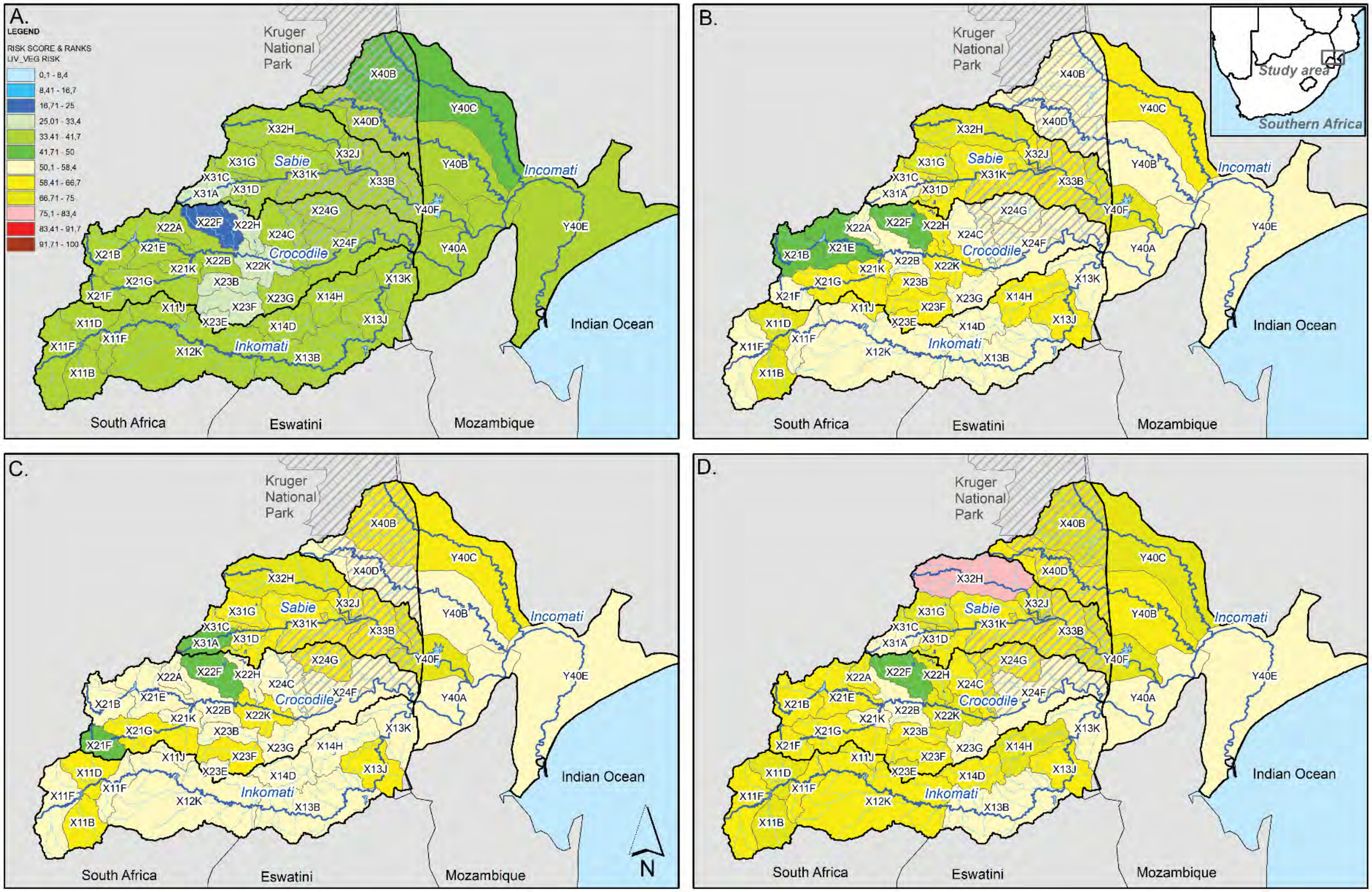


Figure 7-42: Relative risk scores to LIV-VEG-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

7.2.4 DOM-WAT-END endpoint

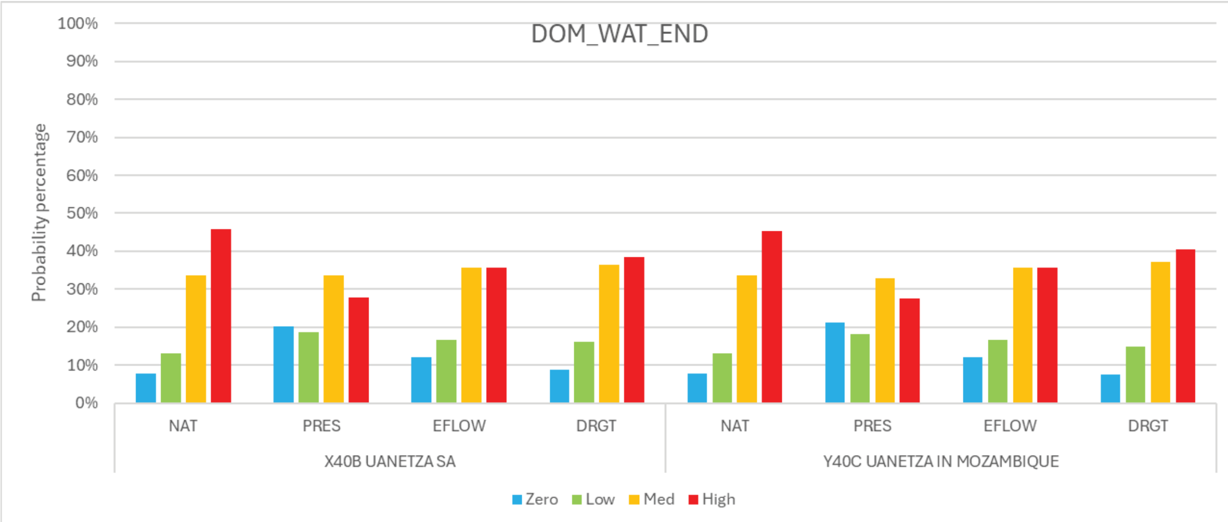


Figure 7-43: Relative risk scores to DOM-WAT-END for the Uanetza catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

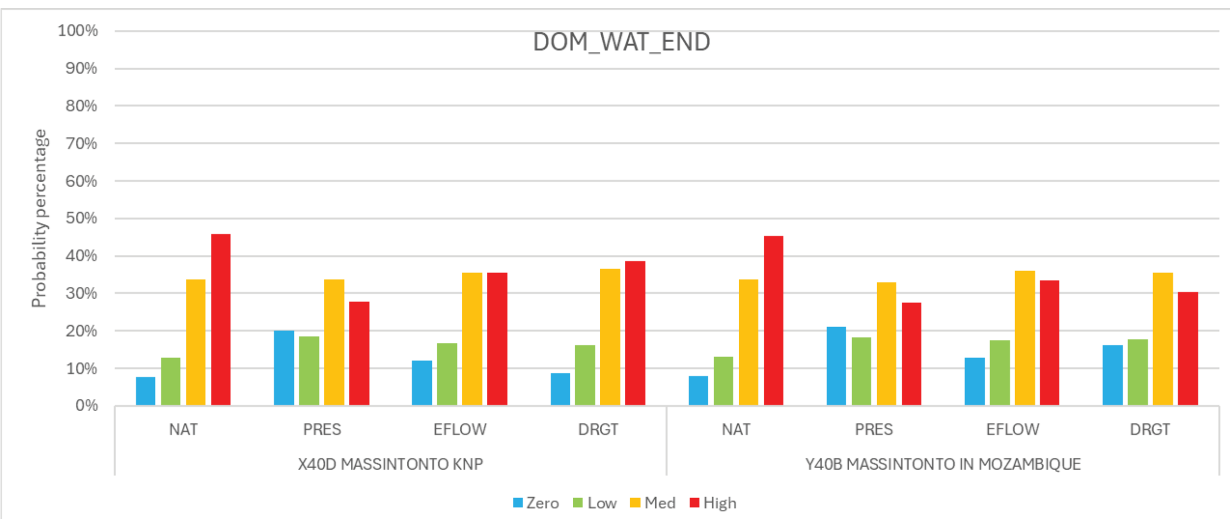


Figure 7-44: Relative risk scores to DOM-WAT-END for the Massintonto catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

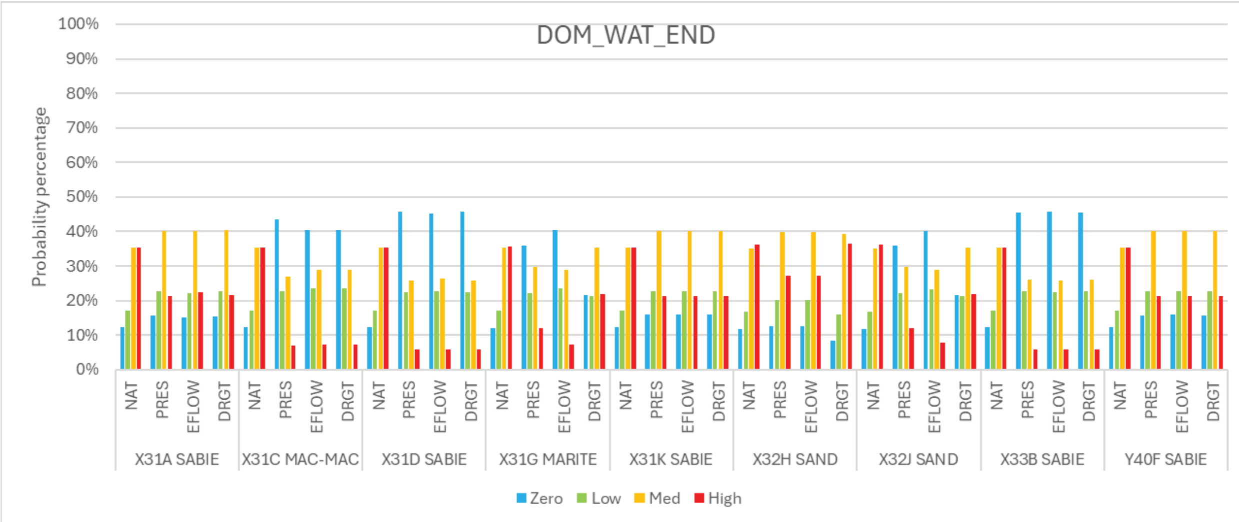


Figure 7-45: Relative risk scores to DOM-WAT-END for the Sabie catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

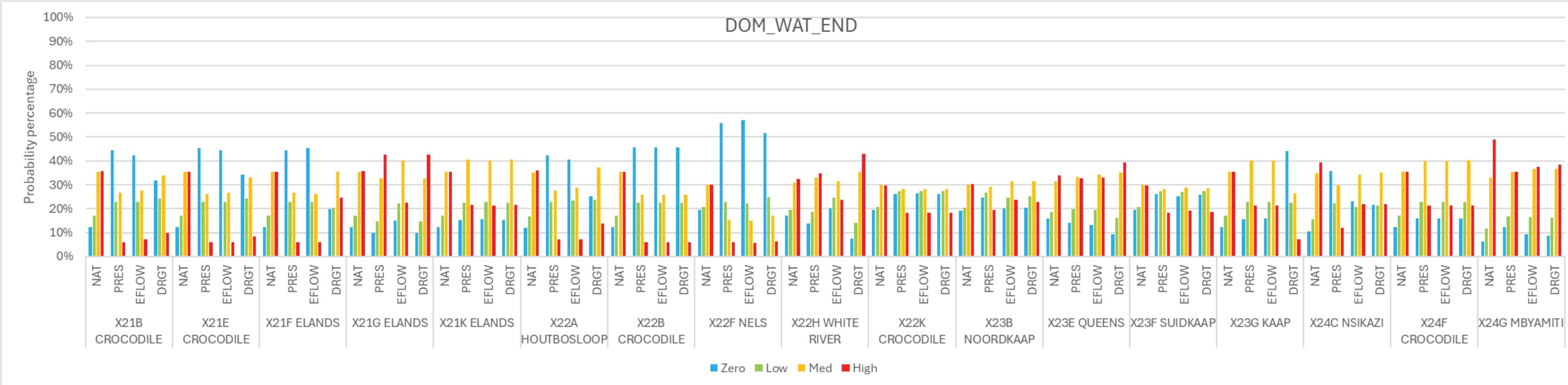


Figure 7-46: Relative risk scores to DOM-WAT-END for the Crocodile catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

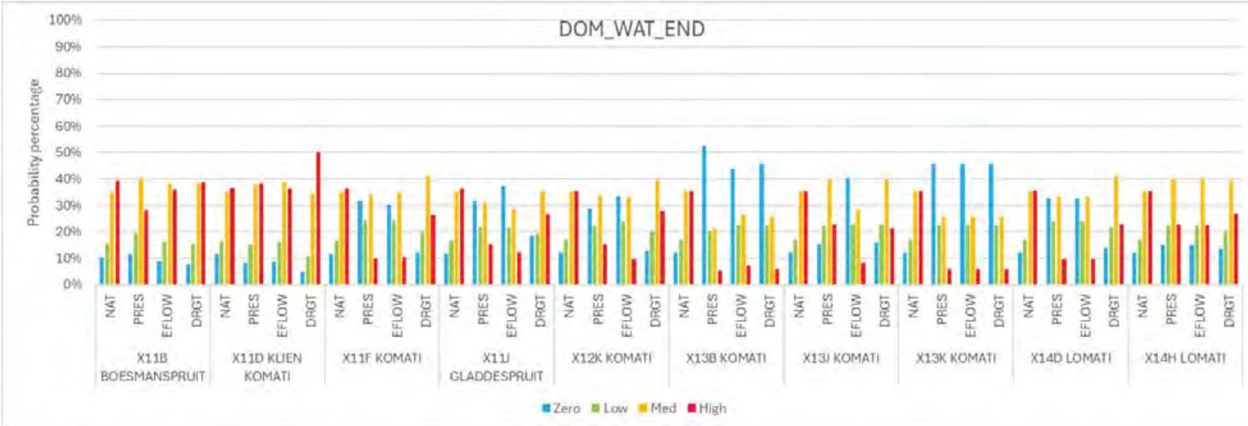


Figure 7-47: Relative risk scores to DOM-WAT-END for the Komati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

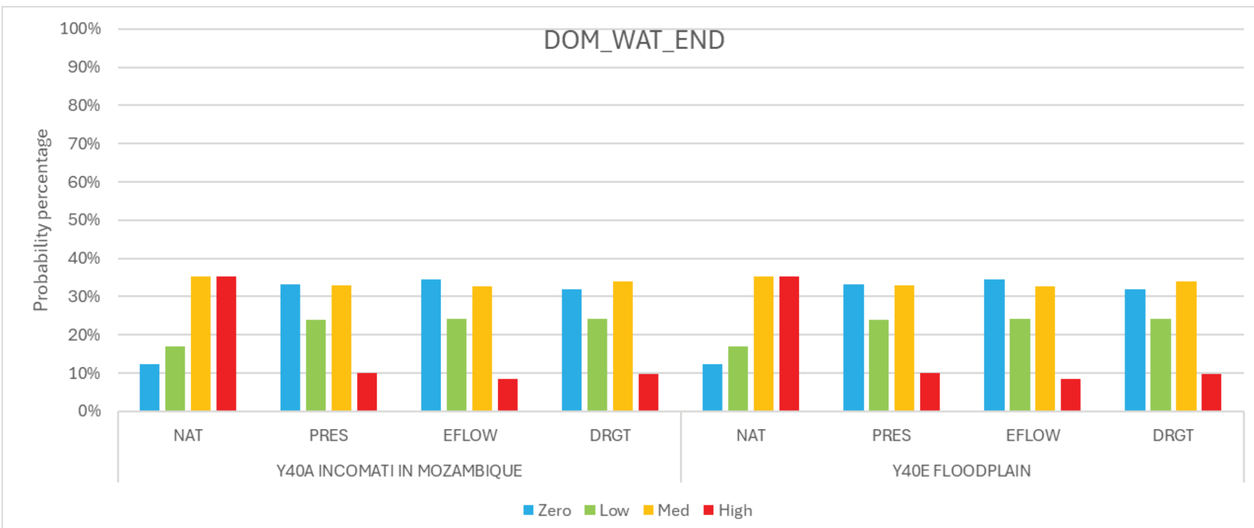


Figure 7-48: Relative risk scores to DOM-WAT-END for the Incomati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

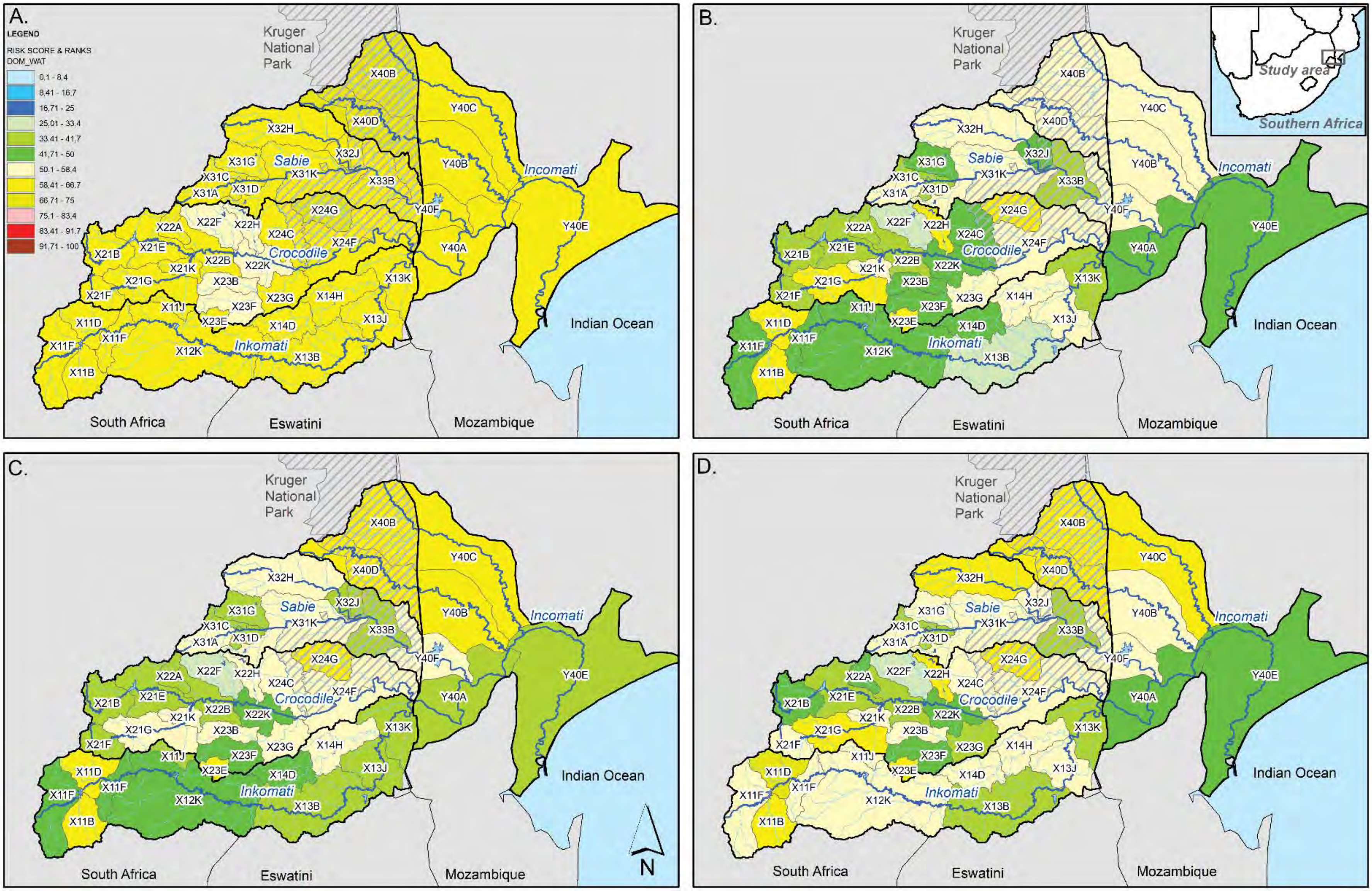


Figure 7-49: Relative risk scores to DOM-WAT-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed.

7.3 Regulatory Services

7.3.1 FLO-ATT-END endpoint

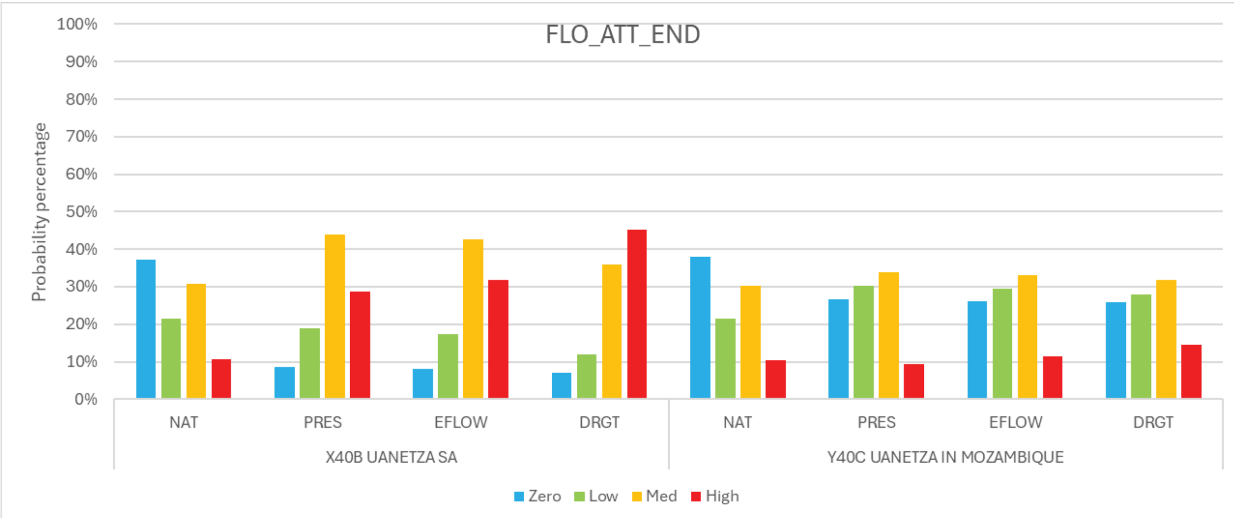


Figure 7-50: Relative risk scores to FLO-ATT-END for the Uanetza catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

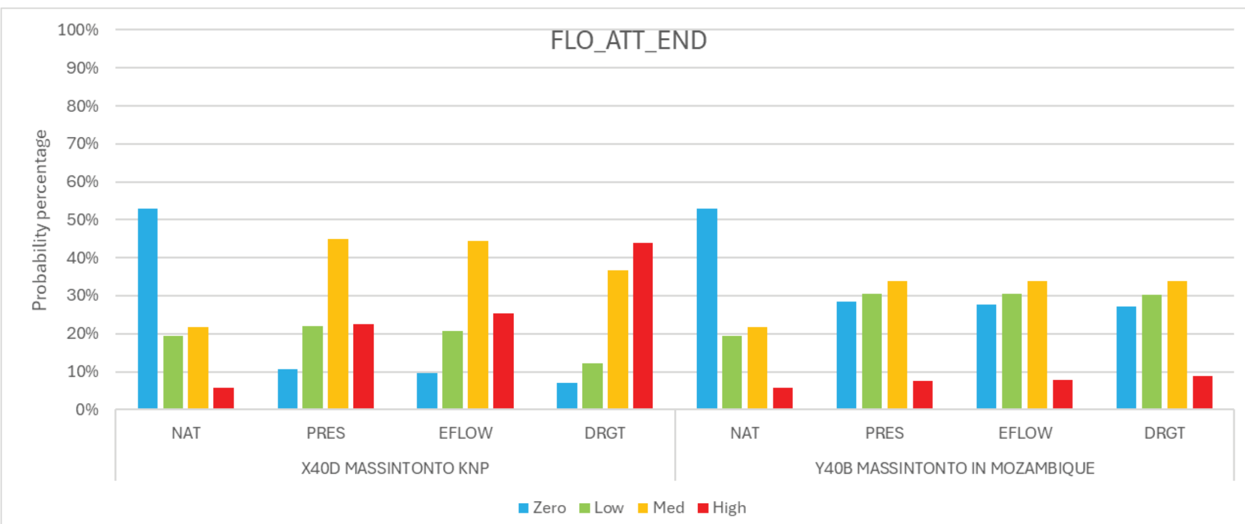


Figure 7-51: Relative risk scores to FLO-ATT-END for the Massintonto catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

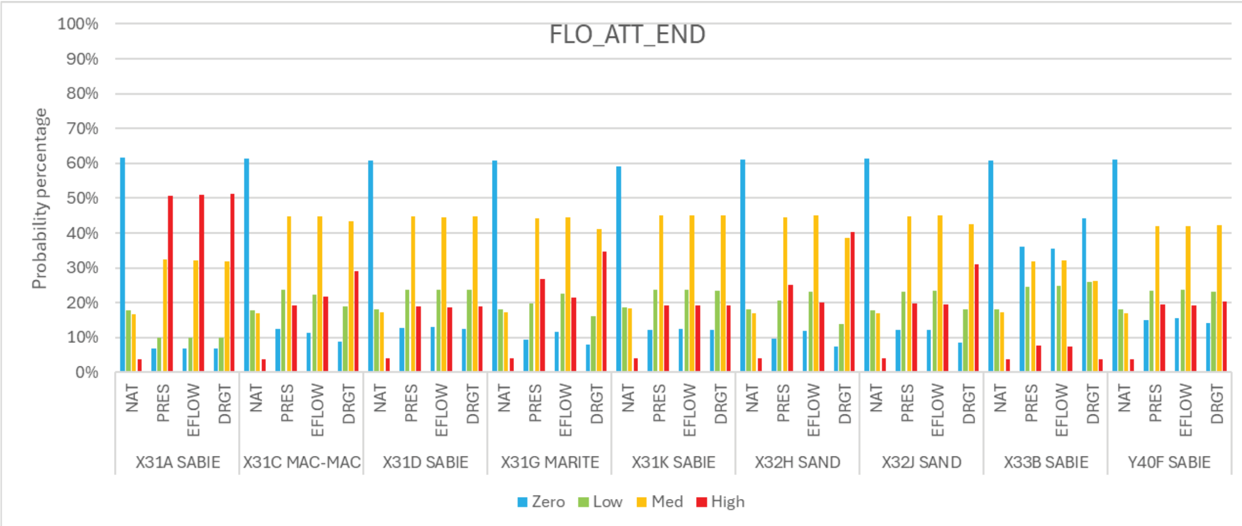


Figure 7-52: Relative risk scores to FLO-ATT-END for the Sabie catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

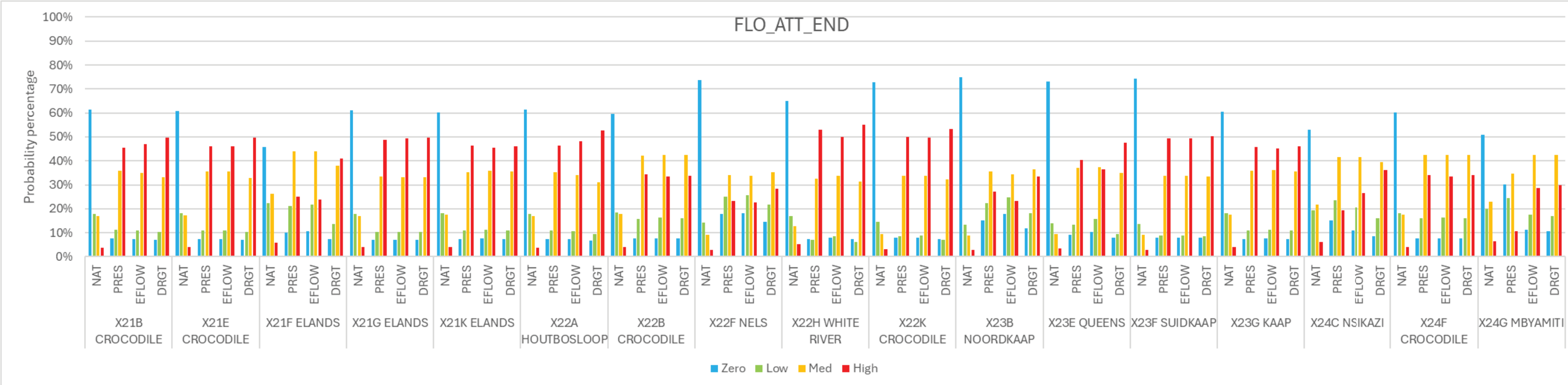


Figure 7-53: Relative risk scores to FLO-ATT-END for the Crocodile catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

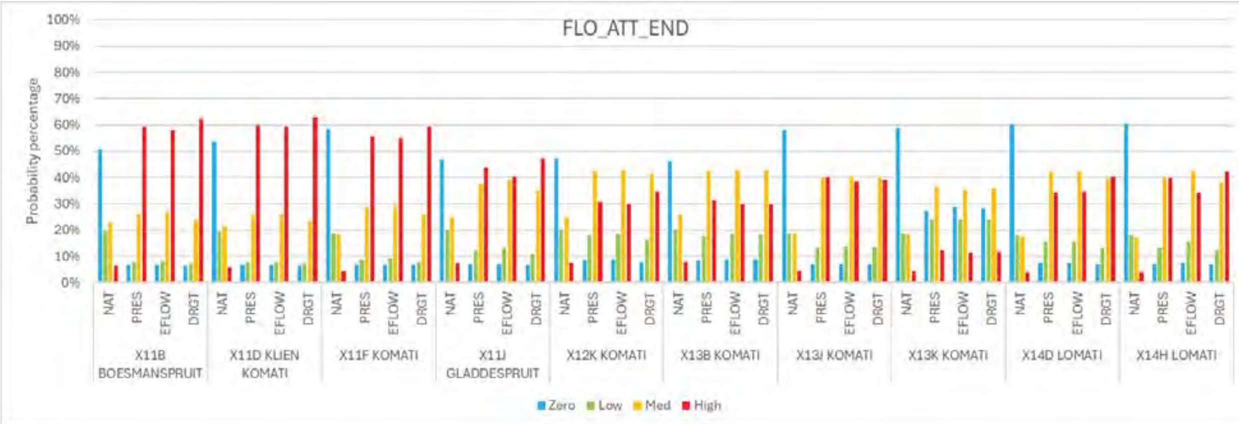


Figure 7-54: Relative risk scores to FLO-ATT-END for the Komati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

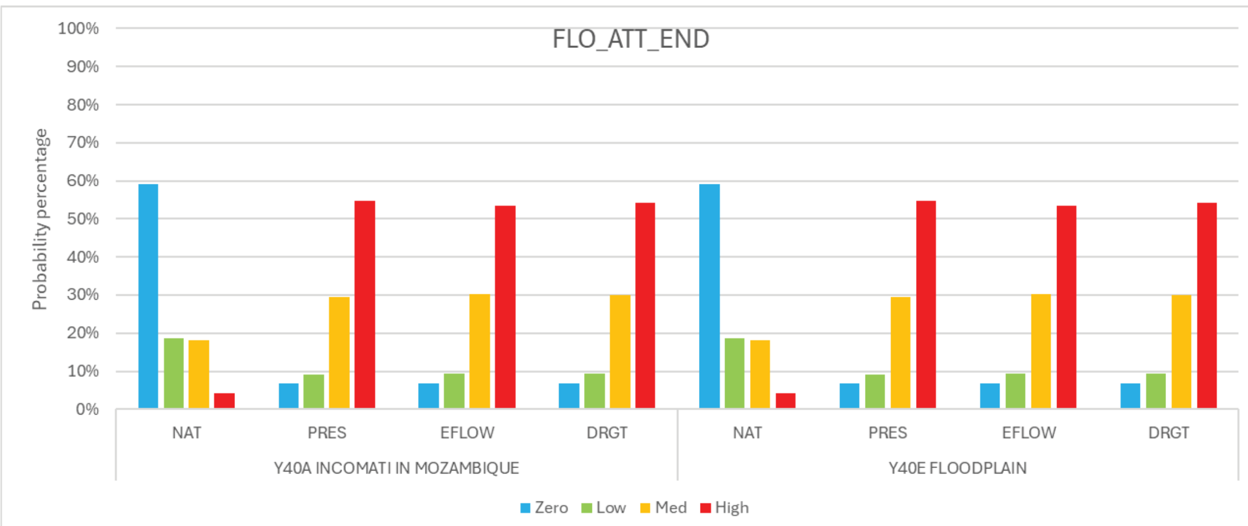


Figure 7-55: Relative risk scores to FLO-ATT-END for the Incomati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

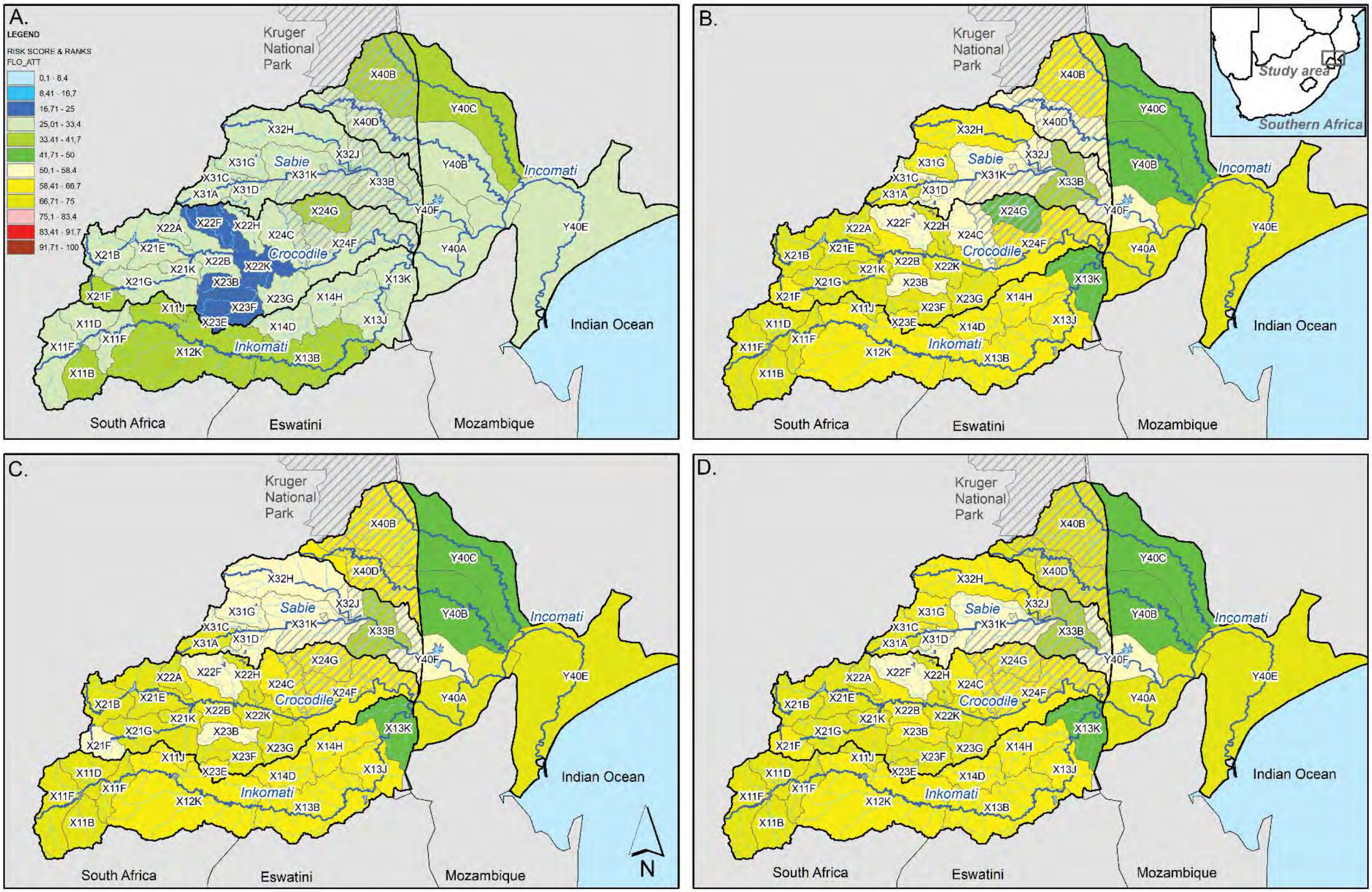


Figure 7-56: Relative risk scores to FLO-ATT-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

7.3.2 RIV-ASS-END endpoint

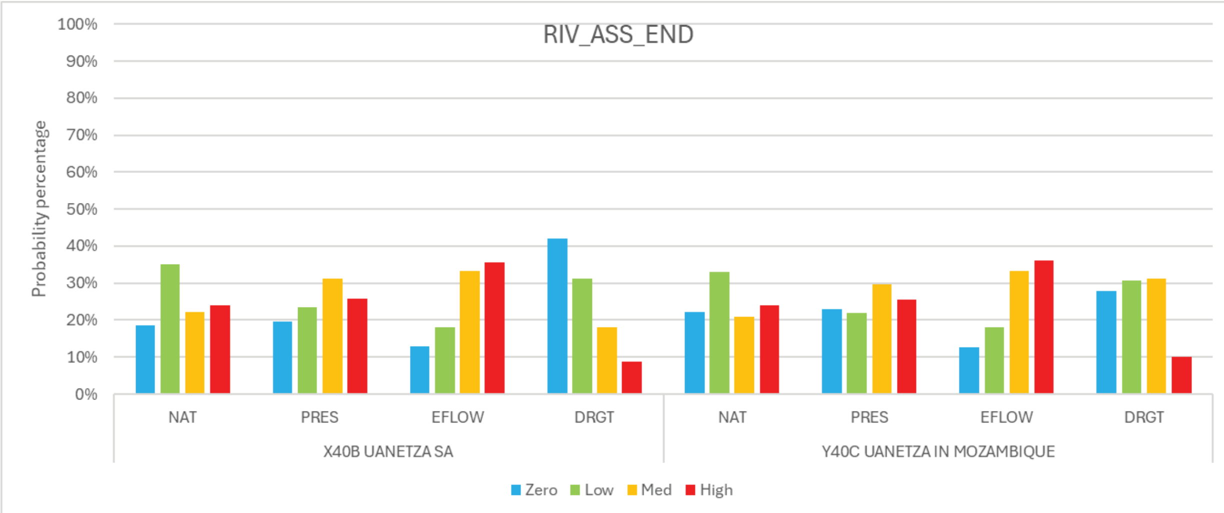


Figure 7-57: Relative risk scores to RIV-ASS-END for the Uanetza catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

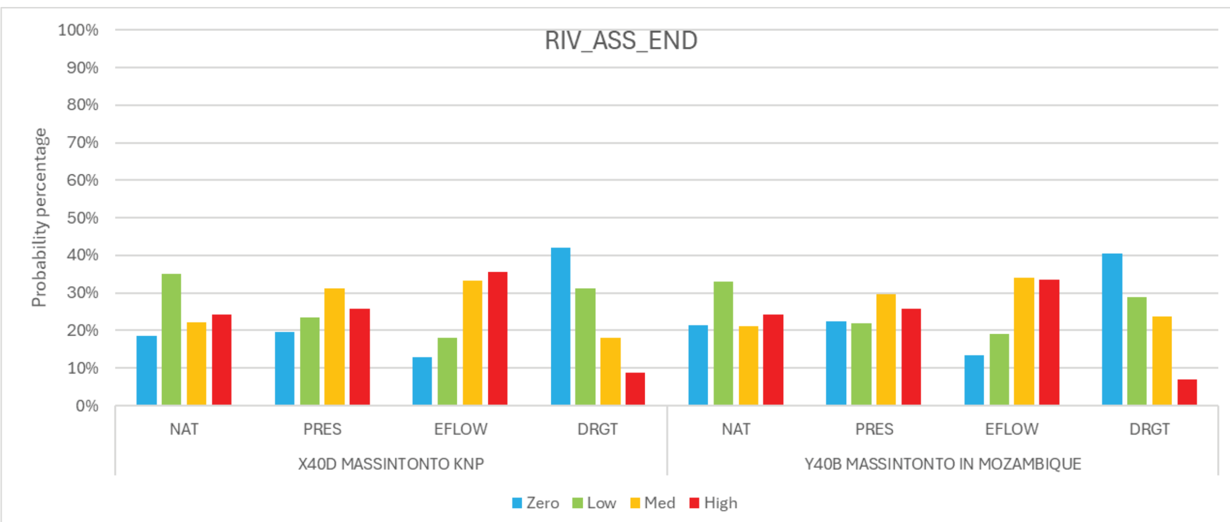


Figure 7-58: Relative risk scores to RIV-ASS-END for the Massintonto catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

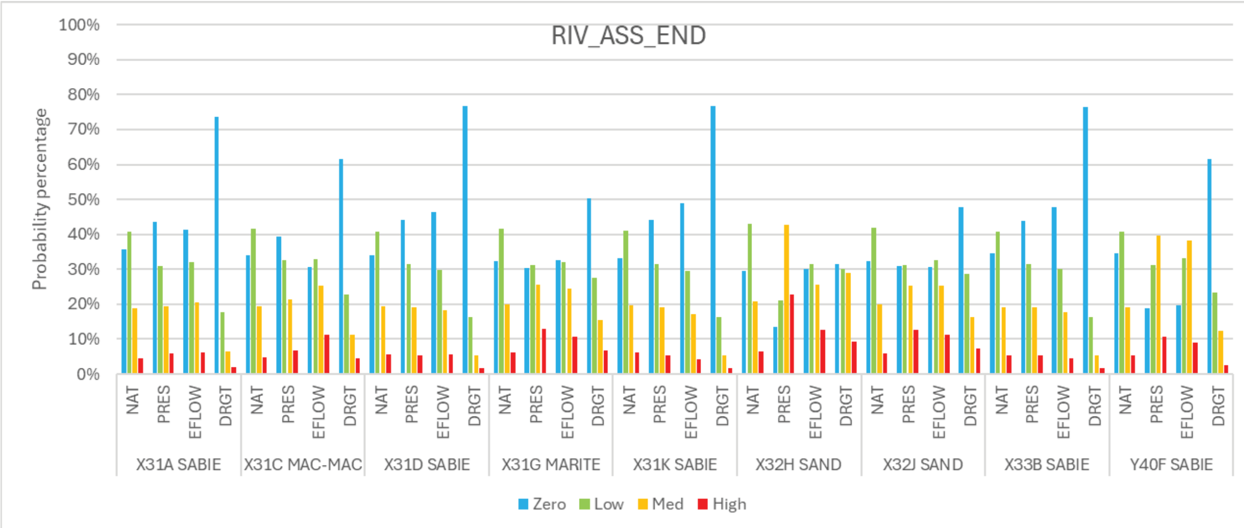


Figure 7-59: Relative risk scores to RIV-ASS-END for the Sabie catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

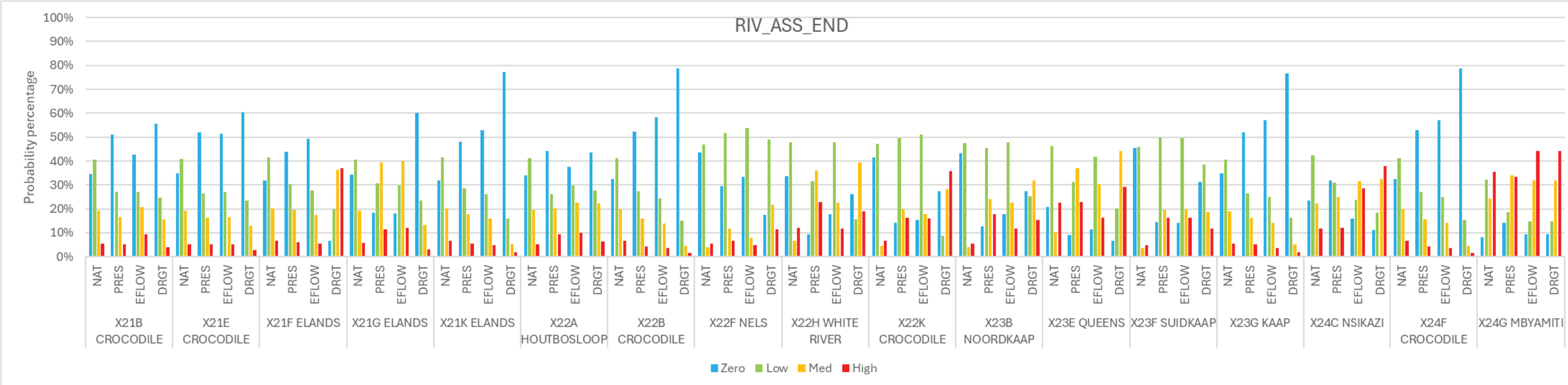


Figure 7-60: Relative risk scores to RIV-ASS-END for the Crocodile catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

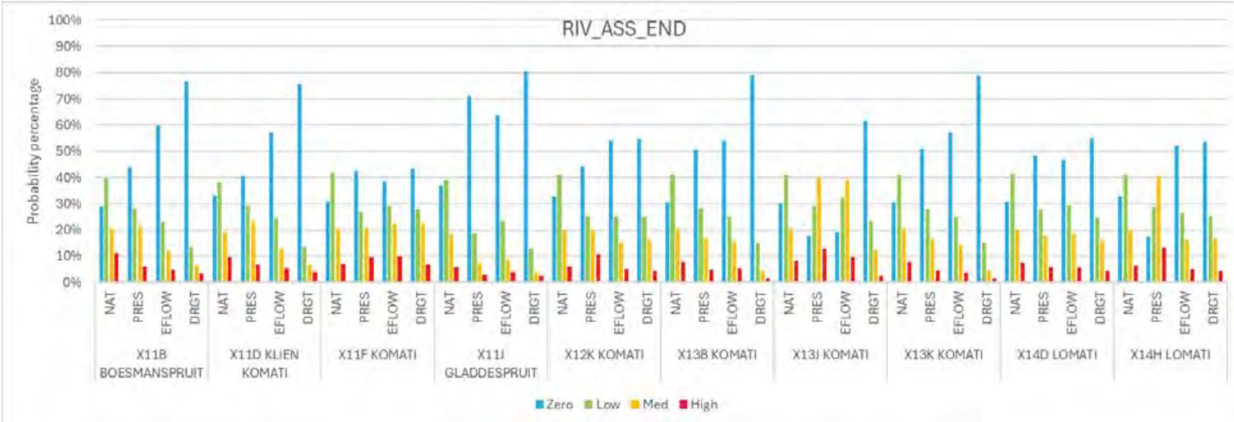


Figure 7-61: Relative risk scores to RIV-ASS-END for the Komati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

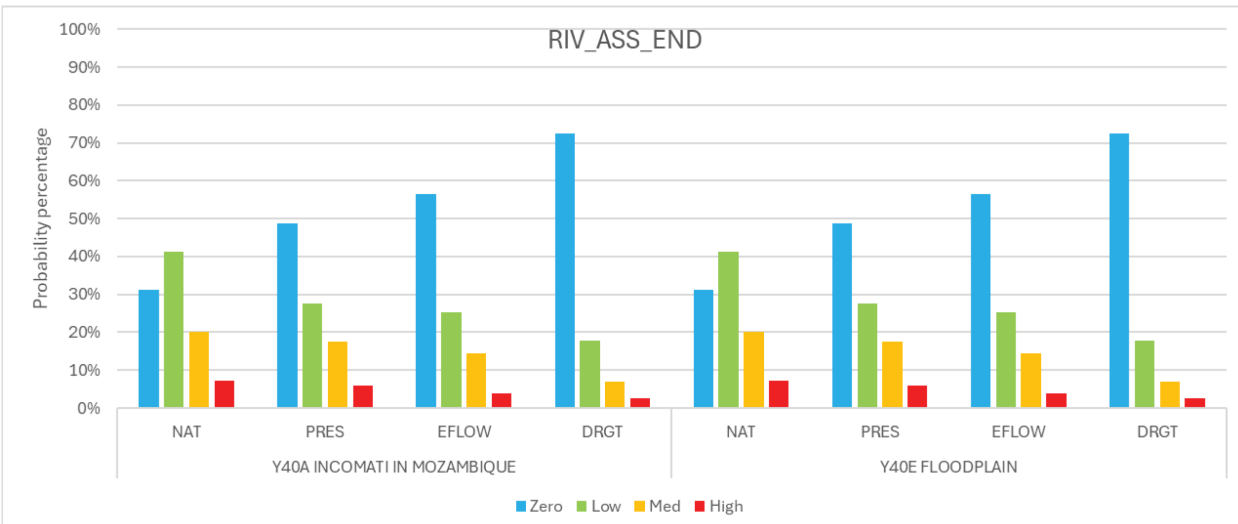


Figure 7-62: Relative risk scores to RIV-ASS-END for the Incomati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

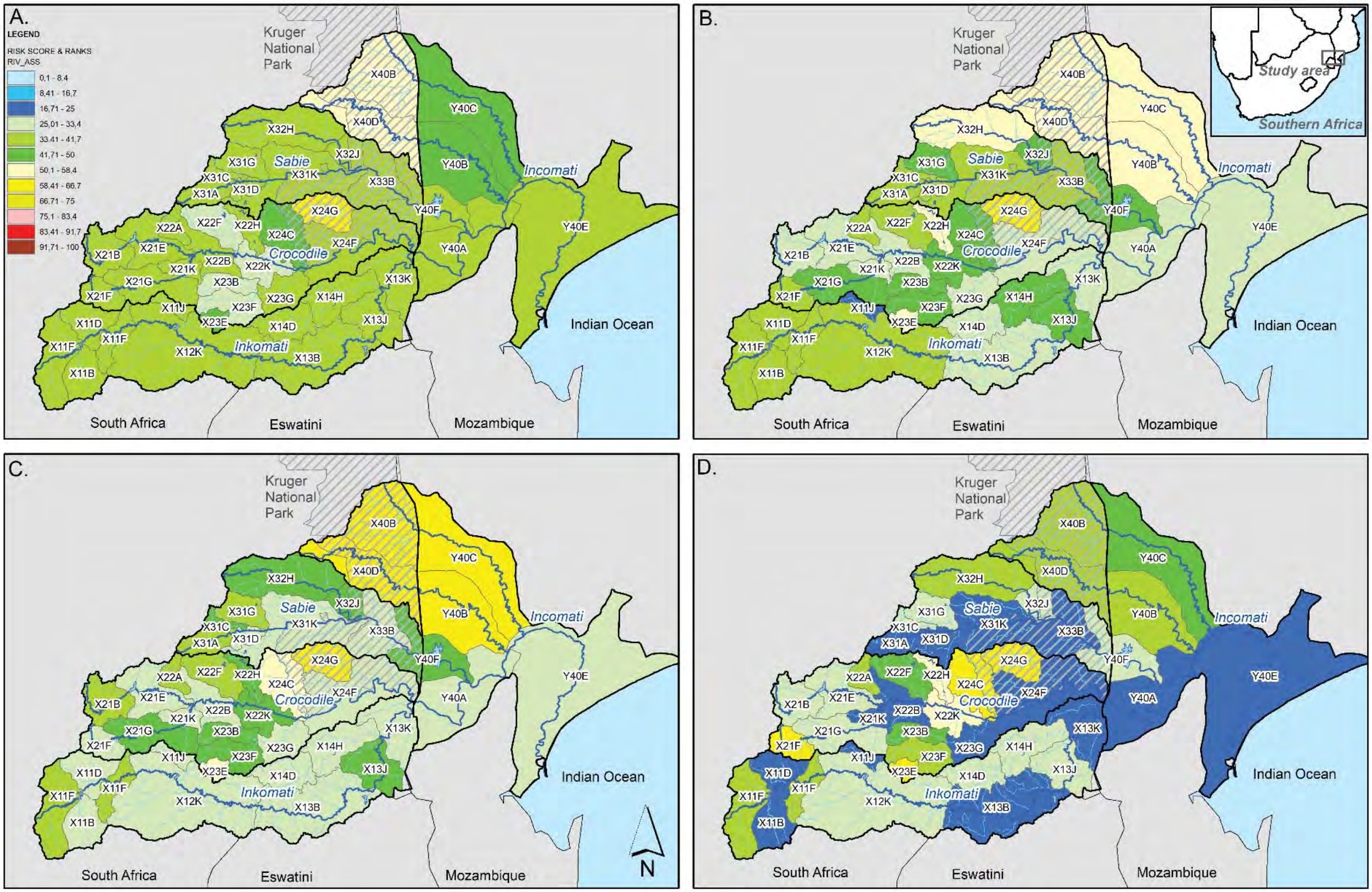


Figure 7-63: Relative risk scores to RIV-ASS-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

7.3.3 WAT-DIS-END endpoint

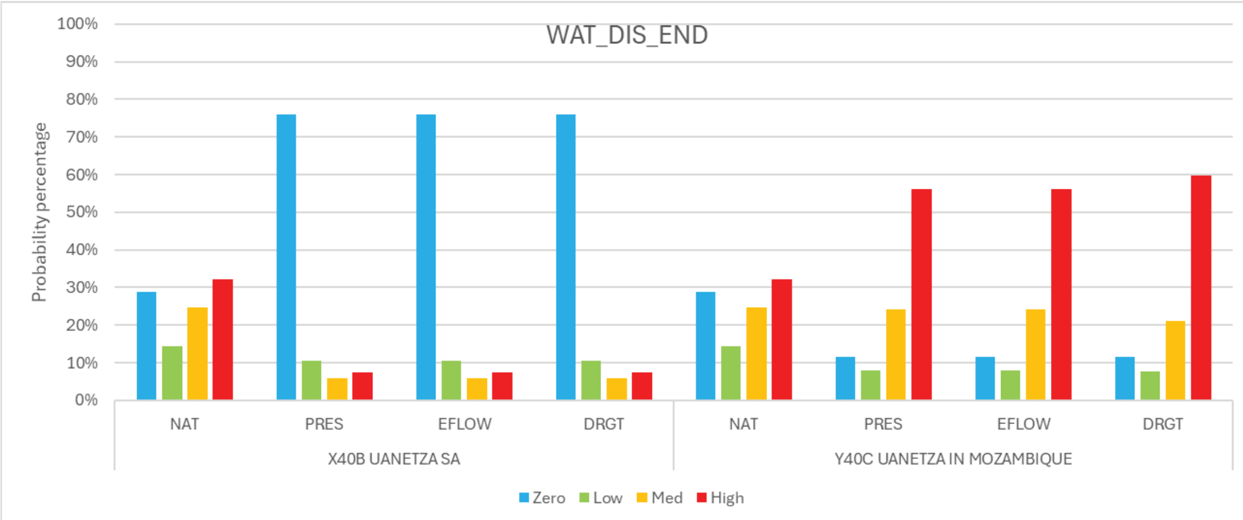


Figure 7-64: Relative risk scores to WAT-DIS-END for the Uanetza catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

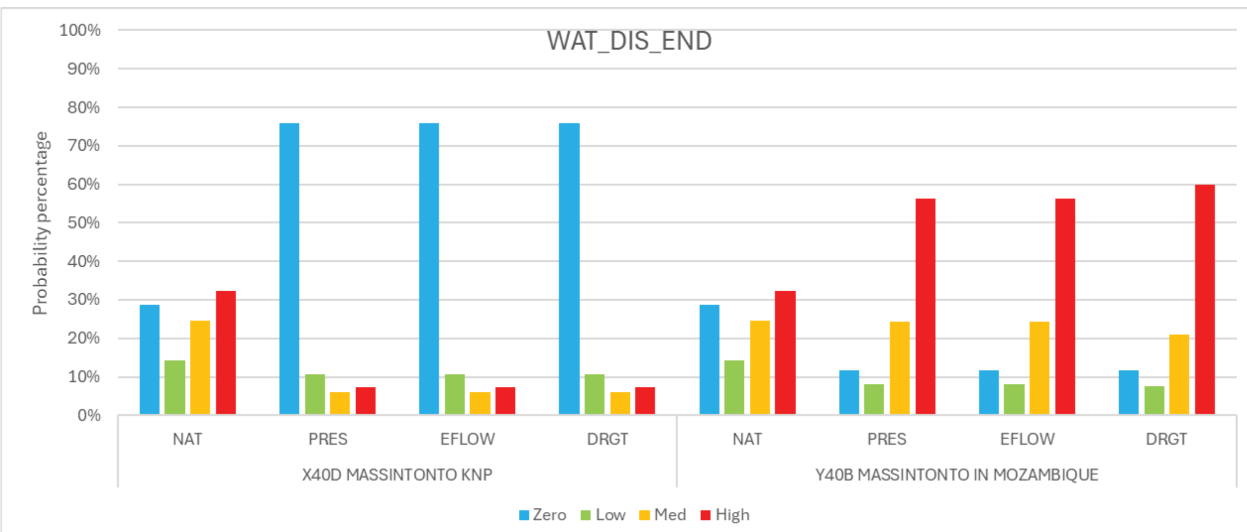


Figure 7-65: Relative risk scores to WAT-DIS-END for the Massintonto catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

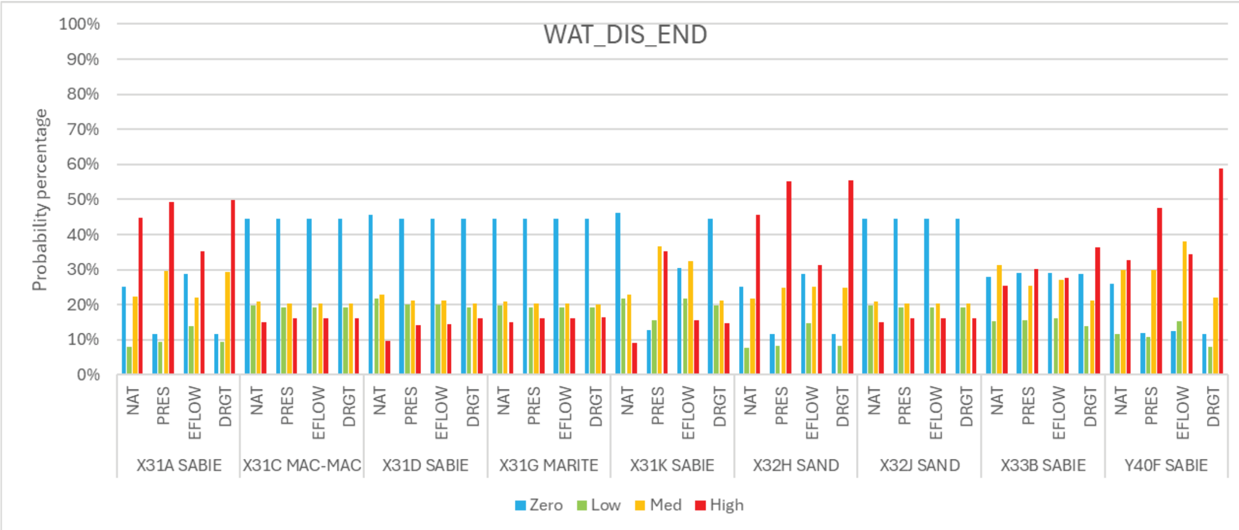


Figure 7-66: Relative risk scores to WAT-DIS-END for the Sabie catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

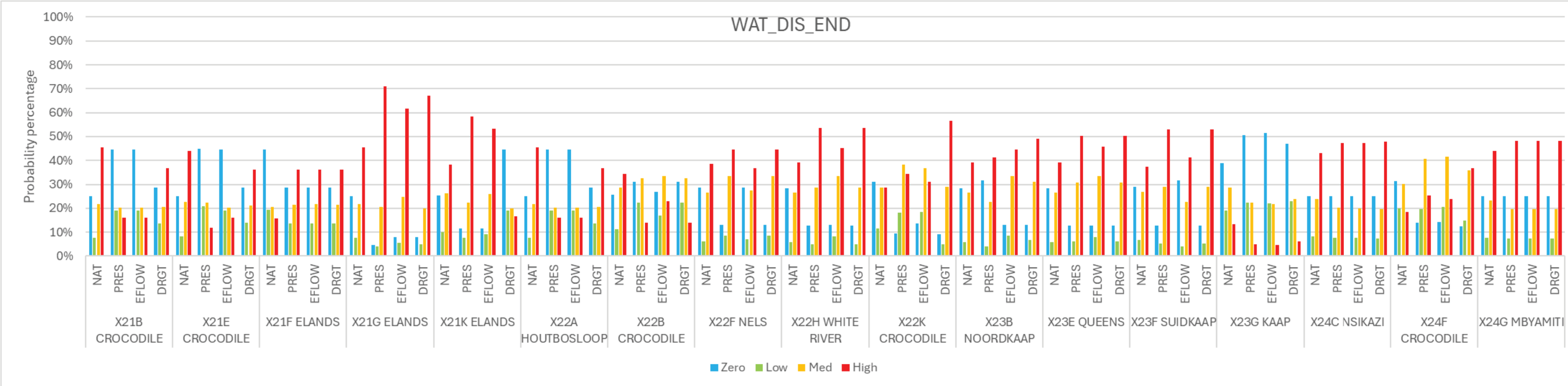


Figure 7-67: Relative risk scores to WAT-DIS-END for the Crocodile catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

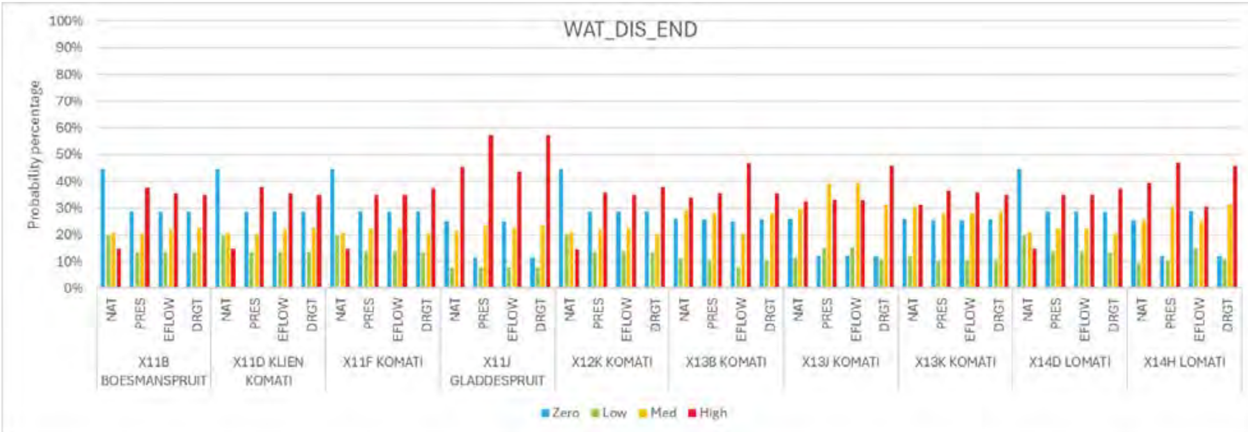


Figure 7-68: Relative risk scores to WAT-DIS-END for the Komati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

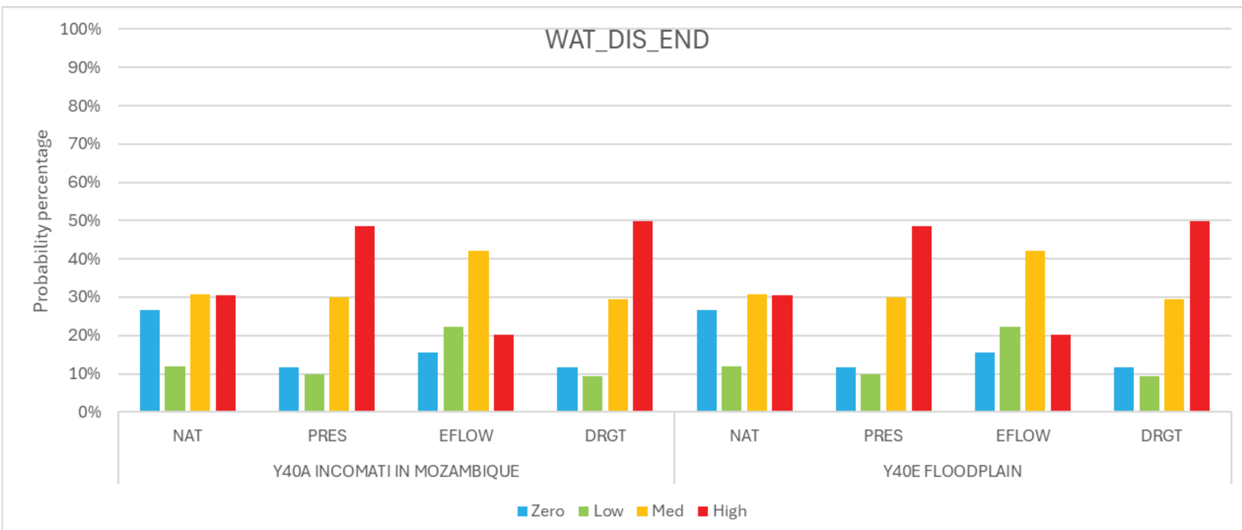


Figure 7-69: Relative risk scores to WAT-DIS-END for the Incomati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

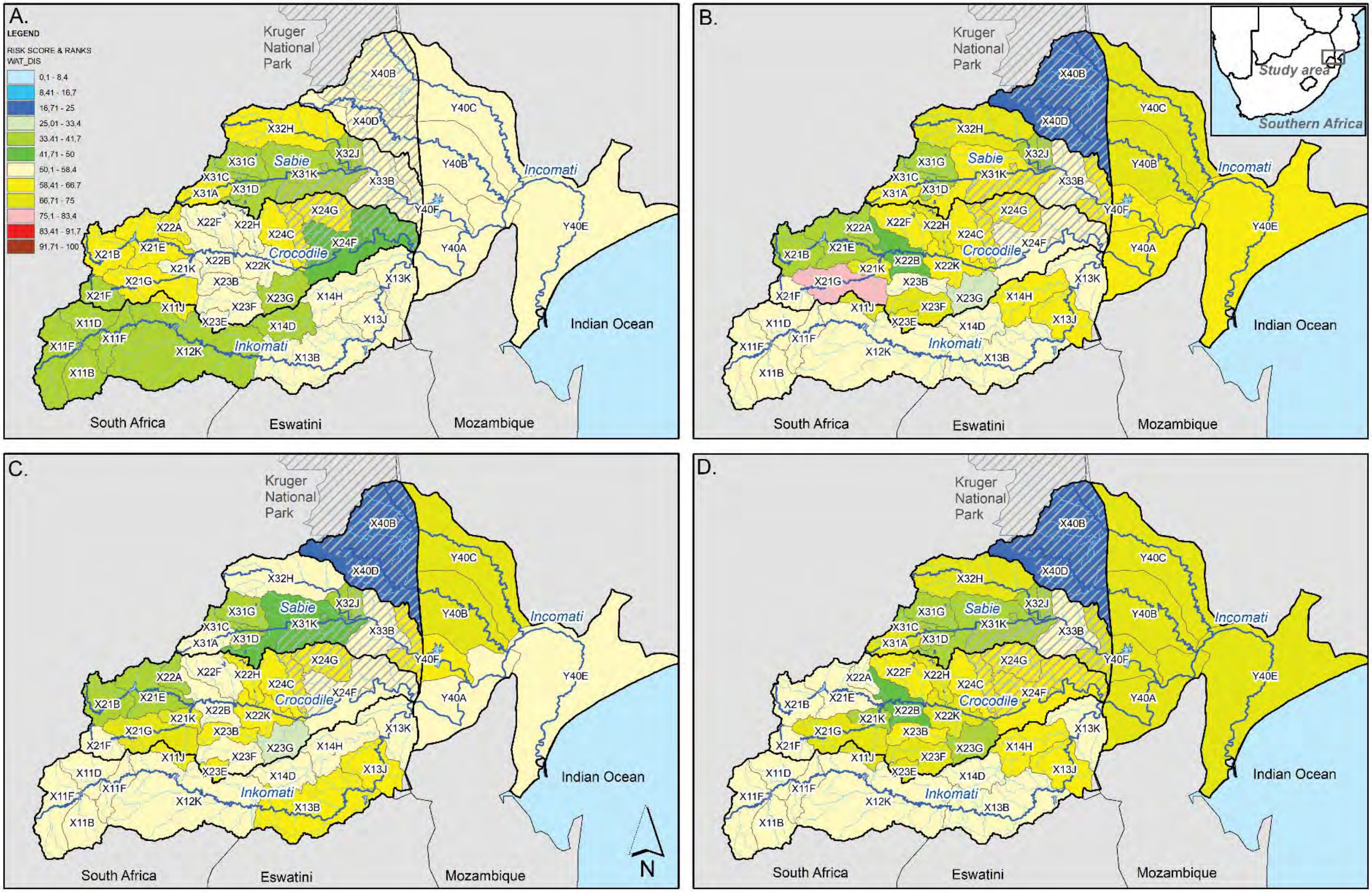


Figure 7-70: Relative risk scores to WAT-DIS-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

7.3.4 RES-RES-END endpoint

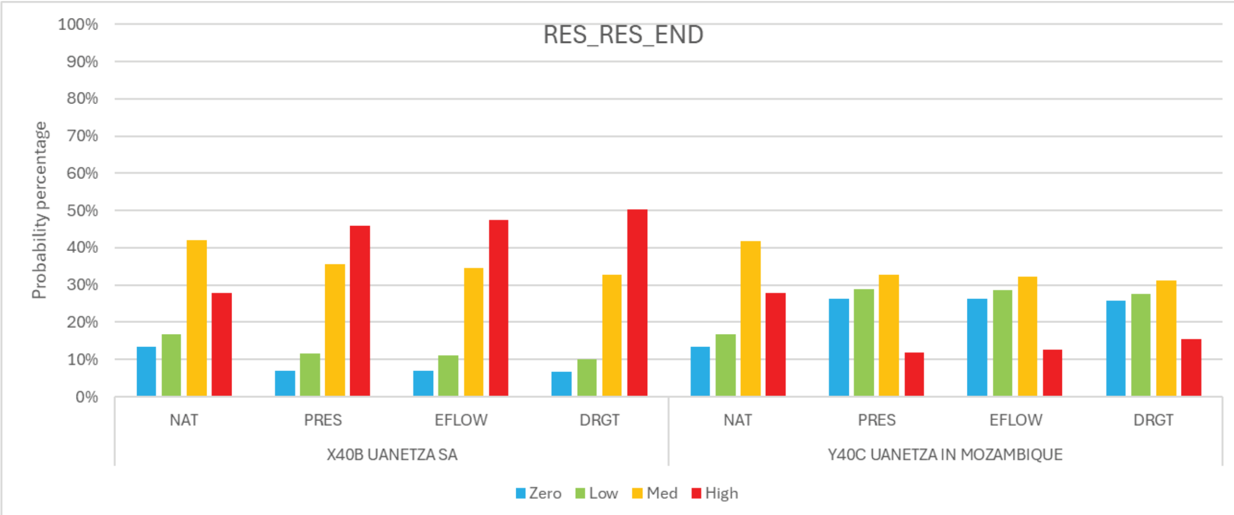


Figure 7-71: Relative risk scores to RES-RES-END for the Uanetza catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

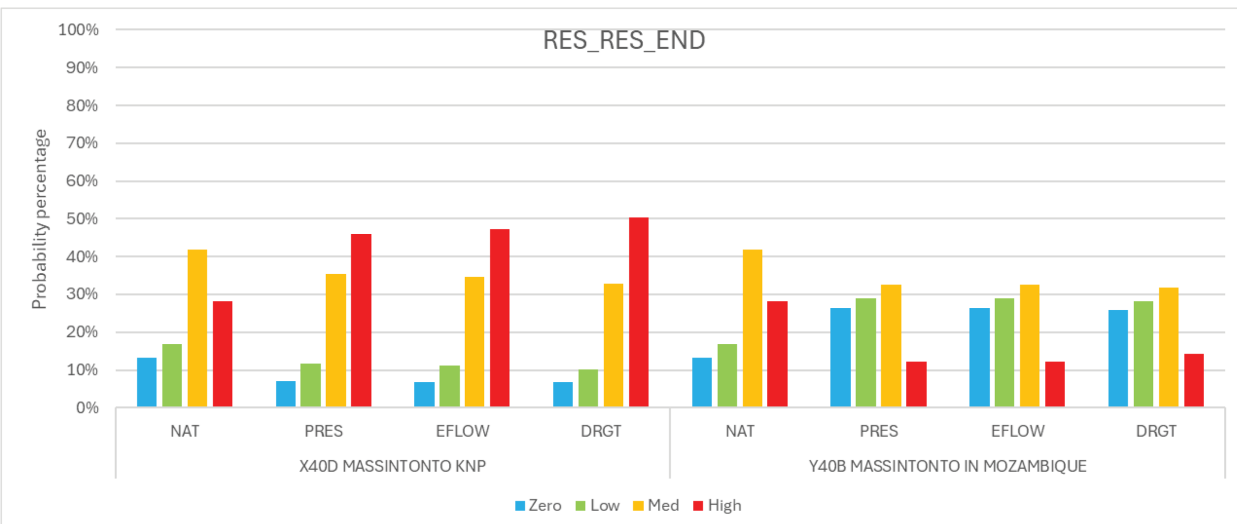


Figure 7-72: Relative risk scores to RES-RES-END for the Massintonto catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

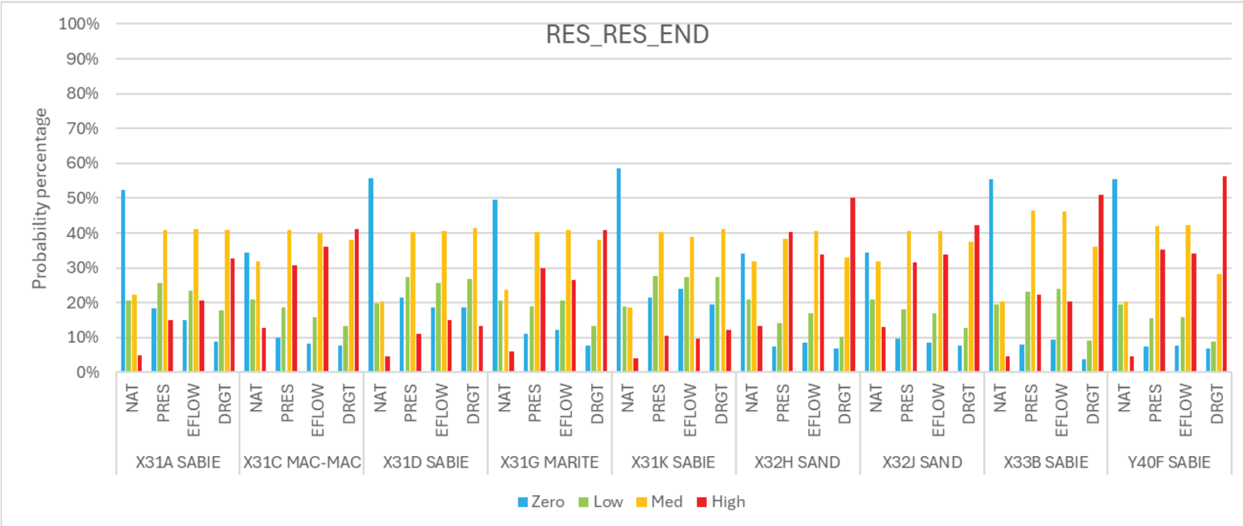


Figure 7-73: Relative risk scores to RES-RES-END for the Sabie catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

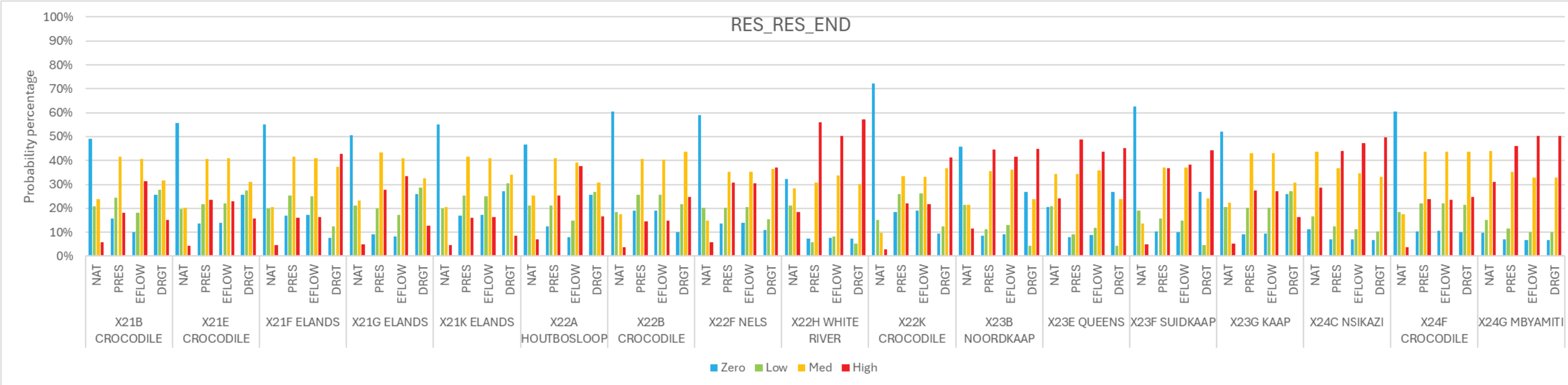


Figure 7-74: Relative risk scores to RES-RES-END for the Crocodile catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

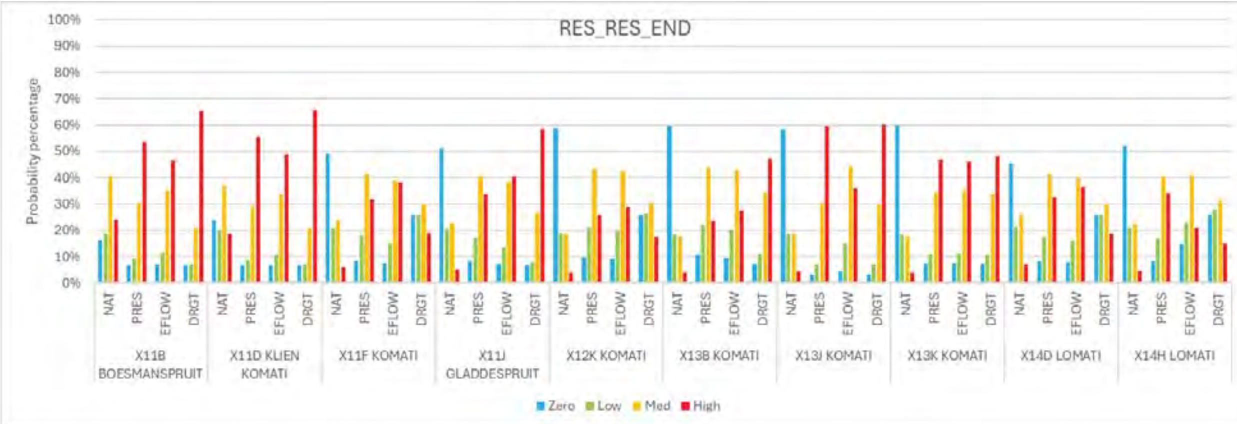


Figure 7-75: Relative risk scores to RES-RES-END for the Komati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

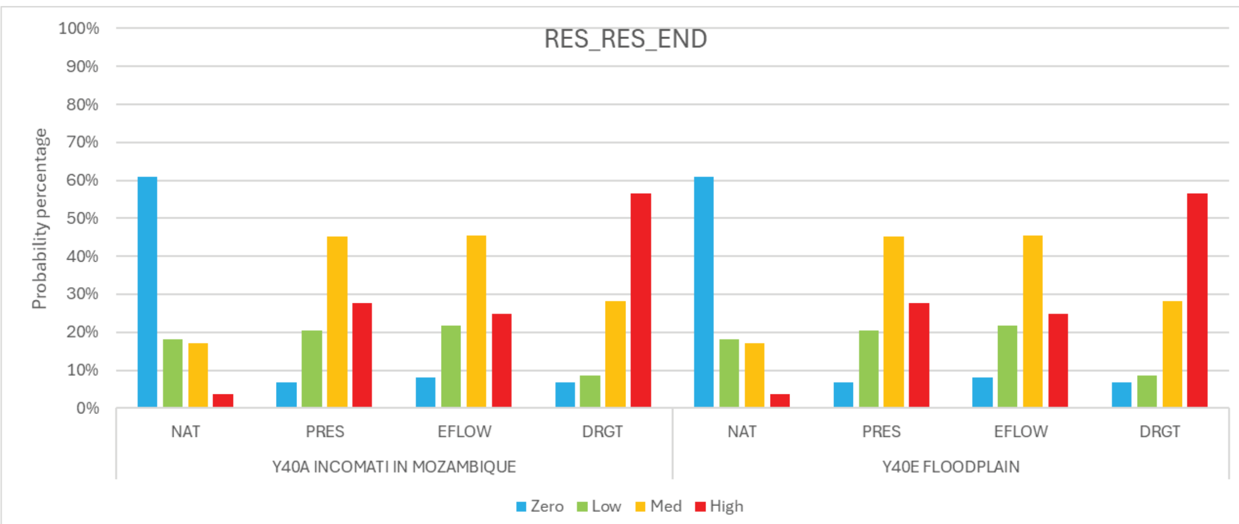


Figure 7-76: Relative risk scores to RES-RES-END for the Incomati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

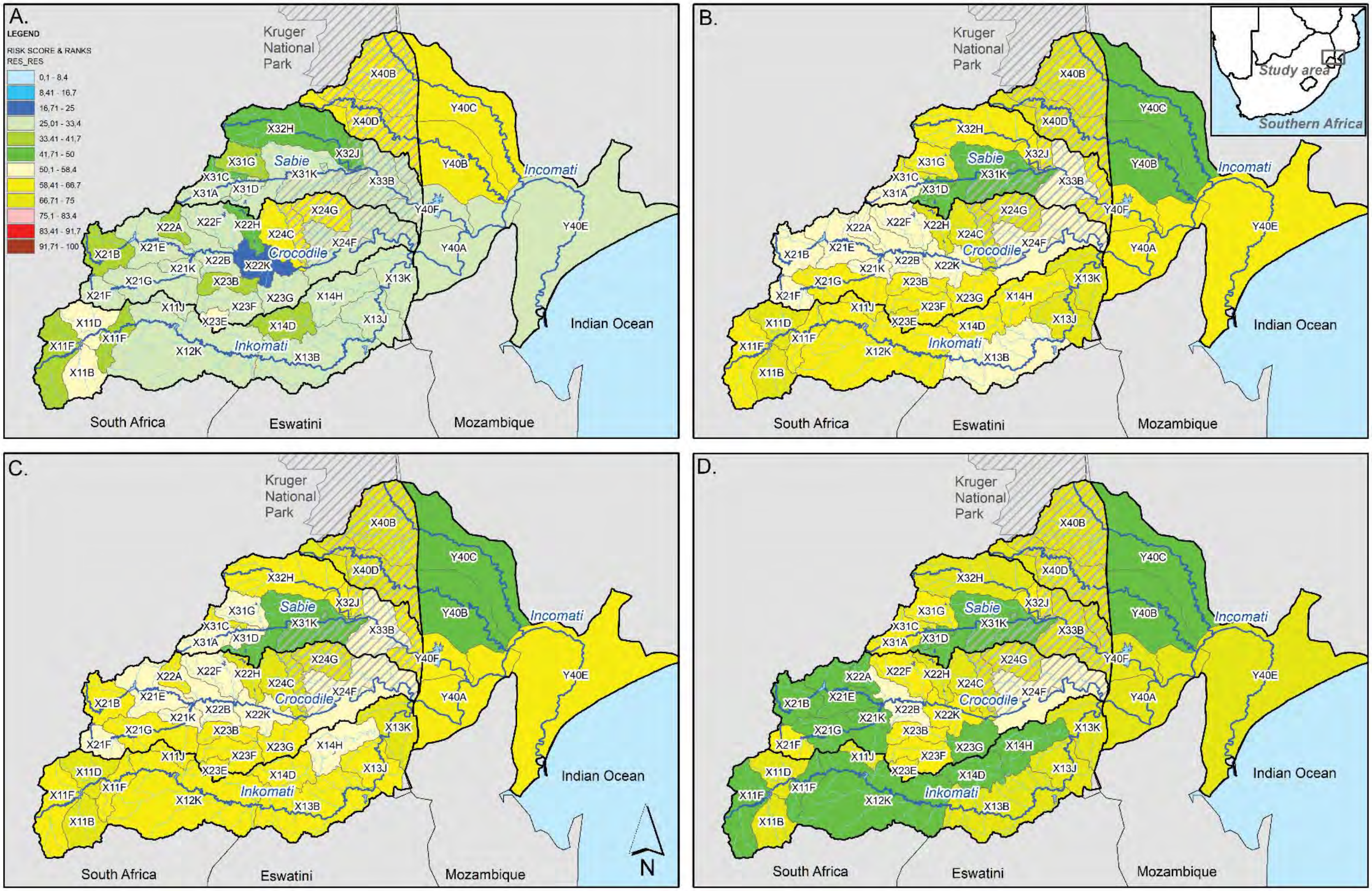


Figure 7-77: Relative risk scores to RES-RES-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

7.4 Cultural Services

7.4.1 REC-SPIR-END endpoint

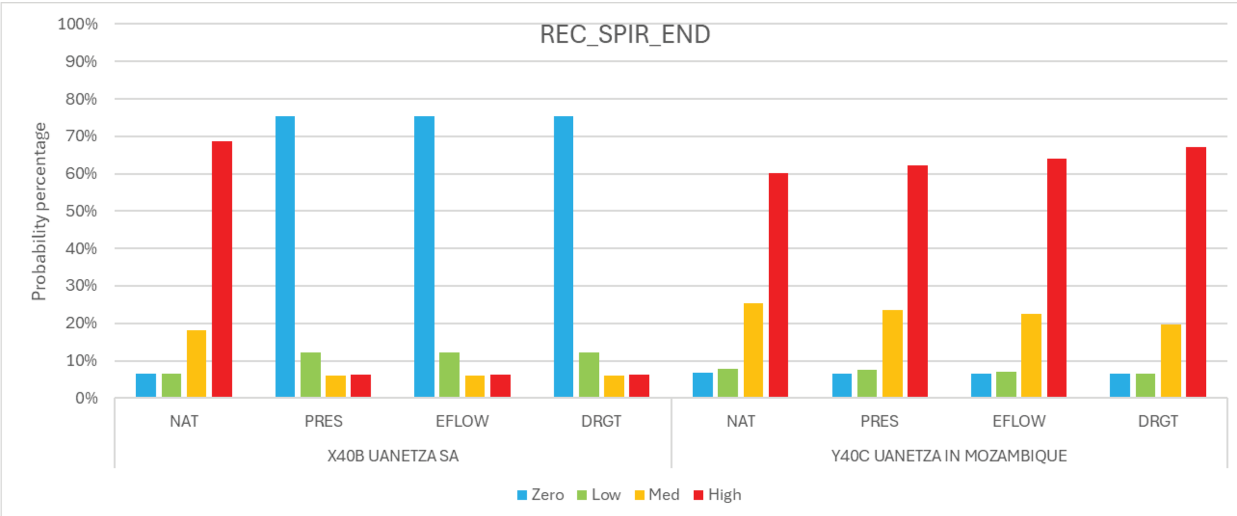


Figure 7-78: Relative risk scores to REC-SPIR-END for the Uanetza catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

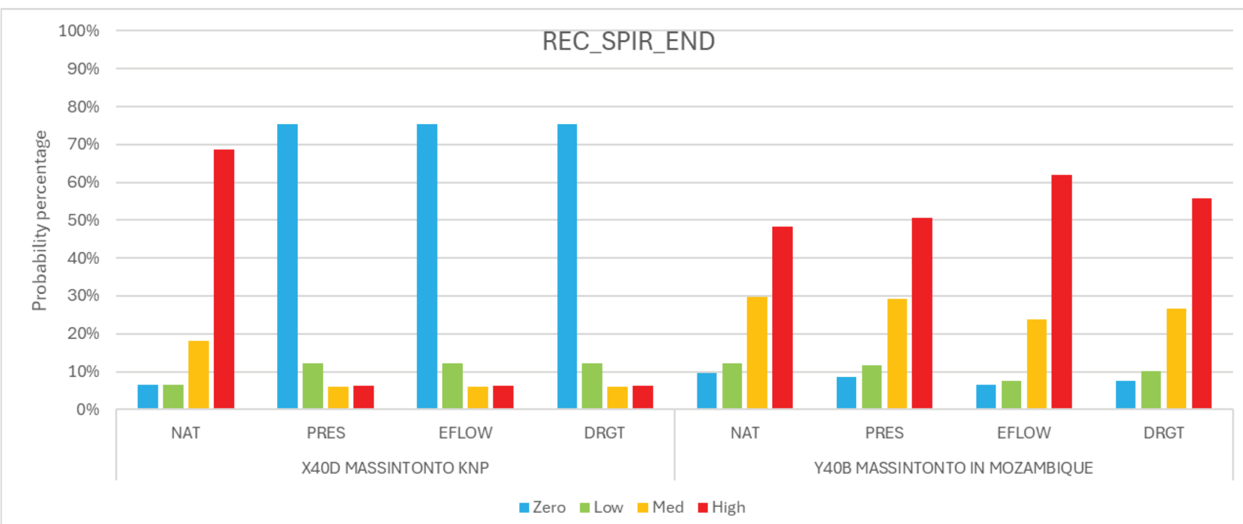


Figure 7-79: Relative risk scores to REC-SPIR-END for the Massintonto catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

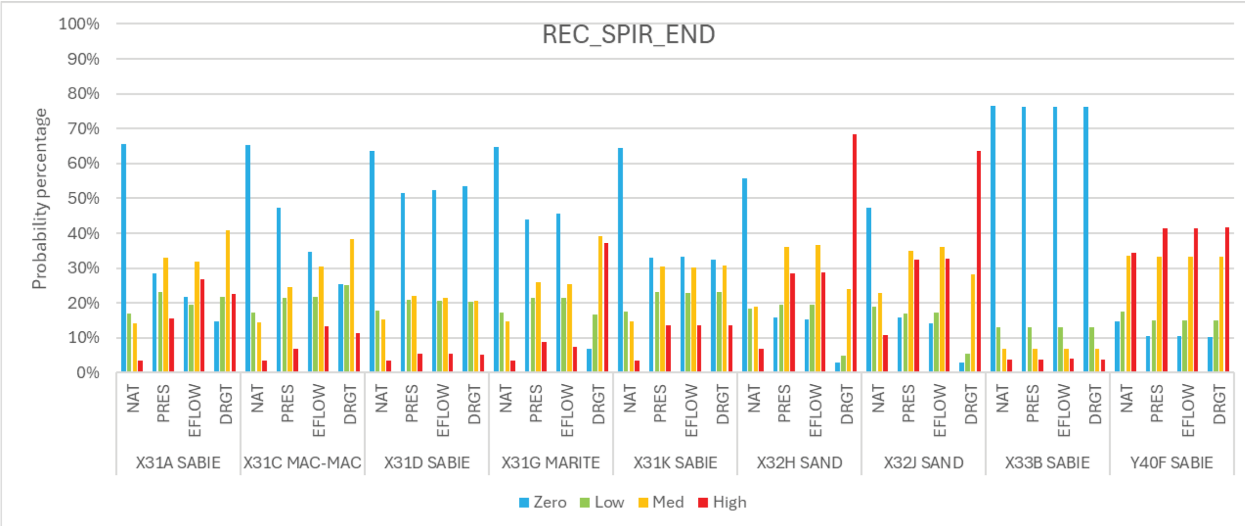


Figure 7-80: Relative risk scores to REC-SPIR-END for the Sabie catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

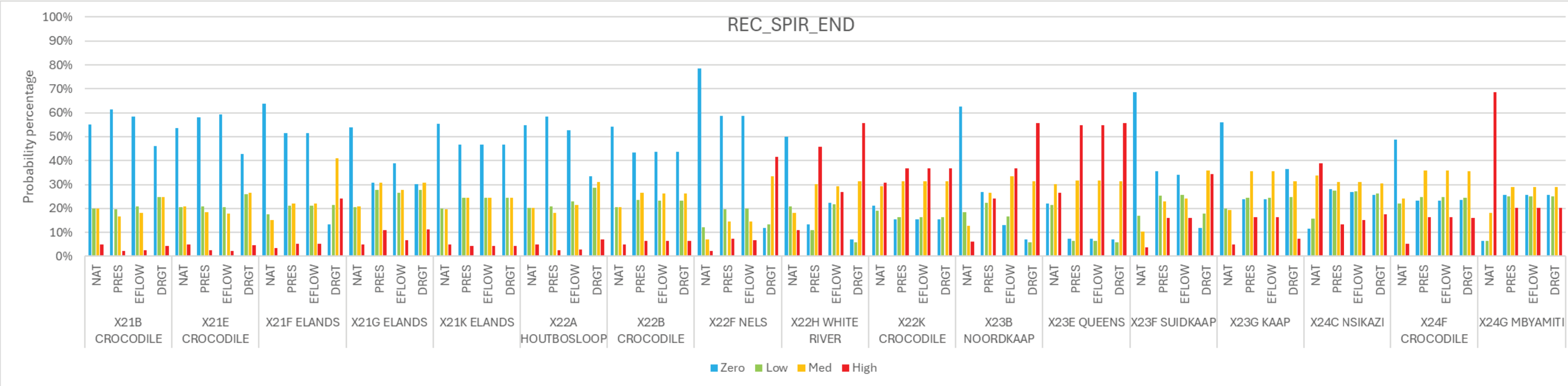


Figure 7-81: Relative risk scores to REC-SPIR-END for the Crocodile catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

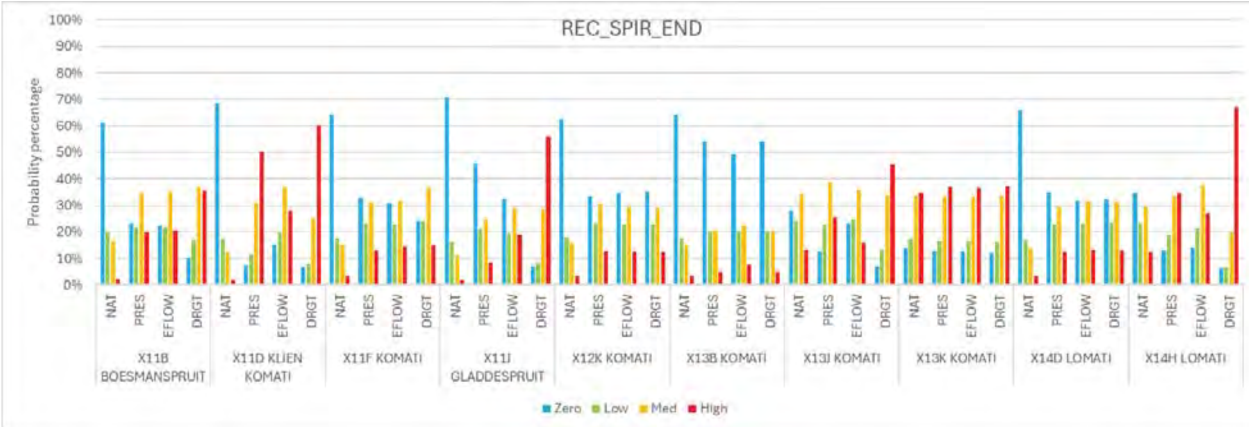


Figure 7-82: Relative risk scores to REC-SPIR-END for the Komati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

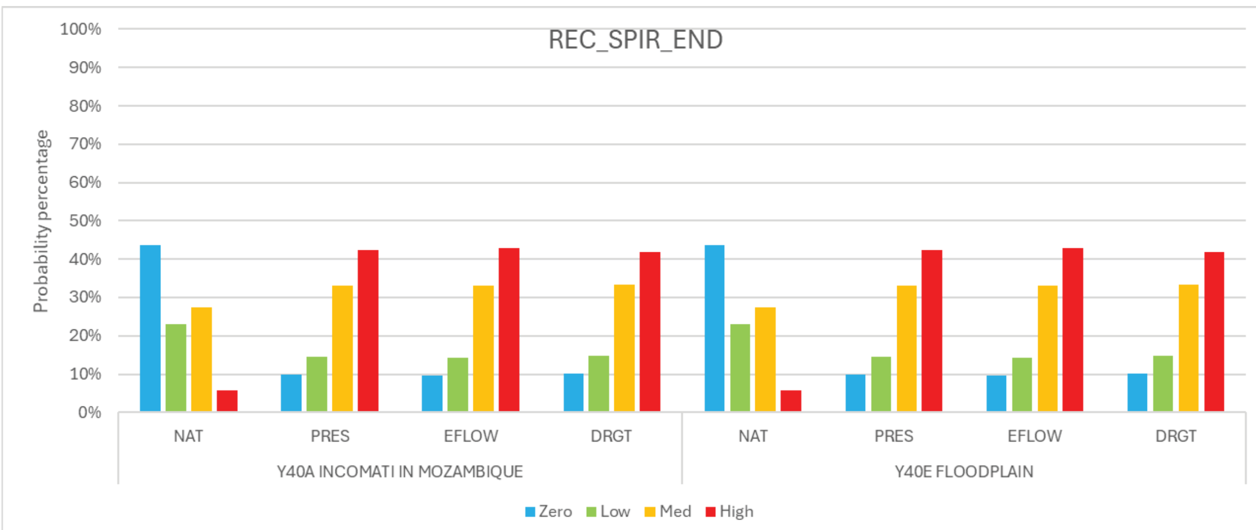


Figure 7-83: Relative risk scores to REC-SPIR-END for the Incomati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

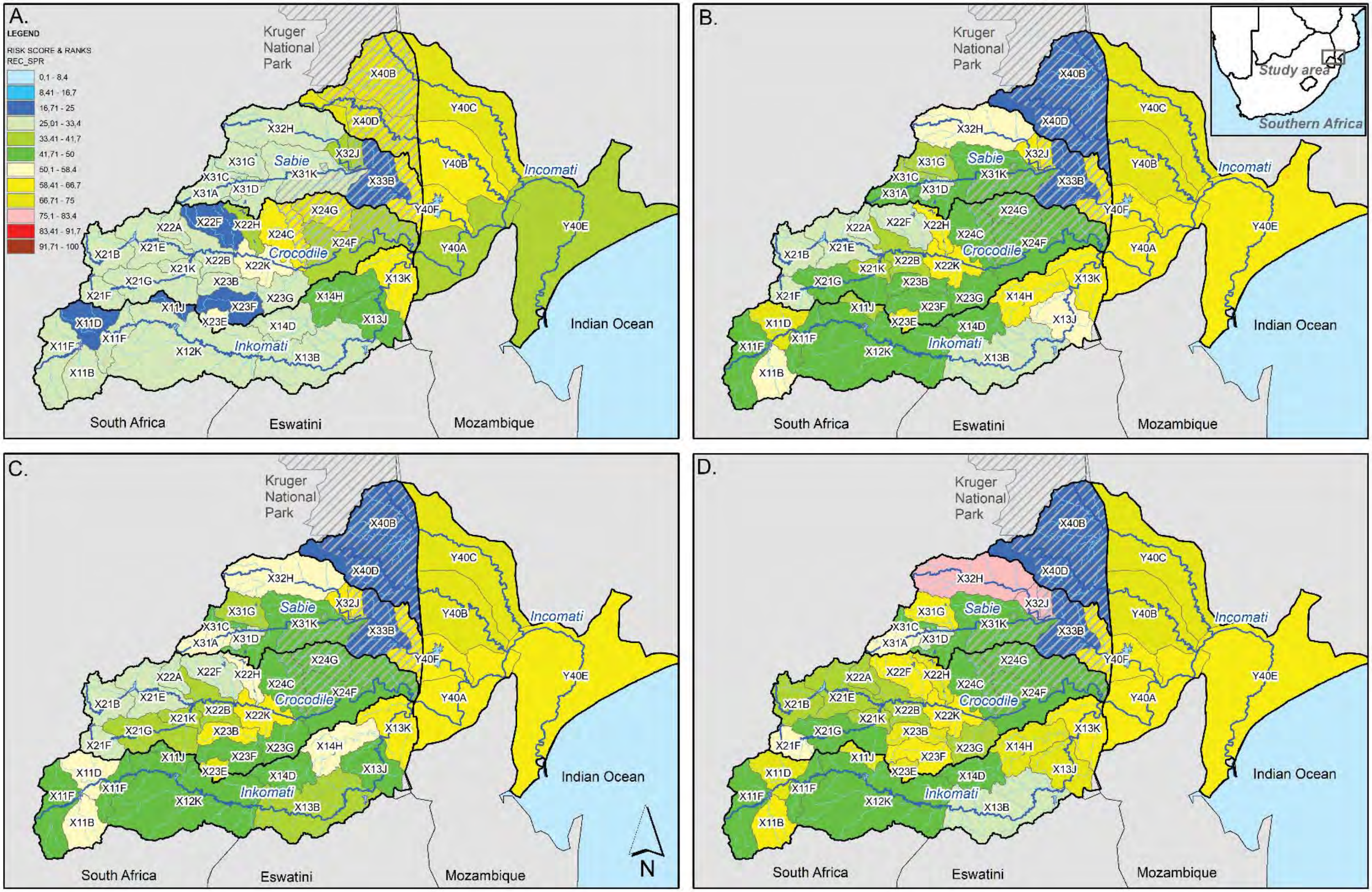


Figure 7-84: Relative risk scores to REC-SPIR-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

7.4.2 TOURISM-END endpoint

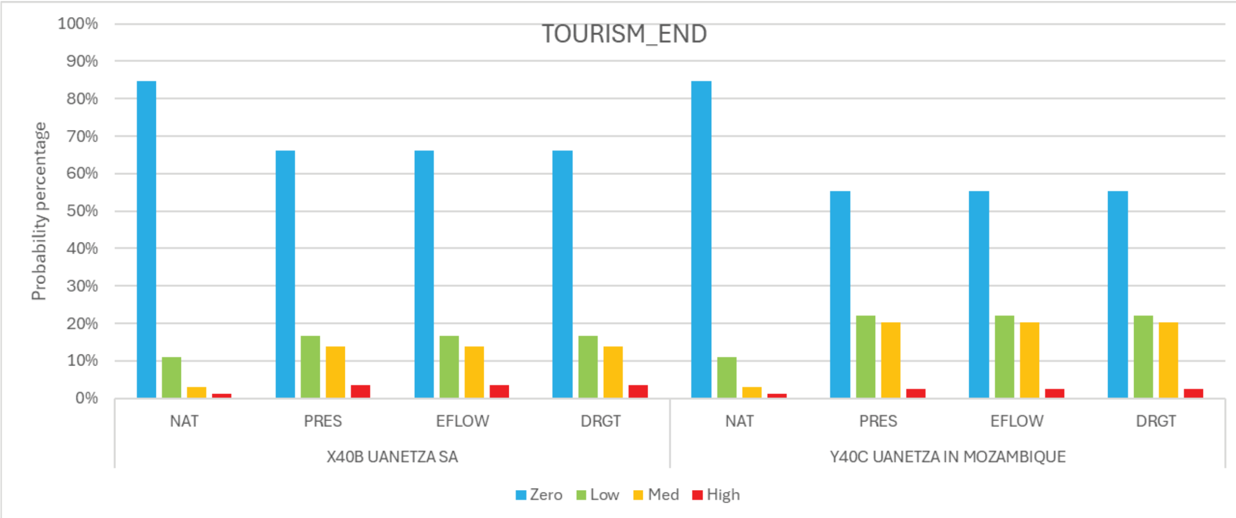


Figure 7-85: Relative risk scores to TOURISM-END for the Uanetza catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

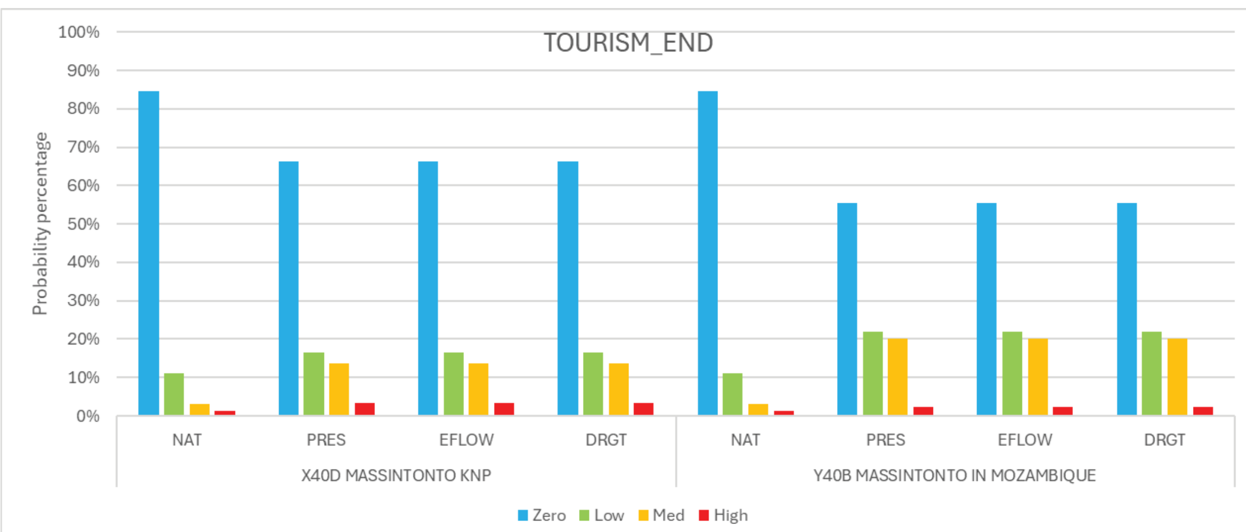


Figure 7-86: Relative risk scores to TOURISM-END for the Massintonto catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

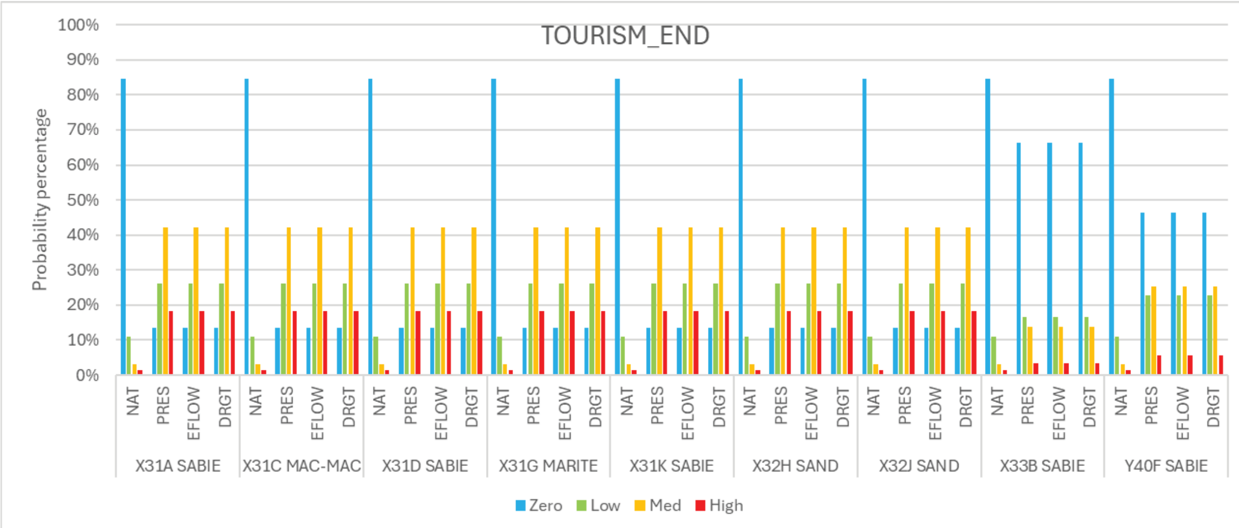


Figure 7-87: Relative risk scores to TOURISM-END for the Sabie catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

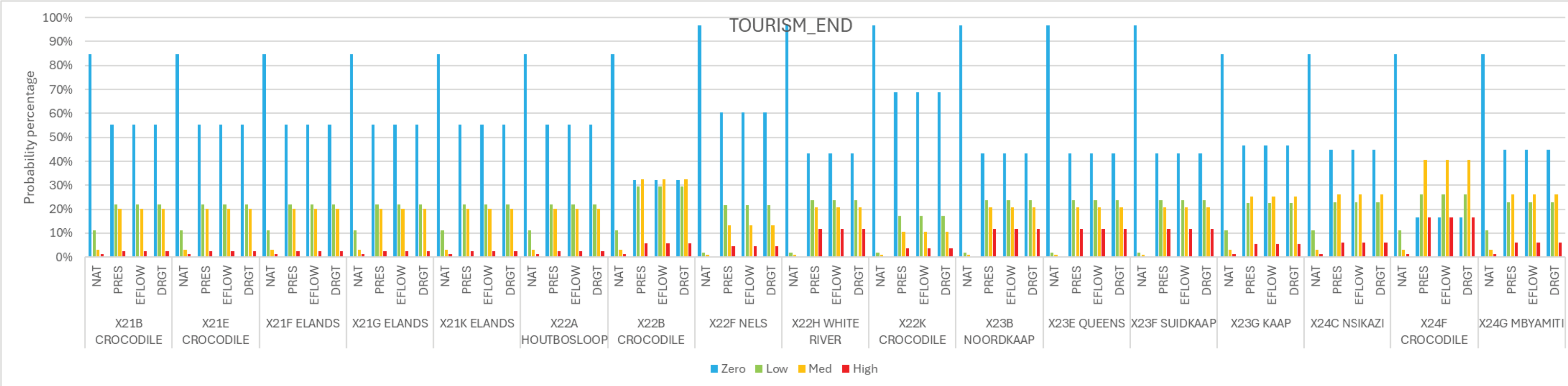


Figure 7-88: Relative risk scores to TOURISM-END for the Crocodile catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

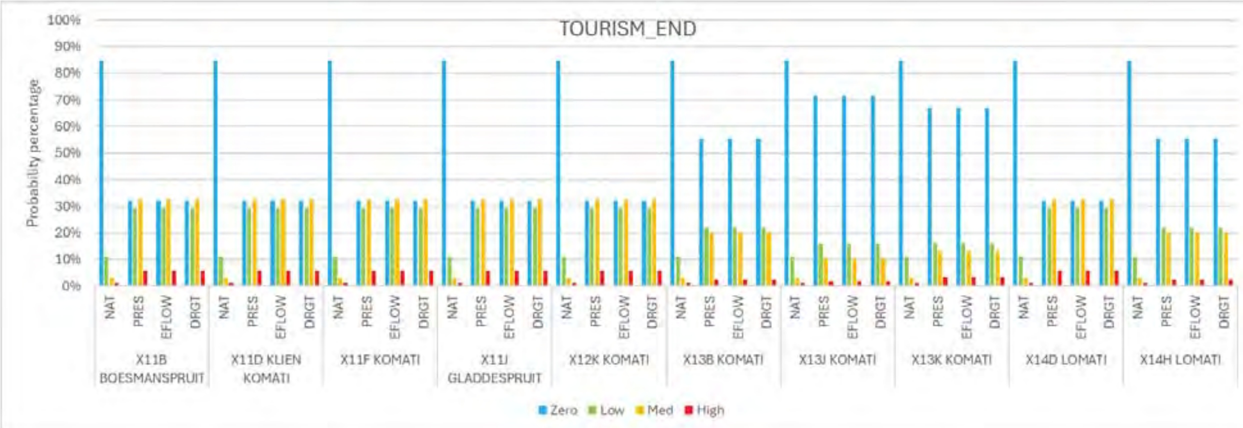


Figure 7-89: Relative risk scores to TOURISM-END for the Komati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

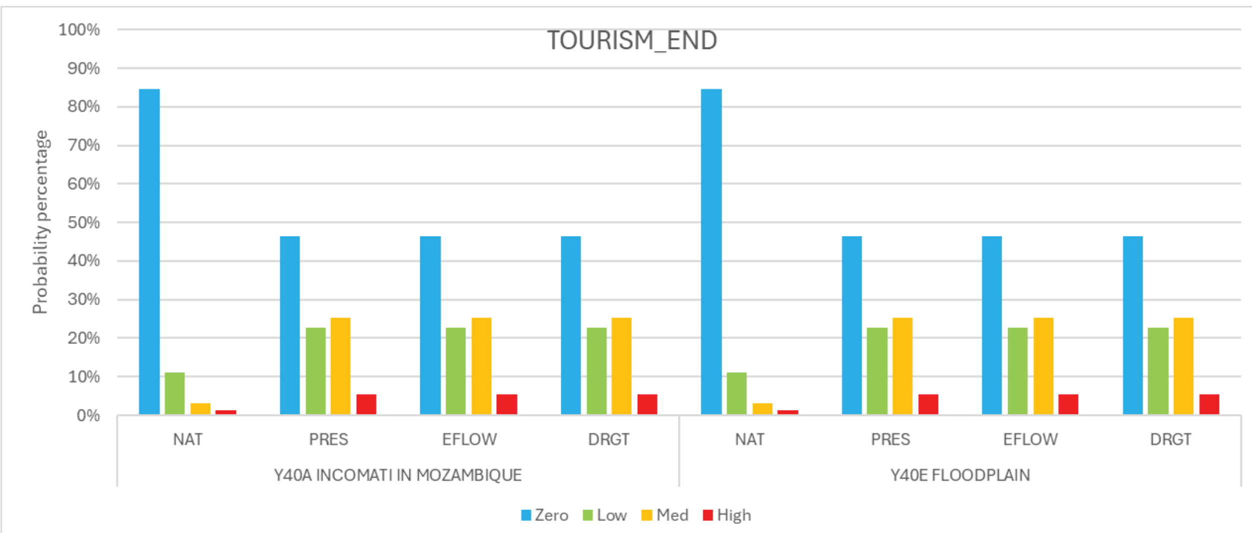


Figure 7-90: Relative risk scores to TOURISM-END for the Incomati catchment for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

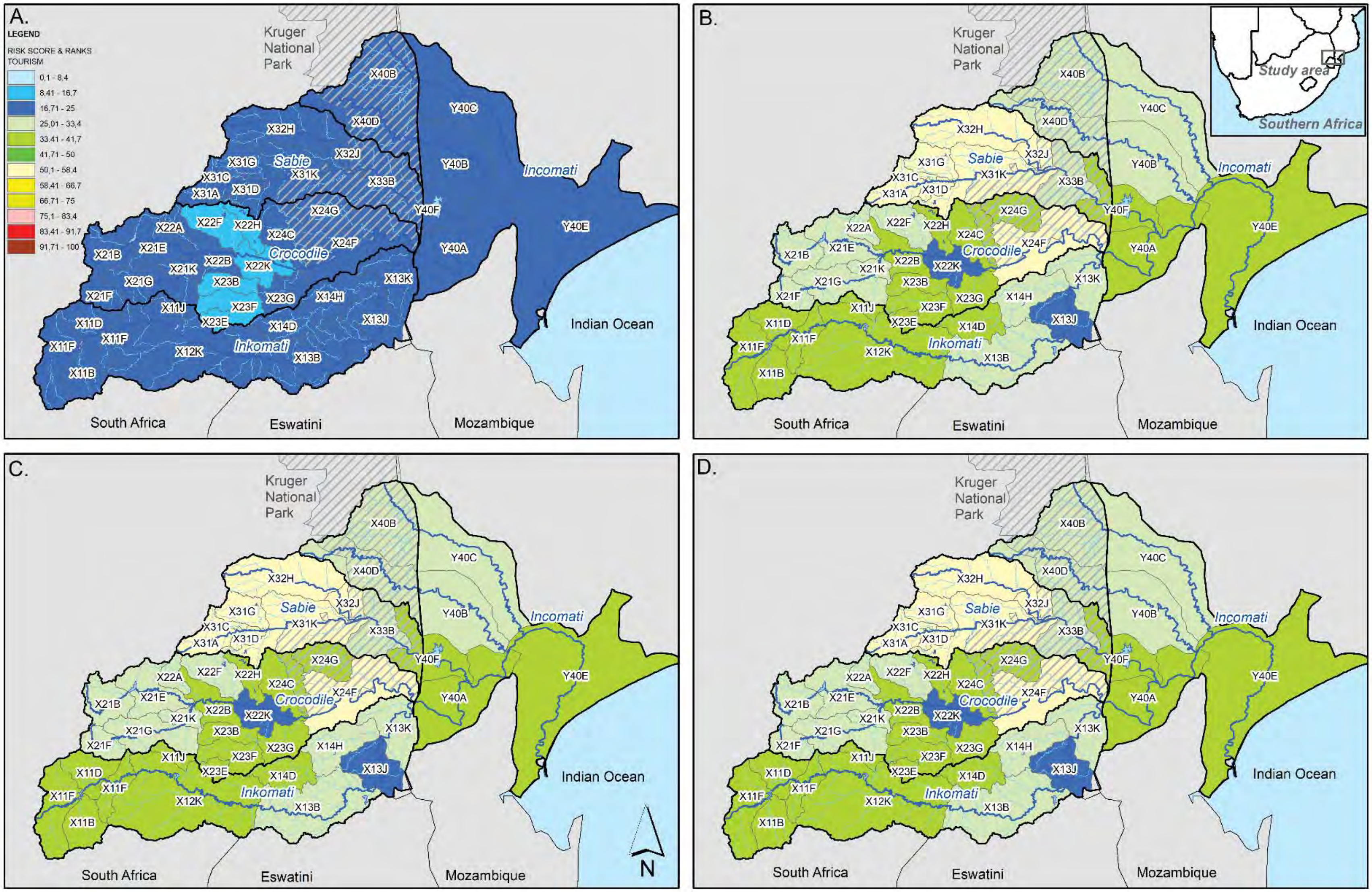


Figure 7-91: Relative risk scores to TOURISM-END per risk region for each scenario (A: Natural, B: Present, C: E-Flow, D: Drought), with possible likely risk rank ranges for zero (relative risk score of 1-25), low (relative risk score of 25-50), moderate (relative risk score of 50-75) and high (relative risk score of 75-100) displayed

8 ANNEXURE 2

8.1 Kaap River sub-basin

In this annexure additional information used to implement the risk framework in the Kaap River sub-basin is presented. This includes sites,

Risk Region 1

Risk Region 1 includes the source of the Noordkaap River and upper catchment till the Belleview Weir and local pump station which is the location of the NKAAP-ENOUS sampling site (Figure 8-1). This risk region is dominated by forestry and agricultural activities including a chicken farm and macadamia farms. The PES EIS study states that this reach of the Noordkaap River is in a largely modified category, the ecological importance is high and ecological sensitivity is very high (DWS, 2014). This is lower than the moderately modified target category set as the RQO for the Noordkaap River (DWS, 2016). The Noorkaap River at the NKAAP-ENOUS sampling site upstream of the weir is a small channel with water passing through at 1.01 m^3 and a pumphouse pump in the righthand side pumping water to the nearby farms and communities. After the weir the river is a fast-medium deep channel passing over boulders and bedrock. Marginal vegetation was mostly Phragmites reeds and some riparian woody trees. Sand and silt were present but not the dominate substrate. Water was clear and very cold.

Figure 8-1: The NKAAP-ENOUS site on the Noordkaap River drone photo.

Risk Region 2

The Noordkaap River continues into Risk Region 2 from the Belleview Weir to the confluence with the Suidkaap River. The upper reach of this risk region is characterised by farming activities while the lower reach of the catchment includes alluvial gold mining and the New Consort Mine. The Mandela Village and New Consort communities are also located within this reach of the river and many community members are reliant on the water resources for survival. Only water quality was assessed at the NKAAP-CONSR site to determine the possible impacts from the mining activities. The site did not have habitat for sampling macroinvertebrates and the very deep pool directly below weir was too deep to sample fish (Figure 8-2). Downstream of the site was completely overgrown with reeds and inaccessible during both survey assessments.

The NKAAP-CONFL site (Figure 8-3A & B) is located just before the confluence with the Suidkaap River to compare the impact that the two rivers are having on the Kaap River. The site has a wide riverbed with various dry channels but during the low flow survey only the main channel had water. During the high flow survey multiple smaller channels had water and access to the main river channel was difficult. A canal flows parallel to the river. The river is surrounded and overgrown with reeds making accessibility difficult (Figure 8-3B). This reach of the Noordkaap River is also in a largely modified category according to the PES EIS study, with high ecological importance and very high ecological sensitivity (DWS, 2014). This is also lower than the moderately modified target category set as the RQO for the Noordkaap River (DWS, 2016).

Figure 8-2: The NKAAP-CONSR site on the Noordkaap River with weir and downstream view

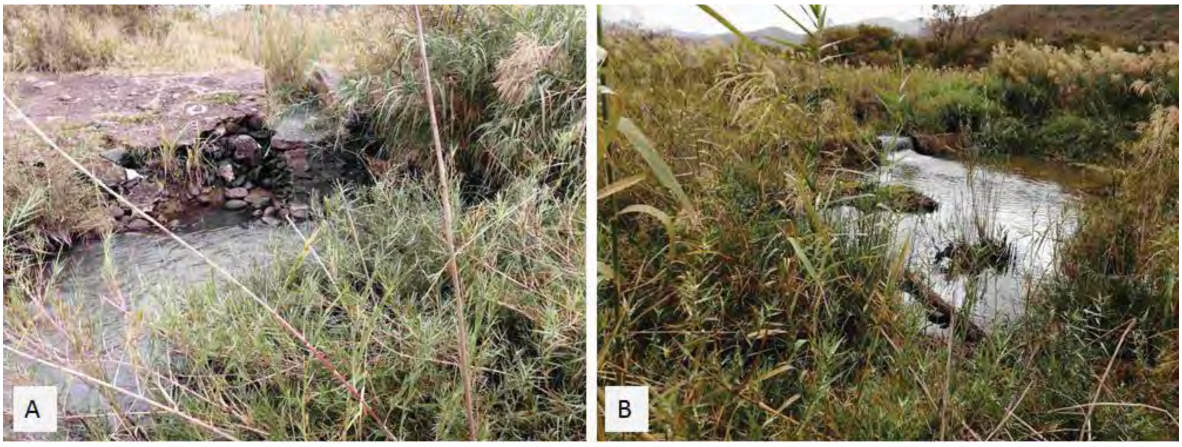


Figure 8-3: The NKAAP-CONFL site on the Noordkaap River with A) bank erosion and B) upstream view

Risk Region 3

Risk Region 3 includes the source and upper catchment of the Suidkaap River with land use dominated by forestry (*Pinus spp*). The PES EIS study places this reach of river in a largely modified category with high ecological importance and very high ecological sensitivity (DWS, 2014). This is lower than the largely targeted natural to moderately modified category (DWS, 2016). The river was sampled at the Glenthorpe weir (SKAAP-GLENT) (Figure 8-4) on the boundary with Risk Region 4. The river at this site is a small stream with lots of shade cover and riparian trees. The dominate substrate were cobbles with evidence of sedimentation from high road densities in the forestry plantations and erosion.

Figure 8-4: The SKAAP-GLENT site on the Suidkaap River.

Risk Region 4

Risk Region 4 spans from the Glenthorpe weir to the confluence with the Queens River and includes the middle catchment of the Suidkaap River. Landuse activities include the Glenthorpe sawmill complex, farming, forestry and rural development properties. The SKAAP-R40RD site (Figure 8-5) was sampled where the R40 road crosses the river. The large bridge creates high shade cover with mostly a pool area under the bridge. A broken culvert in the riverbed created an artificial habitat and the small stream downstream partially overgrown with reeds. Upstream of the bridge there is a small gauging weir diverting the stream through concrete tunnels and a pumphouse pumping water to the nearby farms and communities. This reach of river is in a largely modified state with high ecological importance and very high ecological sensitivity (DWS, 2014). This is lower than the largely natural to moderately modified category target set as the RQO for this reach of the Suidkaap River (DWS, 2016)

Figure 8-5: The SKAAP-R40RD site on the Suidkaap River with downstream view (Drone photo).

Risk Region 5

The source and upper catchment of the Queens River falls within Risk Region 5 which is characterised by forestry and nature reserves. The QUEEN-SELAP site sampled is located at a low-lying bridge in a forestry area (

Figure 8-6). The riparian vegetation is diverse and the instream habitat was diversity. No solid waste or any other signs of pollution were noted at the site during the low flow survey. Little evidence of sedimentation was present. The reach of river is considered to be in a moderately modified category with high ecological importance and very high ecological sensitivity (DWS, 2014). This is lower than the largely natural to moderately modified target category set as the RQO for the Queens River (DWS, 2016).

Figure 8-6: The QUEEN-SELAP site on the Queens Rivers with a top view.

Risk Region 6

The lower catchment of the Queens River to the confluence with the Suidkaap River forms Risk Region 6. The Selapi community is adjacent to the Queens River at the start of this lower catchment with DANROC agriculture on the opposite side of the river. Further downstream but away from the river is the Barbeton correctional services with their WWTW releasing effluent into the river. Other activities in this risk region include Angus mine dumps, more DANROC agriculture and the Thorncraft and Cythna Letty floral reserves. This reach of river of the Queens River is considered to be in a largely modified category with high ecological importance and very high ecological sensitivity (DWS, 2014). This is lower than the largely natural to moderately modified category target set as the RQO for the Queens River (DWS, 2016). The QUEEN-R40RD site (Figure 8-7) was sampled under the R40 road bridge, not far from the confluence with the Suidkaap River. This site has a fish ladder build as part of the weir to provide connectivity for the movement of fish up and downstream of this barrier. The bridge provides high shade cover with mostly a pool area under the bridge. The site is characterised by large boulders with a small stream downstream of the bridge, muddy pools and is partly overgrown with reeds.

Figure 8-7: The QUEEN-R40RD site on the Queens River with and downstream view

Risk Region 7

This lower catchment of the Suidkaap River within Risk Region 7 is considered to be under stress as it is being impacted on by effluent from the Barbeton WWTW, agricultural activities, the Dixie community and Fairview mine. The town of Barbeton and surrounding communities are also found within this risk region, with the Mountain lands and Barbeton nature reserves on the outskirts. The ecological category for this reach of the Suidkaap River is largely modified with a moderate ecological importance and high ecological sensitivity (DWS, 2014). This is lower than the moderately modified category target set as the RQO for the lower reach of the Suidkaap River (DWS, 2016). Three sites were sampled within this risk region to determine the impacts of the various possible stressors. The SKAAP-UPWWT site (Figure 8-8 A & B) is located upstream of the Barbeton WWTW effluent release point next to a water pump station. The site is characterised by a sandy substrate with some cobbles and good marginal vegetation. Overhanging vegetation provided a partially covered canopy with some phragmites reeds present on the banks. The second site (SKAAP-DNWWT) is downstream of the WWTW effluent release point and where the river is wide and shallow with a sandy instream substrate (Figure 8-9). Riparian vegetation is dominated by grassland and some trees with cattle in and around the river. Upstream, the river is narrower with more cobbles and patches of reeds. The SKAAP-BMINE site (Figure 8-10A & B) is further downstream from the SKAAP-DNWWT site to try to identify any impacts from the Fairview mine. This site has a bridge overhead with high human activity like religious activities, clothes washing, informal sand mining as well as signs of cattle activity.

Figure 8-8: The SKAAP-UPWWT site on the Suidkaap River with A) upstream view and B) cross section

Figure 8-9: The SKAAP-DNWWT site on the Suidkaap River with upstream view.

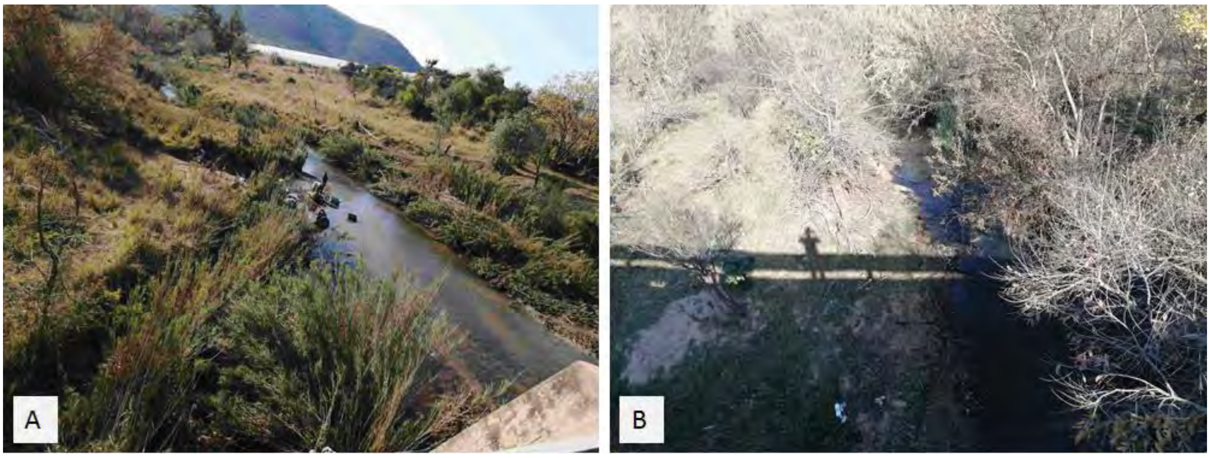


Figure 8-10: The SKAAP-BMINE site on the Suidkaap River with A) downstream view and B) view from the bridge

Risk Region 8

Risk Region 8 includes the upper catchment of the Kaap River. The Mountain lands nature reserve forms a large portion of this risk region. Other land use activities include sand mining, farming, the Sheba community and the Sheba gold mine. This reach of the Kaap River is considered to be in a largely modified category (DWS, 2014) which is lower than the target ecological category of moderately modified (DWS, 2016). The rivers ecological importance and sensitivity are both high (DWS, 2016). Two sites were sampled in this risk region. The KAAPR-JOELK site is downstream of the confluence of the Suidkaap and Queens Rivers and the KAAPR-EURIK site (Figure 8-11A & B) is downstream of Sheba community to determine possible impacts from the community and the Sheba gold mine. The KAAPR-JOELK site was completely overgrown with reeds and the only sampling area was a dirt road that traversed the riverbed (Figure 8-12). The KAAPR-EURIK site had good fast flowing habitat but the deeper areas could only be sampled from the bridge using a cast net.

Figure 8-11: The KAAPR-EURIK site on the Kaap River with A) downstream view and B) view of the bridge

Figure 8-12: The KAAPR-JOELK site from a top and downstream view.

Risk Region 9

Risk Region 9 includes the lower catchment of the Kaap River till where it flows into Crocodile River. The Crocodile Nature reserve forms a large portion of this risk region with the river flowing through a section of the reserve. A lot of agricultural activities take place in this risk region which is considered to be in a largely modified category with high ecological importance and sensitivity (DWS, 2014). This is once again lower than the target ecological category of moderately modified allocated for this river (DWS, 2016), Two sites were sampled in this risk region. The LOUWS-REVOL site (Figure 8-13 A & B) is located on Louws Creek to ascertain any impacts coming from the Louws Creek community and surrounding areas. The site had solid waste in the riverbed obstructing the flow with the banks overgrown with reeds and larger trees downstream. The second site, KAAPR-UCROC (Figure 8-14) is on the Kaap River just before the confluence with the Crocodile River to determine what impact the Kaap River may be having on the Crocodile River. The deeper areas of the site could only be sampled with a cast net due to the possibility of crocodiles. Habitat for sampling macroinvertebrates was minimal due to the depth of the water.

Figure 8-13: The LOUWS-REVOL site on the Louws River with A) view of riparian vegetation downstream and B) upstream view

Figure 8-14: The KAAPR-UCROC site on the Kaap River with an upstream view from the bridge.

8.1.1 Determination of the Present Ecological State for the Kaap sub-basin

The ecological integrity assessment will be carried out using an Ecoclassification approach described below (Kleynhans & Louw, 2007). to determine the ecological state of the rivers within the study area. The approach includes the use of a range of bio-physical assessment procedures called Drivers (physical components) and Responders (biological components). All the approaches used in the assessment are well established and routinely used in a range of river monitoring methods in South Africa including the Ecological Reserve determination procedures, the River Health Programme and the River Ecostatus Monitoring Programme. Determine the Present Ecological State (PES) of the rivers forms one component of the risk assessment.

The Ecoclassification approach makes use of a range of ecological categories (EC; A-F) to describe the state of the biophysical attribute/component being considered (Table 8-1). The biophysical attributes/ components of ecosystems that are considered in an Ecoclassification assessment include:

- System drivers, non-living or abiotic components (physico-chemical, habitat, hydrology) which provide a particular habitat template; and
- Biological responses, living or biotic components (fish, riparian vegetation and aquatic invertebrates) that provide information related to the effect (or response) of the ecosystem to the state of the driver variables.

Table 8-1: Summary of the name and description of the six ecological categories used in the Ecoclassification procedure for the Water quality, Habitat, Fish, Invertebrates and Ecostatus (Kleynhans & Louw, 2007).

Ecological Categories	Name	Description
A	Natural	Unmodified natural
B	Good	Largely natural with few modifications
C	Fair	Moderately modified
D	Poor	Largely modified
E	Seriously modified	Seriously modified
F	Critically modified	Critically or extremely modified

8.1.1.1 Driver Components for the Kaap sub-basin

Water quality

The term water quality is used to describe the physical, chemical, biological and aesthetic properties of water that determine its fitness for a variety of uses, and for the protection of the health and integrity of aquatic ecosystems. Many of these properties are controlled or influenced by components that are either dissolved or suspended in water as a result of either natural or anthropogenic input, or both (DWAF, 1996b). The water quality assessment included both those variables that could be evaluated on site (*in situ*) using a multimeter as well as single sub-surface water samples sent to NWU for analysis. Temperature, pH, oxygen concentration and saturation and electrical conductivity were recorded *in situ* during the low flow assessment as well as bi-weekly. Water samples were collected bi-weekly from three sites (NKAAP-CONSR, SKAAP-BMINE and KAAPR-UCROC) and sent for analysis to provide indications as to the state of the water quality component of the rivers in the study area. The physico-chemical variables analysed (Table 8-2) were pre-selected to provide indications of any probable contamination of the rivers in the form of system variable change (oxygen, temperature and pH), nutrient enrichment, salinization and some toxicants.

The results were assessed by taking the variable limits / ranges of the Target Water Quality Guidelines (TWQG) for domestic use and aquatic ecosystems (DWAF, 1996a and 1996b) into account (Table 8-2). The Target Water Quality Requirements (TWQR) for aquatic ecosystems, are in many instances broadly categorized within the limits that are specific to a particular system. Thus, if no continuous monitoring of a variable exists for a specific period, then these limits cannot be defined for that system. Many guidelines rely on the percentage variation from conditions measured over a specific period in time. A limitation in this study included the use of a single "snap shot" reading to represent the load of the variable of interest for the survey. The results of the IUCMA water monitoring was also included to assess water quality trends over a longer period of time. The Water Quality Guidelines for domestic use were included in the evaluation, as aquatic ecosystem guidelines often do not have parameters defined for specific variables. The reason being that their fate in the environment is negligible (aquatic organisms are unaffected) or has not been determined. Furthermore, local communities in the area rely on the river water for their water needs.

Table 8-2: Water quality variables assessed during the study.

Name	Unit	Name	Unit	Name	Unit
Trace Metals				**Major ions**	
Beryllium	Be µg/L	Molybdenum	Mo µg/L	Sodium	Na mg/L
Boron	B µg/L	Palladium	Pd µg/L	Magnesium	Mg mg/L
Aluminum	Al µg/L	Silver	Ag µg/L	Potassium	K mg/L
Titanium	Ti µg/L	Cadmium	Cd µg/L	Calcium	Ca mg/L
Vanadium	V µg/L	Tin	Sn µg/L	Chlorides	Cl mg/L
Chromium	Cr µg/L	Anthimony	Sb µg/L	Sulphates	SO4 mg/L
Manganese	Mn µg/L	Barium	Ba µg/L	**Nutrients**	
Iron	Fe µg/L	Platinum	Pt µg/L	Ammonium	NH4 mg/L
Cobalt	Co µg/L	Gold	Au µg/L	Nitrate	NO3 mg/L
Nickel	Ni µg/L	Mercury	Hg µg/L	Nitrite	NO2 mg/L
Copper	Cu µg/L	Thallium	Tl µg/L	Phosphates	PO4 mg/L
Zinc	Zn µg/L	Lead	Pb µg/L	**Other**	
Arsenic	As µg/L	Bismuth	Bi µg/L	Turbidity	
Selenium	Se µg/L	Thorium	Th µg/L	Alkalinity	
Rubidium	Rb µg/L	Uranium	U µg/L		
Strontium	Sr µg/L				
Scandium					

8.1.1.2 Response Components for the Kaap sub-basin

Macroinvertebrates

The assessment of freshwater macro-invertebrate biota was conducted using South African Scoring System (SASS) version 5, the bioassessment protocol designed for the rapid water quality assessments (Dickens and Graham, 2002). This bioassessment protocol is based on the presence of aquatic invertebrate families that have different sensitivity ratings to stress (Arimoro *et al.*, 2007). Different families show different sensitivities to pollution and these sensitivities range from highly tolerant families (e.g. Muscidae and Psychodidae) to highly sensitive families (e.g. Oligoneuridae). Thus, this method enables aquatic macro-invertebrate communities to reveal the impact of perturbation and habitat modifications. This report contains the results of the SASS 5 assessment that is expressed using a SASS5 score, Number of taxa and the Average Score Per Taxon (ASPT value). The ecological class for each site will be determined by the biological bands for North Eastern Highlands (upper and lower) and Lowveld (lower) developed by Dallas (2007; Figure 8-15).

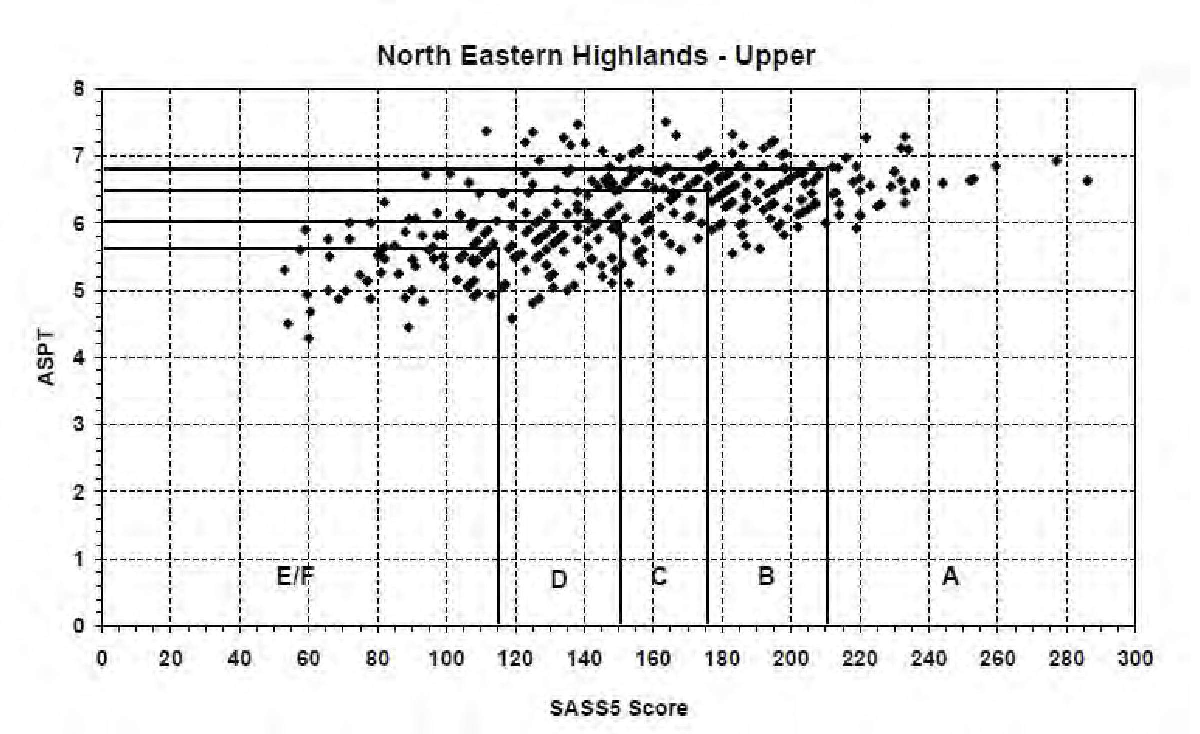


Figure 8-15: Example of the biological band for North Eastern Highlands – Upper (Dallas, 2007)

Fish

Fish have been sampled comprehensively at each site using a range of methods associated with the habitat availability at each site. This included netting techniques and the use of electronarcosis (Meador *et al.*, 1993; Barbour *et al.*, 1999) or commonly termed electroshocking methods, where applicable. The electroshocking technique was implemented at all freshwater sites in habitats that are less than 1 m deep and where the conductivity allowed for the technique to be used. All riffle and rapid areas were effectively sampled using this technique, as was all shallow marginal vegetated areas and obstructions in the river sites. Netting methods included the use of small seine (or drag) nets, and fyke net traps that are deployed, left over night and retrieved. All fish collected are identified in the field and returned unharmed into the rivers.

Freshwater fish community metric assessment

The fish community wellbeing has been evaluated by implementing the Fish Response Assessment Index (FRAI) which was developed by Kleynhans (2007). This index is carried out on a reach scale throughout the study area. The index scores will then be formulated into a relative FRAI index value, which is grouped into one of six descriptive fish assemblage integrity index classes. The classes are comparable with the six Reserve determination classes (Kleynhans and Louw, 2007).

8.1.2 Outcomes of the assessment for the Kaap sub-basin

8.1.2.1 Driver Components for the Kaap sub-basin

Water Quality

In situ water quality

The *in situ* results taken during the high flow survey in October 2021 (Table 8-3) indicate that the conductivity was always higher at sites located further downstream (Kaap and Louwscreek Rivers) with the highest value recorded at the LOUWS-REVOL site. The high conductivity recorded within Louw Creek could also be contributing to the higher value recorded at the KAAPR-UCROC site. The relatively higher conductivity recorded at the NKAAP-CONSR and NKAAP-CONFL sites could be related to the mining activity in the area and the higher value at the SKAAP-DNWWT site is probably due to the effluent discharge from the Barbeton WWTW. Temperature values for all sites are reflective of the beginning of the summer season and the pH values for all sites are within the TWQR for aquatic ecosystems (DWAF, 1996). The dissolved oxygen concentrations for the SKAAP-GLENT, SKAAP-UPWWT and KAAPR-UCROC site were within the TWQR for aquatic ecosystems (DWAF, 1996) but future monitoring will determine if the trend continues as lower values were observed during the low flow survey.

Table 8-3: *In situ water quality results for all sites assessed during the high flow survey, October 2021.*

			Cond (µS/cm)	Temp (°C)	pH	DO (%)	DO (mg/l)
RR1	**NOORDKAAP RIVER**	**NKAAP-ENOUS**	127,20	16,90	7,32	113,90	9,94
RR2		**NKAAP-CONSR**	364,10	24,20	7,61	104,50	7,70
		NKAAP-CONFL	451,30	24,10	8,06	98,90	8,01
RR3	**SUIDKAAP RIVER**	**SKAAP-GLENT**	89,07	18,90	7,65	117,00	10,88
RR4		**SKAAP-R40RD**	161,70	18,70	7,53	107,10	9,47
RR5	**QUEENS RIVER**	**QUEEN-SELAP**	158,40	22,00	8,06	113,50	9,89
RR6		**QUEEN-R40RD**	405,00	20,50	8,00	107,00	9,22
RR7	**SUIDKAAP RIVER**	**SKAAP-UPWWT**	398,20	22,90	7,78	104,40	8,77
		SKAAP-DNWWT	526,70	25,00	8,02	141,60	10,66
RR8	**KAAP RIVER**	**KAAPR-JOELK**	586,90	23,30	7,85	98,70	8,64
		KAAP-EURIK	468,10	23,90	7,94	103,80	8,49
RR9		**KAAPR-UCROC**	775,80	24,30	8,02	117,20	8,62
	LOUWS	**LOUWS-REVOL**	997,60	22,90	8,26	102,90	9,26

Historical *in situ* measurements for the NKAAP-CONSR, SKAAP-BMINE and KAAPR-UCROC sites were monitored from March to July 2021 (Figure 8-16 A-D). The results for these variables were all generally higher for the KAAPR-UCROC site when compared to the other two sites, except for the dissolved oxygen concentrations (Figure 8-16B) that was often lower. The dissolved oxygen concentrations for the KAAPR-UCROC were below the TWQR for the month of April 2021 but stabilised above the TWQR thereafter (Table 8-3). The temperature results (Figure 8-16D) for all the sites show normal seasonal variation and the pH values (Figure 8-16A) are all within the TWQR for aquatic ecosystems (DWAF, 1996b). All three sites showed an increasing trend in electrical conductivity (Figure 8-16C) from March to July 2021. The electrical conductivity was noticeable higher for the KAAPR-UCROC site when compared to the other two sites.

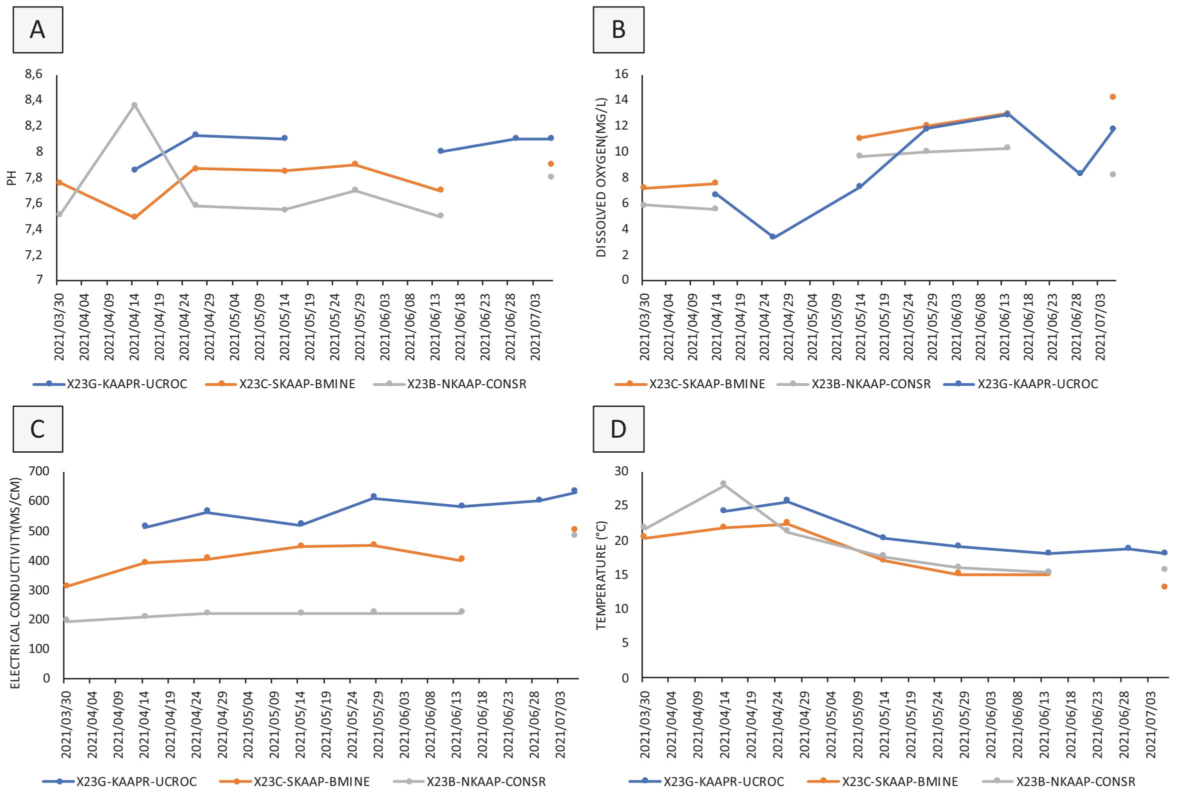


Figure 8-16: In situ water quality results for sites monitored bi-weekly from March to July 2021 with A) pH, B) Dissolved Oxygen (mg/L), C) Electrical conductivity (mS/cm), D) Temperature.

Water analysis

The results of the water analysis undertaken to date for major nutrients is provided in Figure 8-20. Nitrogen and phosphorus are the major nutrients that can contribute towards the excessive growth of plants due to the eutrophication of aquatic ecosystems (Dallas and Day, 2004). Sources of nutrients can be point or diffused sources and result from activities like discharge of sewerage and industrial effluent, and agricultural and urban surface runoff (Dallas and Day, 2004). The RQOs set for Total Inorganic Nitrogen (TIN) is < 4.0 mg/l and for phosphates < 0.125 mg/l. Most of the sites had at least transgressed the accepted phosphate levels once during the timeframe of March 2021 to February 2022 (Figure 8-17D). Many spikes in the concentrations of the nutrients are recorded for the NKAAP-CONSR, SKAAP-BMINE and KAAP-UCROC sites (Figure 8-20A-D). The IUCMA results from 2016 to 2022 (Figure 8-18 to Figure 8-20) indicate that the site associated with the New Consort mine WWTW often has high nitrate, nitrite and phosphate concentrations and towards the end of 2021 and start of 2022, spikes in ammonia concentrations too. The phosphate concentrations at this site often exceeded the RQO of < 0.125 mg/l. The site associated with the Barberton WWTW did not recorded such high concentrations of nitrates and nitrites but excessive concentrations of phosphates (Figure 8-19) and ammonia (Figure 8-20) were record that greatly exceeding the RQOs for TIN and phosphates. High concentrations of nutrients in aquatic systems can have a significant impact on the structure and functioning of biotic communities (Dallas and Day, 2004). Hypertrophic conditions have almost continuous water quality problems that include frequent nuisance growths of aquatic plants and algae blooms, some of which can be toxic to wildlife, livestock and humans (Dallas and Day, 2004).

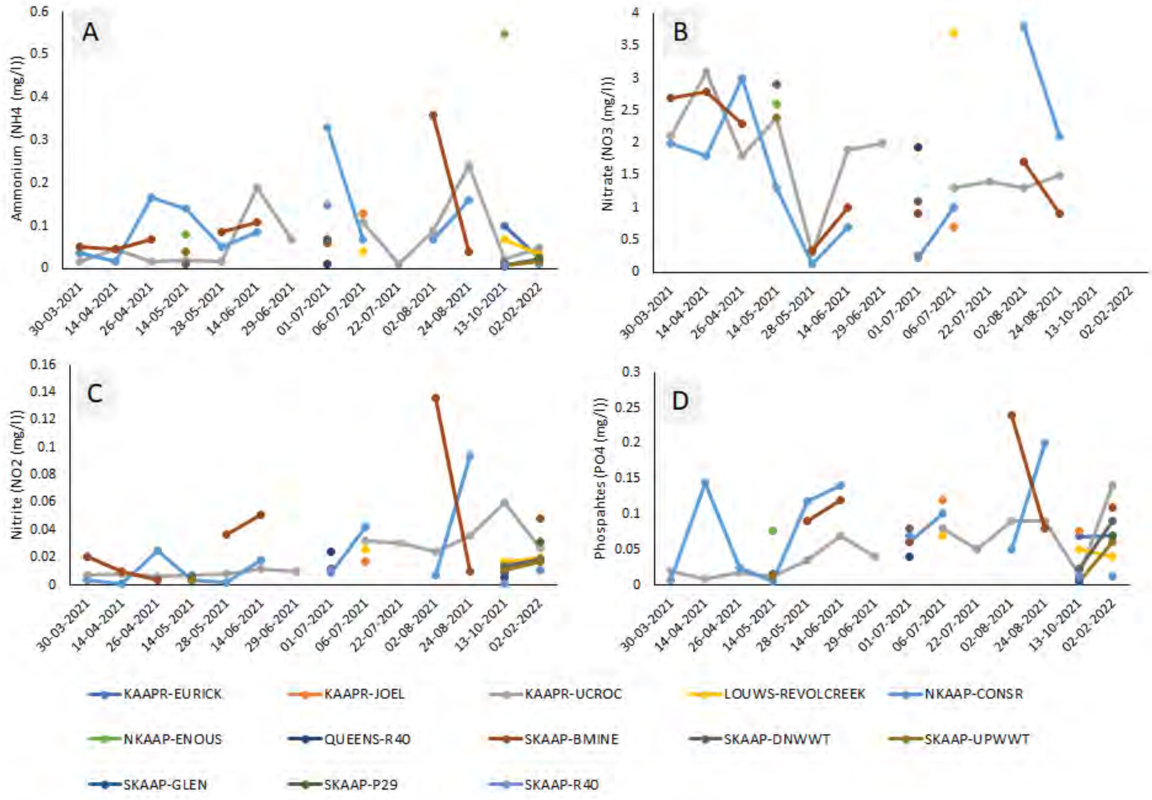


Figure 8-17: Trends in nutrients A) ammonium, B) nitrate, C) nitrite, D) phosphate from March 2021 to February 2022.

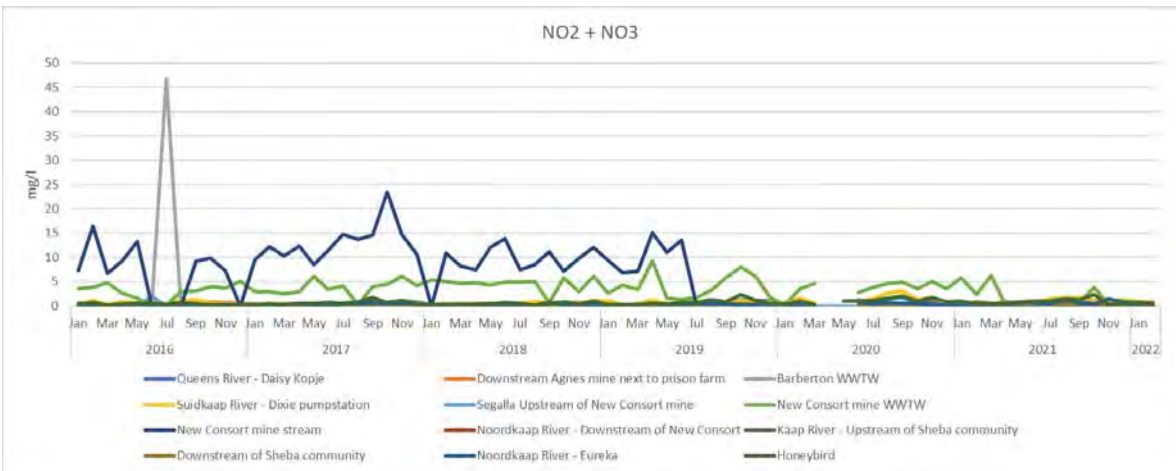


Figure 8-18: Trends in IUCMA data for total nitrates and nitrites from 2016 to 2022

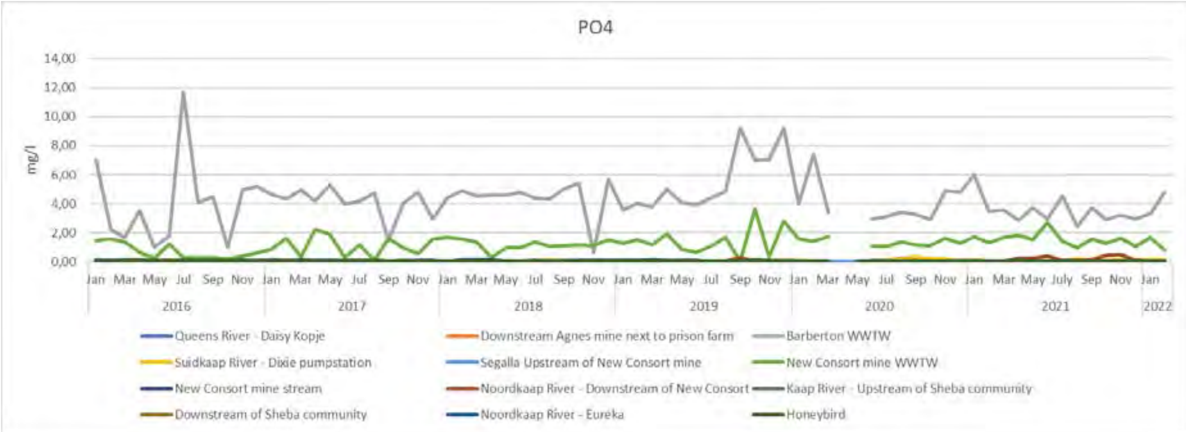


Figure 8-19: Trends in IUCMA data for phosphates from 2016 to 2022

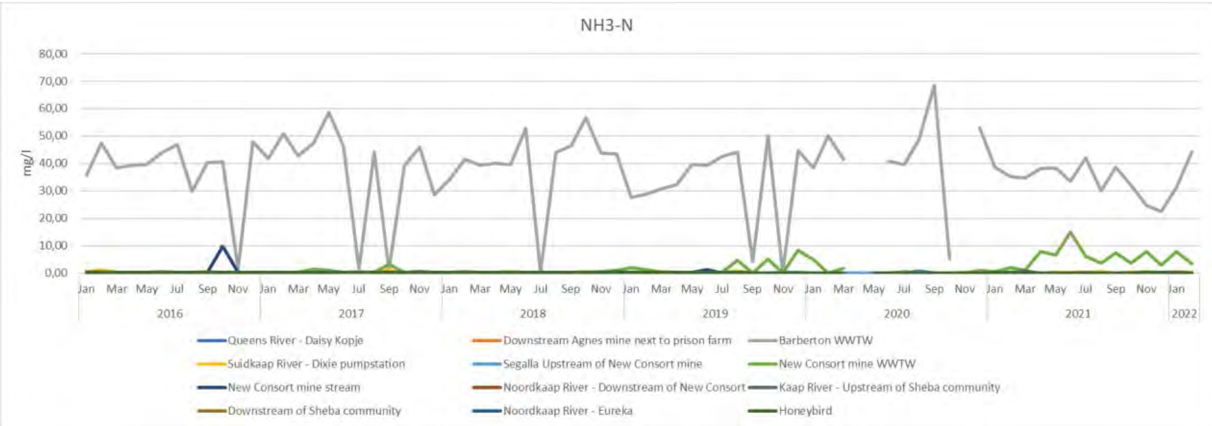


Figure 8-20: Trends in IUCMA data for ammonia from 2016 to 2022

The results for the chloride concentrations (Figure 8-21A) indicate numerous elevated concentrations especially during July and August 2021 at the KAAPR-UCROC site. High chloride concentrations were also recorded at the site on Louws Creek. Elevated concentrations of sulphates (Figure 8-21B) were recorded for many of the sites towards the latter part of 2021 when compared to the beginning of the year, especially at the NKAAP-CONSR, SKAAP-BMINE, SKAAP-DNWWT and KAAPR-JOEL sites. The IUCMA sulphate results (Figure 8-22) indicate that the sites downstream of the Agnes Mine and in the New Consort mine stream consistently recorded elevated sulphate concentrations and the site at the Dixie pumpstation often recorded spikes in sulphate concentrations. Excessive sulphate concentrations can reduce the pH of the aquatic system and have devastating effects on the ecosystem (Dallas and Day, 2004).

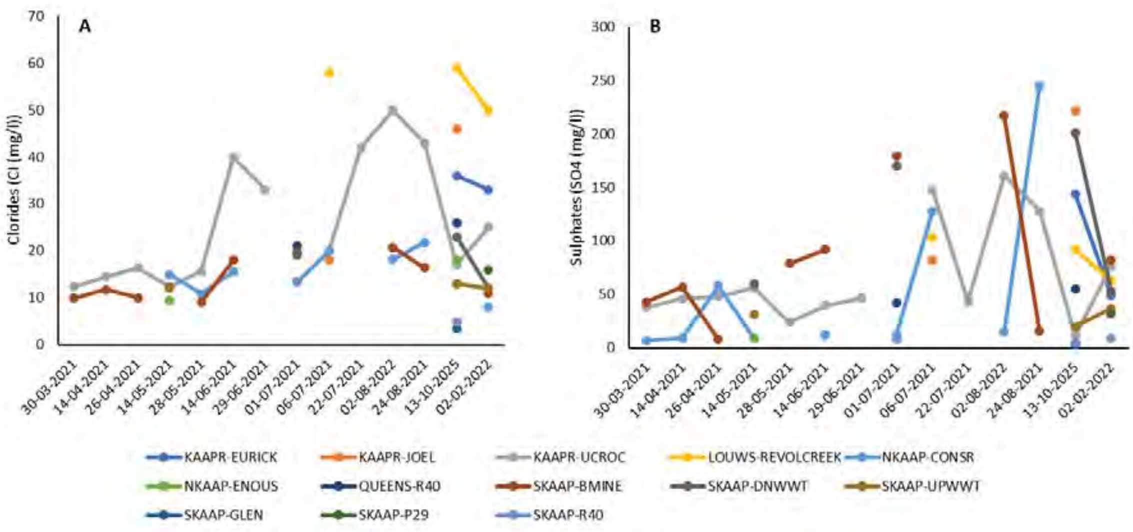


Figure 8-21: Trends in A) chlorides and B) sulphates from March 2021 to February 2022.

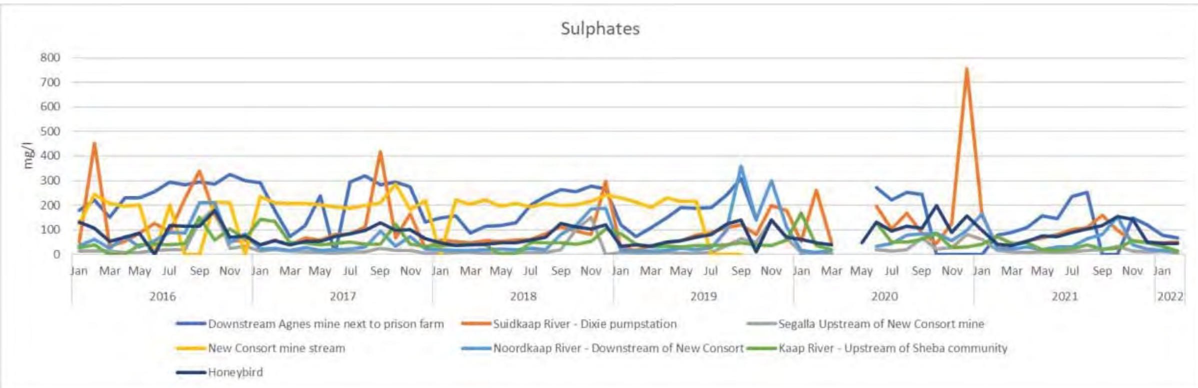


Figure 8-22: Trends in IUCMA data for sulphates from 2016 to 2022

The alkalinity and turbidity results (Figure 8-23A & B) indicate that both these variables were variable across all sites with alkalinity showing higher spike levels from June 2021 across all sites but especially or the KAAP-UCROC site. The turbidity results showed less variability between the sites (Figure 8-23A). Increased turbidity decreases the clarity of water and together with changes in water colour impede light penetration that effect aquatic biotas (Dallas and Day, 2004). The turbidity results also exceeded the TWQR for domestic use as results above 5 NTU and especially those above 10 NTU have aesthetic effects and the water carries a risk of transmission of disease because infectious disease agents and chemicals can be adsorbed onto particulate matter (DWAF, 1996a). Turbidity is an indication of the quantity of suspended solids in the water. The IUCMA results for total suspended solids (Figure 8-24) indicate that the site associated with the Barberton WWTW site has a high concentration of suspended solids. Infrequent increases in turbidity and suspended solids have minimal effect on the aquatic system but continuous high-level inputs can seriously affect riverine biota as it can impact the food chain and change community compositions (Dallas and Day, 2004).

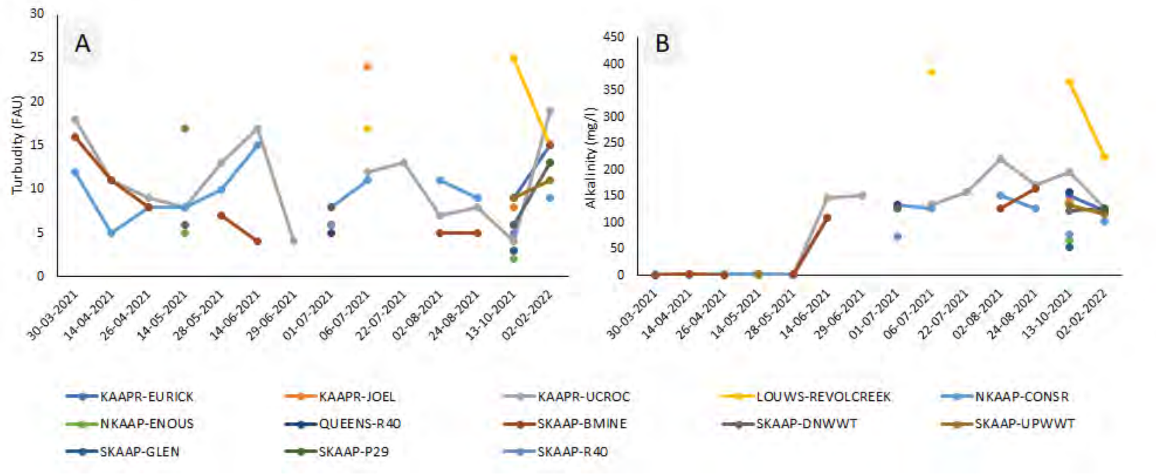


Figure 8-23: Trends in A) turbidity and B) alkalinity from March 2021 to February 2022

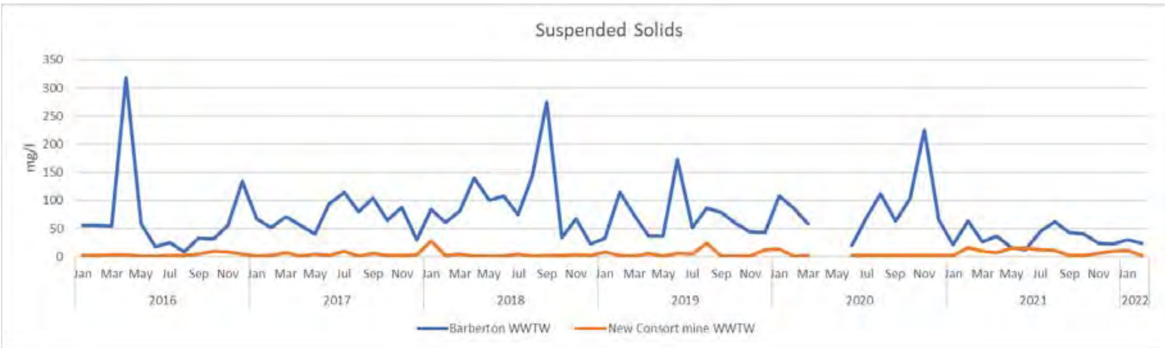


Figure 8-24: Trends in IUCMA data for total suspended solids from 2016 to 2022

Chemical oxygen demand (COD) is "*the amount of oxygen consumed by the abiotic fraction of a water sample*" (Dallas and Day, 2004) and the IUCMA results indicate that the COD results for the site associated with the Barberton WWTW is often very high but a general reduction in COD can be seen in 2021 and early 2022 (Figure 8-25). High COD can result in reduced dissolved oxygen concentrations that will negatively affect the riverine biota.

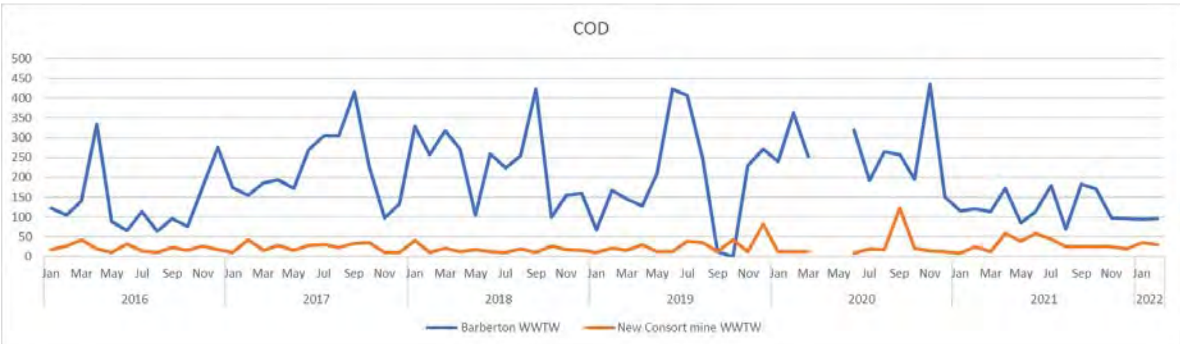


Figure 8-25: Trends in IUCMA data for COD from 2016 to 2022

8.1.2.2 Response Components for the Kaap sub-basin

Macroinvertebrate

The macroinvertebrates of the Kaap River catchment include a total possibility of 68 taxa based on the information provided by the Present Ecological State, Ecological Importance (PES EIS) database of the DWS (DWS, 2014). This information is based on historical monitoring data taken from the sites sampled in five sub-quaternary reaches. The highest number of taxa are expected in the Queens River and lowest number in the lower reach of the Suidkaap River. All the sites are expected to be dominated by taxa that are highly to moderately tolerant to pollution (sensitivity scores 1-10; Gerber and Gabriel, 2002).

The high flow survey (October 2021) results (Table 8-4) indicate that a total of 56 taxa were observed over all the sites. The highest number of taxa were observed at the KAAP-UCROC site and the lowest at the KAAP-JOELK site. The upstream site on the Noordkaap River (NKAAP-ENOUS) obtained a SASS score of 129 but an ASPT of 4.61 placing it in a Largely Modified, D category whereas the downstream site (NKAAP-CONFLU) had a SASS score of 124, ASPT of 6.19 and was in a Moderately Modified, C category. For the sites on the SuidKaap River, the site above the WWTW (SKAAP-UPWWT) had the highest SASS and ASPT scores (179 and 6.63 respectively) resulting in a Largely Natural, B category. The SKAAP-R40RD site had the lowest SASS and ASPT scores of 130 and 4.81 respectively, resulting in a Largely Modified D category. A similar number of taxa were observed at the two sites on the Queens River, but although the SASS and ASPT scores were higher for the upstream QUEEN-SELAP site, both sites were classified as Moderately Modified (C category). The KAAP-EURIK and KAAP-UCROC sites on the Kaap River had the highest SASS scores of all the sites (199 and 206 respectively) with ASPT scores of 7.11 and 6.65 respectively, resulting in the sites been classified as Natural (A category). Louws Creek that flows into the lower reaches of the Kaap River, had the lowest SASS score of all the sites (n = 109) and an ASPT of 5.19, resulting in a E/F or Seriously to Critically Modified category. As expected, the sites with the highest recorded SASS scores (QUEEN-SELAP, SKAAP-UPWWT, SKAAP-DNWWT, KAAP-EURIK and KAAP-UCROC) were also the sites that had a good representation of different biotopes (Table 8-5). The lower ASPT scores at the NKAAP-ENOUS and SKAAP-R40RD site could be an indication of poorer water quality. According to the overall ecological category for each site, the sites in the upper reaches of the catchments were more impaired than those in the lower reaches.

Historical SASS data for sites are provided in Table 8-6 and indicate that the Noordkaap (X2NOOR-SEGAL) and upper reach of the Kaap River (X2KAAP-JOESL) were mainly in a moderately modified category (C category) whereas the lower reach of the Kaap River (X2KAAP-DOLTO) was mostly in a largely modified category (D category). The Queens (X2QUEE-FRANT) and Suidkaap River (X2SUID-CLARE, X2SUID-DIXIE and X2SUID-IMPOP) were in a natural to largely natural category (A-B category).

Table 8-4: Macroinvertebrate species collected during the 2021 October high flow survey

Taxa	Sensitivity	NKAAP-ENOUS	NKAAP-CONFL	SKAAP-GLENT	SKAAP-R40RD	QUEEN-SELAP	QUEEN-R40RD	SKAAP-UPWWT	SKAAP-DNWWT	KAAPR-JOELK	KAAP-EURIK	KAAPR-UCROC	LOUWS-REVOL
PORIFERA	5	A	A								A	B	
TURBELLARIA	3	A		1				A					
ANNELIDA													
Oligochaeta	1	1	A		B	1	B				A	A	
Leeches	3	1	1	A	A	1		1					
CRUSTACEA													
Potamonautidae*	3	1		A	A	B	1	1					1
Atyidae	8		B		B	B	B	B	B	B	B	B	
HYDRACARINA	8	B	1	1	1						1	B	
PLECOPTERA													
Perlidae	12			A		1		B	A	1	A	B	
EPHEMEROPTERA													
Baetidae 2 sp	6	B				B	A		A			B	A
Baetidae > 2 sp	12		A	A	A			B		A	A		
Caenidae	6	1	A	1		B	1	B		A	A	A	A
Heptageniidae	13		A	A		B	1		A	A	A	A	
Leptophlebiidae	9			1		1			A		A	A	
Tricorythidae	9			1		A	1		1	1	1	A	
ODONATA													
Chlorocyphidae	10		A	A		A	1	1	1		1	B	A
Coenagrionidae	4	B	B		A	A	A		B		1	B	A
Lestidae	8											A	A
Corduliidae	8	1							1		A		1
Gomphidae	6	B	A	B	A	B	A	A	A	A	B	1	B
Libellulidae	4	B		1		1	A	B	1		A	A	A
LEPIDOPTERA													
Crambidae	12						A						
HEMIPTERA													

Taxa	Sensitivity	NKAAP-ENOUS	NKAAP-CONFL	SKAAP-GLENT	SKAAP-R40RD	QUEEN-SELAP	QUEEN-R40RD	SKAAP-UPWWT	SKAAP-DNWWT	KAAPR-JOELK	KAAP-EURIK	KAAPR-UCROC	LOUWS-REVOL
Belostomatidae*	3	1	A	1	1		A	A	A				
Gerridae*	5				B		B	A					B
Naucoridae*	7	1			A		A		B	A			
Nepidae*	3				A		1						
Notonectidae	3	A			A								B
Pleidae*	4	1		1	A								1
Veliidae/M.veliidae*	5		B		B		A	A	B	A	A	A	B
TRICHOPTERA													
Hydropsychidae 1 sp	4			1	A		1		A				A
Hydropsychidae 2 sp	6	A				A		A		A			
Hydropsychidae > 2 sp	12		A								B	A	
Ecnomidae	8							1				A	
Philopotamidae	10					1			A				
Cased caddis:													
Hydroptilidae	6				1		1					A	
Leptoceridae	6	1	B	B	B	A	A		B	B	1	A	1
Lepidostomatidae	10							B					
COLEOPTERA													
Dytiscidae*	5	A			1	A	A	A					
Elmidae/Dryopidae*	8					A	1	A		A	B	A	
Gyrinidae*	5	B	B	B	B	B	B	B	B	B	B	B	B
Haliplidae	5					1							
Hydrophilidae*	5				1				1				
Hydraenidae	8							A	1		1		
Sciritidae	12			A				A					
Psephenidae	10					1		B			A	1	
DIPTERA													
Athericidae	10	1						1		1	A	A	1
Chironomidae	2	B	B	B	A	B	B	B	B	B	B	B	A

Taxa	Sensitivity	NKAAP-ENOUS	NKAAP-CONFL	SKAAP-GLENT	SKAAP-R40RD	QUEEN-SELAP	QUEEN-R40RD	SKAAP-UPWWT	SKAAP-DNWWT	KAAPR-JOELK	KAAP-EURIK	KAAPR-UCROC	LOUWS-REVOL
Ceratopogonidae	5	B			A	A			1				
Culicidae	1	1											
Muscidae	1	A		1			A		A			A	1
Psychodidae	1			1									
Simuliidae	5	A	B	B	A	1	B	A	B	B	B	B	
Tabanidae	5		A			A	1	A			A	1	
Tipulidae	5			1									
						GASTROPODA							
Ancylidae	6	1	B		A	1	A					A	B
Lymaeidae	3				B								
Planorbinae*	3			1	1					1			
Physidae	3	1							1				
Thiaridae*	3								A	A	A	B	B
						PELECYPODA							
Corbiculidae	5		B					B		A	B	B	
SASS Score		129	124	149	130	172	158	179	161	131	199	206	109
Number of Taxa		28	20	25	27	27	28	27	26	19	28	31	21
ASPT Score		4,61	6,19	5,96	4,81	6,37	5,64	6,63	6,19	6,89	7,11	6,65	5,19
Ecological Class		D	C	C/D	D	C	C	B	C	B	A	A	E/F

Highly tolerant to pollution

Moderately tolerant to pollution

Very low tolerance to pollution

Table 8-5: Biotope ratings for all sites sampled during the 2021 October high flow survey

Biotopes	NKAAP-ENOUS	NKAAP-CONFL	SKAAP-GLENT	SKAAP-R40RD	QUEEN-SELAP	QUEEN-R40RD	SKAAP-UPWWT	SKAAP-DNWWT	KAAPR-JOELK	KAAP-EURIK	KAAPR-UCROC	LOUWS-REVOL
Stone in current	2	1	2	2	5	4	5	5	3	4	5	3
Stones out current	2	1	0	3	3	1	3	0	0	2	2	2
Bedrock	4	0	0	1	1	0	0	0	0	0	0	0
Aquatic vegetation	1	1	2	3	0	0	0	3	0	0	0	0
Marginal vegetation in current	3	2	5	4	4	2	4	4	2	2	2	1
Marginal vegetation out current	3	2	0	2	2	2	2	3	0	2	0	0
Gravel	1	0	2	0	4	0	3	1	3	2	1	2
Sand	1	4	3	4	3	4	4	3	3	4	1	1
Mud	3	5	1	4	1	3	3	2	1	4	0	3

Table 8-6: Historical SASS data from the River Health Program database for sites sampled in the Kaap River catchment between 1993-2010

RHP Site Code	X2NOOR-SE6AL	X2QUEE-FRANT					X2SUID-CLARE	X2SUID-DIXIE	X2SUID-IMPOP		X2KAAP-JOESL						X2KAAP-DOLTO					
Sampling Date	2011/03/08	1998/10/20	1999/11/10	2001/11/05	2008/02/06	2013/08/22	2010/05/17	2010/03/17	2008/02/06	2013/08/22	1993/07/14	1993/08/25	1993/10/06	1994/06/15	1994/09/14	1995/06/06	1993/07/14	1993/08/25	1993/10/06	1994/06/15	1994/09/14	1995/06/06
PORIFERA																	A	A		A		A
TURBELLARIA		A	A	A	A	A			A	A	A		B		A			A			B	A
OLIGOCHAETA	1					1	B	A	1	A		B	B	A	B	A	A	A	A		A	A
HIRUDINEA					1									B	B	A						
POTAMONAUTIDAE		A	1			A	1	1	1			A				A	A		A	A	A	A
ATYIDAE																		A		A	A	
HYDRACARINA		A	A		A	A	A	1	1										A			
PERLIDAE		B	B		A	A	B	A	1	A												
BAETIDAE 1 SP											C	C	C				C	C	C		C	
BAETIDAE 2 SP									B					B						B		
BAETIDAE > 2 SP	B		B	B	C	B	B	C		C					B	C						B
CAENIDAE		B		A	B	A	A	A	B	B			A			A					A	A
HEPTAGENIIDAE	1	A	A	A	A	B	C	B	A	1						A	A					
LEPTOPHLEBIIDAE	A	B	A	A		A			A				B									A
OLIGONEURIDAE	A						1	A	B													
TRICORYTHIDAE		A	B	B	B	C	A	A	A	B												
CHLOROCYPHIDAE		A	A	A	A	1		1	A				A	B	A	A	B	A	B	B	A	B
COENAGRIONIDAE	1	A		A	A	A			A		B	B	B	B	B	A						
ZYGOPTERA JUVENILES																A						A
AESHNIDAE		A	A	1							B	A		A	A	A				A		
CORDULIIDAE		A			A		1				A	A	A					A		A		
GOMPHIDAE		B	A	B	A	B	A	A	A	B	A	A	A	A	A		B	B	B		A	A
LIBELLULIDAE	B	B	A	1		A		A	1		A	A	A	A	A		A	A		A		A
CRAMBIDAE (PYRALIDAE)								1		1					A							
BELOSTOMATIDAE				1	A		1	A			A		A			A						
CORIXIDAE		A	B	1		A	A			B	A				A		A		A		A	
GERRIDAE		A	A	A	A				B		A		A				A	A		B		
HYDROMETRIDAE								1														
NAUCORIDAE		C	A	B	B	A		1	A		A			A					A		A	
NEPIDAE	A	A	1								A	A	A	A	A							
NOTONECTIDAE	1	A	A	A						A	A		B	A			B	B	A	A		
PLEIDAE		A			1			1														
VELIIDAE/MESOVELIIDAE		A	A	A	B	1		A	B		A	A			A	A	A	A	A		A	A
HYDROPSYCHIDAE 1 SP			B	B		C	A	A	B		B	B	B				B	A	B	B	A	
HYDROPSYCHIDAE 2 SP		B			B					B				B	B	B						B
PHILOPOTAMIDAE						A																
CALAMOCERATIDAE					A																	
HYDROPTILIDAE				A	A											A						
LEPIDOSTOMATIDAE					1				A	A												
LEPTOCERIDAE	A		B	B	A	A	B	B	A	B												
DYTISCIDAE	B	A	A	A		A				A	A										B	
ELMIDAE/DRYOPIDAE		A	A	A	B	B	A	B	B	1				A						B		A
GYRINIDAE			A	A	B	B	A	A		A	A	A		A	A		A	A	A	B	A	
HELODIDAE						A		1														
HYDRAENIDAE							A	B														
HYDROPHILIDAE		B	1																			
PSEPHENIDAE		B	A	A		A		A			A	A	A	A	A	B	A	A	A	B	A	B
ATHERICIDAE		A	1			A	A			A												
CERATOPOGONIDAE		B	A	A	A		A			A												A
CHIRONOMIDAE	A	B	A	B	B	B	C	C	A	B	B	C	B	B	B	A	B	B	A	A	B	B
CULICIDAE															A			A	A	A	A	
MUSCIDAE							A						A	A	A							
SIMULIIDAE	A	A	A		B	B	A	B		B	B	B	A	B	B	B	B	A	A	B	B	B
TABANIDAE		B	A	1	A		1				A	B	A	A	A	A	B	A	A	B	A	A
TIPULIDAE		A	1	1	A	A		A		A												
ANCYLIDAE		B	B	B	A	A									B	B	B	B	B		B	B
BULININAE	B																					
LYMNAEIDAE	B													A	A						A	
PHYSIDAE													A	A				A				A
PLANORBINAE	B	A	1	B							A	A	A			A						
THIARIDAE							1	1														
SPHAERIIDAE			A	B													B	B	A	B	A	
MELANIIDAE												A		B	A		A	A		B	B	A
TRICHOPTERA (CASE CADDIS 1 TYPE)											A	A	A		A							
TRICHOPTERA (CASE CADDIS 2 TYPES)		B																				
SASS Score	91	229	210	183	198	203	161	204	156	147	115	91	116	106	134	114	102	111	91	106	110	129
No of Families	16	35	34	31	30	30	25	29	23	22	23	19	23	22	25	20	21	23	19	20	23	22
ASPT	5.7	6.5	6.2	5.9	6.6	6.8	6.4	7	6.8	6.7	5	4.8	5	4.8	5.4	5.7	4.9	4.8	4.8	5.3	4.8	5.9
Category	C	A	A/B	B	B	A/B	B	A	B	B	C	D	C	C/D	C	C	D	D	D/E	D	D	C

Fish

The fishes of the Kaap River include a total possibility of 44 indigenous species that can occur in the catchment (Table 8-7). The historical knowledge of information on fish communities dates back to collections in 1965 that have been sent to the Albany and JLB Smith Institute of Ichthyology in the Eastern Cape (Scott *et al.*, 2000). Additional information is available from the River Health Monitoring programme of South Africa which has been collated into the PES EIS database (DWS, 2014).

During the high flow survey (October 2021) 14 of the expected 44 fish species were collected throughout the study area (Table 8-8). Of the species collected, three have Mpumalanga Tourism and Parks Agency (MTPA) protection while none of the other important conservation fishes were recorded. The highest diversity of species was collected at in the Noordkaap River (NKAAP-CONFL) and the lowest diversity in the Noordkaap River at NKAAP-ENOUS. *Enteromius trimaculatus* and *Labeobarbus m*arequensis species were collected across most of the sites with *L. marequensis* having the highest abundance. The Kaap River sites (KAAP-EURIK and KAAP-UCROC) has the lowest classification scores and are classified under a class-D/E category (Largely to Seriously Modified) and the remaining Kaap River site (KAAP-JOELK) and the LOUWS-REVOL are classified under the class-D category (Largely Modified). The Suidkaap sites (SKAAP-GLENT; SKAAP-UPWWT and SKAAP-DNWWT) are all classified under the class-D category while SKAAP-R40RD are classified under the class-C category (Moderately Modified). The fish communities of the Noordkaap and Queen Rivers are classified under the class-C/D (NKAAP-ENOUS), class-D (NKAAP-CONFL and QUEEN-R40RD) and class-C (QUEEN-SELAP).

Table 8-7: Table of fishes expected to occur in the Kaap River including resident and potential migratory species associated with the Crocodile River (Source Scott et al., 2006).

ORDER	FAMILY	GENUS & SPECIES	COMMON NAME	ABBR. IN FRAI	IUCN/MTPA CONSERVATION	IUCN CRITERIA
Anguilliformes	Anguillidae	*Anguilla bengalensis labiata*	African mottled eel	ALAB	Near Threatened	A2cd
	Anguillidae	*Anguilla bicolor bicolor*	Shortfin eel	ABIC	MTPA Protection	
	Anguillidae	*Anguilla marmorata*	Giant mottled eel	AMAR	MTPA Protection	
	Anguillidae	*Anguilla mossambica*	Longfin eel	AMOS	Near Threatened	A2bcde
Characiformes	Characidae	*Brycinus imberi*	Imberi	BIMB	NA	
	Characidae	*Hydrocynus vittatus*	Tigerfish	HVIT	MTPA Protection	
	Characidae	*Micralestes acutidens*	Silver robber	MACU	NA	
Cypriniformes	Cyprinidae	*Enteromius annectens*	Broadstriped barb	BANN	NA	
	Cyprinidae	*Enteromius anoplus*	Chubbyhead barb	BANO	Data Deficient	
	Cyprinidae	*Enteromius crocodilensis*	Rosefin barb	BARG	NA	
	Cyprinidae	*Enteromius paludinosus*	Goldie barb	BPAU	NA	
	Cyprinidae	*Enteromius radiatus*	Beira barb	BRAD	NA	
	Cyprinidae	*Enteromius sp. 'neefi cf. South Africa'*	Sidespot barb	BNEE	MTPA Protection	
	Cyprinidae	*Enteromius sp. 'Ohrigstad'*	Ohrigstad barb		MTPA Protection	
	Cyprinidae	*Enteromius sp. 'viviparus cf.*	Mozambique bowstripe barb		MTPA Protection	
	Cyprinidae	*Enteromius spp. 'eutaenia complex'*	Orangefin barb	BEUT	NA	
	Cyprinidae	*Enteromius trimaculatus*	Threespot barb	BTRI	NA	
	Cyprinidae	*Enteromius unitaeniatus*	Longbeard barb	BUNI	NA	
	Cyprinidae	*Enteromius viviparus*	Bowstripe barb	BVIV	NA	
	Cyprinidae	*Labeo congoro*	Purple labeo	LCON	NA	
	Cyprinidae	*Labeo cylindricus*	Redeye labeo	LCYL	NA	
	Cyprinidae	*Labeo molybdinus*	Leaden labeo	LMOL	NA	
	Cyprinidae	*Labeo rosae*	Rednose labeo	LROS	NA	
	Cyprinidae	*Labeo ruddi*	Silver labeo	LRUD	NA	
	Cyprinidae	*Labeobarbus marequensis*	Largescale yellowfish	BMAR	NA	
	Cyprinidae	*Labeobarbus polylepis*	Smallscale yellowfish	BPOL	NA	

ORDER	FAMILY	GENUS & SPECIES	COMMON NAME	ABBR. IN FRAI	IUCN/MTPA CONSERVATION	IUCN CRITERIA
	Cyprinidae	*Mesobola brevianalis*	River sardine	MBRE	MTPA Protection	
	Cyprinidae	*Opsaridium peringueyi*	Southern barred minnow	OPER	MTPA Protection	
Mormyriformes	Mormyridae	*Marcusenius pongolensis*	Bulldog	MMAC	Data Deficient	
	Mormyridae	*Petrocephalus wesselsi*	Southern churchill	PCAT	NA	
Perciformes	Cichlidae	*Chetia brevis*	Orange fringed largemouth	CBRE	Endangered	B1ab(iii,v)+2a b(iii,v)
	Cichlidae	*Coptodon rendalli*	Redbreast tilapia	TREN	NA	
	Cichlidae	*Oreochromis mossambicus*	Mozambique tilapia	OMOS	Near Threatened	A3e
	Cichlidae	*Pseudocrenilabrus philander*	Southern mouthbrooder	PPHI	NA	
	Cichlidae	*Tilapia sparrmanii*	Banded tilapia	TSPA	NA	
	Gobiidae	*Glossogobius callidus*	River goby	GCAL	NA	
	Gobiidae	*Glossogobius giuris*	Tank goby	GGIU	NA	
Siluriformes	Amphiliidae	*Amphilius engelbrachti*	Stargazer (mountain catfish)	AURA	MTPA Protection	
	Clariidae	*Clarias gariepinus*	Sharptooth catfish	CGAR	NA	
	Mochokidae	*Chiloglanis paratus*	Sawfin suckermouth	CPAR	NA	
	Mochokidae	*Chiloglanis pretoriae*	Shortspine suckermouth	CPRE	NA	
	Mochokidae	*Chiloglanis swierstrai*	Lowveld suckermouth	CSWI	NA	
	Mochokidae	*Synodontis zambezensis*	Brown squeaker	SZAM	NA	
	Schilbeidae	*Schilbe intermedius*	Silver catfish	SINT	NA	

Table 8-8: Table of the fish species collected in the study and the results of the FRAI assessment including the adjusted scores with classes.

Taxon	ABBR.	KAAP-EURIK	KAAP-JOELK	KAAP-UCROC	LOUWS-REVOL	NKAAP-ENOUS	NKAAP-CONFL	QUEEN-R40RD	QUEEN-SELAP	SKAAP-DNWWT	SKAAP-GLENT	SKAAP-R40RD	SKAAP-UPWWT
Amphilius engelbrachti	AENG	-	-	-	-	-	-	-	4	-	-	-	-
Clarias gariepinus	CGAR	2	-	-	-	-	-	1	-	-	1	1	-
Coptodon rendalli	CREN	-	-	-	-	-	2	-	-	-	-	-	1
Chiloglanis pretoriae	CPRE	4	-	1	-	2	-	-	7	-	4	1	1
Enteromius spp. 'eutaenia complex'	EEUT	4	7	-	8	-	3	-	17	-	-	-	-
Enteromius trimaculatus	ETRI	1	7	-	7	-	5	5	5	-	-	1	1
nteromius Viviparus	EVIV	-	-	-	-	-	8	7	-	-	-	-	-
Labeobarbus marequensis	LMAR	22	6	29	-	-	16	1	10	22	-	-	10
Labeo molybdinus	LMOL	7	-	11	-	-	7	-	-	1	-	-	1
Micralestes acutidens	MACU	2	4	9	-	-	13	-	-	-	-	-	-
Mesobola brevianalis	MBRE	-	-	-	-	-	6	-	-	-	-	-	-
Opseridium peringuel	OPER	-	-	8	-	-	-	-	-	-	-	-	-
Pseudocrenilabrus philander	PPHI	-	-	-	-	-	3	14	-	-	-	24	-
Tilapia sparrmanii	TSPA	-	-	-	-	2	-	-	5	-	-	-	-
Descriptive statistics	**Abundances**	42	24	58	15	4	63	28	48	23	5	27	14
	Diversity	7	4	5	2	2	9	5	6	2	2	4	5
Adjusted FRAI results	**FRAI score**	38,8	46,2	38,4	52.3	60,8	52,3	61,1	68,6	57,2	55,4	66,1	54,9
	FRAI class	D/E	D	D/E	D	C/D	D	C/D	C	D	D	C	D
*NKAAP-CONS could not be sampled													

8.1.3 Discussion for the Kaap sub-basin

The condition of the *in situ* water quality parameters were all within the TWQR requirements during the October 2021 high flow period survey. Fluctuations observed within the temperatures and turbidity ranges are expected due to seasonal changes in ambient temperatures and increased expected rain. Concerns are raised with some high major nutrient loading in the system attributed to untreated domestic and industrial effluents and agricultural run-off into the system. High nutrient loadings over prolonged periods could lead too excessive bacterial and algae growth that will exceed the dissolve oxygen demand of the system and cause fish kills.

A total of 56 taxa were observed during the macro-invertebrate assessment of which most were moderately to highly tolerant to pollution. The highest number of taxa were observed at the KAAP-UCROC site and the lowest at the KAAP-JOELK site. The macro-invertebrate assessment indicated that the macro-invertebrate communities of the site assessed on the Noordkaap and Queens Rivers were all in a Moderately Modified or Largely Modified (NKAAP-ENOUS site) state and that a loss of natural habitat and biota have occurred but basic ecosystem functions are largely unchanged. The upper reaches of Suidkaap River were also in a Moderately Modified or Largely Modified state as well as the SKAAP-DNWWT site but the macro-invertebrate community of the SKAAP-UPWWT site was in a Largely Natural state indicating only few modifications to the community. Similar results were recorded for the KAAPR-JOEL site whereas the KAAP-EURIK and KAAP-UCROC sites were both in an unmodified, Natural state. Impacts to the macro-invertebrate communities in the upper catchments do not seem to impact the macro-invertebrate communities further downstream.

The fish assessment revealed that during the high flow survey only 14 fish species were collected. The highest diversity of species was collected at in the Noordkaap River (NKAAP-CONFL) and the lowest diversity in the Noordkaap River at NKAAP-ENOUS. The health of the fish communities for the sites on the Noordkaap, Queens and Suidkaap Rivers all ranged between a Moderately to Largely Modified state where losses to the basic ecosystem functions have occurred. The health of the fish communities for sites on the Kaap River was more deteriorated, ranging from a Largely to Seriously Modified state indicating that the loss of ecosystem functions could be extensive. These results indicate that there are water quality and habitat problems in the Kaap River catchment possibly associated with changes in land use activities. Importantly water quality and habitat stressors have been observed to generally increase along the length of the river where fish community wellbeing has been observed to decrease. Of the upper tributaries in the catchment the Suidkaap and Queens Rivers are in a relatively better condition than the Noordkaap but land use activities or sources of stressors increase below the confluence of the Suidkaap and Queens Rivers in the Suidkaap River and below the Suidkaap and Noordkaap Rivers in the Kaap River upstream of its confluence with the Crocodile River. Importantly consider that the reference fish community of the lower Kaap River has been based on the historical distribution of fishes that migrate between the Kaap and Crocodile Rivers. There is a high possibility that stressors that may affect the ability of fish to migrate into the Kaap River from the Crocodile River may exist in the Crocodile River.

The stressors identified in the study area include reduced flows associated with water abstraction and water quality impacts in particular in the Kaap River catchment. The metric scores used in the FRAI assessment resulting in Class D and Class D/E categories in particular were identified as driving metrics. These stressors are spatially associated with the agricultural, infrastructure and mining activities in the Noordkaap River and with similar activities and the impacts associated with the Barbeton urban centre and associated WWTW that discharges into the Suidkaap River below the confluence of the Suidkaap and Queens Rivers. Because of recent high seasonal flows in the Suidkaap and the potential mobility of fish in the river the exact impact of the WWTW on the fish communities cannot be explicitly described as similar community structures were observed in sites above and below the activity.

Finally, there is a high potential and need to contribute to the wellbeing of the fish community of the study area, and the health of the rivers themselves as a result. This includes a range of opportunities to mitigate impacts including better management of flows and associated habitats in the study area, managing water quality impacts and improving river connectivity to allow better movement of species between habitats in the catchment. These mitigation measures are required to improve the condition of the river in an attempt to meet Resource Quality Objective requirements of the river.