NILE-SEC
NILE BASIN INITIATIVE
INITIATIVE DU BASSIN DU NIL

NBI Technical Reports: Wetlands and Biodiversity Series

# Coarse Environmental Flow Assessment for selected reaches in the Nile Basin

WRM/WBS-2022-01

giz Deutsche Gesellschaft
für Internationale
Zusammenarbeit (GIZ) GmbH

On behalf of:
Federal Ministry
for the Environment, Nature Conservation
and Nuclear Safety

of the Federal Republic of Germany

## Document Sheet

This Technical Report series publishes results of work that has been commissioned by the member states through the three NBI Centers (Secretariat based in Entebbe- Uganda, the Eastern Nile Technical Regional Office based in Addis Ababa - Ethiopia and the Nile Equatorial Lakes Subsidiary Action Program Coordination Unit based in Kigali - Rwanda. The content there-in has been reviewed and validated by the Member States through the Technical Advisory Committee and/or regional expert working groups appointed by the respective Technical Advisory Committees.

The purpose of the technical report series is to support informed stakeholder dialogue and decision making in order to achieve sustainable socio-economic development through equitable utilization of, and benefit from, the shared Nile Basin water resources.

| **Document** | |
|---|---|
| Citation | NBI Technical Reports – WRM/WBS-2022-06 |
| Title | Coarse Environmental Flow Assessment for selected reaches in the Nile Basin |
| Series Number | Water Resources Management/ Wetlands and Biodiversity Series 2022-06 |
| Date | August 2022 |
| | |
| **Responsible and Review** | |
| Responsible NBI Center | Nile-Secretariat |
| Responsible NBI | Dr. Michael Kizza |
| Document Review Process | Nile Basin Initiative Wetlands Task Team and Lead Consultant |
| Final Version endorsed | Nile Basin Initiative Wetlands Task Team and Lead Consultant |
| | |
| **Author / Consultant** | |
| Consultant Firm | HYDROC GmbH |
| Authors | Gordon O’Brien, James MacKenzie, Retha Stassen, Georg Petersen, and Melissa Wade |
| | |
| **Project** | |
| Funding Source | German Federal Ministry for Environment, Nature Conservation and Nuclear Safety (BMU) |
| Project Name | Biodiversity Conservation and Sustainable Utilization of Ecosystem Services of Wetlands of Transboundary Relevance in the Nile Basin |
| Project Number | 14.9029.1 |

**Disclaimer**

# EXECUTIVE SUMMAY

Environmental flows (eflows) describe the quantity, timing, and quality of freshwater flows and levels necessary to sustain aquatic ecosystems which, in turn, support human cultures, economies, livelihoods, and well-being (Sensu Arthington *et al.*, 2018). Over the last years, the Nile Basin Initiative (NBI) has developed its "Strategy for Management of Environmental Flows in the Nile Basin", during which an environmental flow assessment methodology (EFM) has been developed. Considering the many development activities in the Nile basin, eflow requirements urgently need to be established in order to ensure sustainable development and holistic planning of the use of water resources. In 2016 the NBI developed an eflow framework to support and coordinate eflow determination processes and management in the basin. This phased framework is not an EFM but a framework to guide the management of eflows including the selection of and use of EFMs and then alignment of eflows and their implementation.

The assessment described in this report is based on the NBI eflow strategy and provides a first implementation step for Nile basin wide consideration of eflows. The report presents the outcomes of a coarse, rapid, and holistic assessment of the consequences of altered flows and other important non-flow environmental drivers of change in the Nile basin, to a range of socio-ecological endpoints. The study area includes nine reaches of rivers or sites within the Nile basin. These sites (also referred to as Risk Regions) are located on a major tributary of Lake Victoria, the Kagera River (RR1 at Kyaka Ferry), on the White Nile below Lake Victoria (RR2 at Jinja), on the White Nile upstream of the Sudd (RR3 at Mongala), on the Baro River (RR4 at Gambela), on the Sobat River (RR5 at Hillet Doleib), the White Nile downstream of the Sudd (RR6 at Malakal), on the Blue Nile (RR7 at Roseires), on the Atbara River (RR8 at Kubor and Wad Elhiliew) and on the lower Main Nile (RR9 at Dongola).

For this coarse assessment the PROBFLO approach implemented includes establishing a Bayesian Network probability model to represent the socio-ecological system for each site. The model was parameterised to represent each site. Thereafter available environmental (flow, water quality and habitat) information as well as vegetation and fish information selected to represent the components of the systems as indicators were established are queried for the assessment. Here the “present condition” scenario for which relevant current data was collected and evaluated, risk was then evaluated and used with ecological indicator information to establish eflows to maintain the sites in a largely natural (Class B), moderately modified (Class C) and largely modified but sustainable state (Class D) associated with flows. These eflows are presented as flow duration tables for each site and each ecological category, with a range of percentiles that represent the flow variability for each scenario. In addition, an ecological category query tool was established to evaluate the proposed ecological class associated with the results of this study. This query tool which is based on the outcomes of the study is providing the ecological integrity category of any discharge value associated with any monthly percentile range. For the sites assessed by holistic eflows method PROBFLO, the socio-ecological consequences of altered flows have been evaluated by assessing the risk of alterations in water flow, to a number of ecological and social endpoints.

After the establishment of eflow scenarios (Class B to Class D) for each reach the socio-ecological consequences of these scenarios were evaluated in PROBFLO. Results include increasing risk to endpoints for most sites as the ecological wellbeing of the rivers deteriorate from reference states to Class B, C and D ecological categories. Similarly, there is a high variability in the resilience and associated risk of altered flows to different endpoints. This includes relatively higher risk to the floodplain biodiversity endpoint compared to the riverine biodiversity and the ecosystem services associated with the river and floodplain ecosystems. In addition to the risk posed to main tributaries (RR1, RR4 and RR5), the site associated with the Sudd Wetland (RR3) were consistently greater than the risk posed to the mainstem Nile River. All of these sites have extensive floodplain ecosystems associated with the mainstem flow that may be contributing to the risk outcomes.

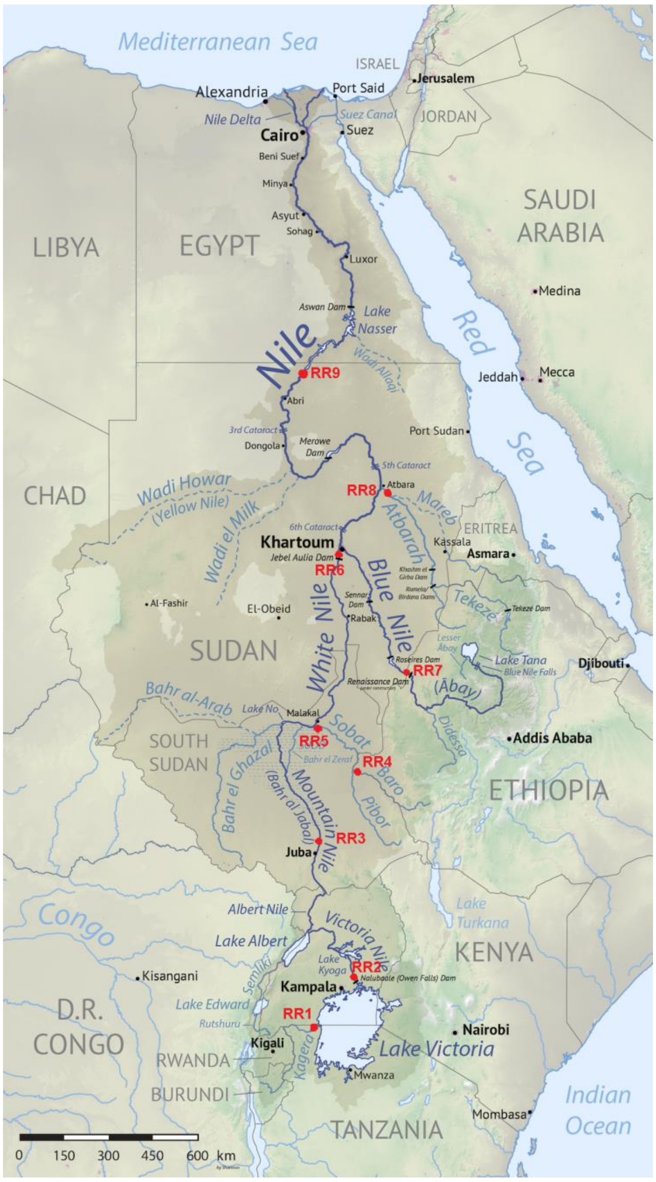
Uncertainty in the assessment is associated with the lack of biophysical data for the project. Here significant gaps exist. Instead, it was necessary to make use of a combination of evidence from global data sets, including those from Earth Observation, published reports and regional experts. Because none of this data was collected directly for the purpose of an eflows assessment, the nature and quality of the data was generally insufficient to ensure a high confidence eflows assessment. In the prevailing circumstances, professional judgement was used to interpret available (limited) data which impacts on confidence in the results. Recommendations to improve the outcomes include the identification of indicators and measures of the socio-ecological system that should be monitored to: (a) validate the outcomes of this assessment, (b) validate the selection and use of the indicators and measures to represent the system of interest, (c) reduce uncertainty associated with available data and its use.

A number of important issues emerge that need to be considered during further planning incorporating the eflows for the region.

- The Nile eflows framework incorporates the determination of reach/local scale management or protection objectives of targets for water resources to direct the management of those resources. In the absence of local scale objectives/targets eflows should be determined for a range of low to high use and protection scenarios that can be sustainable. In this case study, eflows have been determined to maintain the ecosystems in a largely natural state (Class B), moderately modified state (Class C) or largely modified but sustainable state (Class D). Ideally the vision and objectives would rank the balance between use and protection of the ecosystem in terms of risk, and would provide benchmarks that would enable the eflows to be structured to ensure that the objectives would be met. By providing a range of alternative use and protection scenarios or Class B, C and D states for eflows stakeholders can determine the balance between the use and protection of resources for the reaches of rivers considered and have appropriate eflows and socio-ecological consequence information for these tradeoff discussions.
- Existing data available to determine the eflows was limited, but adequate to conduct a coarse study. It is important thus that the eflows that are presented in this study are recognised as coarse and a first step and indication of eflow assessment. Prior to implementation of these recommendations some of the flow-ecosystem and flow-ecosystem service relationships proposed in the study should be verified. This requires a better understanding of the components of the ecosystems considered in the study, the dynamics of these systems and how people utilise associated ecosystem services and threaten these systems.

- Relative risk outcomes for all of the assessed development scenarios generally correlate to the proposed integrity classes selected for the assessment. In some occasions where the risk is proposed to be more severe (>50% high risk) than proposed ecological class descriptions, the outcomes should be considered with caution.

An overview of the results per reach (Riske Region (RR), refer to figure below) are provided below:



**RR1 – Kagera River**

The Kagera is characterised by wetlands and agricultural areas with the latter increasing and encroaching both forested as well as wetland areas, leading to land cover change, and respectively to changed, runoff patterns. In addition, water abstraction for irrigation is leading to a reduction of flows with respective impacts on the environment, especially during low flow conditions. It would be of particular interest here to assess these development scenarios in the Kagera basin to fully understand impacts on the environment and livelihoods. The results of the assessments, same as e.g. in the Mara, would provide a good set of information, that, within limitation, can also be projected to other upper catchment sites in the basin.

Low flows (dry and wet base flows) are important for the Kagera River and should be provided to ensure adequate habitats to maintain the ecology of the river. It is also important to note that the river is perennial and that the 99.9 percentile flow specified for each month provides for non-zero flows. Thus, any future operation of the system or water resource developments should accommodate the minimum flow requirements.

Results include increasing risk to endpoints as the ecological wellbeing of the rivers deteriorate from reference states to Class B, C and D ecological categories. Similarly, there is a high variability in the resilience and associated risk of altered flows to different endpoints. This includes relatively higher risk to the floodplain biodiversity endpoint compared to the riverine biodiversity and the ecosystem services associated with the river and floodplain ecosystems. A probability of high risk (>50%) was recorded for Class D for the floodplain services endpoint and for Class C and D for the floodplain biodiversity endpoint.

### RR2 – Victoria Nile

The Victoria Nile downstream of Lake Victoria is controlled by the lake outflow and governed by the "Agreed Curve" that mimics natural flow conditions at the hydropower stations that mark the outlet of the lake. Releases are linked to lake water level providing natural, i.e. prehydropower, flow conditions. In recent years it has been observed that releases from the lake have not always been adhering to the "Agreed Curve" for reasons e.g. discussed by Sutcliffe & Petersen (2007) in " Lake Victoria: derivation of a corrected natural water level series ". In addition, lake levels are dependent on inflow and rainfall over the lake area which again are related to climate conditions and landuse practices in the larger Lake Victoria catchment which should be broadly monitored for early knowledge acquisition, also considering cumulative effects. On the Victoria Nile itself there is some further hydropower potential that my lead to changes in the flow patterns. Here eflow aspects need to be considered when designing dam operations.

Low flows (dry and wet base flows) are important for this reach of river and should be provided to ensure adequate habitats to maintain the ecology of the river. It is also important to note that the river is perennial and that the 99.9 percentile flow specified for each month provides for non-zero flows. Thus, any future operation of the system or water resource developments should accommodate these minimum flow requirements.

Results include increasing risk to endpoints as the ecological wellbeing of the rivers deteriorate from reference states to Class B and C ecological categories. The risk to the floodplain and river services and to river biodiversity reduces for Class D category. No probability of high risk (>50%) was recorded for any of the endpoints.

### RR3 – Bahr El Jebel

The Bahr el Jebel upstream of the Sudd inflow at Mongala is dependent of inflowing water from the Equatorial Lakes region and may be affected by changing upstream land use, water consumption and hydropower developments. Changes in the flow patterns at this location would have potentially serious consequences for the downstream Sudd wetlands that are dependent on the flood pulses for the functioning of the permanent swamps as well as the seasonally flooded grasslands. Upstream catchment developments and change therefore should be closely monitored.

Low flows (dry and wet base flows) are important for the river and should be provided to ensure adequate habitats to maintain the ecology of the river. The low percentage for the flood requirements is due to the ‘flat’ hydrograph as most of the flows occur as high base flows. It is also important to note that the river is perennial and that the 99.9 percentile flow specified for each month provides for non-zero flows. Thus, any future operation of the system or water resource developments should accommodate the minimum flow requirements.

Results include increasing risk to endpoints as the ecological wellbeing of the rivers deteriorate from reference states to Class B, C and D ecological categories. Similarly, there is a high variability in the resilience and associated risk of altered flows to different endpoints. This includes relatively higher risk to the floodplain biodiversity endpoint compared to the riverine biodiversity and the ecosystem services associated with the river and floodplain ecosystems. A probability of high risk (>45%) was recorded for Class C and D for the floodplain and river services endpoints and floodplain biodiversity endpoint and for Class D for the river biodiversity endpoint.

### RR4 – Baro River

The Baro River upstream of the Machar Marshes at Gambela is fed by runoff from the Ethiopian highlands and as such susceptible to change with changing landcover in the upper catchments caused by deforestation and expanding agricultural areas. In addition, potential hydropower developments as well as water abstractions may increase in the future with these aspects leading to changes in the quantity and timing of flows. These flows are a driver for the Machar Marsh ecosystem that is partly fed by spill from the Baro and may be affected by changing river discharges. Close monitoring of landuse change is respectively recommended.

Low flows (dry and wet base flows) are important for the river and should be provided to ensure adequate habitats to maintain the ecology of the river. It is also important to note that the river is perennial and that the 99.9 percentile flow specified for each month provides for non-zero flows. Thus, any future operation of the system or water resource developments should accommodate the minimum flow requirements.

Results include increasing risk to endpoints as the ecological wellbeing of the rivers deteriorate from reference states to Class B, C and D ecological categories. Similarly, there is a high variability in the resilience and associated risk of altered flows to different endpoints. This includes relatively higher risk to the floodplain biodiversity endpoint compared to the riverine biodiversity and the ecosystem services associated with the river and floodplain ecosystems. A probability of high risk (>45%) was recorded for Class D for the floodplain services endpoint and >50% probability of high risk for Class D for the floodplain biodiversity endpoint.

### RR5 – Sobat River

The Sobat River is fed by the Baro-Akobo-Sobat basin, draining large parts of South Sudan as well as the Ethiopian escarpment. Flows are rainfall dependent. The system is currently largely unmodified though developments in the Ethiopian upper catchment may lead to modifications of the runoff patterns in the long term. Flows as compared to environmental flow requirements are shown in Figure 192. Deviations may be attributed to limitations in data availability for setting up the hydrological and hydraulic models. Eflow understanding (and modelling results) would strongly benefit from meteorological, hydrological and ecological data acquisition in this area.

Low flows are important for the Sobat River and should be provided to ensure adequate habitats to maintain the ecology of the river. It is also important to note that the river is perennial and although the minimum flows for April can be a little as 1 $m^3/s$, no zero flows occur. It is important that the 99.9 percentile flow specified for each month are provided. Thus, any future operation of the system or water resource developments should accommodate the minimum flow requirements.

Results include increasing risk to endpoints as the ecological wellbeing of the rivers deteriorate from reference states to Class B, C and D ecological categories. Similarly, there is a high variability in the resilience and associated risk of altered flows to different endpoints. This includes relatively higher risk to the floodplain biodiversity endpoint compared to the riverine biodiversity and the ecosystem services associated with the river and floodplain ecosystems. A probability of high risk (>50%) was recorded for Class C and D for the floodplain services and biodiversity endpoints and >45% probability of high risk for Class D for the river services and biodiversity endpoints.

**RR6 – White Nile River**

The White Nile drains the large upper Nile basin, receiving its inflow mainly from the Bahr el Jebel and Sobat rivers, and is as such directly dependent on the developments in these basins. Downstream the White Nile is a main contributor to the main Nile and as such modifications in flow, accumulatively, may show effects in the lower basin.

Low flows (dry and wet base flows) are important for the White Nile River and should be provided to ensure adequate habitats to maintain the ecology of the river. It is also important to note that the river is perennial and that the 99.9 percentile flow specified for each month provides for non-zero flows. Thus, any future operation of the system or water resource developments should accommodate the minimum flow requirements.

Results include increasing risk to endpoints as the ecological wellbeing of the rivers deteriorate from reference states to Class B, C and D ecological categories. Similarly, there is a high variability in the resilience and associated risk of altered flows to different endpoints. This includes relatively higher risk to the floodplain biodiversity endpoint compared to the riverine biodiversity and the ecosystem services associated with the river and floodplain ecosystems. No probability of high risk (>50%) was recorded for any endpoint.

**RR7 – Blue Nile River**

The Blue Nile drains the large Ethiopian part of the Nile basin and is directly dependent on rainfall and runoff from there. The basin is undergoing significant developments with agricultural land use change and e.g. the GERD (Grand Ethiopian Renaissance Dam) potentially leading to significant changes in the runoff patterns. Especially the influence of GERD and its operation schedule needs to be carefully investigated as it is influencing the entire downstream Nile basin.

Low flows (dry and wet base flows) are important for the Blue Nile River and should be provided to ensure adequate habitats to maintain the ecology of the river. It is also important to note that the river is perennial and that the 99.9 percentile flow specified for each month provides for non-zero flows. Thus, any future operation of the system or water resource developments should accommodate the minimum flow requirements.

Results include increasing risk to endpoints as the ecological wellbeing of the rivers deteriorate from reference states to Class B, C and D ecological categories. Similarly, there is a high variability in the resilience and associated risk of altered flows to different endpoints. This includes relatively higher risk to the river biodiversity endpoint compared to the floodplain biodiversity and the ecosystem services associated with the river and floodplain ecosystems. A probability of high risk (>50%) was recorded for Class D for the river's services endpoint.

**RR8 – Atbara River**

The Atbara River features highly seasonal flows. The flow regime may be altered by dams and weirs as well as water abstraction for irrigation. Especially cumulative effects are of importance here, considering the irrigation potential along its course. Respective developments should be closely monitored as the Atbara significantly contributes to the Nile flows.

Both flow components are important for the Atbara River and should be provided to ensure adequate habitats to maintain the ecology of the river. It is also important to note that the river is perennial, although with very low flows during the dry season, and that the 99.9 percentile flow specified for each month provides for non-zero flows. Thus, any future operation of the system or water resource developments should accommodate the minimum flow requirements.

The PROBFLO assessment could not be undertaken due to insufficient hydraulics and socio or ecological information.

**RR9 – Main Nile River**

The main Nile below the confluence of the Blue and White Nile has been significantly altered through a series of dams that have completely changed the flow regime. In addition, the waters are extensively used for irrigation, leading to significant abstractions. Wetlands along this stretch and in particular the Nile Delta have been significantly modified and converted to agricultural land. In this regard, the Nile Delta is a very vulnerable ecosystem, as under pressure from agricultural practices, a growing population, as well as changed flow patterns as compared to the original Nile flows. Eflow assessments for the Nile Delta or any other reaches of the Nile in Egypt have so far not been conducted but are strongly recommended.

Low flows (dry and wet base flows) are important for the Nile River and should be provided to ensure adequate habitats to maintain the ecology of the river. It is also important to note that the river is perennial and that the 99.9 percentile flow specified for each month provides for non-zero flows. Thus, any future operation of the system or water resource developments should accommodate the minimum flow requirements.

Results include increasing risk to endpoints as the ecological wellbeing of the rivers deteriorate from reference states to Class B, C and D ecological categories. Similarly, there is a high variability in the resilience and associated risk of altered flows to different endpoints. This includes relatively higher risk to the floodplain biodiversity endpoint compared to the riverine biodiversity and the ecosystem services associated with the river and floodplain ecosystems. No probability of high risk (>50%) was recorded for any endpoint.

This study provides outcomes of the first coarse determination of eflows for sites in the Nile Basin with reference to the Nile eflows framework so these outcomes can contribute to the coordinated management of eflows in the basin. These outcomes include eflows for nine reaches of rivers in the basin, provided for a range of use level scenarios associated with changes in the condition of the resources. These outcomes cane be integrated into the Nile Decision Support System (DSS) and used to contribute to the sustainable management of resources in the basin. The confidence of the outcomes of this coarse eflow assessment should be improved in an adaptive management context. We recommend that the flow-ecosystem and flow-ecosystem relationships for each reach considered should be tested through a monitoring programme. This programme should include water quality, flows, ecosystem condition and ecosystem service components. The data collected from this monitoring can address uncertainty in this coarse eflow assessment and improve eflow projections for the study.

# TABLE OF CONTENTS

# ACRONYMS

| | |
|---|---|
| AZE | Alliance for Zero Extinctions |
| BF | Base Flows |
| BN | Bayesian Network |
| BN-RRM | Bayesian Network Relative Risk Model |
| CPT | Conditional Probability Tables |
| DEM | Digital Elevation Model. |
| DMR | Desktop Reserve Model |
| eflow | Environmental Flow |
| EFR | Environmental Flow Requirements |
| ERA | Ecological Risk Assessment |
| FDC | Flow Duration Curves |
| FUT | Future Scenario |
| MAR | Mean Annual Runoff |
| MCM | Million Cubic Metres |
| NBI | Nile Basin Initiative |
| NILETAC | Nile Technical Advisory Committee |
| REF | Reference Flows |
| RoR | Reach of River |
| RR | Risk Region |
| RRM | Relative Risk Model |
| SD | Standard Deviation |
| SE | Social Endpoints |
| YoY | Young of Year |

# 1 INTRODUCTION

## 1.1 General

The Nile Basin Initiative (NBI) is an intergovernmental partnership of ten Nile basin countries with the shared vision "to achieve sustainable socio-economic development through the equitable utilization of, and benefit from, the common Nile basin water resources". To achieve the sustainable management of the water resources within the Nile basin, a framework of policy, strategy and guidance instruments for the management and assessment of aquatic ecosystems was developed. This included the development of the Nile EFlows Framework that provides general standards and norms for environmental flows (eflows) in the Nile basin. In 2016 the Nile Basin Initiative prepared a guidance document on eflows titled, "Nile EFlows Framework Technical Implementation Manual" (NBI, 2016a). This contributed to the development of the Nile eflows strategy (2016), part of the NBI "Strategy for Management of Environmental Flows in the Nile Basin". The current study described in this report is built on this approach.

Environmental flows describe the quantity, timing, and quality of freshwater flows and levels necessary to sustain aquatic ecosystems, and that this supports, or contributes to human cultures, economies, livelihoods, and well-being (Arthington et al., 2018). These efows can be established for aquatic ecosystems including; rivers, streams, springs, floodplain and other wetlands, lakes, coastal waterbodies, including lagoons and estuaries, and groundwater-dependent ecosystems. In the Nile Basin eflows have been identified as an important component of sustainable water resources management in the basin which has resulted in the establishment of the Nile eflows stratergy (NBI, 2017). *Here is an extract from the Nile Eflows Strategy for reference to this coarse eflows assessment of nine reaches of rivers in the Nile Basin:*

*According to the strategy eflows are necessary for the maintenance of biodiversity and ecosystems services that the Nile Rivers provide including provisioning (e.g. water for basic human right to water, livelihoods from fisheries), regulating (e.g. water quality) and cultural and supporting services (NBI, 2017)). To maintain these ecosystem services, water needs to be allocated to sustain the functioning of the river ecosystem. Flow alterations can result in habitat changes that may lead to changes in the diversity of aquatic ecosystems and the ecosystem services they provide. The loss of ecosystem services can therefore involve a risk to the sustainability of the shared water resources water resources and the inherent tradeoffs between water resources development and the alteration of ecosystem services have to be managed based on clear objectives and sound knowledge of the associated eflow requirements. Recognizing this need, and based on the objectives of NBI's Environmental and Social Policy, which requires NBI (1) "to provide a set of principles and fields of action for the integration of environmental and social concerns in NBI programs" (2) "to provide guidance for managing transboundary environmental and social impacts of national activities", (3) "to provide support to Nile Basin countries for the protection and conservation of critical Nile Basin environmental resources" and (4) "to demonstrate commitment of the NBI and Nile countries to international best practices with regard to environmental and social management of development activities", NBI has developed an approach to support the establishment of environmental flows management in the basin. This document provides the strategy for its implementation (NBI, 2017).*

*Although many countries have developed drinking water quality and basic need standards, this is not the case for standards or guidelines for ecosystem basic water requirements. A few countries have started the process of legislating on the allocation of water resources to the environment, for example by the creation of two reserves of water: one for human needs and the other as an ecological reserve. The human reserve is for the purposes of drinking, food preparation, and hygiene. The ecological reserve focuses on the water needed to maintain ecosystem health, including aquatic species. To date, only a few member states of the Nile Basin have explicitly articulated the issue of environmental -flows and included it in their policies (NBI, 2017).*

*Among the Nile Basin countries, Tanzania and Kenya are the only countries that have established policies and strategies, while Rwanda, Sudan and Ethiopia have general statements and provisions in their respective water policy documents, and Uganda is currently reviewing its policy accordingly (NBI, 2017).*

*The Nile eflows strategy also supports NBI member countries to respond to international conventions and agreements through which they have committed to addressing the health of their freshwater systems and specifically environmental flows. Under the Sustainable Development Goals (SDGs) countries have committed to by 2030 substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity (Target 6.4.2), including environmental flows. Under the Convention on Biological Diversity (CBD)*[3] *Aichi Biodiversity Targets for 2020, countries have committed to a number of targets that are directly related to the protection of environmental flows – including Target 2 on mainstreaming biodiversity into national development planning, Target 5 on reducing the rate of loss of habitats in including aquatic ecosystems and Target 14 on restoration and safeguarding of ecosystems that provide essential services that contribute to human well-being. Also under the RAMSAR convention guidelines for the allocation and management of water for maintaining the ecological functions of wetlands (Resolution VIII.1, 2002) have been adopted and recommended approaches captured in the RAMSAR guidance documents (NBI, 2017).*

The study undertakes a series of nine coarse eflow assessments of important reaches of rivers in the Nile basin. The aim is to determined the eflow requirements of these nine reaches that are suitable to maintain the ecosystems as near natural (Class B), moderately modified (Class C) and largely modified but sustainable (Class D), with regards to their ecological state. With this data, available flows that exceed the Class B can loosely be attributed to a pristine class (Class A) and flows below the Class D category requirements can be considered to result in an unsustainable ecosystem that is in a severely or critically modified ecological state (Class E or F). The approach adopted to undertake these eflow assessments includes the use of PROBFLO a holistic EFA (NBI, 2016a; O'Brien et al., 2019). This regional scale ecological risk assessment based approach allows for the evaluation of a range of socio-ecological consequences of altered flows to selected social (including livelihoods of human communities) and ecological (including biodiversity and ecosystem processes) endpoints. This approach has been applied to provide the eflow requirements to maintain the ecosystem of the nine reaches considered in the study in:

(a) a largely natural, Class B ecological state and associated minimal resource use,
(b) a moderately modified, Class C ecological state and associated moderate resource use and,
(c) a largely modified, but sustainable Class D ecological state and the high resource use.

The PROBFLO approach includes ten procedural steps that have been aligned to the seven phases of the Nile Eflows Framework for this case study (NBI, 2016a). This confidence of the application of the PROBFLO method in the context of the Nile Eflows Framework depends on the uncertainty associated with available:

a. hydrology data representing the historical and present volume, timing, duration and frequency of flows,
b. hydraulic data to understand the flow variability as physical habitat characteristics and
c. non-flow physical divers of river ecosystems including water quality and sediment/geomorphological information for example, and
d. indicators of the ecosystems and ecological processes and relationships with flows that are proposed to be affected by altered flows and finally,
e. indicators of the ecosystem-services and social processes and relationships with flows that are proposed to be affected by altered flows.

With a good understanding of these socio-ecological aspects of the water resources being evaluated confident eflow assessments cane be undertaken. In this case study low confident hydraulic data and limited ecosystem and ecosystem service data is available. In this case study we relied on available local data and our understanding of other African ecosystems with similar hydrological characteristics to propose hypothetical flow-ecosystem and flow-ecosystem service relationships. These low confident outcomes can easily be improved with more data to represent these processes in the Nile Basin.

## 1.2 The Nile Basin

The Nile River, at 6 695km in length, is the longest river in the world with a drainage area of approximately 3.2 million km$^2$ (NBI, 2012; NBI, 2016b). The Nile River runs through eleven countries, namely: Burundi, DR Congo, Egypt, Ethiopia, Eritrea, Kenya, Rwanda, South Sudan, Sudan, Tanzania, and Uganda (Figure 1A) and the Nile basin is home to over 257 million people (NBI, 2016b). The Nile River has two main tributaries; the White Nile with its upstream catchments fed by rivers originating in Burundi, Rwanda, Tanzania and Kenya, and the Blue Nile originating in Ethiopia (NBI, 2012; NBI, 2016b). Other tributaries of the Nile are the Sobat River draining parts of the south-west Ethiopia, and eastern parts of South Sudan the Atbara river passing through Sudan and the Bahr el Ghazal draining the western part of South Sudan (NBI, 2012). The Nile River also features seventeen Ramsar wetland sites including the Sudd Wetland as well as varies lakes including Lake Victoria. The Nile basin comprises three broad sub-systems, these are the Eastern Nile sub-system, the Equatorial Nile sub-system and the Main Nile Zone (NBI, 2012). These have been divided into ten sub-basins, namely: Main Nile, Atbara, Blue Nile, White Nile, Baro-Akobo-Sobat, Bahr El Jebel, Bahr El Ghazal, Lake Albert, Victoria Nile, Lake Victoria (Figure 1B). The basin is also divided into sixteen terrestrial ecoregions (Figure 1C). The gradual change in elevation and climatic conditions from north to south within the basin, results in a prominent latitudinal gradation in vegetation and fauna; accompanied by a marked decrease in the diversity of plant and animal species.

Population growth is predicted to be the major driver for future food and water requirements in the Nile basin. Agricultural, hydropower production, wetlands, water supply, navigation, fisheries and tourism are among the many sectors depending on water resources and providing livelihoods for the riparian population (NBI, 2016b). The countries within the Nile basin, together, use almost 90% of the regions renewable water resources and most of the stream flow is allocated for industrial, domestic, aquiculture and ecological water supply (NBI, 2016b).

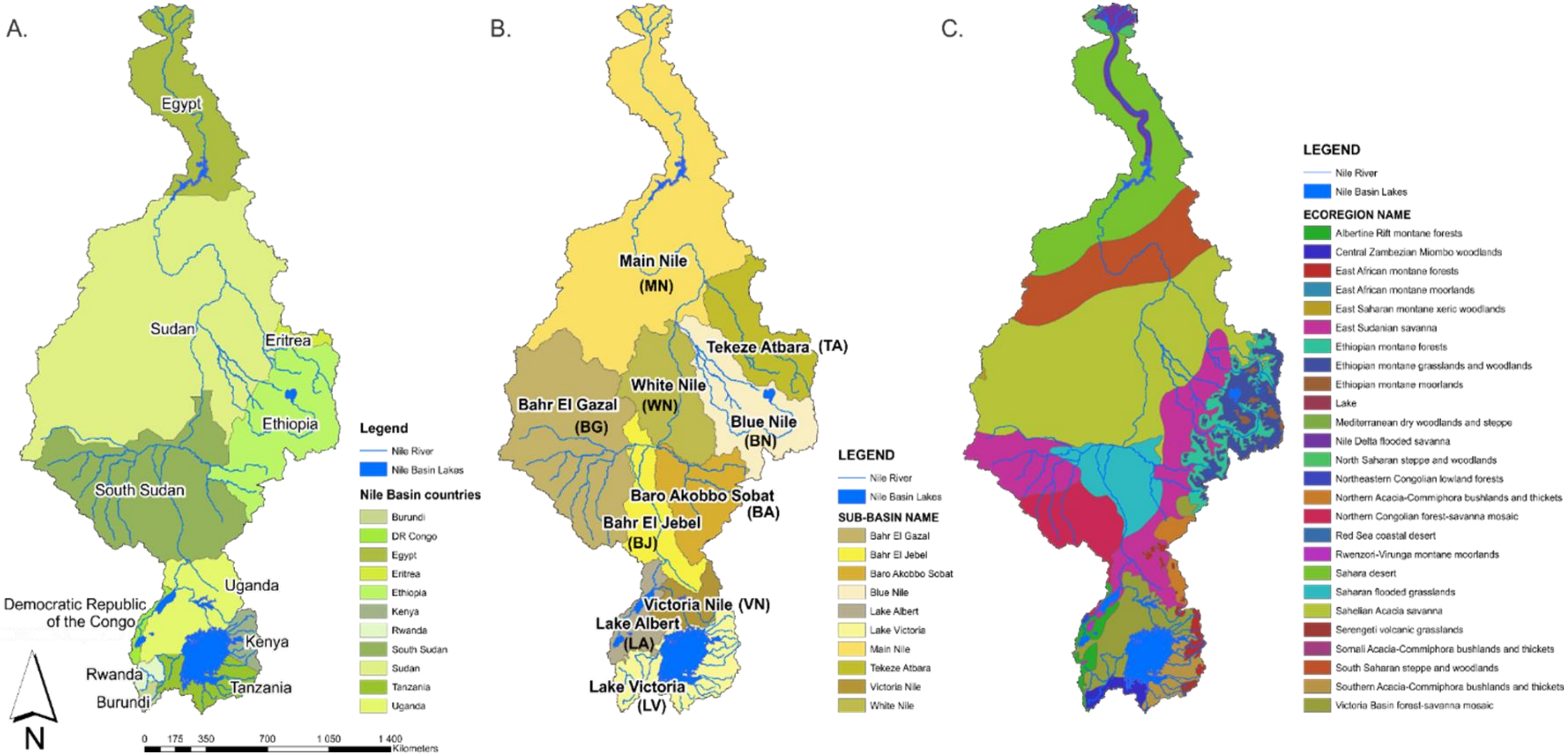


Figure 1: The countries (A), sub-basins(B) and ecoregions (C) within the Nile basin

## 1.3 Environmental Flows

Environmental flows (eflows) describe the quantity, quality and timing of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and wellbeing that depend on these ecosystems (Brisbane Declaration, 2007). Environmental flows are important for the maintenance of ecosystems services where reduced river flows generally result in a reduction of all services provided by the river including; provisioning (water for domestic and agriculture, fish etc.), regulating (nutrient processing, water quality etc.), cultural and supporting services. To maintain these ecosystem services, water needs to be allocated to sustaining the ecology of rivers. The loss of ecosystem services means a risk to all of the people in the Nile basin, with those living closest to nature (i.e. the poor) being the most vulnerable. Environmental flows are also important for the maintenance of ecosystem processes and biodiversity as flow alterations result in habitat changes that leads to changes in the diversity of aquatic communities and associated processes. Species adapted to natural flow regimes are vulnerable to altered flows and should be the first to disappear from rivers. These changes may facilitate undesirably tolerant species including exotics that may benefit from eflow alterations. Environmental flows are also important for current and futures water resource developments upon which many communities and national economies may depend.

There are numerous eflow methodologies that have been developed globally that may be suitable for application in the Nile basin (NBI, 2016a; Horne et al., 2017). Lessons learnt from the development of the many EFMs and their extensive application has resulted in the development of principles that should be considered when selecting suitable methods for application (Lloyd et al., 2003; Poff, and Zimmerman, 2010; O'Brien and Wepener, 2012; Landis et al., 2013; Poff and Matthews, 2013; NBI, 2016a). These principles include:

- The application of EFMs only provide predictions of the probable effects of altered eflow regimes, based on available data and expertise. Only when the flows are implemented can these predictions be tested and verified. The application of EFMs and associated EFR implementation should always form part of an adaptive management process.
- Environmental Flow Methods are structured lines of evidence or tools designed to process existing data and knowledge of the flow-ecosystem and flow-ecosystem service relationships, and describe EFRs to maintain ecosystem features and processes in desired conditions. Suitable EFMs should therefore, and are most likely to, provide the similar eflow recommendations for a river/ecosystem.
- Any EFM can only provide accurate and high confidence EFR recommendations, if the data and information available are comprehensive and accurate. High confidence eflow recommendations still need to be implemented, monitored and evaluated in an adaptive management cycle.
- All EFMs develop EFRs that are based on available hydrological information and rated hydraulic cross-sections. The accuracy of and confidence in flow recommendations, is highly dependent on the length and accuracy of the measured flow time series, and the accuracy of the hydraulic surveys and model used. If there is limited (or no) measured flow record and hydraulic data, the confidence in the EFA will be low, no matter how accurate and extensive the ecological, water quality, geomorphological, social and economic information and analyses may be.

- The main differences between rapid and comprehensive EFMs (apart from costs and resources needed), include the confidence of the EFR recommendations and comprehensive EFMs detail the drivers of, and motivations for the recommended flows. Holistic EFMs can now also describe the overall socio-ecological consequences of altered flows and contribute to tradeoff decisions between ecosystem use and protection.
- While many methodologies require a considerable degrees of professional judgement and some new transparent, evidence based, holistic EFMs are available, all approaches should be implemented by specialist, experiences practitioners who can implement the EFMs correctly.
- EFMs should be evidence based and explicitly present the uncertainty associated with the assessment, holistic EFMs should Integrated environmental threats, such as climate change and water resource use requirements associated with human population growth for example, with EFRs.
- Application of EFMs and the implementation of EFRs should be an adaptive process, in which management decisions are taken on the basis of best available information and knowledge, the consequences of those decisions are monitored continuously, and the decisions are revisited and may be modified in the light of more accurate, detailed information and higher confidence knowledge.
- Stakeholder understanding and involvement in the eflow process is an essential precursor for successful implementation. You can have the best science and the most effective specialists, but if the stakeholders don’t understand what environmental flows are, what they are for, and why they are important, there is very little chance of successful implementation.
- The outcomes of EFMs are usually predictions of the flows required to sustain a river and its features in particular environmental condition, with descriptions of the specific effects of the flows. The decision to allocate and implement all, part or none of the recommended flows will normally reside with the relevant water management authority.
- Environmental Flow Methods can be implemented at different levels of confidence to address different management questions. The uncertainty associated with the application of low confidence assessments should be considered before eflow recommendations are implemented. And the precautionary approach and adaptive management principles should be adopted in these situations.

Environmental flow methodologies can be categorised into four main categories including: hydrological, hydraulic rating, habitat simulation (or rating), and holistic methods including regional frameworks that are sometimes separated into their own category (Horne et al., 2018). Although there are opportunities to apply hydrological, hydraulic rating and habitat simulation EFMs for selected case studies (NBI, 2016a). Holistic EFAs that incorporate the other types of eflow categories are considered to be best practice, and have been developed to facilitate the establishment of the balance between the use and protection of water resources on a holistic scale rather than meet the protection or use requirements of a few target ecosystem components (Arthington et al., 2004, NBI, 2016a). The approach confirms to the precautionary principle by simulating the “natural flows paradigm”, including the volume, timing and duration of flows as far as possible to meet known social and ecological endpoints (Arthington et al. 1992; King and Tharme 1994; Poff et al. 1997;

Arthington et al., 2004). Holistic EFAs are generally based on the use and protection requirements of multiple stakeholders, who together establish a vision for the wellbeing of the ecosystem being analysed in the EFA (Arthington et al., 2004).

The PROBFLO regional scale eflows approach is a robust holistic eflow approach that has been developed in Africa and applied extensively across the continent to address the socio-ecological consequences of altered flows and determine eflows (O'Brien et al., 2019). This approach that is reviewed in the Nile EFlow Framework (NBI, 2016) and has been selected for this study. PROBFLO established by O'Brien *et al.* (2019) is a Regional Scale Ecological Risk Assessment (ERA) eflow evaluation and determination method that is graphically presented in ten procedural steps. The Regional Scale ERA method incorporating the Relative Risk Model (RRM) used in PROBFLO was established in 1997 in response to the need to apply ERAs on multiple spatial scales, and include multiple sources, stressors and receptors in considerations of spatial and temporal ecosystem dynamics (Landis and Wiegers, 1997; 2007). The approach, which includes the RRM, has been widely implemented, reviewed and proven to be a robust probabilistic modelling tool to contribute to the sustainable management of ecological resources (Landis and Wiegers 2007). Recent developments in eflow frameworks (Poff *et al.*, 2010; NBI, 2016a), now also call for holistic, regional scale, probabilistic eflow assessments that consider flow and non-flow drivers of change in socio-ecological context. The Bayesian Network Relative Risk Model (BN-RRM) approach incorporated into this regional scale eflow assessment method we have called PROBFLO (O'Brien et al, 2019), similarly offers a robust approach to eflow assessments that can make a positive contribution to the sustainable management of water resources. The approach provides true transparency and adaptability options for holistic eflow management. PROBFLO has already been implemented in two major case studies (Lesotho Highlands and Nile basin) where its flexibility and functionality has been demonstrated. In both case studies, the evidence based outcomes facilitated informed environmental management decision making, in the context of social and ecological aspirations. From these outcomes, stakeholders have in addition, been able to consider sustainable social and ecological tradeoffs between, to balance the use and protection of water resources. Although the accuracy of the PROBFLO projections used to guide sustainable water resource use needs to be validated when developments takes place, the adaptability of the approach allows for the incorporation of new information rapidly which will inform adaptive management. The approach is being established within adaptive management processes of existing case studies and applied in new case studies for a wide range of water resources with diverse social and ecological objectives.

In this report presents the application of PROBFLO to nine sites in the Nile Basin, the approach adopted, outcomes, uncertainties associated with the assessment and recommendations for appropriate use and or implementation of eflows determined in the study.

## 1.4 Study Area

The study area includes nine reaches of rivers or sites within the Nile basin (Table 1 and Figure 2). Sites, also referred to as Risk Regions (RR) in the context of the PROBFLO assessment (O'Brien *et al.*, 2018) are located on a major tributary of Lake Victoria, the Kagera River (RR1 at Kyaka Ferry), on the White Nile below Lake Victoria (RR2 at Jinja), on the White Nile upstream of the Sudd (RR3 at Mongala), on the Baro River (RR4 at Gambela), on the Sobat River (RR5 at Hillet Doleib), the White

Nile downstream of the Sudd (RR6 at Malakal), on the Blue Nile (RR7 at Roseires), on the Atbara River (RR8 at Kubor and Wad Elhiliew) and on the lower Main Nile (RR9 at Dongola). Further details for selecting these RR are provided in Section 2.5.1.

**Table 1: Summary of the reaches of rivers/sites considered in the study including GPS location, hydrology weir/site used for the analysis and period of hydrological data available for the assessment.**

| RR | Reach Name | Latitude | Longitude | Site/Weir | Period |
|---|---|---|---|---|---|
| RR1 | Kagera River | -1.24943 | 31.420205 | Kyaka Ferry | 1952-1989 |
| RR2 | Victoria Nile downstream of Lake Victoria | 0.515718 | 33.12336 | Jinja | 1963-2013 |
| RR3 | Bahr el Jebel upstream of Sudd inflow | 4.885574 | 31.646235 | Mongala | 1963-1981 |
| RR4 | Baro River upstream of Machar Marshes | 8.247126 | 34.576519 | Gambela | 1977-2004 |
| RR5 | Sobat River upstream of mouth (confluence with White Nile) | 9.335111 | 31.588712 | Hillet Doleib | 1906-1982 |
| RR6 | White Nile upstream of Jebel Aulia | 9.538513 | 31.643643 | Malakal | 1963-2006 |
| RR7 | Blue Nile downstream of GERD | 11.859816 | 34.375262 | El Diem/ Roseires | 1921-2013 |
| RR8 | Atbara River | 14.364169 | 35.855135 | Kubor and Wad Elhiliew | 1921-2001 |
| RR9 | Main Nile upstream of Lake Nasser | 19.183147 | 30.489857 | Dongola | 1944-2008 |

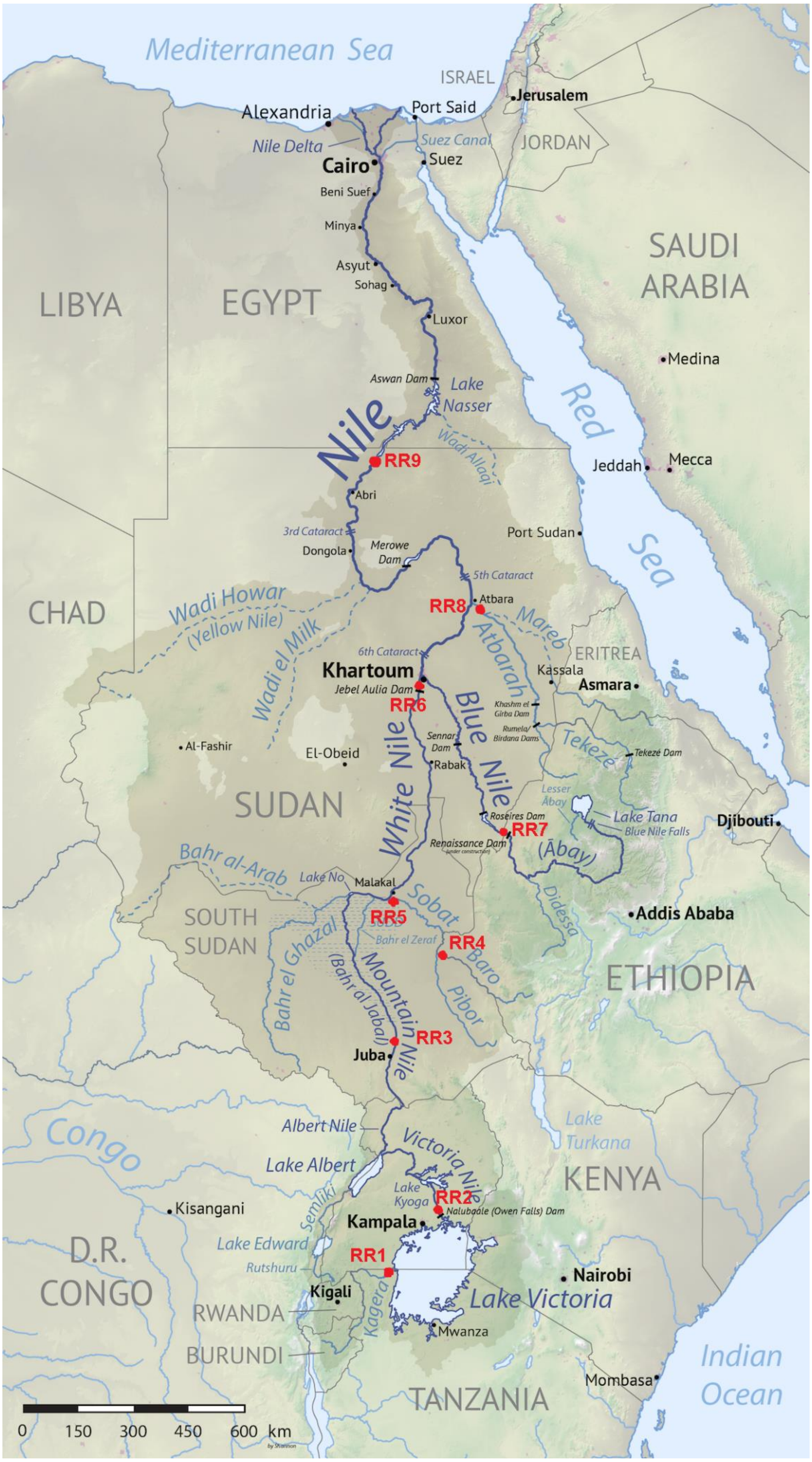


Figure 2: The Nile basin including assessment locations

# 2 METHODOLOGY

## 2.1 Nile Eflows Framework

The Nile Eflows Framework has been designed to address the requirements of a suitable eflows framework for the Nile Basin and current best practice eflows management frameworks and eflows assessment methods into an adaptable, scientifically valid eflows management framework for the Nile Basin (summarised in Figure 3). The Framework integrates seven best eflows management practice principles (collaborations, equitability, sustainability, evidence based, requisite simplicity, transparency and adaptability) so that the approach conforms to best management practice (Figure 4). The seven procedural steps of the eflows Framework include:

- **Phase 1**: Situation Assessment and Alignment Process, aligns existing site and regional scale information and the plan for the new eflows assessment with regional and basin scale management objectives and ensures that regional and spatial scale assessment requirements are considered.
- **Phase 2:** Governance and Resource Quality Objectives Setting, this phase ensures that local and regional eflow governance requirements are considered/applied in eflow assessments, and describes the vision and Resource Quality Objectives determination procedures.
- **Phase 3:** Hydrological Foundation, this phase includes the baseline evaluation/modelling of hydrology data for the site/regional eflows assessments. *This phase usually forms the foundation phase of EFA method applications*. Available flow data, rainfall and evaporation data, water abstraction data, land use data and other information that may affect flows is used in this phase to characterise baseline flows and potentially describe any differences between these baseline flows and current flows.
- **Phase 4:** Ecosystem Type Classification. Although no two rivers are exactly the same, systems that share physical features, and or occur within similar ecoregions and or contain similar animals may generally respond to flow alterations in a similar manner. This theory is the basis for the importance of characterising the ecosystem type being considered for eflow assessments in an effort to assist with future assessments.
- **Phase 5:** Flow Alterations, here alterations in flows from baseline or current flows are modelled and described. These descriptions are then used in further phases of the where the socio-ecological consequences of these altered flows can be determined.
- **Phase 6:** Flow-Ecological-Ecosystem Services Linkages. The importance of understanding what the consequences of altered flows will be, initially requires an understanding of the flow-ecological relationships for ecosystem protection considerations, and flow-ecosystem service relationships to describe social consequences of altered flows. *This phase usually forms an important part of holistic eflow assessment methods.*
- **Phase 7:** EFlows Setting and Monitoring, in this phase the flows required to maintain the socio-ecological system in the desired condition established in the Framework is detailed for implementation. Within these eflow requirements many uncertainties associated with the availability of evidence used in the assessment, the understanding of the flow-ecology and flow-ecosystem service relationships and analyses procedures used can be addressed through the establishment of a monitoring programme. Monitoring data is used to test these hypotheses which drives the adaptive management process.

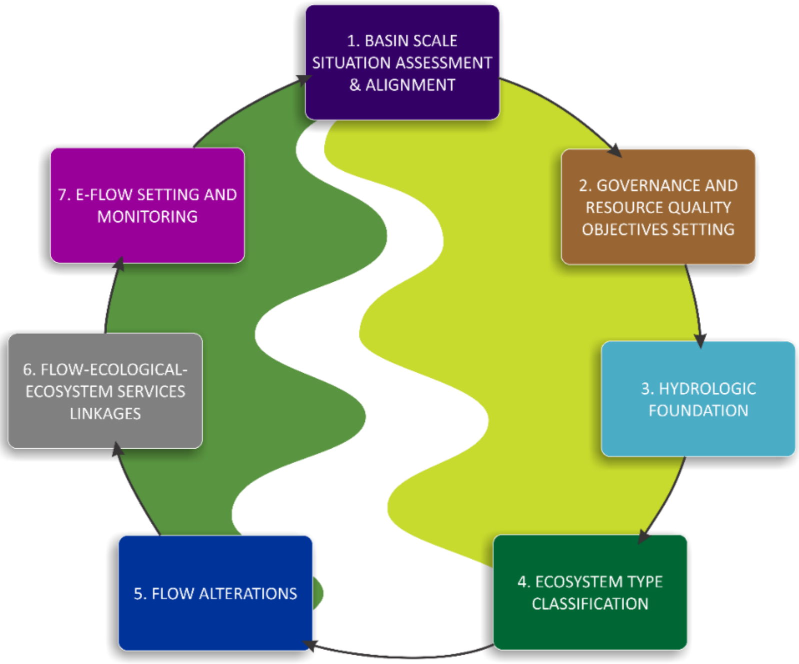


**Figure 3: Summary of the seven phases of the Nile Eflows Framework established to direct the management of eflows in the Nile Basin.**

**Figure 4: Seven principles of best Environmental Flow (eflow) management practice for an eflow framework for the Nile Basin.**

The holistic PROBFLO Environmental Flow (eflows) Assessment approach was used as the basis for assessment of the nine selected reaches of rivers for the Nile basin and the alignment of the PROBFLO approach to the Nile Eflows Framework is provided in Table 2.

Table 2: Alignment of Nile Eflow Framework phases with the PROBFLO steps.

| Phase | NBI Recommended Tasks (NBI, 2016) | Tasks completed during the PROBLO assessment |
|---|---|---|
| **Phase 1**: Situation Assessment and Alignment Process | ○ Review existing local and transboundary governance structures relevant to eflows management activities,<br>○ Review available information (including knowledge) relevant to eflow assessment management,<br>○ Align eflow activities to existing local and transboundary activities,<br>○ Describe available resources, evidence for eflows assessments and monitoring and management capacity, and<br>○ Describe uncertainties and provide recommendations. | *The Nile Eflow framework has been established to contribute to the life cycle of flow management in the Nile Basin. Phase 1, 2, 3 and 4 of the framework do not specifically deal with eflow determinations, but all of the information is used to direct suitable application of EFAs.*<br><br>For application of the PROBFLO approach (*see Phase 5-7 of the framework*) to be truly "holistic", the eflow determination must be undertaken in the context of the situation of water resource use and protection and aligned to existing processes. As such this step is paralleled in a PROBFLO assessment if the process has not been undertaken in the Nile Eflows Framework. In a PROBFLO assessment the situation assessment and alignment process aligns to steps 1 and 2 of the EFA including:<br>**Step 1: Vision exercise:**<br>1. Resource Quality Objectives<br>2. Endpoints for PROBFLO study<br>**Step 2: Mapping and data analyses:**<br>1. Mapping<br>2. Spatial reference data analyses |
| **Phase 2:** Governance and Resource Quality Objectives Setting | ○ Establish suitable stakeholder group for RQO determination,<br>○ Determine RQO for eflow assessment:<br>  ○ Rapid preliminary Vision and RQO setting<br>  ○ Vision and RQO setting<br>  ○ Describe spatial area (Risk region) demarcation process to choose suitable spatial areas for eflow assessment<br>○ Consider adaptive management processes/requirements, and<br>○ Describe uncertainties and provide recommendations. | For the application of the PROBFL approach (*see Phase 5-7 of the framework*) the assessment is based on a suitable vision and associated reach scale (local) targets or objectives to direct the use and protection of water resources. To achieve this, this phase of the Framework is paralleled in a PROBFLO assessment, if the process has not been undertaken in the Framework. This includes the following step in PROBFLO:<br>**Step 1: Vision exercise:**<br>1. Resource Quality Objectives<br>2. Endpoints for PROBFLO study |

| | | |
|---|---|---|
| **Phase 3:** Hydrological Foundation | ○ Generate reference hydrology/hydrographs for EFA,<br>○ Generate developed hydrographs for EFA<br>○ Descriptive hydrology using appropriate statistics and update database, and<br>○ Describe uncertainties and provide recommendations. | For the application of the PROBFL approach (*see Phase 5-7 of the framework*) a range of hydrological statistics are required that are complementary to the hydrological foundation phase of the Framework. These assessments are undertake in PROBFLO during the data collection and analyses step (**Step 2**). |
| **Phase 4:** Ecosystem Type Classification | ○ Classify ecosystem types for eflow assessments based on:<br>○ Hydrological characteristics,<br>○ Geomorphic characteristics, and<br>○ Biological characteristics.<br>○ Consider the effects of existing ecosystem wellbeing on response of socio-ecological components of different types of ecosystems,<br>○ Provide descriptive maps and update database, and<br>○ Describe uncertainties and provide recommendations. | For the application of the PROBFL approach (*see Phase 5-7 of the framework*) information representing the dynamics of the ecosystem being evaluated is required. This information compliments the ecosystem type classification of the framework for the sites that are being assessed. These assessments are undertake in PROBFLO during the data collection and analyses step (Step 2) and the Risk Region Selection step (Step 3). |
| **Phase 5:** Flow Alterations | ○ Evaluate flow alterations for eflow assessment,<br>○ Develop hydrological scenarios to represent flow options,<br>○ Provide descriptive maps and update database; and<br>○ Describe uncertainties and provide recommendations. | The Nile Eflows Framework phases 5 to 7 are achieved through the application of EFAs. For the Nile Eflows Framework holistic methods including PROBFLO are recommended. Here the application of the PROBFLO steps are aligned to the framework phases 5-7 as follows (*PROBFLO Step 1 to 3 is aligned to phases 1 and 2 of the Framework as described above*):<br>**Step 4:** Conceptual model development. In this step in the PROBFLO process models that represent causal pathways of probable risk or influence (causality) are established to represent the socio-ecological system being considered in the case study. Suitable indicators of the system and relationships between indicators (variables). This qualitative process partially meets the requirements of Phase 6 & 7 of the framework.<br>**Step 5:** Ranking Scheme is established to allow for the calculation of risk to the endpoints selected in PROBFLO. Ranks are comparable between indicators of the system established in Step 4.<br>**Step 6:** Calculate Risk. In this step the hydrological foundation *Phase 3* of the framework outcomes (hydrological statistics |
| **Phase 6:** Flow-Ecological-Ecosystem Services Linkages | ○ Describe flows-ecosystem-ecosystem-services relationships for assessment,<br>○ Consider additional non-flow drivers of change,<br>○ Establish flows-ecosystem-ecosystem-services hypotheses, and<br>○ Describe uncertainties and recommendations. | |

| | | |
|---|---|---|
| **Phase 7:** EFlows Setting and Monitoring | ○ Set eflow requirements through application of selected methods:<br>  ○ Describe uncertainties with eflow requirements,<br>  ○ Describe uncertainty associated with the cumulative effects of non-flow drivers of change, and<br>  ○ Discuss uncertainty associated with the EFM used and resource and evidence availability.<br>○ Provide recommendations to reduce uncertainty for Eflow requirements and establish adaptive management process, and<br>○ Develop a monitoring plan and recommendations for adaptive management. | representing volume, timing, frequency and duration of flows), hydraulics and Ecosystem type *Phase 4* (or habitat characteristics of flows), water quality, geomorphic characteristics, biological and social characteristics of ecosystems and the relationships established in Step 4 (*Phase 5* and *Phase 6*) are evaluated in PROBFLO. The outcome includes eflows settings (*Phase 7*).<br>**Step 7:** Uncertainty evaluation. An important aspect of eflows assessments includes evaluations of uncertainty that affects the PROBFLO outcomes or eflows setting (Phase 7).<br>**Step 8:** Hypothesis establishment to reduce uncertainty. In this step monitoring recommendations are established to reduce uncertainty associated with available data, understanding of the processes and the assessment in an adaptive management context by establishing and implementing suitable monitoring.<br>**Step 9:** Test hypotheses. In this step good practice application of PROBFLO includes learning from monitoring implementing the findings and adjusting the risk assessment. This represents the adaptive management functionality of the approach.<br>**Step 10:** Communicate Outcome. Clear communication of the process is vital to the uptake of the outcomes and the implementation of recommendations from the assessment. |

## 2.2 Application of the PROBFLO Approach for the Low Confidence Environmental Flow Assessment for Selected Sites in the Nile Basin

In this study a regional scale ecological risk assessment using the PROBFLO Environmental Flow (eflows) Assessment approach has been carried out at nine selected reaches of rivers for the Nile basin, following the NBI "Strategy for Management of Environmental Flows in the Nile Basin". Available information with limited ecosystem driver evaluations has been used to implement the ten procedural steps of PROBFLO according to the method presented in O'Brien *et al.* (2018). This PROBFLO assessment includes the evidence based establishment of a socio-ecological system model, to evaluate the probabilistic consequences of multiple flow and non-flow stressors in the Nile basin to multiple social and ecological endpoints, on a regional spatial scale (represented by nine reaches of rivers or sites). The PROBFLO assessment can be undertaken at different levels of confidence and complexity (NBI, 2016a). The assessment described in this report was based only on available desktop information with no field surveys undertaken and is considered to be a low confidence (coarse) assessment. The "present condition" scenario, for this low confidence assessment, for which relevant current data can be collected and evaluated, risk has been evaluated and used with ecological indicator information to establish eflows to maintain the sites in a largely natural (Class B), moderately modified (Class C) and largely modified but sustainable state (Class D) associated with flows. The eflows for the Atbara River site (RR8) was not determined using PROBFLO but the Desktop Reserve hydrological assessment method by Hughes *et al.* (2014) due to the lack of suitable hydraulic and associated socio-ecological information.

### 2.2.1 PROBFLO framework for eflows

PROBFLO assessments are undertaken by specialists in close collaboration with the stakeholders and authorised counterparts representing the water resources being evaluated and society. Holistic, best practice eflow principles require objective and tradeoff decisions usually incorporated into PROBFLO assessments to be based on the desires of society within local and regional legislative contexts. Within the Nile basin context this has been achieved by generating eflow requirements for each site being considered to achieve a largely natural (Class B), moderately modified (Class C) and largely modified but sustainable state (Class D) associated with flows (Table 3).

**Table 3: Summary of the name and description of the six ecological categories used in the eflow assessment to represent the tradeoff between the state of the ecosystem and the availability of water to use.**

| 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 |

The ten procedural steps followed during the low confidence assessment of the nine river reaches is provided in Figure 5 and discussed below.

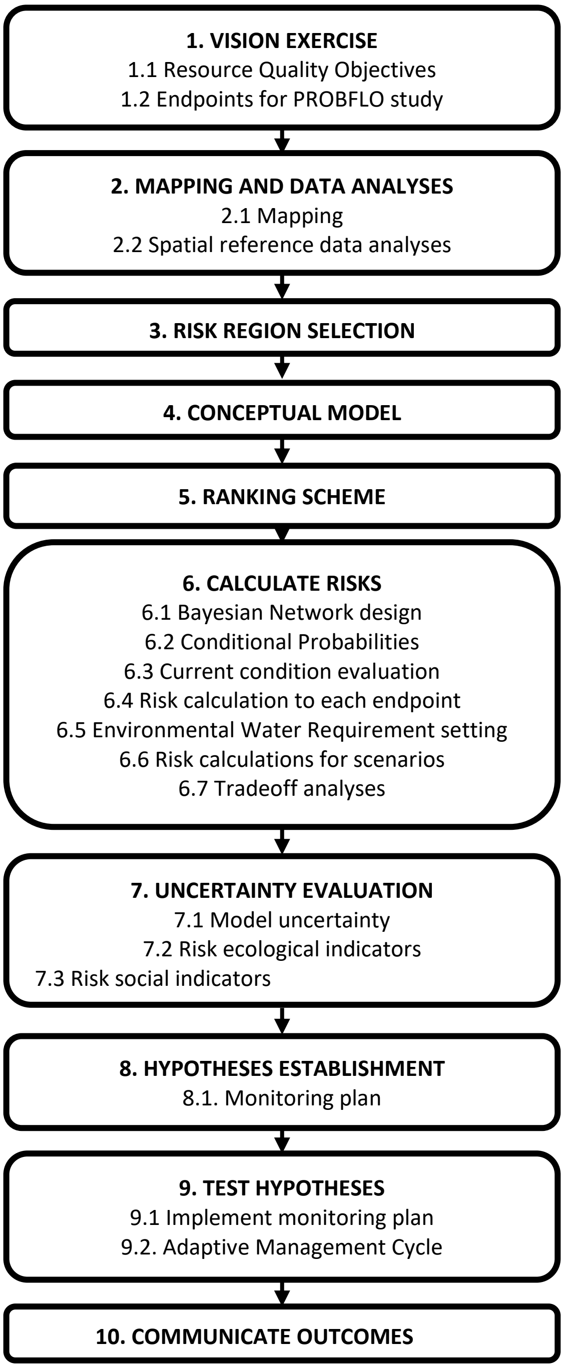


**Figure 5: The PROBFLO framework including the ten procedural steps that will be implemented in the Nile basin case study.**

## 2.3 Step 1: Vision Exercise

The importance of having clear water resource management objectives for a regional scale risk assessment study is imperative as this directs all of the components of the study. Although the purpose of the risk assessment is to evaluate endpoints that are exposed to relatively different risks from sources and stressors in different regions of the study area, in the context of risk pathways, you need to first have an understanding of what managers/stakeholders care about in the landscape and what should be tested in a study. Integrated Water Resource Management strategies, regional management plans and frameworks, national legislation, and established eflow assessment tools advocate the establishment of clear goals or visions to direct the use and protection of water resources (Mitchell, 2005; Dudgeon *et al.*, 2006; Richter *et al.*, 2006; Poff *et al.*, 2010; King and Pienaar 2011; NBI, 2016a). The vision for the study area that initially described the desired level of use and protection should be established within a legislative context. The shared vision objective of the NBI is to '*achieve sustainable socio-economic development through the equitable utilization of, and benefit from, the common Nile basin water resources*' (www.nilebasin.org). In this coarse eflow assessment no water resource use commitments have been made in the context of protection requirements to define a vision for the balance between the use and protection of each site. The approach adopted in this study to provide outcomes for a Class B, C and D allows stakeholders to evaluate and make tradeoff decisions for the use and protection of the water resources in the Nile basin.

In the absence of a detailed stakeholder consultation process, advocated as best practice (NBI, 2016a) during the determination of eflows, and following the recommendation of Horne et al (2017), the following approach to clarifying the Vision and setting the endpoints has been adopted:

1. Statements from existing policy and strategies, that give expression, either intentional or by inference, to a vision or management objective for any aspect that may be related to eflows, are reproduced here. This approach assumes that the official policies and strategies that are already in existence are indeed expressions of the requirements of stakeholders, while acknowledging that this may not always be the case.
2. A number of endpoints are defined. These are important parts of the intersection of natural resources and the livelihoods of people that are at risk as a results of changes in management of the system. Some of the endpoints are purely socio-economic in nature, thus those things that the people need from the sustained existence of the Nile basin. Other endpoints are purely ecological and are those aspects of the ecosystem that need to be maintained to ensure a fully functional ecosystem, which in turn will reflect on the provision of livelihoods to the people.
3. The final vision, objectives and endpoints contained in this document will be presented to key stakeholders in the region for discussion. Note that in this process any recommendations for a Vision, Objective or Endpoint that differ from official policy or strategy, would require a change to the official perspective and thus will be referred back to processes outside of this project for resolution.

*The Nile eflow strategy (NBI, 2016) strategy was prepared by the Nile Technical Advisory Committee (NILETAC) and Nile Basin Environmental Flows Expert Group through the course of the 'Preparation of NBI Guidance Document on Environmental Flows' - Project1. The Strategy preparation process involved two consultation workshops with a regional working group drawn from NBI countries - from the 29th July to 1st August 2015 in Kigali, Rwanda and 25th to 26th April 2016 in Addis Ababa, Ethiopia; a review of international practice in environmental flow management (documented in Background Document 1: Environmental Flow Assessment: A review of global practices and experiences), a desk level assessment of the Nile Basin aquatic ecosystems types and their status (compiled as Background Document II: Aquatic ecosystems of the Nile Basin, their wellbeing and response to flow alterations) and a review of experiences with eflow management in the Nil Basin countries (compiled in Background Document III: Management of environmental flows in the Nile River Basin: practices and experiences). From the strategy the vision for the successful management of environmental - flows in the Nile Basin is: "A Nile Basin in which water resources are developed and managed while sustaining the river flows required for healthy freshwater and estuarine ecosystems supporting human livelihoods and wellbeing that depend on them". The vision objective is "to achieve sustainable water resources development through management of the Nile Basin's flows required to sustain the freshwater and estuarine ecosystems and the human livelihoods and wellbeing that depend on these ecosystems." This vision is based on both the NBI's Shared Vision and the Brisbane Declaration's definition of environmental flows.*

Endpoints have been defined as "*specific entities and their attributes that are at risk and that are expressions of a management goal*" (USEPA, 2003). For example, if the Vision and Objectives for the Nile basin includes the provision of fish as a protein source for the local inhabitants, then the endpoint will be that fish are indeed being provided by the system to be used by local inhabitants. This supply of fish may be at risk due to the drivers of change (including quantities and quality of water), thus upstream dams may be impacting on the ability of the fish to breed, impacting on the supply of fish to communities. The endpoint is thus a measure that fish are available to communities, which is then one of the indicators of success or failure to achieve the Vision for the resource.

For each of the issues that are described in the context above, both the social and economic as well as the ecosystem activities, there is a level of risk of failure of supply in the event that the water cycle fails to deliver. Figure 6 is an illustration of how the endpoints are hypothetically related to the sources of stress in the system. If, for example, there is a link between the sources of stress (e.g. abstraction of water for agriculture), the stressors (e.g. the quantity of streamflow affected by the abstraction), which impacts on the water-related habitats (e.g. the instream volume of water), ultimately this would result in an impact on achievement of those endpoints that are affected by this causal chain. This initial conceptual model is used to build a representative socio-ecological system model in the PROBFLO assessment to represent how the system may respond to altered flows in the case study.

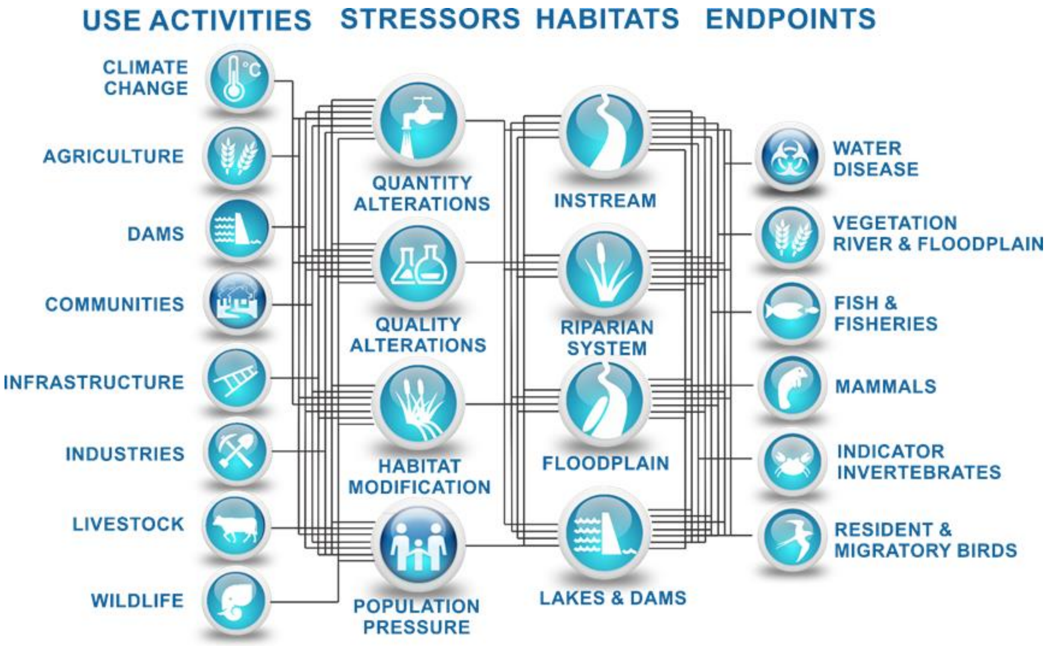


**Figure 6: Simplified conceptual model for the eflow assessment of the Nile basin depicting causal risk pathways between sources, (use activities), stressors, habitats and endpoints considered in the study.**

As indicated, there are two main categories of endpoints. Firstly, the social endpoints, include livelihood aspects related to the Nile basin that would be at risk of failure as a result of developments in the region that are impacting on water quantity and quality. Secondly, the ecosystem endpoints, characteristics of the ecosystem that are necessary for the entire system to continue as a functional ecosystem that is providing services to society.

It is important to note that the vision, objectives and endpoints are based on a review of policy and literature including official management plans etc., without consultation with the stakeholders at different levels. Such a consultation would embark on an intensive process as it is inevitable that new objectives would be raised by stakeholders that are at odds with what is already contained in policy. Thus, if such a process is initiated, it needs to be integrated with policy revision, but this was not within the mandate of this assignment.

## 2.4 Step 2: Mapping and Data Analysis

During this step, the spatial extent of the study area must be defined including the identification of potential sources, habitats and impacts (O'Brien *et al.*, 2018). Hydrology, hydraulics, vegetation and fish data was used in this coarse eflow assessment and the availability of data is provided in Table 4.

Table 4: Data availability for each river reach

| Data availability | RR1 | RR2 | RR3 | RR4 | RR5 | RR6 | RR7 | RR8 | RR9 |
|---|---|---|---|---|---|---|---|---|---|
| Hydrology | Historical data available. Refer to hydrological section. | Historical data available. Refer to hydrological section. | Historical data available. Refer to hydrological section. | Historical data available. Refer to hydrological section. | Historical data available. Refer to hydrological section. | Historical data available. Refer to hydrological section. | Historical data available. Refer to hydrological section. | Limited hydrological data available. Data modelled from regional information for the study. | Historical data available. Refer to hydrological section. |
| Hydraulics | No empirical data available. Low confident desktop hydraulic assessment using satellite data and contour information. | No empirical data available. Low confident desktop hydraulic assessment using satellite data and contour information. | No empirical data available. Low confident desktop hydraulic assessment using satellite data and contour information. | No empirical data available. Low confident desktop hydraulic assessment using satellite data and contour information. | No empirical data available. Low confident desktop hydraulic assessment using satellite data and contour information. | No empirical data available. Low confident desktop hydraulic assessment using satellite data and contour information. | No empirical data available. Low confident desktop hydraulic assessment using satellite data and contour information. | No empirical data available. Low confident desktop hydraulic assessment using satellite data and contour information. | No empirical data available. Low confident desktop hydraulic assessment using satellite data and contour information. |
| Ecological data | Google based images available for vegetation and habitat consideration with a range of historical photographs. Some limited ecological data available for the region. Suitable for application for the site. Regional fish data available for analyses. | Google based images available for vegetation and habitat consideration with a range of historical photographs. Some limited ecological data available the region suitable for application for the site. Regional fish data available for analyses. | Google based images available for vegetation and habitat consideration with a range of historical photographs. Some limited ecological data available the region suitable for application for the site. Regional fish data available for analyses. | Google based images available for vegetation and habitat consideration with a range of historical photographs. Regional fish data available for analyses. | Google based images available for vegetation and habitat consideration with a range of historical photographs. Some limited ecological data available the region suitable for application for the site. Regional fish data available for analyses. | Google based images available for vegetation and habitat consideration with a range of historical photographs. Some limited ecological data available the region suitable for application for the site. Regional fish data available for analyses. | Google based images available for vegetation and habitat consideration with a range of historical photographs. Regional fish data available for analyses. | Google based images available for vegetation and habitat consideration with a range of historical photographs. | Google based images available for vegetation and habitat consideration with a range of historical photographs. Regional fish data available for analyses. |
| Social data | Limited regional information available to describe social context of the area. Applied to satellite imagery for region. | Limited regional information available to describe social context of the area. Applied to satellite imagery for region. | Limited regional information available to describe social context of the area. Applied to satellite imagery for region. | Limited regional information available to describe social context of the area. Applied to satellite imagery for region. | Limited regional information available to describe social context of the area. Applied to satellite imagery for region. | Limited regional information available to describe social context of the area. Applied to satellite imagery for region. | Limited regional information available to describe social context of the area. Applied to satellite imagery for region. | Limited regional information available to describe social context of the area. Applied to satellite imagery for region. | Limited regional information available to describe social context of the area. Applied to satellite imagery for region. |

## 2.5 Step 3: Risk Region Selection

The Nile River region is dealing with multiple stressors that threaten the livelihoods of many communities and the dynamic ecosystem processes, aquatic habitats and biodiversity of the region. Important stressors include the excessive use of land and water resources resulting in habitat alteration, flow alterations and pollution, with limited investments in water infrastructure, resulting in food insecurity, rampant poverty, and high rates of population growth and urbanization. The region contends with a highly variable climate, especially in the northern part of the basin, that causes significant societal and environmental impacts. During the dry phase of the 1970’s and 1980’s large droughts affected the livelihoods of communities in the region, which in turn affected the development (economic growth) potential of the region. There are concerns that during the 21st Century climate change may exacerbate and accelerate the existing trends in poverty, under development and environmental degradation in the region along with the high biodiversity and ecosystem processes (Sissoko *et al.* 2011). During the drought connectivity between the river and floodplain and associated lakes was minimal resulting in major socio-ecological impacts including loss of life and endangerment of many endemic species. The PROBFLO approach includes the relative evaluation of multiple sources of stressors to endpoints on a regional scale which should be spatially and temporally referenced for regional comparisons/evaluations in a PROBFLO assessment (Landis 2004; Landis & Wiegers 2007; O’Brien *et al.* 2018).

In this study available data has been used to describe the socio-ecological ecosystem of concern. Available evidence has been reviewed and spatially referenced with uncertainties associated with the availability and quality of data used in the assessment documented for evaluation in Step 7.

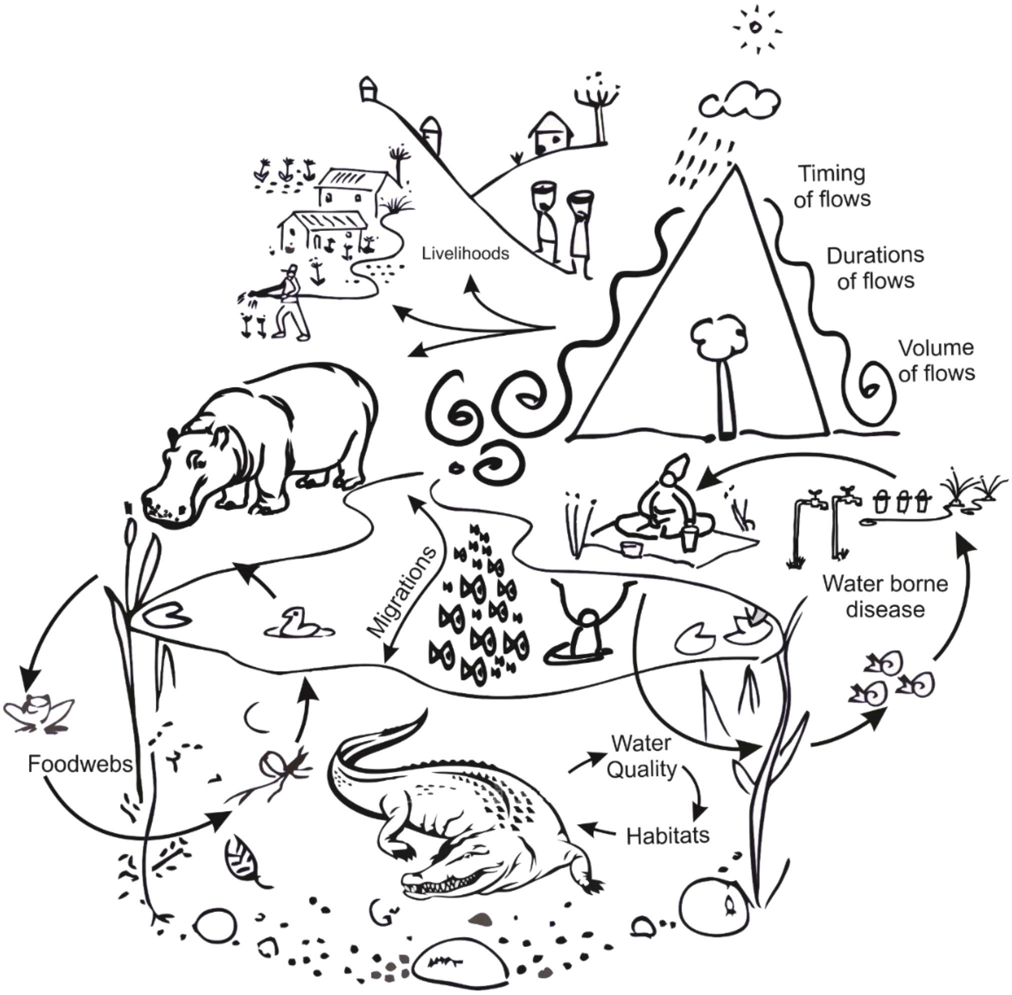


**Figure 7: Schematic representation of the socio-ecological system of the Nile basin used to establish a probabilistic ecological risk assessment model for the study to evaluate the socio-ecological consequences of altered flow and non-flow stressors to social and ecological endpoints selected to represent what we care about in the study are where these endpoints occur.**

### 2.5.1 Risk region selection

For the selection of risk regions in this study, a combination of the management objectives, source information, and available habitat data was used to establish geographical risk regions for the relative risk assessment (Landis 2004; O'Brien and Wepener, 2012). This allows the outcomes of the assessment 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. For this study the nine sites selected were based on a consultation process with the Nile Technical Advisory Committee representatives at the eflow assessment for the Nile basin regional consultation and training workshop from 6-7 September 2018, Nairobi, Kenya. Sites were based on their locality for representation of regional water resources use and protection issues and represent socio-ecological hot-spot regions from each sub-basin of the Nile basin that will contribute to the implementation of the Nile Basin Decision Support System.

### 2.5.2 Scenario selection

In this risk assessment a range of water resource use scenarios associated with a range of ecological categories (Table 3) and associated states of driver components of ecosystems have been considered to evaluate temporal risk projections. Following the development of a socio-ecological model to represent the system, and how it responds to changes in natural environmental variability and land-use changes (multiple stressors) a range of water resource use, protection and or climate change projection scenarios can be evaluated. In the PROBFLO approach scenarios that meet hypothetical requirements to attain a Class B, C and D were considered.

## 2.6 Step 4: Conceptual Model

In this step, following the evaluation of available evidence and a standard list of social and ecological indicators for a desktop PROBFLO assessment (ANNEXURE E: LIST OF THE STANDARD SOCIAL AND ECOLOGICAL INDICATORS USED IN A DESKTOP PROBFLO ASSESSMENT.), a series of conceptual models that link flow variability to endpoints of interest are presented. These conceptual models are used to describe hypothesised relationships between multiple sources, stressors, habitats and impacts to endpoints selected for the study. Through this process scientists are able to generate hypotheses that represent the socio-ecological processes of the system being evaluated, and probable cause and effect relationships of: (1) sources to stressors to (2) multiple receptors in relation to (3) their impacts on the endpoints, selected for the study. The conceptual models for the case studies presented, addressed the requirements of the PROBFLO approach. The PROBFLO conceptual model thus conforms to the regional scale eflow framework procedures in: (1) the selection of socio-ecological endpoints, to direct the hydrologic foundations for the study including the selection of hydrological statistics required, (2) to classify ecosystem types based on geomorphic, water quality, quantity and ecoregion considerations, and with this data, (3) to incorporate evidence based flow-ecosystem relationships and flow-ecosystem service relationships, with relevant non-flow variable relationships upon which the assessment is based.

Following the development of the conceptual model, a master general model was initially developed. Thereafter detailed models were established for each endpoint. These conceptual models represent our understanding of the relationships between sources and endpoints in the study and can be adapted with new information. The detailed conceptual models were used to develop risk models for each endpoint in the study and were then used to generate Bayesian Network models for each endpoint and an Integrated Bayesian Network is also produced (Figure 8). A detailed conceptual model development overview is presented for each endpoint (Step 6). Following the completion of risk models using NeticaTM BN software (by Norsys Software) for each endpoint they were integrated into a Bayesian Network model for the study (see the data and model folders for the large operating model).

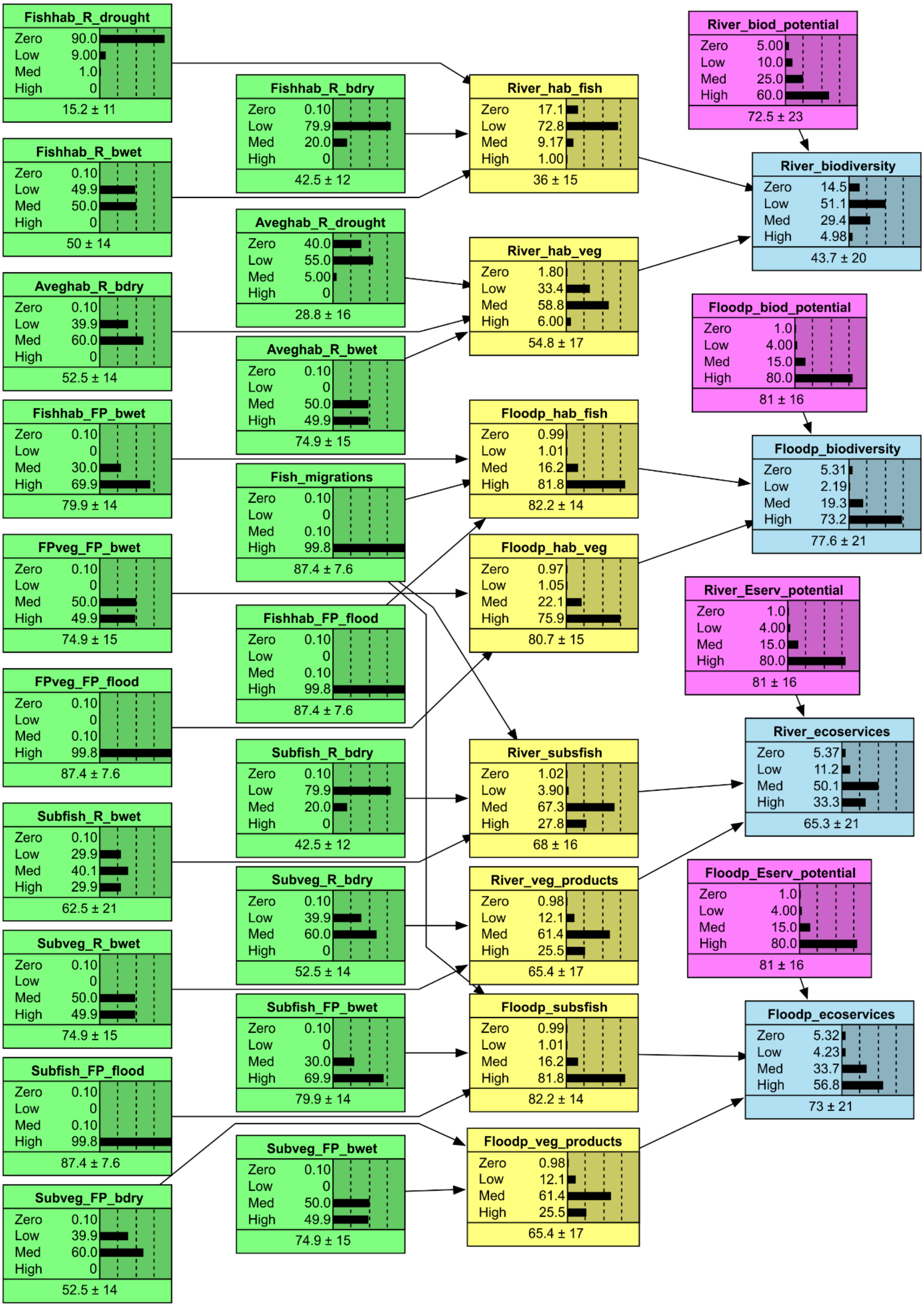


**Figure 8:** Master Bayesian Network for the coarse eflow assessment of the Nile River coarse eflow assessment.

## 2.7 Step 5: Ranking Scheme

Ranking schemes are used to represent the state of variables, with unique measures and units to be comparable as non-dimensional ranks and combined in BN-RRMs (Landis, 2004; Landis *et al.*, 2016; O'Brien *et al.* 2018). Four states designated as zero, low, moderate and high, as traditionally used in RRMs (Colnar & Landis, 2007; O'Brien and Wepener, 2012; Hines & Landis 2014; Landis *et al.* 2016), have been incorporated into the PROBFLO process (O'Brien *et al.* 2018). The states represent the range of wellbeing conditions, levels of impacts and management ideals as follows:

- **Zero**: pristine state, no impact/risk, comparable to preanthropogenic source establishment, baseline or reference state,
- **Low**: largely natural state/low impact/risk, ideal range for sustainable ecosystem use,
- **Moderate**: moderate use or modified state, moderate impact/risk representing threshold of potential concern or alert range, and
- **High**: significantly altered or impaired state, unacceptably high impact/risk.

This ranking scheme selected for the PROBFLO assessment in this study represents the full range of potential risk to the ecosystem and ecosystem services with management options. Low risk states usually represent management targets with little impact and moderate risk states represent partially suitable ecosystem conditions that usually warrant management/mitigation measures to avoid high risk conditions. The incorporation of Bayesian Network (BN) modelling into PROBFLO, allows the approach to incorporate the variability between ranks for each model variable, represented as a percentage for each rank. Indicator flow and non-flow variables representing the socio-ecological system being evaluated in a PROBFLO assessment are selected (linked to endpoints), and unique measures and units of measurement are converted into, and represented by ranks for integration in BN assessments. For the BN assessment ranks are assigned scores along a percentage continuum representing the state of the variables using natural breaks of 0.25 (zero), 0.5 (low), 0.75 (moderate) and 1 (high) in the calculation.

## 2.8 Step 6: Calculate Risks

The Bayesian Network models include nodes to represent indicators of the socio-ecological system being evaluated, measures (with units) and interactions between variables that are initially set up, justified, tested and then applied (O'Brien *et al.*, 2019). These models can be analysed individually or integrated using a range of BN modelling tools, using nodes representing variables that share the same indicators and measures. Bayesian Networks are probabilistic modelling networks that graphically represent joint probability distributions over a set of statistical values (Pollino *et al.*, 2007; Korb and Nicholson, 2010). They include parent or input nodes and child or conditional nodes with links that represent causal relationships between nodes combined by Conditional Probability Tables (CPTs) (Mccann *et al.*, 2006; Landis *et al.* 2016;). Conditional Probability Tables describe conditional probabilities between the occurrence of states in the parent nodes and the resulting probabilities of states in the child nodes (Landis *et al.*, 2016). In this case study, we made use of the Netica$^{TM}$ BN software by Norsys Software (http://www.norsys.com/) to perform the assessments.

The BNs are initially used to evaluate the risk of anthropogenic/natural hazards to endpoints per risk region, in a relative manner for comparisons, for multiple temporal periods (high or low flow months and wet or drought phases etc.) and have been included in a relative manner to each other. Bayesian Networks make use of available data and expert solicitations as evidence to represent risks to current or present scenarios. Present projections of risk to the endpoints can generally easily be validated using available data, knowledge of existing relationships between variables and by carrying out directed field survey campaigns to describe/test risk relationships. Present risk projections are then calibrated by evaluating benchmark or historical scenario risk projections using the established models, which can often be validated with historical data.

To evaluate the socio-ecological consequences of alternative water resource use scenarios, tradeoffs of acceptable risk to social and ecological endpoints are initially established for each risk region by establishing a hypothetical flow scenario proposed to meet a Class B, C and D ecological state. These tradeoffs of acceptable risk, comparable with the vision of sustainable use (Class B-D) for the resources of the study area, are represented in the BNs as forced endpoint risk distributions or profiles. These profiles usually range between low and moderate risk with usually no high risk probabilities. In relation to the definitions of the ranks used in PROBFLO, tradeoffs of acceptable risk for eflow determination should only dominate the “moderate” risk range when there is certainty that the eflow requirements can be provided, such as in the case of eflow releases from a dam. In case studies where there is high uncertainty associated with the ability to provide eflow requirements, such as the management of multiple water resource users to cumulatively maintain eflows, then a buffer should be provided according to the definition of ranks and the “low” risk range should be selected. After the selection of tradeoffs of acceptable risk are established the calibrated BNs are forced to generate the state (rank distributions) of input flow variables used in the assessments.

These flow related variable state requirements that are spatially and temporally referenced are provided to a hydrologist to describe the eflow requirements which can be presented in various formats, such as daily or monthly water (usually $m^3/s$) discharge percentiles (see Hydrology specialist report section). During the eflow determination procedures the state of non-flow variable nodes, which contribute to the risk to endpoints, associated with flow variables can either be maintained in their current state, and described as such or amended with available water resource use information. This can include the increased requirement of water for Basic Human Needs, for increases in growth of human populations depending on the resource for example. Following the establishment of eflows, the socio-ecological consequences of altered flows, associated with alternative water resource management options or climate change variability, for example, can be evaluated in a relative manner by generating and evaluating a range of future scenarios in PROBFLO.

Risk outcomes directly obtained from the Netica Bayesian Network assessment are presented per RR with averages, standard deviation (SD) and risk rank probability profiles.

With PROBFLO a probabilistic system model is established to represent the socio-ecological system being evaluated. This model is set up using evidence representing the present/current conditions that can be validated with field data/evidence. After calibrating the model with historical data to that the response of the model to changes in environmental variable state changes is realistic, the model is used to establish eflows. This is achieved by selecting desired risk profiles for the endpoints considered in the study, forcing the model to reflect these profiles and using it to model eflow ecosystem driver statistics. These statistics are then used to describe desired hydrological variables which can be integrated to develop an integrated hydrograph. This hydrograph is then shaped to mimic the shape of the natural hydrograph and then tested again to ensure that the socio-ecological consequences of the integrated eflows scenario still results in risk profiles comparable with the chosen risk profiles for the eflow assessment.

## 2.9 Step 7: Uncertainty Evaluation and Way Forward

Best ecological risk assessment practice requires the explicit evaluation of uncertainty, or confidence assessment, (O'Brien and Wepener 2012; Landis, 2004; O'Brien *et al.*, 2018), which has been incorporated into the PROBFLO approach. Any and all aspects of uncertainty associated with the entire application of the PROBFLO approach for the Nile basin including objectives and endpoint selection for the assessment, availability and use of evidence, expert solicitations and model uncertainty for example, must be addressed. In an effort to reduce uncertainty, the BN-RRM approach adopted by PROBFLO inherently considers uncertainty associated with cause and effect relationships and the use of real data with expert solicitations. The additional incorporation of entropy reduction analysis in relative risk calculations using Monte Carlo simulations also contributes to uncertainty reduction in PROBFLO. Additional analyses of the sensitivity of the BN-RRM should be addressed within the uncertainty evaluation section (Pollino *et al.*, 2007; Hines and Landis, 2014), where the relative influence of input nodes on the endpoints can be evaluated as part of the PROBFLO assessment. These results of the uncertainty assessment are used to provide context to the stakeholders of a PROBFLO assessment and contribute to the decision making process in eflow assessment studies.

For all of the BNs created in this study the sensitivity of the input variables was evaluated in Netica using the "Sensitivity to Findings" tool. This approach allows for the relative contribution of each variable to be evaluated (ANNEXURE G UNCERTAINTY ANALYSES SECTION: SENSITIVITY ANALYSIS OF THE BAYESIAN NETWORK). These assessments are used to evaluate model structure and interpret risk result outcomes with the stakeholders of the assessment (Marcot, 2012; Landis *et al.*, 2016). From this assessment the test demonstrates that both PROBFLO operators and specialist who provided inputs to the outcomes contribute to the sensitivity of the model and its outcomes. When the operators change the model and its parameters and or the input data changes the model responds to changes. Sensitivity analyses demonstrate that the models are sufficiently small (number of tiers) to allow input variables to have a direct contribution to the endpoint outcomes.

Additional important areas of uncertainty observed in the study include:

- Cause and effect risk pathways are dependent on our understanding of the relationships between flows and non-flow driver variables and ecosystem processes and functions. Knowledge of these relationships are relatively limited result in inherent uncertainty. The generation of and testing of hypotheses to reduce uncertainty should be considered, especially if outcomes are used to change water resource use scenarios.
- The study addressed the socio-ecological consequence of alternative water use scenarios to the wellbeing of the ecosystem (based on endpoints) and associated availability of and conditions of ecosystem services. The study did not address the social impacts (including economic impact) associated with loss of natural products to communities and any visual and or aesthetic impacts of the developments.

## 2.10 Step 8: Hypothesis Establishment

A monitoring programme measures the state of the ecosystem over space and over time. This is required for management of the Nile basin, as different management actions are possible and their consequences need to be assessed and compared. The success of this monitoring programme will heavily depend on having well-articulated questions and objectives, which for this study have been formulated in the conceptual model (see Step 4). The conceptual model describes the process of interaction between altered water flows and the endpoints of management.

While this monitoring programme concentrates on the biophysical components of the ecosystem, it would be possible to also include variables of a socio-economic nature thus, to monitor the attainment of the endpoints that have been used (see Step 1). Such a programme would then be a more complete social-ecological monitoring programme but is not within the mandate of this project.

The purpose of the monitoring programme for the implementation of the eflows is as follows:

1. To collect biophysical data demonstrating the response of the ecosystem to alterations in flow. This data can be used to validate or update the eflows assessment which had to predict the likely response of the system to altered flows.
2. To provide data that can be used to evaluate the state of the ecosystem in relation to the vision and objectives (endpoints) that have been set.
3. To provide data that can be used for day-to-day management of flows in the system, to ensure achievement of the eflows and thus to minimise risk to the users of the system.

Monitoring needs to take place over space and time. The spatial distribution of the monitoring effort needs to consider the spatial distribution of the ecosystem itself, the differences between the upstream rivers, the floodplain and the single river downstream. The influence of time on the monitoring programme relates to the required confidence in the biophysical data that is collected, as this varies over time in response to seasonal changes. The greater the frequency of monitoring, the greater the certainty that all of the seasonal changes will be described so that an overall picture of the ecosystem can be presented. However, pragmatism is necessary in order to contain the costs of monitoring to what is reasonable.

### 2.10.1 Monitoring the ecosystem

The various components of the ecosystem will respond differently to catchment activities including the alteration of flows. Monitoring each of these different components will provide different perspectives on the success at managing the eflows, thus while a particular flow regime may benefit the fish population, it may not benefit the invertebrates. Those components that need to be considered because they were used for understanding the requirements of the ecosystem and thus for the development of the eflows were the hydrology, hydraulics, sediments, water quality, vegetation, fish, mammals, birds and invertebrates. Each of these components has very different requirements for monitoring as will be shown below.

### 2.10.2 Monitoring over space

Management of eflows for the entire system requires management particularly of the flows in the upstream Nile basin rivers, but the main impacts will be recorded in the Nile. It is important to acknowledge, that the mandate of the project was to concentrate on the Nile and not to continue downstream. It would be possible to link these eflows with the entire system, including the Lower Nile River and Estuary/Delta, but that is not done here.

### 2.10.3 Monitoring over time

Ecosystems change naturally over time, and even more so in the case of the Nile when there is an annual flood event, driving a radical change between the annual flood and the dry season in between.

Monitoring thus needs to capture the range of change in the ecosystem, as both the high flow and the low flow are important for ecosystem sustainability.

### 2.10.4 Adaptive management

It is important that this monitoring programme should form part of an Adaptive Management cycle, where it is understood that the results that are returned from the monitoring should inform a progressive improvement not only of the monitoring itself, but also a refinement of the objectives and targets that are set.

A proposed adaptive management cycle is shown in Figure 9. This involves selection of the areas and sites that, when monitored, would best represent the state of the ecosystem for the Nile, and then description of the vision and objectives for the area and the sites. Note that the sites selected may differ for each indicator, thus within the chosen area, one site may be appropriate to monitor the fish, while another the hydrology and another the vegetation. It is then necessary to prioritise the possible indicators for each area and site, monitoring only those indicators that will give an indication of the state of the ecosystem as affected by eflows, although in a wider management perspective, this monitoring could be integrated with other monitoring programmes that have different objectives. Having selected the indicators, then a numerical target for each indicator should be selected, the achievement of which will indicator that the ecosystem is reflecting the vision and objectives that were set for the area/site (see Dickens et al, 2018). Monitoring actions should then be implemented at the required levels of intensity. Periodically, once in ten years, a review of all of the steps so far should be carried out and evaluated for progress towards meeting the vision and objectives, before changes should be made to the cycle for the next ten years.

Figure 9: Adaptive management cycle and monitoring programme for the Nile Basin

### 2.10.5 Progressive monitoring

What is provided below in Table 5 is a system of progressive monitoring that can be implemented as the capacity of the governance systems are improved. Thus Level 1 monitoring is the bare minimum that should be implemented to manage the ecosystem in terms of eflows, but that will be associated with a higher level of risk that it will not reflect all of the changes that may be going on in the ecosystem. Level 3 monitoring will be appropriate where the management capacity is fully in place and where much higher certainty in the results is required, ensuring with much less risk that the endpoints are achieved.

**Table 5:** Progressive monitoring recommendations for eflows according to resource availability.

| Progressive monitoring | Human capacity/expertise | Confidence | Uncertainty contribution to risk | Monitoring components and type of data collected | | | |
|---|---|---|---|---|---|---|---|
| | | | | **Hydrology** | **Hydraulics** | **Ecological information** | **Social information** |
| **Level 1** | Low: limited management capacity and specialisation. | High uncertainty | High | Establish gauged section, monitor monthly average flows by reading gauge plates. | Collect 1D hydraulics for rated section, photograph instream/floodplain habitats associated with discharge. | Review regional information and initiate low confidence biodiversity/fisheries assessment. | Monitor use of ecosystem services and document activities and relationship between activities and seasonal flow variability. |
| **Level 2** | Moderate: Moderate management capacity and usually low specialisation, some access to consultants/scientists. | Moderate uncertainty | Moderate | Establish gauged section, monitor daily flows by reading gauge plates and reporting regularly. | Collect 1D hydraulics for rated section, photograph instream/floodplain habitats associated with discharge, evaluate velocity depth profiles associated with 1D section. | Determine baseline biodiversity and ecosystem process information. Monitor fisheries catch and undertake simple species (e.g.. Indicator fish) recruitment surveys etc. Review local community knowledge of ecosystem state. | Evaluate the state of ecosystem services and document activities and relationship between activities and seasonal flow variability. |
| **Level 3** | High: High management capacity and specialisation or access to specialists. | High confidence | Low | Establish gauged section, monitor hourly flows (discharge) remotely. | Collect 2D hydraulics for reach associated with rated section, photograph instream/floodplain habitats associated with discharge, model various velocity depth profiles associated with reach. | Determine baseline biodiversity and ecosystem process information. Collect local flow-ecosystem relationship data and associated response of ecosystem to flow variability. | Evaluate the state of ecosystem services and determine flow-ecosystem service relationship and consequences of altered flows. |

## 2.11 Assumptions and Limitations

This is a coarse application of the holistic PROBFLO approach as developed under the NBI "Strategy for Management of Environmental Flows in the Nile Basin" to nine river reaches in the Nile basin. The approach is based on available literature and knowledge of the rivers considered. No empirical data has been used in the determination of the eflows for these rivers and no missing data has been collected through field campaigns or specific assessments. The outcomes should be considered with caution and not used to implement water resource use development without further in-detail studies. While useful for planning and regional management of water resources, the approach has also successfully developed a risk assessment framework that can be updated with data/evidence to reduce uncertainty in the eflow recommendations and associated risk projections.

Such detailed studies should include site specific data collection of biological, physical and social attributes of the socio-ecological system being considered. In particular median monthly flow was used in this study that should be improved to daily flow considerations. Hydraulic analyses undertaken in this study is of low confidence and made use of spatial datasets with respective limitations in their accuracy. Detailed cross section information with associated discharge data and habitat (velocities, depths, geomorphology and cover features) should be collected. Non-flow related water quality and disturbance to wildlife impacts should be evaluated for local and regional consideration of multiple stressors in the region.

Improvements to the flow-ecosystem and flow-ecosystem-service relationships established in this study is required. These relationships associated with environmental and flow related ecosystem driver information should include reach specific biodiversity, ecosystem process and connectivity information that should be collected in the field. In addition to ecological processes, provisioning, regulation and cultural services should be characterised and linked to flows and non-flow variables.

The outcomes of this assessment are useful for planning and can be foundational for the establishment of a regional eflow monitoring programme where nations have the opportunity to collectively implement this risk assessment framework in each region, share the information and improve on our understanding of the socio-ecological systems and eflows required to maintain them. This opportunity will also allow stakeholders of each region to be capacitated using a collaborative framework where information can be shared and used to contribute to the management of transboundary resources.

### 2.11.1 The Vision and Endpoints

The vision, objectives and endpoints selected for the study are based on a review of policy and literature including official management plans etc., without consultation with regional and local stakeholders. A stakeholder engagement process may result in the determination of additional objectives for eflow assessments in the region.

### 2.11.2 Data Limitations

The approach of the coarse eflows study is to make use of existing and mostly limited datasets to conduct first stage eflow assessments at different reaches in the Nile basin. As it was not foreseen to collect additional data and to close data gaps, it is respectively unavoidable that the level of confidence in the study results is limited by the detail of data used to conduct the analysis. No empirical site specific ecological information is available that can directly be linked to the hydrology and hydraulics assessment to establish flow-ecosystem relationships required for the PROBFLO assessment. The approach does however allow for desktop assessments using satellite and aerial imagery for habitat and plant evaluations, and regional and inferred information for instream assessments. In this case study hypothetical flow-ecosystem relationships are established to represent the requirements of the ecosystem for the assessment from available information. For this case study only fish and riparian vegetation has been used to establish ecological requirements for eflows. Here ecologists identified indicators of eflows and their requirements for a Class B, Class C and Class D ecological state. These requirements were provided to the hydrologist to establish hypothetical flow scenarios that meet these requirements. A flow-ecosystem risk model representing the integrated socio-ecological system was then established using PROBFLO. This was used to evaluate the socio-ecological consequences of the altered Class B, Class C and Class D flow scenarios to range of social and ecological endpoints. The endpoints represent a range of social and ecological components of the system that we care about. For this study we selected requirements of indicator species that represent biodiversity and the provision of food and building materials and natural products as ecosystem services. While being coarse, the approach follows NBIs "Strategy for Management of Environmental Flows in the Nile basin" requirements.

# 3 RESULTS OVERVIEW

## 3.1 Vision and Endpoints

The vision for this study is based on the objective of the NBI is to '*achieve sustainable socio-economic development through the equitable utilization of, and benefit from, the common Nile basin water resources*' (www.nilebasin.org). In this coarse eflow assessment however no water resource use commitments have been made in the context of protection requirements to define a vision for the balance between the use and protection of each site. In this case study eflows to achieve a Class B, Class C and Class D (Table 3)

For this study the vision for the rivers considered is to determine the eflow requirements to maintain the rivers in a largely natural (Class B), moderately modified (Class C) and largely modified but sustainable state (Class D). These states relate to low, moderate and high use allocations to allow tradeoff considerations. Following from the Vision the following list of endpoints have been selected (Table 6).

**Table 6 Social (SE) and Ecological (EE) Endpoints. The eflow code is that code that is used for Bayesian Network modelling.**

| ENDPOINT NUMBER (DESCRIPTION, EFLOW CODE) | DESCRIPTION |
|---|---|
| **Social Endpoints (SE)** | |
| **Floodplain ecosystem services** | Maintain the provision of natural products and associated provisioning and regulating services including maintenance of the quality of the floodplain for subsistence harvesting and agriculture. |
| **River ecosystem services** | Maintain provision of natural products, primarily focused on availability of fish for subsistence fisheries, and other provisioning and regulating service conditions. |
| **Ecological Endpoints (EE)** | |
| **Floodplain biodiversity** | Maintain habitats and indicator species that represent the existing biodiversity of the floodplains and key ecosystem processes associated with protecting biodiversity. |
| **River biodiversity** | Maintain habitats and indicator species that represent the existing biodiversity of the rivers and key ecosystem processes associated with protecting biodiversity. |

## 3.2 Data Analysis

An overview for each component is provided in the sections below but the detailed results are divided provided in Sections 4 for each river reach. Also consider the literature review outcomes in ANNEXURE A: LITERATURE REVIEW OF SOCIO-ECOLOGICAL AND FLOW INFORMATION TO DETERMINE COARSE EFLOWS FOR SELECTED SITES IN THE NILE BASIN.

### 3.2.1 Hydrology Assessment

#### 3.2.1.1 Background to hydrological data

The availability of long-term (>30 years) daily or monthly hydrological data to represent climatic variability, especially where high variability within year and between years are experienced, is required for the determination of the Environmental Flow Requirements (EFR or eflows) to provide high confidence results.

It is important to note the following regarding the hydrological data, namely to (i) summarise the primary sources of hydrological data and information available, (ii) the selection of specific hydrological datasets for use during the eflows assessment, (iii) provide an overview of the catchment and its developments, and, (iv) summarise any changes to the hydrology e.g. changes to the gauging weir, discharge tables or any other changes that will reduce the confidence in the data. These are required to provide the baseline or reference flows to build the hydrological foundation for the EFR determination.

These reference flows can refer to natural or minimally impacted flows at certain points in the rivers (important tributaries, Environmental Flow Requirement sites, gauging weirs, or large development sites) in a catchment or at the outlet of an entire basin. If a long enough observed flow record is available from a gauging station, the record period could be separated for both baseline (before developments) and for present day development conditions. For example, if the observed flow record is from 1920 to 2015 and the only development was the construction of a dam and associated infrastructure for irrigation in 1960, the period 1920 to 1960 could be used as baseline and the latter period as present day flows.

The main graphs and statistics required for these flow records are hydrographs (monthly or daily), mean, median (high variability), minimum, maximum, flood peaks, etc. to provide information to the ecologists at the various selected sites. The ecologists use these baseline or reference flows, together with the hydraulic information to develop the ecological and the socio-economic response relationships. Thereafter, using this set of ecologically relevant flow variables, river segments within a region are classified into a few distinctive flow regimes that are expected to have different ecological characteristics.

It further serves as the baseline for comparisons with altered flows, namely present day flows or possible future flows (development scenarios) at sites where managers may want to make allocations or other water management decisions, as well as sites where biological data have been collected.

#### 3.2.1.2 Availability of hydrological data

Monthly observed flows for various record periods were obtained for each of the nine selected reaches of river or sites in the Nile basin. The reaches of river, also referred to as Risk Regions (RR), record periods and Reference Mean Annual Runoff (MAR) are summarised in the table (Table 7) below and the locations of the selected sites are presented in Figure 2.

Table 7: Selected reaches of river, record periods and Reference MARs for the Nile basin

| RR | River | Reach Name | Site/ Weir | Period | Reference MAR (MCM) |
|---|---|---|---|---|---|
| RR1 | Kagera | Kagera River | Kyaka Ferry | 1952-1989 | 6 979 |
| RR2 | Victoria Nile | Victoria Nile downstream of Lake Victoria | Jinja | 1963-2013 | 34 024 |
| RR3 | Bahr el Jebel | Bahr el Jebel upstream of Sudd inflow | Mongala | 1963-1981 | 50 479 |
| RR4 | Baro River | Baro River upstream of Machar Marshes | Gambela | 1977-2004 | 12 176 |
| RR5 | Sobat | Sobat River upstream of mouth (confluence with White Nile) | Hillet Doleib | 1906-1982 | 13 651 |
| RR6 | White Nile | White Nile upstream of Jebel Aulia | Malakal | 1963-2006 | 32 043 |
| RR7 | Blue Nile | Blue Nile downstream of GERD | El Diem/Roseires | 1921-2013 | 49 712 |
| RR8 | Atbara | Atbara River | Kubor and Wad Elhiliew | 1921-2001 | 12 616 |
| RR9 | Nile | Main Nile upstream of Lake Nasser | Dongola | 1944-2008 | 77 513 |

The record periods for RR2, RR3 and RR6 on the main stem Nile River are longer than indicated in the table, namely RR2 from 1948-2013, RR3 from 1905-1981 and RR6 from 1928-2006. However, due to a hydrological upwards 'shift' in the outflows from Lake Victoria in the early 1960's, the record periods were split into a pre1962 and post-1962. The EFR assessment was based on the higher, post-1962 flows with the earlier flows as a scenario to compare with the ecological requirements. Due to the high flow contribution of the Blue Nile (RR7), this 'shift' doesn't show in the flow record of RR9 (Main Nile River) (Figure 2).

#### 3.2.1.3 Approach for EFR determination

The Desktop Reserve Model (DRM) within the SPATSIM framework (Hughes and Munster, 1999) was used to calculate the Environmental Flow Requirements at the selected sites per reach of river. The following information and data were used in the model to determine the EFR:

i. Reference flows: These are the monthly observed flows at each of the selected sites for the various periods as in Table 4 that were used to determine the EFRs.
ii. Monthly flow distributions: Initial monthly flow distributions were selected and adjusted to fit the flow characteristics of the reference flows. These include, annual peak and low flow months, shape of low flow months, low and high flow assurance rules.
iii. Ecological information: Ecological information was provided by the ecologists for selected quantity indicators that formed part of the BN formulation. These indicators included inter alia flow requirements for fish and riparian vegetation. Requirements were provided for a B (or near natural) state for various months, including highest and lowest flow months. These requirements were specified as critical low/ drought flows (~99% of time), dry (~70-80% of time) and wet (40-60% of time) base flows, freshets (10% of time) and annual floods. The dry and wet base flows are also referred to as maintenance low flows. The annual flood requirements were specified in terms of flood peaks, timing (which months) and duration. The detailed descriptions of these indicators, the rationale and the relationships are provided in various other sections of this report. These requirements were first checked

against the reference flows to ensure that the requirements were not higher than the reference flows.

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, especially the critical low and dry flows. These parameters were then used to interpolate flows for those months where no ecological data was available. Separation was undertaken for each of the reference flow records using the technique developed by

Additionally, base flow separation has been undertaken for each of the flow records, using the technique developed by Hughes, et al (2002). This was to compare the maintenance flow results of the DRM with the base flows (BF) to ensure adequate protection of the aquatic ecosystems.

As the flows of the Kagera River (RR1) and the mainstem Nile River from the outflow of Lake Victoria (RR2, RR3, RR6 and RR9) have a much flatter hydrograph (see graphs in next section), the base flows (maintenance low flows) and drought flows were taken as the same and no drought flows were specified separately. However, drought flows were specified for the tributaries with more peaked hydrographs, thus showing a distinct difference between a wet and dry season.

#### 3.2.1.4 EFR results per reach of river

The results are presented as tables showing the flow requirements for the highest and lowest flow month at selected percentile values and the annual flood requirements in terms of discharge, months when required and the duration in days. The hydrographs indicate the reference and base flows compared to the EFR and for RR2, RR3 and RR6 also include the reference flows for the period before 1960. Flow duration curves (FDCs) per RR for selected months are also presented.

#### 3.2.1.5 Conclusions and Recommendations

The EFRs as determined for this study used the following data:

(i) Monthly observed flows at selected sites within the nine reaches of river; and
(ii) Ecological data for specific months for critical low flows, dry and wet base flows and annual floods.

The main stem Nile River (RR2, RR3 and RR6) flow characteristics are different to the tributaries with a more flattened monthly hydrograph, which indicated that there is not a distinct difference between wet and dry seasons, except for RR9 where a wet and dry season is present due to flow contribution from the Blue Nile River. Thus, drought flow requirements were not specified separately for these reaches of river.

The results of the EFR determination show that the total requirement ranges between 42% and 65% for most of the reaches of river. RR8 (Atbara River) has a total requirement of 30.5% that could be due to the limited ecological information that was available for use, especially the flood requirements.

The dry and wet base flows are the more important flow component for the maintenance of these reaches of river, with percentage requirements ranging between 32% and 48%. Again, the Atbara River (RR8) only requires 16% for the low flows.

All of the systems are perennial, although the Atbara River can almost be seen as a seasonal river due to the very low flows during the dry months. It is thus important that any water resource developments take cognisance of this and ensure that the minimum flows as specified in this report be implemented.

## 3.3 Hydraulic Assessment

### 3.3.1 Input data preparation

The hydraulic model HEC-RAS5 is used for calculating the hydraulic conditions at the points of interest. Data preparations have been carried out in the QGIS environment. The most important data for the hydraulic modelling is the topographic data. For this study, the MERIT DEM[1] is used. The MERIT DEM is an improved and carefully processed version of the SRTM[2] and ALOS-30m[3] DEMs, resulting in a higher accuracy and a removal of artificial patterns and noise. In case the MERIT DEM is used for commercial purposes, the results derived from the DEM have to be made publicly available according to the Open Database License (ODbL 1.0). All elevation values within this report are based on the MERIT DEM with the respective accuracy.

### 3.3.2 Model domain and cross section spacing

The model domain and the cross section spacing to be considered up- and downstream of the location of interest depends on different characteristics such as flow volume, water surface (or channel) slope, river size as well as required spatial detail of the model results. Samuels (1990) and Castellarin *et al.* (2009) give guidelines on cross section spacing and what locations the model domain should cover:

- All sites of key interest
- Adjacent to major structures
- Cross sections should be representative of the river geometry
- Cross section spacing $\Delta x$ can be approximated by the following equation:
    - $\Delta x \approx k \cdot B$ where $k$ = 10-20 and $B$ is the river width

To reduce the effects of the boundary conditions, the upper- and lower model domain boundary must be sufficiently far away from the point of interest. In addition, the extent of the floodplain must be defined based on its topography. Therefore, from the point of interest, four cross sections were placed up- and downstream with the spacing width depending on the slope (low slope, $k$ approaches 20, high slope, $k$ approaches 10). The elevation difference between the cross sections was taken from the average longitudinal slope based on the DEM upstream and downstream the point of interest. If the elevation difference between the upper and lower cross section based on the DEM did not exceed 2m, additional cross sections are added with the maximum spacing $\Delta x = 20 \cdot B$. This ensures that backwater effects and boundary conditions do not influence the hydraulics at the locations of interest too significantly. In addition, in case the points are located in proximity to confluences (e.g. RR5, Hillet Doleib) or upstream of reservoirs (e.g. RR9, Dongola), a distance was kept to allow 2m elevation difference to the downstream water levels. Model domain extent and cross section spacing is summarized in Table 8.

---

[1] http://hydro.iis.u-tokyo.ac.jp/~yamadai/MERIT_DEM/

[2] https://www2.jpl.nasa.gov/srtm/

[3] https://www.eorc.jaxa.jp/ALOS/en/aw3d30/index.htm

### 3.3.3 Cross section elevation and bathymetry

The bathymetry across the river channel and the longitudinal slope is the most important input data for hydraulic calculations. Due to limited data availability, an individual methodology was applied at the points of interest. This enabled a consideration of the actual data sources to obtain the best possible cross section elevation. The cross section was defined at the point of interest and duplicated to the remaining cross sections where distances and elevation differences remain as described above:

- **Survey data**: At cross sections where bathymetric and survey data were available, those were used to define the river bed topography. This method yields the highest accuracy if cross section data is representative for the actual conditions (i.e. recent survey at a relatively stable channel section).
- **Hydraulic data**: For locations where no survey data, but hydrographic data were available, channel geometry was deduced from observations of discharge, water level, flow area or flow width. This method yields reasonable results if hydraulic data is recent and if the channel section is stable.
- **Bankfull flow**: For locations where no survey or hydraulic data were available, bankfull flow was calculated, which approximately lies at the 1.5yr return period and the channel topography can be adjusted to confine bankfull flow. This method can be used in data scarce regions.

The selected method used at each location is summarized in Table 8.

Table 8. Points of interest, the applied methodology for obtaining the channel cross section and additional channel and cross section properties

| ID | River | Latitude | Longitude | Channel bathymetry method | Bank width [m] | Ineffective area elevation [mASL] | Slope [m/m] |
|---|---|---|---|---|---|---|---|
| RR1 | Kagera | -1.2494 | 31.4202 | Bankfull | 119 | -- | 0.000120 |
| RR2 | Victoria Nile | 0.5018 | 33.1382 | Survey | 150 | -- | 0.002024 |
| RR3 | Bahr El Jebel | 4.8856 | 31.6462 | Survey | 624 | -- | 0.000187 |
| RR4 | Baro | 8.2483 | 34.5769 | Survey | 181 | 435 | 0.000167 |
| RR5 | Sobat | 9.3016 | 31.6577 | Bankfull | 187 | -- | 0.000089 |
| RR6 | White Nile | 9.6592 | 31.7477 | Bankfull | 270 | -- | 0.000050 |
| RR7 | Blue Nile | 11.8598 | 34.3753 | Survey | 641 | -- | 0.000060 |
| RR8 | Atbara | 14.3642 | 35.8551 | Bankfull | 317 | -- | 0.000364 |
| RR9 | Main Nile | 19.1831 | 30.4899 | Flood level | 681 | 227 | 0.000068 |

### 3.3.4 Ineffective flow areas

For 1D simulations, low-lying elevation values within a cross section will become inundated if water level in the channel rises above the respective elevation. In reality, this is only the case, if flood waters can overtop the channel (either at the location or somewhere upstream). Potentially, this can severely overestimate the conveyance capacity of the cross section. Therefore, ineffective flow areas can be assigned in HEC-RAS. This means that unless the water level rises above a certain threshold, lower lying areas will not convey water. An example is shown in Figure 10. Ineffective flow areas for all model domains are taken from the upper bank elevation along the flow path from the DEM.

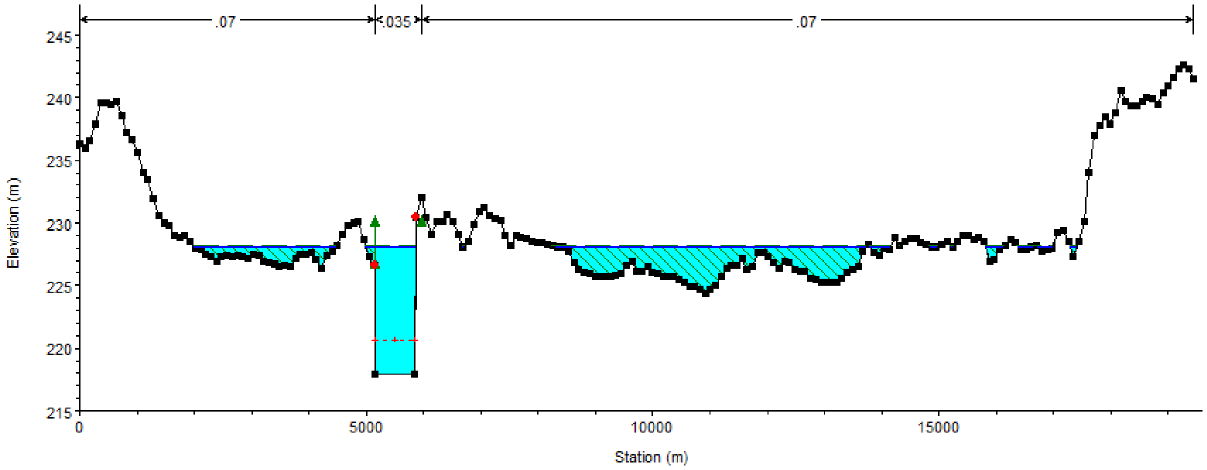


Figure 10: HEC-RAS cross section with water level (blue), hatched area represents ineffective flow area unless water level rises to and above the small green triangles

### 3.3.5 Up- and downstream boundary conditions

Up- and downstream boundary conditions are the water surface slope calculated from the DEM. Therefore, a sufficiently long section along the thalweg of the channel was analysed (Table 8).

### 3.3.6 Modelling and calibration

In locations where survey data was available, Manning's n roughness values were adjusted within reasonable ranges to match available hydraulic observations[4]. Where no hydraulic observations were available, a HEC-RAS base model was built with typical Mannings n roughness values 0.03 for the channel and between 0.035 (smooth surface, no vegetation) and 0.07 (densely vegetated) for the floodplain and cross sections taken from the DEM. Bottom elevations in the DEM are the water surface, which generally need to be deepened to represent the actual channel bed. A trapezoidal channel topography with bank slopes of 45° was therefore iteratively deepened to confine the bankfull flow within the banks. The 1.5yr return period, approximately corresponding to bankfull flow, was calculated from a NileDSS simulation. The DSS was run on a daily time step from 1965-2014 and the 1.5yr return period was calculated from the 50-year period (Table 9). All flow data entered to HEC-RAS is summarized in ANNEXURE C: HYDRAULIC FLOW DATA FOR HEC-RAS CALCULATED FROM DAILY SIMULATIONS FROM THE NileDSS (1965-2014).

Table 9. 1.5-year return period [m$^3$/s] based on simulated data from the NileDSS

| | **1.5-year Return Period Flow from NileDSS 1965-2014 [m$^3$/s]** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Distribution** | **RR1** | **RR2** | **RR3** | **RR4** | **RR5** | **RR6** | **RR7** | **RR8** | **RR9** |
| gum | 244 | 1 050 | 1 377 | 884 | 746 | 1 285 | 7 216 | 1 452 | 9 018 |
| pe3 | 253 | 1 056 | 1 335 | 899 | 766 | 1 294 | 7 759 | 1 349 | 8 988 |
| gev | 252 | 1 057 | 1 358 | 898 | 764 | 1 294 | 7 756 | 1 407 | 9 019 |
| wei | 252 | 1 051 | 1 329 | 894 | 766 | 1 291 | 7 804 | 1 331 | 8 954 |
| gam | 247 | 1 065 | 1 393 | 896 | 754 | 1 298 | 7 309 | 1 374 | 9 137 |
| **AVERAGE** | **249** | **1 056** | **1 359** | **894** | **759** | **1 293** | **7 569** | **1 383** | **9 023** |

---

[4] The Nile Basin Volumes II and IV

It must be noted, that the 1.5yr return period flow is only approximately depicting bankfull flow conditions. Therefore, additional cross section characteristics were investigated from which information about inundation extent and frequency could be deduced. These descriptions are briefly given for the points of interest in the following subsections. Each point of interest is individually assessed using QGIS with the Profile Tool and Quick Map Services Plugin on the MERIT DEM and Google Satellite images. The site location and ID (yellow dot with number, corresponds to the IDs given in Table 8) is shown together with the cross section location (red line) on satellite images (Google Earth/Digital Globe). Below the images, the diagram shows the cross section (elevation along the red line), where the small red dot in the upper satellite images is marked by the centre of the cross line in the lower diagram. Numbers in the diagram show elevation in mASL (y-Axis) and distance from left in meters (x-axis).

The calibrated models were finally run for a range of flow percentiles, which were calculated from the daily simulations from the NileDSS for overall as well as monthly percentiles (see ANNEXURE C: HYDRAULIC FLOW DATA FOR HEC-RAS CALCULATED FROM DAILY SIMULATIONS FROM THE NileDSS (1965-2014)).

## 3.4 Vegetation Assessment

### 3.4.1 General Setting

#### *3.4.1.1 Broad-scale Vegetation*

The Nile basin is subdivided into sixteen terrestrial ecoregions (NBI, 2012; Figure 11). There is a gradual change in elevation and climatic conditions from south to north which accompanies a marked decrease in the diversity of plant and animal species. Not all the ecoregions are represented by the placement of eflows sites, with only the Sahara desert, Sahelian acacia savanna, Sudanian savanna, Grassland and Forest-Savanna mosaic being relevant. While these broad ecoregions do not necessarily denote the type and characteristics of the riparian vegetation, they frequently contribute to their general characteristics and also may be included in some of the species compliment within the zone.

***Forest-Savanna Mosaic***

Forest-Savanna mosaic dominates to the west and north of Lake Victoria, and is notable for its high degree of endemism as well as floral and faunal diversity. This ecoregion is characterised by a bimodal wet season with high rainfall periods from March to May and October to November. Annual rainfall ranges from more than 2000 mm over Lake Victoria to 1000 mm on the border with the Sudanian savannah ecoregion. Dominant forest trees are from the genera *Celtis, Diospyros, Uvariopsis*, and *Holoptelea*, while the woodlands are dominated by *Terminalia, Albizia, Combretum, Grewia*, and *Lonchocarpus*. Grassland areas are dominated by *Hyperrhenia, Themeda, Vetiveria, Pennisetum, Loudetia, Imperata, Adropogon, Setaria*, and *Cynodon*. This ecoregion has a number of protected areas and large populations of African savannah mammals which frequently utilise riparian and wetland habitats. Risk region 1 and 2 occur within this ecoregion.

***Sudanian Savanna***

This ecoregion lies to the south of the Sahel and is divided by the Sudd into western and eastern blocks. It is generally flat, with elevation ranging from 200 to 1000 m. Climate is tropical and strongly seasonal, with annual rainfall ranging from 600 to 1000 mm. Undifferentiated woodland, mostly deciduous, dominates with an understorey of shrubs, herbs and grasses. Typical trees in the western block include *Acacia, Combretum, Terminalia, Anagoissus*, and *Kigelia* genera, while the eastern block is dominated by *Combretum, Terminalia, Anogeissus, Boswellia, Lannea*, and *Stereospermum* genera. Bamboo (*Oxytenantehra abyssinica*) is prominent in the western river valleys of Ethiopia. Dominant grasses include *Hyparrhenia, Cymbopogon, Echinochloa, Sorghum*, and *Pennisetum* genera. The eflows site representing risk region 7 occurs within this ecoregion.

***Sahelian Savanna***

This is the largest ecoregion in the Nile basin and forms a transition zone between the true Sahara Desert and the wooded savannah biomes. It is characterised by mostly flat, low-lying topography, a hot tropical climate and notably seasonal rainfall. Annual rainfall, ranges from 600 to 2000 mm and occurs mostly from May to September. Hot dry winds from the north often introduce dust and sand from the Sahara during the dry season. Vegetation is characterized as Sahel acacia wooded grassland and deciduous bushland. The most common tree species is *Vachellia (Acacia) tortilis* but other genera include *Acacia, Commiphora, Balanites*, and *Boscia*. Grass cover is predominantly comprised of *Cenchrus biflorus, Schoenefeldia gracilis*, and *Aristida stipoides*. Away from permanent water, the dominant land-use is pastoral nomadism, with cattle as the main livestock, while close to permanent water irrigated agriculture is practised, especially along the banks of the Blue Nile. The eflows sites representing risk regions 6 and 8 occur within this ecoregion.

***Sahara Desert***

The Nile basin has 1.34 million square kilometres of arid and hyper-arid land. This occurs as an arid belt which is comprised of three ecoregions: south Saharan steppe and woodland, Sahara desert and north Saharan steppe and woodlands. The Sahara desert covers parts of the northern area of The Sudan and nearly all of Egypt. Temperatures in the hottest months may exceed 50$^{o}$C, and plummet to below freezing in the coldest. The region is characterized by hot, dust-filled winds that blow for much of the year. Annual rainfall is below 25 mm and multi-year droughts are common. Vegetation in the desert is rare, which is dominated by bare soil or rock. Scanty and stunted vegetation dominated by *Acacia, Tamarix*, and *Calotropis* genera can be found along some wadis and dayas. The eflows site representing risk region 9 occurs within this ecoregion and is markedly distinct from it.

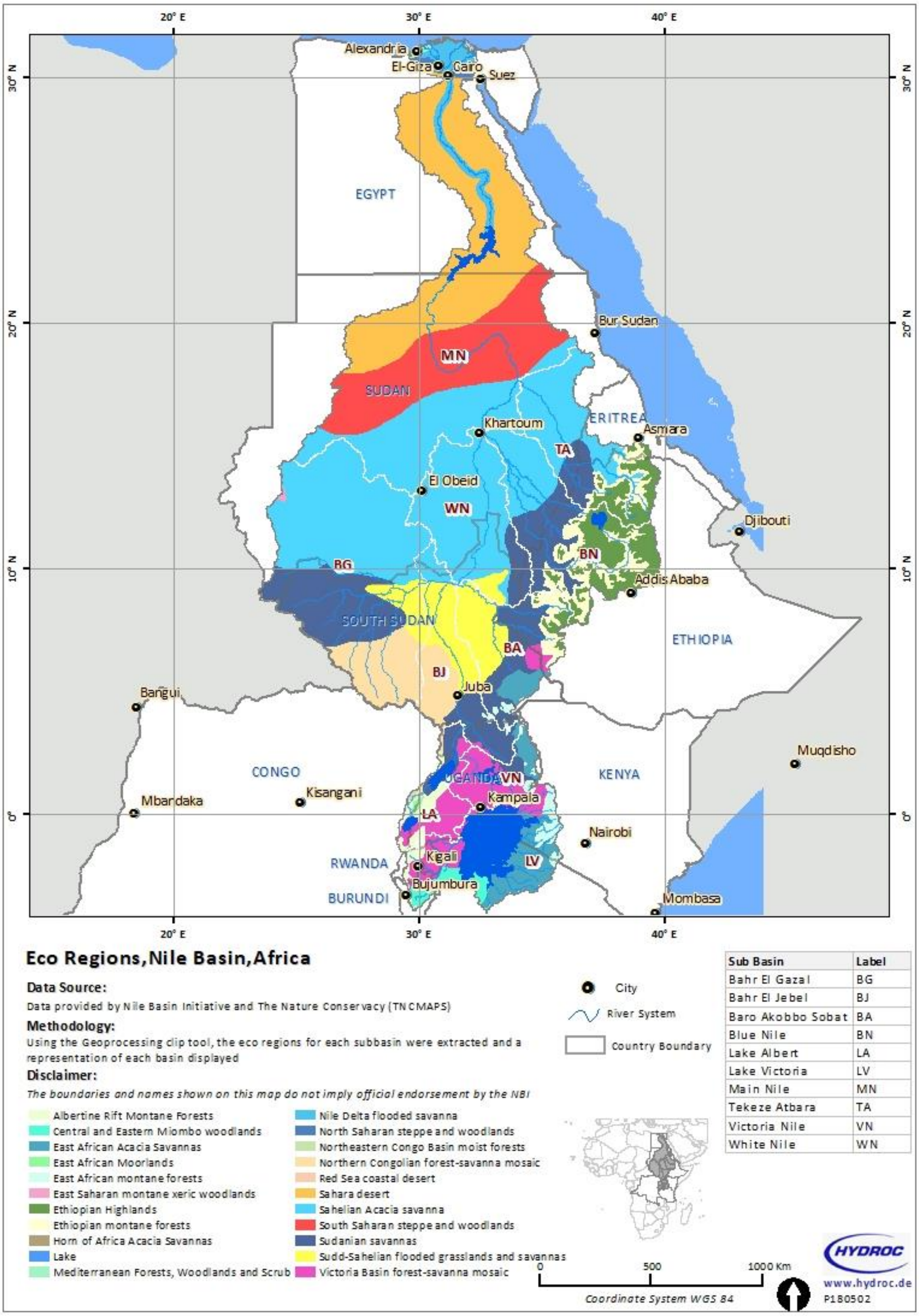


Figure 11: Ecoregions in the Nile basin (taken from NBI, 2012).

### 3.4.2 Endpoints

#### *3.4.2.1 Vegetation Endpoints*

Much of the Nile basin displays seasonal hydrological variation to lesser or greater, and varying degrees. This high degree of variation in flows and floods drive and form both riverine and wetland (including floodplains) habitats, and the flooding regime and subsidence drive the biology and responses of both fauna and flora on which people are dependent. The approach taken in this study recognises the value of both social as well as ecosystem endpoints, both of which are largely flood dependent.

#### *3.4.2.2 Ecosystem Endpoints*

The ecosystem endpoints relate to the most vital vegetation habitats with the aim to maintain habitats and ecosystem processes for critical indicator macrophytes and riparian vegetation. Given the limitation of riparian indicators at cross section sites, the following vital habitat/indicator combinations were chosen to represent ecosystem endpoints:

1) Aquatic vegetation
2) Non-woody riparian vegetation, notably obligates such as reeds and sedges (e.g. Papyrus)
3) Non-woody floodplain vegetation, notably grasses e.g. Wild Rice
4) Woody riparian vegetation, notably bank fringe species

#### *3.4.2.3 Social Endpoints*

Social endpoints were based on those components of the vegetation that are vital to sustaining livelihoods and as such the aim is to maintain indigenous vegetation components in order to sustain community livelihoods including natural vegetation production and subsistence agriculture. This includes floodplains and receding floods for recession agriculture. Since the social endpoints are intrinsically linked to the overall wellbeing of the ecosystem, including the maintenance of biodiversity, they are similar to the ecosystem endpoints in terms of their flow requirements. The following important social endpoints that relate to vegetation were considered:

1) Maintenance of aquatic vegetation that sustain instream fauna e.g. fish and shrimps that people harvest.
2) Non-woody riparian vegetation, notably obligates such as reeds and sedges (e.g. Papyrus) that people harvest for household use and also have some nutritional value.
3) Non-woody floodplain vegetation, notably grasses which are important for livestock grazing. This area is also important for agricultural activities.
4) Woody riparian vegetation, notably bank fringe species and tree lines. These species have value for their timber and also fuel.

#### *3.4.2.4 Conceptual Model*

A conceptual model of the endpoints listed above, and how they generally relate to one another, is shown in Figure 12 ecosystem endpoints and Figure 13 for social endpoints.

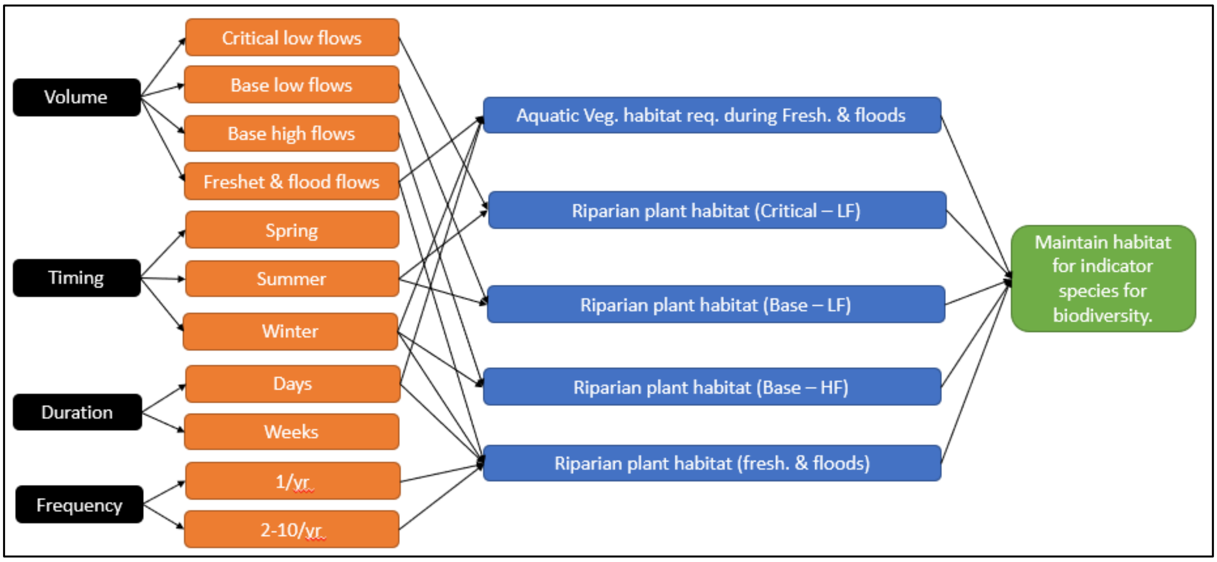


Figure 12: Conceptual model of Riparian / Flood environment representing ecosystem endpoints.

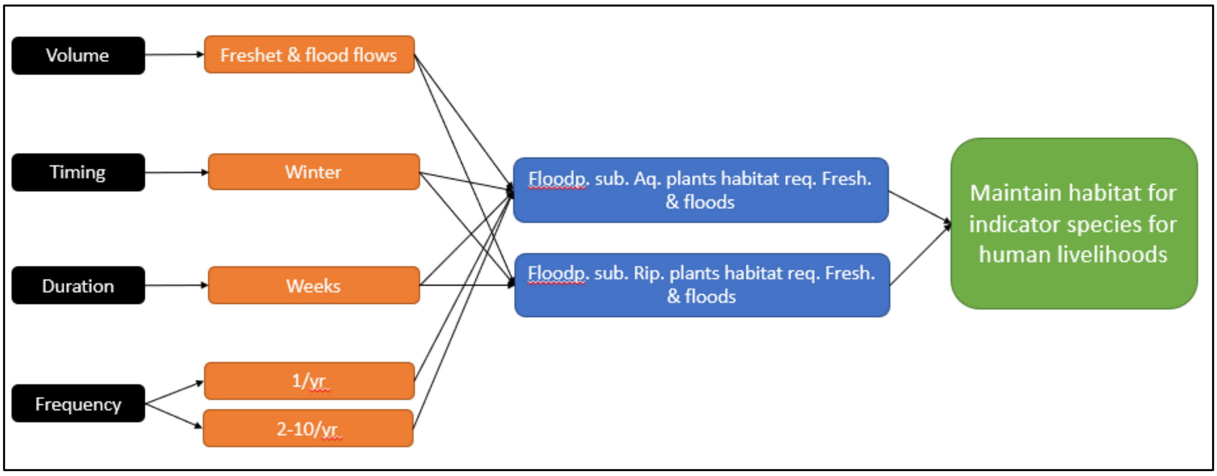


Figure 13: Conceptual model of human livelihoods endpoint.

### 3.4.3 Ecosystem-Flow Linkages

#### *3.4.3.1 Endpoint Drivers*

The ultimate drivers of all ecosystem and social endpoints is the flow regime and rainfall. Vital components of the flow regime include perenniality (wet and dry season base flows), timing (seasonality) of floods, magnitude and duration of flood events and by implication the distribution of depth/area parameters associated with floods, and critical drought flow magnitudes for the long-term survival of biological components. Various biotic indicators show niche preference for combinations of the drivers and have been modelled as such. Based on the available biological information at cross section sites, and together with hydraulics at each site, the driver components [within the model] were quantified for a B-category as determined by discernible riparian indicators. Interpolation was frequently required due to lack of biological data specific to sites.

#### *3.4.3.2 Model Justifications*

The following justifications capture the direct response of important vegetation indicators (for endpoints) to components of flow, and relate to the response mechanisms modelled above (all blue boxes in Figure 12 and Figure 13). Higher risk rank scores and definitions represent declining ecosystem health and wellbeing.

- Riparian vegetation is flood dependent but in different ways to floodplain vegetation. Since riparian vegetation is less transient to flow regime of the dry season is also important. Hence, a combination of wet and dry season base flows and flood timing was used as drivers.
- The wet season base flow is the flow required to activate and flood riparian zone vegetation in the wet season growing months, and applies mainly to the non-woody or small shrub components. Although the use of a base flow does not sufficiently describe the flashiness of a flooding regime, it is assumed that the system is large enough to have less volatile floods with flooding period itself consisting more of a gradual rise followed by recession months later.
- The dry season base flow should ideally fluctuate within this range for the duration of the dry season. This is the flow required to activate the more flow sensitive marginal zone species where these exist, or where these are transient non-woody species that quickly colonise wet or moist sands. More importantly however, these flows are required to maintain perenniality of rivers and soil water levels for use by phreatophytic riparian plants, particularly riparian forest species. In the absence of detailed indicators this was defined relative to the wet base flow and reduced in elevation by 1m (based on rooting depth tolerances of species in general).
- The timing of floods is critical for biological cues and to ensure that ecosystem functions and use and sustainability are protected. The more natural the timing of floods the lower the risk to the resource due to its timing or mis-timing. High risk would be floods in the dry season for example, or the absence of flooding when a natural (defined by failed rainfall, not by over storage or abstraction) drought is not occurring.

#### *3.4.3.3 Defining Risk to Vegetation*

The alteration of driver dynamics, in this case flows and by implication floods, results in risk to the vegetation. Optimal driver state results in low risk to all vegetation endpoints but does not consider the effects of non-flow related impacts, such as ever increasing grazing and trampling pressures, and the impacts of human density and resource use. However, as flows may decline so the risk to vegetation endpoints increases. This risk has been described and quantified for each of the response variables, as well as for each of the response variables within different risk regions, and represents declining ecological health or ecosystem wellbeing.

## 3.5 Fish Assessment

### 3.5.1 Introduction

The interest in African fish has only gained momentum in the 1870's but particularly during the early 1900's the interest in fishes from Africa and in particular the Nile River Basin were considered after initial expeditions into central Africa were undertaken by Günther (1873), Guimarães (1884), Boulenger (1887, 1902, 1912), Schilthius L (1891) and Pellegrin DJ (1900 and 1901). Thereafter only recently in the late 1900's to early twenty first centaury interest has again been regenerated (Winemiller and Adite 1997, Stiassny and Schaefer 2005, Stuassny *et al.* 2006 for example). Relative to other parts of the world, very little is known about the fish of the Nile River Basin as a whole and their biology and ecology.

Until recently >320 species (in 60 genera), of which approximately 62 percent are endemic were believed to occur in the Nile basin (Boulenger, 1965; Greenwood, 1976). Today a global information system on fishes named FishBase, which is a global biodiversity information system on FinFishes lists >500 species of fish (see ANNEXURE D: SUMMARY OF THE FISH SPECIES THAT OCCUR IN THE NILE BASIN AND THEIR MIGRATORY REQUIREMENTS, HABITAT REQUIREMENTS AND POTENTIAL POPULATION STATE/TREND.) and some estimate there to be >800 species in the basin (Witte *et al.*, 2009). Unfortunately some of the limited information on fishes from the basin suggests that there has been a considerable decline, and in some cases an almost total disappearance, of many of the native Nile basin fishes (Ogutu-Ohwayo, 1990; Bailey, 1994; Schwartz *et al.*, 2006; Vijverberg *et al.*, 2009: Closs *et al.*, 2015). Fisheries losses have been observed in Lake Victoria and Kyoga in East Africa since the development of the fisheries of these lakes was initiated at the beginning of this century (Ogutu-Ohwayo, 1990), and changes in ecosystem state, over exploitation and alien invasive species have affected many other community in the region (Vijverberg *et al.*, 2009: Closs *et al.*, 2015).

Fish are not only good indicators of ecological health, they are charismatic animals that people easily relate to and they are an important source of food for many human communities throughout the world (Jørgensen and Costanza, 2016; Siddig *et al.*, 2016). As indicators of ecological health; (1) fish are useful in that they are long-lived and are therefore good indicators of long-term exposure to impacts, (2) they occupy a wide range of aquatic habitat usually due to their mobility allowing for the consideration of multiple, diverse environments, (3) communities are comprised of a range of species from different trophic levels integrating and allowing for the consideration of a range of environmental changes and (4) when established as sensitive umbrella species the conservation of some species can allow for the protection of large diversity of other species and associated ecosystems processes (Baumgartner *et al.*, 2014). Fish have been used extensively as ecological indicators of altered flows in eflow studies (Zhao *et al.*, 2018; Kuriqi *et al.*, 2017; Poff *et al.*, 2017; O'Brien *et al.*, 2019). In many case studies for hydraulic rating, habitat simulating and or holistic eflow assessment fish have been successfully used to determine eflows (Horne *et al.*, 2017)

In this study, available fish species information for each reach of river (RoR) considered in the study and regional biology and ecology information that may provide information on the habitat and or flow requirements of the species has been used to establish flow requirements for this eflow assessment.

Changes to the hydrological regimes of rivers have affected a range of biota including freshwater fishes. Flow variability and alterations largely influence the range of physical habitat available to fish at various life history stages. Many of these fishes have linked their biological rhythms to flow variability and often optimise changes to facilitate spawning, growth and dispersal (Baumgartner *et* *al.*, 2014). In case studies such as this one where many species occur but limited information is available to describe the biological and or ecological requirements of specific species a guild or trait approach can be adopted. Here we assume that flow alteration is a main determinant that structures freshwater fish communities, and that guilds of species with similar traits are useful to evaluate the response of species to altered flows (Baumgartner *et al.*, 2014). Four broad guild groups have been proposed for these types of assessments and include: long-lived apex predators, flow dependent specialists, foraging generalists and floodplain specialists. Each of these guilds were applied in this study to identify flow dependent habitat requirements of indicator species believed to occur with each case study.

Within the rivers and floodplains of the Nile basin many tertiary consumer, usually piscivourous apex predatory fishes occur including the good representation of the tigerfish group *Hydrocynus spp.* Other important species include the Nile perch (*Lates sp*.) and the African obscure snakehead *Parachanna obscura*. Additional cyprinid (*Labeobarbus spp.*) and catfish (*Bargus sp.*) are all important predators of the system. The species of this guild are dependent on the fish community that they depend on for food making them good indicators of overall ecosystem conditions. Their life cycle ecology and associated flow dependencies vary considerable including: (1) ontogenetic shifts in diets and habitat use for different life stages (2) some are rheophillic others limnophillic and others still are floodplain specialists, (3) some have longitudinal migration requirements and others have lateral migration requirements (Baumgartner *et al.*, 2014; O'Brien *et al.*, 2014). For this study the known life cycle history of the *Labeobarbus spp.* and *Hydrocynus spp.* were primarily used to establish requirements for the apex predator guild (Økland *et al.*, 2005; Goodier *et al.*, 2011; O'Brien *et al.*, 2012; 2013; 2014; 2017; Ramesh *et al.*, 2018; Burnett *et al.*, 2018).

The yellowfish are extremely slow growing (maturing >seven years) appear to be facultative migrators and probably undertake spawning migrations to reduce competition between young and adults of the same species and or reduce interspecies competition and predation. They have the ability to migrate swiftly en masse upstream during warm months of the year and extend their normal home range into the temperate parts of ecosystems to spawn. Many species will only successfully spawn if suitable flow cues are provided for a minimum of a few weeks demonstrating the species high requirements for high flood and or fresh flows that must be maintain for up to weeks at a time. Spawning occurs in rheophillic habitats and eggs are deposited into gravel bed substrates, which is again closely linked to flows. Recruited larvae and fry use inundated marginal zones and flood plains to avoid predation and as young of year (YoY) they adopt rheophillic behaviour and use lotic riverine habitats. These fishes can also proliferate in lentic lake and floodplain ecosystems and have been known to recruit into both ecosystems. Where lotic habitats are removed however population declines and associated community structure changes have been documented. The diet of the *Labeobarbus spp.* varies and populations have been observed to occupy 2nd and or tertiary tropic levels in food chains. These fishes readily forage for food and many are specialist predators. With the knowledge of their biology and ecology they have been used extensively to contribute to eflow determination studies worldwide. Flows are proposed per relevant site initially by considering the historical flow variability. For rivers that are highly seasonal (consider RR6-RR9) the importance of seasonal cues is considered to be relatively more important than rivers that are more aseasonal (RR1 to RR3) for example. However, changing a river from an aseasonal system into a highly seasonal system would have severe impacts to the ecosystem. For these fishes flows are considered to provide ecological cues (timing, volume and duration of flows), provide river connectivity and maintain connectivity to support recruitment (volume, timing and duration of flows), habitat for feeding, refuge and spawning (volumes) and flows to maintain the water quality, substrates and cover features associated with the life cycle ecology of the species. Consider that although very limited specific biology and ecology information for these fishes is available these hypotheses used to establish eflow requirements should be verified and adaptations should be incorporated into the assessment in an adaptive management context.

The tigerfish group (*Hydrocynus spp.*) are pinnacle predatory fishes of the lower and middle reaches of the Nile basin and large tributaries. These predators are slow growing (>25 yrs) but attain large sizes (>20 kg) and are veracious piscivous that will also prey on birds, mammals and reptiles if opportunity is available. These fish prefer large open water and although they use lentic habitats, they are lotic, rheophillic specialists that dominate rivers. Due to their large size they prefer deep rivers (>2 m) and are very successfully migrators that can move large distances (>200 km) per season. Migrations are believed to take place for spawning and for food. Adults spawn in deep glide habitats associated with sandy/gravel beds. larvae and fry initially prefer marginal vegetated habitats, backwater pools and floodplains. Fingerlings immediately start to patrol and predate on invertebrates until they attain a size that allows them to effectively hunt fish in open/deep (>1m) habitats. The maintenance of the food web is important for these fishes and as such often other guilds must be considered to maintain these predators.

Many true rheophillic fishes that are dependent on flowing habitats to survive occur within the Nile basin. Although many of these fishes are small and require relatively shallow habitats with high velocities, few are large growing. Many of the *Labeo spp.* are for example true rheophillic species that have a similar ecology to the *Labeobarbus spp.* a close relative but often differ by requiring deeper fast flowing habitats. These fishes are also very effective migrators and can pioneer into seasonal tributaries relatively quickly. Similarly, to *Labeobarbus spp.* successful recruitment requires suitable flows to maintained to condition habitats and ensure spawning and recruitment of larvae. These fishes are particularly vulnerable to reversed hydrographs and or hydropeaking activities that disrupt ecological cues and often result in failed recruitment. Other rheophillics include for example numerous Siluriforme fishes, *Mastacembelus frenatus* and *Garra spp*. these species are all dependent on flowing (lotic) habitats associated with rocky or bedrock substrates. These fishes are usually incapable of using lentic habitats for refuge and often excessive reductions in flows that result in loss of lotic habitats can have a major impact in these specialist species.

Species that have specialist foraging biologies include cyprinids, Cichlids, Siluriformes and Distichodontidaens. Many of the Mormyridaens in the Nile basin in particular have highly specialised foraging behaviours. The species are dependent on the availability of food, habitat conditions and often water quality associated with flows. In many cases river habitat characteristics which these specialists depend on is closely associated with continuous high flows and or floods that remove and deposit habitats. These fishes are so highly adapted to these conditions that they have developed electric organs to aid in the location of and capture of prey. They are also considered to be gregarious and use electric signals to communicate. They represent some of the most vulnerable species in the basin.

Finally there are many floodplain species that are either obligatory floodplain species that do not use mainstem rivers (such as many Nothobranchiidaens and some Cichlids), and species that require floodplains to complete components of their life cycles (such as some Cichlids, Cyprinids, Cyprinodontiformes and Siluriformes). While some species are floodplain habitat specialist and don't use the rivers by completing their life cycles within floodplains, with some ability to lay eggs in the mud during low flows or in the case of the Lung fish *Protopterus aethiopicus* to be able to bury itself into the mud and for a cocoon, most have lateral migrations. Within the Nile River, especially in areas where floodplains are associated with seasonal high flows the maintenance of this guild is very important to maintain diversity and fisheries. Not only do these fishes require high flows to inundate floodplains and maintain them for many months to recruit successfully, they require flows to provide cues for migrations and flows to maintain cover and sediment characteristics of habitats. All of these requirements were considered in this study.

## 3.6 Risk Region and Scenario Selection

The risk regions selection for the Nile basin was based on a number of criteria, including available hydrology. Another consideration included the selection of sites (risk regions) where changes in flows from natural/reference to present day due to developments (dam construction, irrigation or hydropower). The final number of RRs selected were nine (Figure 2), one on a major tributary of Lake Victoria, the Kagera River (RR1 at Kyaka Ferry), on the White Nile below Lake Victoria (RR2 at Jinja), on the White Nile upstream of the Sudd (RR3 at Mongala), on the Baro River (RR4 at Gambela), on the Sobat River (RR5 at Hillet Doleib), the White Nile downstream of the Sudd (RR6 at Malakal), on the Blue Nile (RR7 at Roseires), on the Atbara River (RR8 at Kubor and Wad Elhiliew) and on the lower Main Nile (RR9 at Dongola).

For this assessment, the scenarios that meet hypothetical requirements to attain a Class B, C and D were considered for each risk region.

## 3.7 Conceptual Models

Figure 14 to Figure 19 provide a series of conceptual models that link flow variability to endpoints of interest and describe hypothesised relationships between multiple sources, stressors, habitats and impacts to endpoints selected for the study. Figure 20 provides an example of the detailed models that were established for each endpoint. These conceptual models represent our understanding of the relationships between sources and endpoints in the study and can be adapted with new information. Figure 21 provides an example of the risk model developed for each endpoint based on the conceptual models.

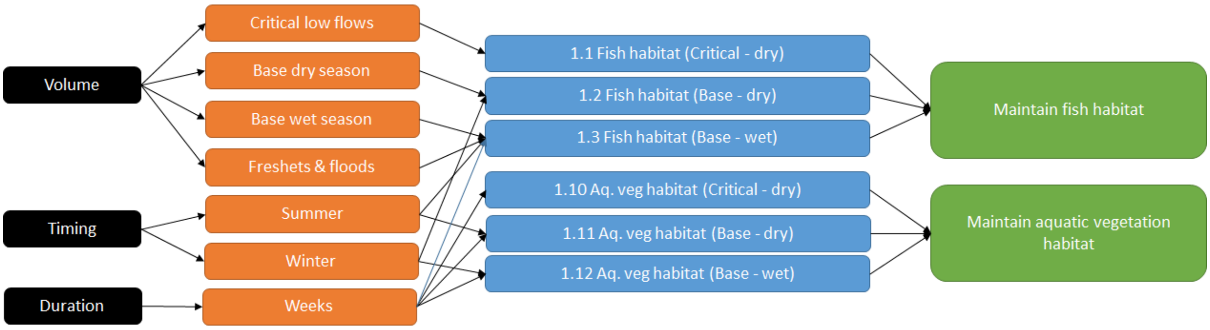


**Figure 14: Conceptual model linking flows and flow variability to instream habitat indicators and ecological endpoints for all nine sites in the study.**

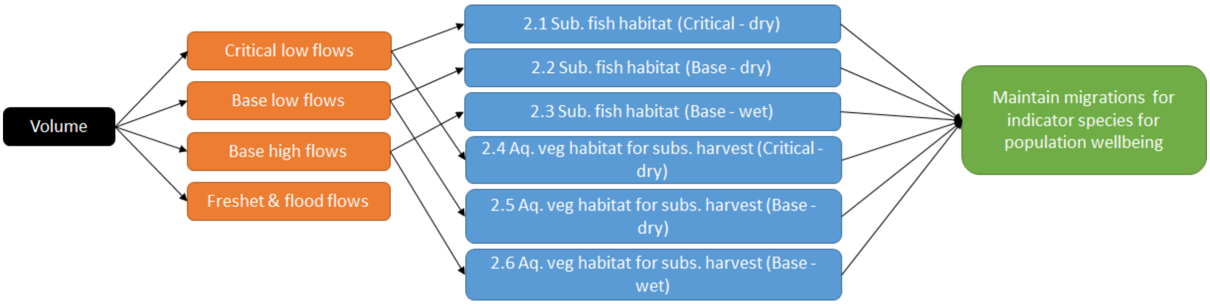


**Figure 15: Conceptual model linking flows and flow variability to instream process indicators and ecological endpoints for all nine sites in the study.**

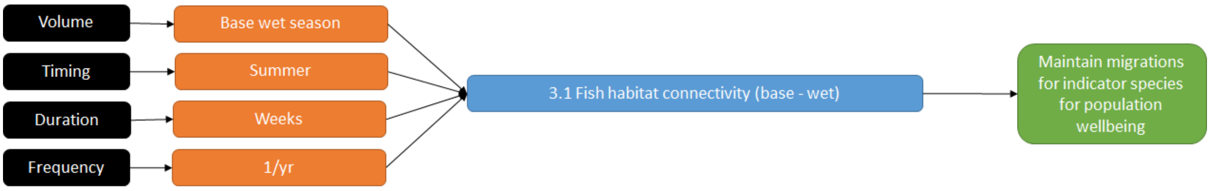


**Figure 16: Conceptual model linking flows and flow variability to instream social endpoints for all nine sites in the study.**

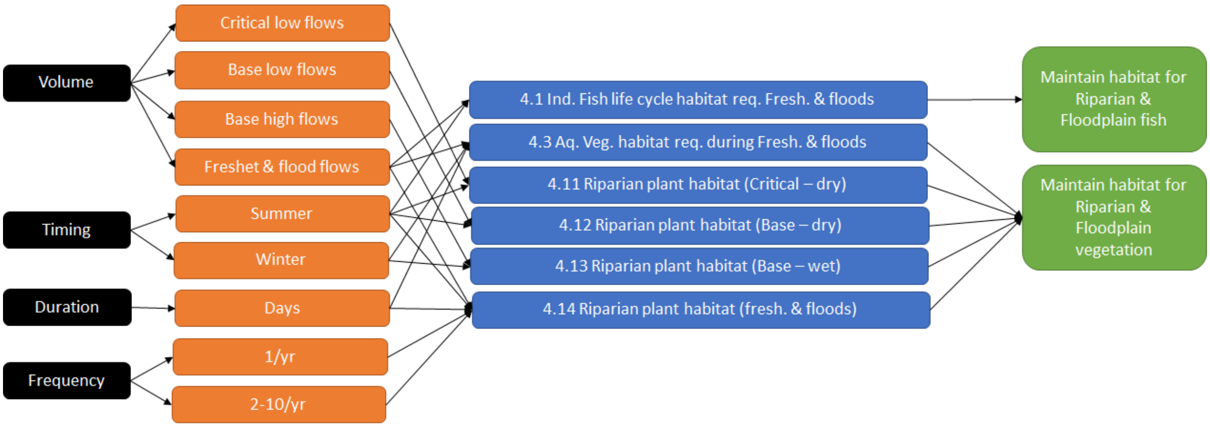


**Figure 17: Conceptual model linking flows and flow variability of riparian and floodplain habitat indicators and ecological endpoints for all nine sites in the study.**

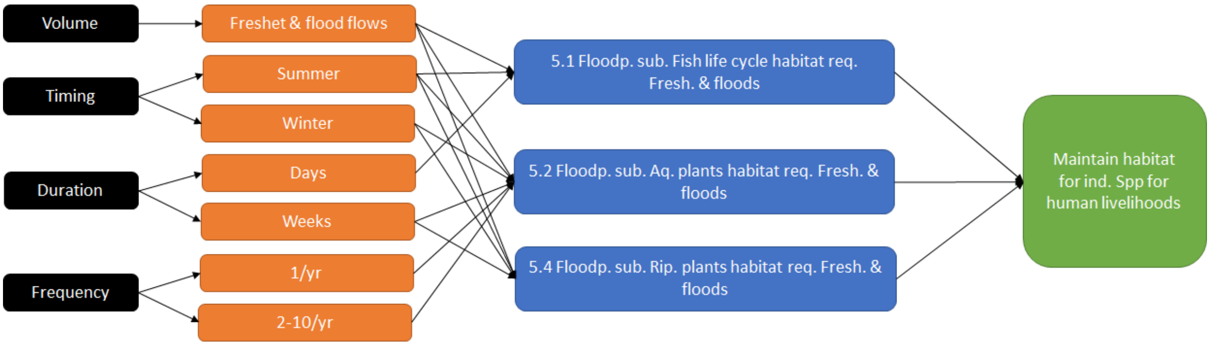


**Figure 18: Conceptual model linking flows and flow variability of riparian and floodplain derived social indicators for social endpoints for all nine sites in the study.**

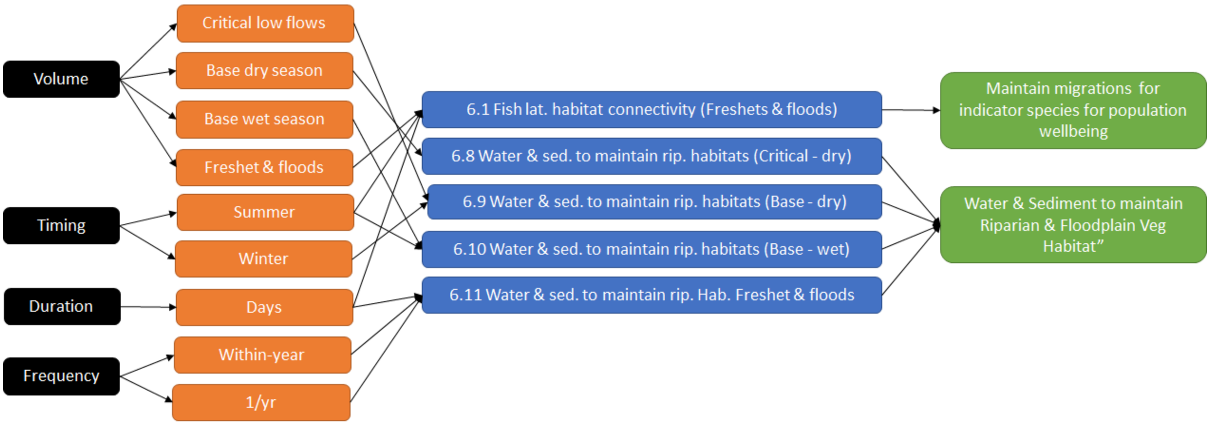


**Figure 19: Conceptual model linking flows and flow variability of riparian process indicators and ecological endpoints for all nine sites in the study.**

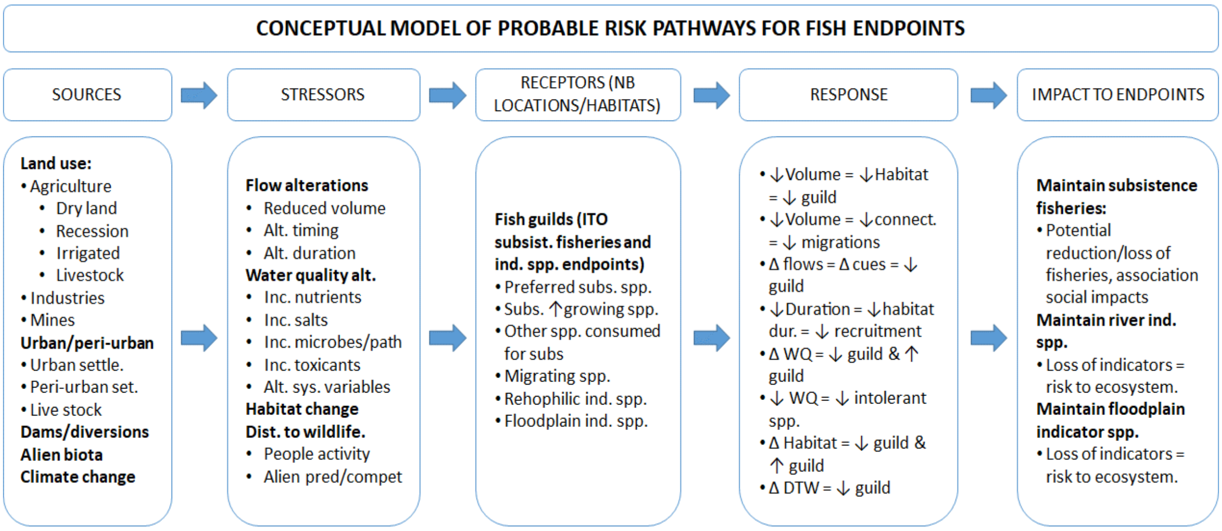


**Figure 20: Detailed conceptual model for fish used to direct the formation of the risk model for fish endpoints.**

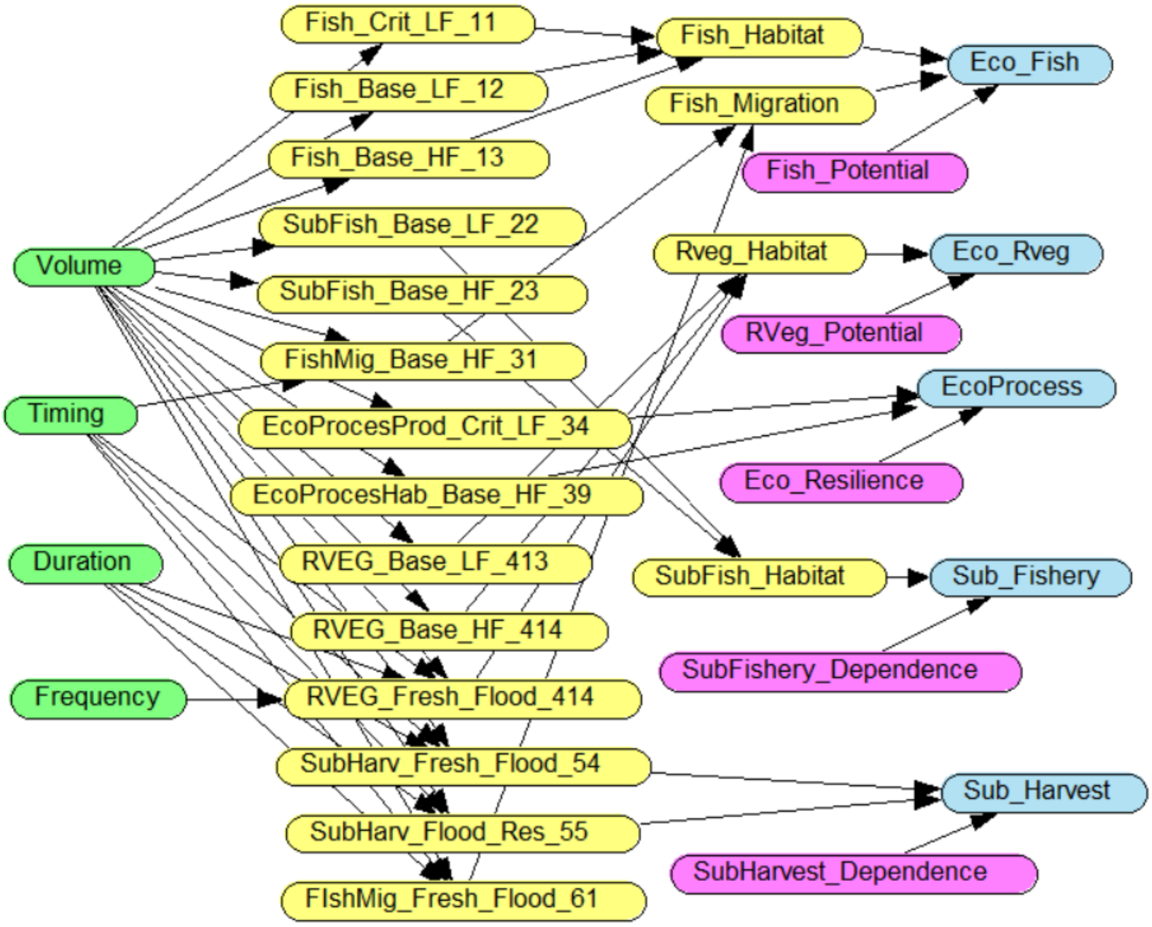
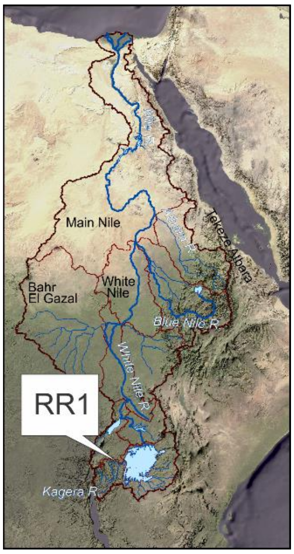


**Figure 21: Schematic representation of the risk model developed to represent the risk pathways and socio-ecological response of altered volume, timing and duration of flows to the endpoints selected in the study. Green nodes represent input environmental variable information related to the exposure 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 endpoints to occur in a risk region which represents the effects part of the risk model. The blue nodes represent the endpoint.**

# 4 RESULTS PER RISK REGION

## 4.1 RR1 – Kagera River



The Kagera River drains the headwaters of the White Nile and is the largest river in the Lake Victoria basin (NBI, 2008). The Kagera River Basin covers approximately 60 500 km$^2$ and covers portions of Burundi, Rwanda, Tanzania and Uganda. The river is fed by three main tributaries, namely: the Nyabarongo River, the Akanyaru River and the Ruvubu River and most of the runoff originates in the upper half of the catchment (NBI, 2008). The river reach selected for the assessment is at the start of the lower reach of the Kagera River at the Kyaka Ferry (Latitude -1.24943; longitude 31.420205).

### 4.1.1 Data Analysis

#### 4.1.1.1 Hydrology Assessment

The results are presented as tables showing the flow requirements for the highest and lowest flow month at selected percentile values and the annual flood requirements in terms of discharge, months when required and the duration in days. The hydrographs indicate the reference and base flows compared to the EFR. Flow duration curves (FDCs) per RR for selected months are also presented.

The Kagera River flows into Lake Victoria and has a record period spanning 38 years (1952-1989) with a Reference MAR of 6 979 MCM. The flow requirements for selected months and percentiles (low flows and floods) that were used to determine the EFR is summarised in the Table 10 below.

Table 10: Selected flow requirements for RR1 – Kagera River

| | **Flow requirements ($m^3/s$) – low flows** | | |
|---|---|---|---|
| **Percentiles** | **May** | **Oct** | |
| **10** | 160 | 120 | |
| **50** | 146 | 98 | |
| **99.9** | 39 | 45 | |
| | **Flow requirements– annual floods** | | |
| | **May** | **Jun** | **Jul** |
| **Peak flows ($m^3/s$)** | 440 | 360 | 360 |
| **Duration (days)** | 30 | 28 | 28 |

These selected requirements, together with the DRM were used to determine the EFR for each month. The results of the final EFR for RR1 is shown in Table 11 below.

Table 11: Final EFR for RR1 – Kagera River (flows in $m^3/s$)

| **RR1** | **Jan** | **Feb** | **Mar** | **Apr** | **May** | **Jun** | **Jul** | **Aug** | **Sep** | **Oct** | **Nov** | **Dec** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 95.4 | 106.5 | 112.6 | 122.0 | 142.0 | 138.5 | 130.4 | 118.3 | 118.1 | 112.6 | 114.7 | 112.2 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Minimum | 48.2 | 53.7 | 52.0 | 56.7 | 59.1 | 60.9 | 57.9 | 53.4 | 51.4 | 47.8 | 47.9 | 46.9 |
| Maximum | 120.1 | 134.1 | 164.3 | 165.5 | 197.1 | 198.6 | 189.1 | 155.5 | 144.6 | 131.8 | 122.8 | 120.8 |
| Percentiles | | | | | | | | | | | | |
| 0.1 | 120.1 | 134.1 | 164.3 | 165.5 | 197.1 | 198.6 | 189.1 | 155.5 | 144.6 | 131.8 | 122.8 | 120.8 |
| 1 | 120.1 | 134.1 | 164.3 | 165.5 | 197.1 | 198.6 | 189.1 | 155.5 | 144.6 | 131.8 | 122.8 | 120.8 |
| 5 | 120.1 | 134.1 | 164.2 | 165.3 | 197.0 | 198.3 | 188.5 | 155.3 | 144.6 | 131.7 | 122.8 | 120.8 |
| 10 | 119.9 | 134.0 | 160.1 | 164.8 | 196.4 | 197.6 | 187.7 | 154.9 | 144.1 | 131.5 | 122.8 | 120.7 |
| 15 | 119.7 | 133.5 | 157.9 | 164.0 | 195.1 | 196.1 | 186.4 | 153.7 | 143.5 | 131.1 | 122.7 | 120.6 |
| 20 | 119.1 | 133.1 | 152.3 | 163.0 | 193.8 | 194.2 | 183.4 | 152.0 | 142.8 | 130.0 | 122.6 | 120.6 |
| 30 | 117.2 | 130.2 | 147.7 | 157.8 | 187.5 | 187.1 | 175.1 | 147.5 | 139.8 | 127.3 | 122.3 | 120.3 |
| 40 | 114.1 | 125.1 | 137.7 | 145.6 | 180.5 | 169.3 | 160.4 | 138.7 | 131.2 | 122.1 | 121.9 | 119.5 |
| 50 (median) | 105.9 | 118.8 | 116.8 | 139.1 | 153.4 | 154.5 | 138.0 | 122.3 | 122.0 | 113.3 | 121.1 | 119.0 |
| 60 | 97.3 | 106.4 | 97.2 | 110.7 | 136.8 | 124.9 | 108.6 | 113.4 | 115.1 | 109.8 | 119.5 | 117.8 |
| 70 | 79.2 | 93.8 | 85.6 | 92.5 | 102.3 | 98.6 | 94.1 | 102.1 | 108.1 | 107.2 | 116.3 | 115.3 |
| 80 | 67.5 | 75.1 | 65.4 | 76.1 | 84.3 | 73.5 | 70.4 | 86.5 | 101.8 | 104.7 | 112.2 | 111.2 |
| 85 | 58.1 | 65.5 | 60.8 | 66.9 | 70.3 | 68.5 | 66.6 | 77.4 | 89.2 | 98.0 | 106.8 | 106.7 |
| 90 | 53.9 | 60.0 | 56.6 | 62.0 | 64.7 | 65.0 | 61.1 | 68.9 | 81.0 | 90.5 | 102.0 | 100.0 |
| 95 | 50.1 | 55.6 | 53.3 | 58.1 | 61.1 | 62.0 | 58.9 | 58.0 | 66.6 | 78.7 | 84.7 | 79.3 |
| 99 | 48.7 | 54.0 | 52.4 | 56.7 | 59.8 | 61.1 | 57.9 | 53.6 | 57.0 | 55.8 | 58.1 | 46.9 |
| 99.9 | 48.3 | 53.7 | 52.0 | 56.7 | 59.2 | 60.9 | 57.9 | 53.4 | 52.0 | 48.6 | 48.9 | 46.9 |

The summary of the EFR for RR1 (Table 12) shows that 57% of the flows in the Kagera River is required for ecological functioning, with the low flows (flows occurring more than 50% of the time) making up the bulk of the requirement and floods only 10% of the ecological requirement. Thus, low flows (dry and wet base flows) are important for the Kagera River and should be provided to ensure adequate habitats to maintain the ecology of the river. It is also important to note that the river is perennial and that the 99.9 percentile flow specified for each month provides for non-zero flows. Thus, any future operation of the system or water resource developments should accommodate the minimum flow requirements.

Table 12: Summary of final EFR for RR 1– Kagera River

| **RR** | **River** | **Reference (MCM)** | **% Requirement** | | | | **Volume Requirement (MCM)** | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | **Low flows** | **Drought flows** | **Floods** | **Total** | **Low flows** | **Drought flows** | **Floods** | **Total** |
| RR1 | Kagera | 6 979 | 47.7 | Not specified | 10.0 | 57.7 | 3 349 | Not specified | 705 | 4 054 |

The monthly hydrograph of the Reference flows (REF), base flows (BF) and EFR for a B state for the Kagera River is shown Figure 22. This indicates that the EFR is less than the base flows of the monthly Reference flows. The FDC for October (low flow season) (Figure 23) also indicates that the EFR for a B state is less than the base flows of the reference flows for most of the time. However, the FDC for May (Figure 24) shows that the ecological requirements are almost the same as the base flows.

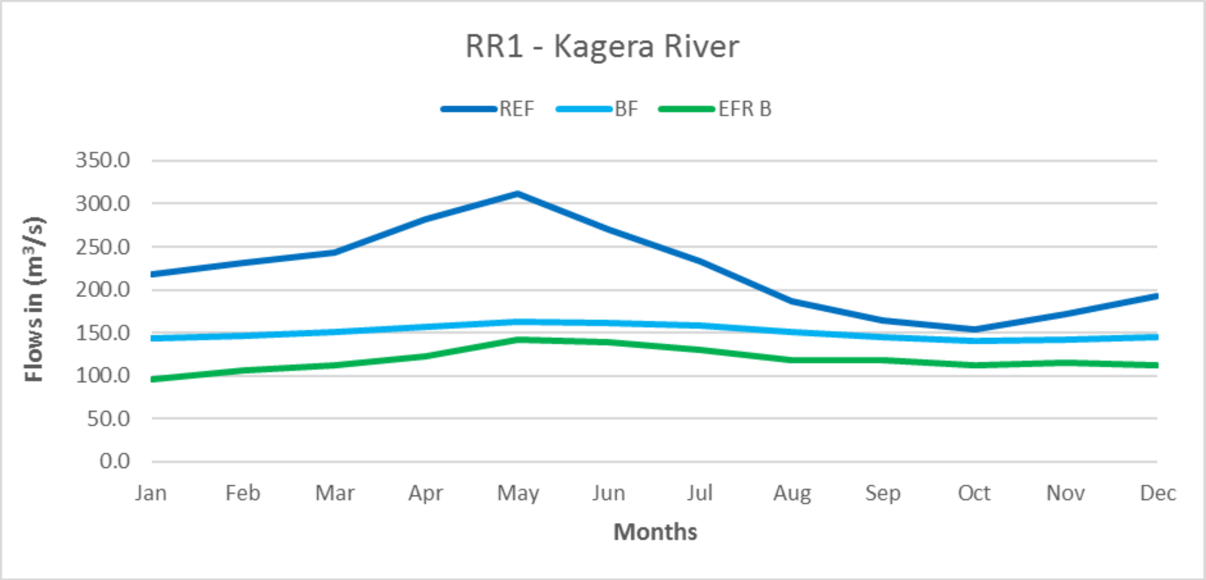


Figure 22: Monthly hydrograph for RR1 – Kagera River

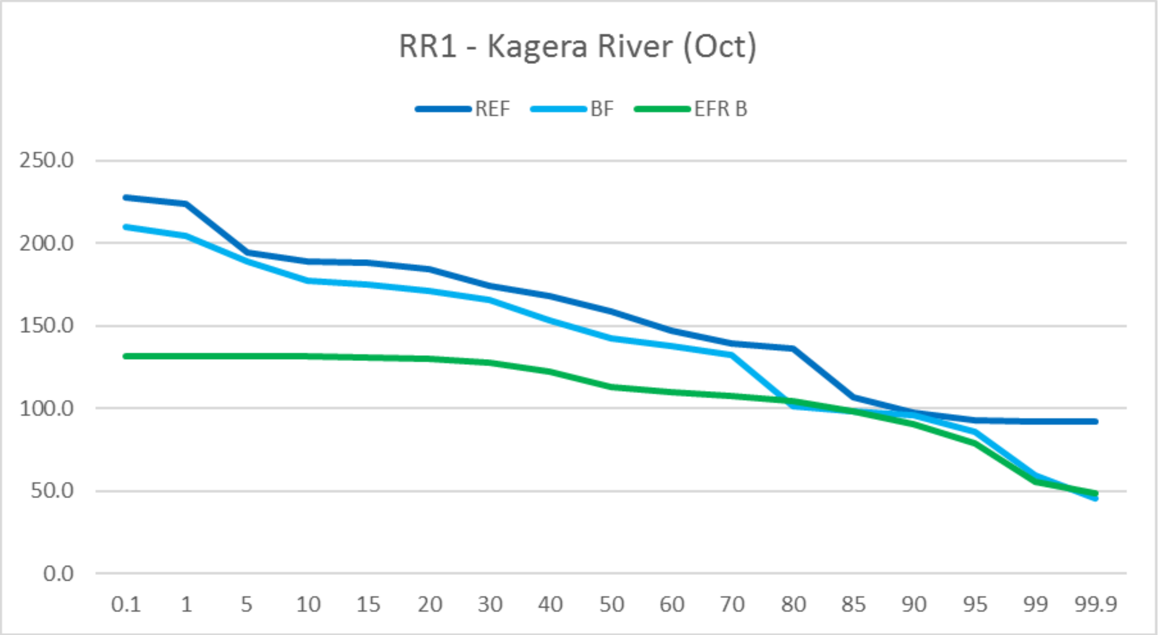


Figure 23: Flow duration curve for October (low flows) in RR1 – Kagera River

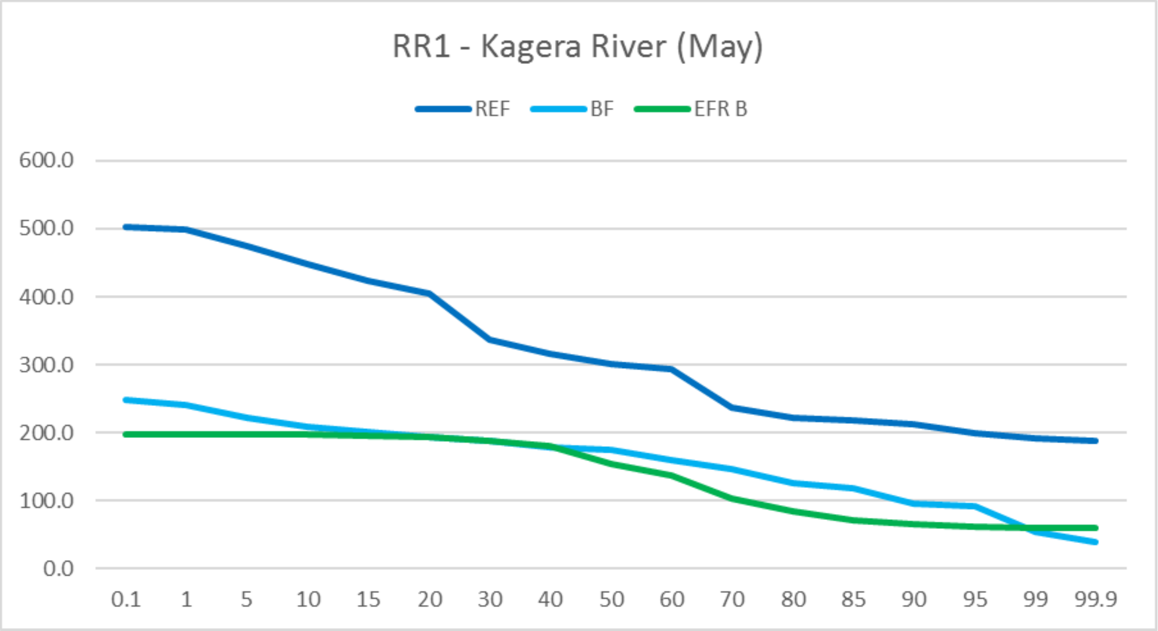


Figure 24: Flow duration curve for May (wet season) in RR1 – Kagera River

#### 4.1.1.2 Hydraulic Assessment

It must be noted, that the 1.5yr return period flow is only approximately depicting bankfull flow conditions. Therefore, additional cross section characteristics were investigated from which information about inundation extent and frequency could be deduced. These descriptions are briefly given for the points of interest. Each point of interest is individually assessed using QGIS with the Profile Tool and Quick Map Services Plugin on the MERIT DEM and Google Satellite images. The site location and ID (yellow dot with number, corresponds to the IDs given in Table 14) is shown together with the cross section location (red line) on satellite images (Google Earth/Digital Globe). Below the images, the diagram shows the cross section (elevation along the red line), where the small red dot in the upper satellite images is marked by the centre of the cross line in the lower diagram. Numbers in the diagram show elevation in mASL (y-Axis) and distance from left in meters (x-axis).

Table 13. Points of interest, the applied methodology for obtaining the channel cross section and additional channel and cross section properties

| ID | River | Latitude | Longitude | Channel bathymetry method | Bank width [m] | Ineffective area elevation [mASL] | Slope [m/m] |
|---|---|---|---|---|---|---|---|
| RR1 | Kagera | -1.2494 | 31.4202 | Bankfull | 119 | -- | 0.000120 |

Figure 25 shows the DEM cross section at the Kagera river. No additional survey data or hydraulic information was available. Buildings exist along a contour line of 1149mASL. Together with the bankfull flow discharge, this information was used to calibrate channel depth below the DEM level of 4m.

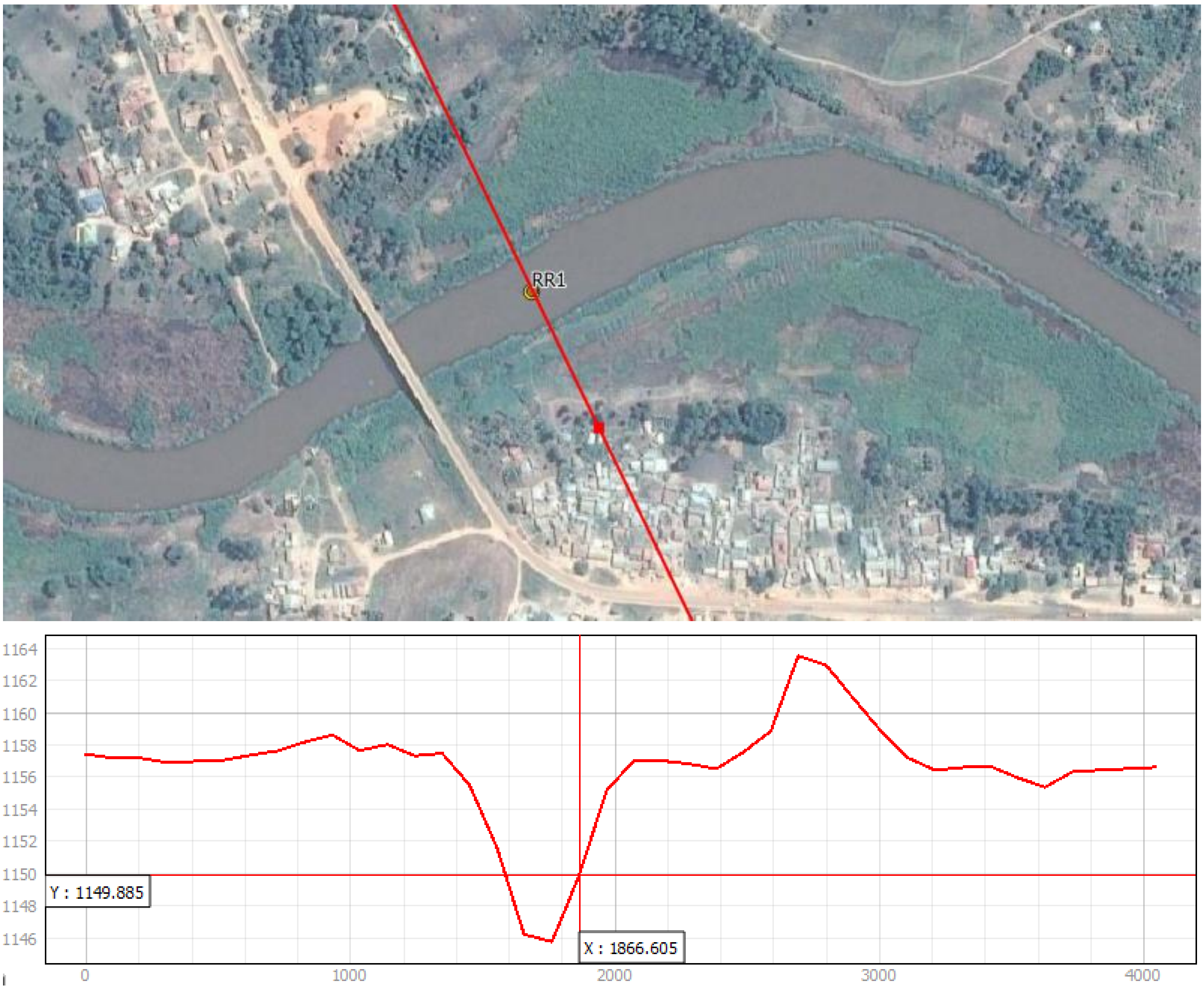


Figure 25. Kagera River cross section at Kyaka, indicating that the elevation that is rarely flooded lies above 1149mASL

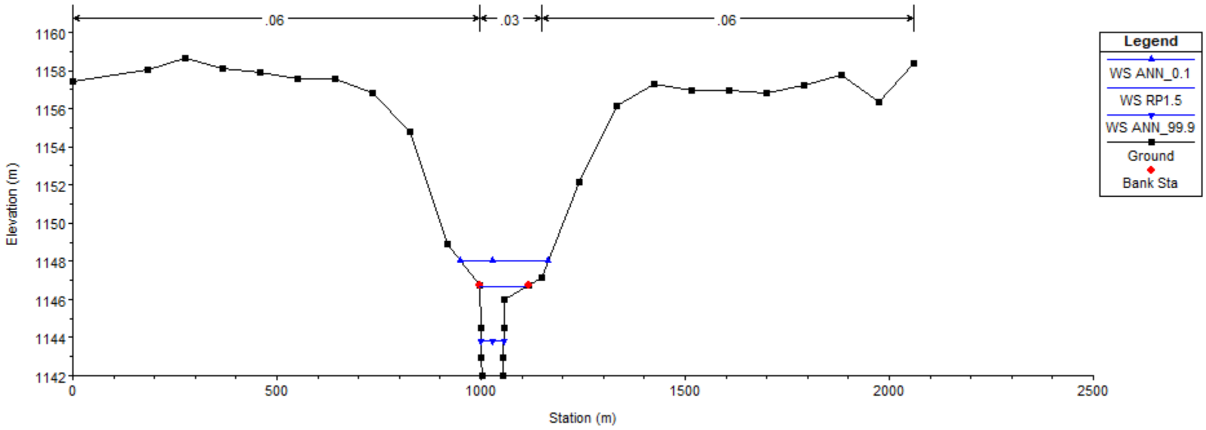


Figure 26: Cross sectional profile of the hydraulic site for RR1

### 4.1.1.3 Vegetation Assessment

This risk region is represented by the Kagera River at Kyaka Ferry with the cross section shown as a red line in Figure 27. Vegetation at this site displays a clear woody and non-woody zone (Figure 27 and Figure 28). The active channel, which averages 60-65m wide appears to be fringed by a narrow band of shrub species followed by a more extensive lower zone / wet bank dominated by flood dependent non-woody species such as *Phragmites, Cyperus, Oyza, Juncus* and *Typha*. This sub-zone is extensively utilised for agricultural activities, which will include grazing of livestock. A tall tree zone, which includes *Acacia* and *Eucalyptus* species, exists beyond that and is heavily interspersed by human dwellings and activities.

Figure 27: Google Earth © satellite image at Kyaka Ferry on the Kagera River representing risk region 1.

Figure 28: Photograph showing the Kagera River and associated vegetation at the bridge near Kyaka Ferry (photo courtesy of Google Earth).

Based on the available biological information at cross section sites, and together with hydraulics at each site, the driver components [within the model] were quantified for a B-category (Table 14) as determined by discernible riparian indicators (Table 15). Interpolation was frequently required due to lack of biological data specific to sites.

Table 14: Quantification of driver components for a B-category system (Values are discharge).

| **General description** | | **RR1** |
|---|---|---|
| Bank full for non-woody fringe vegetation | Wet Base | 195 |
| Wet base less 1m in elevation | Dry Base | 90 |
| Wet base less 1.5m in elevation | Critical Low | 63 |
| Between woody and non-woody limits | Freshette | 360 |
| To the base of woody vegetation (Tall tree line) | Annual flood | 440 |

Table 15: Riparian indicators utilized to quantify driver components for a B-category system.

| RR1 | channel width (m) | Discharge | Chan depth | Month | Indicators |
|---|---|---|---|---|---|
| Wet Base | 64 | 195 | 3.5 | Jun | Reeds & low shrub |
| Dry Base | 58 | 90 | 2.5 | Feb | Reeds & low shrub |
| Critical Low | 57 | 63 | 2 | Feb | Reeds & low shrub |
| Freshette | 185 | 360 | 3.6 | May-Jul | Flood reeds |
| Annual flood | 220 | 440 | 3.85 | Jun | Tall tree line |

## Defining Risk to Vegetation

The alteration of driver dynamics, in this case flows and by implication floods, results in risk to the vegetation. Optimal driver state results in low risk to all vegetation endpoints but does not consider the effects of non-flow related impacts, such as ever increasing grazing and trampling pressures, and the impacts of human density and resource use. However, as flows may decline so the risk to vegetation endpoints increases. This risk has been described and quantified for each of the response variables (Table 16), as well as for each of the response variables within different risk regions, and represents declining ecological health or ecosystem wellbeing.

Table 16: Justifications and driver quantification for interaction of vegetation components within the model.

| Bayesian Network variable title, measure - (BN node name) | Rank (score) | Rank definition and measure for variable | RR1 |
|---|---|---|---|
| Aveghab_R_bwet | Zero (25) | 10% higher percentile than B] base | > 210 |
| | Low (50) | bank full for non-woody vegetation | 210 - 195 |
| | Moderate (75) | between [B] dry base and [B] wet base | 195 - 90 |
| | High (100) | as low as normal (B) dry base | < 90 |
| FPveg_FP_bwet | Zero (25) | 10% higher percentile than B] base | > 210 |
| | Low (50) | bank full for non-woody vegetation | 210 - 195 |
| | Moderate (75) | between [B] dry base and [B] wet base | 195 - 90 |
| | High (100) | as low as normal (B) dry base | < 90 |
| Aveghab_R_drought | Zero (25) | 95% [B] dry season max month | > 92 |
| | Low (50) | critical low flows for [B] | 92 - 63 |
| | Moderate (75) | 99% dry season max | 63 - 55 |
| | High (100) | | < 55 |
| Aveghab_R_bdry | Zero (25) | wet base | > 195 |
| | Low (50) | wet base less 1m | 195 - 90 |
| | Moderate (75) | critical low | 90 - 63 |
| | High (100) | critical low | < 63 |
| FPveg_FP_flood | Zero (25) | to the base of woody vegetation (Tall tree line):annual | > 440 |
| | Low (50) | between woody and non-woody limits: freshette | 440 - 360 |
| | Moderate (75) | no flood: 20% higher than wet base percentile | 360 - 220 |
| | High (100) | | < 220 |
| Subveg_R_bdry | Zero (25) | wet base | > 195 |
| | Low (50) | wet base less 1m | 195 - 90 |
| | Moderate (75) | critical low | 90 - 63 |

| Bayesian Network variable title, measure - (BN node name) | Rank (score) | Rank definition and measure for variable | RR1 |
|---|---|---|---|
|  | High (100) | critical low | < 63 |
| Subveg_R_bwet | Zero (25) | 10% higher percentile than B] base | > 210 |
|  | Low (50) | bank full for non-woody vegetation | 210 - 195 |
|  | Moderate (75) | between [B] dry base and [B] wet base | 195 - 90 |
|  | High (100) | as low as normal (B) dry base | < 90 |
| Subveg_FP_bdry | Zero (25) | wet base | > 195 |
|  | Low (50) | wet base less 1m | 195 - 90 |
|  | Moderate (75) | critical low | 90 - 63 |
|  | High (100) | critical low | < 63 |
| Subveg_FP_bwet | Zero (25) | 10% higher percentile than B] base | > 210 |
|  | Low (50) | bank full for non-woody vegetation | 210 - 195 |
|  | Moderate (75) | between [B] dry base and [B] wet base | 195 - 90 |
|  | High (100) | as low as normal (B) dry base | < 90 |

### 4.1.1.4 Fish Assessment

For the determination of instream flow requirements for the Kagera River eight species of fishes that have habitat and or migratory requirements that occur within the river were selected for the assessment (Table 17). The hydrograph is relative stable in this area and longitudinal and lateral habitat connectivity is provided throughout the year. Based on the relative size species attains and biology and ecology information the depth and velocity requirements were determined as well as minimum depths to maintain lateral and longitudinal migrations for these indicator species. This information was aligned to the seasonal flows of the system and used to establish flow requirements that were provided to the hydrologist to determine eflow requirements (Figure 29, Figure 30 and Figure 31).

**Table 17: Fishes selected to determine eflows for RR1. Hypothesised preferences for habitats (depth and velocity) and migratory notes provided for each species.**

| Min. Depth (mm) | Min. Vel (m/s) | Weight | Kagera River (Rwanda) indicator spp. | Details |
|---|---|---|---|---|
| 500 | 1 | 3 | *Labeo spp.* | Good rheophillic species long.↑↑ & lat. Potamodromous migrations. |
| 500 | 0.5 | 2 | *Polypterus spp.* | Good rheophillic species long. & lat. Potamodromous migrations. |
| 650 | 0.8 | 2 | Alestes spp. | Good rheophillic species long.↑↑ & lat. Potamodromous migrations. |
| 450 | 0.5 | 2 | Brycinus spp. | Good rheophillic species long.↑↑ & lat. Potamodromous migrations. |
| 200 | 1 | 1 | *Mastacembelus frenatus* | Temperate spp. Longitudal migrations, not highly relevant to lower Kagera R. Site. |
| 450 | 0.5 | 1 | *Bargus spp.* | Good rheophillic species but limited information |
| 300 | 0.5 | 1 | *Auchenoglanis spp.* | Good rheophillic species but limited information |
| 300 | 0.3 | 1 | *Schilbe spp.* | Good rheophillic species long. & lat. Potamodromous migrations. |

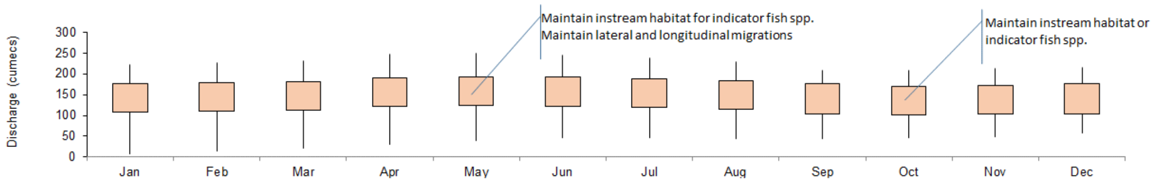


**Figure 29: Reference hydrograph from RR1 with key fish biology and ecology requirements.**

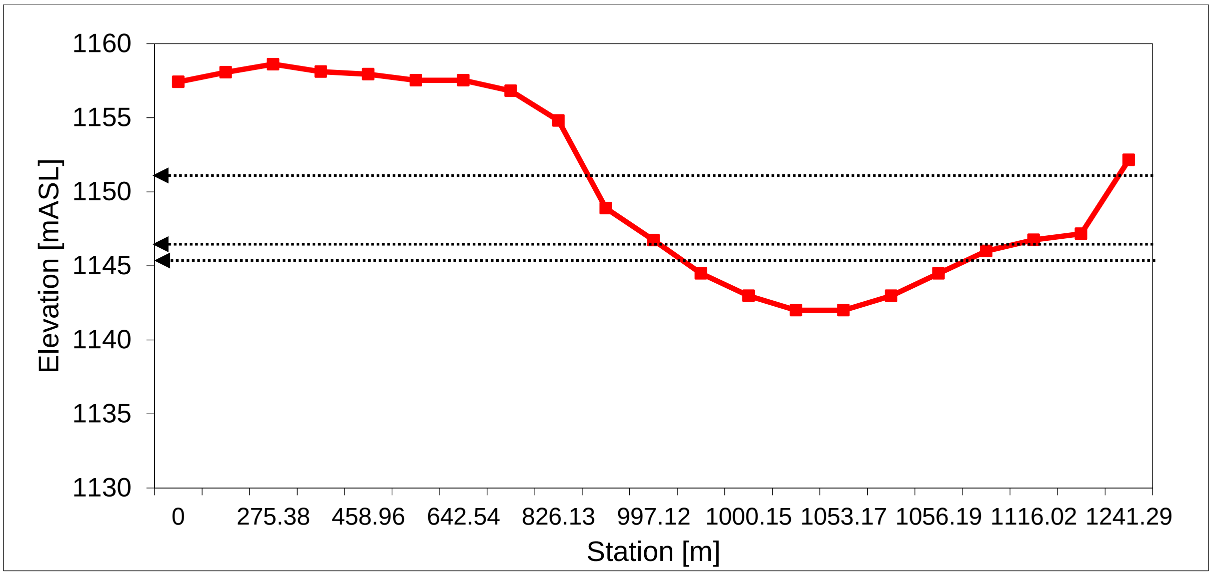


Figure 30: Cross section of RR1 with flow elevations highlighted for key fish biology and ecology events selected in the study for eflow determination.

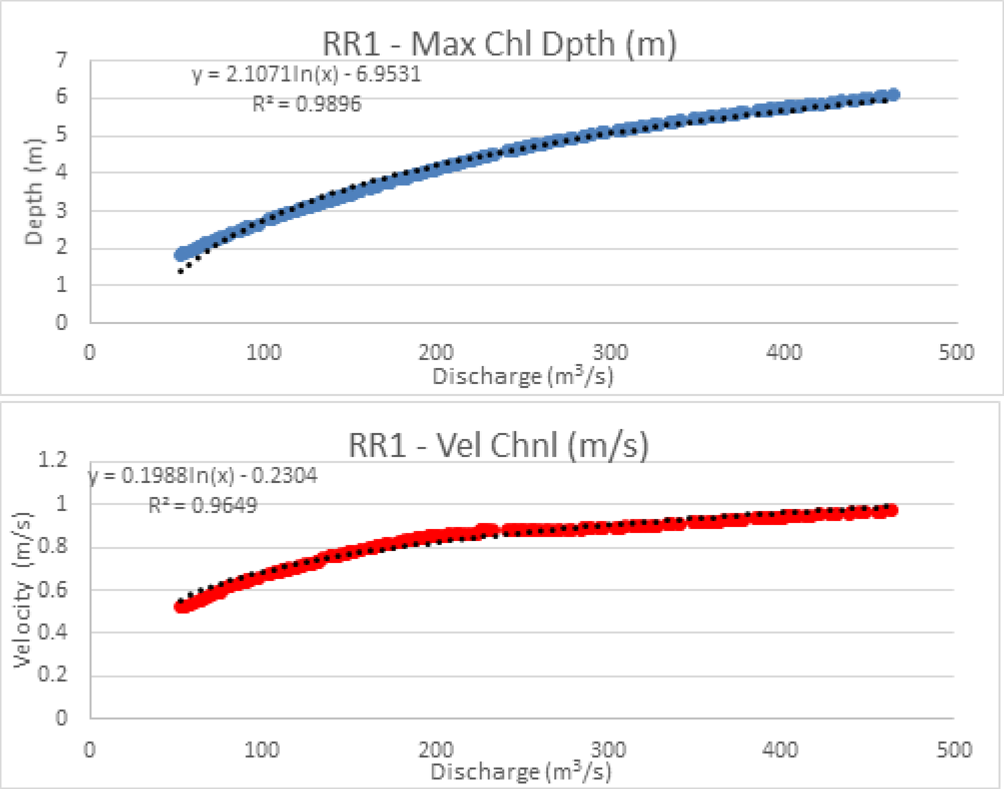


Figure 31: Flow depth (Blue) and Velocity depth (Red) relationships established for the study used to determine flow requirements for fishes.

### 4.1.2 Calculate Risk

Following the determination of flows to maintain the ecosystems associated with each site in each ecological category a summary of the flow requirements associated with these scenarios is generated (Table 18). These hydrographs were used in the risk assessment as scenarios to compare the socio-ecological consequences of altered flows associated with each scenario (ecological category).

Table 18: Summary of the floods required to provide for key socio-ecological processes in the Nile River per ecological category Class considered in the study.

| RR | River | Flow Component | Percentage EFR per Ecological Class | | |
|---|---|---|---|---|---|
| | | | B | C | D |
| 1 | Kagera River | Drought flows | Included in Maintenance Low flows | | |
| | | Maintenance (or base) flows Low (or dry) period | 48% | 29% | 17% |
| | | Maintenance (or base) flows high (or wet) period | 10% | 9% | 4% |
| | | **Total** | **58%** | **38%** | **21%** |

The reference hydrographs and median flows for ecological categories B, C and D considered in the risk assessment for RR1 – Kagera River are graphically presented in Figure 32 and Figure 33. The rank thresholds for indicators selected for this site were used to query this hydrology data and evaluate the socio-ecological consequences of altered flows in the system using PROBFLO.

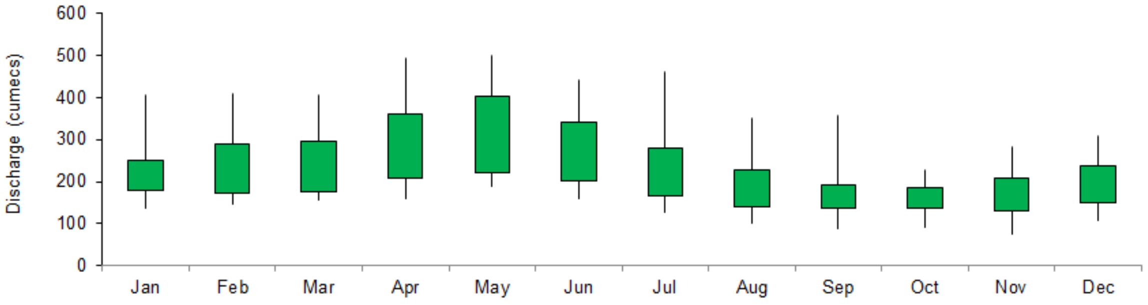


Figure 32: Box and whisker plot summary of the reference (Class A) average monthly ($m^3/s$) flows observed in RR1 in the study. Whiskers represent 0.01%tiles and 99.9%tiles and box 20%tile and 80%tiles.

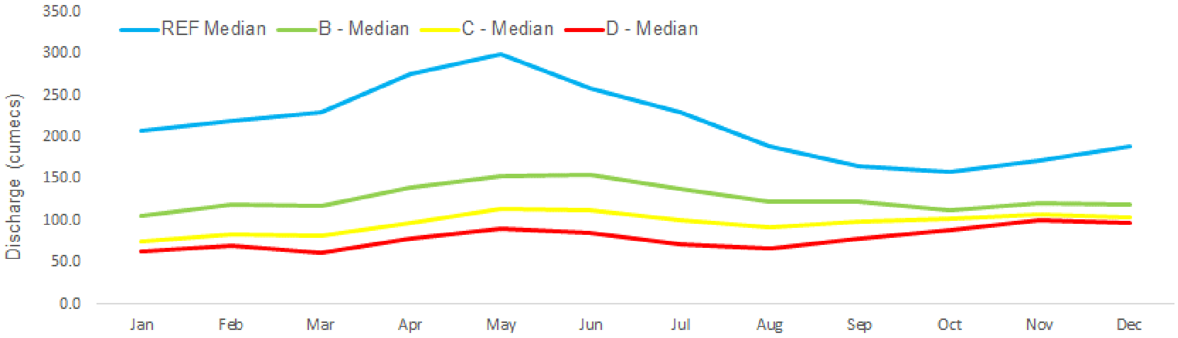


Figure 33: Relative graphs (medians) of the reference (Class A or pristine), Class B (near natural), Class C (moderately modified) and Class D (largely modified) average monthly flows ($m^3/s$) flows observed in RR1 in the study. Whiskers represent 0.01%tiles and 99.9%tiles and box 20%tile and 80%tiles.

Risk outcomes directly obtained from the Netica Bayesian Network assessment are presented per RR with averages, standard deviation (SD) and risk rank probability profiles.

### *Floodplain ecosystem services endpoint*

The relative risk to the floodplain ecosystem services endpoint showed an increasing trend in risk from Class A and B to Class D (Figure 34). The results for Class A and B were dominated by low to moderate risk with SD extending into the moderate risk range. The results for Class C and D were dominated by moderate risk with SD extending into the high risk range. From Figure 35 results include a >50% possibility of high risk to the floodplain services for Class D.

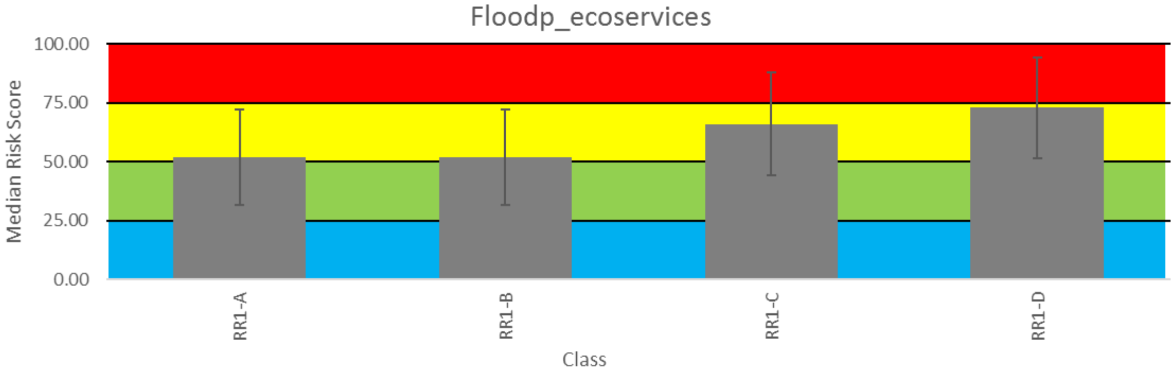


**Figure 34: Relative Risk (median, with standard deviation) of multiple stressors associated with eflow scenarios to Floodplain ecosystem services endpoint considered in the study (Class A (A), Class B (B), Class C (C) and Class (D)). Risk rank ranges for Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) risk included.**

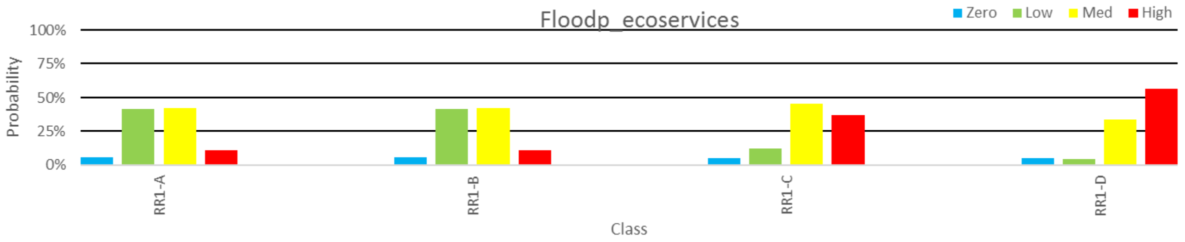


**Figure 35: Probability of risk rank occurrence for ranks Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) of multiple stressors associated with eflow scenarios to Floodplain ecosystem services endpoint considered in the study.**

***River ecosystem services endpoint***

The relative risk to the river ecosystem services endpoint showed an increasing trend in risk from Class A and B to Class D (Figure 36). The results for Class A and B were dominated by low risk with SD extending into the moderate risk range. The result and SD for Class C were in the moderate range. The result for Class D was also showed moderate risk with SD extending into the high risk range. Results in Figure 37 reveals no probabilities of high risk (>45%) for this RR.

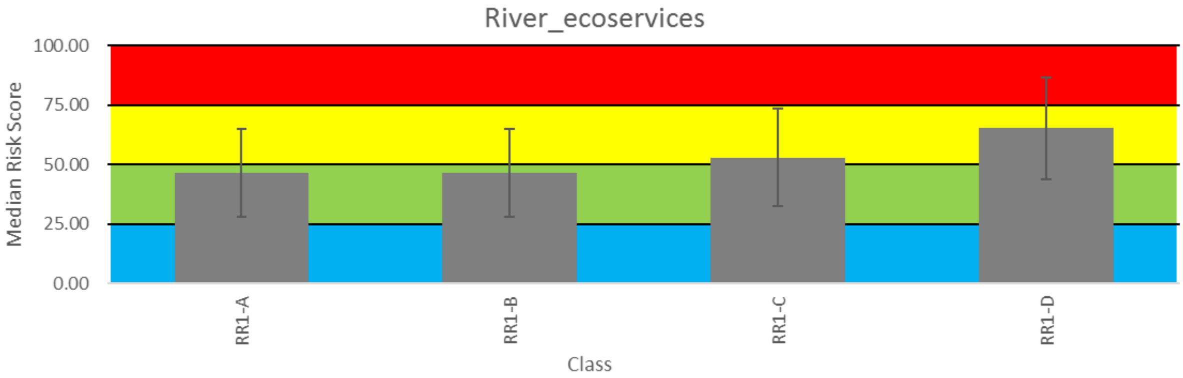


**Figure 36: Relative Risk (median, with standard deviation) of multiple stressors associated with eflow scenarios to River ecosystem services endpoint considered in the study (Class A (A), Class B (B), Class C (C) and Class (D)). Risk rank ranges for Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) risk included.**

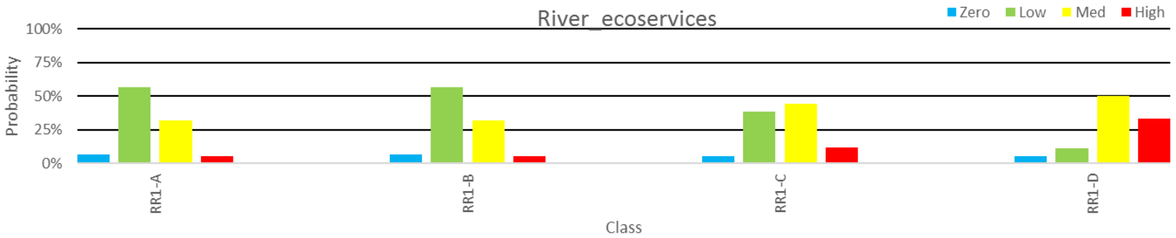


**Figure 37: Probability of risk rank occurrence for ranks Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) of multiple stressors associated with eflow scenarios to River ecosystem services endpoint considered in the study.**

***Floodplain biodiversity endpoint***

The relative risk to the floodplain biodiversity endpoint showed an increasing trend in risk from Class A and B to Class D (Figure 38). The results for Class A and B showed moderate risk with SD extending into the high risk ranges. The results for Class C and D showed moderate to high risk with SD extending into the high risk range. The probability of high risk (>50%) to the endpoint for Class C and D (Figure 39).

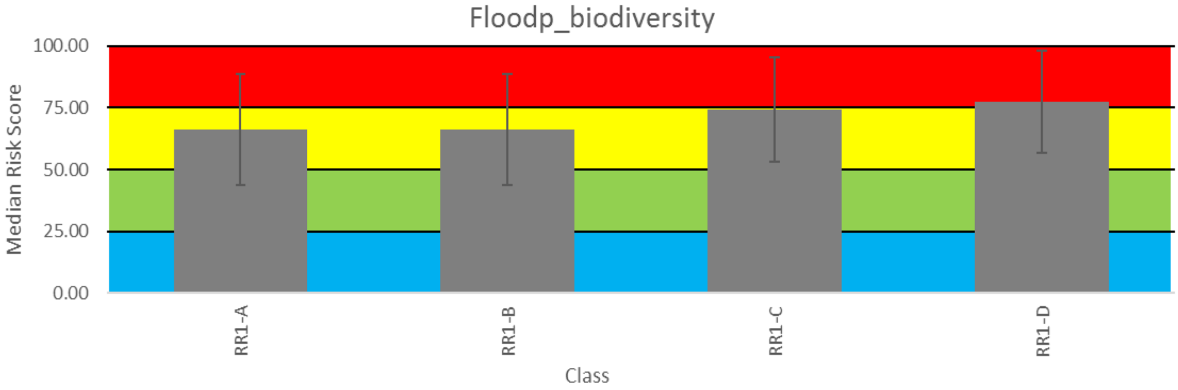


**Figure 38: Relative Risk (median, with standard deviation) of multiple stressors associated with eflow scenarios to Floodplain biodiversity endpoint considered in the study (Class A (A), Class B (B), Class C (C) and Class (D)). Risk rank ranges for Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) risk included.**

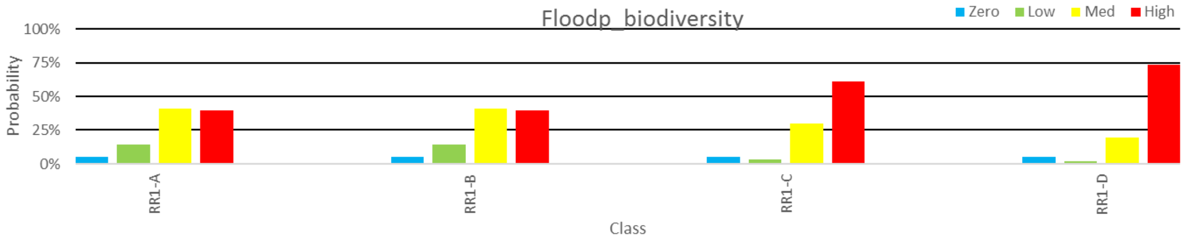


**Figure 39: Probability of risk rank occurrence for ranks Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) of multiple stressors associated with eflow scenarios to Floodplain biodiversity endpoint considered in the study.**

***River biodiversity endpoint***

The relative risk to the floodplain biodiversity endpoint did not reveal much difference between Classes A to Class D (Figure 40). The results revealed low risk for Classes A-D, with SD often extending into the moderate risk range. No high risk (>50%) to the riverine biodiversity was displayed for this RR (Figure 41).

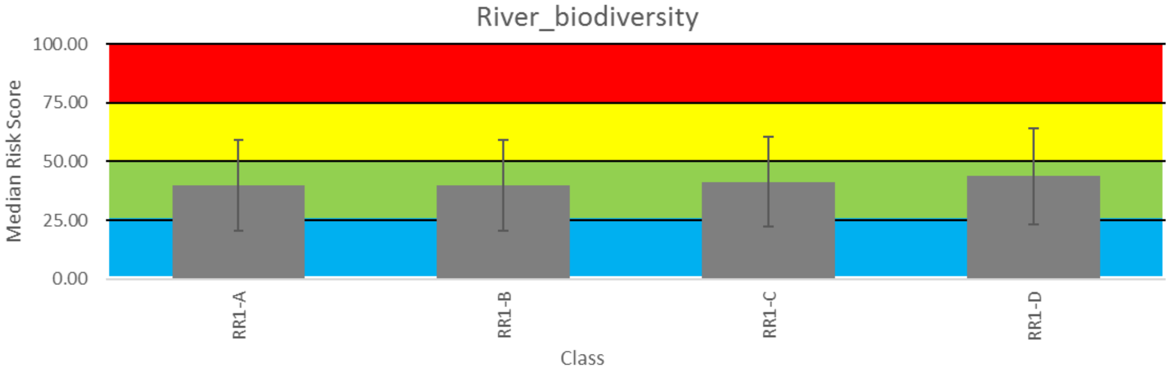


**Figure 40: Relative Risk (median, with standard deviation) of multiple stressors associated with eflow scenarios to River biodiversity endpoint considered in the study (Class A (A), Class B (B), Class C (C) and Class (D)). Risk rank ranges for Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) risk included.**

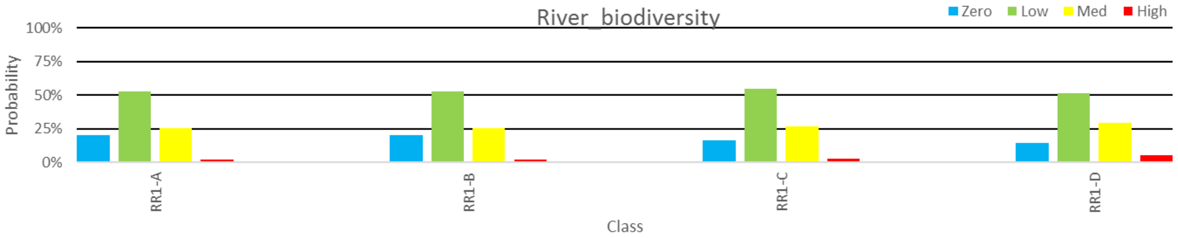


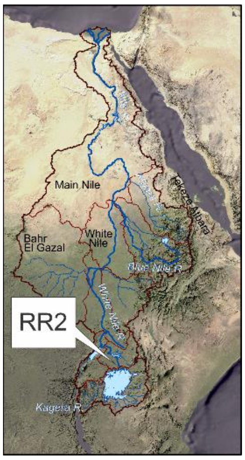
**Figure 41: Probability of risk rank occurrence for ranks Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) of multiple stressors associated with eflow scenarios to River biodiversity endpoint considered in the study.**

### 4.1.3 Conclusion for RR1

Low flows (dry and wet base flows) are important for the Kagera River and should be provided to ensure adequate habitats to maintain the ecology of the river. It is also important to note that the river is perennial and that the 99.9 percentile flow specified for each month provides for non-zero flows. Thus, any future operation of the system or water resource developments should accommodate the minimum flow requirements.

Results include increasing risk to endpoints as the ecological wellbeing of the rivers deteriorate from reference states to Class B, C and D ecological categories. Similarly, there is a high variability in the resilience and associated risk of altered flows to different endpoints. This includes relatively higher risk to the floodplain biodiversity endpoint compared to the riverine biodiversity and the ecosystem services associated with the river and floodplain ecosystems. A probability of high risk (>50%) was recorded for Class D for the floodplain services endpoint and for Class C and D for the floodplain biodiversity endpoint.

## 4.2 RR2 – Victoria Nile



The Victoria Nile originates from the Equatorial Lakes region and is one of the Equatorial Nile sub systems (NBI, 2016b). It emerges from Lake Victoria, travels northwest passing through Lake Kyoga and Lake Albert where it emerges as the Albert Nile (NBI,2012). The river reach selected for the assessment is at Jinja where the Victoria Nile emerges from Lake Victoria (Latitude 0.515718; longitude 33.12336).

### 4.2.1 Data Analysis

#### 4.2.1.1 Hydrology Assessment

The results are presented as tables showing the flow requirements for the highest and lowest flow month at selected percentile values and the annual flood requirements in terms of discharge, months when required and the duration in days. The hydrographs indicate the reference and base flows compared to the EFR and include the reference flows for the period before 1960. Flow duration curves (FDCs) per RR for selected months are also presented.

This reach is downstream of Lake Victoria and has flows for the period 1948-2013. This record period was split in 1962 due to the upwards ‘shift’ in the outflows from Lake Victoria in the early 1960s. The final record period upon which the EFR is based is 1963-2013 with a Reference MAR of 34 024 MCM. The flow requirements for selected months and percentiles (low flows and floods) that were used to determine the EFR is summarised in Table 19 below.

Table 19: Selected flow requirements for RR2 – Victoria Nile

<table>
<tr><th></th><th colspan="6">Flow requirements (m³/s) – low flows</th></tr>
<tr><th>Percentiles</th><th colspan="3">May</th><th colspan="3">Oct</th></tr>
<tr><td><b>15</b></td><td colspan="3">950</td><td colspan="3">600</td></tr>
<tr><td><b>50</b></td><td colspan="3">600</td><td colspan="3">500</td></tr>
<tr><td><b>99.9</b></td><td colspan="3">460</td><td colspan="3">425</td></tr>
<tr><th></th><th colspan="6">Flow requirements– annual floods</th></tr>
<tr><th></th><th colspan="2">May</th><th colspan="2">Jun</th><th colspan="2">Jul</th></tr>
<tr><td><b>Peak flows (m³/s)</b></td><td colspan="2">1450</td><td colspan="2">1450</td><td colspan="2">1450</td></tr>
<tr><td><b>Duration (days)</b></td><td colspan="2">30</td><td colspan="2">28</td><td colspan="2">28</td></tr>
</table>

These selected requirements, together with the DRM were used to determine the EFR for each month. The results of the final EFR for RR2 is shown in Table 20 below.

Table 20: Final EFR for RR2 – Victoria Nile (flows in m³/s)

| RR2 | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 544.5 | 563.4 | 550.8 | 608.2 | 752.4 | 764.2 | 734.9 | 601.8 | 583.7 | 561.8 | 579.0 | 568.2 |
| Minimum | 467.1 | 436.7 | 463.8 | 486.0 | 501.4 | 518.4 | 502.5 | 477.0 | 451.8 | 419.7 | 445.2 | 466.2 |
| Maximum | 583.2 | 626.0 | 577.5 | 651.3 | 902.5 | 933.0 | 904.1 | 654.9 | 600.2 | 579.7 | 595.8 | 581.3 |
| Percentiles | | | | | | | | | | | | |
| 0.1 | 583.2 | 626.0 | 577.5 | 651.3 | 902.5 | 933.0 | 904.1 | 654.9 | 600.2 | 579.7 | 595.8 | 581.3 |
| 1 | 583.2 | 626.0 | 577.5 | 651.3 | 902.5 | 933.0 | 904.1 | 654.9 | 600.2 | 579.7 | 595.8 | 581.3 |

| RR2 | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 583.2 | 625.9 | 577.4 | 651.2 | 902.3 | 932.3 | 903.2 | 654.6 | 600.2 | 579.7 | 595.7 | 581.3 |
| 10 | 583.0 | 625.1 | 577.4 | 650.5 | 901.5 | 931.0 | 902.0 | 654.2 | 600.1 | 579.5 | 595.6 | 581.3 |
| 15 | 582.5 | 624.9 | 576.9 | 649.4 | 899.0 | 927.3 | 897.8 | 652.4 | 599.9 | 579.3 | 595.5 | 581.1 |
| 20 | 581.6 | 623.9 | 576.5 | 646.5 | 891.5 | 916.3 | 886.8 | 648.2 | 599.6 | 579.0 | 595.1 | 580.8 |
| 30 | 579.6 | 619.6 | 575.4 | 642.8 | 881.8 | 903.3 | 873.4 | 642.2 | 599.1 | 578.4 | 594.7 | 580.3 |
| 40 | 574.4 | 610.8 | 573.0 | 631.4 | 854.1 | 864.5 | 834.7 | 625.5 | 598.2 | 577.3 | 593.8 | 579.9 |
| 50 (median) | 564.6 | 594.4 | 568.7 | 611.6 | 806.2 | 801.8 | 773.3 | 598.6 | 596.8 | 576.0 | 591.8 | 578.2 |
| 60 | 547.6 | 558.3 | 558.1 | 594.7 | 721.5 | 694.3 | 675.7 | 582.9 | 593.5 | 572.4 | 589.8 | 576.2 |
| 70 | 516.5 | 530.3 | 547.0 | 590.1 | 649.1 | 625.4 | 611.1 | 578.5 | 589.4 | 568.5 | 584.1 | 573.4 |
| 80 | 500.0 | 490.0 | 526.4 | 584.4 | 574.6 | 593.0 | 574.9 | 572.8 | 581.4 | 559.4 | 576.9 | 567.0 |
| 85 | 485.5 | 464.9 | 509.1 | 574.6 | 564.2 | 583.2 | 566.9 | 564.5 | 571.3 | 547.0 | 563.1 | 558.7 |
| 90 | 477.8 | 454.5 | 494.6 | 566.3 | 555.7 | 574.3 | 556.7 | 554.8 | 558.9 | 535.1 | 554.2 | 549.6 |
| 95 | 470.4 | 441.5 | 473.5 | 531.5 | 529.9 | 543.7 | 527.2 | 522.3 | 519.5 | 498.1 | 520.9 | 520.5 |
| 99 | 467.3 | 437.3 | 463.8 | 486.0 | 501.4 | 518.4 | 502.5 | 477.0 | 452.2 | 420.2 | 445.7 | 466.2 |
| 99.9 | 467.1 | 436.8 | 463.8 | 486.0 | 501.4 | 518.4 | 502.5 | 477.0 | 451.8 | 419.7 | 445.3 | 466.2 |

The summary of the EFR for RR2 (Table 21) shows that almost 54% of the flows downstream of Lake Victoria is required for ecological functioning, with the low flows (flows occurring more than 50% of the time) making up the bulk of the requirement and floods only 7.6% of the ecological requirement. Thus, low flows (dry and wet base flows) are important for this reach of river and should be provided to ensure adequate habitats to maintain the ecology of the river. It is also important to note that the river is perennial and that the 99.9 percentile flow specified for each month provides for non-zero flows. Thus, any future operation of the system or water resource developments should accommodate these minimum flow requirements.

Table 21: Summary of final EFR for RR2 – Victoria Nile

| RR | River | Reference (MCM) | % Requirement | | | | Volume Requirement (MCM) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Low flows | Drought flows | Floods | Total | Low flows | Drought flows | Floods | Total |
| RR2 | Victoria Nile | 34 024 | 45.7 | Not specified | 7.60 | 53.5 | 15 614 | Not specified | 2 592 | 18 206 |

The monthly hydrograph of the REF, BF, flows for 1948-1961 (Sc) and EFR for a B state for the Victoria Nile River is shown in Figure 42. This indicates that the EFR is similar to the flows before the upward 'shift' in the hydrology. Both the FDC for October (low flow season) (Figure 43) and May (wet season) (Figure 44) indicate that the EFR for a B state is similar to the flows before 1960.

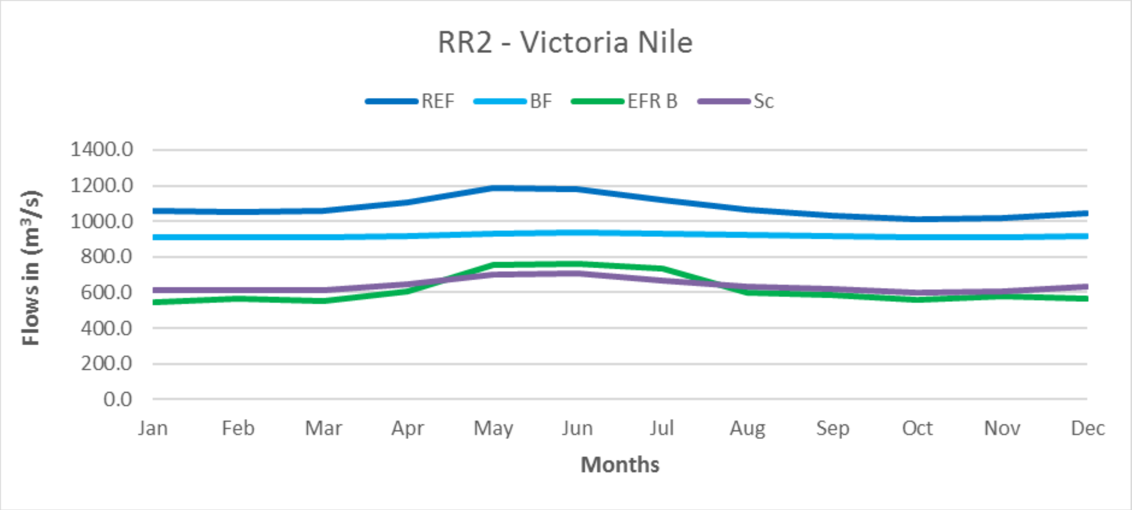


Figure 42: Monthly hydrograph for RR2 – Victoria Nile

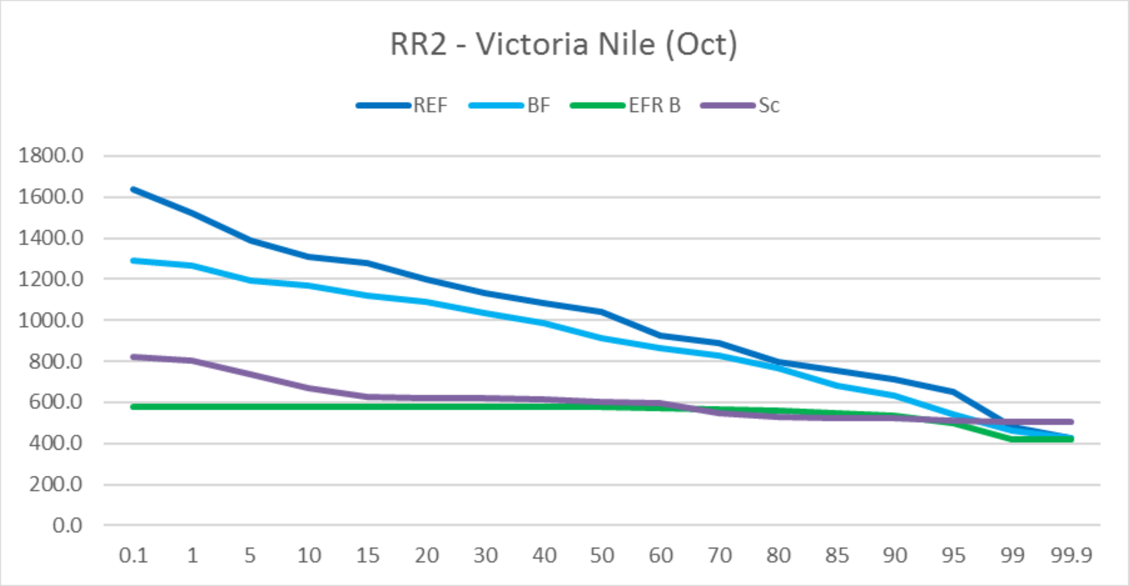


Figure 43: Flow duration curve for October (low flows) in RR2 – Victoria Nile

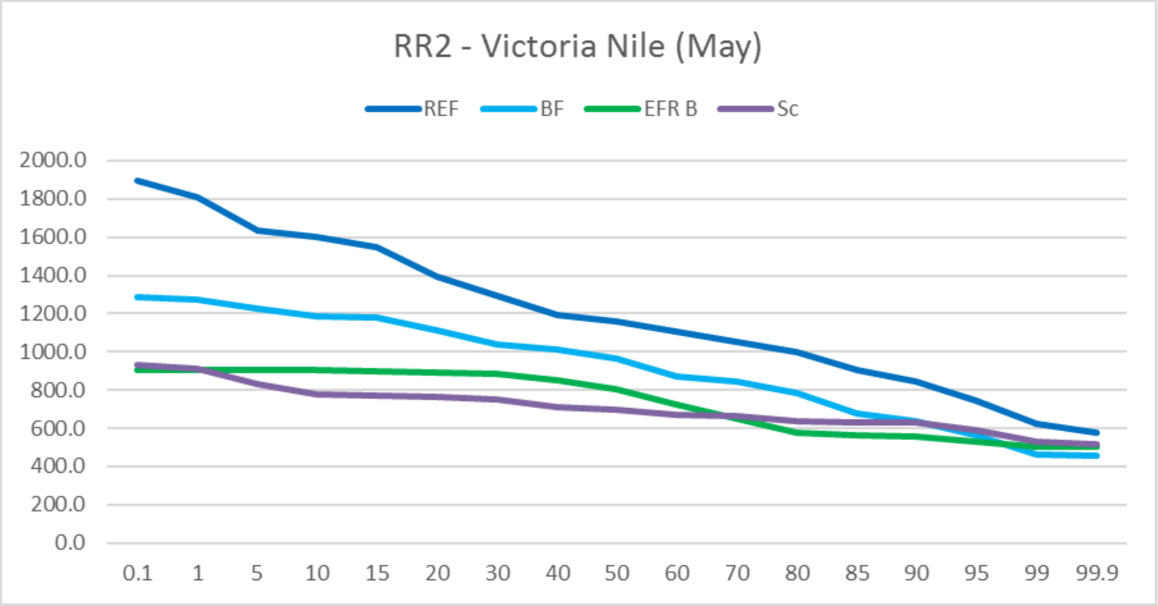


Figure 44: Flow duration curve for May (wet season) in RR2 – Victoria Nile

#### 4.2.1.2 Hydraulic Assessment

It must be noted, that the 1.5yr return period flow is only approximately depicting bankfull flow conditions. Therefore, additional cross section characteristics were investigated from which information about inundation extent and frequency could be deduced. These descriptions are briefly given for the points of interest. Each point of interest is individually assessed using QGIS with the Profile Tool and Quick Map Services Plugin on the MERIT DEM and Google Satellite images. The site location and ID (yellow dot with number, corresponds to the IDs given in Table 22) is shown together with the cross section location (red line) on satellite images (Google Earth/Digital Globe). Below the images, the diagram shows the cross section (elevation along the red line), where the small red dot in the upper satellite images is marked by the centre of the cross line in the lower diagram. Numbers in the diagram show elevation in mASL (y-Axis) and distance from left in meters (x-axis).

Table 22. Points of interest, the applied methodology for obtaining the channel cross section and additional channel and cross section properties

| ID | River | Latitude | Longitude | Channel bathymetry method | Bank width [m] | Ineffective area elevation [mASL] | Slope [m/m] |
|---|---|---|---|---|---|---|---|
| RR2 | Victoria Nile | 0.5018 | 33.1382 | Survey | 150 | -- | 0.002024 |

The site is located downstream of the Bujagali Hydropower station. A cross section survey from September 2017 (WREM International Inc, 2017) is available about 200m downstream of the dam site. The cross section survey covers sufficient parts of the banks so that no additional data merging with the DEM is required (Figure 45).

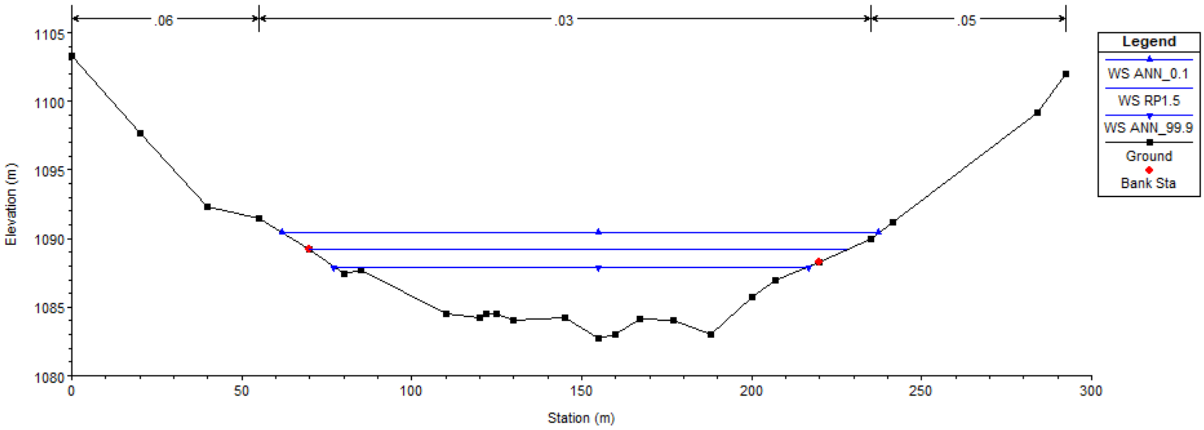


Figure 45. Cross section of the Victoria Nile downstream the Bujugali Hydropower station

### 4.2.1.3 Vegetation Assessment

This risk region is represented by the Victoria Nile River downstream of Lake Victoria at Jinja (Figure 46). Unfortunately, the cross section was placed further upstream and did not represent the areas vegetation well. Vegetation at this site generally does not display a clear woody and non-woody zone nor a flood dependent zone and occurs as mixed and scattered woody and non-woody areas (Figure 46 and Figure 47). The active channel is complex with islands and rapids and ranges in width from 140-380m wide. Non-woody areas appear as shortly cropped grasses, mainly from high grazing pressure, while woody vegetation comprises tall trees which are scattered by high human density impacts such as settlements and agricultural activities.

Figure 46: Google Earth © satellite image at Jinja on the Victoria Nile River downstream of Lake Victoria representing risk region 2.

Figure 47: Photograph showing the Victoria Nile River downstream of Lake Victoria and associated vegetation at Jinja (photo courtesy of Google Earth).

Based on the available biological information at cross section sites, and together with hydraulics at each site, the driver components [within the model] were quantified for a B-category (Table 23) as determined by discernible riparian indicators (Table 24). Interpolation was frequently required due to lack of biological data specific to sites.

Table 23: Quantification of driver components for a B-category system (Values are discharge).

| General description | | RR2 |
|---|---|---|
| Bank full for non-woody fringe vegetation | Wet Base | 720 |
| Wet base less 1m in elevation | Dry Base | 297 |
| Wet base less 1.5m in elevation | Critical Low | 208 |
| Between woody and non-woody limits | Freshette | 1186 |
| To the base of woody vegetation (Tall tree line) | Annual flood | 1450 |

Table 24: Riparian indicators utilized to quantify driver components for a B-category system.

| RR2 | channel width (m) | Discharge | Chan depth | Month | Indicators |
|---|---|---|---|---|---|
| Wet Base | Can't use this xs - no indicators along transect | 720 | | | |
| Dry Base | | 297 | | | Used hydraulic metrics |
| Critical Low | | 208 | | | |
| Freshette | | 1186 | | | |
| Annual flood | 170 | 1450 | 4.8 | May-Jul | Tall tree line |

### Defining Risk to Vegetation

The alteration of driver dynamics, in this case flows and by implication floods, results in risk to the vegetation. Optimal driver state results in low risk to all vegetation endpoints but does not consider the effects of non-flow related impacts, such as ever increasing grazing and trampling pressures, and the impacts of human density and resource use. However, as flows may decline so the risk to vegetation endpoints increases. This risk has been described and quantified for each of the response variables (Table 25), as well as for each of the response variables within different risk regions, and represents declining ecological health or ecosystem wellbeing.

Table 25: Justifications and driver quantification for interaction of vegetation components within the model.

| Bayesian Network variable title, measure - (BN node name) | Rank (score) | Rank definition and measure for variable | RR2 |
|---|---|---|---|
| Aveghab_R_bwet | Zero (25) | 10% higher percentile than B] base | > 855 |
| | Low (50) | bank full for non-woody vegetation | 855 - 720 |
| | Moderate (75) | between [B] dry base and [B] wet base | 720 - 340 |
| | High (100) | as low as normal (B) dry base | < 340 |
| FPveg_FP_bwet | Zero (25) | 10% higher percentile than B] base | > 855 |
| | Low (50) | bank full for non-woody vegetation | 855 - 720 |
| | Moderate (75) | between [B] dry base and [B] wet base | 720 - 340 |
| | High (100) | as low as normal (B) dry base | < 340 |

| **Bayesian Network variable title, measure - (BN node name)** | **Rank (score)** | **Rank definition and measure for variable** | **RR2** |
|---|---|---|---|
| Aveghab_R_drought | Zero (25) | 95% [B] dry season max month | > 295 |
| | Low (50) | crtical low flows for [B] | 295 - 205 |
| | Moderate (75) | 99% dry season max | 205 - 180 |
| | High (100) | | < 180 |
| Aveghab_R_bdry | Zero (25) | wet base | > 640 |
| | Low (50) | wet base less 1m | 640 - 295 |
| | Moderate (75) | critical low | 295 - 205 |
| | High (100) | critical low | < 205 |
| FPveg_FP_flood | Zero (25) | to the base of woody vegetation (Tall tree line):annual | > 1450 |
| | Low (50) | between woody and non-woody limits: freshette | 1450 - 1185 |
| | Moderate (75) | no flood: 20% higher than wet base percentile | 1185 - 810 |
| | High (100) | | < 810 |
| Subveg_R_bdry | Zero (25) | wet base | > 640 |
| | Low (50) | wet base less 1m | 640 - 295 |
| | Moderate (75) | critical low | 295 - 205 |
| | High (100) | critical low | < 205 |
| Subveg_R_bwet | Zero (25) | 10% higher percentile than B] base | > 855 |
| | Low (50) | bank full for non-woody vegetation | 855 - 720 |
| | Moderate (75) | between [B] dry base and [B] wet base | 720 - 340 |
| | High (100) | as low as normal (B) dry base | < 340 |
| Subveg_FP_bdry | Zero (25) | wet base | > 640 |
| | Low (50) | wet base less 1m | 640 - 295 |
| | Moderate (75) | critical low | 295 - 205 |
| | High (100) | critical low | < 205 |
| Subveg_FP_bwet | Zero (25) | 10% higher percentile than B] base | > 855 |
| | Low (50) | bank full for non-woody vegetation | 855 - 720 |
| | Moderate (75) | between [B] dry base and [B] wet base | 720 - 340 |
| | High (100) | as low as normal (B) dry base | < 340 |

#### 4.2.1.4 Fish Assessment

For the determination of instream flow requirements for the Victoria Nile River (Uganda) eight species of fishes that have habitat and or migratory requirements that occur within the river were selected for the assessment (Table 26). Based on the relative size species attains and biology and ecology information the depth and velocity requirements were determined as well as minimum depths to maintain lateral and longitudinal migrations for these indicator species. This information was aligned to the seasonal flows of the system and used to establish flow requirements that were provided to the hydrologist to determine eflow requirements (Figure 48, Figure 49 and Figure 50). Similarly, to RR1, the hydrograph is relatively aseasonal and as such the system does not have specific ecological cues and or freshet of floods that drive life cycle changes in the ecosystem. The site is located below the Jinga hydropower facility downstream of Lake Victoria. Here the any abnormal flow releases from Lake Victoria may threaten the vulnerable ecosystem downstream of the lake including the reach between the lake and the Sudd Wetland.

Table 26: Fishes selected to determine eflows for RR2. Hypothesised preferences for habitats (depth and velocity) and migratory notes provided for each species.

| Min. Depth (mm) | Min. Vel (m/s) | Weight | Nile River (Uganda) indicator spp. | Details |
|---|---|---|---|---|
| 1200 | 1 | 3 | *Labeobarbus/Labeo spp.* | Good rheophillic species long.↑↑ & lat. Potamodromous migrations. |
| 1000 | 0.5 | 2 | *Polypterus spp.* | Good rheophillic species long. & lat. Potamodromous migrations. |
| 650 | 0.8 | 2 | Alestes spp. | Good rheophillic species long.↑↑ & lat. Potamodromous migrations. |
| 450 | 0.5 | 2 | Brycinus spp. | Good rheophillic species long.↑↑ & lat. Potamodromous migrations. |
| 400 | 1 | 1 | *Mastacembelus frenatus* | Temperate spp. Longitudinal migrations, not highly relevant to lower Jinja Nile R. Site. |
| 600 | 1 | 1 | Amphilius spp. | Longitudinal migrations, probably prefers smaller rivers. |
| 1000 | 0.5 | 1 | *Bargus spp.* | Good rheophillic species but limited information |
| 1000 | 0.3 | 1 | *Schilbe spp.* | Good rheophillic species long. & lat. Potamodromous migrations. |

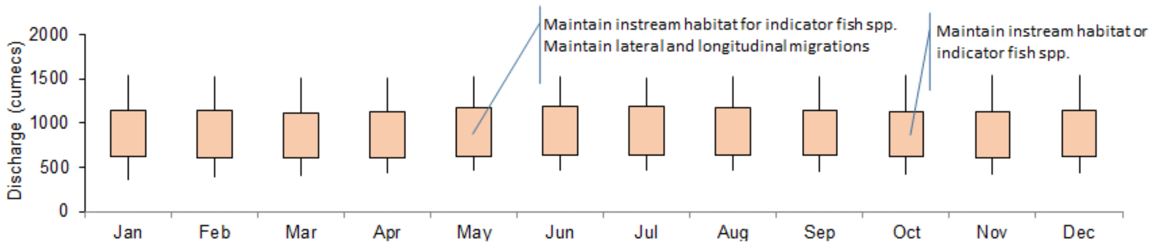


Figure 48: Reference hydrograph from RR2 with key fish biology and ecology requirements.

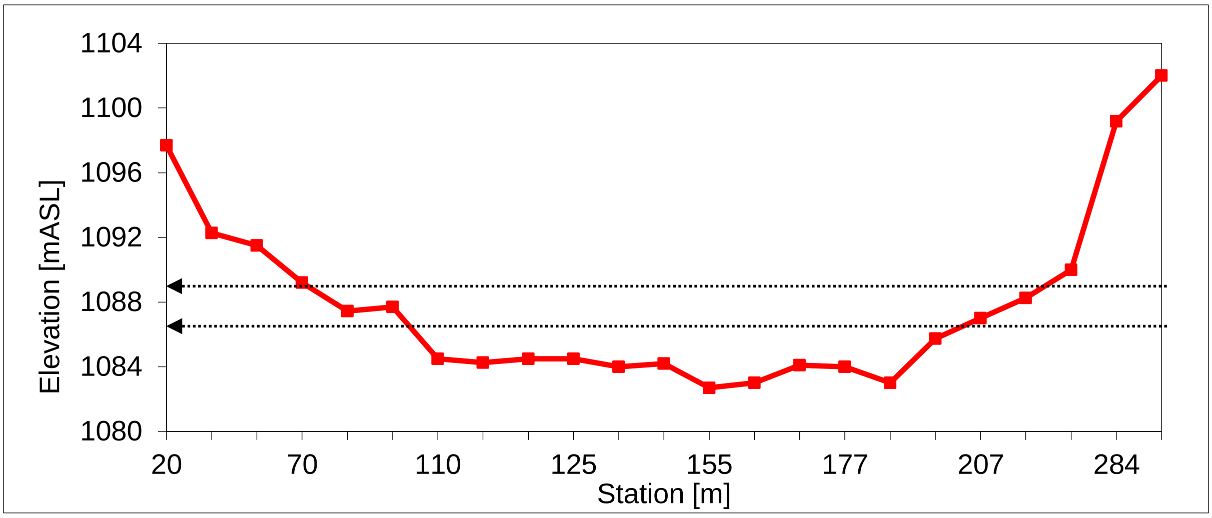
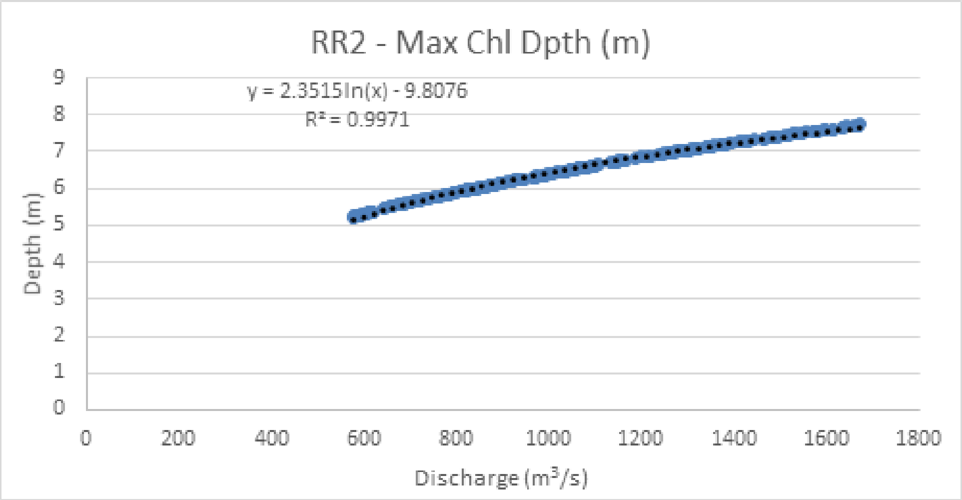


Figure 49: Cross section of RR2 with flow elevations highlighted for key fish biology and ecology events selected in the study for eflow determination.



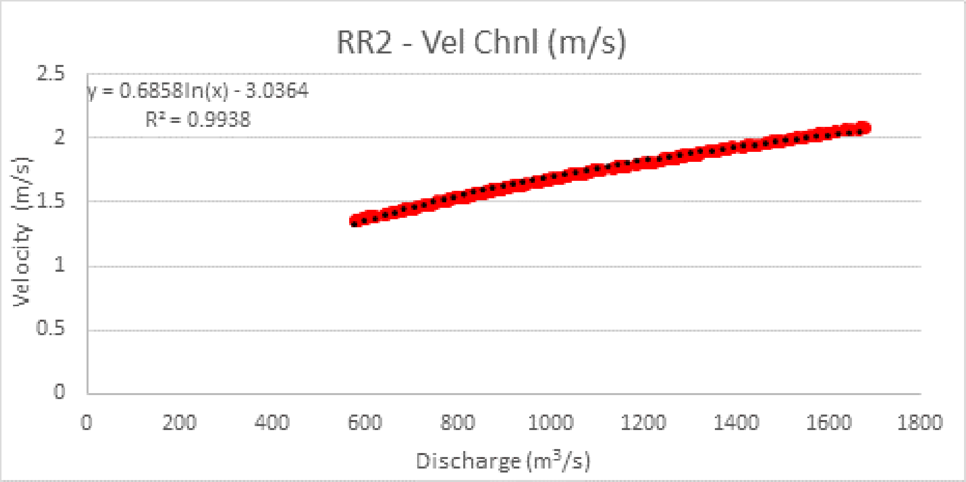


Figure 50: Flow depth (Blue) and Velocity depth (Red) relationships established for the study used to determine flow requirements for fishes.

### 4.2.2 Calculate Risk

Following the determination of flows to maintain the ecosystems associated with each site in each ecological category a summary of the flow requirements associated with these scenarios is generated (Table 27). These hydrographs were used in the risk assessment as scenarios to compare the socio-ecological consequences of altered flows associated with each scenario (ecological category).

Table 27: Summary of the floods required to provide for key socio-ecological processes in the Nile River per ecological category Class considered in the study.

| **RR** | **River** | **Flow Component** | **Percentage EFR per Ecological Class** | | |
|---|---|---|---|---|---|
| | | | **B** | **C** | **D** |
| 2 | White Nile (Victoria Nile) | Drought flows | Included in Maintenance Low flows | | |
| | | Maintenance (or base) flows Low (or dry) period | 46% | 32% | 23% |
| | | Maintenance (or base) flows high (or wet) period | 8% | 5% | 5% |
| | | **Total** | **54%** | **37%** | **29%** |

The reference hydrographs and median flows for ecological categories B, C and D considered in the risk assessment for RR2 – Victoria Nile River are graphically presented in Figure 51 and Figure 52. The rank thresholds for indicators selected for this site were used to query this hydrology data and evaluate the socio-ecological consequences of altered flows in the system using PROBFLO.

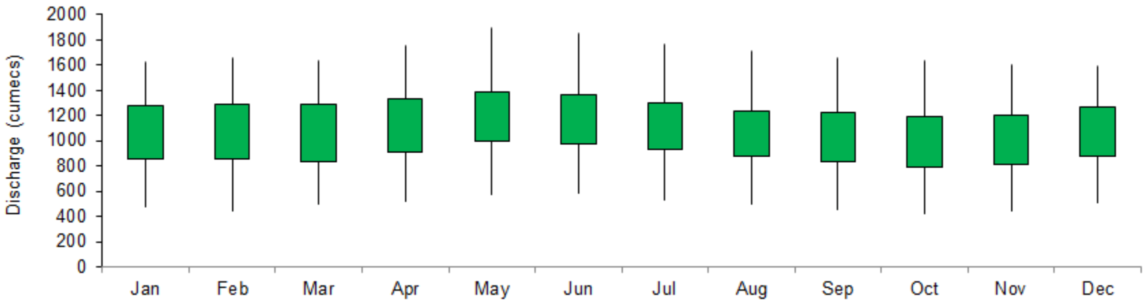


Figure 51: Box and whisker plot summary of the reference (Class A) average monthly ($m^3/s$) flows observed in RR2 in the study. Whiskers represent 0.01%tiles and 99.9%tiles and box 20%tile and 80%tiles.

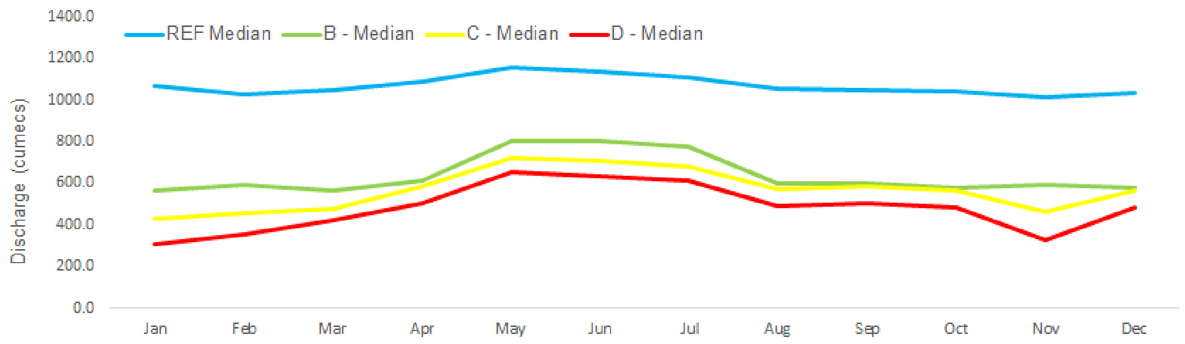


**Figure 52: Relative graphs (medians) of the reference (Class A or pristine), Class B (near natural), Class C (moderately modified) and Class D (largely modified) average monthly flows ($m^3/s$) flows observed in RR2 in the study. Whiskers represent 0.01%tiles and 99.9%tiles and box 20%tile and 80%tiles.**

Risk outcomes directly obtained from the Netica Bayesian Network assessment are presented per RR with averages, standard deviation (SD) and risk rank probability profiles.

### *Floodplain ecosystem services endpoint*

The relative risk to the floodplain ecosystem serves endpoint showed an increasing trend in risk from Class A to Class C but a decrease for Class D (Figure 53). The results for Class A revealed a zero to low risk with SD extending into the low risk range. The results for Classes B, C and D revealed low risk with SD for Classes B and D extending into the moderate risk range. The SD for Class C extended into the moderate to high risk range. Figure 54 results indicate no possibility of high (>50%), risk to the floodplain services for this RR.

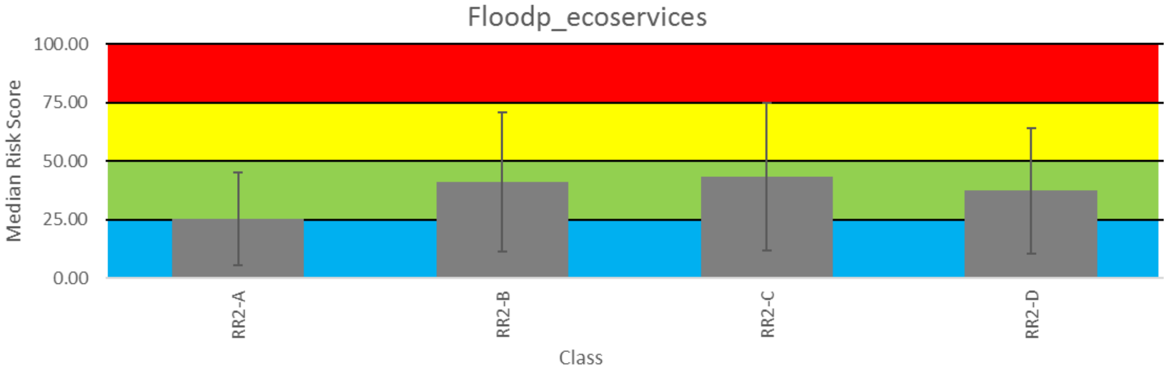


**Figure 53: Relative Risk (median, with standard deviation) of multiple stressors associated with eflow scenarios to Floodplain ecosystem services endpoint considered in the study (Class A (A), Class B (B), Class C (C) and Class (D)). Risk rank ranges for Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) risk included.**

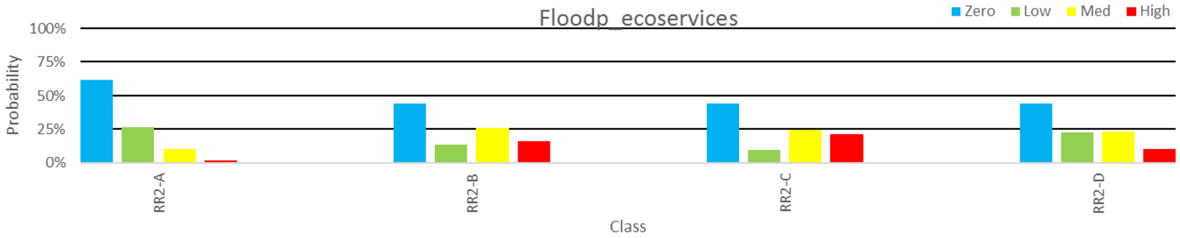


Figure 54: Probability of risk rank occurrence for ranks Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) of multiple stressors associated with eflow scenarios to Floodplain ecosystem services endpoint considered in the study.

### *River ecosystem services endpoint*

The relative risk to the floodplain ecosystem services endpoint showed an increasing trend in risk from Class A to Class C but a decrease for Class D (Figure 55). The results for Class A revealed a zero risk with SD extending into the low risk range. The results for Classes B, C and D revealed low risk with SD extending into the moderate risk range. Results in Figure 56 includes no probabilities of high risk (>45%) for this RR.

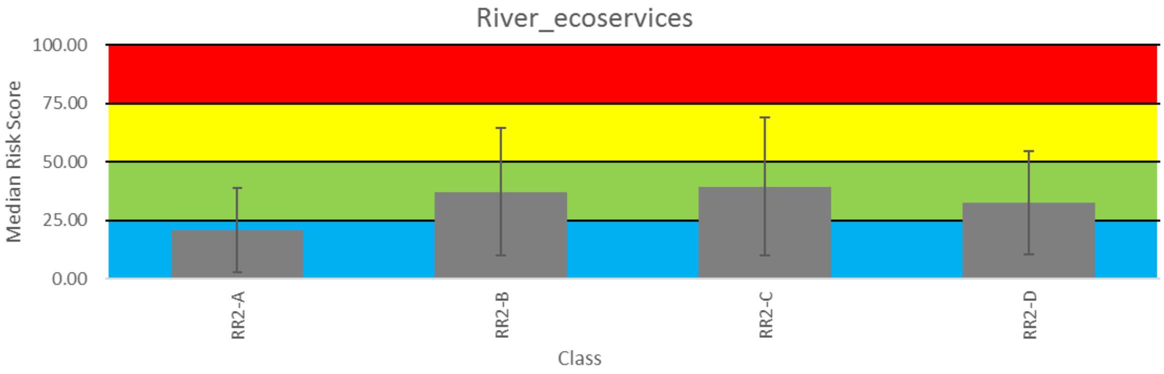


Figure 55: Relative Risk (median, with standard deviation) of multiple stressors associated with eflow scenarios to River ecosystem services endpoint considered in the study (Class A (A), Class B (B), Class C (C) and Class (D)). Risk rank ranges for Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) risk included.

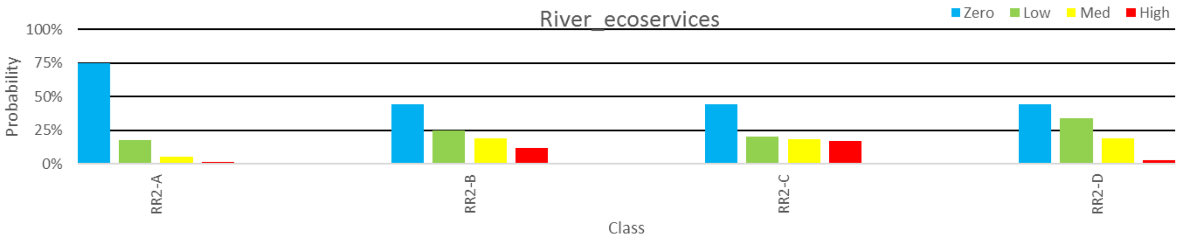


Figure 56: Probability of risk rank occurrence for ranks Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) of multiple stressors associated with eflow scenarios to River ecosystem services endpoint considered in the study.

### *Floodplain biodiversity endpoint*

The relative risk to the floodplain biodiversity endpoint showed an increasing trend in risk from Class A to Class D (Figure 57). The results for Class A and D revealed low risk with SD for Classes B and C extending into the moderate risk range. The SD for Class A was in the low to moderate range and for Class D, moderate to high range. No probability of high risk (>50%) to the endpoint was shown (Figure 58).

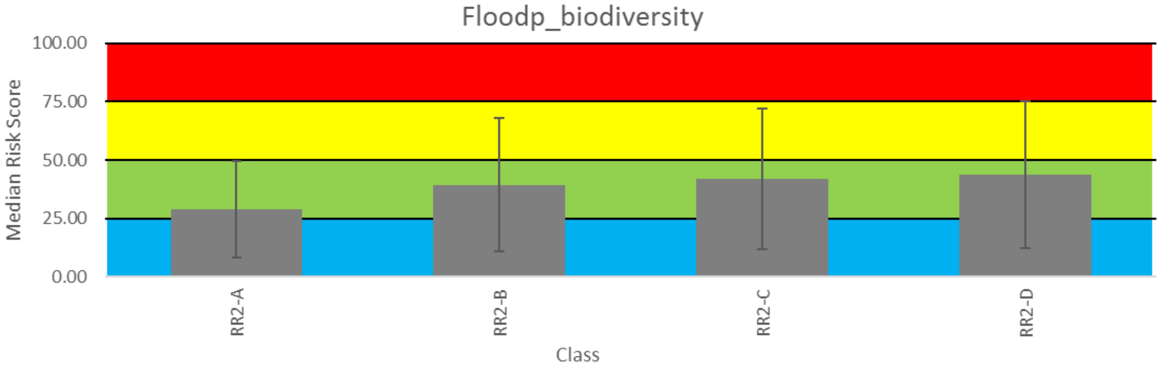


**Figure 57: Relative Risk (median, with standard deviation) of multiple stressors associated with eflow scenarios to Floodplain biodiversity endpoint considered in the study (Class A (A), Class B (B), Class C (C) and Class (D)). Risk rank ranges for Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) risk included.**

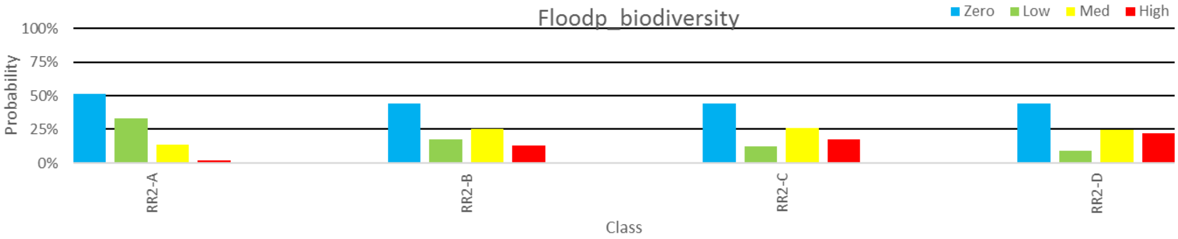


**Figure 58: Probability of risk rank occurrence for ranks Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) of multiple stressors associated with eflow scenarios to Floodplain biodiversity endpoint considered in the study.**

### *River biodiversity endpoint*

The relative risk to the floodplain biodiversity endpoint generally showed an increasing trend in risk from Class A to Class C but a decrease for Class D (Figure 59). The results for Class A revealed a zero risk with SD extending into the low risk range. The results for Classes B, C and D revealed low risk with SD extending into the moderate risk range. No high risk (>50%) to the riverine biodiversity was shown for this RR (Figure 60).

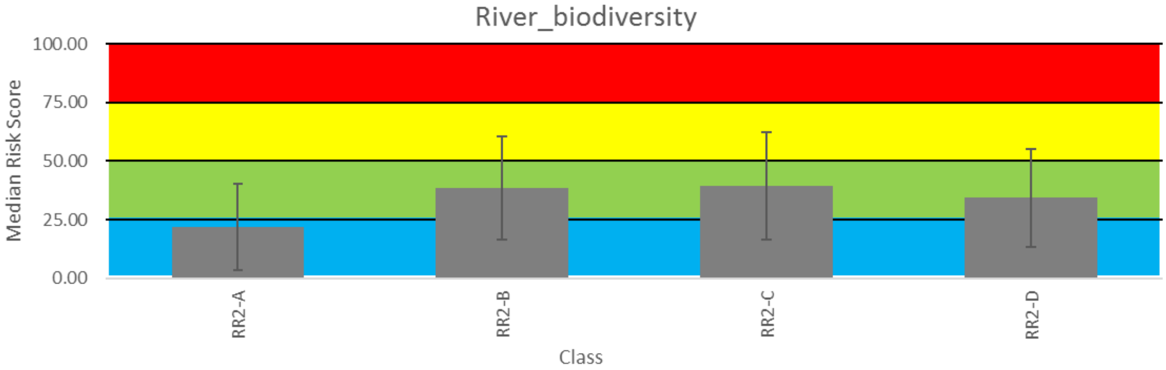


**Figure 59: Relative Risk (median, with standard deviation) of multiple stressors associated with eflow scenarios to River biodiversity endpoint considered in the study (Class A (A), Class B (B), Class C (C) and Class (D)). Risk rank ranges for Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) risk included.**

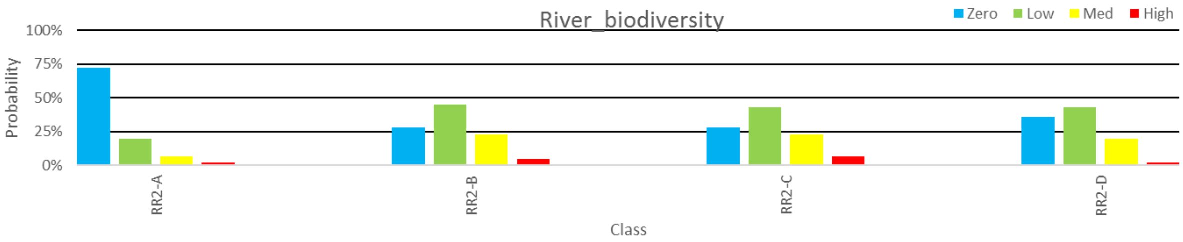


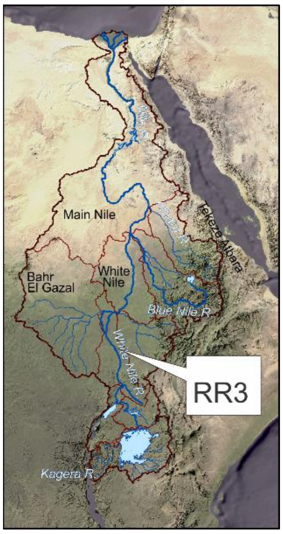
**Figure 60: Probability of risk rank occurrence for ranks Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) of multiple stressors associated with eflow scenarios to River biodiversity endpoint considered in the study.**

### 4.2.3 Conclusion for RR2

Low flows (dry and wet base flows) are important for this reach of river and should be provided to ensure adequate habitats to maintain the ecology of the river. It is also important to note that the river is perennial and that the 99.9 percentile flow specified for each month provides for non-zero flows. Thus, any future operation of the system or water resource developments should accommodate these minimum flow requirements.

Results include increasing risk to endpoints as the ecological wellbeing of the rivers deteriorate from reference states to Class B and C ecological categories. The risk to the floodplain and river services and to river biodiversity reduces for Class D category. No probability of high risk (>50%) was recorded for any of the endpoints.

## 4.3 RR3 – Bahr El Jebel



The Albert Nile emerges from Lake Albert and when it reaches Nimule the river narrows considerably and turns westward from where it is known as Bahr el Jebel; river of the mountains (NBI, 2012). The Bahr el Jabel flows through the Sudd, meets the Bahr el Ghazal at Lake No, flows eastward to join the Sobat River and together they form the White Nile (NBI, 2012). The Bahr el Jebel sub-basin is a complex basin due to having many seasonal inflows and approximately half the flow in the Bahr el Jebel River is lost to evaporation in the Sudd Wetland and swamps (2008). The river reach selected for the assessment is at Mongala upstream of the Sudd inflow (Latitude 4.885574; longitude 31.646235).

### 4.3.1 Data Analysis

#### 4.3.1.1 Hydrology Assessment

This reach is upstream of the confluence with the Sobat River and the record period selected for the EFR determination spanning 1962-1981 with a Reference MAR of 50 479 MCM. The entire record period of 1905-1981 was split in 1962 due to the upwards 'shift' in the outflows from Lake Victoria in the early 1960s.

The monthly hydrograph is very 'flat' (see graph) with almost no difference in wet and dry season. However, September was selected as the high flow month and March as the low flow month. The flow requirements for these selected months and percentiles that were used to determine the EFR is summarised in Table 28 below.

Table 28: Selected flow requirements for RR3 – Bahr el Jebel

<table>
<tr><th></th><th colspan="6">Flow requirements (m³/s) – low flows</th></tr>
<tr><th>Percentiles</th><th colspan="3">Sep</th><th colspan="3">Mar</th></tr>
<tr><td>15</td><td colspan="3">950</td><td colspan="3">950</td></tr>
<tr><td>50</td><td colspan="3">600</td><td colspan="3">500</td></tr>
<tr><td>99.9</td><td colspan="3">395</td><td colspan="3">320</td></tr>
<tr><th></th><th colspan="6">Flow requirements– annual floods</th></tr>
<tr><th></th><th colspan="2">Aug</th><th colspan="2">Sep</th><th colspan="2">Oct</th></tr>
<tr><td>Peak flows (m³/s)</td><td colspan="2">1450</td><td colspan="2">1450</td><td colspan="2">1450</td></tr>
<tr><td>Duration (days)</td><td colspan="2">30</td><td colspan="2">28</td><td colspan="2">28</td></tr>
</table>

These selected requirements, together with the DRM were used to determine the EFR for each month. The results of the final EFR for RR3 is shown in Table 29 below.

Table 29: Final EFR for RR3 – Bahr el Jebel (flows in $m^3/s$)

| RR3 | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 733.6 | 787.2 | 739.0 | 763.1 | 850.0 | 918.2 | 915.2 | 1010.5 | 1017.1 | 970.6 | 924.4 | 811.1 |
| Minimum | 400.1 | 427.9 | 403.3 | 417.3 | 421.0 | 480.1 | 464.8 | 490.0 | 426.0 | 412.6 | 420.1 | 388.0 |
| Maximum | 858.5 | 923.1 | 841.6 | 870.6 | 981.4 | 1023.9 | 1086.2 | 1228.2 | 1308.0 | 1092.0 | 1051.1 | 862.7 |
| Percentiles | | | | | | | | | | | | |

| RR3 | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.1 | 858.5 | 923.1 | 841.6 | 870.6 | 981.4 | 1023.9 | 1086.2 | 1228.2 | 1308.0 | 1092.0 | 1051.1 | 862.7 |
| 1 | 858.5 | 923.1 | 841.6 | 870.6 | 981.4 | 1023.9 | 1086.2 | 1228.2 | 1308.0 | 1092.0 | 1051.1 | 862.7 |
| 5 | 858.5 | 923.1 | 841.6 | 870.6 | 981.4 | 1023.9 | 1086.2 | 1228.2 | 1308.0 | 1092.0 | 1051.1 | 862.7 |
| 10 | 858.5 | 923.1 | 841.6 | 870.6 | 981.4 | 1023.9 | 1074.5 | 1210.3 | 1282.8 | 1092.0 | 1051.1 | 862.7 |
| 15 | 858.5 | 923.1 | 841.6 | 870.6 | 981.4 | 1023.9 | 1062.9 | 1192.7 | 1258.3 | 1092.0 | 1051.1 | 862.7 |
| 20 | 856.8 | 921.3 | 840.3 | 869.3 | 979.7 | 1022.5 | 1051.0 | 1175.0 | 1234.2 | 1090.1 | 1049.3 | 862.2 |
| 30 | 849.3 | 913.1 | 834.8 | 863.6 | 972.7 | 1017.4 | 1027.2 | 1140.7 | 1195.3 | 1082.1 | 1036.6 | 860.7 |
| 40 | 836.5 | 890.0 | 822.4 | 848.9 | 962.4 | 1010.3 | 999.7 | 1112.9 | 1137.9 | 1064.5 | 1024.3 | 858.5 |
| 50 (median) | 816.8 | 872.4 | 810.7 | 836.4 | 942.6 | 998.1 | 981.8 | 1084.8 | 1111.6 | 1047.5 | 983.8 | 856.5 |
| 60 | 769.7 | 832.3 | 788.3 | 803.3 | 904.4 | 978.1 | 946.9 | 1025.7 | 1006.5 | 991.3 | 935.6 | 852.6 |
| 70 | 696.0 | 747.5 | 726.1 | 751.2 | 833.7 | 923.9 | 885.7 | 980.7 | 938.0 | 923.5 | 870.2 | 839.7 |
| 80 | 591.5 | 634.6 | 637.2 | 659.2 | 720.0 | 835.9 | 802.3 | 867.6 | 808.0 | 852.6 | 842.4 | 808.2 |
| 85 | 534.4 | 573.0 | 580.6 | 600.7 | 647.6 | 771.0 | 740.8 | 798.7 | 725.3 | 846.4 | 815.3 | 782.2 |
| 90 | 480.0 | 514.2 | 518.8 | 536.8 | 568.7 | 689.3 | 663.2 | 712.0 | 635.0 | 833.9 | 766.3 | 735.0 |
| 95 | 433.7 | 464.2 | 457.1 | 473.0 | 489.7 | 590.6 | 569.7 | 607.3 | 542.7 | 786.3 | 660.7 | 632.8 |
| 99 | 406.9 | 435.2 | 414.1 | 428.5 | 434.7 | 502.2 | 485.8 | 513.5 | 449.3 | 487.3 | 468.2 | 437.0 |
| 99.9 | 400.8 | 428.6 | 404.4 | 418.4 | 422.3 | 482.3 | 466.9 | 492.4 | 428.3 | 420.1 | 424.9 | 392.9 |

The summary of the EFR for RR3 (Table 30) shows that almost 46% of the flows in the river is required for ecological functioning, with the low flows (flows occurring more than 50% of the time) making up the bulk of the requirement and floods only 6% of the ecological requirement. Thus, low flows (dry and wet base flows) are important for the river and should be provided to ensure adequate habitats to maintain the ecology of the river. The low percentage for the flood requirements is due to the 'flat' hydrograph as most of the flows occur as high base flows. It is also important to note that the river is perennial and that the 99.9 percentile flow specified for each month provides for non-zero flows. Thus, any future operation of the system or water resource developments should accommodate the minimum flow requirements.

Table 30: Summary of final EFR for RR3 – Bahr el Jebel

| RR | River | Reference (MCM) | % Requirement | | | | Volume Requirement (MCM) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Low flows | Drought flows | Floods | Total | Low flows | Drought flows | Floods | Total |
| RR3 | Bahr el Jebel | 50 479 | 45.8 | Not specified | 6.2 | 52.0 | 22 932 | Not specified | 3 091 | 26 024 |

The monthly hydrograph of the REF, BF, flows for 1905-1961 (Sc) and EFR for a B state for Bahr el Jebel is shown in Figure 61. This indicates that the EFR is similar to the flows before the upward 'shift' in the hydrology. Both the FDC for March (low flow season) (Figure 62) and September (wet season) (Figure 63) indicate that the EFR for a B state is similar to the flows before 1960.

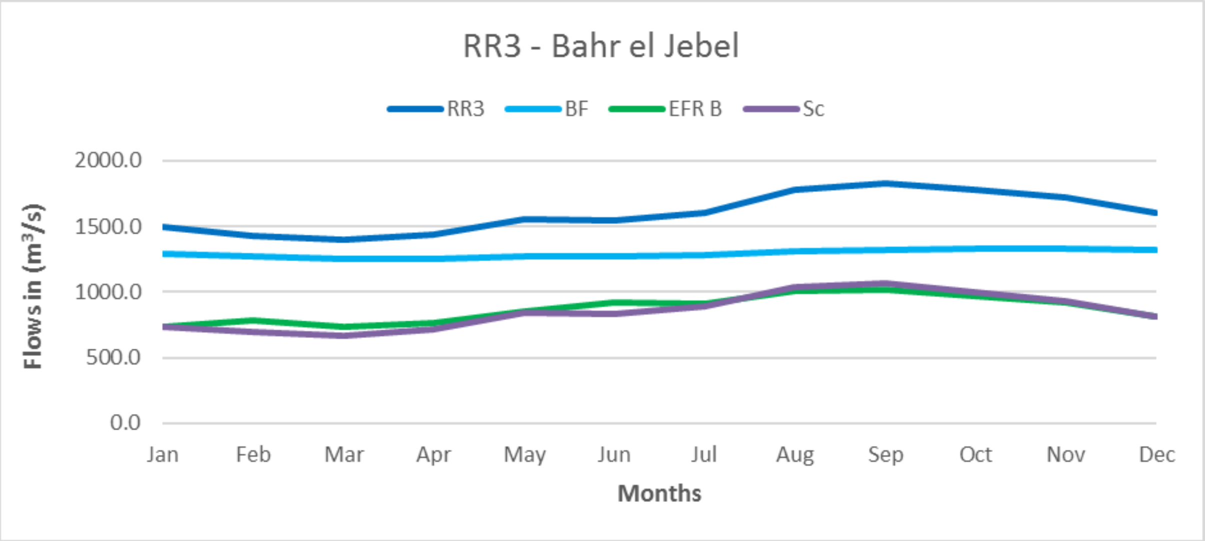


Figure 61: Monthly hydrograph for RR3 – Bahr el Jebel

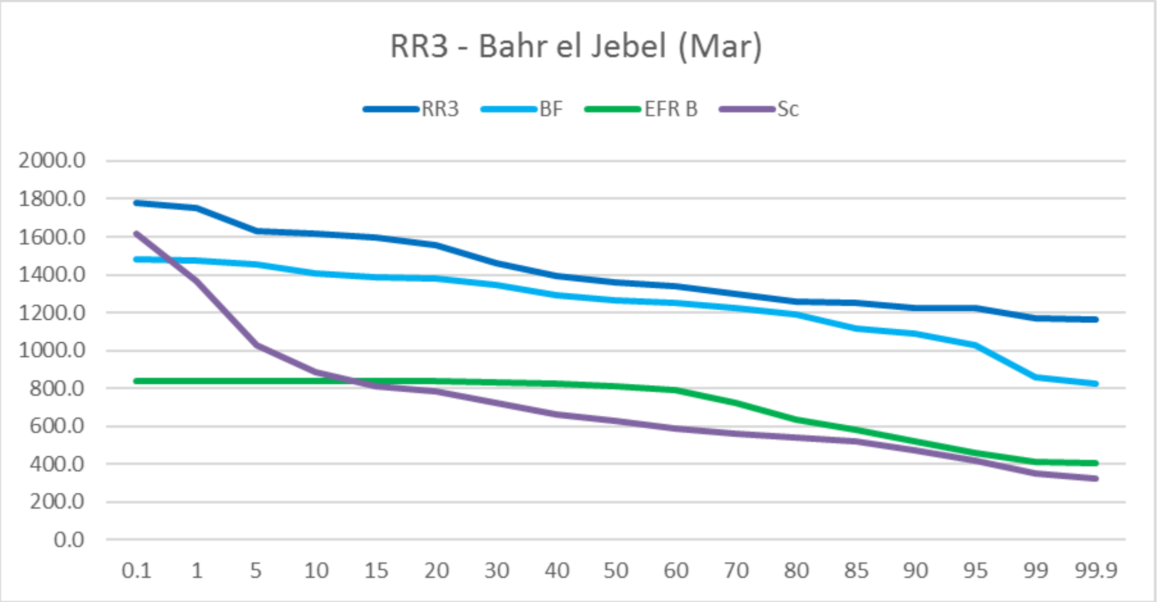


Figure 62: Flow duration curve for March (low flows) in RR3 – Bahr el Jebel

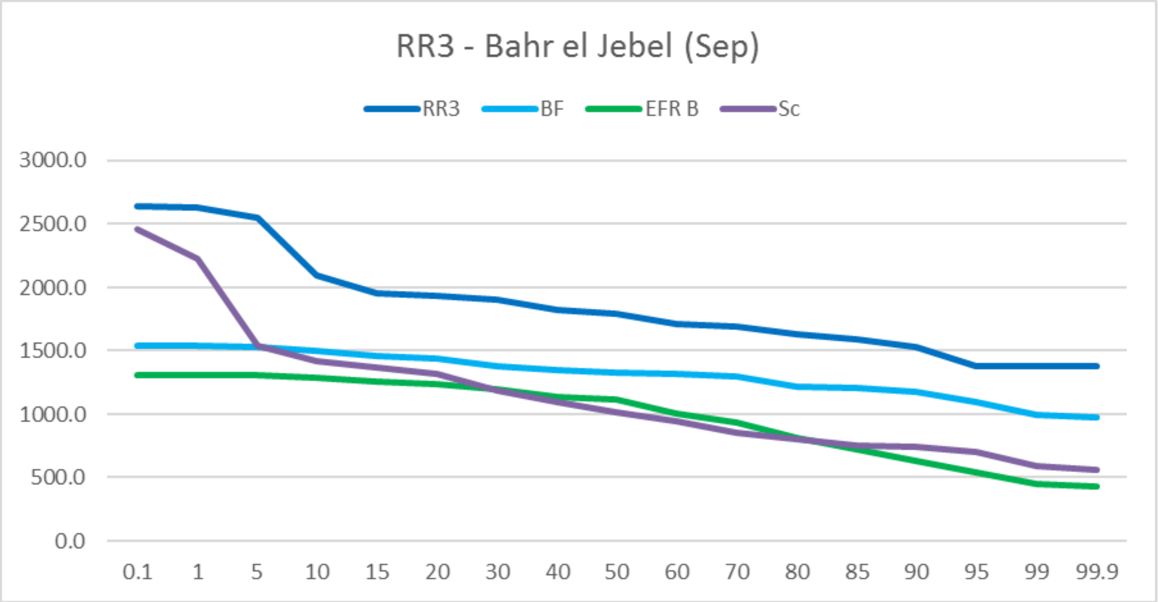


Figure 63: Flow duration curve for September (wet season) in RR3 – Bahr el Jebel

#### 4.3.1.2 Hydraulic Assessment

It must be noted, that the 1.5yr return period flow is only approximately depicting bankfull flow conditions. Therefore, additional cross section characteristics were investigated from which information about inundation extent and frequency could be deduced. These descriptions are briefly given for the points of interest. Each point of interest is individually assessed using QGIS with the Profile Tool and Quick Map Services Plugin on the MERIT DEM and Google Satellite images. The site location and ID (yellow dot with number, corresponds to the IDs given in Table 31 and Table 8) is shown together with the cross section location (red line) on satellite images (Google Earth/Digital Globe). Below the images, the diagram shows the cross section (elevation along the red line), where the small red dot in the upper satellite images is marked by the centre of the cross line in the lower diagram. Numbers in the diagram show elevation in mASL (y-Axis) and distance from left in meters (x-axis).

Table 31. Points of interest, the applied methodology for obtaining the channel cross section and additional channel and cross section properties

| ID | River | Latitude | Longitude | Channel bathymetry method | Bank width [m] | Ineffective area elevation [mASL] | Slope [m/m] |
|---|---|---|---|---|---|---|---|
| RR3 | Bahr El Jebel | 4.8856 | 31.6462 | Survey | 624 | -- | 0.000187 |

Figure 64 shows an elevation comparison at Juba airport, indicating that the elevation that is rarely flooded lies above 459mASL. Also, scattered buildings exist in the vegetated area north of the airport in the left floodplain, leading to the assumption that the left floodplain is not regularly flooded. At the site, survey data is available from 2017 which is used to correct the bathymetry between the banks (Figure 65). Roughness values in the channel were raised to 0.035 to reach flooding of the floodplain for the 0.1 annual flow percentile.

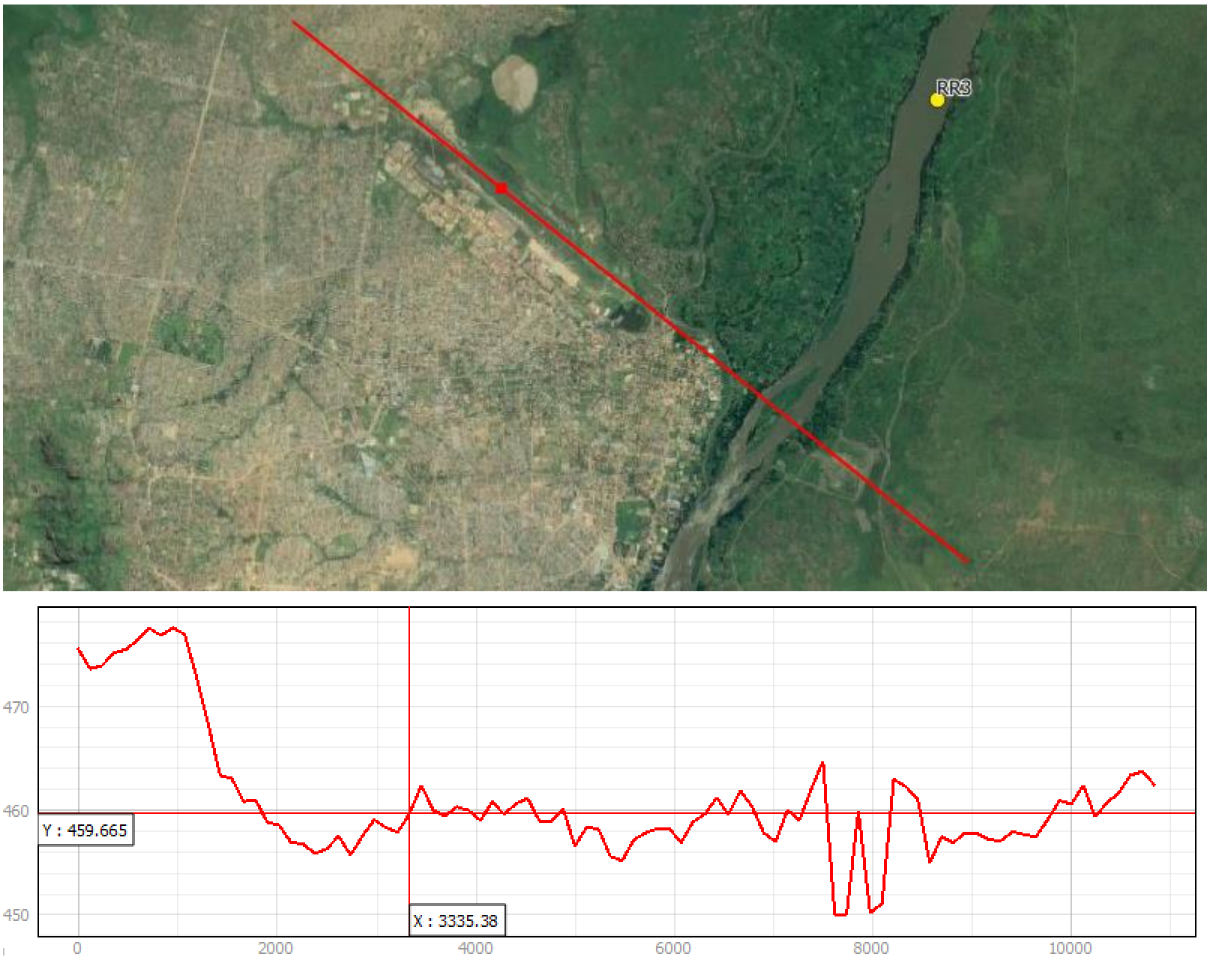


Figure 64. Bahr el Jebel cross section at Juba airport

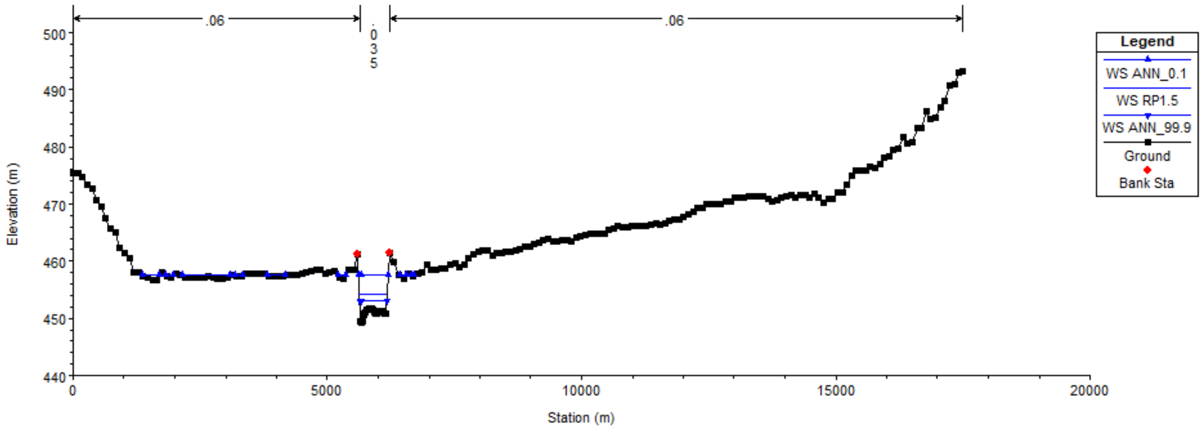


Figure 65: Cross sectional profile of the hydraulic site for RR3

### 4.3.1.3 Vegetation Assessment

This risk region is represented by the Bahr el Jebel upstream of the Sudd inflow at Mangala near Juba, with the cross section shown as a red line in Figure 66. Vegetation at this site displays a distinct high density woody fringe along the active channel, scattered and mixed woody and non-woody vegetation across an extensive floodplain area and includes secondary distributary channels and backwater areas. (Figure 66 and Figure 67). The active channel is about 500-510m wide with additional distributary channels on the left bank (LB). This zone is extensively utilised for agricultural activities, which will include grazing of livestock and is heavily impacted from a high density of people at Juba. As a result, the tree component is scattered and the grassland component short.

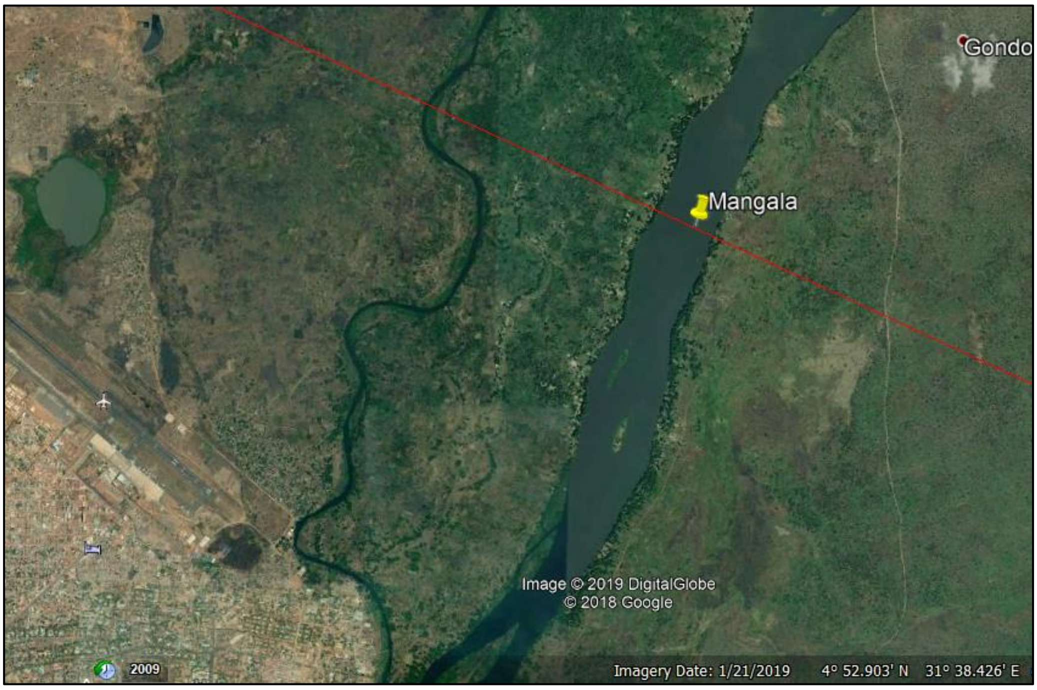


Figure 66: Google Earth © satellite image at Mongala on the Bahr el Jebel upstream of the Sudd inflow, representing risk region 3.

Figure 67: Photograph showing the Bahr el Jebel upstream of the Sudd inflow and associated vegetation at Mongala near Juba (photo courtesy of Google Earth).

Based on the available biological information at cross section sites, and together with hydraulics at each site, the driver components [within the model] were quantified for a B-category (Table 32) as determined by discernible riparian indicators (Table 33). Interpolation was frequently required due to lack of biological data specific to sites.

Table 32: Quantification of driver components for a B-category system (Values are discharge).

| General description | | RR3 |
|---|---|---|
| Bank full for non-woody fringe vegetation | Wet Base | 960 |
| Wet base less 1m in elevation | Dry Base | 736 |
| Wet base less 1.5m in elevation | Critical Low | 708 |
| Between woody and non-woody limits | Freshette | 1430 |
| To the base of woody vegetation (Tall tree line) | Annual flood | 3615 |

**Table 33: Riparian indicators utilized to quantify driver components for a B-category system.**

| RR3 | channel width (m) | Discharge | Chan depth | Month | Indicators |
|---|---|---|---|---|---|
| Wet Base | 545 | 960 | 2.51 | Jun | Reeds & low shrub |
| Dry Base | no look-up possible | 736 | | Feb | |
| Critical Low | no look-up possible | 708 | | Feb | |
| Freshette | | 1430 | | May-Jul | |
| Annual flood | 605 | 3615 | 5.4 | Sep | Tall tree line |

## Defining Risk to Vegetation

The alteration of driver dynamics, in this case flows and by implication floods, results in risk to the vegetation. Optimal driver state results in low risk to all vegetation endpoints but does not consider the effects of non-flow related impacts, such as ever increasing grazing and trampling pressures, and the impacts of human density and resource use. However, as flows may decline so the risk to vegetation endpoints increases. This risk has been described and quantified for each of the response variables (Table 34), as well as for each of the response variables within different risk regions, and represents declining ecological health or ecosystem wellbeing.

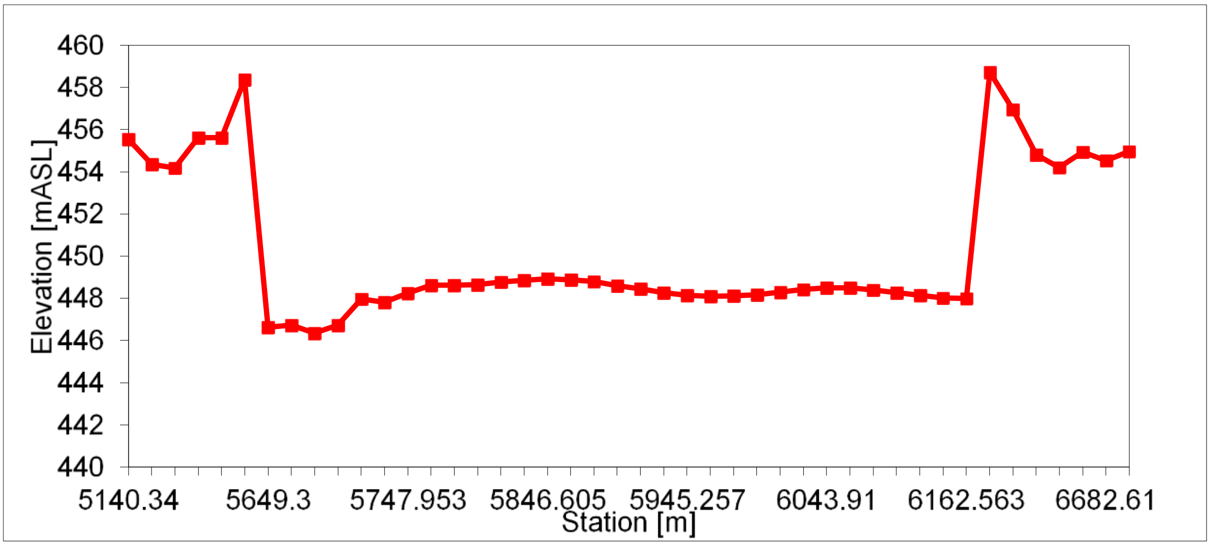
**Table 34: Justifications and driver quantification for interaction of vegetation components within the model.**

| Bayesian Network variable title, measure - (BN node name) | Rank (score) | Rank definition and measure for variable | RR3 |
|---|---|---|---|
| Aveghab_R_bwet | Zero (25) | 10% higher percentile than B] base | > 1010 |
| | Low (50) | bank full for non-woody vegetation | 1010 - 960 |
| | Moderate (75) | between [B] dry base and [B] wet base | 960 - 736 |
| | High (100) | as low as normal (B) dry base | < 736 |
| FPveg_FP_bwet | Zero (25) | 10% higher percentile than B] base | > 1010 |
| | Low (50) | bank full for non-woody vegetation | 1010 - 960 |
| | Moderate (75) | between [B] dry base and [B] wet base | 960 - 736 |
| | High (100) | as low as normal (B) dry base | < 736 |
| Aveghab_R_drought | Zero (25) | 95% [B] dry season max month | > 520 |
| | Low (50) | crtical low flows for [B] | 520 - 460 |
| | Moderate (75) | 99% dry season max | 460 - 415 |
| | High (100) | | < 415 |
| Aveghab_R_bdry | Zero (25) | wet base | > 960 |
| | Low (50) | wet base less 1m | 960 - 736 |
| | Moderate (75) | critical low | 736 - 708 |
| | High (100) | critical low | < 708 |

| **Bayesian Network variable title, measure - (BN node name)** | **Rank (score)** | **Rank definition and measure for variable** | **RR3** |
|---|---|---|---|
| FPveg_FP_flood | Zero (25) | to the base of woody vegetation (Tall tree line):annual | > 3615 |
| | Low (50) | between woody and non-woody limits: freshette | 3615 - 1430 |
| | Moderate (75) | no flood: 20% higher than wet base percentile | 1430 - 1110 |
| | High (100) | | < 1110 |
| Subveg_R_bdry | Zero (25) | wet base | > 960 |
| | Low (50) | wet base less 1m | 960 - 736 |
| | Moderate (75) | critical low | 736 - 708 |
| | High (100) | critical low | < 708 |
| Subveg_R_bwet | Zero (25) | 10% higher percentile than B] base | > 1010 |
| | Low (50) | bank full for non-woody vegetation | 1010 - 960 |
| | Moderate (75) | between [B] dry base and [B] wet base | 960 - 736 |
| | High (100) | as low as normal (B) dry base | < 736 |
| Subveg_FP_bdry | Zero (25) | wet base | > 960 |
| | Low (50) | wet base less 1m | 960 - 736 |
| | Moderate (75) | critical low | 736 - 708 |
| | High (100) | critical low | < 708 |
| Subveg_FP_bwet | Zero (25) | 10% higher percentile than B] base | > 1010 |
| | Low (50) | bank full for non-woody vegetation | 1010 - 960 |
| | Moderate (75) | between [B] dry base and [B] wet base | 960 - 736 |
| | High (100) | as low as normal (B) dry base | < 736 |

#### 4.3.1.4 Fish Assessment

For the determination of instream flow requirements for the Nile River (South Sudan upstream of the Sudd Wetland) five species of fishes that have habitat and or migratory requirements that occur within the river were selected for the assessment (Table 35). These species include species that represent the transition from the main stem Nile River and the Sudd Wetland. Based on the relative size species attains and biology and ecology information the depth and velocity requirements were determined as well as minimum depths to maintain lateral migrations in particular and longitudinal migrations between the wetland and the river. This information was aligned to the seasonal flows of the system and used to establish flow requirements that were provided to the hydrologist to determine eflow requirements (Figure 68, Figure 69



and Figure 70).

**Table 35: Fishes selected to determine eflows for RR3. Hypothesised preferences for habitats (depth and velocity) and migratory notes provided for each species.**

| Min. Depth (mm) | Min. Vel (m/s) | Weight | Nile River (South Sudan) indicator spp. | Details |
|---|---|---|---|---|
| 1200 | 1 | 3 | *Labeobarbus/Labeo spp.* | Good rheophillic species long.↑↑ & lat. Potamodromous migrations. |
| 650 | 0.8 | 2 | Alestes spp. | Good rheophillic species long.↑↑ & lat. Potamodromous migrations. |
| 450 | 0.5 | 2 | Brycinus spp. | Good rheophillic species long.↑↑ & lat. Potamodromous migrations. |
| 1000 | 0.5 | 1 | *Bargus spp.* | Good rheophillic species but limited information |
| 1000 | 0.3 | 1 | *Schilbe spp.* | Good rheophillic species long. & lat. Potamodromous migrations. |

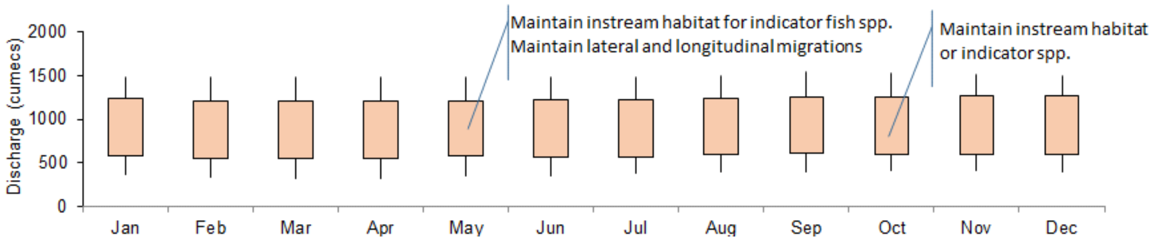


Figure 68: Reference hydrograph from RR3 with key fish biology and ecology requirements.

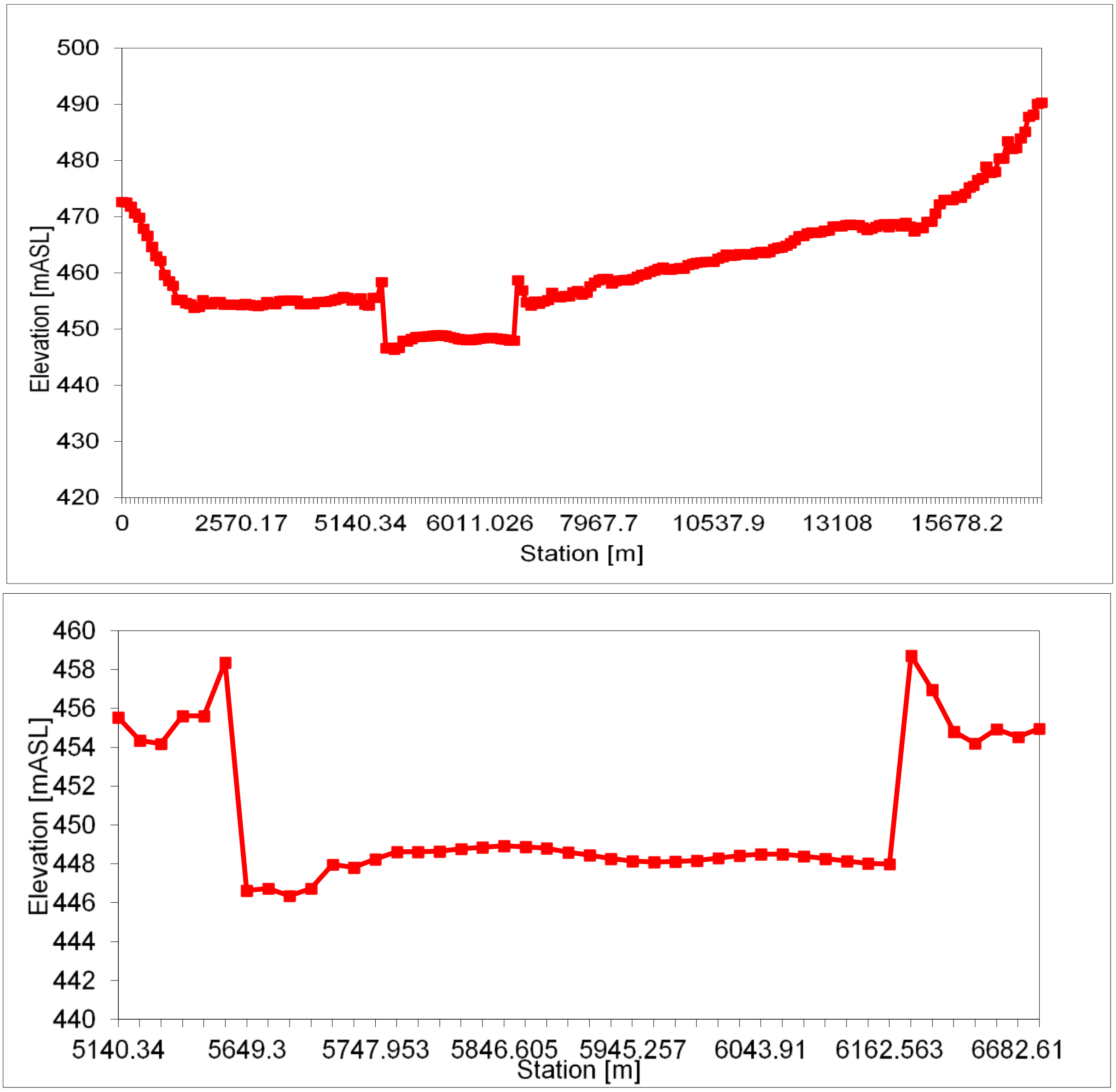
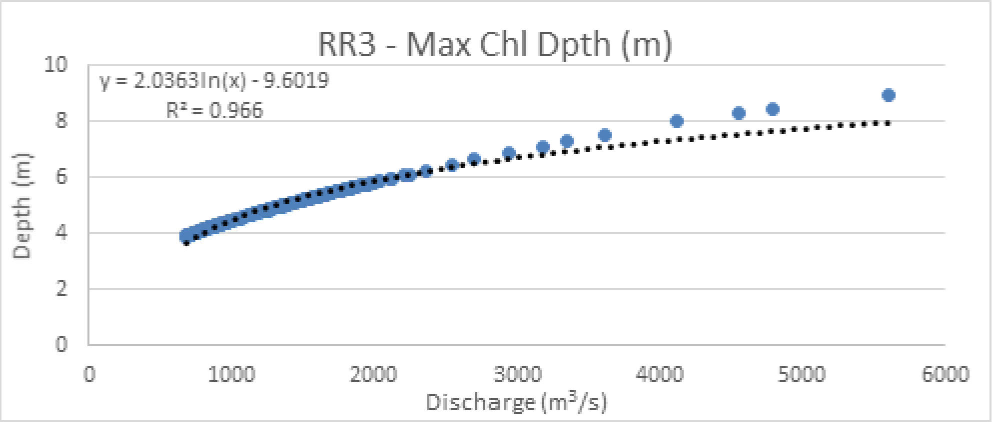


Figure 69: Cross section of RR3 with flow elevations highlighted for key fish biology and ecology events selected in the study for eflow determination.



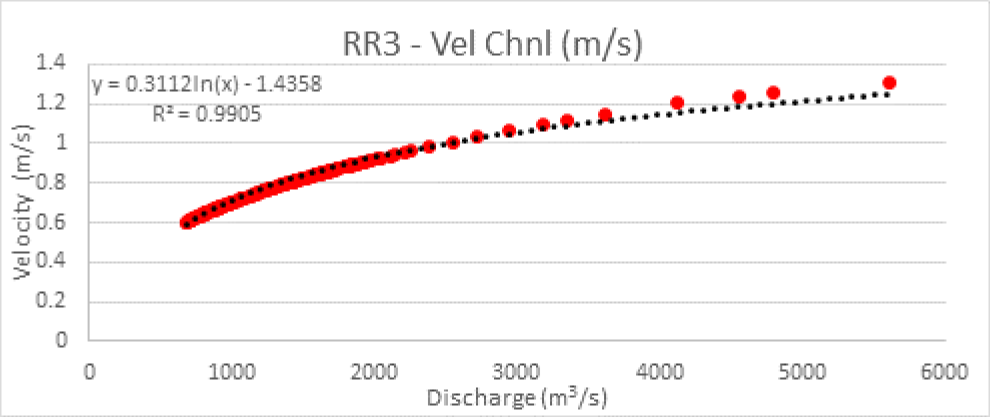


Figure 70: Flow depth (Blue) and Velocity depth (Red) relationships established for the study used to determine flow requirements for fishes.

### 4.3.2 Calculate Risk

Following the determination of flows to maintain the ecosystems associated with each site in each ecological category a summary of the flow requirements associated with these scenarios is generated (Table 36). These hydrographs were used in the risk assessment as scenarios to compare the socio-ecological consequences of altered flows associated with each scenario (ecological category).

Table 36: Summary of the floods required to provide for key socio-ecological processes in the Nile River per ecological category Class considered in the study.

| **RR** | **River** | **Flow Component** | **Percentage EFR per Ecological Class** | | |
|---|---|---|---|---|---|
| | | | **B** | **C** | **D** |
| 3 | White Nile (Bahr el Jebel) | Drought flows | Included in Maintenance Low flows | | |
| | | Maintenance (or base) flows Low (or dry) period | 46% | 22% | 19% |
| | | Maintenance (or base) flows high (or wet) period | 6% | 4% | 3% |
| | | **Total** | **52%** | **26%** | **21%** |

The reference hydrographs and median flows for ecological categories B, C and D considered in the risk assessment for RR3 – Nile River (Bahr et Jebel) are graphically presented in Figure 71 and Figure 72. The rank thresholds for indicators selected for this site were used to query this hydrology data and evaluate the socio-ecological consequences of altered flows in the system using PROBFLO.

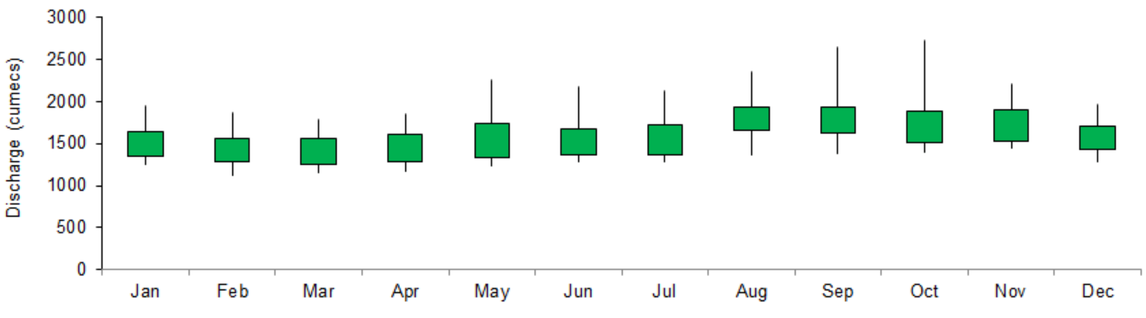


Figure 71: Box and whisker plot summary of the reference (Class A) average monthly (m³/s) flows observed in RR3 in the study. Whiskers represent 0.01%tiles and 99.9%tiles and box 20%tile and 80%tiles.

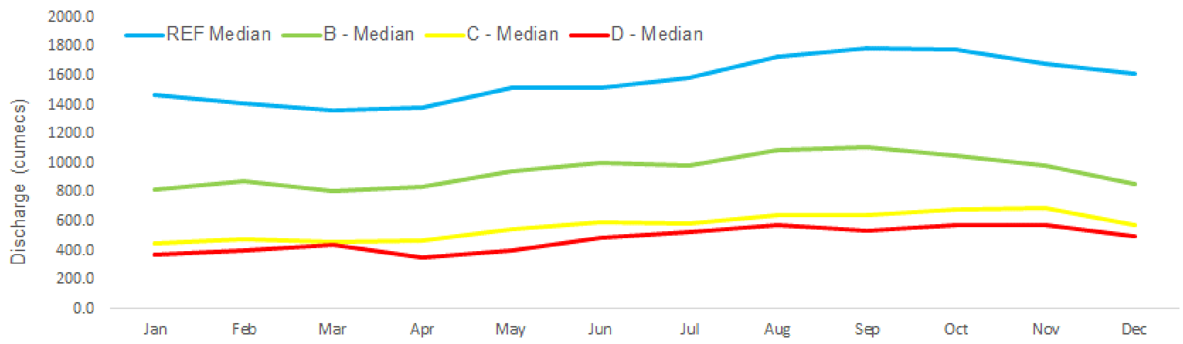


**Figure 72: Relative graphs (medians) of the reference (Class A or pristine), Class B (near natural), Class C (moderately modified) and Class D (largely modified) average monthly flows ($m^3/s$) flows observed in RR3 in the study. Whiskers represent 0.01%tiles and 99.9%tiles and box 20%tile and 80%tiles.**

Risk outcomes directly obtained from the Netica Bayesian Network assessment are presented per RR with averages, standard deviation (SD) and risk rank probability profiles.

***Floodplain ecosystem services endpoint***

The relative risk to the floodplain ecosystem serves endpoint showed an increasing trend in risk from Class A to Class D (Figure 73). The results for Class A and B were low risk with SD extending into the moderate risk range. The results for Class C and D were moderate risk with SD extending into the high risk range. From Figure 74, results include a >50% possibility of high risk to the floodplain services for Class C and D.

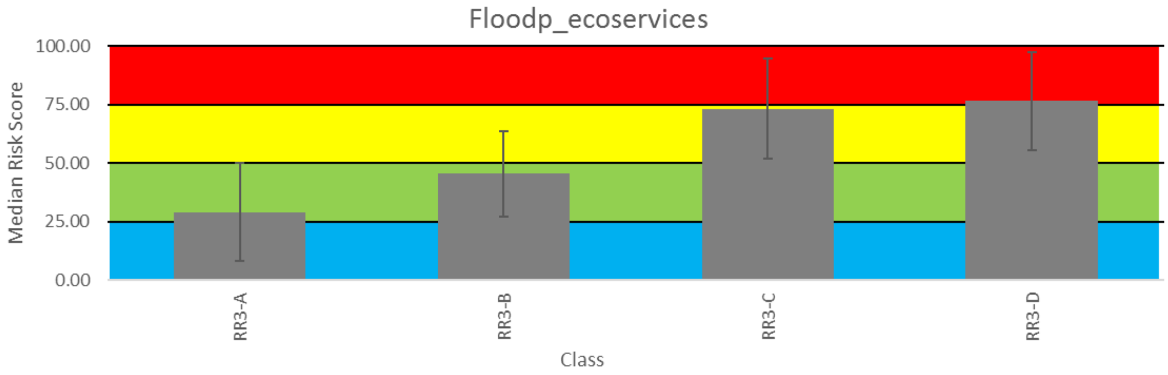


**Figure 73: Relative Risk (median, with standard deviation) of multiple stressors associated with eflow scenarios to Floodplain ecosystem services endpoint considered in the study (Class A (A), Class B (B), Class C (C) and Class (D)). Risk rank ranges for Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) risk included.**

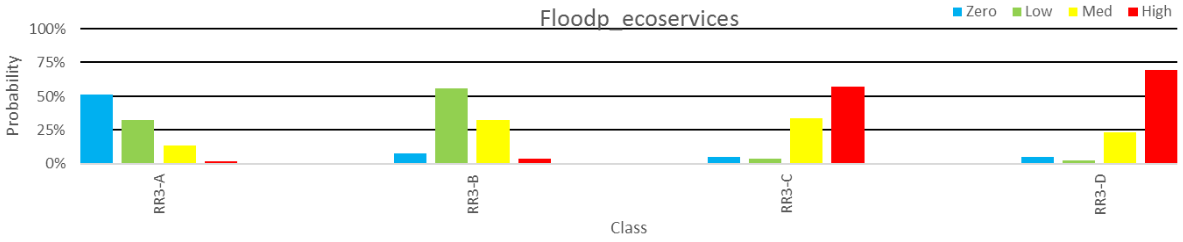


Figure 74: Probability of risk rank occurrence for ranks Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) of multiple stressors associated with eflow scenarios to Floodplain ecosystem services endpoint considered in the study.

### *River ecosystem services endpoint*

The relative risk to the river ecosystem services endpoint showed an increasing trend in risk from Class A to Class D (Figure 75). The results for Class A revealed a zero risk with SD in the low risk range. Class B revealed low risk with SD in the moderate range and Class C and D both showed moderate risk with SD in high risk range. Results in Figure 76 includes probabilities of high risk (>45%) to Class C and D.

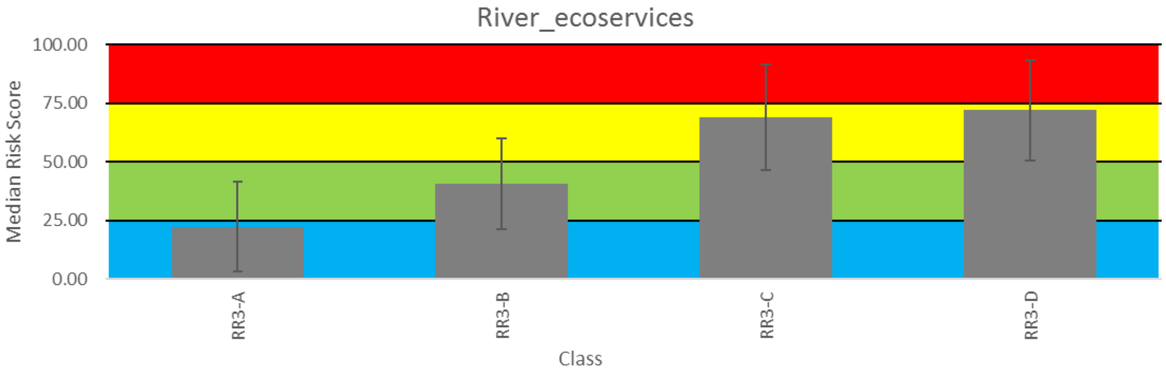


Figure 75: Relative Risk (median, with standard deviation) of multiple stressors associated with eflow scenarios to River ecosystem services endpoint considered in the study (Class A (A), Class B (B), Class C (C) and Class (D)). Risk rank ranges for Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) risk included.

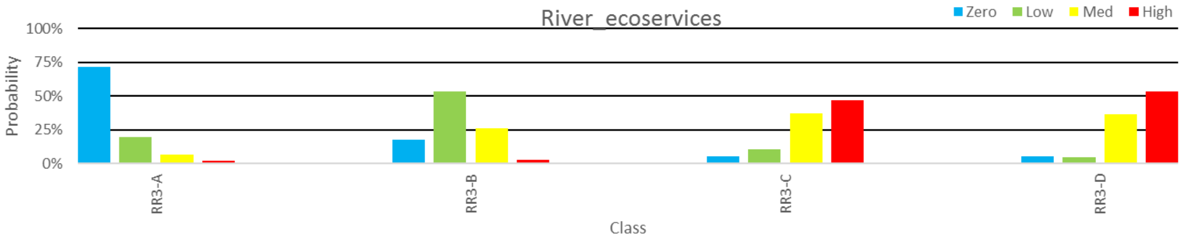


Figure 76: Probability of risk rank occurrence for ranks Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) of multiple stressors associated with eflow scenarios to River ecosystem services endpoint considered in the study.

### *Floodplain biodiversity endpoint*

The relative risk to the floodplain biodiversity endpoint showed an increasing trend in risk from Class A to Class D (Figure 77). The results for Class A revealed a low risk with SD in the moderate risk range. Class B revealed low to moderate risk with SD in the moderate range and Class C and D both showed moderate to high risk with SD in high risk range. Figure 78 showed probability of high risk (>50%) to the endpoint for Class C and D.

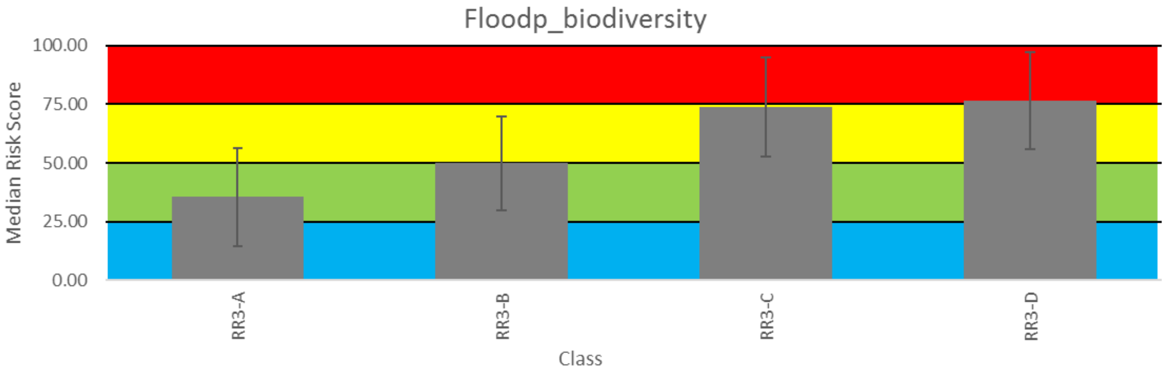


**Figure 77: Relative Risk (median, with standard deviation) of multiple stressors associated with eflow scenarios to Floodplain biodiversity endpoint considered in the study (Class A (A), Class B (B), Class C (C) and Class (D)). Risk rank ranges for Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) risk included.**

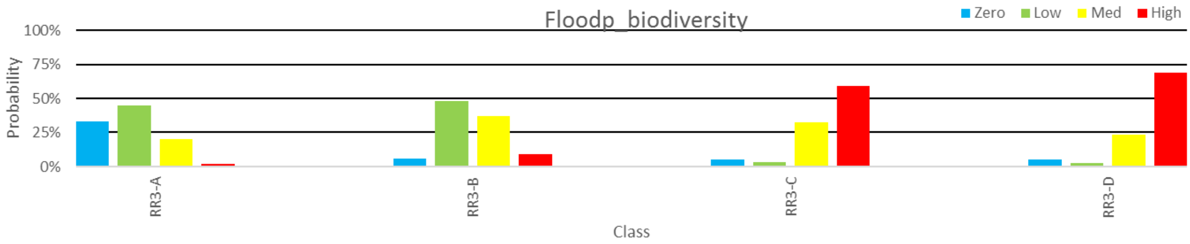


**Figure 78: Probability of risk rank occurrence for ranks Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) of multiple stressors associated with eflow scenarios to Floodplain biodiversity endpoint considered in the study.**

### ***River biodiversity endpoint***

The relative risk to the floodplain biodiversity endpoint showed an increasing trend in risk from Class A to Class D (Figure 79). The results for Class A revealed a zero risk with SD in the low risk range. Class B revealed low risk with SD in the moderate range and Class C and D both showed moderate risk with SD in high risk range. High risk (>45%) to the riverine biodiversity was revealed for Class D (Figure 80).

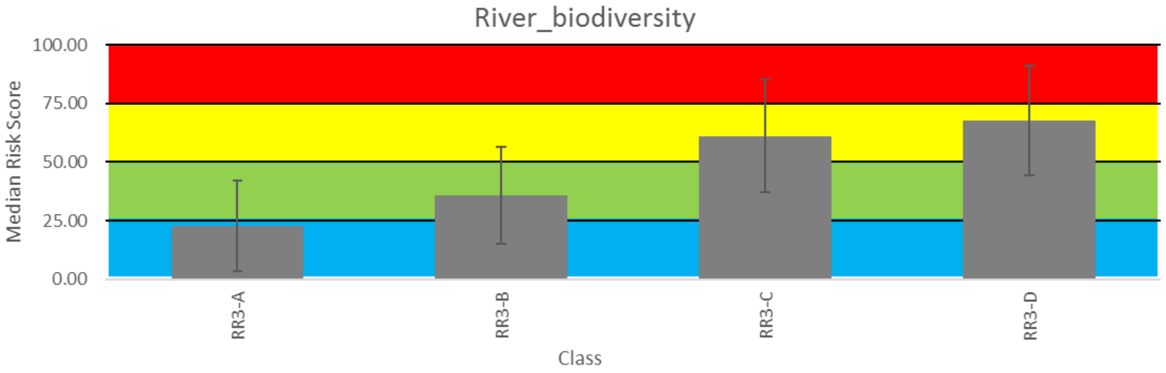


**Figure 79: Relative Risk (median, with standard deviation) of multiple stressors associated with eflow scenarios to River biodiversity endpoint considered in the study (Class A (A), Class B (B), Class C (C) and Class (D)). Risk rank ranges for Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) risk included.**

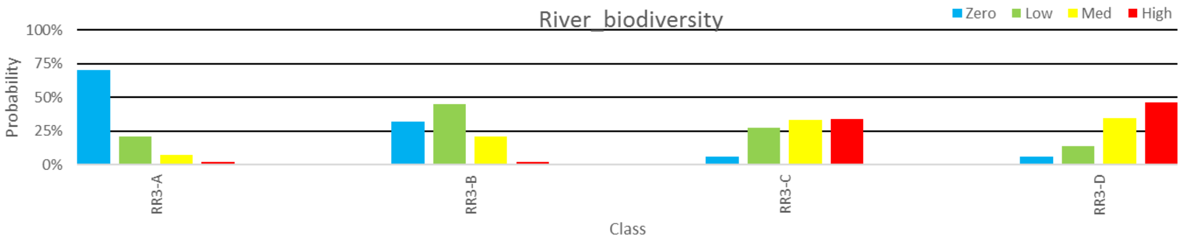


Figure 80: Probability of risk rank occurrence for ranks Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) of multiple stressors associated with eflow scenarios to River biodiversity endpoint considered in the study.

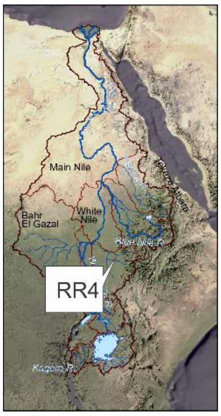
### 4.3.3 Conclusion for RR3

Low flows (dry and wet base flows) are important for the river and should be provided to ensure adequate habitats to maintain the ecology of the river. The low percentage for the flood requirements is due to the ‘flat’ hydrograph as most of the flows occur as high base flows. It is also important to note that the river is perennial and that the 99.9 percentile flow specified for each month provides for non-zero flows. Thus, any future operation of the system or water resource developments should accommodate the minimum flow requirements.

Results include increasing risk to endpoints as the ecological wellbeing of the rivers deteriorate from reference states to Class B, C and D ecological categories. Similarly, there is a high variability in the resilience and associated risk of altered flows to different endpoints. This includes relatively higher risk to the floodplain biodiversity endpoint compared to the riverine biodiversity and the ecosystem services associated with the river and floodplain ecosystems. A probability of high risk (>45%) was recorded for Class C and D for the floodplain and river services endpoints and floodplain biodiversity endpoint and for Class D for the river biodiversity endpoint.

## 4.4 RR4 – Baro River

The Baro River originates in the Ethiopian Highlands and is a tributary of the Sobat River (NBI, .2008). Portions of the Baro River’s flow spills through channels to large wetlands known as the Machar Marshes (NBI, .2008) and the river reach selected for the assessment is at Gambela, upstream of these marshes (Latitude 8.247126; longitude 34.576519).



### 4.4.1 Data Analysis

#### 4.4.1.1 Hydrology Assessment

The results are presented as tables showing the flow requirements for the highest and lowest flow month at selected percentile values and the annual flood requirements in terms of discharge, months when required and the duration in days. The hydrographs indicate the reference and base flows compared to the EFR. Flow duration curves (FDCs) per RR for selected months are also presented.

The Baro River is a tributary of the Sobat River and has a record period spanning 28 years (1977-2004) with a Reference MAR of 12 176 MCM. The flow requirements for selected months and percentiles (low flows and floods) that were used to determine the EFR is summarised in Table 37 below.

**Table 37: Selected flow requirements for RR4 – Baro River**

| | Flow requirements ($m^3$/s) – low flows | | |
|---|---|---|---|
| **Percentiles** | **Mar** | **Sep** | |
| 15 | - | 250 | |
| 50 | 35 | 110 | |
| 99.9 | 15 | 55 | |
| | **Flow requirements– annual floods** | | |
| | **Aug** | **Sep** | **Oct** |
| Peak flows ($m^3$/s) | 850 | 950 | 660 |
| Duration (days) | 10 | 10 | 10 |

These selected requirements, together with the DRM were used to determine the EFR for each month. The results of the final EFR for RR4 is shown in Table 38 below.

**Table 38: Final EFR for RR4 – Baro River (flows in $m^3$/s)**

| RR4 | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 84.4 | 57.3 | 46.6 | 51.9 | 70.1 | 137.2 | 282.3 | 374.0 | 438.3 | 354.2 | 227.6 | 134.8 |
| Minimum | 34.9 | 23.6 | 18.2 | 16.2 | 23.8 | 59.7 | 103.9 | 140.1 | 150.5 | 120.2 | 92.4 | 58.0 |
| Maximum | 112.2 | 82.1 | 65.5 | 65.9 | 84.2 | 157.1 | 369.6 | 487.5 | 608.7 | 426.0 | 277.2 | 177.0 |
| Percentiles | | | | | | | | | | | | |
| 0.1 | 112.2 | 82.1 | 65.5 | 65.9 | 84.2 | 157.1 | 369.6 | 487.5 | 608.7 | 426.0 | 277.2 | 177.0 |
| 1 | 112.2 | 82.1 | 65.5 | 65.9 | 84.2 | 157.1 | 369.6 | 487.5 | 608.7 | 426.0 | 277.2 | 177.0 |
| 5 | 112.2 | 82.1 | 65.5 | 65.9 | 84.2 | 157.1 | 369.6 | 487.5 | 608.7 | 426.0 | 277.2 | 177.0 |
| 10 | 112.2 | 74.8 | 65.5 | 65.9 | 84.2 | 157.1 | 363.3 | 479.4 | 595.8 | 426.0 | 277.2 | 177.0 |
| 15 | 112.2 | 70.4 | 64.6 | 65.9 | 84.2 | 157.1 | 356.2 | 471.6 | 575.2 | 426.0 | 277.2 | 177.0 |
| 20 | 112.0 | 69.4 | 56.4 | 65.8 | 84.2 | 157.0 | 348.9 | 460.8 | 567.1 | 425.6 | 277.0 | 174.6 |
| 30 | 106.7 | 67.6 | 53.2 | 64.7 | 83.7 | 156.3 | 335.2 | 443.2 | 540.4 | 423.0 | 273.9 | 162.2 |
| 40 | 100.1 | 65.2 | 50.8 | 59.0 | 82.5 | 154.9 | 322.1 | 425.5 | 512.6 | 417.2 | 271.9 | 152.3 |
| 50 (median) | 88.3 | 59.6 | 45.0 | 56.7 | 80.2 | 152.4 | 308.0 | 413.1 | 480.0 | 408.0 | 257.0 | 148.0 |
| 60 | 78.7 | 55.3 | 43.3 | 54.8 | 74.4 | 145.2 | 273.9 | 362.1 | 420.7 | 376.0 | 238.2 | 134.8 |
| 70 | 70.2 | 49.0 | 40.5 | 45.7 | 66.2 | 135.2 | 253.1 | 336.3 | 373.2 | 334.5 | 213.8 | 125.7 |
| 80 | 59.9 | 45.2 | 39.6 | 38.9 | 54.7 | 118.7 | 220.5 | 293.5 | 307.2 | 276.4 | 172.4 | 94.1 |
| 85 | 51.5 | 41.4 | 33.7 | 31.1 | 50.6 | 106.1 | 184.8 | 245.5 | 279.2 | 241.5 | 152.6 | 83.4 |
| 90 | 43.0 | 33.0 | 31.4 | 30.0 | 40.7 | 93.5 | 170.6 | 227.8 | 226.8 | 205.4 | 119.7 | 69.7 |
| 95 | 39.3 | 25.7 | 23.0 | 23.9 | 29.9 | 78.6 | 143.2 | 186.7 | 170.0 | 151.2 | 104.1 | 63.8 |
| 99 | 35.5 | 24.1 | 18.9 | 17.4 | 24.8 | 64.5 | 114.2 | 151.6 | 152.5 | 125.0 | 95.3 | 58.9 |
| 99.9 | 34.9 | 23.7 | 18.3 | 16.3 | 23.9 | 60.1 | 105.0 | 141.3 | 150.7 | 120.7 | 92.7 | 58.1 |

The summary of the EFR for RR4 (Table 39) shows that almost 50% of the flows in the Baro River is required for ecological functioning, with the low flows (flows occurring more than 50% of the time) making up the bulk of the requirement and floods only 10% of the ecological requirement. Thus, low flows (dry and wet base flows) are important for the river and should be provided to ensure adequate habitats to maintain the ecology of the river.

As the river shows a distinct dry and wet season, with the peak flows in August, September and October, drought flows were specified separately to the maintenance low flows. It is also important to note that the river is perennial and that the 99.9 percentile flow specified for each month provides for non-zero flows. Thus, any future operation of the system or water resource developments should accommodate the minimum flow requirements.

Table 39: Summary of final EFR for RR4 – Baro River

| RR | River | Reference (MCM) | % Requirement | | | | Volume Requirement (MCM) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Low flows | Drought flows | Floods | Total | Low flows | Drought flows | Floods | Total |
| RR4 | Baro | 12 176 | 47.7 | 15.0 | 10.4 | 49.6 | 4 709 | 1 803 | 1 246 | 5 954 |

The monthly hydrograph of the REF, BF and EFR for a B state for the Baro River is shown in Figure 81. This indicates that the EFR is close to the base flows for the dry season (see also FDC for March - Figure 82). However, the EFR is higher in the wet season as the system requires floods for the maintenance of ecological integrity as also shown in the FDC for September (Figure 83).

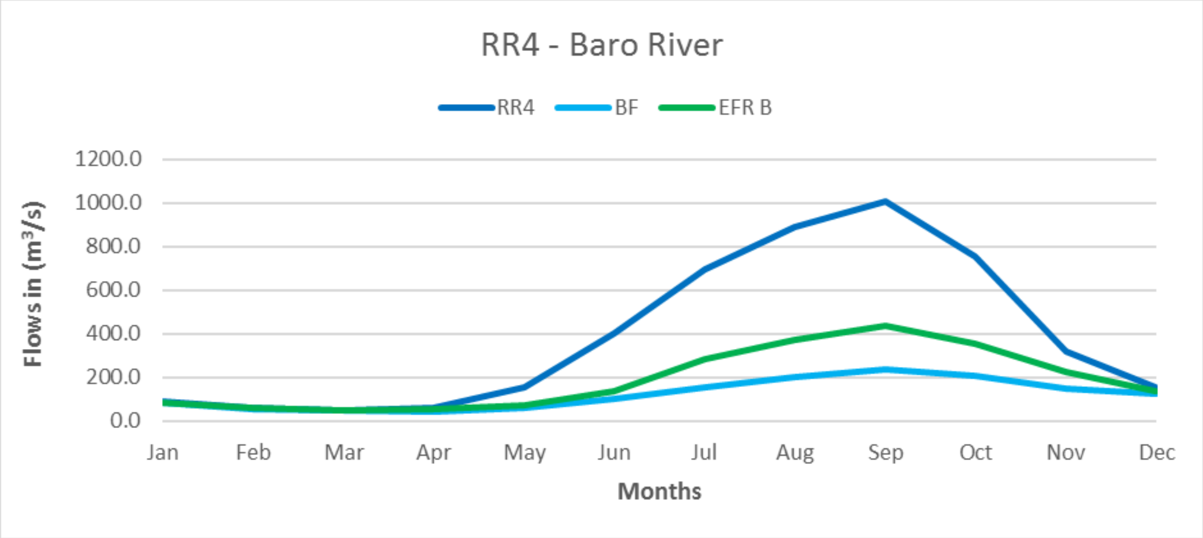


Figure 81: Monthly hydrograph for RR4 – Baro River

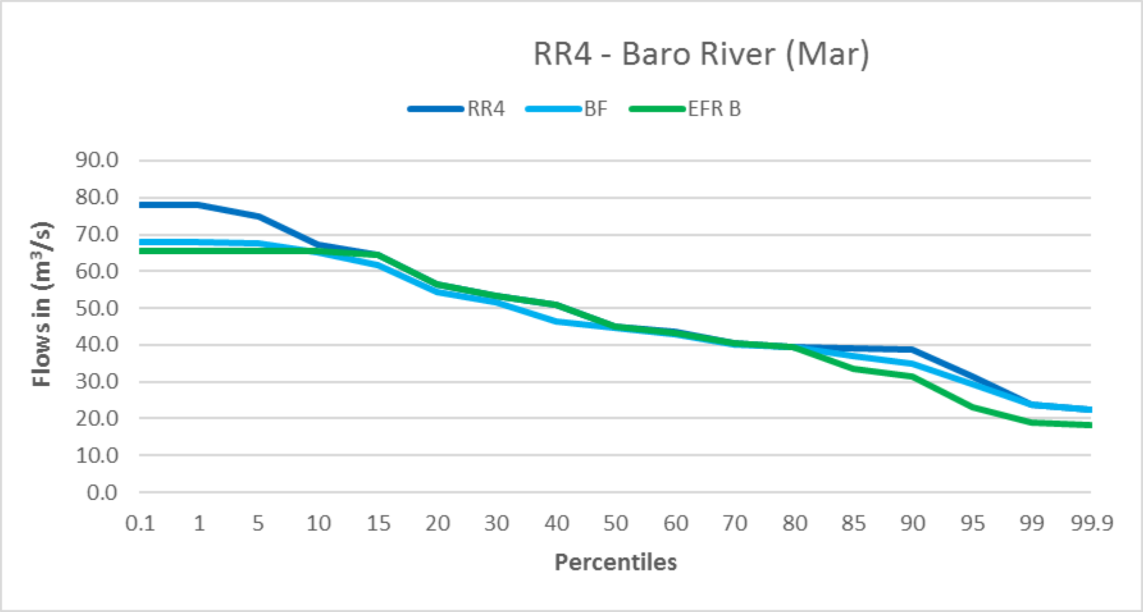


Figure 82: Flow duration curve for March (low flows) in RR4 – Baro River

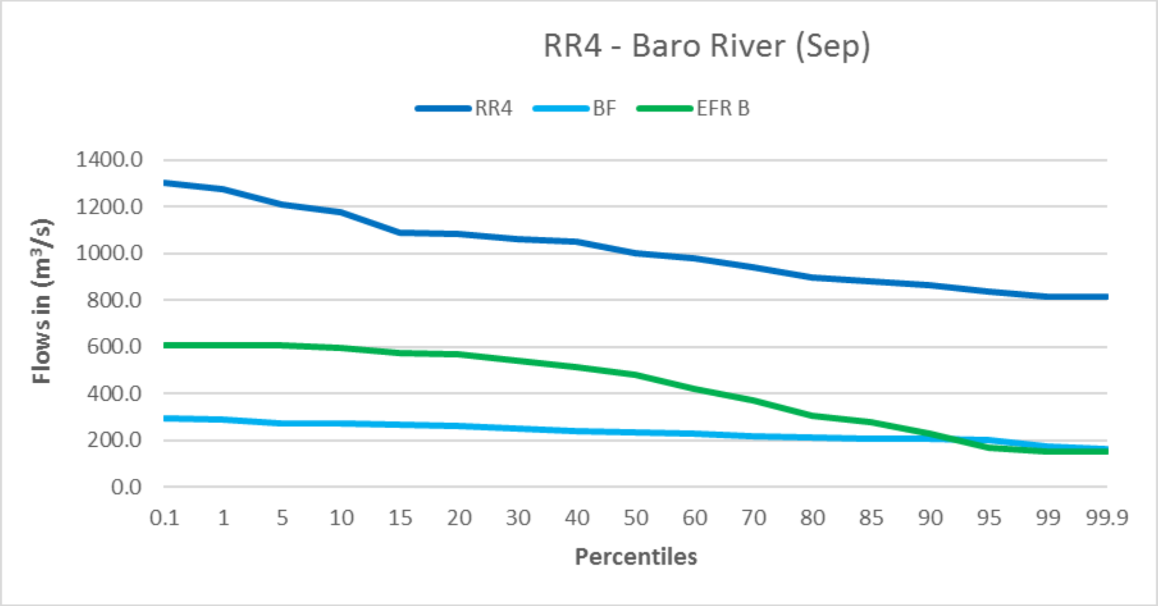


Figure 83: Flow duration curve for September (wet season) in RR4 – Baro River

### 4.4.1.2 Hydraulic Assessment

It must be noted, that the 1.5yr return period flow is only approximately depicting bankfull flow conditions. Therefore, additional cross section characteristics were investigated from which information about inundation extent and frequency could be deduced. These descriptions are briefly given for the points of interest. Each point of interest is individually assessed using QGIS with the Profile Tool and Quick Map Services Plugin on the MERIT DEM and Google Satellite images. The site location and ID (yellow dot with number, corresponds to the IDs given in Table 40) is shown together with the cross section location (red line) on satellite images (Google Earth/Digital Globe). Below the images, the diagram shows the cross section (elevation along the red line), where the small red dot

in the upper satellite images is marked by the centre of the cross line in the lower diagram. Numbers in the diagram show elevation in mASL (y-Axis) and distance from left in meters (x-axis).

Table 40. Points of interest, the applied methodology for obtaining the channel cross section and additional channel and cross section properties

| ID | River | Latitude | Longitude | Channel bathymetry method | Bank width [m] | Ineffective area elevation [mASL] | Slope [m/m] |
|---|---|---|---|---|---|---|---|
| RR4 | Baro | 8.2483 | 34.5769 | Survey | 181 | 435 | 0.000167 |

Figure 84 shows the DEM cross section at Gambela. Note that the river channel is shifted and not well represented in the DEM and that DEM elevations of the settlements can therefore not be used to assess inundation frequencies. At Gambela, a surveyed cross section is available from 2012, which was used to correct DEM elevations in between the banks (Figure 85). No further adjustment of Mannings n values was necessary to confine bankfull flow between the banks.

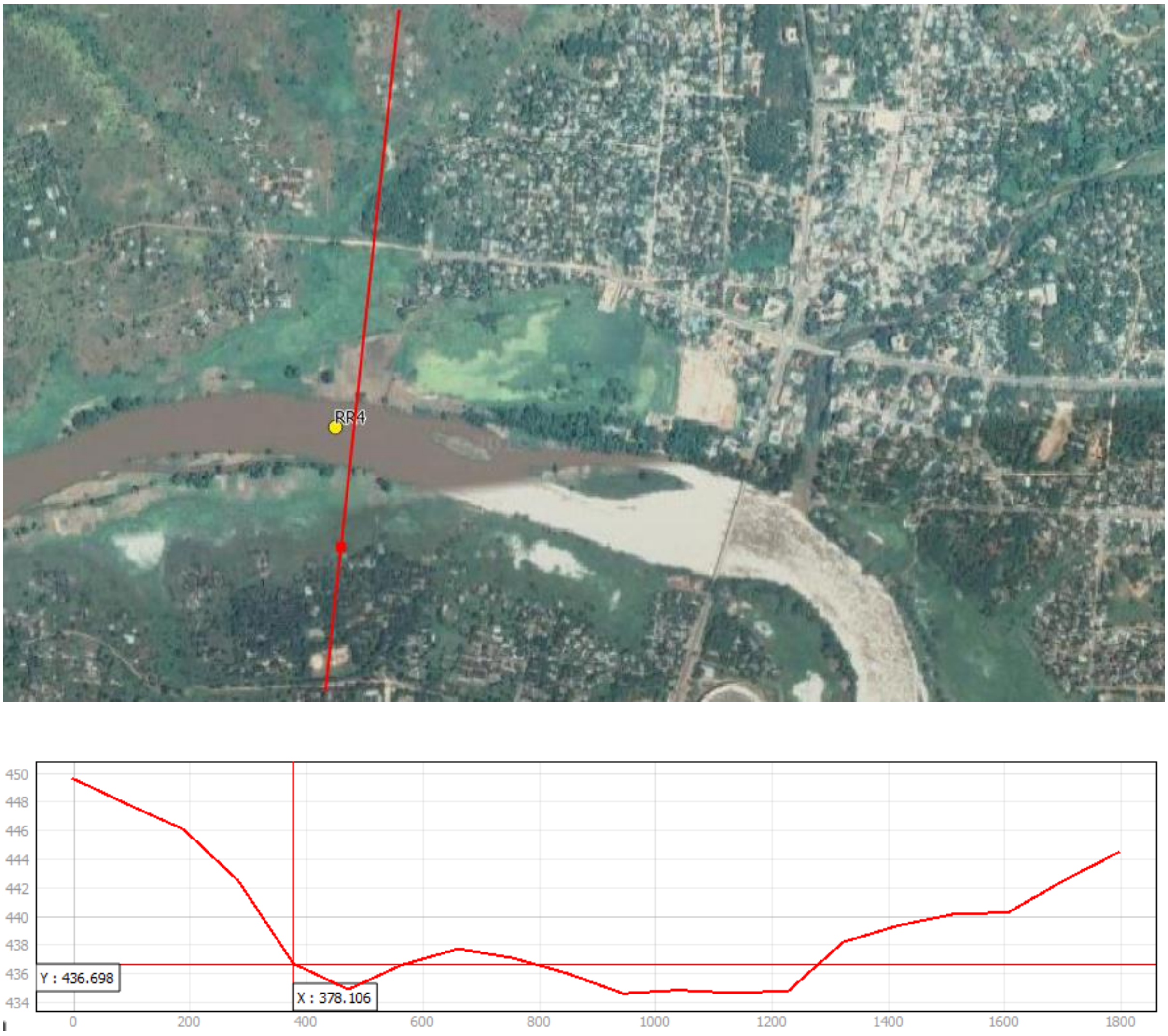


Figure 84. Baro cross section at Gambela.

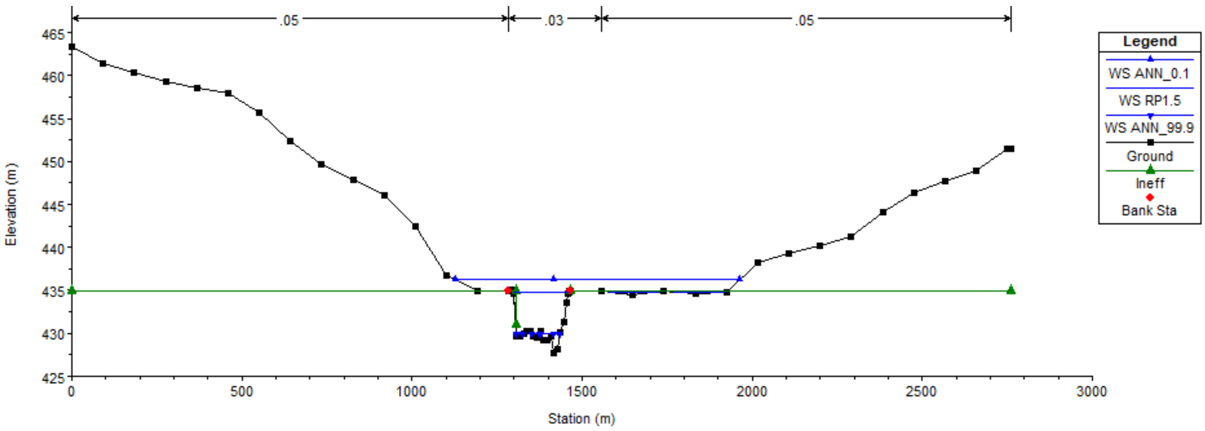


Figure 85: Cross sectional profile of the hydraulic site for RR4

#### 4.4.1.3 Vegetation Assessment

This risk region is represented by the Baro River upstream of the Machar Marshes near Gambela with the cross section shown as a red line in Figure 86. Vegetation at this site displays a clear woody and non-woody zone. The active channel, which averages 160m wide appears to have levee along much of its length and this supports a distinct band of tall dense tree and shrub species. This is followed by a more extensive lower zone / wet bank dominated by flood dependent non-woody species such as *Phragmites, Cyperus, Oyza, Juncus* and *Typha*. The area is utilised for agricultural activities, which will include grazing of livestock, but also caters for high density human population.

Figure 86: Google Earth © satellite image at Gambela on the Baro River upstream of the Machar Marshes representing risk region 4.

Based on the available biological information at cross section sites, and together with hydraulics at each site, the driver components [within the model] were quantified for a B-category (Table 41) as determined by discernible riparian indicators (Table 42). Interpolation was frequently required due to lack of biological data specific to sites.

Table 41: Quantification of driver components for a B-category system (Values are discharge).

| General description | | RR4 |
|---|---|---|
| Bank full for non-woody fringe vegetation | Wet Base | 360 |
| Wet base less 1m in elevation | Dry Base | 55 |
| Wet base less 1.5m in elevation | Critical Low | 24 |
| Between woody and non-woody limits | Freshette | 660 |
| To the base of woody vegetation (Tall tree line) | Annual flood | 850 |

Table 42: Riparian indicators utilized to quantify driver components for a B-category system.

| RR4 | channel width (m) | Discharge | Chan depth | Month | Indicators |
|---|---|---|---|---|---|
| Wet Base | 147 | 360 | 3 | Aug | Reeds |
| Dry Base | 138 | 55 | 1.3 | Mar | Reeds |
| Critical Low | 110 | 24 | 0.7 | Mar | Reeds |
| Freshette | 174 | 660 | 4.3 | Aug-Sep | Flood reeds |
| Annual flood | 230 | 850 | 4.75 | Aug | Tall tree line |

### Defining Risk to Vegetation

The alteration of driver dynamics, in this case flows and by implication floods, results in risk to the vegetation. Optimal driver state results in low risk to all vegetation endpoints but does not consider the effects of non-flow related impacts, such as ever increasing grazing and trampling pressures, and the impacts of human density and resource use. However, as flows may decline so the risk to vegetation endpoints increases. This risk has been described and quantified for each of the response variables (Table 43), as well as for each of the response variables within different risk regions, and represents declining ecological health or ecosystem wellbeing.

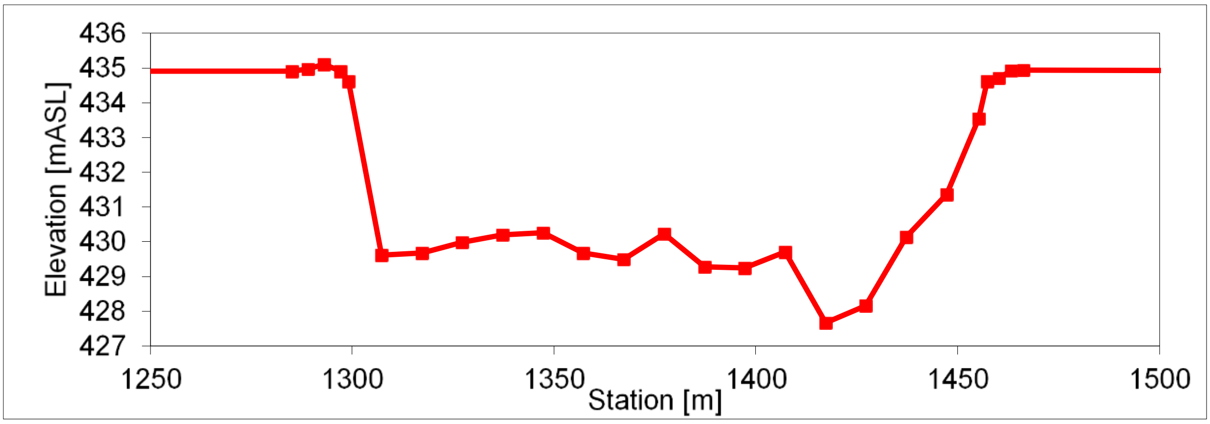
Table 43: Justifications and driver quantification for interaction of vegetation components within the model.

| Bayesian Network variable title, measure - (BN node name) | Rank (score) | Rank definition and measure for variable | RR4 |
|---|---|---|---|
| Aveghab_R_bwet | Zero (25) | 10% higher percentile than B] base | > 480 |
| | Low (50) | bank full for non-woody vegetation | 480 - 360 |
| | Moderate (75) | between [B] dry base and [B] wet base | 360 - 120 |
| | High (100) | as low as normal (B) dry base | < 120 |
| FPveg_FP_bwet | Zero (25) | 10% higher percentile than B] base | > 480 |
| | Low (50) | bank full for non-woody vegetation | 480 - 360 |
| | Moderate (75) | between [B] dry base and [B] wet base | 360 - 120 |
| | High (100) | as low as normal (B) dry base | < 120 |
| Aveghab_R_drought | Zero (25) | 95% [B] dry season max month | > 32 |
| | Low (50) | crtical low flows for [B] | 32 - 24 |
| | Moderate (75) | 99% dry season max | 24 - 19 |

| **Bayesian Network variable title, measure - (BN node name)** | **Rank (score)** | **Rank definition and measure for variable** | **RR4** |
|---|---|---|---|
| | High (100) | | < 19 |
| Aveghab_R_bdry | Zero (25) | wet base | > 360 |
| | Low (50) | wet base less 1m | 360 - 55 |
| | Moderate (75) | critical low | 55 - 24 |
| | High (100) | critical low | < 24 |
| FPveg_FP_flood | Zero (25) | to the base of woody vegetation (Tall tree line):annual | > 850 |
| | Low (50) | between woody and non-woody limits: freshette | 850 - 660 |
| | Moderate (75) | no flood: 20% higher than wet base percentile | 660 - 540 |
| | High (100) | | < 540 |
| Subveg_R_bdry | Zero (25) | wet base | > 360 |
| | Low (50) | wet base less 1m | 360 - 55 |
| | Moderate (75) | critical low | 55 - 24 |
| | High (100) | critical low | < 24 |
| Subveg_R_bwet | Zero (25) | 10% higher percentile than B] base | > 480 |
| | Low (50) | bank full for non-woody vegetation | 480 - 360 |
| | Moderate (75) | between [B] dry base and [B] wet base | 360 - 120 |
| | High (100) | as low as normal (B) dry base | < 120 |
| Subveg_FP_bdry | Zero (25) | wet base | > 360 |
| | Low (50) | wet base less 1m | 360 - 55 |
| | Moderate (75) | critical low | 55 - 24 |
| | High (100) | critical low | < 24 |
| Subveg_FP_bwet | Zero (25) | 10% higher percentile than B] base | > 480 |
| | Low (50) | bank full for non-woody vegetation | 480 - 360 |
| | Moderate (75) | between [B] dry base and [B] wet base | 360 - 120 |
| | High (100) | as low as normal (B) dry base | < 120 |

#### 4.4.1.4 Fish Assessment

For the determination of instream flow requirements for the Baro River (Ethiopia) nine species of fishes that have habitat and or migratory requirements that occur within the river were selected for the assessment (Table 44). This river is relatively more seasonal that RR1 to RR3 and there is a close relationship with high flows and the associate floodplain in the Baro River system. Based on the relative size species attains and biology and ecology information the depth and velocity requirements were determined as well as minimum depths to maintain lateral and longitudinal migrations for these indicator species. This information was aligned to the seasonal flows of the system and used to establish flow requirements that were provided to the hydrologist to determine eflow requirements (Figure 87, Figure 88



and Figure 89).

Table 44: Fishes selected to determine eflows for RR4. Hypothesised preferences for habitats (depth and velocity) and migratory notes provided for each species.

| Min. Depth (mm) | Min. Vel (m/s) | Weight | Baro River indicator spp. | Details |
|---|---|---|---|---|
| 450 | 0.8 | 3 | *Polypterus sp.* | Limnophillic/floodplain species long.↑↑ & lat. Potamodromous migrations. |
| 1000 | 1.2 | 3 | *Labeo sp.* | Good rheophillic species long.↑↑ & lat. Potamodromous migrations. |
| 1200 | 1 | 3 | *Alestes sp.* | Good rheophillic species long.↑↑ & lat. Potamodromous migrations. |
| 2000 | 0.8 | 3 | *Hydrocynus sp.* | Good rheophillic species long.↑↑ & lat. Potamodromous migrations. |
| 1200 | 0.8 | 2 | *Bagrus spp.* | Semi-rheophillic species long.↑↑ & lat. Potamodromous migrations. |
| 650 | 0.2 | 2 | *Oreochromis sp.* | Lotic, limnophillic/floodplain species long.↑↑ & lat. Potamodromous migrations. |
| 1200 | 0.5 | 2 | *Distichodus sp.* | Semi-rheophillic species long.↑↑ & lat. Potamodromous migrations. |
| 1200 | 0.6 | 1 | *Clarias gariepinus* | Lotic, limnophillic/floodplain species long.↑↑ & lat. Potamodromous migrations. |
| 1600 | 0.2 | 1 | *Heterobranchus sp.* | Limnophillic/floodplain species long.↑↑ & lat. Potamodromous migrations. |

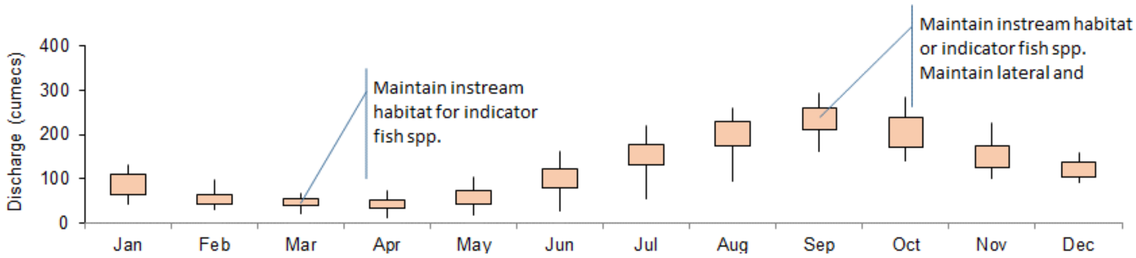
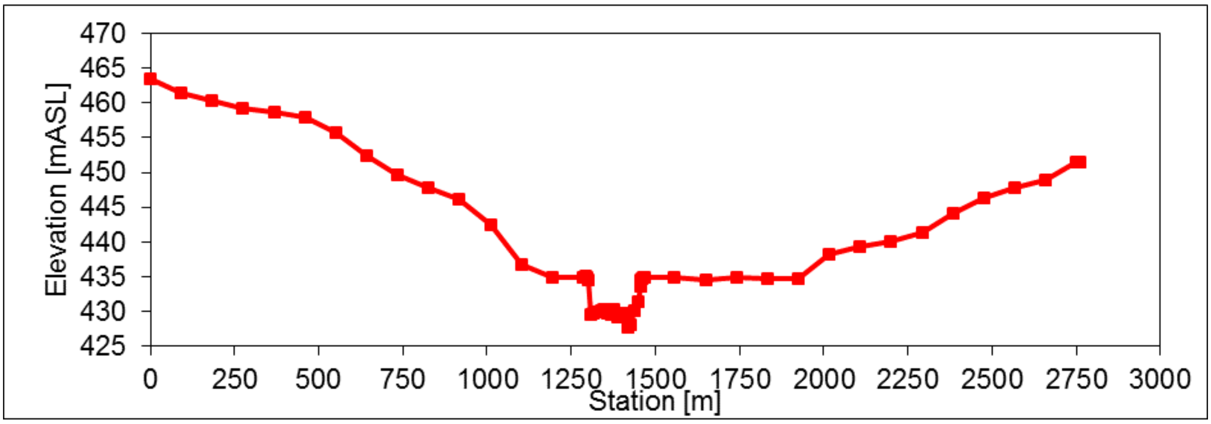


Figure 87: Reference hydrograph from RR4 with key fish biology and ecology requirements.



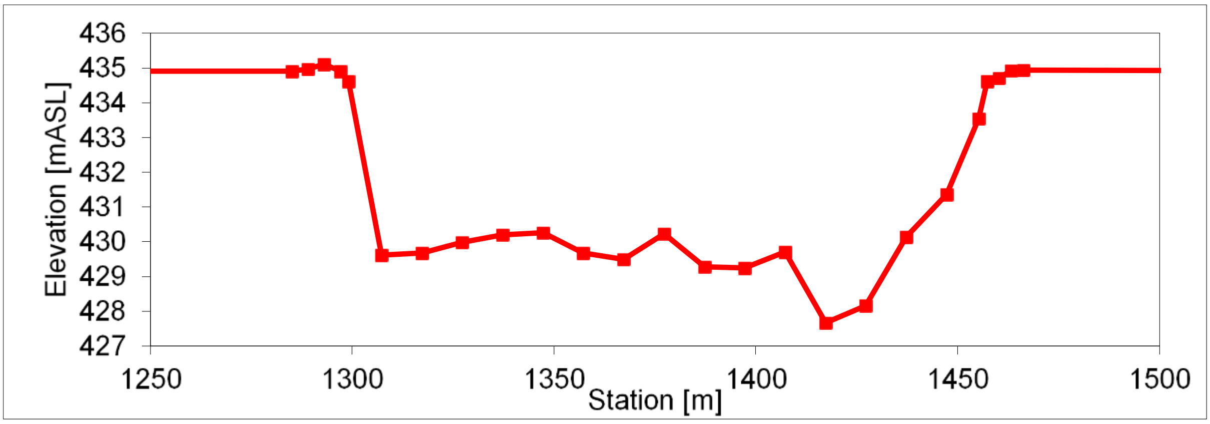


Figure 88: Cross section of RR4 with flow elevations highlighted for key fish biology and ecology events selected in the study for eflow determination.

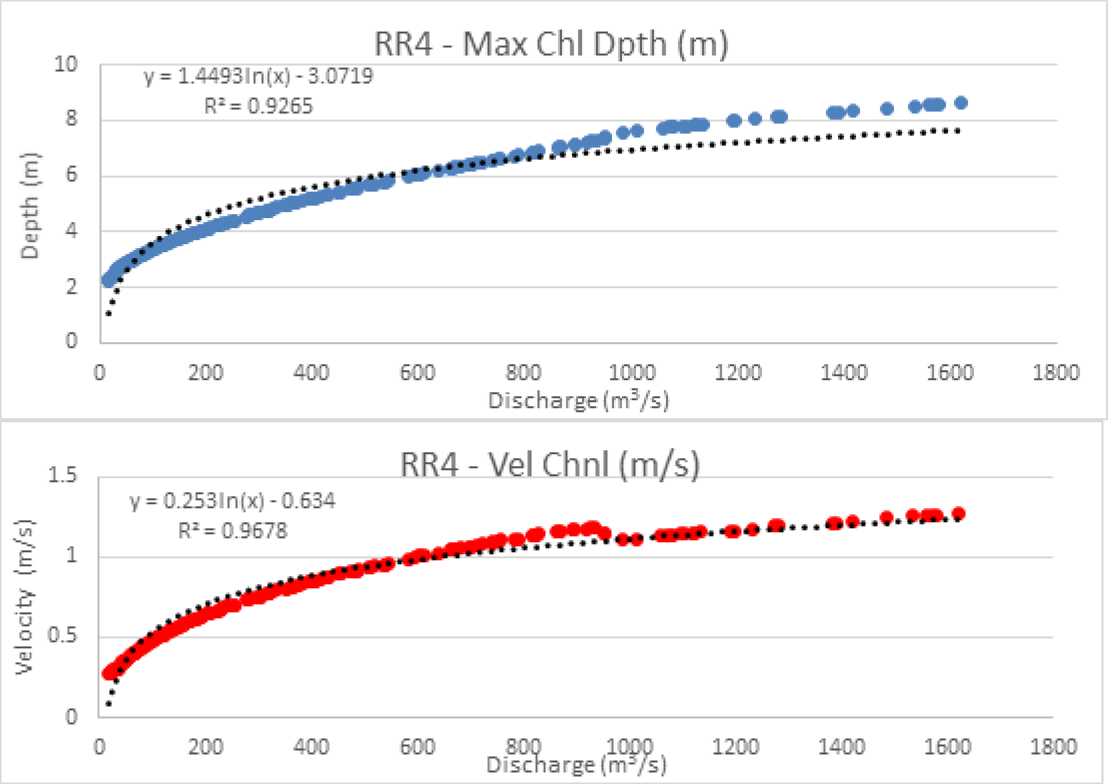


Figure 89: Flow depth (Blue) and Velocity depth (Red) relationships established for the study used to determine flow requirements for fishes.

### 4.4.2 Calculate Risk

Following the determination of flows to maintain the ecosystems associated with each site in each ecological category a summary of the flow requirements associated with these scenarios is generated (Table 45). These hydrographs were used in the risk assessment as scenarios to compare the socio-ecological consequences of altered flows associated with each scenario (ecological category).

Table 45: Summary of the floods required to provide for key socio-ecological processes in the Nile River per ecological category Class considered in the study.

| **RR** | **River** | **Flow Component** | **Percentage EFR per Ecological Class** | | |
|---|---|---|---|---|---|
| | | | **B** | **C** | **D** |
| 4 | Baro River | Drought flows | 15% | 12% | 11% |
| | | Maintenance (or base) flows Low (or dry) period | 39% | 23% | 11% |
| | | Maintenance (or base) flows high (or wet) period | 10% | 3% | 1% |
| | | **Total** | **50%** | **26%** | **13%** |

The reference hydrographs and median flows for ecological categories B, C and D considered in the risk assessment for RR4 – Baro River are graphically presented in Figure 90 and Figure 91. The rank thresholds for indicators selected for this site were used to query this hydrology data and evaluate the socio-ecological consequences of altered flows in the system using PROBFLO.

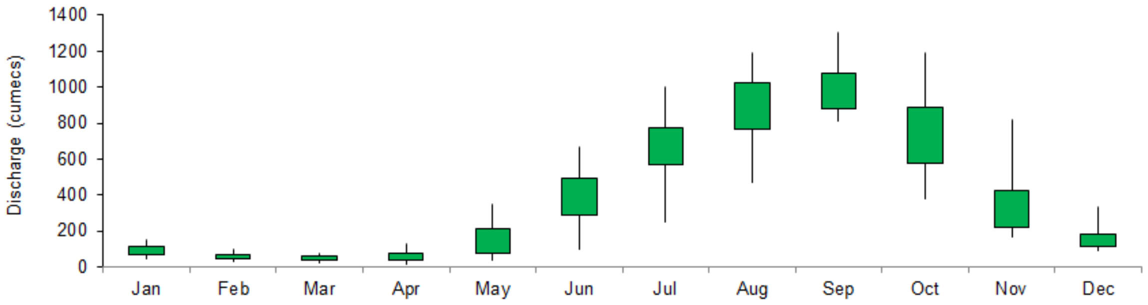


**Figure 90: Box and whisker plot summary of the reference (Class A) average monthly (m$^3$/s) flows observed in RR4 in the study. Whiskers represent 0.01%tiles and 99.9%tiles and box 20%tile and 80%tiles.**

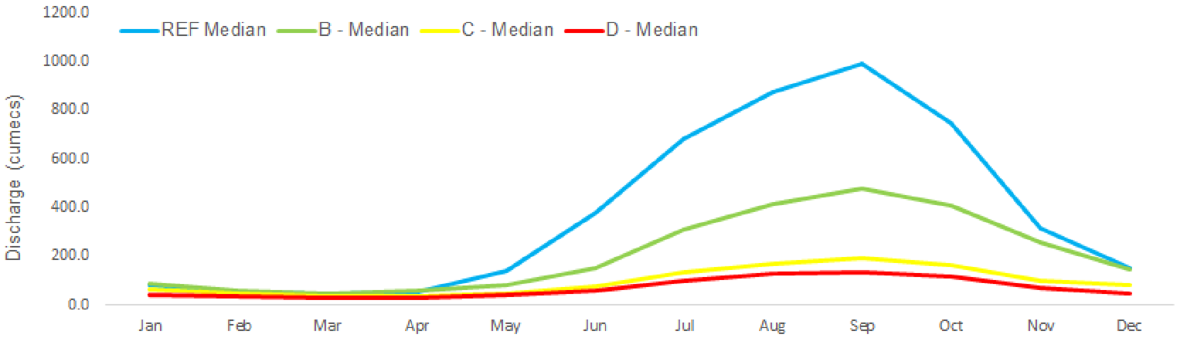


**Figure 91: Relative graphs (medians) of the reference (Class A or pristine), Class B (near natural), Class C (moderately modified) and Class D (largely modified) average monthly flows (m$^3$/s) flows observed in RR4 in the study. Whiskers represent 0.01%tiles and 99.9%tiles and box 20%tile and 80%tiles.**

Risk outcomes directly obtained from the Netica Bayesian Network assessment are presented per RR with averages, standard deviation (SD) and risk rank probability profiles.

### *Floodplain ecosystem services endpoint*

The relative risk to the floodplain ecosystem serves endpoint showed an increasing trend in risk from Class A to Class D (Figure 92). The results for Class A and B revealed low risk with SD extending into the moderate risk range. The results for Class C and D revealed moderate risk with SD extending into the high risk range. From Figure 93, results include a >45% possibility of high risk to the floodplain services for Class D.

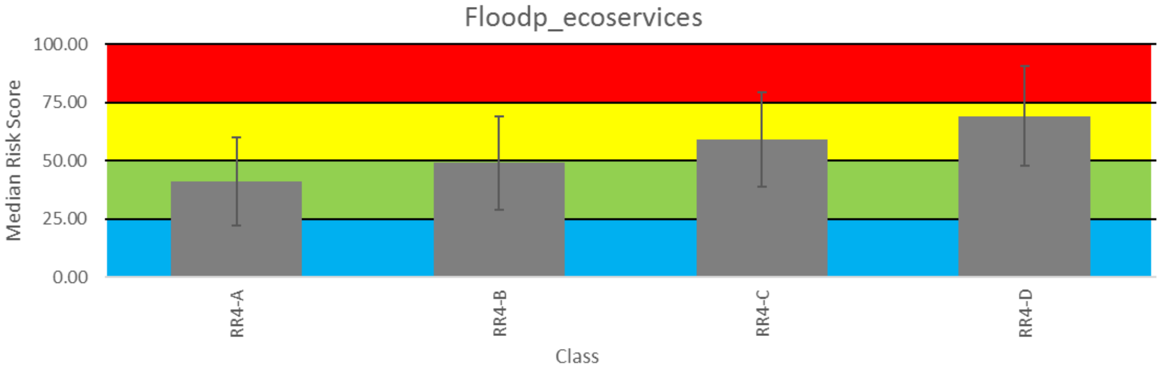


**Figure 92: Relative Risk (median, with standard deviation) of multiple stressors associated with eflow scenarios to Floodplain ecosystem services endpoint considered in the study (Class A (A), Class B (B), Class C (C) and Class (D)). Risk rank ranges for Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) risk included.**

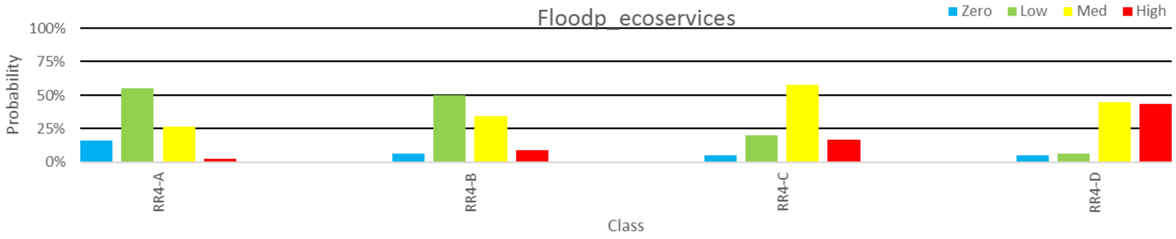


**Figure 93: Probability of risk rank occurrence for ranks Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) of multiple stressors associated with eflow scenarios to Floodplain ecosystem services endpoint considered in the study.**

### *River ecosystem services endpoint*

The relative risk to the river ecosystem services endpoint showed an increasing trend in risk from Class A to Class D (Figure 94). The results for Class A and B revealed low risk with SD extending into the moderate risk range. The results for Class C revealed low to moderate risk with SD extending into the moderate risk range and for Class D, moderate risk with SD extending into the high risk ranges. Results in Figure 95 show no probability of high risk (>45%) to this endpoint for this RR.

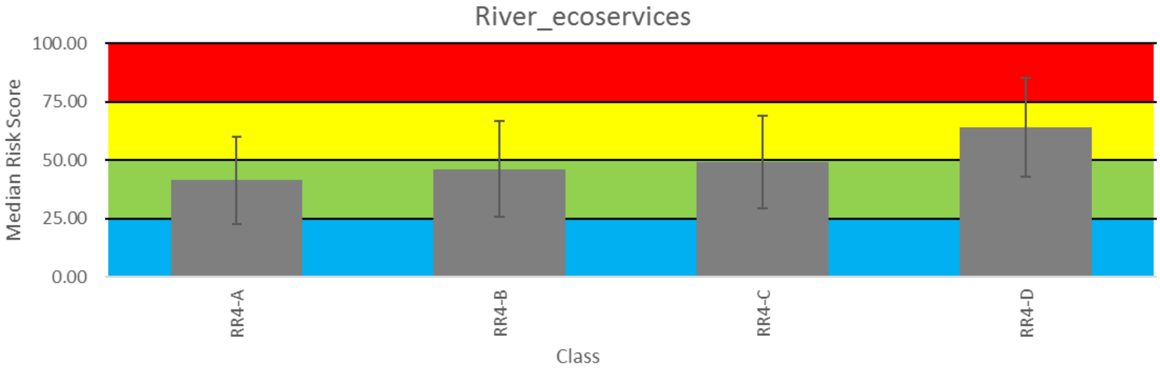


**Figure 94: Relative Risk (median, with standard deviation) of multiple stressors associated with eflow scenarios to River ecosystem services endpoint considered in the study (Class A (A), Class B (B), Class C (C) and Class (D)). Risk rank ranges for Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) risk included.**

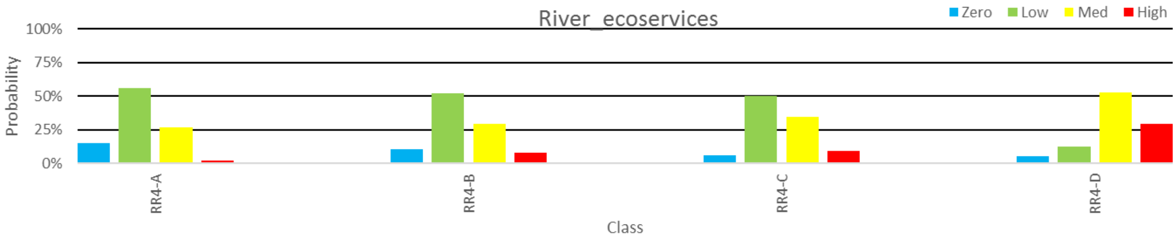


**Figure 95: Probability of risk rank occurrence for ranks Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) of multiple stressors associated with eflow scenarios to River ecosystem services endpoint considered in the study.**

***Floodplain biodiversity endpoint***

The relative risk to the floodplain biodiversity endpoint showed an increasing trend in risk from Class A to Class D (Figure 96). The results for Class A was zero to low risk with SD extending into low risk range. The results for Classes B and C revealed moderate risk with SD extending into moderate risk range for Class B and the high risk range for Class C. The results for Class D revealed moderate to high risk with SD extending into the high risk range. The probability of high risk (>50%) to the endpoint for Class D (Figure 97).

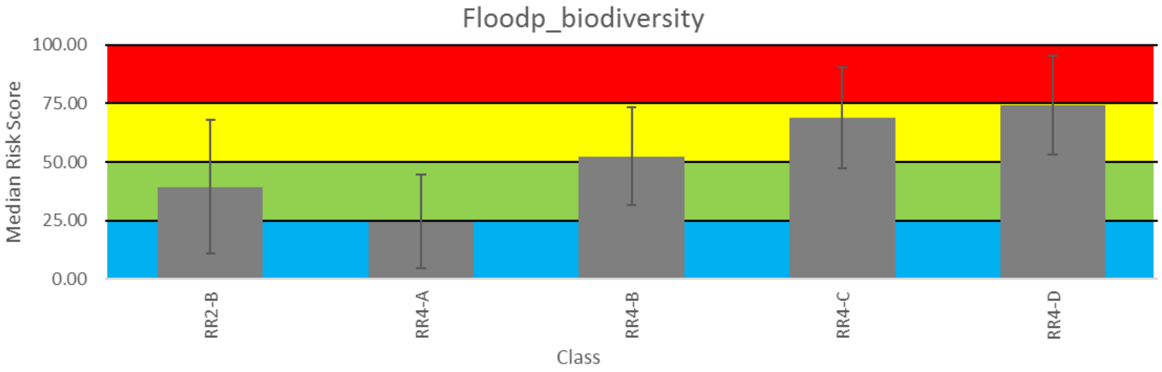


**Figure 96: Relative Risk (median, with standard deviation) of multiple stressors associated with eflow scenarios to Floodplain biodiversity endpoint considered in the study (Class A (A), Class B (B), Class C (C) and Class (D)). Risk rank ranges for Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) risk included.**

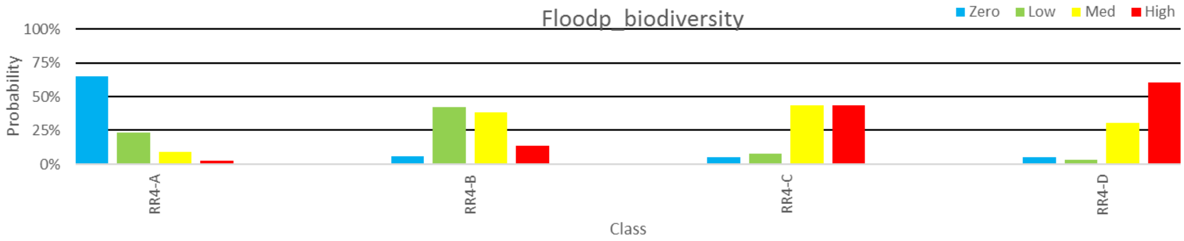


**Figure 97: Probability of risk rank occurrence for ranks Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) of multiple stressors associated with eflow scenarios to Floodplain biodiversity endpoint considered in the study.**

***River biodiversity endpoint***

The relative risk to the floodplain biodiversity endpoint showed an increasing trend in risk from Class A to Class D (Figure 98). The results revealed low risk for Classes A-D, with SD extending into the moderate risk range. No high risk (>50%) was revealed to the riverine biodiversity for this RR (Figure 99).

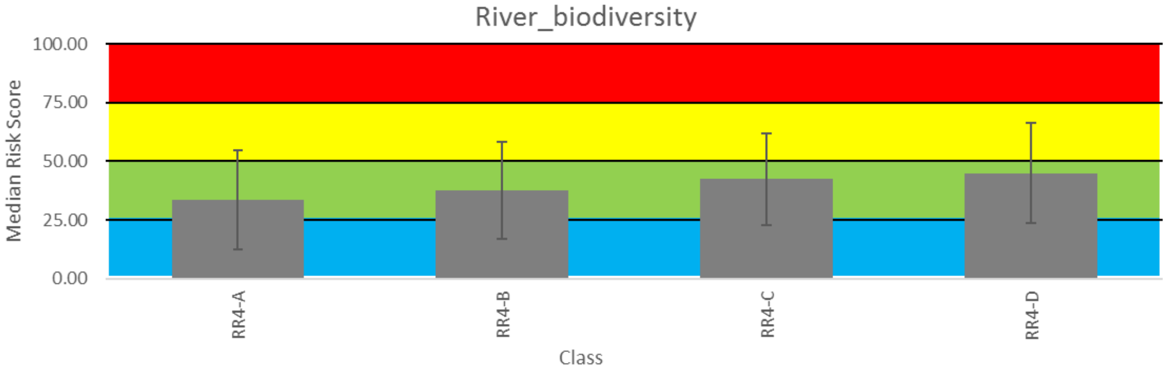


**Figure 98: Relative Risk (median, with standard deviation) of multiple stressors associated with eflow scenarios to River biodiversity endpoint considered in the study (Class A (A), Class B (B), Class C (C) and Class (D)). Risk rank ranges for Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) risk included.**

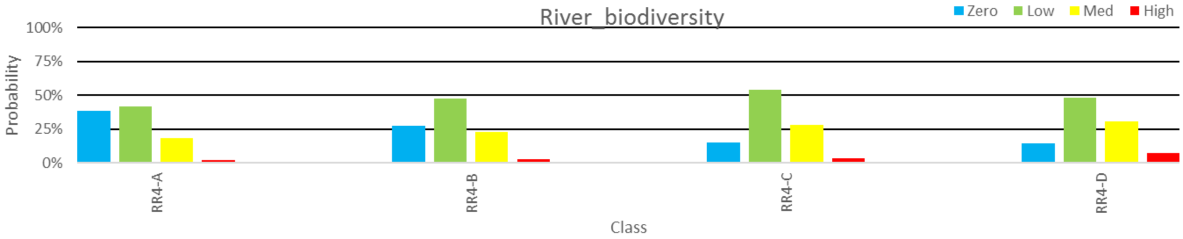


**Figure 99: Probability of risk rank occurrence for ranks Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) of multiple stressors associated with eflow scenarios to River biodiversity endpoint considered in the study.**

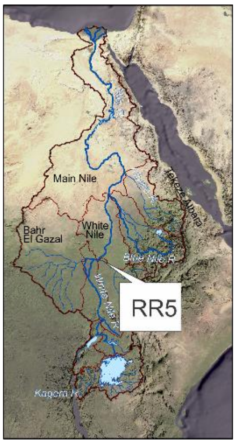
### 4.4.3 Conclusion for RR4

Low flows (dry and wet base flows) are important for the river and should be provided to ensure adequate habitats to maintain the ecology of the river. It is also important to note that the river is perennial and that the 99.9 percentile flow specified for each month provides for non-zero flows. Thus, any future operation of the system or water resource developments should accommodate the minimum flow requirements.

Results include increasing risk to endpoints as the ecological wellbeing of the rivers deteriorate from reference states to Class B, C and D ecological categories. Similarly, there is a high variability in the resilience and associated risk of altered flows to different endpoints. This includes relatively higher risk to the floodplain biodiversity endpoint compared to the riverine biodiversity and the ecosystem services associated with the river and floodplain ecosystems. A probability of high risk (>45%) was recorded for Class D for the floodplain services endpoint and >50% probability of high risk for Class D for the floodplain biodiversity endpoint.

## 4.5 RR5 – Sobat River

The Baro and Pibor Rivers are tributaries of the Sobat River that joins the Bahr el Jebel River to form the White Nile (NBI, 2008). The Sobat River is characterised by high, seasonally variable, flows that originate from the Ethiopian Highlands (NBI, 2012). The river reach selected for the assessment is at Hillet Doleib, upstream of the confluence with the White Nile (Latitude 9.335111; longitude 31.588712).



### 4.5.1 Data Analysis

#### 4.5.1.1 Hydrology Assessment

The results are presented as tables showing the flow requirements for the highest and lowest flow month at selected percentile values and the annual flood requirements in terms of discharge, months when required and the duration in days. The hydrographs indicate the reference and base flows compared to the EFR. Flow duration curves (FDCs) per RR for selected months are also presented.

The Sobat River is a tributary of the White Nile with the confluence close to Malakal on the White Nile. The record period at the site is from 1906-1982 with a Reference MAR of 13 651 MCM. The flow requirements for selected months and percentiles (low flows and floods) that were used to determine the EFR is summarised in Table 46 below.

Table 46: Selected flow requirements for RR5 – Sobat River

| | **Flow requirements ($m^3/s$) – low flows** | |
|---|---|---|
| **Percentiles** | **Apr** | **Nov** |
| 15 | - | 300 |
| 50 | 55 | 175 |
| 99.9 | 1.3 | 105 |

| | **Flow requirements– annual floods** | | |
|---|---|---|---|
| | **Sep** | **Oct** | **Nov** |
| Peak flows ($m^3/s$) | 470 | 470 | 675 |
| Duration (days) | 10 | 10 | 10 |

These selected requirements, together with the DRM were used to determine the EFR for each month. The results of the final EFR for RR5 is shown in Table 47 below.

Table 47: Final EFR for RR5 – Sobat River (flows in $m^3/s$)

| **RR5** | **Jan** | **Feb** | **Mar** | **Apr** | **May** | **Jun** | **Jul** | **Aug** | **Sep** | **Oct** | **Nov** | **Dec** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 195.48 | 115.41 | 74.79 | 72.35 | 96.24 | 146.11 | 207.74 | 265.23 | 302.12 | 314.06 | 330.79 | 283.16 |
| Minimum | 60.1 | 33.2 | 18.7 | 0.8 | 45.2 | 74.6 | 93.2 | 112.9 | 130.1 | 143.6 | 155.5 | 122.8 |
| Maximum | 246.9 | 155.8 | 107.7 | 100.4 | 104.0 | 160.8 | 260.9 | 337.7 | 410.5 | 367.3 | 384.0 | 335.8 |
| Percentiles | | | | | | | | | | | | |

| RR5 | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.1 | 246.9 | 155.8 | 107.7 | 100.4 | 104.0 | 160.8 | 260.9 | 337.7 | 410.5 | 367.3 | 384.0 | 335.8 |
| 1 | 246.9 | 155.8 | 107.7 | 100.4 | 104.0 | 160.8 | 260.9 | 337.7 | 410.5 | 367.3 | 384.0 | 335.8 |
| 5 | 246.9 | 155.8 | 107.7 | 100.4 | 104.0 | 160.8 | 260.9 | 337.7 | 410.5 | 367.3 | 384.0 | 335.8 |
| 10 | 246.9 | 155.8 | 107.7 | 100.4 | 104.0 | 160.8 | 260.2 | 333.7 | 405.8 | 367.3 | 384.0 | 335.8 |
| 15 | 246.9 | 155.8 | 107.7 | 100.4 | 104.0 | 160.8 | 254.4 | 328.7 | 396.8 | 367.3 | 384.0 | 335.8 |
| 20 | 246.8 | 155.7 | 107.7 | 100.4 | 104.0 | 160.8 | 249.9 | 321.6 | 383.6 | 367.2 | 384.0 | 335.7 |
| 30 | 244.8 | 154.3 | 99.0 | 100.1 | 103.8 | 160.1 | 237.8 | 305.9 | 361.4 | 365.0 | 381.6 | 332.8 |
| 40 | 239.6 | 146.6 | 85.1 | 99.2 | 103.5 | 159.0 | 231.2 | 293.3 | 340.1 | 360.8 | 376.5 | 327.1 |
| 50 (median) | 228.3 | 126.2 | 78.4 | 74.5 | 103.1 | 156.6 | 222.1 | 280.8 | 320.9 | 351.2 | 367.5 | 315.0 |
| 60 | 208.1 | 104.5 | 69.4 | 62.3 | 102.3 | 152.2 | 205.5 | 255.1 | 285.3 | 333.1 | 348.4 | 285.8 |
| 70 | 176.7 | 93.3 | 60.2 | 51.6 | 100.9 | 142.9 | 192.2 | 238.6 | 256.5 | 295.9 | 318.0 | 250.9 |
| 80 | 128.0 | 74.7 | 47.6 | 43.7 | 92.3 | 129.5 | 161.7 | 204.4 | 214.1 | 244.8 | 258.0 | 215.2 |
| 85 | 104.6 | 60.4 | 41.1 | 40.4 | 86.5 | 126.6 | 148.4 | 186.6 | 192.9 | 215.3 | 230.0 | 209.7 |
| 90 | 87.7 | 45.7 | 33.6 | 37.4 | 76.6 | 120.8 | 141.5 | 181.0 | 186.8 | 201.8 | 221.8 | 200.3 |
| 95 | 71.4 | 37.3 | 23.5 | 30.2 | 55.9 | 104.9 | 126.2 | 173.2 | 168.6 | 182.3 | 197.8 | 174.8 |
| 99 | 64.9 | 33.8 | 19.1 | 1.2 | 45.5 | 74.6 | 93.2 | 112.9 | 130.1 | 143.6 | 155.5 | 131.3 |
| 99.9 | 60.6 | 33.2 | 18.7 | 0.8 | 45.2 | 74.6 | 93.2 | 112.9 | 130.1 | 143.6 | 155.5 | 123.7 |

The summary of the EFR for RR5 (Table 48) shows that 46.2% of the flows in the Sobat River is required for ecological functioning, with the low flows (flows occurring more than 50% of the time) making up the bulk of the requirement at 33.2% and floods 13.0% of the ecological requirement. Thus, low flows are important for the Sobat River and should be provided to ensure adequate habitats to maintain the ecology of the river. It is also important to note that the river is perennial and although the minimum flows for April can be a little as 1 $m^3/s$, no zero flows occur. It is important that the 99.9 percentile flow specified for each month are provided. Thus, any future operation of the system or water resource developments should accommodate the minimum flow requirements.

As the river shows a distinct dry and wet season, with the peak flows in September, October and November, drought flows were specified separately to the maintenance low flows.

**Table 48: Summary of final EFR for RR5 – Sobat River**

| RR | River | Reference (MCM) | % Requirement | | | | Volume Requirement (MCM) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Low flows | Drought flows | Floods | Total | Low flows | Drought flows | Floods | Total |
| RR5 | Sobat | 13 651 | 33.2 | 18.1 | 13.0 | 46.2 | 4 524 | 2 462 | 1 769 | 6 294 |

The monthly hydrograph of the REF, BF and EFR for a B state for the Sobat River is shown in Figure 100. This indicates that the EFR is close to the base flows for the dry season (see also FDC for April - Figure 101 ). However, the EFR is higher in the wet season as the system requires floods for the maintenance of ecological integrity as also shown in the FDC for November (Figure 102).

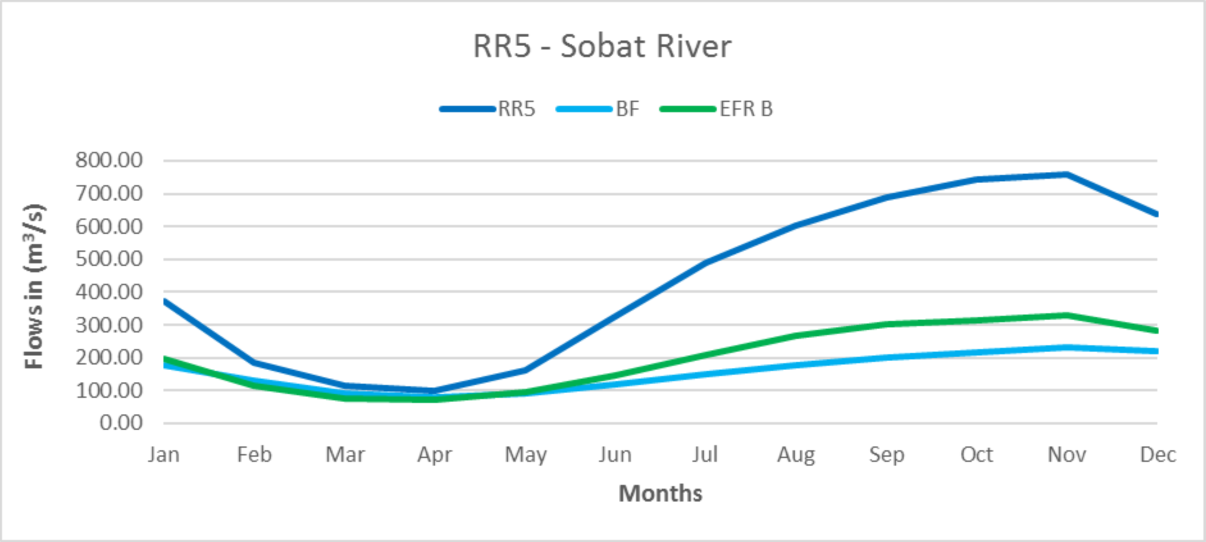


Figure 100: Monthly hydrograph for RR5 – Sobat River

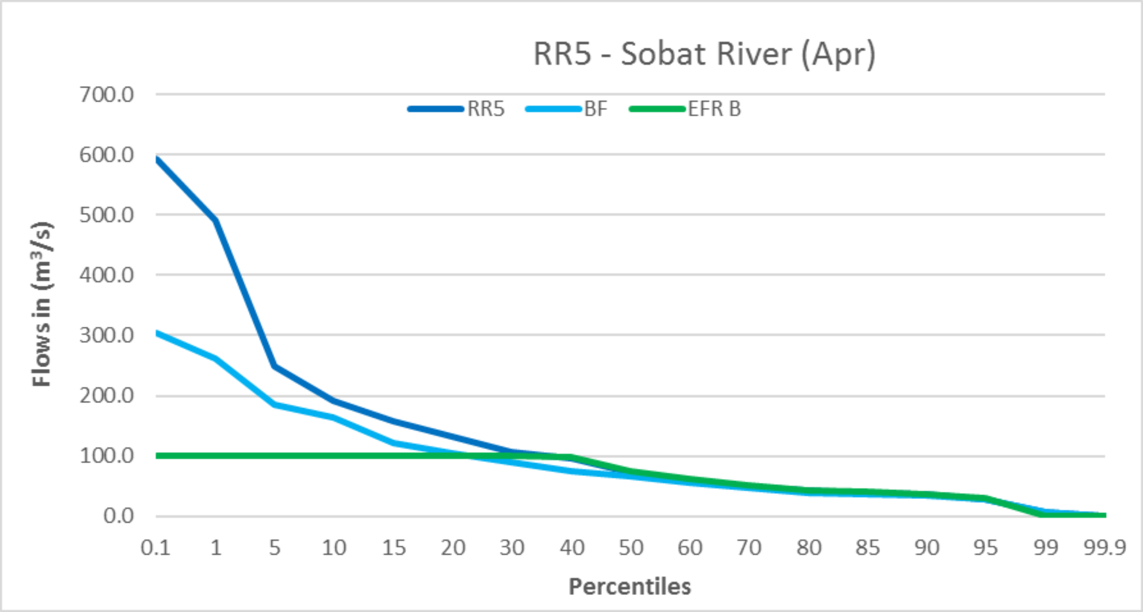


Figure 101: Flow duration curve for April (low flows) in RR5 – Sobat River

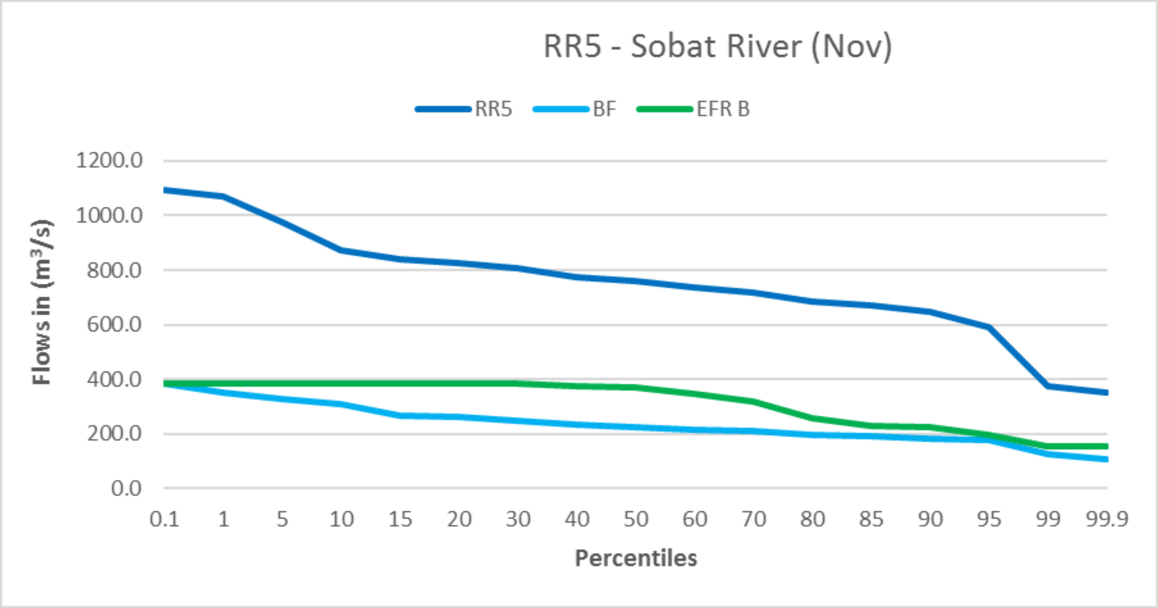


Figure 102: Flow duration curve for November (wet season) in RR5 – Sobat River

### 4.5.1.2 Hydraulic Assessment

It must be noted, that the 1.5yr return period flow is only approximately depicting bankfull flow conditions. Therefore, additional cross section characteristics were investigated from which information about inundation extent and frequency could be deduced. These descriptions are briefly given for the points of interest. Each point of interest is individually assessed using QGIS with the Profile Tool and Quick Map Services Plugin on the MERIT DEM and Google Satellite images. The site location and ID (yellow dot with number, corresponds to the IDs given in Table 49) is shown together with the cross section location (red line) on satellite images (Google Earth/Digital Globe). Below the images, the diagram shows the cross section (elevation along the red line), where the small red dot in the upper satellite images is marked by the centre of the cross line in the lower diagram. Numbers in the diagram show elevation in mASL (y-Axis) and distance from left in meters (x-axis).

Table 49. Points of interest, the applied methodology for obtaining the channel cross section and additional channel and cross section properties

| ID | River | Latitude | Longitude | Channel bathymetry method | Bank width [m] | Ineffective area elevation [mASL] | Slope [m/m] |
|---|---|---|---|---|---|---|---|
| RR5 | Sobat | 9.3016 | 31.6577 | Bankfull | 187 | -- | 0.000089 |

Figure 103 shows that no distinct settlement is located near the point of interest. Channel bed incision will therefore be calibrated based on bankfull flow and hydraulic information available from the Nile basin Volumes. Calibrated flow velocities and water depths are within the ranges given in the data. Final calibrated channel incision was 5.7m and Mannings n values set to 0.06 due to the vegetated floodplains (Figure 104).

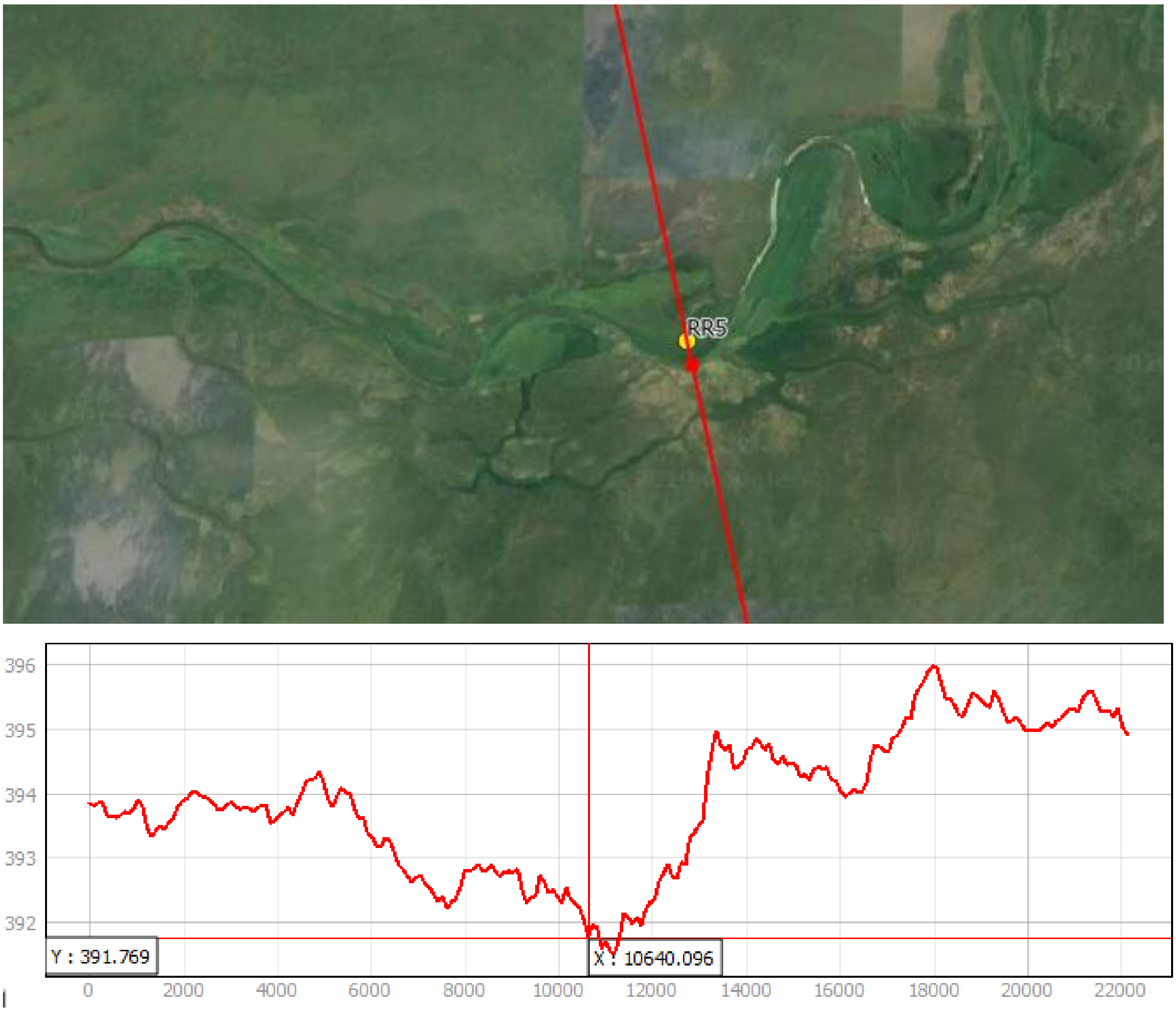


Figure 103. Sobat cross section near Hillet Doleib based on the DEM

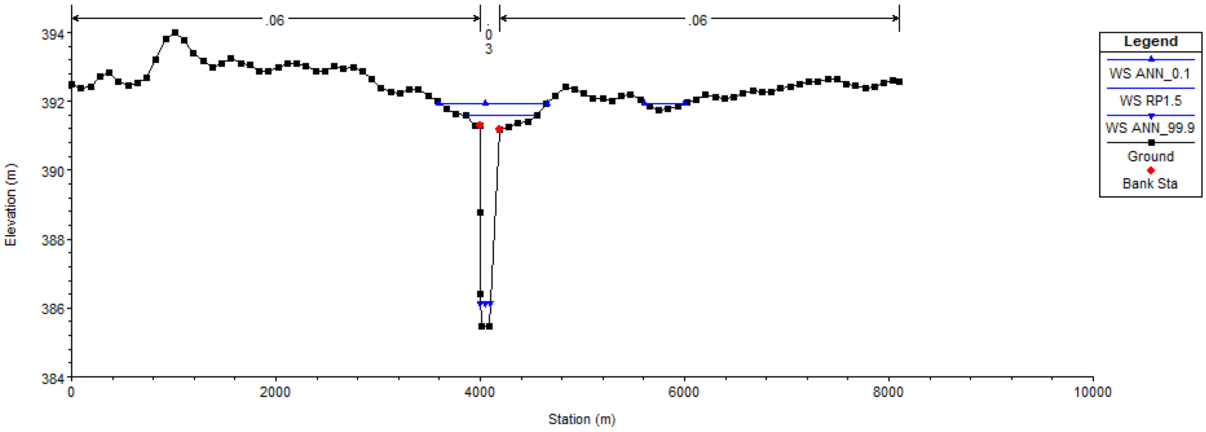


Figure 104: Cross sectional profile of the hydraulic site for RR5

### 4.5.1.3 Vegetation Assessment

This risk region is represented by the Sobat River upstream of its confluence with the White Nile near Hillet Doleib, with the cross section shown as a red line in Figure 105. Vegetation at this site is sparse to absent (Figure 105 and Figure 106), is dominated by non-woody components representative of the Grassland ecoregion within which it occurs (mainly *Cyperus, Typha* and *Oryza*), but has some influence from nearby Sahelian acacia savanna. The active channel averages 90m wide and meanders through some floodplain areas with multiple lateral drainage channels.

**Figure 105: Google Earth © satellite image at Hillet Doleib on the Sobat River upstream of the confluence with the White Nile, representing risk region 5.**

Figure 106: Photograph showing the Sobat River upstream of the confluence with the White Nile and lack of associated vegetation (photo courtesy of Google Earth).

Based on the available biological information at cross section sites, and together with hydraulics at each site, the driver components [within the model] were quantified for a B-category (Table 50) as determined by discernible riparian indicators (Table 51). Interpolation was frequently required due to lack of biological data specific to sites.

Table 50: Quantification of driver components for a B-category system (Values are discharge).

| **General description** | | **RR5** |
|---|---|---|
| Bank full for non-woody fringe vegetation | Wet Base | 270 |
| Wet base less 1m in elevation | Dry Base | 110 |
| Wet base less 1.5m in elevation | Critical Low | 45 |
| Between woody and non-woody limits | Freshette | 470 |
| To the base of woody vegetation (Tall tree line) | Annual flood | 675 |

Table 51: Riparian indicators utilized to quantify driver components for a B-category system.

| **RR5** | **channel width (m)** | **Discharge** | **Chan depth** | **Month** | **Indicators** |
|---|---|---|---|---|---|
| Wet Base | 150 | 270 | 2.8 | Aug | Reeds & low shrub |
| Dry Base | 110 | 110 | 1.8 | Mar | Reeds & low shrub |
| Critical Low | 110 | 45 | 1.3 | Mar | Reeds & low shrub |
| Freshette | | 470 | | Sep-Oct | Flood reeds |
| Annual flood | 450 | 675 | 4.1 | Sep | Tall tree line |

### Defining Risk to Vegetation

The alteration of driver dynamics, in this case flows and by implication floods, results in risk to the vegetation. Optimal driver state results in low risk to all vegetation endpoints but does not consider the effects of non-flow related impacts, such as ever increasing grazing and trampling pressures, and the impacts of human density and resource use. However, as flows may decline so the risk to vegetation endpoints increases. This risk has been described and quantified for each of the response variables (Table 52), as well as for each of the response variables within different risk regions, and represents declining ecological health or ecosystem wellbeing.

Table 52: Justifications and driver quantification for interaction of vegetation components within the model.

| Bayesian Network variable title, measure - (BN node name) | Rank (score) | Rank definition and measure for variable | RR5 |
|---|---|---|---|
| Aveghab_R_bwet | Zero (25) | 10% higher percentile than B] base | > 330 |
| | Low (50) | bank full for non-woody vegetation | 330 - 270 |
| | Moderate (75) | between [B] dry base and [B] wet base | 270 - 110 |
| | High (100) | as low as normal (B) dry base | < 110 |
| FPveg_FP_bwet | Zero (25) | 10% higher percentile than B] base | > 330 |
| | Low (50) | bank full for non-woody vegetation | 330 - 270 |
| | Moderate (75) | between [B] dry base and [B] wet base | 270 - 110 |
| | High (100) | as low as normal (B) dry base | < 110 |
| Aveghab_R_drought | Zero (25) | 95% [B] dry season max month | > 45 |
| | Low (50) | crtical low flows for [B] | 45 - 37 |
| | Moderate (75) | 99% dry season max | 37 - 20 |
| | High (100) | | < 20 |
| Aveghab_R_bdry | Zero (25) | wet base | > 270 |
| | Low (50) | wet base less 1m | 270 - 110 |
| | Moderate (75) | critical low | 110 - 45 |
| | High (100) | critical low | < 45 |
| FPveg_FP_flood | Zero (25) | to the base of woody vegetation (Tall tree line):annual | > 675 |
| | Low (50) | between woody and non-woody limits: freshette | 675 - 470 |
| | Moderate (75) | no flood: 20% higher than wet base percentile | 470 - 365 |
| | High (100) | | < 365 |
| Subveg_R_bdry | Zero (25) | wet base | > 270 |
| | Low (50) | wet base less 1m | 270 - 110 |
| | Moderate (75) | critical low | 110 - 45 |
| | High (100) | critical low | < 45 |
| Subveg_R_bwet | Zero (25) | 10% higher percentile than B] base | > 330 |
| | Low (50) | bank full for non-woody vegetation | 330 - 270 |
| | Moderate (75) | between [B] dry base and [B] wet base | 270 - 110 |
| | High (100) | as low as normal (B) dry base | < 110 |
| Subveg_FP_bdry | Zero (25) | wet base | > 270 |
| | Low (50) | wet base less 1m | 270 - 110 |
| | Moderate (75) | critical low | 110 - 45 |
| | High (100) | critical low | < 45 |
| Subveg_FP_bwet | Zero (25) | 10% higher percentile than B] base | > 330 |
| | Low (50) | bank full for non-woody vegetation | 330 - 270 |
| | Moderate (75) | between [B] dry base and [B] wet base | 270 - 110 |
| | High (100) | as low as normal (B) dry base | < 110 |

### 4.5.1.4 Fish Assessment

For the determination of instream flow requirements for the Sobat River nine species of fishes that have habitat and or migratory requirements that occur within the river were selected for the assessment (Table 53). Based on the relative size species attains and biology and ecology information the depth and velocity requirements were determined as well as minimum depths to maintain lateral and longitudinal migrations for these indicator species. This information was aligned to the seasonal flows of the system and used to establish flow requirements that were provided to the hydrologist to determine eflow requirements (Figure 105, Figure 106 and Figure 109). Interestingly, the seasonality of flows observed are as variable as RR4 but the peak flow period shifts almost two months earlier than RR4, upstream of this site.

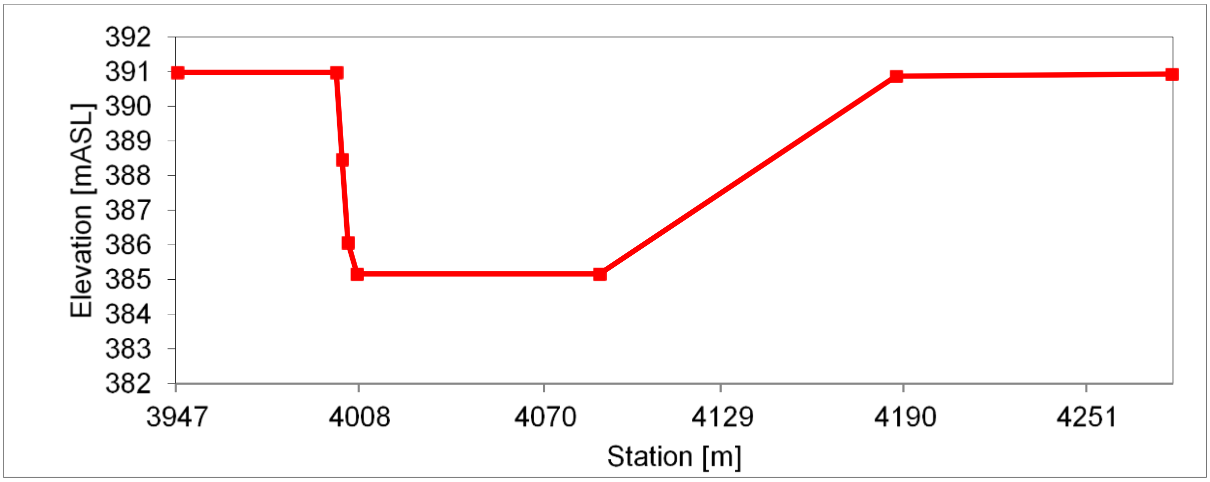


Table 53: Fishes selected to determine eflows for RR5. Hypothesised preferences for habitats (depth and velocity) and migratory notes provided for each species.

| Min. Depth (mm) | Min. Vel (m/s) | Weight | Sobat River indicator spp. | Details |
|---|---|---|---|---|
| 450 | 0.8 | 3 | *Polypterus sp.* | Limnophillic/floodplain species long.↑↑ & lat. Potamodromous migrations. |
| 1000 | 1.2 | 3 | *Labeo sp.* | Good rheophillic species long.↑↑ & lat. Potamodromous migrations. |
| 1200 | 1 | 3 | *Alestes sp.* | Good rheophillic species long.↑↑ & lat. Potamodromous migrations. |
| 2000 | 0.8 | 3 | *Hydrocynus sp.* | Good rheophillic species long.↑↑ & lat. Potamodromous migrations. |
| 1200 | 0.8 | 2 | *Bagrus spp.* | Semi-rheophillic species long.↑↑ & lat. Potamodromous migrations. |
| 650 | 0.2 | 2 | *Oreochromis sp.* | Lotic, limnophillic/floodplain species long.↑↑ & lat. Potamodromous migrations. |
| 1200 | 0.5 | 2 | *Distichodus sp.* | Semi-rheophillic species long.↑↑ & lat. Potamodromous migrations. |
| 1200 | 0.6 | 1 | *Clarias gariepinus* | Lotic, limnophillic/floodplain species long.↑↑ & lat. Potamodromous migrations. |
| 1600 | 0.2 | 1 | *Heterobranchus sp.* | Limnophillic/floodplain species long.↑↑ & lat. Potamodromous migrations. |

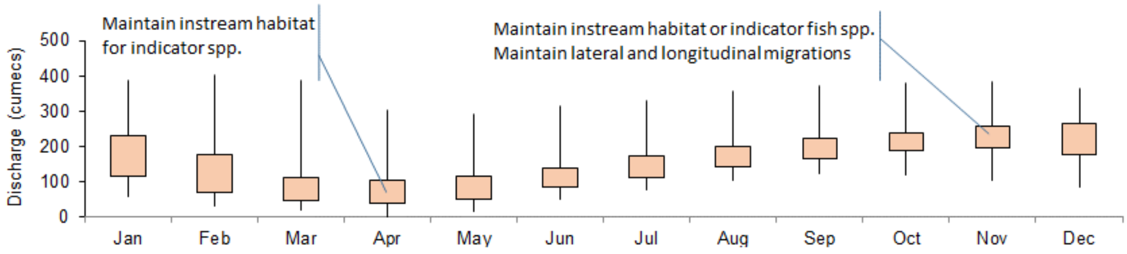


Figure 107: Reference hydrograph from RR5 with key fish biology and ecology requirements.

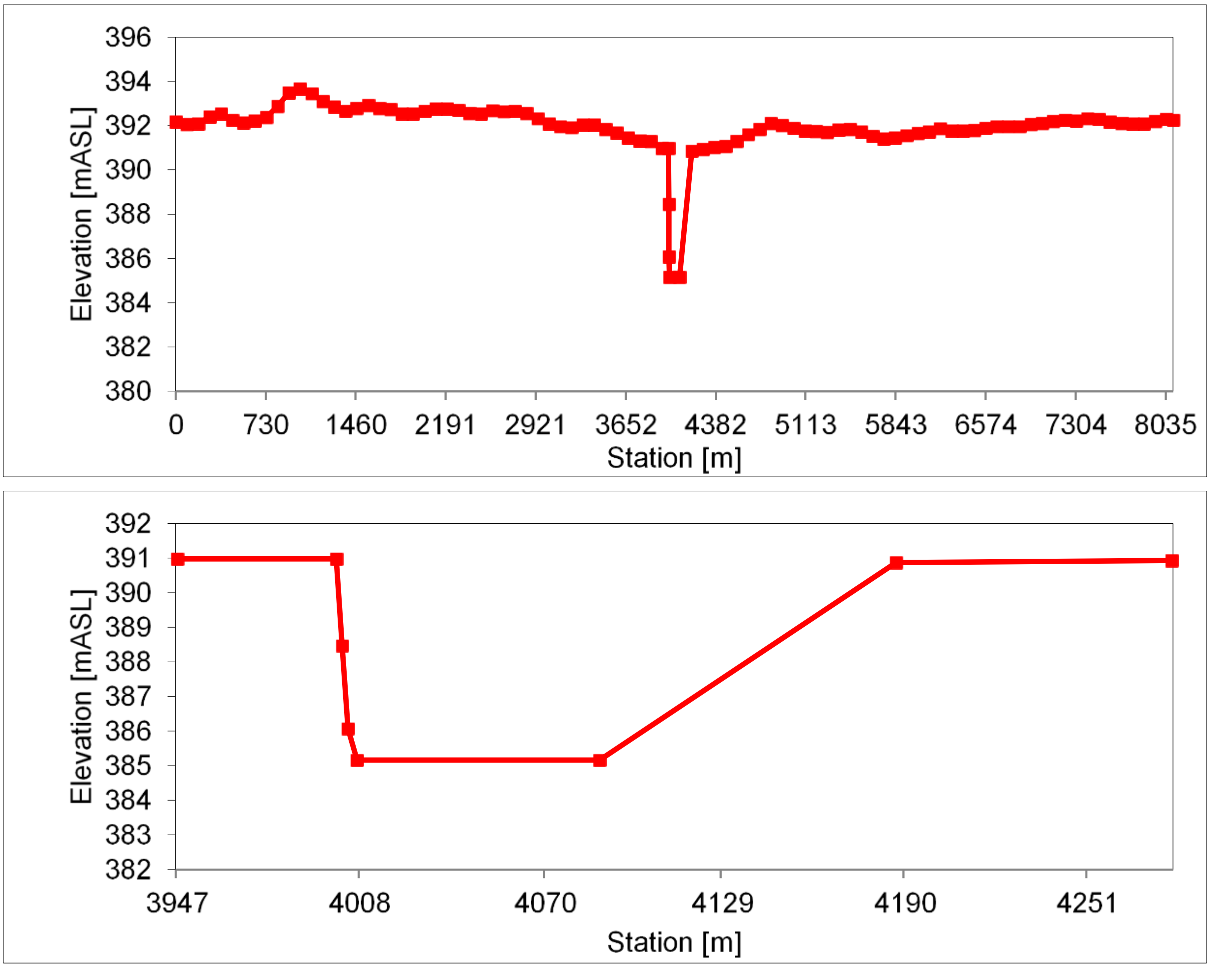


Figure 108: Cross section of RR5 with flow elevations highlighted for key fish biology and ecology events selected in the study for eflow determination.

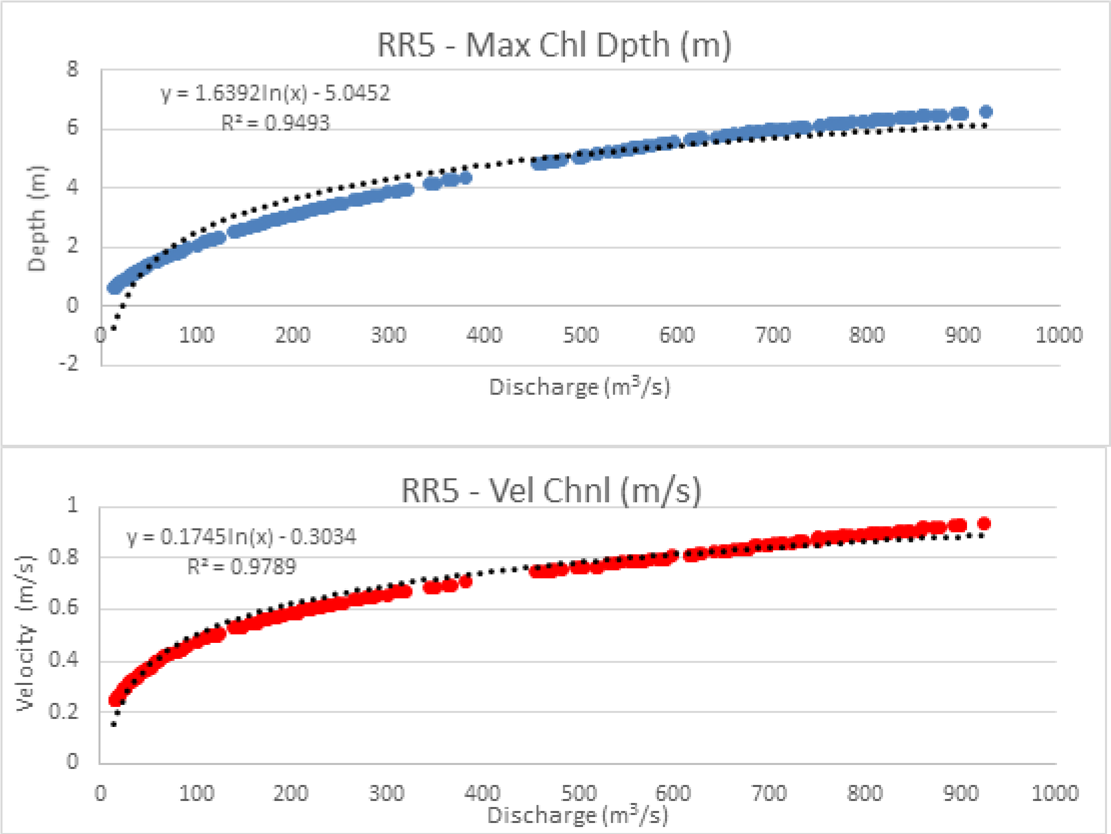


Figure 109: Flow depth (Blue) and Velocity depth (Red) relationships established for the study used to determine flow requirements for fishes.

### 4.5.2 Calculate Risk

Following the determination of flows to maintain the ecosystems associated with each site in each ecological category a summary of the flow requirements associated with these scenarios is generated (Table 54). These hydrographs were used in the risk assessment as scenarios to compare the socio-ecological consequences of altered flows associated with each scenario (ecological category).

Table 54: Summary of the floods required to provide for key socio-ecological processes in the Nile River per ecological category Class considered in the study.

| **RR** | **River** | **Flow Component** | **Percentage EFR per Ecological Class** | | |
|---|---|---|---|---|---|
| | | | **B** | **C** | **D** |
| 5 | Sobat River | Drought flows | 18% | 9% | 7% |
| | | Maintenance (or base) flows Low (or dry) period | 33% | 15% | 7% |
| | | Maintenance (or base) flows high (or wet) period | 13% | 4% | 2% |
| | | **Total** | **46%** | **19%** | **9%** |

The reference hydrographs and median flows for ecological categories B, C and D considered in the risk assessment for RR5 – Sobat River are graphically presented in Figure 110 and Figure 111. The rank thresholds for indicators selected for this site were used to query this hydrology data and evaluate the socio-ecological consequences of altered flows in the system using PROBFLO.

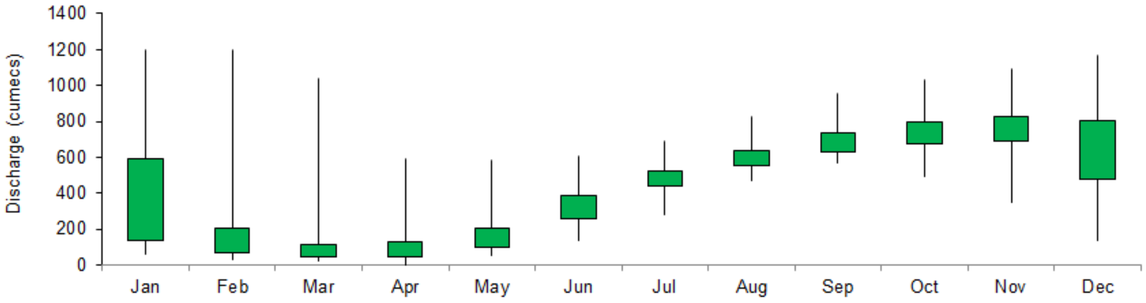


**Figure 110: Box and whisker plot summary of the reference (Class A) average monthly (m³/s) flows observed in RR5 in the study. Whiskers represent 0.01%tiles and 99.9%tiles and box 20%tile and 80%tiles.**

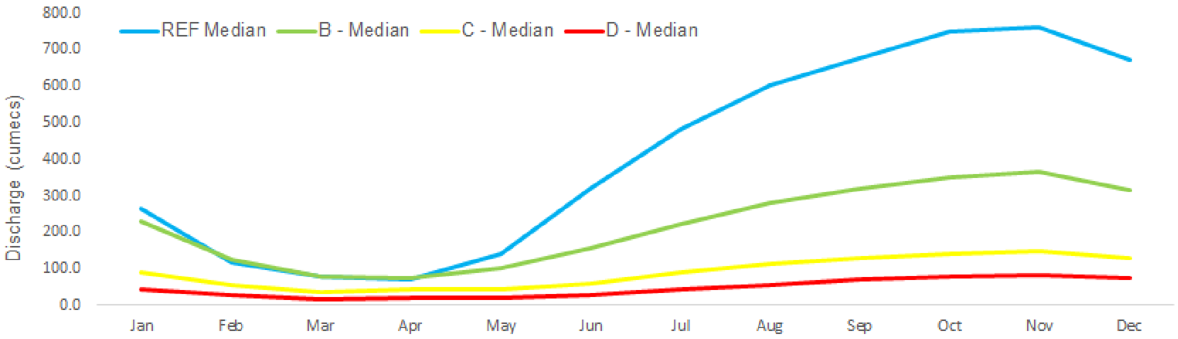


**Figure 111: Relative graphs (medians) of the reference (Class A or pristine), Class B (near natural), Class C (moderately modified) and Class D (largely modified) average monthly flows (m³/s) flows observed in RR5 in the study. Whiskers represent 0.01%tiles and 99.9%tiles and box 20%tile and 80%tiles.**

Risk outcomes directly obtained from the Netica Bayesian Network assessment are presented per RR with averages, standard deviation (SD) and risk rank probability profiles.

### *Floodplain ecosystem services endpoint*

The relative risk to the floodplain ecosystem serves endpoint showed an increasing trend in risk from Class A to Class D (Figure 112). The results for Class A revealed a low risk and for Class B a low to moderate risk with SD extending into the moderate risk range for both these Classes. The results for Class C and D revealed moderate to high risk with SD extending into the high risk range. From Figure 113, results include a >50% possibility of high risk to the floodplain services for Class C and D.

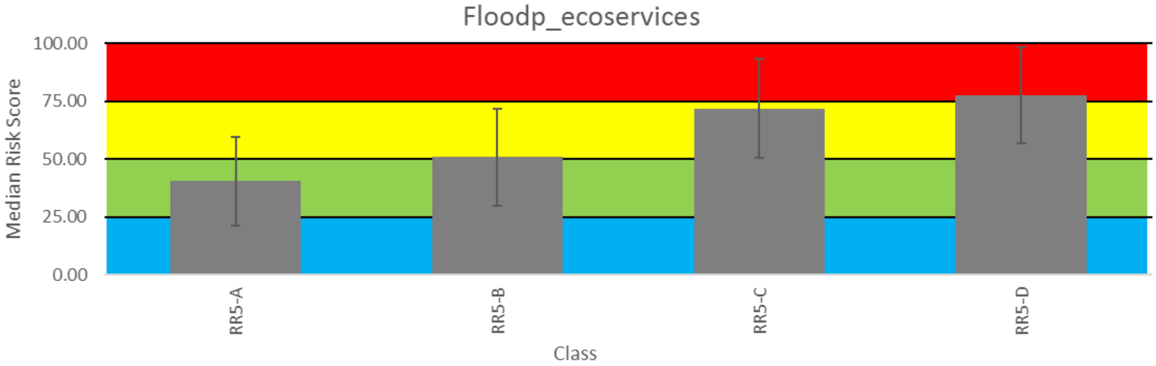


**Figure 112: Relative Risk (median, with standard deviation) of multiple stressors associated with eflow scenarios to Floodplain ecosystem services endpoint considered in the study (Class A (A), Class B (B), Class C (C) and Class (D)). Risk rank ranges for Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) risk included.**

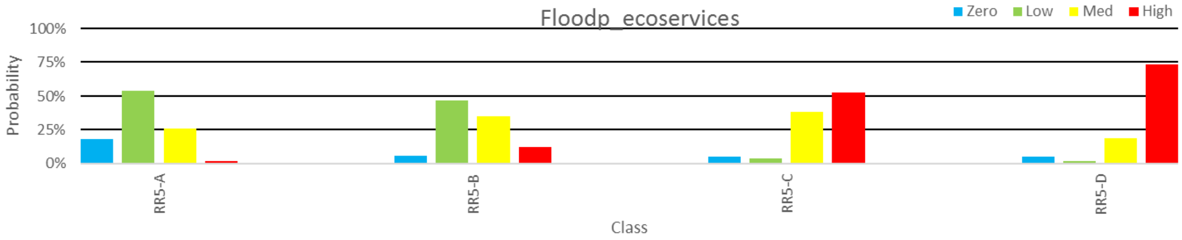


**Figure 113: Probability of risk rank occurrence for ranks Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) of multiple stressors associated with eflow scenarios to Floodplain ecosystem services endpoint considered in the study.**

### *River ecosystem services endpoint*

The relative risk to the river ecosystem services endpoint showed an increasing trend in risk from Class A to Class D (Figure 114). The results for Class A revealed low risk and for Class B, low to moderate risk with the SD for both Classes extending into the moderate risk range. The results for Class C revealed moderate risk and for Class D moderate to high risk with the SD for both Classes extending into the high risk ranges. Results in Figure 115 includes probabilities of high risk (>45%) for Class D.

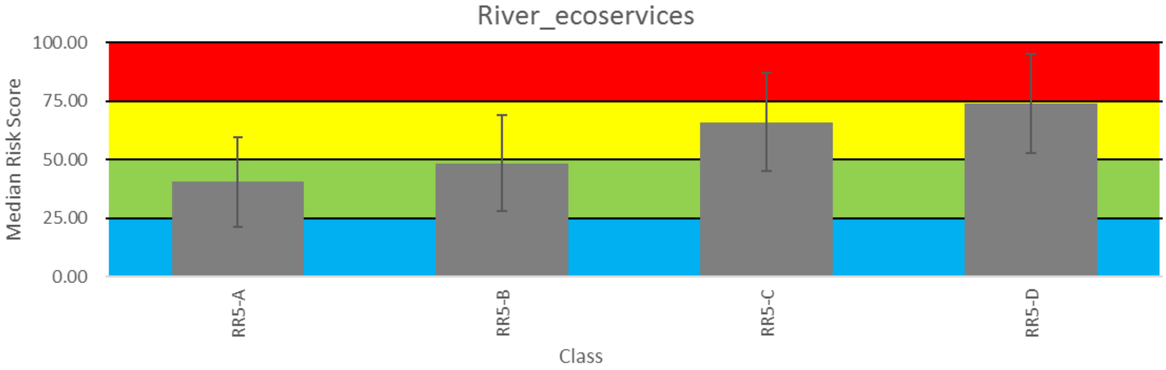


**Figure 114: Relative Risk (median, with standard deviation) of multiple stressors associated with eflow scenarios to River ecosystem services endpoint considered in the study (Class A (A), Class B (B), Class C (C) and Class (D)). Risk rank ranges for Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) risk included.**

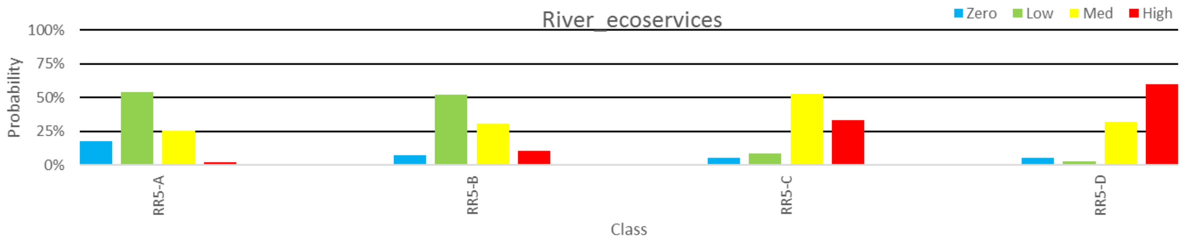


**Figure 115: Probability of risk rank occurrence for ranks Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) of multiple stressors associated with eflow scenarios to River ecosystem services endpoint considered in the study.**

### *Floodplain biodiversity endpoint*

The relative risk to the floodplain biodiversity endpoint showed an increasing trend in risk from Class A to Class D (Figure 116). The results for Class A revealed zero to low risk with the SD extending into the low risk range. Class B revealed low to moderate risk with the SD extending into the moderate risk range. The results for Class C and D revealed moderate to high risk with SD extending into the high risk range. The probability of high risk (>50%) to the endpoint was seen for Class C and D (Figure 117).

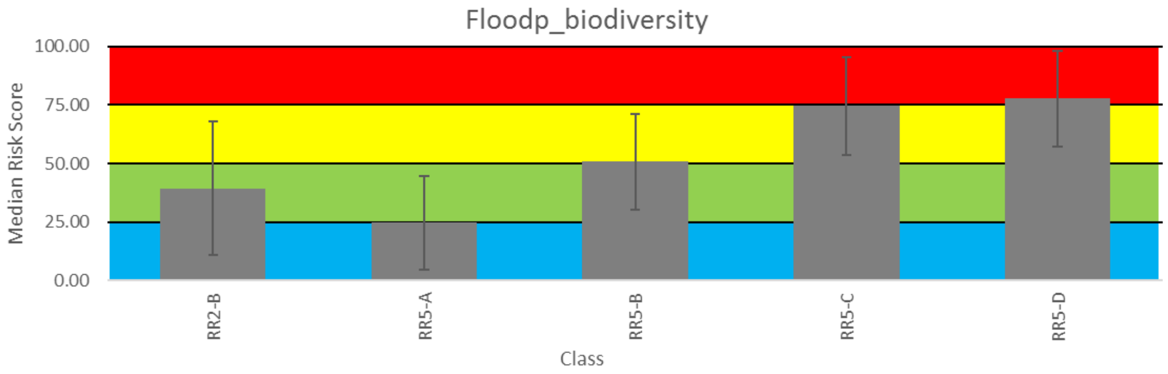


**Figure 116: Relative Risk (median, with standard deviation) of multiple stressors associated with eflow scenarios to Floodplain biodiversity endpoint considered in the study (Class A (A), Class B (B), Class C (C) and Class (D)). Risk rank ranges for Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) risk included.**

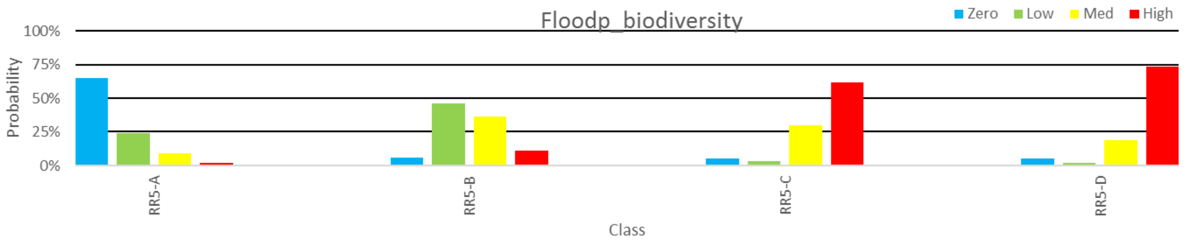


**Figure 117: Probability of risk rank occurrence for ranks Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) of multiple stressors associated with eflow scenarios to Floodplain biodiversity endpoint considered in the study.**

### *River biodiversity endpoint*

The relative risk to the floodplain biodiversity endpoint showed an increasing trend in risk from Class A to Class D (Figure 118). The results revealed low risk for Classes A and B, with SD extending into the moderate risk range. The results for Class C revealed low to moderate risk and for Class D moderate risk with SD for both Classes extending into the high risk range. High risk (>45%) to the riverine biodiversity was apparent for Class D (Figure 119).

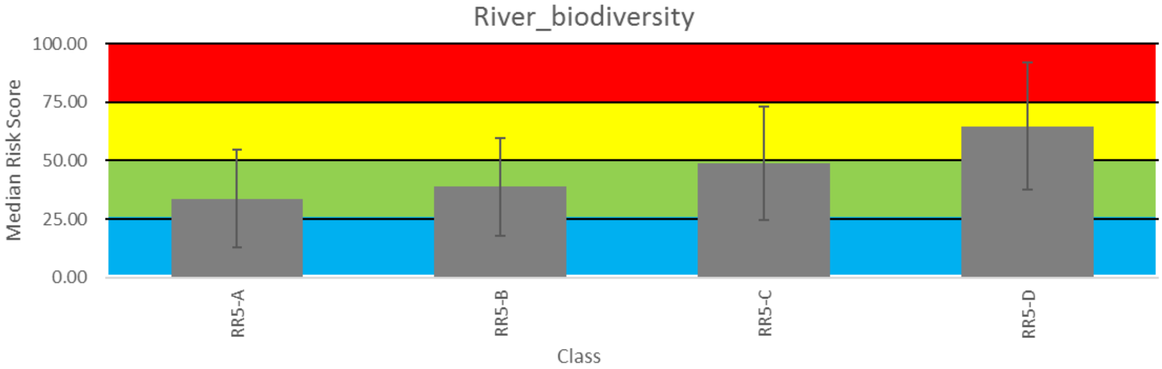


Figure 118: Relative Risk (median, with standard deviation) of multiple stressors associated with eflow scenarios to River biodiversity endpoint considered in the study (Class A (A), Class B (B), Class C (C) and Class (D)). Risk rank ranges for Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) risk included.

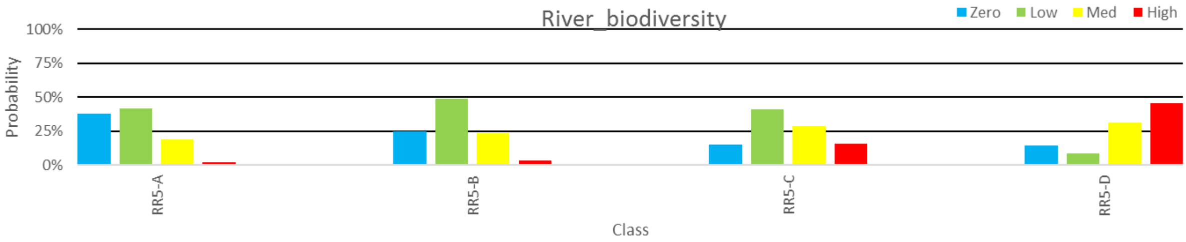


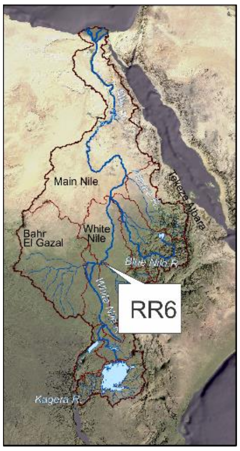
Figure 119: Probability of risk rank occurrence for ranks Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) of multiple stressors associated with eflow scenarios to River biodiversity endpoint considered in the study.

### 4.5.3 Conclusion for RR5

Low flows are important for the Sobat River and should be provided to ensure adequate habitats to maintain the ecology of the river. It is also important to note that the river is perennial and although the minimum flows for April can be a little as 1 $m^3$/s, no zero flows occur. It is important that the 99.9 percentile flow specified for each month are provided. Thus, any future operation of the system or water resource developments should accommodate the minimum flow requirements.

Results include increasing risk to endpoints as the ecological wellbeing of the rivers deteriorate from reference states to Class B, C and D ecological categories. Similarly, there is a high variability in the resilience and associated risk of altered flows to different endpoints. This includes relatively higher risk to the floodplain biodiversity endpoint compared to the riverine biodiversity and the ecosystem services associated with the river and floodplain ecosystems. A probability of high risk (>50%) was recorded for Class C and D for the floodplain services and biodiversity endpoints and >45% probability of high risk for Class D for the river services and biodiversity endpoints.

## 4.6 RR6 – White Nile River



The White Nile originates at the confluence of the Bahr el Jebel and Sobat Rivers above Malakal and flows northwards and joins the Blue Nile at Khartoum to form the Main Nile River (NBI, 2012). The White Nile only contributes about 15% percent of the annual Nile discharge with not much seasonal variation (NBI, 2012). The river reach selected for the assessment is at Malakal, upstream of Jebel Aulia (Latitude 9.538513; longitude 31.643643).

### 4.6.1 Data Analysis

#### 4.6.1.1 Hydrology Assessment

The results are presented as tables showing the flow requirements for the highest and lowest flow month at selected percentile values and the annual flood requirements in terms of discharge, months when required and the duration in days. The hydrographs indicate the reference and base flows compared to the EFR and include the reference flows for the period before 1960. Flow duration curves (FDCs) per RR for selected months are also presented.

This reach of river is just downstream of the confluence of the Sobat River at Malakal and has flows for the period 1928-2006. This record period was split in 1962 due to the upwards 'shift' in the outflows from Lake Victoria in the early 1960s. The final record period upon which the EFR is based is from 1963-2006 with a Reference MAR of 32 043 MCM.

Similar to RR3, the monthly hydrograph is very 'flat' (see graph) with very little difference in wet and dry season. However, November was selected as the high flow month and April as the low flow month. The flow requirements for these selected months and percentiles that were used to determine the EFR is summarised in Table 55 below.

Table 55: Selected flow requirements for RR6 – White Nile River

| | **Flow requirements ($m^3/s$) – low flows** | |
|---|---|---|
| **Percentiles** | **Apr** | **Nov** |
| 15 | - | 800 |
| 50 | 450 | 600 |
| 99.9 | 270 | 430 |

| | **Flow requirements– annual floods** | | |
|---|---|---|---|
| | **Sep** | **Oct** | **Nov** |
| Peak flows ($m^3/s$) | 1 450 | 1 450 | 1 540 |
| Duration (days) | 30 | 28 | 28 |

These selected requirements, together with the DRM were used to determine the EFR for each month. The results of the final EFR for RR6 is shown in Table 56 below.

Table 56: Final EFR for RR6 – White Nile River (flows in m$^3$/s)

| RR6 | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 655.37 | 537.17 | 492.71 | 486.25 | 521.64 | 591.74 | 683.57 | 783.82 | 874.70 | 880.28 | 884.49 | 789.46 |
| Minimum | 388.0 | 378.0 | 339.1 | 332.1 | 329.5 | 354.4 | 367.3 | 388.1 | 416.4 | 425.2 | 437.1 | 416.6 |
| Maximum | 769.5 | 605.3 | 545.0 | 540.2 | 587.2 | 652.5 | 836.9 | 976.8 | 1186.7 | 1302.1 | 1314.3 | 1313.3 |
| Percentiles | | | | | | | | | | | | |
| 0.1 | 769.5 | 605.3 | 545.0 | 540.2 | 587.2 | 652.5 | 836.9 | 976.8 | 1186.7 | 1290.1 | 1301.7 | 1296.4 |
| 1 | 769.5 | 605.3 | 545.0 | 540.2 | 587.2 | 652.5 | 836.9 | 976.8 | 1186.7 | 1182.2 | 1188.9 | 1144.2 |
| 5 | 769.5 | 605.3 | 545.0 | 540.2 | 587.2 | 652.5 | 836.9 | 976.8 | 1186.7 | 1023.4 | 1022.7 | 920.0 |
| 10 | 769.5 | 605.3 | 545.0 | 540.2 | 587.2 | 652.5 | 833.7 | 962.6 | 1152.0 | 1023.4 | 1022.7 | 920.0 |
| 15 | 769.5 | 605.3 | 545.0 | 540.2 | 587.2 | 652.5 | 820.1 | 950.6 | 1145.7 | 1023.4 | 1022.7 | 920.0 |
| 20 | 769.3 | 605.2 | 544.6 | 540.2 | 587.1 | 652.4 | 803.7 | 929.8 | 1109.8 | 1023.4 | 1022.7 | 920.0 |
| 30 | 763.8 | 600.5 | 543.0 | 538.1 | 583.2 | 650.3 | 780.1 | 894.2 | 1044.2 | 1018.2 | 1017.5 | 912.5 |
| 40 | 753.9 | 595.3 | 538.5 | 532.9 | 579.0 | 646.2 | 755.8 | 861.3 | 983.4 | 1005.2 | 1002.9 | 899.1 |
| 50 (median) | 729.6 | 580.3 | 529.0 | 524.3 | 567.2 | 636.5 | 714.3 | 820.2 | 909.1 | 968.8 | 969.4 | 863.3 |
| 60 | 668.1 | 548.2 | 509.7 | 500.4 | 545.5 | 622.5 | 675.7 | 749.0 | 809.5 | 924.6 | 917.6 | 796.8 |
| 70 | 606.0 | 508.2 | 481.2 | 474.4 | 505.5 | 590.1 | 642.2 | 714.8 | 751.7 | 835.6 | 842.1 | 704.9 |
| 80 | 498.2 | 442.5 | 430.1 | 425.6 | 444.8 | 527.7 | 574.9 | 620.0 | 636.7 | 700.0 | 682.7 | 582.7 |
| 85 | 458.8 | 422.8 | 395.1 | 389.1 | 410.3 | 492.3 | 512.6 | 582.2 | 563.3 | 593.3 | 616.7 | 568.1 |
| 90 | 429.3 | 405.3 | 377.9 | 370.0 | 380.4 | 454.9 | 477.6 | 567.0 | 551.9 | 548.7 | 575.8 | 550.2 |
| 95 | 402.5 | 385.8 | 354.0 | 347.0 | 346.7 | 397.9 | 410.9 | 551.2 | 508.5 | 507.2 | 525.4 | 510.0 |
| 99 | 390.3 | 379.9 | 339.1 | 333.6 | 332.0 | 363.3 | 380.1 | 456.6 | 425.7 | 443.0 | 461.6 | 418.7 |
| 99.9 | 388.2 | 378.2 | 339.1 | 332.3 | 329.7 | 355.3 | 368.6 | 394.9 | 417.3 | 427.0 | 439.5 | 416.8 |

The summary of the EFR for RR6 (Table 57) shows that 64% of the flows in this reach is required for ecological functioning, with the low flows (flows occurring more than 50% of the time) making up the bulk of the requirement and floods only 16.8% of the ecological requirement. Thus, low flows (dry and wet base flows) are important for the White Nile River and should be provided to ensure adequate habitats to maintain the ecology of the river. It is also important to note that the river is perennial and that the 99.9 percentile flow specified for each month provides for non-zero flows. Thus, any future operation of the system or water resource developments should accommodate the minimum flow requirements.

Table 57: Summary of final EFR for RR6 – White Nile River

| **RR** | **River** | **Reference (MCM)** | **% Requirement** | | | | **Volume Requirement (MCM)** | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | **Low flows** | **Drought flows** | **Floods** | **Total** | **Low flows** | **Drought flows** | **Floods** | **Total** |
| RR6 | White Nile | 32 043 | 47.5 | Not specified | 16.8 | 64.3 | 15 209 | Not specified | 5 382 | 20 592 |

The monthly hydrograph of the REF, BF, flows for 1928-1961 (Sc) and EFR for a B state for the White Nile River is shown in Figure 120. This indicates that the EFR is close to the flows for the period before the upward 'shift' during the lower flow months (also see FDC for April - Figure 121), but the higher flow months (Figure 122) are much lower than before the 1960s.

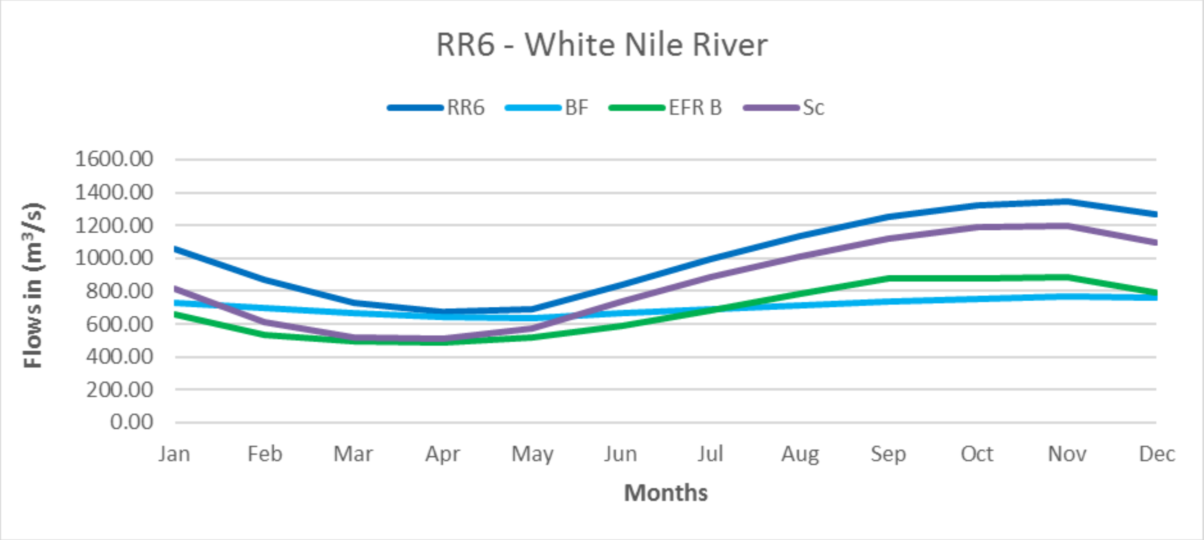


Figure 120: Monthly hydrograph for RR6 – White Nile River

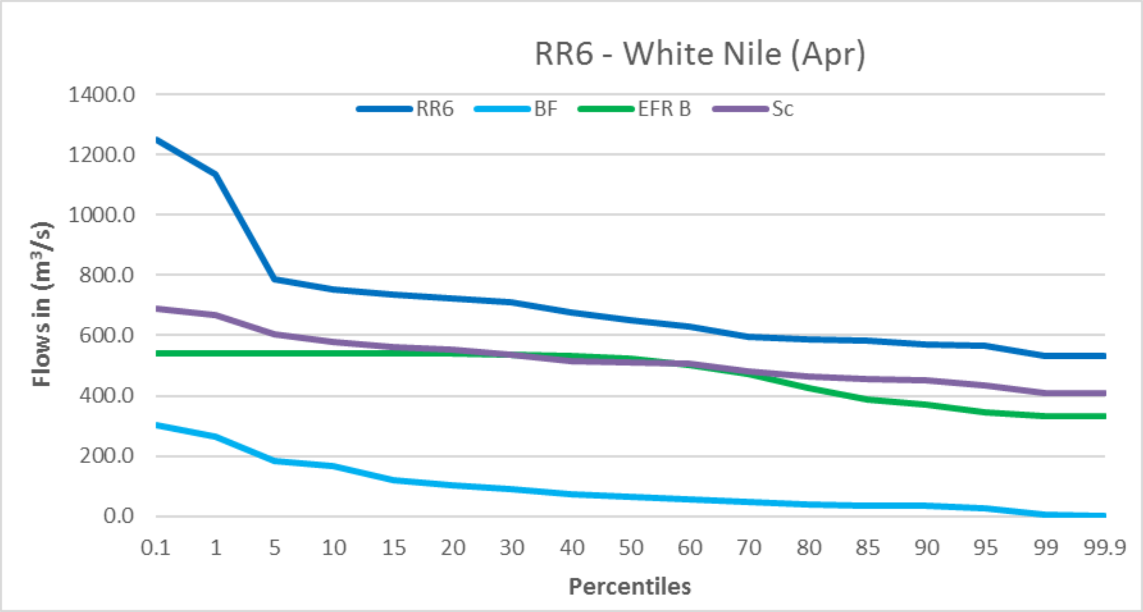


Figure 121: Flow duration curve for April (low flows) in RR6 – White Nile River

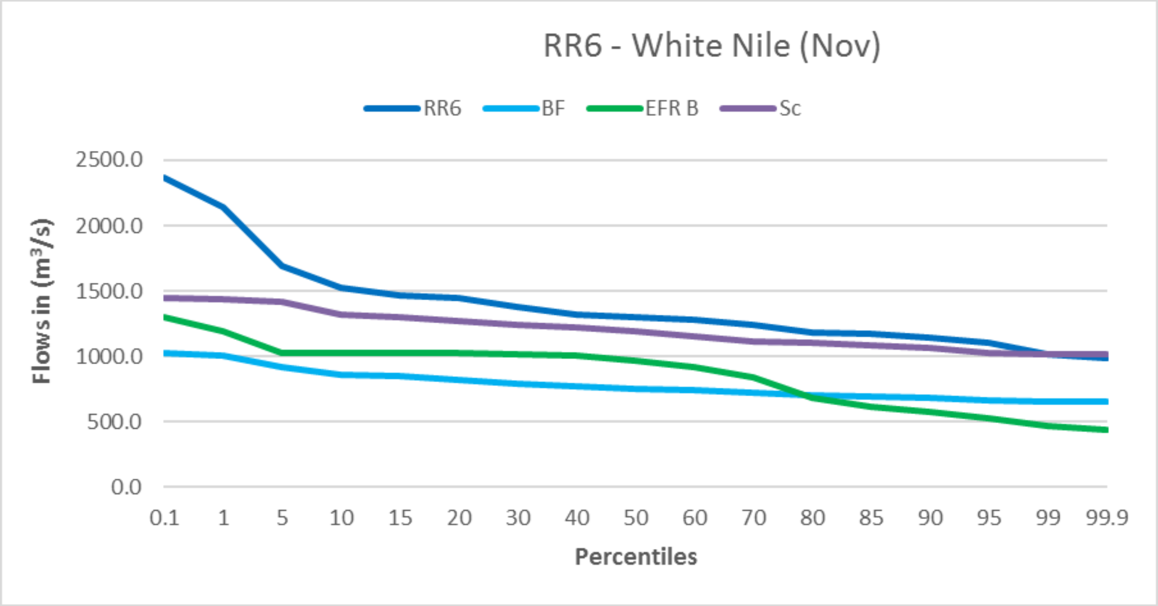


Figure 122: Flow duration curve for November (wet season) in RR6 – White Nile River

### 4.6.1.2 Hydraulic Assessment

It must be noted, that the 1.5yr return period flow is only approximately depicting bankfull flow conditions. Therefore, additional cross section characteristics were investigated from which information about inundation extent and frequency could be deduced. These descriptions are briefly given for the points of interest. Each point of interest is individually assessed using QGIS with the Profile Tool and Quick Map Services Plugin on the MERIT DEM and Google Satellite images. The site location and ID (yellow dot with number, corresponds to the IDs given in Table 58Table 49) is shown together with the cross section location (red line) on satellite images (Google Earth/Digital Globe). Below the images, the diagram shows the cross section (elevation along the red line), where the small red dot in the upper satellite images is marked by the centre of the cross line in the lower diagram. Numbers in the diagram show elevation in mASL (y-Axis) and distance from left in meters (x-axis).

Table 58. Points of interest, the applied methodology for obtaining the channel cross section and additional channel and cross section properties

| ID | River | Latitude | Longitude | Channel bathymetry method | Bank width [m] | Ineffective area elevation [mASL] | Slope [m/m] |
|---|---|---|---|---|---|---|---|
| RR6 | White Nile | 9.6592 | 31.7477 | Bankfull | 270 | -- | 0.000050 |

Figure 123 and Figure 124 shows the cross section at Malakal. No additional survey data is available. The satellite image shows, that dense settlements are located directly near the riverbank. It is hence expected that flooding is mostly below the 390m contour line. This and hydraulic information available from the Nile Basin Volumes was used to calibrate the model. Calibrated flow velocities and water depths are within the ranges given in the Nile Basin Volumes data. The channel at Malakal was deepened by 4m and roughness values in the floodplains set to 0.05 and 0.07 due to the vegetated areas.

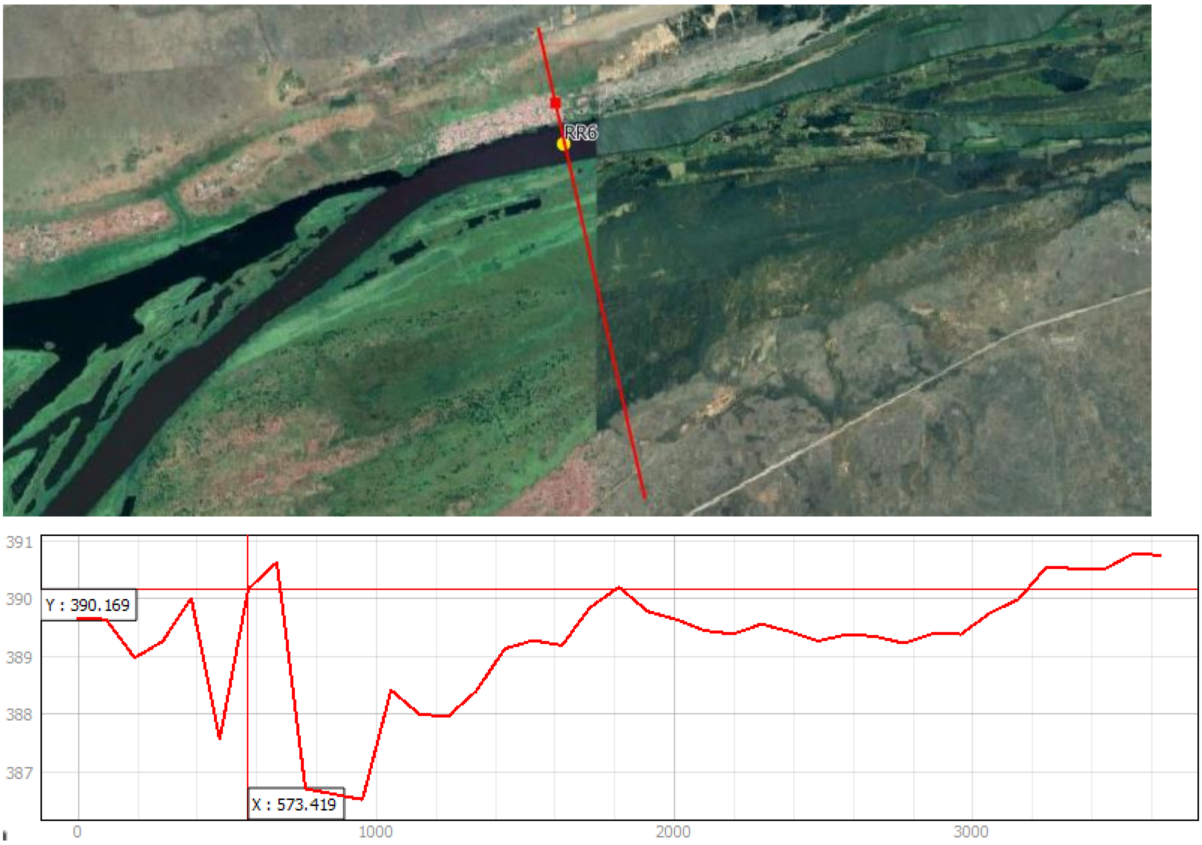


Figure 123: Malakal cross section with settlements approximately at elevation 390mASL

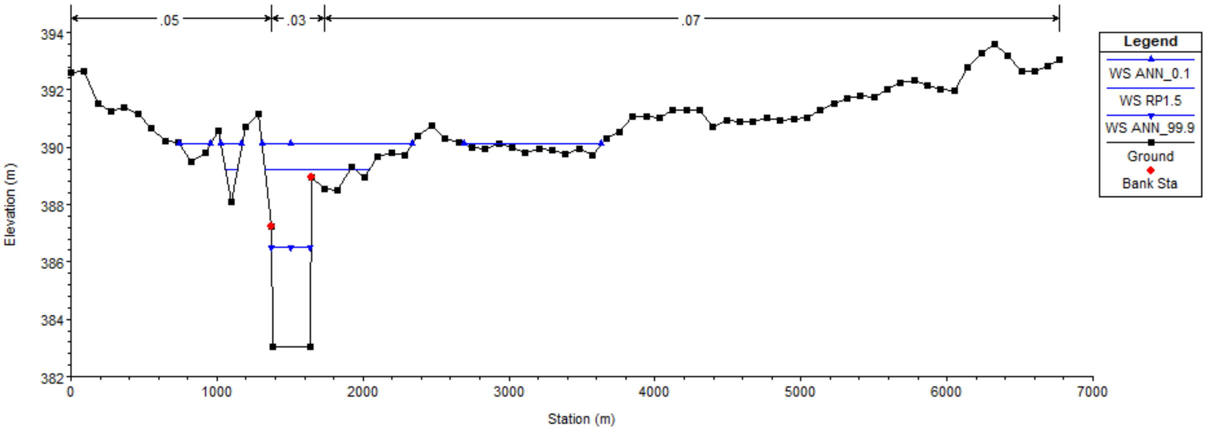


Figure 124: Cross sectional profile of the hydraulic site for RR6

### 4.6.1.3 Vegetation Assessment

This risk region is represented by the White Nile upstream of Jebel Aulia at Malakal with the cross section shown as a red line in Figure 125. Vegetation at this site displays both woody and non-woody components, but is dominated by non-woody species including several hydrophytes (Figure 125 and Figure 126). The active channel, which averages 280-300m wide has a distinckt linear woody component, but with a more extensive lower zone / wet bank dominated by flood dependent non-woody species such as Phragmites, Cyperus, Oyza, Juncus and Typha, and with open water and back flooded areas. Several aquatic plants are also represented, including Trapa and Potamogeton. The area is extensively utilised for agricultural activities, which will include grazing of livestock and growing wild rice.

Figure 125: Google Earth © satellite image at Malakal on the White Nile upstream of Jebel Aulia representing risk region 6.

Figure 126: Photograph showing the White Nile upstream of Jebel Aulia and associated vegetation near Malakal (photo courtesy of Google Earth).

Based on the available biological information at cross section sites, and together with hydraulics at each site, the driver components [within the model] were quantified for a B-category (Table 59) as determined by discernible riparian indicators (Table 60). Interpolation was frequently required due to lack of biological data specific to sites.

Table 59: Quantification of driver components for a B-category system (Values are discharge).

| General description | | RR6 |
|---|---|---|
| Bank full for non-woody fringe vegetation | Wet Base | 1005 |
| Wet base less 1m in elevation | Dry Base | 540 |
| Wet base less 1.5m in elevation | Critical Low | 420 |
| Between woody and non-woody limits | Freshette | 1450 |
| To the base of woody vegetation (Tall tree line) | Annual flood | 1540 |

Table 60: Riparian indicators utilized to quantify driver components for a B-category system.

| RR6 | channel width (m) | Discharge | Chan depth | Month | Indicators |
|---|---|---|---|---|---|
| Wet Base | 325 | 1005 | 5.3 | Sep-Oct | Reeds & low shrub |
| Dry Base | 270 | 540 | 4.2 | Apr | Reeds & low shrub |
| Critical Low | 260 | 420 | 3.6 | Apr | Reeds & low shrub |
| Freshette | 450 | 1450 | 6.4 | Aug-Nov | Flood reeds |
| Annual flood | 1240 | 1540 | 6.6 | Sep-Oct | Tall tree line |

### Defining Risk to Vegetation

The alteration of driver dynamics, in this case flows and by implication floods, results in risk to the vegetation. Optimal driver state results in low risk to all vegetation endpoints but does not consider the effects of non-flow related impacts, such as ever increasing grazing and trampling pressures, and the impacts of human density and resource use. However, as flows may decline so the risk to vegetation endpoints increases. This risk has been described and quantified for each of the response variables (Table 61), as well as for each of the response variables within different risk regions, and represents declining ecological health or ecosystem wellbeing.

Table 61: Justifications and driver quantification for interaction of vegetation components within the model.

| Bayesian Network variable title, measure - (BN node name) | Rank (score) | Rank definition and measure for variable | RR6 |
|---|---|---|---|
| Aveghab_R_bwet | Zero (25) | 10% higher percentile than B] base | > 1180 |
| | Low (50) | bank full for non-woody vegetation | 1180 - 1005 |
| | Moderate (75) | between [B] dry base and [B] wet base | 1005 - 540 |
| | High (100) | as low as normal (B) dry base | < 540 |
| FPveg_FP_bwet | Zero (25) | 10% higher percentile than B] base | > 1180 |
| | Low (50) | bank full for non-woody vegetation | 1180 - 1005 |
| | Moderate (75) | between [B] dry base and [B] wet base | 1005 - 540 |
| | High (100) | as low as normal (B) dry base | < 540 |
| Aveghab_R_drought | Zero (25) | 95% [B] dry season max month | > 420 |
| | Low (50) | critical low flows for [B] | 420 - 355 |
| | Moderate (75) | 99% dry season max | 355 - 333 |
| | High (100) | | < 333 |
| Aveghab_R_bdry | Zero (25) | wet base | > 1005 |
| | Low (50) | wet base less 1m | 1005 - 540 |
| | Moderate (75) | critical low | 540 - 420 |
| | High (100) | critical low | < 420 |
| FPveg_FP_flood | Zero (25) | to the base of woody vegetation (Tall tree line):annual | > 1540 |
| | Low (50) | between woody and non-woody limits: freshette | 1540 - 1450 |
| | Moderate (75) | no flood: 20% higher than wet base percentile | 1450 - 1025 |
| | High (100) | | < 1025 |
| Subveg_R_bdry | Zero (25) | wet base | > 1005 |
| | Low (50) | wet base less 1m | 1005 - 540 |
| | Moderate (75) | critical low | 540 - 420 |
| | High (100) | critical low | < 420 |
| Subveg_R_bwet | Zero (25) | 10% higher percentile than B] base | > 1180 |
| | Low (50) | bank full for non-woody vegetation | 1180 - 1005 |
| | Moderate (75) | between [B] dry base and [B] wet base | 1005 - 540 |
| | High (100) | as low as normal (B) dry base | < 540 |
| Subveg_FP_bdry | Zero (25) | wet base | > 1005 |
| | Low (50) | wet base less 1m | 1005 - 540 |
| | Moderate (75) | critical low | 540 - 420 |
| | High (100) | critical low | < 420 |
| Subveg_FP_bwet | Zero (25) | 10% higher percentile than B] base | > 1180 |
| | Low (50) | bank full for non-woody vegetation | 1180 - 1005 |
| | Moderate (75) | between [B] dry base and [B] wet base | 1005 - 540 |
| | High (100) | as low as normal (B) dry base | < 540 |

#### 4.6.1.4 Fish Assessment

For the determination of instream flow requirements for the White Nile River (South Sudan downstream of the Sudd) seven species of fishes that have habitat and or migratory requirements that occur within the river were selected for the assessment (Table 62). Based on the relative size species attains and biology and ecology information the depth and velocity requirements were determined as well as minimum depths to maintain lateral and longitudinal migrations for these indicator species. This information was aligned to the seasonal flows of the system and used to establish flow requirements that were provided to the hydrologist to determine eflow requirements (Figure 127, Figure 128 and Figure 129). At this site the influence of the aseasonal flows and retention capacity of the Sudd reduces seasonality of the flows observed at this site. Again, changes in seasonality would have serious consequences to the fish fauna of the reach.

Table 62: Fishes selected to determine eflows for RR6. Hypothesised preferences for habitats (depth and velocity) and migratory notes provided for each species.

| Min. Depth (mm) | Min. Vel (m/s) | Weight | White Nile River indicator spp. | Details |
|---|---|---|---|---|
| 1000 | 1.2 | 3 | *Labeo sp.* | Good rheophillic species long.↑↑ & lat. Potamodromous migrations. |
| 2000 | 0.8 | 3 | *Hydrocynus sp.* | Good rheophillic species long.↑↑ & lat. Potamodromous migrations. |
| 1200 | 0.8 | 2 | *Bagrus spp.* | Semi-rheophillic species long.↑↑ & lat. Potamodromous migrations. |
| 650 | 0.2 | 2 | *Oreochromis sp.* | Lotic, limnophillic/floodplain species long.↑↑ & lat. Potamodromous migrations. |
| 1200 | 0.5 | 2 | *Distichodus sp.* | Semi-rheophillic species long.↑↑ & lat. Potamodromous migrations. |
| 1600 | 0.2 | 1 | *Lates spp.* | Semi-rheophillic species long.↑↑ & lat. Potamodromous migrations. |
| 1200 | 0.6 | 1 | *Clarias gariepinus* | Lotic, limnophillic/floodplain species long.↑↑ & lat. Potamodromous migrations. |

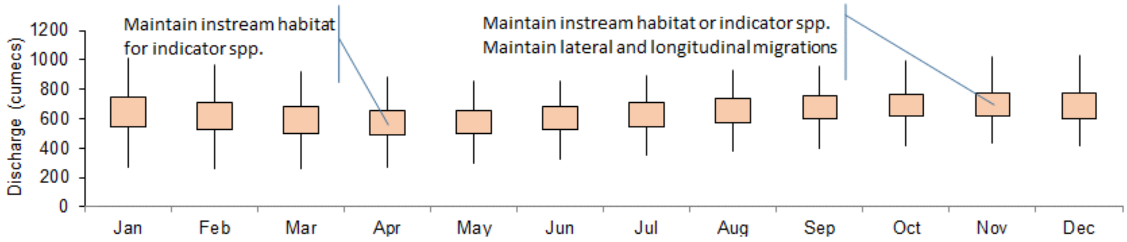


Figure 127: Reference hydrograph from RR6 with key fish biology and ecology requirements.

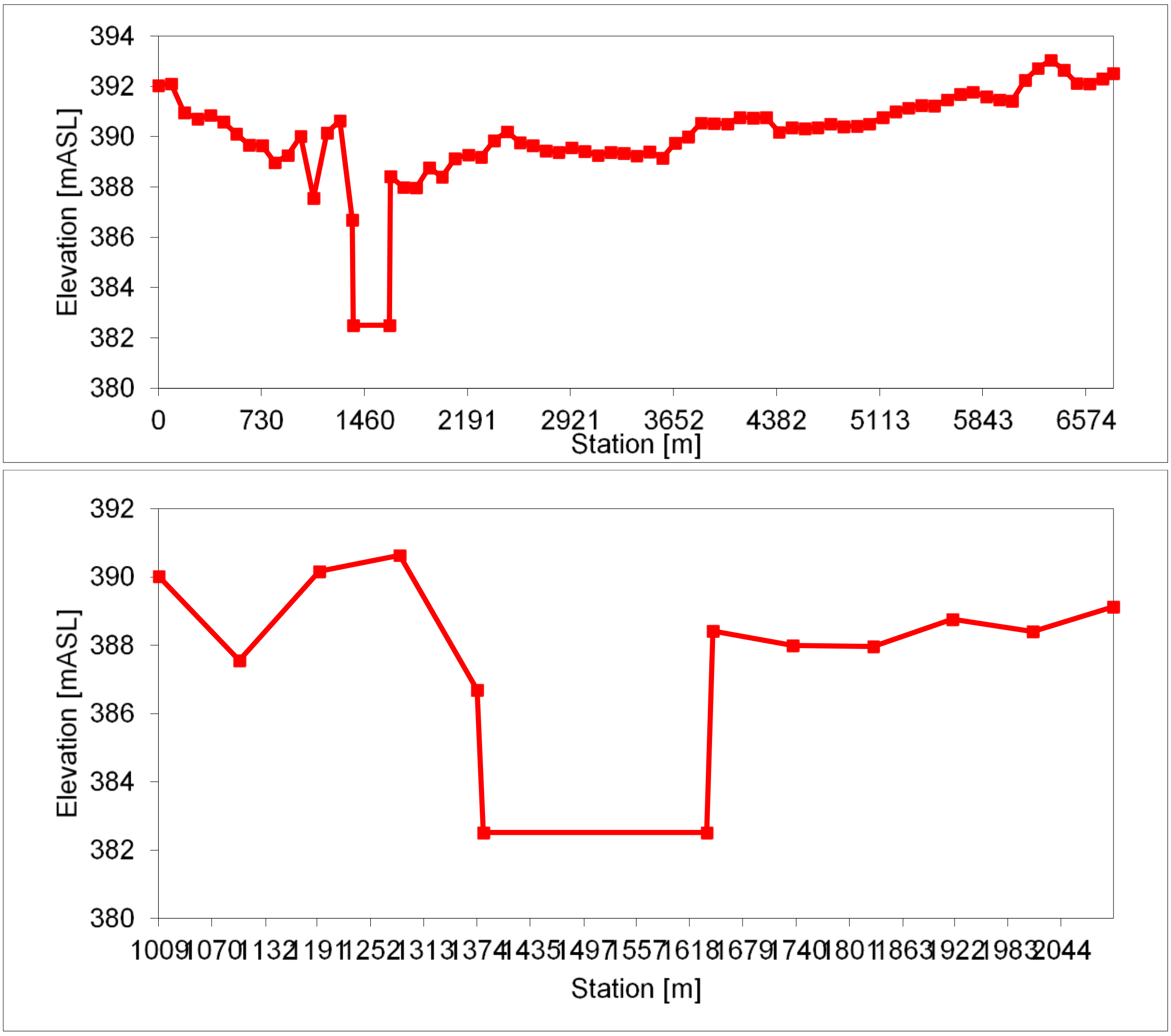
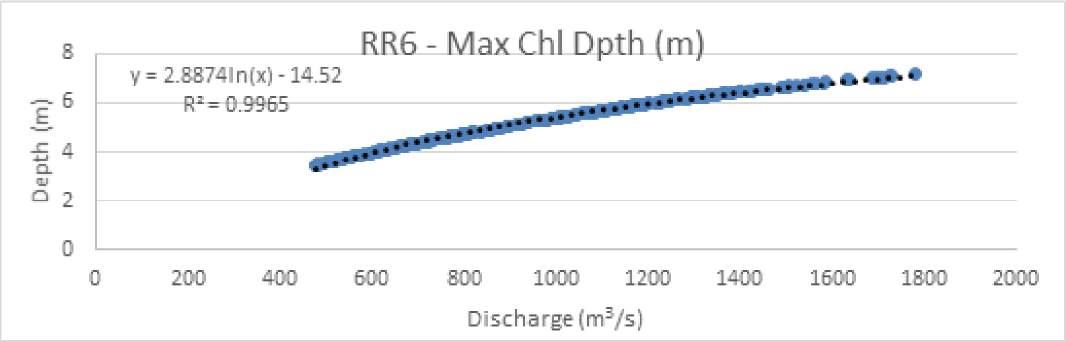


Figure 128: Cross section of RR6 with flow elevations highlighted for key fish biology and ecology events selected in the study for eflow determination.



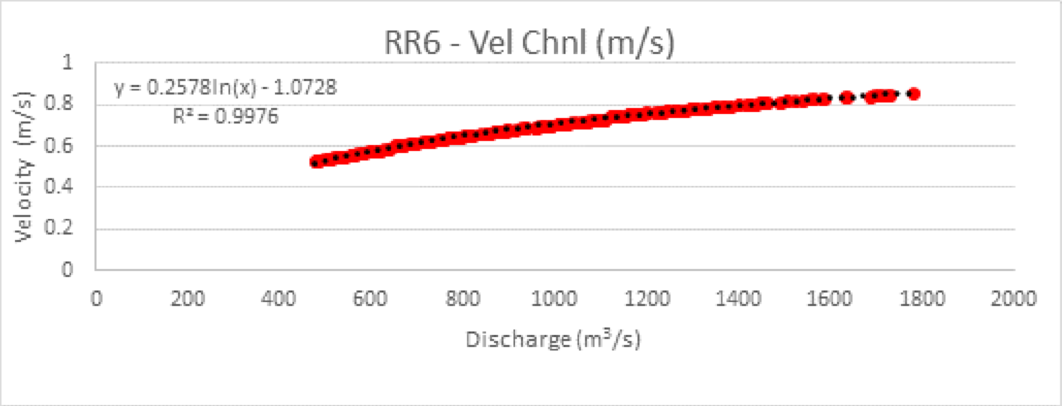


Figure 129: Flow depth (Blue) and Velocity depth (Red) relationships established for the study used to determine flow requirements for fishes.

### 4.6.2 Calculate Risk

Following the determination of flows to maintain the ecosystems associated with each site in each ecological category a summary of the flow requirements associated with these scenarios is generated (Table 63). These hydrographs were used in the risk assessment as scenarios to compare the socio-ecological consequences of altered flows associated with each scenario (ecological category).

Table 63: Summary of the floods required to provide for key socio-ecological processes in the Nile River per ecological category Class considered in the study.

| RR | River | Flow Component | Percentage EFR per Ecological Class | | |
|---|---|---|---|---|---|
| | | | **B** | **C** | **D** |
| 6 | White Nile (Malakal) | Drought flows | Included in Maintenance Low flows | | |
| | | Maintenance (or base) flows Low (or dry) period | 47.5% | 34.1% | 27.4% |
| | | Maintenance (or base) flows high (or wet) period | 16.8% | 9.2% | 7.0% |
| | | **Total** | **64.3%** | **43.2%** | **34.3%** |

The reference hydrographs and median flows for ecological categories B, C and D considered in the risk assessment for RR6 – White Nile River are graphically presented in Figure 130 and Figure 131. The rank thresholds for indicators selected for this site were used to query this hydrology data and evaluate the socio-ecological consequences of altered flows in the system using PROBFLO.

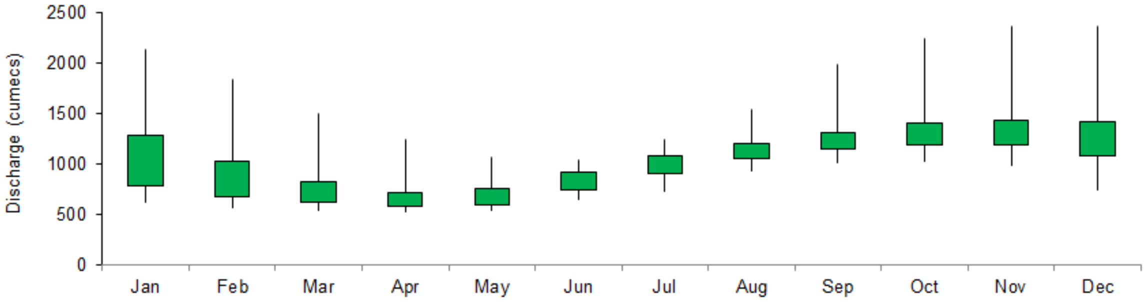


Figure 130: Box and whisker plot summary of the reference (Class A) average monthly (m³/s) flows observed in RR6 in the study. Whiskers represent 0.01%tiles and 99.9%tiles and box 20%tile and 80%tiles.

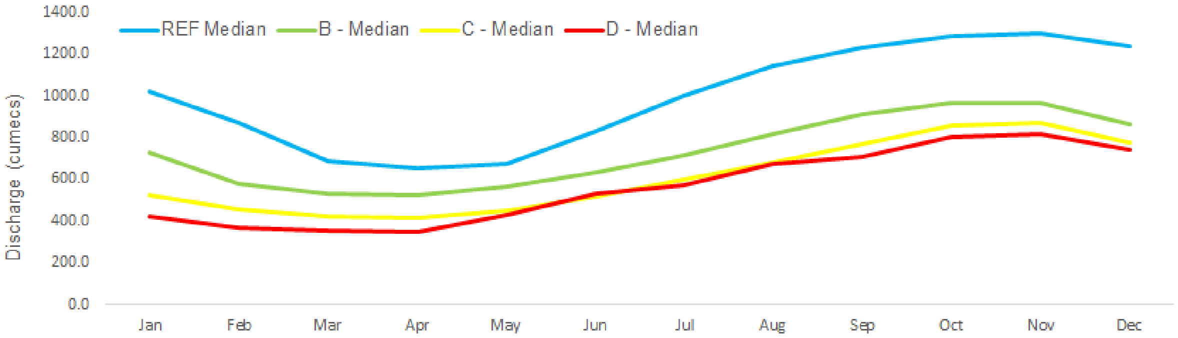


**Figure 131: Relative graphs (medians) of the reference (Class A or pristine), Class B (near natural), Class C (moderately modified) and Class D (largely modified) average monthly flows (m³/s) flows observed in RR6 in the study. Whiskers represent 0.01%tiles and 99.9%tiles and box 20%tile and 80%tiles.**

Risk outcomes directly obtained from the Netica Bayesian Network assessment are presented per RR with averages, standard deviation (SD) and risk rank probability profiles.

***Floodplain ecosystem services endpoint***

The relative risk to the floodplain ecosystem serves endpoint showed an increasing trend in risk from Class A to Class D (Figure 132). The results for Class A and B revealed low risk with SD extending into the moderate risk range. The results for Class C and D revealed moderate risk with SD extending into the high risk range. From Figure 133, no possibility of high (>50%) risk to the floodplain services for this RR.

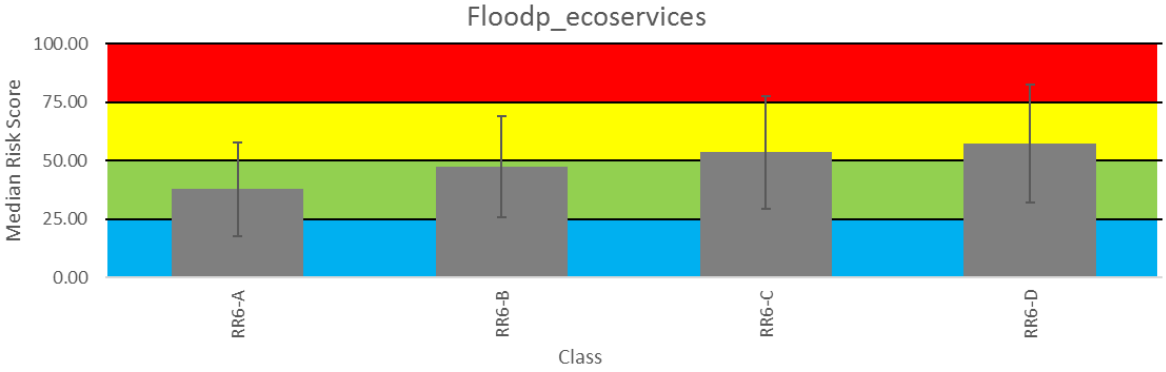


**Figure 132: Relative Risk (median, with standard deviation) of multiple stressors associated with eflow scenarios to Floodplain ecosystem services endpoint considered in the study (Class A (A), Class B (B), Class C (C) and Class (D)). Risk rank ranges for Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) risk included.**

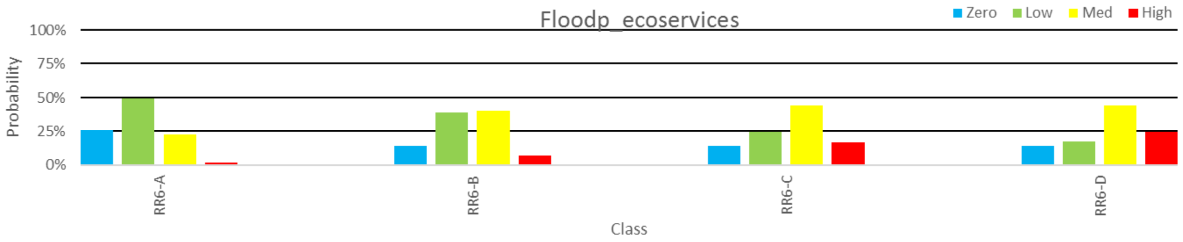


**Figure 133: Probability of risk rank occurrence for ranks Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) of multiple stressors associated with eflow scenarios to Floodplain ecosystem services endpoint considered in the study.**

***River ecosystem services endpoint***

The relative risk to the river ecosystem services endpoint showed an increasing trend in risk from Class A to Class D (Figure 134). The results for Class A to C revealed low risk with SD extending into the moderate risk range. The results for Class D revealed moderate risk with SD extending into the high risk ranges. Results in Figure 135 includes no probabilities of high risk (>45%) to the endpoint for this RR.

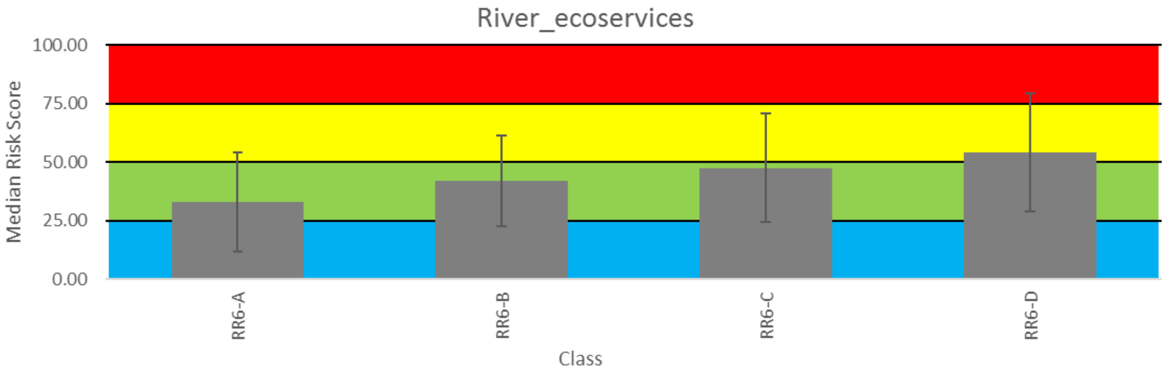


**Figure 134: Relative Risk (median, with standard deviation) of multiple stressors associated with eflow scenarios to River ecosystem services endpoint considered in the study (Class A (A), Class B (B), Class C (C) and Class (D)). Risk rank ranges for Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) risk included.**

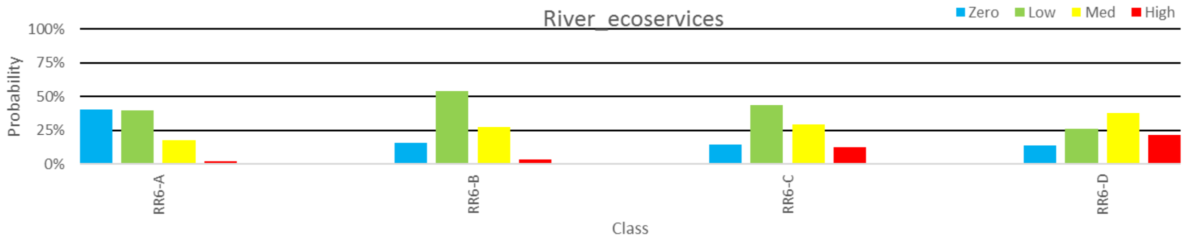


**Figure 135: Probability of risk rank occurrence for ranks Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) of multiple stressors associated with eflow scenarios to River ecosystem services endpoint considered in the study.**

***Floodplain biodiversity endpoint***

The relative risk to the floodplain biodiversity endpoint showed an increasing trend in risk from Class A to Class D (Figure 136). The results for Class A revealed low risk with SD extending into the moderate risk range. The results for Classes B to D revealed moderate risk with SD extending into the high risk range. No probability of high risk (>50%) to the endpoint for this RR (Figure 137).

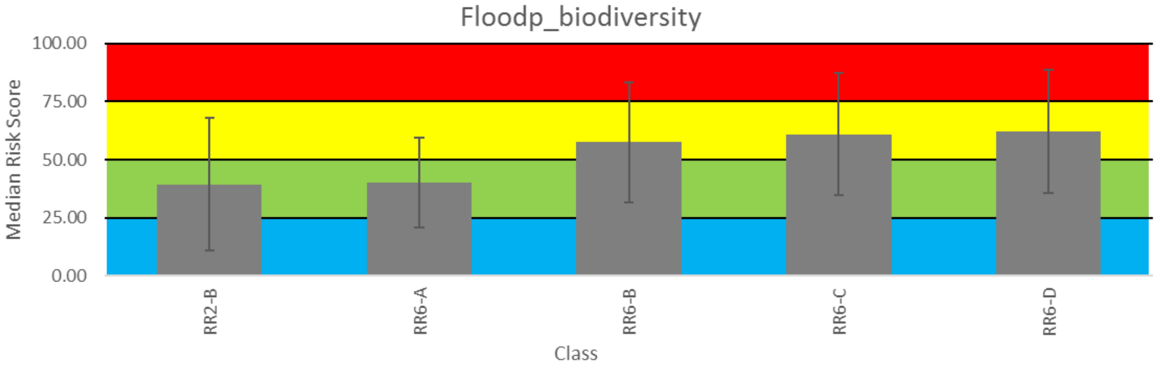


**Figure 136: Relative Risk (median, with standard deviation) of multiple stressors associated with eflow scenarios to Floodplain biodiversity endpoint considered in the study (Class A (A), Class B (B), Class C (C) and Class (D)). Risk rank ranges for Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) risk included.**

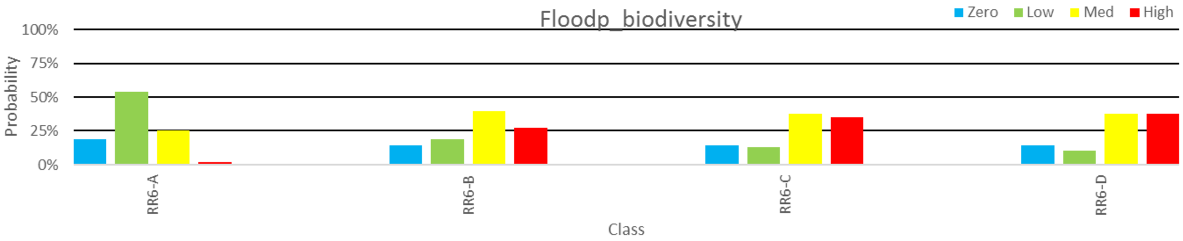


**Figure 137: Probability of risk rank occurrence for ranks Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) of multiple stressors associated with eflow scenarios to Floodplain biodiversity endpoint considered in the study.**

### *River biodiversity endpoint*

The relative risk to the floodplain biodiversity endpoint showed an increasing trend in risk from Class A to Class D (Figure 138). The results revealed low risk for Classes A to C, with SD extending into the moderate risk range. The results for Class D revealed moderate risk with SD extending into the high risk range. No high risk (>50%) to the riverine biodiversity was shown for this RR (Figure 139).

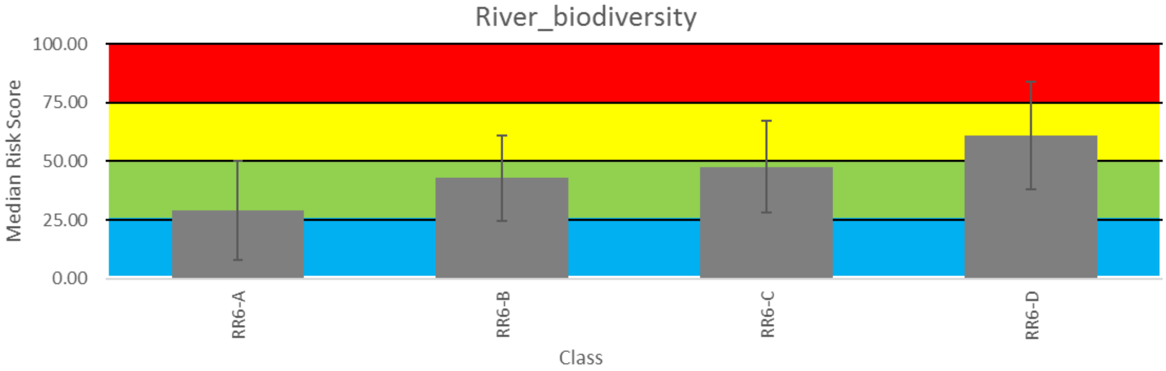


**Figure 138: Relative Risk (median, with standard deviation) of multiple stressors associated with eflow scenarios to River biodiversity endpoint considered in the study (Class A (A), Class B (B), Class C (C) and Class (D)). Risk rank ranges for Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) risk included.**

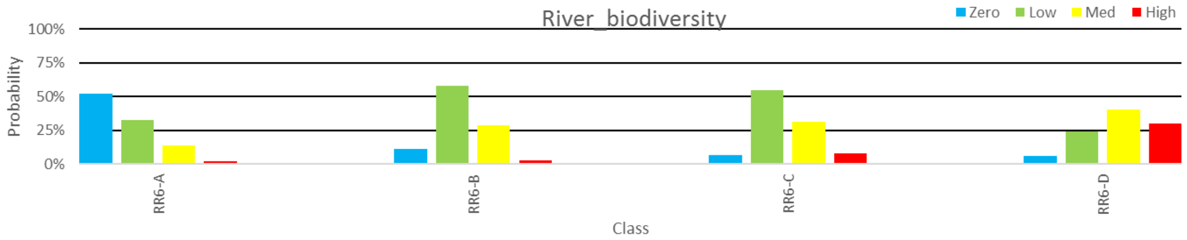


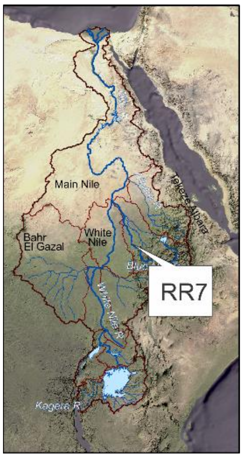
**Figure 139: Probability of risk rank occurrence for ranks Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) of multiple stressors associated with eflow scenarios to River biodiversity endpoint considered in the study.**

### 4.6.3 Conclusion for RR6

Low flows (dry and wet base flows) are important for the White Nile River and should be provided to ensure adequate habitats to maintain the ecology of the river. It is also important to note that the river is perennial and that the 99.9 percentile flow specified for each month provides for non-zero flows. Thus, any future operation of the system or water resource developments should accommodate the minimum flow requirements.

Results include increasing risk to endpoints as the ecological wellbeing of the rivers deteriorate from reference states to Class B, C and D ecological categories. Similarly, there is a high variability in the resilience and associated risk of altered flows to different endpoints. This includes relatively higher risk to the floodplain biodiversity endpoint compared to the riverine biodiversity and the ecosystem services associated with the river and floodplain ecosystems. No probability of high risk (>50%) was recorded for any endpoint.

## 4.7 RR7 – Blue Nile River



The source of the Blue Nile is the Little Abbay River in the Ethiopian Highlands which flows into Lake Tana from where the Blue Nile discharges (NBI, 2008). The Blue Nile is joined by numerous rivers including the Rahad and Dinder Rivers before meeting the White Nile at Khartoum to form the Main Nile River (NBI, 2012). The river reach selected for the assessment is at El Diem/Roseires, downstream of GERD (Latitude 11.859816; longitude 34.375262).

### 4.7.1 Data Analysis

#### 4.7.1.1 Hydrology Assessment

The results are presented as tables showing the flow requirements for the highest and lowest flow month at selected percentile values and the annual flood requirements in terms of discharge, months when required and the duration in days. The hydrographs indicate the reference and base flows compared to the EFR. Flow duration curves (FDCs) per RR for selected months are also presented.

The Blue Nile is a major tributary of the Nile and contributes more than 60% of the total flows in the lower Nile River. The record period used for this EFR determination is from 1921-2013 with a Reference MAR of 49 712 MCM. The monthly hydrograph shows a distinct wet/ dry season characteristic with the peak flows in August. The low flow season (mainly March and April) records flows of less than 100 $m^3$/s. Thus, drought flow requirements were specified separately to the maintenance low flows for the Blue Nile River. The flow requirements for selected months and percentiles (low flows and floods) that were used to determine the EFR is summarised in Table 64 below.

Table 64: Selected flow requirements for RR7 – Blue Nile River

| | **Flow requirements ($m^3$/s) – low flows** | |
|---|---|---|
| **Percentiles** | **Apr** | **Aug** |
| 15 | - | 1 500 |
| 50 | 80 | 800 |
| 99.9 | 45 | 350 |

| | **Flow requirements– annual floods** | | |
|---|---|---|---|
| | **Jul** | **Aug** | **Sep** |
| Peak flows ($m^3$/s) | 1 500 | 2 100 | 2 100 |
| Duration (days) | 14 | 14 | 14 |

These selected requirements, together with the DRM were used to determine the EFR for each month. The results of the final EFR for RR7 is shown in Table 65.

Table 65: Final EFR for RR7 – Blue Nile River (flows in $m^3/s$)

| RR7 | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 280.88 | 186.54 | 141.18 | 132.65 | 190.40 | 362.45 | 1026.96 | 1897.58 | 1660.99 | 1012.99 | 591.88 | 392.91 |
| Minimum | 119.8 | 80.7 | 56.4 | 48.2 | 73.9 | 143.9 | 367.9 | 723.4 | 637.9 | 412.7 | 260.4 | 196.6 |
| Maximum | 411.9 | 310.5 | 237.6 | 221.4 | 237.1 | 416.8 | 1331.1 | 2425.3 | 2263.8 | 1213.7 | 703.8 | 474.9 |
| Percentiles | | | | | | | | | | | | |
| 0.1 | 411.9 | 310.0 | 237.6 | 221.4 | 237.1 | 416.8 | 1331.1 | 2425.3 | 2263.8 | 1213.7 | 703.8 | 474.9 |
| 1 | 411.9 | 305.6 | 237.6 | 221.4 | 237.1 | 416.8 | 1331.1 | 2425.3 | 2263.8 | 1213.7 | 703.8 | 474.9 |
| 5 | 411.9 | 295.3 | 237.6 | 221.4 | 237.1 | 416.8 | 1331.1 | 2425.3 | 2263.8 | 1213.7 | 703.8 | 474.9 |
| 10 | 396.7 | 255.2 | 222.4 | 216.2 | 237.1 | 416.8 | 1329.5 | 2423.8 | 2240.6 | 1213.7 | 703.8 | 474.9 |
| 15 | 356.5 | 243.1 | 182.7 | 196.7 | 237.1 | 416.8 | 1296.1 | 2374.6 | 2198.0 | 1213.7 | 703.8 | 474.9 |
| 20 | 346.0 | 220.8 | 170.9 | 185.8 | 237.0 | 416.6 | 1272.1 | 2327.4 | 2129.7 | 1213.5 | 703.6 | 474.8 |
| 30 | 332.2 | 206.5 | 154.9 | 159.4 | 235.5 | 414.8 | 1217.0 | 2235.3 | 2023.1 | 1204.5 | 699.6 | 471.5 |
| 40 | 298.1 | 196.8 | 143.1 | 138.3 | 231.6 | 411.2 | 1167.5 | 2151.8 | 1918.5 | 1189.4 | 687.3 | 463.9 |
| 50 (median) | 285.2 | 184.8 | 134.8 | 119.6 | 210.6 | 401.9 | 1103.4 | 2061.3 | 1815.1 | 1149.0 | 661.9 | 446.2 |
| 60 | 264.0 | 174.5 | 126.9 | 108.6 | 183.6 | 386.5 | 1011.5 | 1882.9 | 1617.8 | 1076.6 | 628.1 | 406.7 |
| 70 | 254.6 | 166.4 | 120.5 | 96.3 | 162.0 | 361.1 | 934.3 | 1753.2 | 1437.9 | 966.4 | 559.8 | 350.3 |
| 80 | 217.7 | 149.4 | 105.3 | 93.0 | 140.2 | 302.8 | 794.7 | 1465.5 | 1158.5 | 765.0 | 447.3 | 281.6 |
| 85 | 182.2 | 128.8 | 100.0 | 85.6 | 126.6 | 273.4 | 704.1 | 1332.8 | 1010.1 | 662.7 | 400.4 | 255.1 |
| 90 | 153.4 | 106.5 | 90.9 | 80.7 | 105.0 | 232.2 | 599.5 | 1136.9 | 862.5 | 561.8 | 342.1 | 227.1 |
| 95 | 130.4 | 88.3 | 67.3 | 59.2 | 84.3 | 177.1 | 447.8 | 858.0 | 696.1 | 458.6 | 285.3 | 204.8 |
| 99 | 121.5 | 82.0 | 57.4 | 48.9 | 74.9 | 143.9 | 367.9 | 723.4 | 637.9 | 412.7 | 260.4 | 196.6 |
| 99.9 | 120.0 | 80.8 | 56.5 | 48.3 | 74.0 | 143.9 | 367.9 | 723.4 | 637.9 | 412.7 | 260.4 | 196.6 |

The summary of the EFR for RR7 (Table 66) shows that 42% of the flows in the Blue Nile River is required for ecological functioning, with the low flows (flows occurring more than 50% of the time) making up the bulk of the requirement at 32%. The drought requirement is 15% with the floods less than 10% of the ecological requirement. Thus, low flows (dry and wet base flows) are important for the Blue Nile River and should be provided to ensure adequate habitats to maintain the ecology of the river. It is also important to note that the river is perennial and that the 99.9 percentile flow specified for each month provides for non-zero flows. Thus, any future operation of the system or water resource developments should accommodate the minimum flow requirements.

Table 66: Summary of final EFR for RR7 – Blue Nile River

| **RR** | **River** | **Reference (MCM)** | **% Requirement** | | | | **Volume Requirement (MCM)** | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | **Low flows** | **Drought flows** | **Floods** | **Total** | **Low flows** | **Drought flows** | **Floods** | **Total** |
| RR7 | Lue Nile | 49 712 | 32.4 | 15.4 | 9.6 | 41.9 | 16 115 | 7 690 | 4 756 | 20 871 |

The monthly hydrograph of the REF, BF and EFR for a B state for the Blue Nile River is shown in Figure 140. This indicates that the EFR is almost equal to the reference flows during the low flow months (Figure 141). Although floods are still required during the wetter months, these are much lower than the reference flows. The FDC for April (low flow season) (Figure 142) indicates that the EFR requires almost 100% of the reference flows.

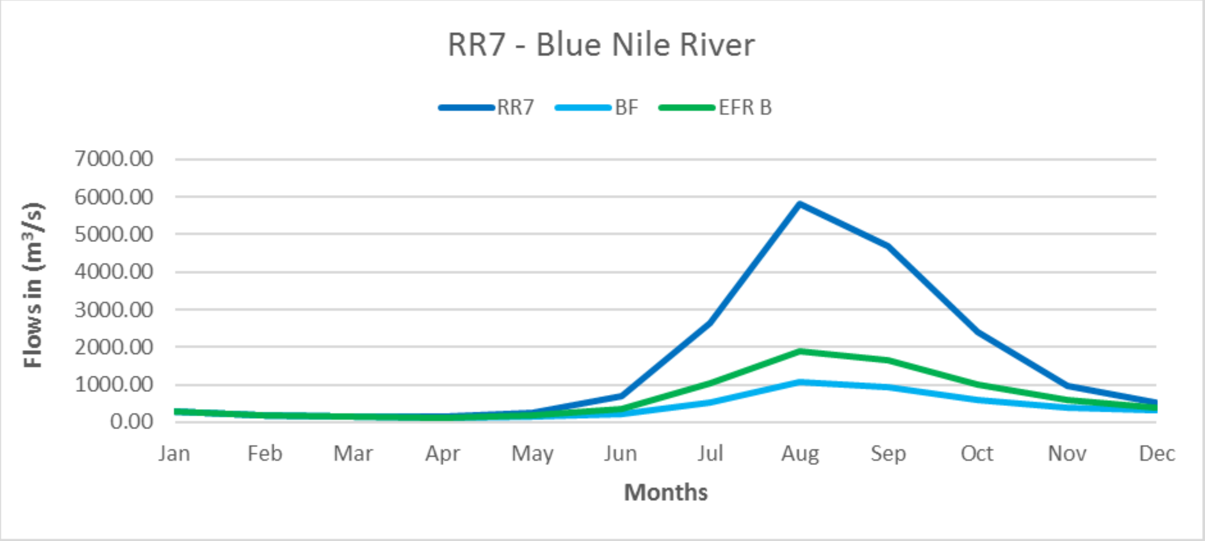


Figure 140: Monthly hydrograph for RR7 – Blue Nile River

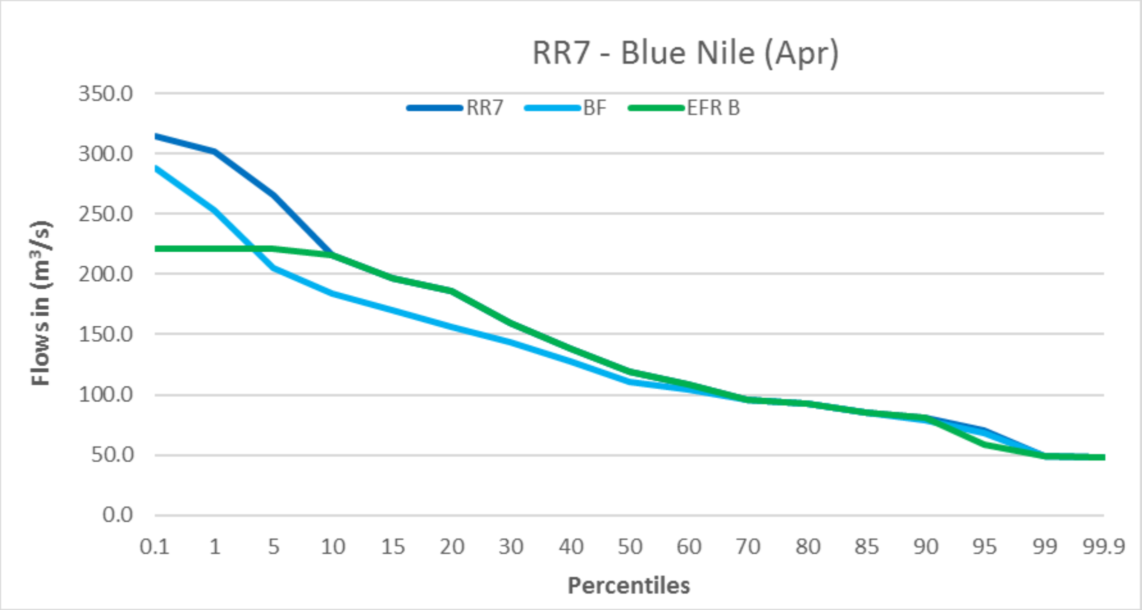


Figure 141: Flow duration curve for April (low flows) in RR7 – Blue Nile River

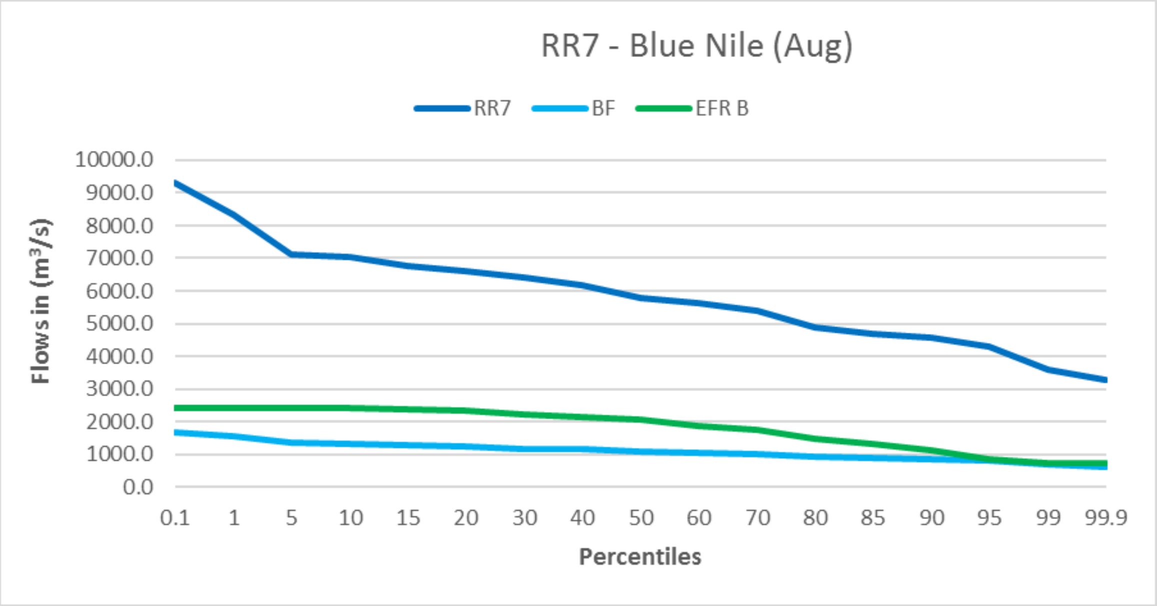


Figure 142: Flow duration curve for August (wet season) in RR7 – Blue Nile River

### 4.7.1.2 Hydraulic Assessment

It must be noted, that the 1.5yr return period flow is only approximately depicting bankfull flow conditions. Therefore, additional cross section characteristics were investigated from which information about inundation extent and frequency could be deduced. These descriptions are briefly given for the points of interest. Each point of interest is individually assessed using QGIS with the Profile Tool and Quick Map Services Plugin on the MERIT DEM and Google Satellite images. The site location and ID (yellow dot with number, corresponds to the IDs given in Table 67) is shown together with the cross section location (red line) on satellite images (Google Earth/Digital Globe). Below the images, the diagram shows the cross section (elevation along the red line), where the small red dot

in the upper satellite images is marked by the centre of the cross line in the lower diagram. Numbers in the diagram show elevation in mASL (y-Axis) and distance from left in meters (x-axis).

Table 67. Points of interest, the applied methodology for obtaining the channel cross section and additional channel and cross section properties

| ID | River | Latitude | Longitude | Channel bathymetry method | Bank width [m] | Ineffective area elevation [mASL] | Slope [m/m] |
|---|---|---|---|---|---|---|---|
| RR7 | Blue Nile | 11.8598 | 34.3753 | Survey | 641 | -- | 0.000060 |

Figure 143 and Figure 144 shows the cross section from the DEM at Roseires. Cross section survey data from 2009 is available at this location which was merged to the data from the DEM in HEC-RAS, so that it is not needed to calibrate channel depth. The 1.5yr return period calculated for the site is not related to the natural conditions due to the artificial release from Roseires dam. Therefore, no calibration of Manning’s n values was carried out.

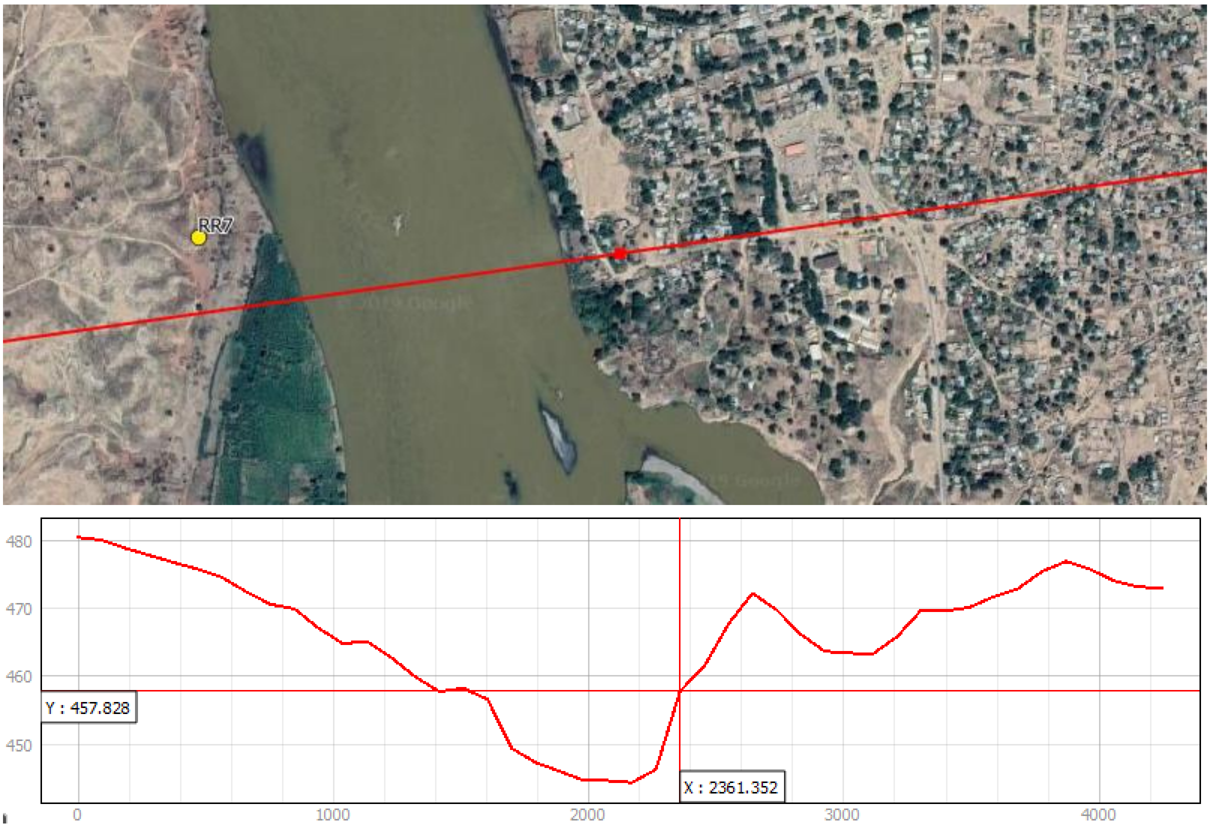


Figure 143: Roseires cross section, deeply incised next to the settlement

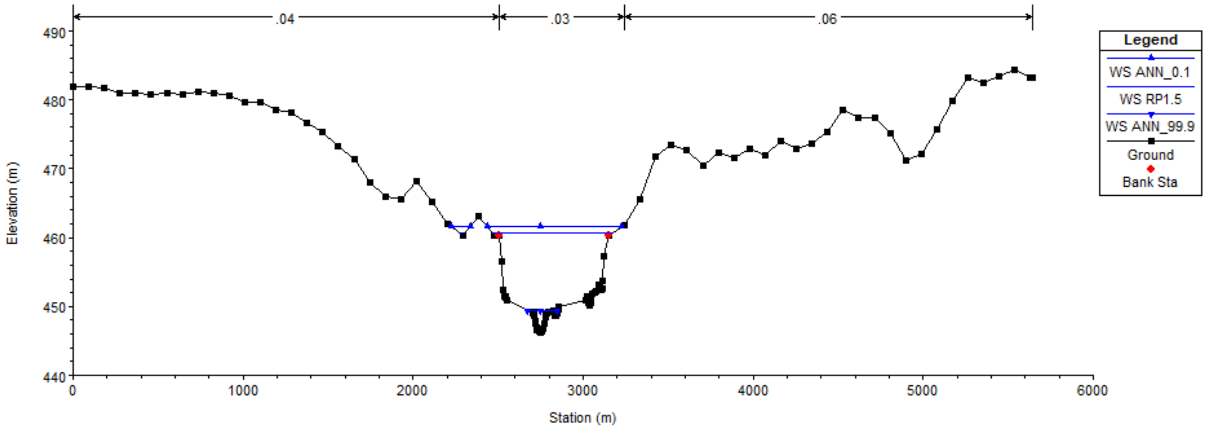


Figure 144: Cross sectional profile of the hydraulic site for RR7

### 4.7.1.3 Vegetation Assessment

This risk region is represented by the Blue Nile downstream of GERD at Roseires with the cross section shown as a red line in Figure 145. Vegetation at this site is sparse and scattered where agriculture or irrigation does not take place although remnants of a distinct tall tree linear zone along the active channel exists and much of the vegetation is either cultivated or comprised of non-woody sedges and grasses along the channel in rocky areas (Figure 145 and Figure 146). Closer views of smaller islands, however, suggest that more extensive natural vegetation occurred before resource utilisation pressure became high. Figure 147 for example shows such an island with clear natural riparian vegetation compared to cultivated areas or remnant vegetation within high density dwellings. The active channel averages 450m wide and some degree of braiding occurs with flood channels, distributaries, backwaters and islands being common.

Figure 145: Google Earth © satellite image at Roseires on the Blue Nile downstream of GERD representing risk region 7.

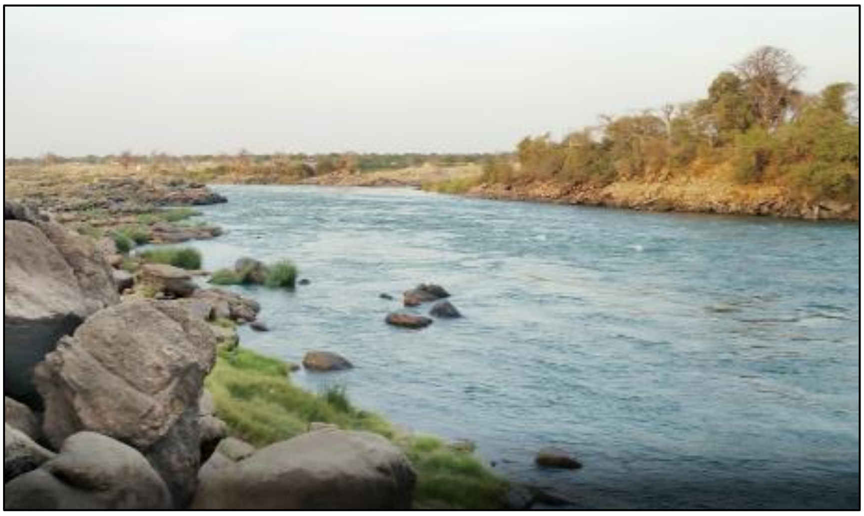


Figure 146: Photograph showing the Blue Nile downstream of GERD and associated vegetation at the bridge near Roseires (photo courtesy of Google Earth).

Figure 147: Google Earth © satellite image at Roseires on the Blue Nile downstream of GERD showing closer view with more detail.

Based on the available biological information at cross section sites, and together with hydraulics at each site, the driver components [within the model] were quantified for a B-category (Table 68) as determined by discernible riparian indicators (Table 69). Interpolation was frequently required due to lack of biological data specific to sites.

Table 68: Quantification of driver components for a B-category system (Values are discharge).

| General description | | RR7 |
|---|---|---|
| Bank full for non-woody fringe vegetation | Wet Base | 1880 |
| Wet base less 1m in elevation | Dry Base | 120 |
| Wet base less 1.5m in elevation | Critical Low | 85 |
| Between woody and non-woody limits | Freshette | 2100 |

| | | |
|---|---|---|
| To the base of woody vegetation (Tall tree line) | Annual flood | 2500 |

Table 69: Riparian indicators utilized to quantify driver components for a B-category system.

| RR7 | channel width (m) | Discharge | Chan depth | Month | Indicators |
|---|---|---|---|---|---|
| Wet Base | 550 | 1880 | 2.45 | Aug | Sand bars |
| Dry Base | 515 | 120 | 2 | Apr | |
| Critical Low | 345 | 85 | 1.2 | May | |
| Freshette | 580 | 2100 | 4 | Jul-Oct | Tree base |
| Annual flood | 590 | 2500 | 4.8 | Jul-Aug | Tall tree line 2 channel |

## Defining Risk to Vegetation

The alteration of driver dynamics, in this case flows and by implication floods, results in risk to the vegetation. Optimal driver state results in low risk to all vegetation endpoints but does not consider the effects of non-flow related impacts, such as ever increasing grazing and trampling pressures, and the impacts of human density and resource use. However, as flows may decline so the risk to vegetation endpoints increases. This risk has been described and quantified for each of the response variables (Table 70), as well as for each of the response variables within different risk regions, and represents declining ecological health or ecosystem wellbeing.

Table 70: Justifications and driver quantification for interaction of vegetation components within the model.

| Bayesian Network variable title, measure - (BN node name) | Rank (score) | Rank definition and measure for variable | RR7 |
|---|---|---|---|
| Aveghab_R_bwet | Zero (25) | 10% higher percentile than B] base | > 2000 |
| | Low (50) | bank full for non-woody vegetation | 2000 - 1880 |
| | Moderate (75) | between [B] dry base and [B] wet base | 1880 - 1380 |
| | High (100) | as low as normal (B) dry base | < 1380 |
| FPveg_FP_bwet | Zero (25) | 10% higher percentile than B] base | > 2000 |
| | Low (50) | bank full for non-woody vegetation | 2000 - 1880 |
| | Moderate (75) | between [B] dry base and [B] wet base | 1880 - 1380 |
| | High (100) | as low as normal (B) dry base | < 1380 |
| Aveghab_R_drought | Zero (25) | 95% [B] dry season max month | > 85 |
| | Low (50) | critical low flows for [B] | 85 - 60 |
| | Moderate (75) | 99% dry season max | 60 - 49 |
| | High (100) | | < 49 |
| Aveghab_R_bdry | Zero (25) | wet base | > 200 |
| | Low (50) | wet base less 1m | 200 - 120 |
| | Moderate (75) | critical low | 120 - 85 |
| | High (100) | critical low | < 85 |
| FPveg_FP_flood | Zero (25) | to the base of woody vegetation (Tall tree line):annual | > 2500 |
| | Low (50) | between woody and non-woody limits: freshette | 2500 - 2100 |

| Bayesian Network variable title, measure - (BN node name) | Rank (score) | Rank definition and measure for variable | RR7 |
|---|---|---|---|
|  | Moderate (75) | no flood: 20% higher than wet base percentile | 2100 - 1900 |
|  | High (100) |  | < 1900 |
| Subveg_R_bdry | Zero (25) | wet base | > 200 |
|  | Low (50) | wet base less 1m | 200 - 120 |
|  | Moderate (75) | critical low | 120 - 85 |
|  | High (100) | critical low | < 85 |
| Subveg_R_bwet | Zero (25) | 10% higher percentile than B] base | > 2000 |
|  | Low (50) | bank full for non-woody vegetation | 2000 - 1880 |
|  | Moderate (75) | between [B] dry base and [B] wet base | 1880 - 1380 |
|  | High (100) | as low as normal (B) dry base | < 1380 |
| Subveg_FP_bdry | Zero (25) | wet base | > 200 |
|  | Low (50) | wet base less 1m | 200 - 120 |
|  | Moderate (75) | critical low | 120 - 85 |
|  | High (100) | critical low | < 85 |
| Subveg_FP_bwet | Zero (25) | 10% higher percentile than B] base | > 2000 |
|  | Low (50) | bank full for non-woody vegetation | 2000 - 1880 |
|  | Moderate (75) | between [B] dry base and [B] wet base | 1880 - 1380 |
|  | High (100) | as low as normal (B) dry base | < 1380 |

### 4.7.1.4 Fish Assessment

For the determination of instream flow requirements for the Nile River (Uganda) eight species of fishes that have habitat and or migratory requirements that occur within the river were selected for the assessment (Table 71). Based on the relative size species attains and biology and ecology information the depth and velocity requirements were determined as well as minimum depths to maintain lateral and longitudinal migrations for these indicator species. This information was aligned to the seasonal flows of the system and used to establish flow requirements that were provided to the hydrologist to determine eflow requirements (Figure 148, Figure 149 and Figure 150).

**Table 71: Fishes selected to determine eflows for RR7. Hypothesised preferences for habitats (depth and velocity) and migratory notes provided for each species.**

| Min. Depth (mm) | Min. Vel (m/s) | Weight | Blue Nile River indicator spp. | Details |
|---|---|---|---|---|
| 1000 | 1.2 | 3 | *Labeo sp.* | Good rheophillic species long.↑↑ & lat. Potamodromous migrations. |
| 2000 | 1.2 |  | *Labeobarbus spp.* | Good rheophillic species long.↑↑ & lat. Potamodromous migrations. |
| 2000 | 0.8 | 3 | *Hydrocynus sp.* | Good rheophillic species long.↑↑ & lat. Potamodromous migrations. |
| 1200 | 0.8 | 2 | *Bagrus spp.* | Semi-rheophillic species long.↑↑ & lat. Potamodromous migrations. |
| 650 | 0.2 | 2 | *Oreochromis sp.* | Lotic, limnophillic/floodplain species long.↑↑ & lat. Potamodromous migrations. |
| 1200 | 0.5 | 2 | *Distichodus sp.* | Semi-rheophillic species long.↑↑ & lat. Potamodromous migrations. |
| 1200 | 0.6 | 1 | *Clarias gariepinus* | Lotic, limnophillic/floodplain species long.↑↑ & lat. Potamodromous migrations. |

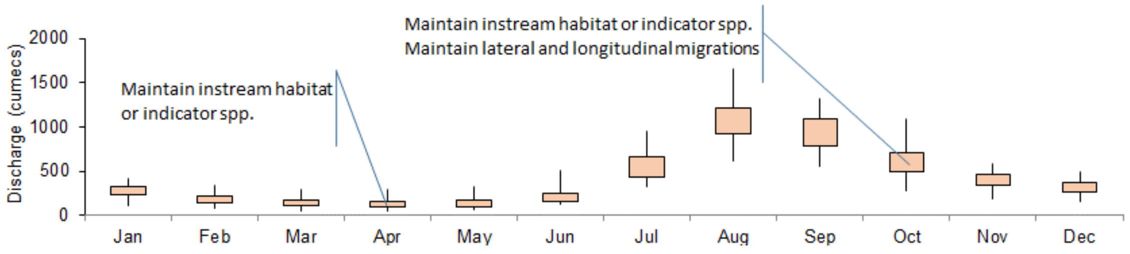


Figure 148: Reference hydrograph from RR7 with key fish biology and ecology requirements.

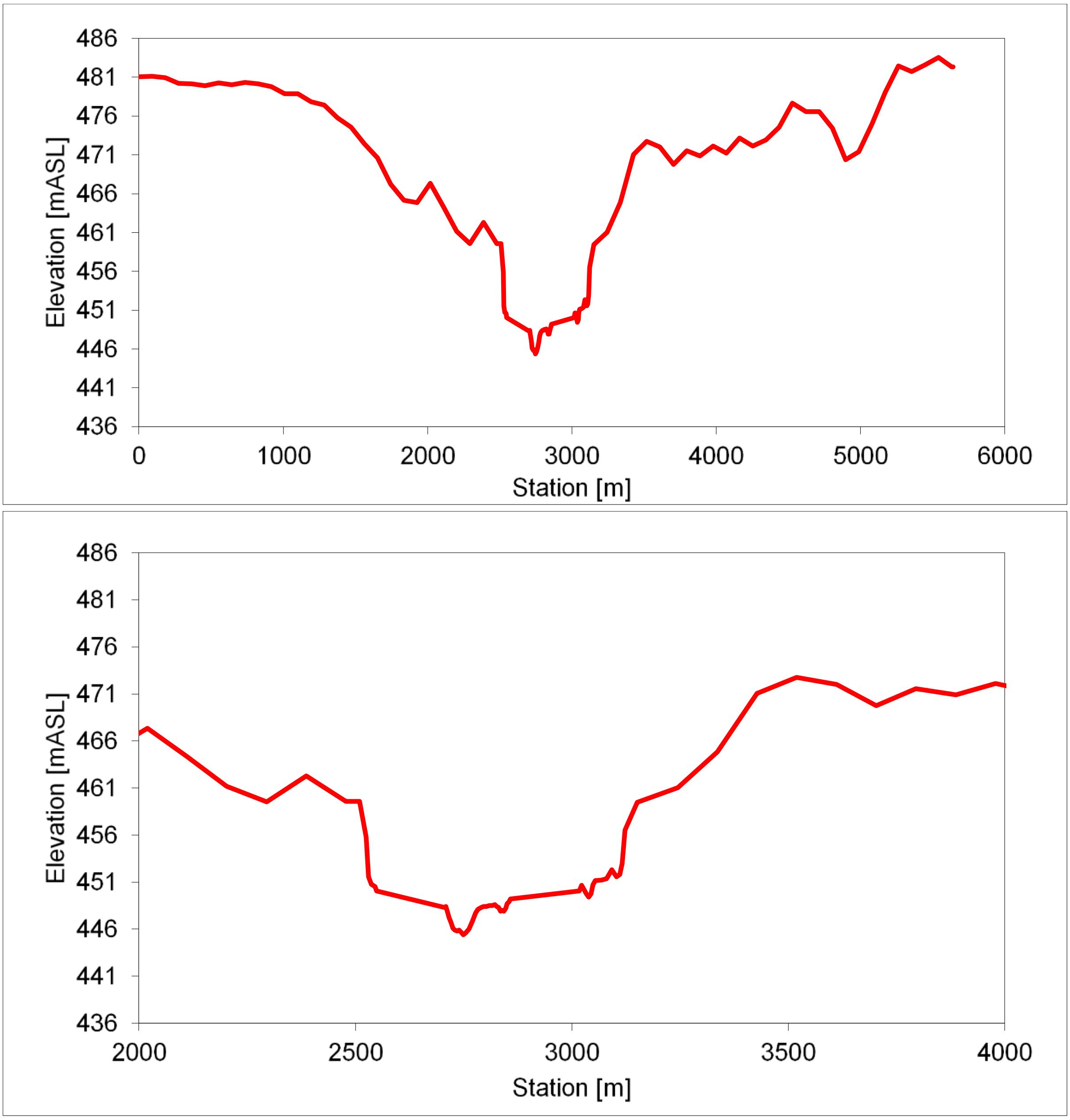


Figure 149: Cross section of RR7 with flow elevations highlighted for key fish biology and ecology events selected in the study for eflow determination.

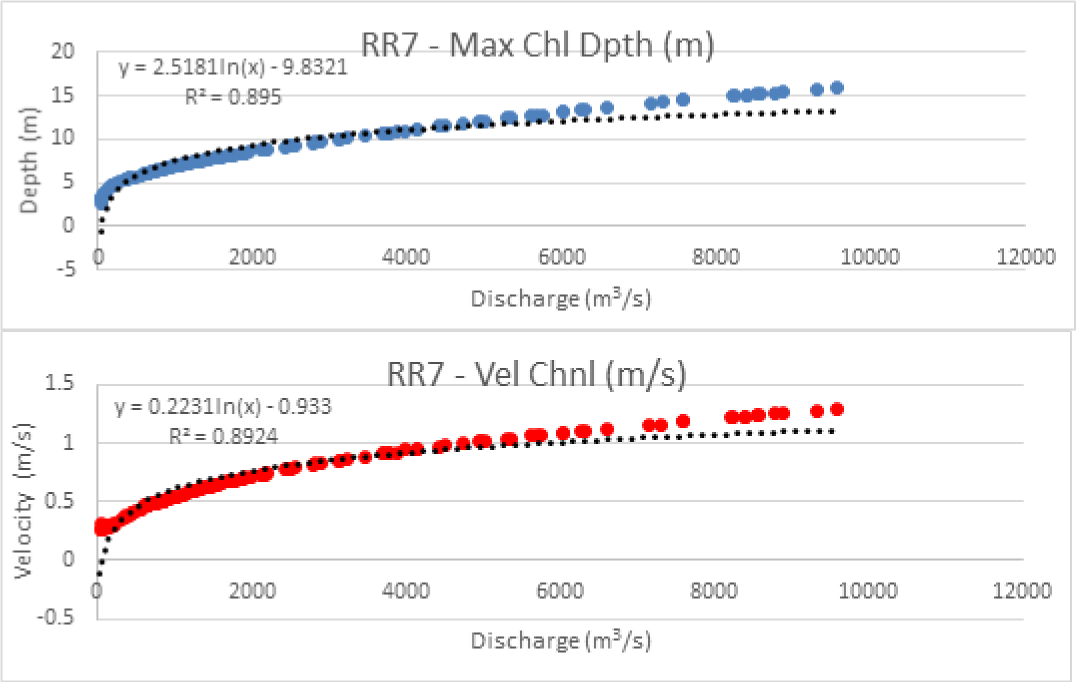


Figure 150: Flow depth (Blue) and Velocity depth (Red) relationships established for the study used to determine flow requirements for fishes.

### 4.7.2 Calculate Risk

Following the determination of flows to maintain the ecosystems associated with each site in each ecological category a summary of the flow requirements associated with these scenarios is generated (Table 72). These hydrographs were used in the risk assessment as scenarios to compare the socio-ecological consequences of altered flows associated with each scenario (ecological category).

Table 72: Summary of the floods required to provide for key socio-ecological processes in the Nile River per ecological category Class considered in the study.

| RR | River | Flow Component | Percentage EFR per Ecological Class | | |
|---|---|---|---|---|---|
| | | | B | C | D |
| 7 | Blue Nile River (Roseries) | Drought flows | 15.4% | 12.7% | 10.3% |
| | | Maintenance (or base) flows Low (or dry) period | 32.3% | 19.8% | 11.7% |
| | | Maintenance (or base) flows high (or wet) period | 9.6% | 2.9% | 2.3% |
| | | **Total** | **41.9%** | **22.6%** | **14.0%** |

The reference hydrographs and median flows for ecological categories B, C and D considered in the risk assessment for RR7 – Blue Nile River are graphically presented in Figure 151 and Figure 152. The rank thresholds for indicators selected for this site were used to query this hydrology data and evaluate the socio-ecological consequences of altered flows in the system using PROBFLO.

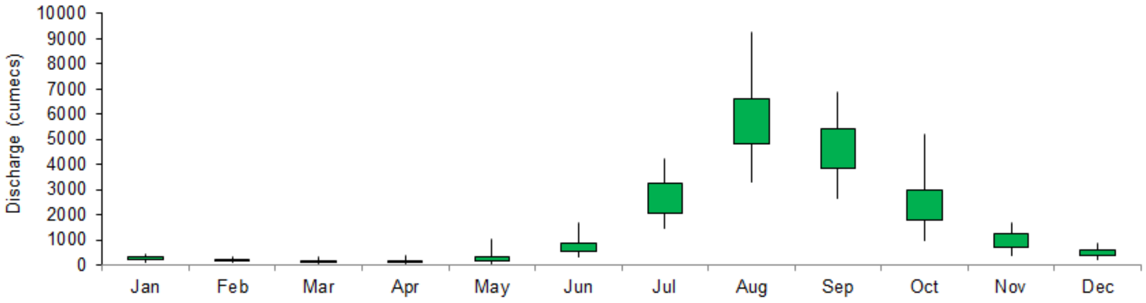


Figure 151: Box and whisker plot summary of the reference (Class A) average monthly (m³/s) flows observed in RR7 in the study. Whiskers represent 0.01%tiles and 99.9%tiles and box 20%tile and 80%tiles.

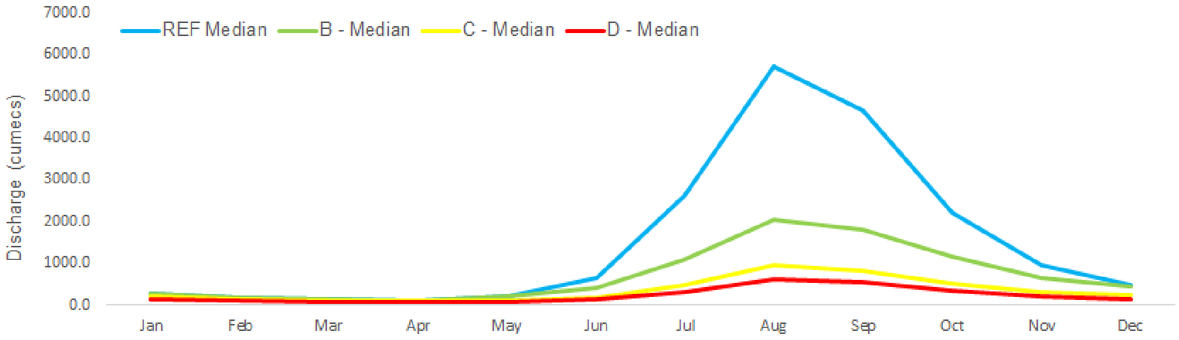


Figure 152: Relative graphs (medians) of the reference (Class A or pristine), Class B (near natural), Class C (moderately modified) and Class D (largely modified) average monthly flows (m³/s) flows observed in RR7 in the study. Whiskers represent 0.01%tiles and 99.9%tiles and box 20%tile and 80%tiles.

Risk outcomes directly obtained from the Netica Bayesian Network assessment are presented per RR with averages, standard deviation (SD) and risk rank probability profiles.

### *Floodplain ecosystem services endpoint*

The relative risk to the floodplain ecosystem serves endpoint showed an increasing trend in risk from Class A to Class D (Figure 153). The results for Class A and B revealed low risk with SD for Class A staying within the low risk range but the SD for Class B extending into the moderate risk range. The results for Class C and D revealed low risk with SD extending into the high risk range. From Figure 154 results, no possibility of high (>50%) risk to the floodplain services for this RR.

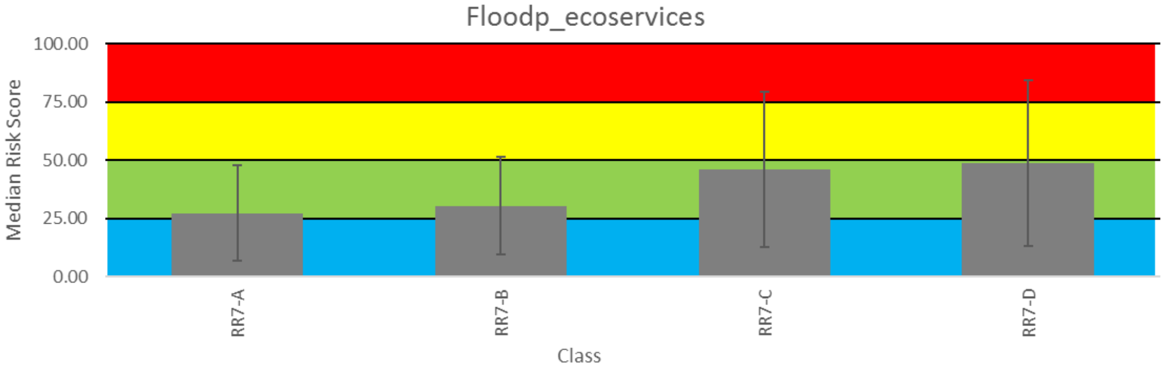


**Figure 153: Relative Risk (median, with standard deviation) of multiple stressors associated with eflow scenarios to Floodplain ecosystem services endpoint considered in the study (Class A (A), Class B (B), Class C (C) and Class (D)). Risk rank ranges for Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) risk included.**

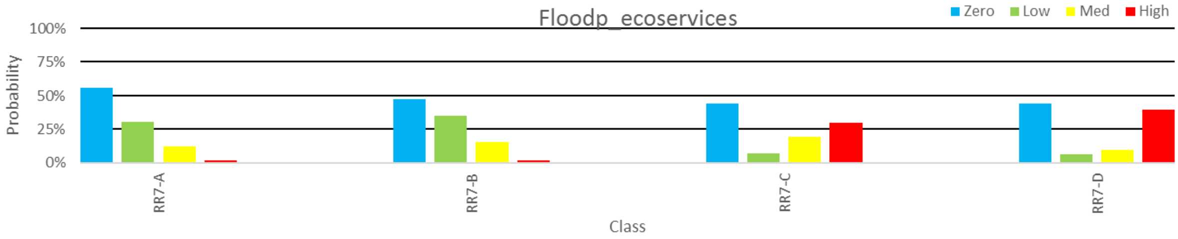


**Figure 154: Probability of risk rank occurrence for ranks Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) of multiple stressors associated with eflow scenarios to Floodplain ecosystem services endpoint considered in the study.**

### *River ecosystem services endpoint*

The relative risk to the river ecosystem services endpoint showed an increasing trend in risk from Class A to Class D (Figure 155). The results for Class A and B revealed low risk with SD extending into the moderate risk range. The results for Class C and D revealed moderate risk with SD extending into the high risk ranges. Results Figure 156 includes probabilities of high risk (>50%) to the endpoint for Class D.

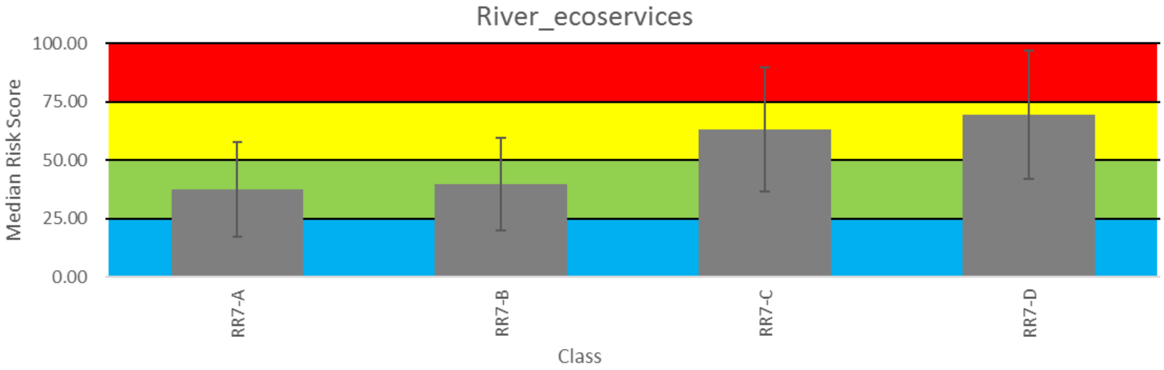


**Figure 155: Relative Risk (median, with standard deviation) of multiple stressors associated with eflow scenarios to River ecosystem services endpoint considered in the study (Class A (A), Class B (B), Class C (C) and Class (D)). Risk rank ranges for Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) risk included.**

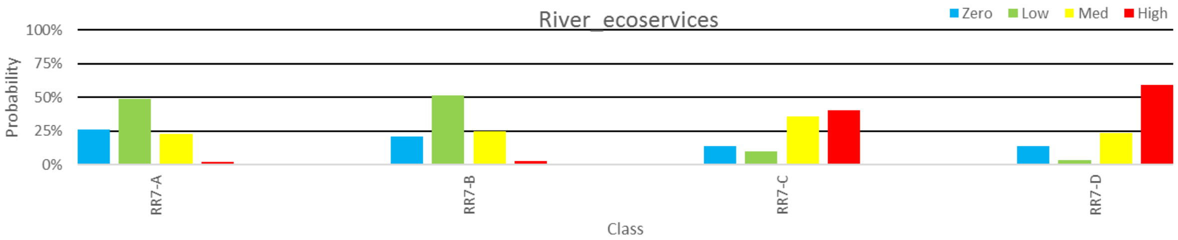


**Figure 156: Probability of risk rank occurrence for ranks Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) of multiple stressors associated with eflow scenarios to River ecosystem services endpoint considered in the study.**

### *Floodplain biodiversity endpoint*

The relative risk to the floodplain biodiversity endpoint showed an increasing trend in risk from Class A to Class D (Figure 157). The results for Class A revealed zero risk with SD extending into the low risk range. The results for Classes B to D revealed moderate risk with SD for Class B extending into moderate risk range and for Classes C and D into the high risk range. No probability of high risk (>50%) to the endpoint for this RR (Figure 158).

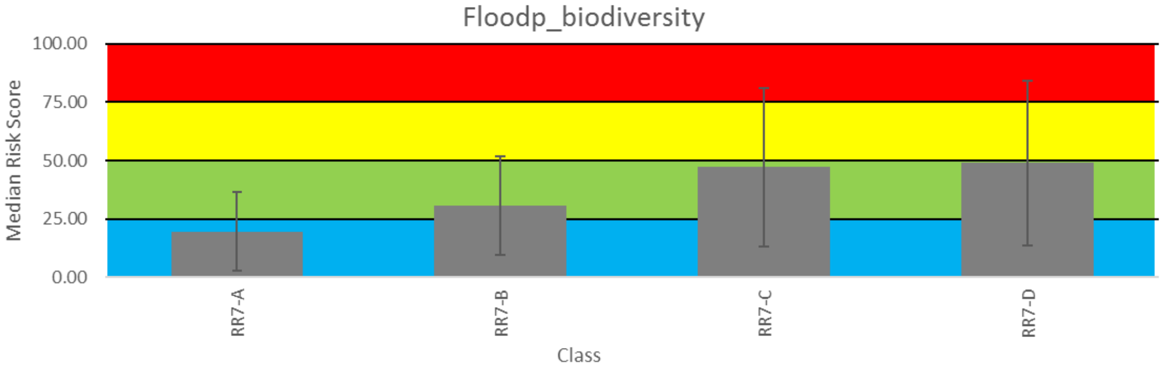


**Figure 157: Relative Risk (median, with standard deviation) of multiple stressors associated with eflow scenarios to Floodplain biodiversity endpoint considered in the study (Class A (A), Class B (B), Class C (C) and Class (D)). Risk rank ranges for Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) risk included.**

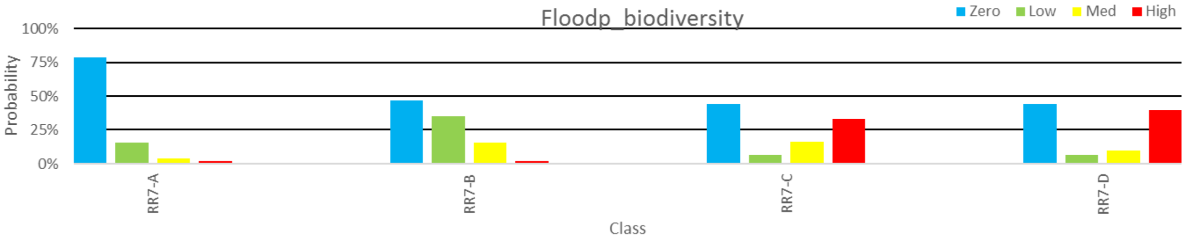


**Figure 158: Probability of risk rank occurrence for ranks Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) of multiple stressors associated with eflow scenarios to Floodplain biodiversity endpoint considered in the study.**

### *River biodiversity endpoint*

The relative risk to the floodplain biodiversity endpoint showed an increasing trend in risk from Class A to Class D (Figure 159). The results revealed low risk for Classes A and B, with SD extending into the moderate risk range. The results for Class B revealed low to moderate risk with SD extending into the moderate risk range. Class D revealed moderate risk with SD extending into the high risk range. No high risk (>50%) to the riverine biodiversity was shown for this RR (Figure 160).

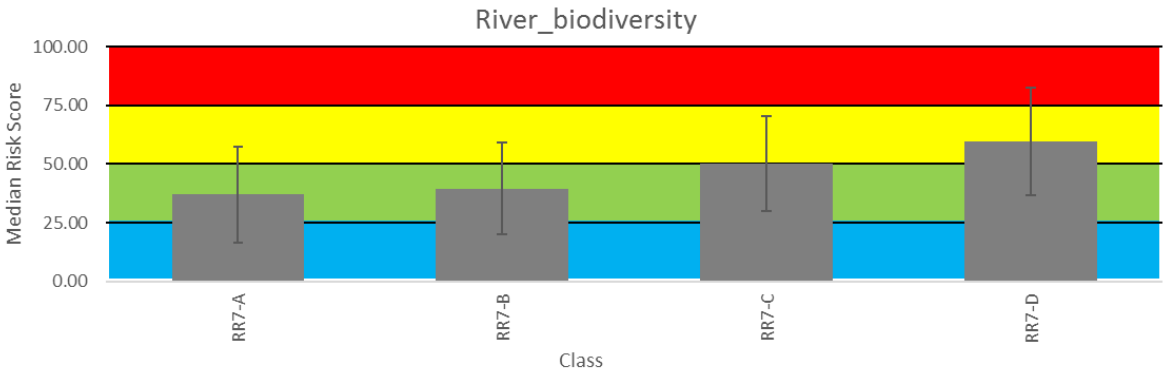


Figure 159: Relative Risk (median, with standard deviation) of multiple stressors associated with eflow scenarios to River biodiversity endpoint considered in the study (Class A (A), Class B (B), Class C (C) and Class (D)). Risk rank ranges for Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) risk included.

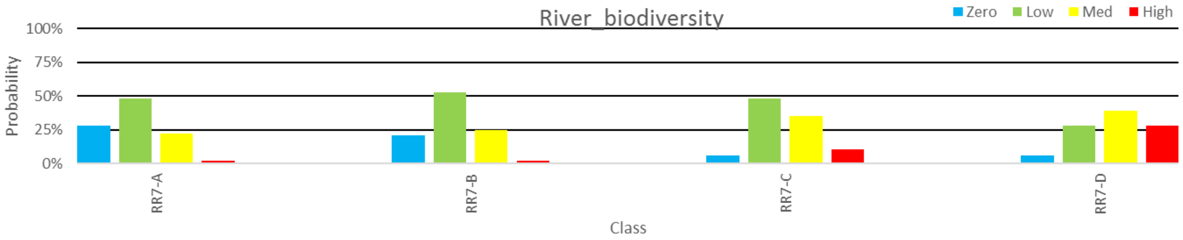


Figure 160: Probability of risk rank occurrence for ranks Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) of multiple stressors associated with eflow scenarios to River biodiversity endpoint considered in the study.

### 4.7.3 Conclusion for RR7

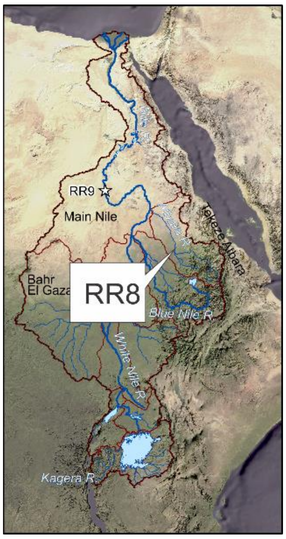
Low flows (dry and wet base flows) are important for the Blue Nile River and should be provided to ensure adequate habitats to maintain the ecology of the river. It is also important to note that the river is perennial and that the 99.9 percentile flow specified for each month provides for non-zero flows. Thus, any future operation of the system or water resource developments should accommodate the minimum flow requirements.

Results include increasing risk to endpoints as the ecological wellbeing of the rivers deteriorate from reference states to Class B, C and D ecological categories. Similarly, there is a high variability in the resilience and associated risk of altered flows to different endpoints. This includes relatively higher risk to the river biodiversity endpoint compared to the floodplain biodiversity and the ecosystem services associated with the river and floodplain ecosystems. A probability of high risk (>50%) was recorded for Class D for the river's services endpoint.

## 4.8 RR8 – Atbara River

The Atbara River originates in the Ethiopian Highlands and is one of the tributaries of the Main Nile River (NBI, 2012). The river reach selected for the assessment is at Kubor and Wad Elhiliew (Latitude 14.364169; longitude 35.855135).

The eflows for the Atbara River site (RR8) was not determined using PROBFLO but the Desktop Reserve hydrological assessment method by Hughes *et al.* (2014) due to the lack of suitable hydraulic and associated socio-ecological information.



### 4.8.1 Data Analysis

#### 4.8.1.1 Hydrology Assessment

The results are presented as tables showing the flow requirements for the highest and lowest flow month at selected percentile values and the annual flood requirements in terms of discharge, months when required and the duration in days. The hydrographs indicate the reference and base flows compared to the EFR. Flow duration curves (FDCs) per RR for selected months are also presented.

The Atbara River is a minor tributary of the lower Nile River with a record period spanning 1921-2001 with a Reference MAR of 12 616 MCM. The flow data shows that the Atbara River is almost a seasonal system with very low flows from December to April/ May. Thus, the flow requirements for selected months and percentiles (low flows and floods) that were used to determine the EFR included specific drought requirements for the river.

Limited ecological information was available for this EFR determination and the DRM output was used with only a few changes to at least maintain the base flows. The information available is summarised in Table 73 below.

Table 73: Selected flow requirements for RR8 – Atbara River

| | **Flow requirements ($m^3/s$) – low flows** | |
|---|---|---|
| **Percentiles** | **Feb** | **Aug** |
| 15 | - | 500 |
| 50 | 6.0 | 200 |
| 99.9 | 0.5 | 60 |
| | **Flow requirements– annual flood** | |
| | **Aug** | |
| Peak flows ($m^3/s$) | 2 500 | |
| Duration (days) | 10 | |

These selected requirements, together with the DRM were used to determine the EFR for each month. The results of the final EFR for RR8 is shown in Table 74 below.

Table 74: Final EFR for RR8 – Atbara River (flows in $m^3/s$)

| RR8 | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 13.47 | 10.39 | 10.58 | 11.90 | 14.08 | 28.01 | 305.73 | 647.78 | 317.21 | 85.94 | 39.25 | 22.63 |
| Minimum | 1.1 | 0.8 | 1.1 | 1.9 | 3.0 | 11.0 | 73.9 | 149.4 | 80.0 | 29.1 | 6.2 | 1.9 |
| Maximum | 18.2 | 14.2 | 13.8 | 15.2 | 17.7 | 32.0 | 432.2 | 928.0 | 482.4 | 104.5 | 50.3 | 31.0 |
| Percentiles | | | | | | | | | | | | |
| 0.1 | 18.2 | 14.2 | 13.8 | 15.2 | 17.7 | 32.0 | 432.2 | 928.0 | 482.4 | 104.5 | 50.3 | 31.0 |
| 1 | 18.2 | 14.2 | 13.8 | 15.2 | 17.7 | 32.0 | 432.2 | 928.0 | 482.4 | 104.5 | 50.3 | 31.0 |
| 5 | 18.2 | 14.2 | 13.8 | 15.2 | 17.7 | 32.0 | 432.2 | 928.0 | 482.4 | 104.5 | 50.3 | 31.0 |
| 10 | 18.2 | 14.2 | 13.8 | 15.2 | 17.7 | 32.0 | 430.5 | 924.8 | 473.0 | 104.5 | 50.3 | 31.0 |
| 15 | 18.2 | 14.2 | 13.8 | 15.2 | 17.7 | 32.0 | 413.6 | 872.4 | 460.6 | 104.5 | 50.3 | 31.0 |
| 20 | 18.2 | 14.2 | 13.7 | 15.2 | 17.7 | 31.9 | 402.5 | 854.2 | 436.1 | 104.5 | 50.3 | 30.9 |
| 30 | 18.0 | 14.0 | 13.6 | 15.0 | 17.6 | 31.8 | 376.9 | 802.8 | 406.2 | 103.9 | 49.9 | 30.6 |
| 40 | 17.5 | 13.9 | 13.5 | 14.8 | 17.3 | 31.6 | 353.1 | 749.5 | 374.8 | 102.3 | 48.5 | 29.8 |
| 50 (median) | 16.4 | 12.8 | 12.8 | 14.2 | 16.6 | 31.0 | 330.2 | 698.4 | 344.0 | 99.1 | 47.2 | 28.0 |
| 60 | 14.4 | 9.8 | 11.8 | 13.1 | 15.4 | 29.9 | 285.8 | 599.7 | 290.2 | 92.7 | 42.7 | 24.5 |
| 70 | 10.3 | 9.8 | 9.6 | 11.1 | 13.2 | 27.7 | 261.8 | 548.6 | 252.2 | 81.3 | 35.6 | 17.0 |
| 80 | 9.0 | 7.0 | 7.0 | 8.1 | 9.8 | 24.8 | 218.5 | 455.9 | 194.8 | 66.2 | 26.7 | 11.7 |
| 85 | 4.8 | 3.7 | 5.2 | 6.2 | 7.8 | 21.8 | 186.2 | 388.0 | 160.0 | 53.3 | 20.5 | 8.1 |
| 90 | 3.0 | 2.3 | 3.5 | 4.4 | 5.7 | 20.0 | 147.0 | 304.6 | 124.9 | 42.7 | 14.4 | 5.1 |
| 95 | 3.0 | 1.3 | 1.9 | 2.8 | 3.9 | 13.6 | 102.7 | 210.5 | 94.6 | 33.6 | 9.0 | 2.9 |
| 99 | 1.2 | 0.9 | 1.2 | 2.0 | 3.1 | 11.0 | 73.9 | 149.4 | 80.0 | 29.1 | 6.4 | 2.0 |
| 99.9 | 1.1 | 0.8 | 1.1 | 1.9 | 3.0 | 11.0 | 73.9 | 149.4 | 80.0 | 29.1 | 6.2 | 1.9 |

The summary of the EFR for RR8 (Table 75) shows that 30% of the flows in the Atbara River is required for ecological functioning, with the low flows (flows occurring more than 50% of the time) and flood requirements almost equally important. Thus, both flow components are important for the Atbara River and should be provided to ensure adequate habitats to maintain the ecology of the river. It is also important to note that the river is perennial, although with very low flows during the dry season, and that the 99.9 percentile flow specified for each month provides for non-zero flows. Thus, any future operation of the system or water resource developments should accommodate the minimum flow requirements.

Table 75: Summary of final EFR for RR8 – Atbara River

| RR | River | Reference (MCM) | % Requirement | | | | Volume Requirement (MCM) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Low flows | Drought flows | Floods | Total | Low flows | Drought flows | Floods | Total |
| RR8 | Atbara | 12 616 | 15.6 | 6.0 | 14.9 | 30.5 | 1 960 | 749 | 1 867 | 3 827 |

The monthly hydrograph of the REF, BF and EFR for a B state for the Atbara River is shown in Figure 161. This graph indicates that the EFR is almost equal to the reference low flows (see also FDC for February - Figure 162). Much less floods are required compared to the reference flows. However, it should be noted that the flood requirements are based on very limited ecological information and these results should be used with care when any water resource development that will impact on the high flows (Figure 163) of the Atbara River is considered.

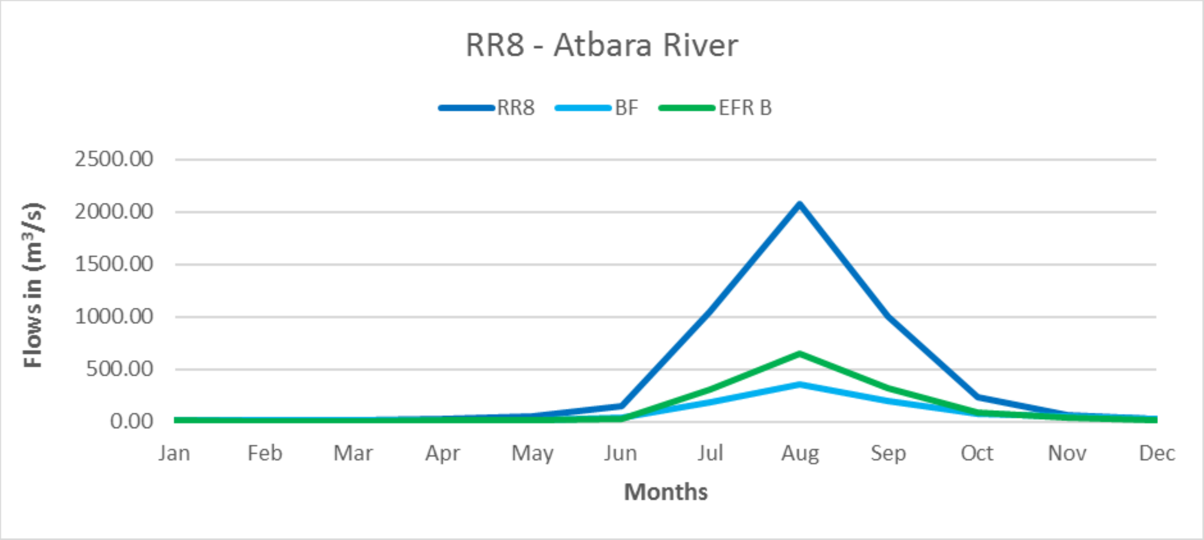


Figure 161: Monthly hydrograph for RR8 – Atbara River

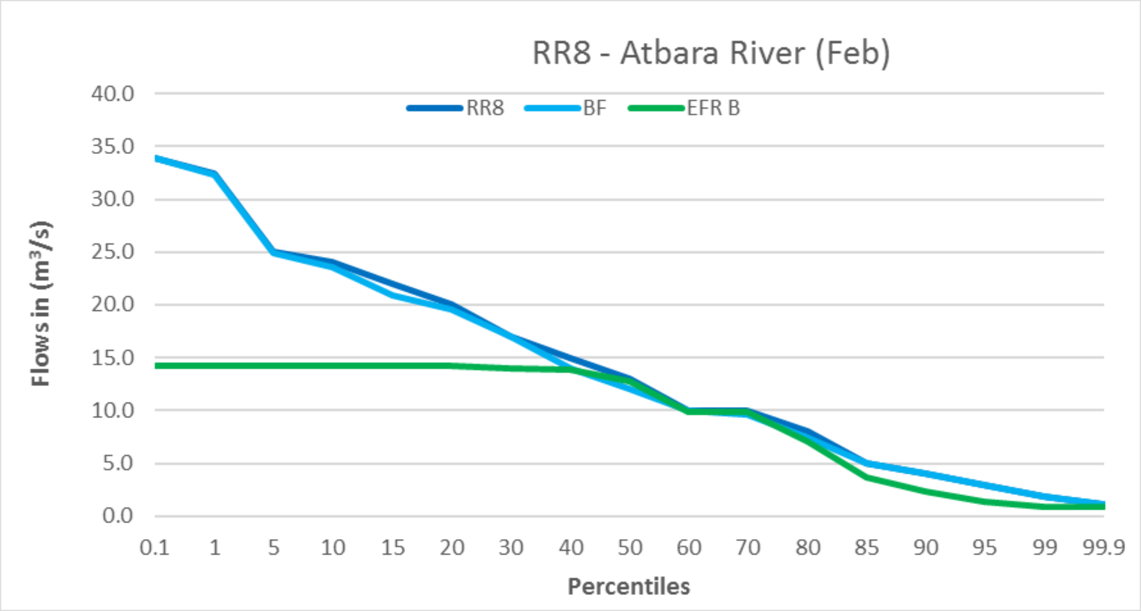


Figure 162: Flow duration curve for February (low flows) in RR8 – Atbara River

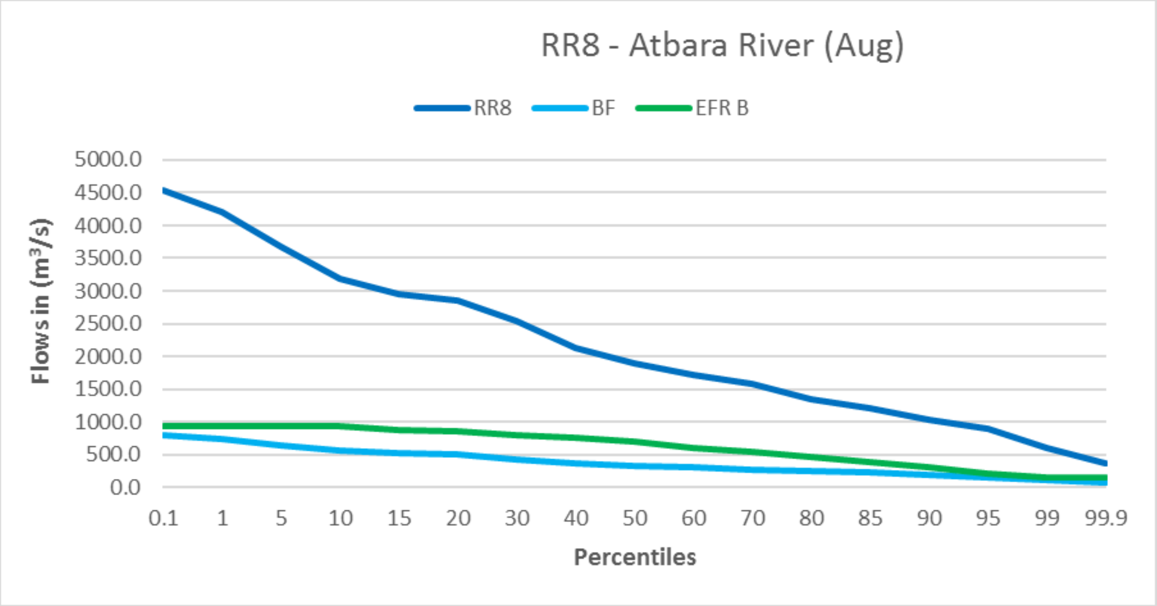


Figure 163: Flow duration curve for August (wet season) in RR8 – Atbara River

#### 4.8.1.2 Hydraulic Assessment

It must be noted, that the 1.5yr return period flow is only approximately depicting bankfull flow conditions. Therefore, additional cross section characteristics were investigated from which information about inundation extent and frequency could be deduced. These descriptions are briefly given for the points of interest. Each point of interest is individually assessed using QGIS with the Profile Tool and Quick Map Services Plugin on the MERIT DEM and Google Satellite images. The site location and ID (yellow dot with number, corresponds to the IDs given in Table 76) is shown together with the cross section location (red line) on satellite images (Google Earth/Digital Globe). Below the images, the diagram shows the cross section (elevation along the red line), where the small red dot in the upper satellite images is marked by the centre of the cross line in the lower diagram. Numbers in the diagram show elevation in mASL (y-Axis) and distance from left in meters (x-axis).

Table 76. Points of interest, the applied methodology for obtaining the channel cross section and additional channel and cross section properties

| ID | River | Latitude | Longitude | Channel bathymetry method | Bank width [m] | Ineffective area elevation [mASL] | Slope [m/m] |
|---|---|---|---|---|---|---|---|
| RR8 | Atbara | 14.3642 | 35.8551 | Bankfull | 317 | -- | 0.000364 |

At the Atbara cross section, no distinct settlement is located in proximity to the point of interest, only agricultural use of the floodplain exists (Figure 164; Figure 165). Channel bed incision was therefore calibrated based on bankfull flow. The channel bed was not further deepened but adjusted to a more parabolic shape as visible through the sandbanks on the satellite image. Roughness values were set to 0.04 for the channel and 0.06 for the floodplain.

Figure 164. Cross section and elevation at the Atbara with no particular reference point for deducing information for calibration of channel depths

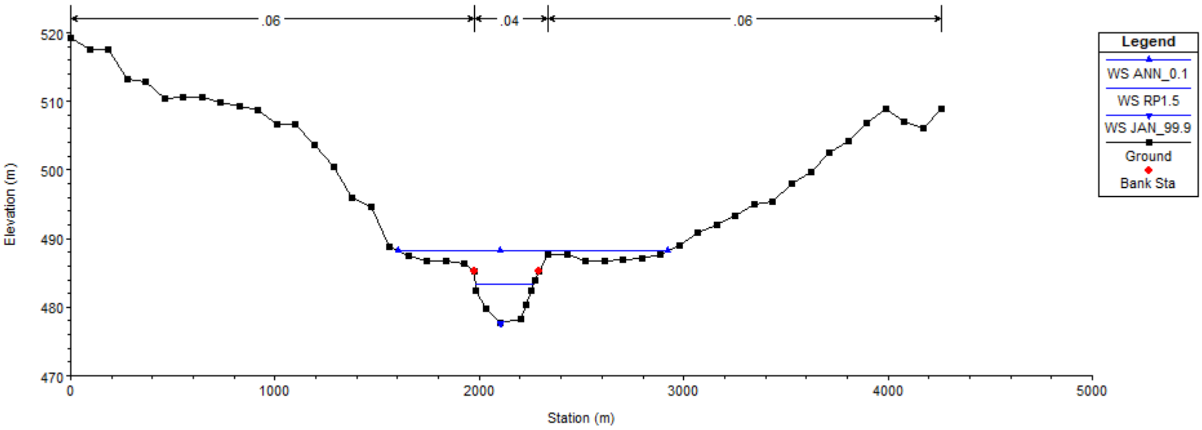


Figure 165: Cross sectional profile of the hydraulic site for RR8

### 4.8.1.3 Vegetation Assessment

This risk region is represented by the Atbara River at Kubor and Wad Elhiliew with the cross section shown as a red line in Figure 166. Vegetation at this site is scattered and sparse and is mostly represented by terrestrial species from the Sahelian savanna ecoregion, notably *Vachellia* (*Acacia*) *sahel* (Figure 166 and Figure 167). The active channel, which averages 270m wide appears to be fringed by a narrow band of tree and shrub species followed by extensive agriculture. It is likely that much of the natural riparian vegetation along the river has been replaced by agricultural species and activities. The area also appears to be erosion sensitive.

Figure 166: Google Earth © satellite image at Kubor and Wad Elhiliew on the Atbara River representing risk region 8.

Figure 167: Photograph showing the Atbara River and associated vegetation at Kubor and Wad Elhiliew (photo courtesy of Google Earth).

### 4.8.2 Calculate Risk

Following the determination of flows to maintain the ecosystems associated with each site in each ecological category a summary of the flow requirements associated with these scenarios is generated (Table 77). These hydrographs were used in the risk assessment as scenarios to compare the socio-ecological consequences of altered flows associated with each scenario (ecological category).

Table 77: Summary of the floods required to provide for key socio-ecological processes in the Nile River per ecological category Class considered in the study.

| RR | River | Flow Component | Percentage EFR per Ecological Class |
|---|---|---|---|

|  |  |  | B | C | D |
|---|---|---|---|---|---|
| 8 | Atbara River (Kubor and Wad Elhiliew) | Drought flows | 6.0% | 6.0% | 6.0% |
|  |  | Maintenance (or base) flows Low (or dry) period | 15.6% | 13.2% | 6.7% |
|  |  | Maintenance (or base) flows high (or wet) period | 14.9% | 8.9% | 6.9% |
|  |  | **Total** | **30.5%** | **22.1%** | **13.6%** |

The reference hydrographs and median flows for ecological categories B, C and D considered in the risk assessment for RR8 – Atbara River are graphically presented in Figure 168 and Figure 169. The data from this assessment has not been used in the PROBFLO assessment due to insufficient hydraulics and socio or ecological information.

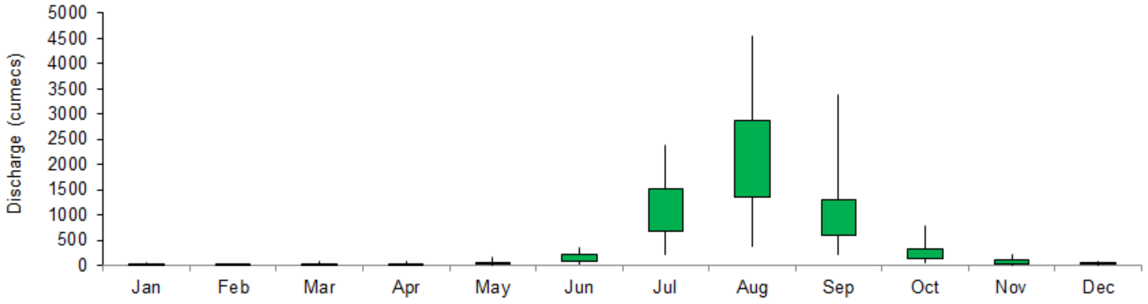


**Figure 168: Box and whisker plot summary of the reference (Class A) average monthly (m³/s) flows observed in RR8 in the study. Whiskers represent 0.01%tiles and 99.9%tiles and box 20%tile and 80%tiles.**

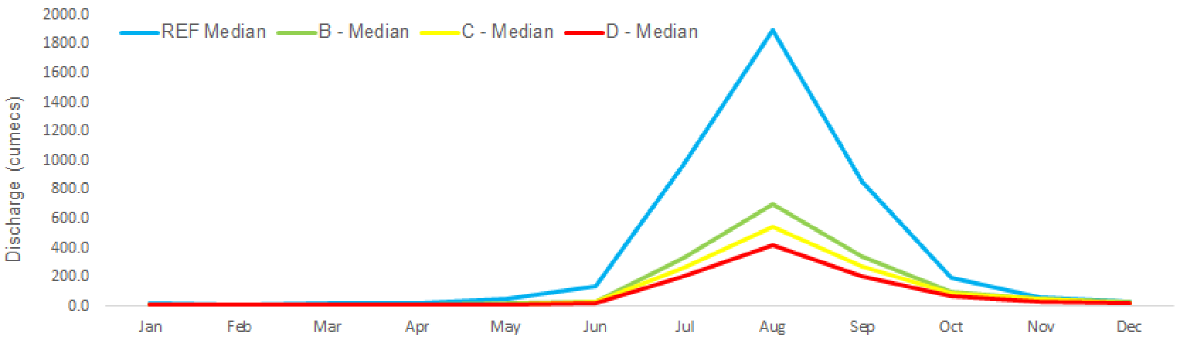


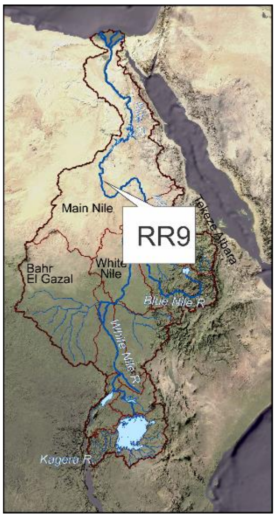
**Figure 169: Relative graphs (medians) of the reference (Class A or pristine), Class B (near natural), Class C (moderately modified) and Class D (largely modified) average monthly flows (m³/s) flows observed in RR8 in the study. Whiskers represent 0.01%tiles and 99.9%tiles and box 20%tile and 80%tiles.**

### 4.8.3 Conclusion for RR8

Both flow components are important for the Atbara River and should be provided to ensure adequate habitats to maintain the ecology of the river. It is also important to note that the river is perennial, although with very low flows during the dry season, and that the 99.9 percentile flow specified for each month provides for non-zero flows. Thus, any future operation of the system or water resource developments should accommodate the minimum flow requirements.

The PROBFLO assessment could not be undertaken due to insufficient hydraulics and socio or ecological information.

## 4.9 RR9 – Main Nile River



The Blue Nile and White Nile Rivers combine at Khartoum to from the Main Nile River that flows northwards into Lake Nasser from where it eventually discharges into the Mediterranean Sea at the Nile Delta (NBI, 2012).The Main Nile system is divided into two section by the High Aswan Dam. The section above the dam is the Main Nile in Sudan and the section downstream is the Egyptian Nile that includes the Nile Valley and the Nile Delta (NBI, 2008). The river reach selected for the assessment is at Dongola, upstream of Lake Nasser (Latitude 19.183147; longitude 30.489857).

### 4.9.1 Data Analysis

#### 4.9.1.1 Hydrology Assessment

The results are presented as tables showing the flow requirements for the highest and lowest flow month at selected percentile values and the annual flood requirements in terms of discharge, months when required and the duration in days. The hydrographs indicate the reference and base flows compared to the EFR. Flow duration curves (FDCs) per RR for selected months are also presented.

This reach is the main Nile River upstream of Lake Nasser with the site at Dongola. The record period of the flows is from 1944 to 2008 with a Reference MAR of 77 513 MCM. The monthly hydrograph shows that the Nile River in this reach has low and high flow characteristics, compared to the Nile River in the upper reaches (RR2, RR3 and RR6) that showed a much flatter hydrograph. This is mainly due to the influence of the flows from the Blue Nile River (RR7) with similar high and low flow seasons.
Thus, the flow requirements include drought flows that are specified separately to the maintenance low flows. The flow requirements for selected months and percentiles (low flows and floods) that were used to determine the EFR is summarised in Table 78 below.

Table 78: Selected flow requirements for RR9 – Nile River

| | **Flow requirements ($m^3/s$) – low flows** | |
|---|---|---|
| **Percentiles** | **Mar** | **Sep** |
| 15 | - | 2 000 |
| 50 | 600 | 1 300 |
| 99.9 | 200 | 960 |

| | **Flow requirements– annual floods** | | |
|---|---|---|---|
| | **Aug** | **Sep** | **Oct** |
| Peak flows ($m^3/s$) | 6 900 | 6 900 | 4 800 |
| Duration (days) | 14 | 14 | 10 |

These selected requirements, together with the DRM were used to determine the EFR for each month. The results of the final EFR for RR9 is shown in Table 79.

Table 79: Final EFR for RR9 – Nile River (flows in m³/s)

| RR9 | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 903.64 | 789.80 | 724.70 | 783.37 | 757.13 | 783.04 | 1300.81 | 2833.09 | 3125.50 | 1899.42 | 1375.16 | 1083.92 |
| Minimum | 289.6 | 267.3 | 231.4 | 247.1 | 239.2 | 237.8 | 325.6 | 645.9 | 706.7 | 495.0 | 373.7 | 308.8 |
| Maximum | 1150.3 | 1038.0 | 908.9 | 963.5 | 932.7 | 935.0 | 1711.7 | 3822.9 | 4497.6 | 2257.1 | 1574.6 | 1224.8 |
| Percentiles |  |  |  |  |  |  |  |  |  |  |  |  |
| 0.1 | 1150.3 | 1038.0 | 908.9 | 963.5 | 932.7 | 935.0 | 1711.7 | 3822.9 | 4497.6 | 2257.1 | 1574.6 | 1224.8 |
| 1 | 1150.3 | 1038.0 | 908.9 | 963.5 | 932.7 | 935.0 | 1711.7 | 3822.9 | 4497.6 | 2257.1 | 1574.6 | 1224.8 |
| 5 | 1150.3 | 1038.0 | 908.9 | 963.5 | 932.7 | 935.0 | 1711.7 | 3822.9 | 4497.6 | 2257.1 | 1574.6 | 1224.8 |
| 10 | 1150.3 | 1038.0 | 908.9 | 963.5 | 932.7 | 935.0 | 1707.1 | 3787.8 | 4473.3 | 2257.1 | 1574.6 | 1224.8 |
| 15 | 1150.3 | 1038.0 | 908.9 | 963.5 | 932.7 | 935.0 | 1675.0 | 3683.2 | 4309.5 | 2257.1 | 1574.6 | 1224.8 |
| 20 | 1149.7 | 1036.8 | 907.7 | 962.5 | 932.1 | 934.3 | 1644.6 | 3585.4 | 4156.2 | 2254.4 | 1573.4 | 1224.6 |
| 30 | 1140.4 | 1017.9 | 901.6 | 953.3 | 926.0 | 928.2 | 1580.8 | 3405.2 | 3868.3 | 2240.1 | 1562.9 | 1213.3 |
| 40 | 1114.6 | 937.3 | 862.6 | 936.9 | 907.3 | 913.3 | 1518.4 | 3218.7 | 3533.8 | 2199.7 | 1535.5 | 1187.6 |
| 50 (median) | 1030.8 | 910.8 | 803.1 | 911.9 | 878.1 | 897.2 | 1453.5 | 3056.0 | 3332.6 | 2118.1 | 1464.9 | 1130.0 |
| 60 | 966.8 | 785.8 | 742.1 | 845.8 | 817.1 | 829.4 | 1318.0 | 2706.8 | 2861.9 | 1956.0 | 1361.2 | 1087.9 |
| 70 | 801.2 | 694.3 | 693.5 | 743.2 | 700.9 | 774.5 | 1164.9 | 2483.9 | 2493.7 | 1682.7 | 1239.0 | 1065.8 |
| 80 | 585.5 | 520.4 | 533.6 | 574.5 | 557.2 | 661.3 | 993.5 | 2104.9 | 1964.2 | 1450.6 | 1227.9 | 1021.2 |
| 85 | 458.2 | 400.7 | 427.6 | 469.6 | 438.0 | 526.1 | 824.6 | 1783.3 | 1887.3 | 1434.1 | 1210.9 | 968.1 |
| 90 | 374.8 | 337.6 | 345.3 | 362.9 | 343.2 | 419.5 | 645.2 | 1721.3 | 1855.4 | 1395.2 | 1180.5 | 855.8 |
| 95 | 322.7 | 292.8 | 273.7 | 290.3 | 286.2 | 325.2 | 462.9 | 1642.6 | 1780.6 | 1350.8 | 1137.4 | 747.0 |
| 99 | 289.6 | 267.3 | 231.4 | 247.1 | 239.2 | 237.8 | 325.6 | 645.9 | 706.7 | 495.0 | 373.7 | 308.8 |
| 99.9 | 289.6 | 267.3 | 231.4 | 247.1 | 239.2 | 237.8 | 325.6 | 645.9 | 706.7 | 495.0 | 373.7 | 308.8 |

The summary of the EFR for RR9 (Table 80) shows that 55% of the flows in the Nile River is required for ecological functioning, with the low flows (flows occurring more than 50% of the time) making up the bulk of the requirement and floods only 14% of the ecological requirement. Thus, low flows (dry and wet base flows) are important for the Nile River and should be provided to ensure adequate habitats to maintain the ecology of the river. It is also important to note that the river is perennial and that the 99.9 percentile flow specified for each month provides for non-zero flows. Thus, any future operation of the system or water resource developments should accommodate the minimum flow requirements.

Table 80: Summary of final EFR for RR9 – Nile River

| **RR** | **River** | **Reference (MCM)** | **% Requirement** | | | | **Volume Requirement (MCM)** | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | **Low flows** | **Drought flows** | **Floods** | **Total** | **Low flows** | **Drought flows** | **Floods** | **Total** |
| RR9 | Nile | 77 513 | 41.3 | 13.2 | 13.6 | 55.0 | 31 969 | 10 209 | 10 554 | 42 523 |

The monthly hydrograph of the REF, BF and EFR for a B state for the Nile River is shown in Figure 170. This graph indicates that the EFR requires a large proportion of the base flows during the low flow season (see also FDC for March - Figure 171). Much less flows are required during the wet season as can be seen in the FDC for September (Figure 172).

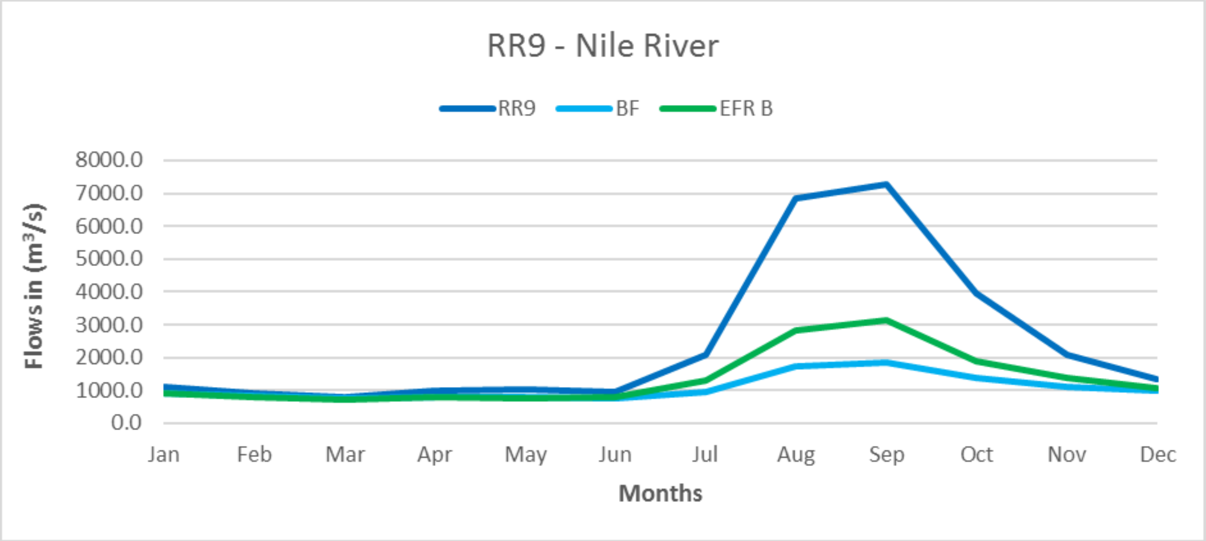


Figure 170: Monthly hydrograph for RR9 – Nile River

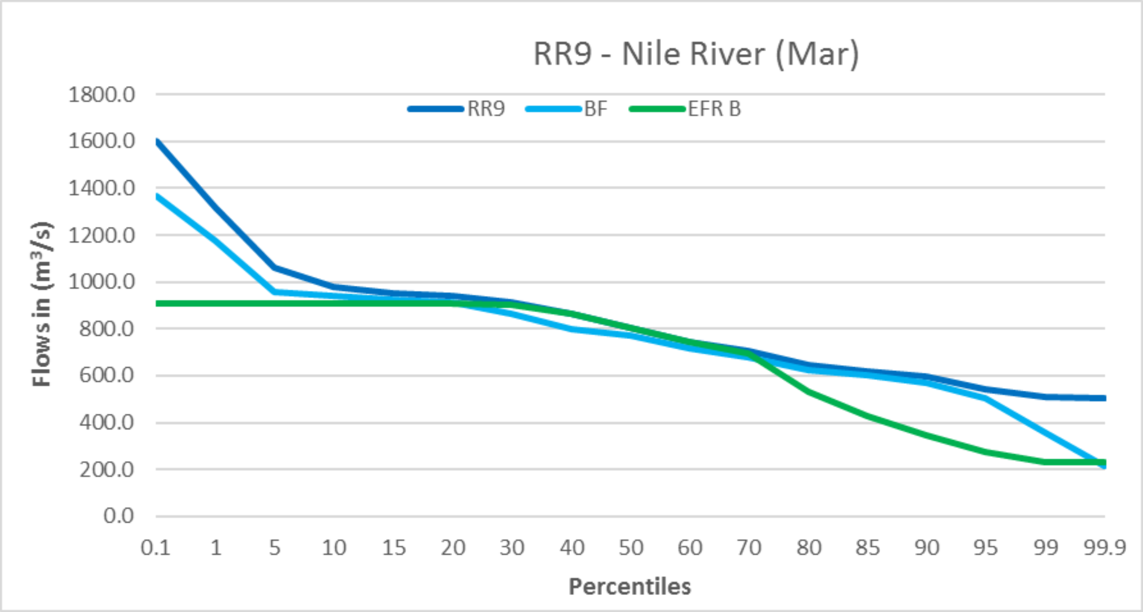


Figure 171: Flow duration curve for March (low flows) in RR9 – Nile River

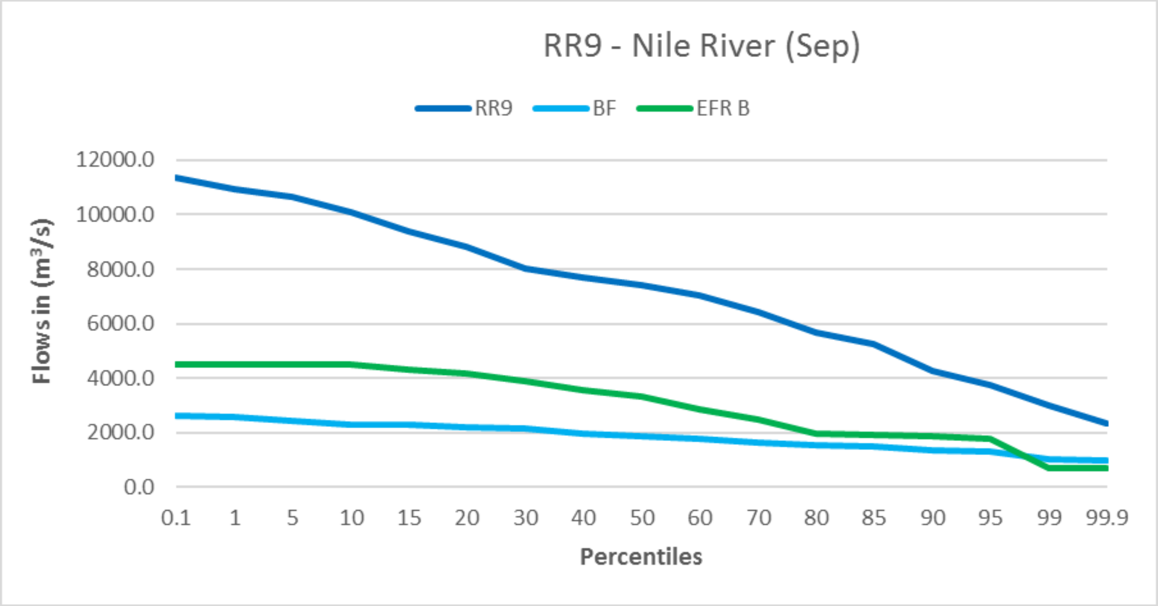


Figure 172: Flow duration curve for September (wet season) in RR9 – Nile River

#### 4.9.1.2 Hydraulic Assessment

It must be noted, that the 1.5yr return period flow is only approximately depicting bankfull flow conditions. Therefore, additional cross section characteristics were investigated from which information about inundation extent and frequency could be deduced. These descriptions are briefly given for the points of interest. Each point of interest is individually assessed using QGIS with the Profile Tool and Quick Map Services Plugin on the MERIT DEM and Google Satellite images. The site location and ID (yellow dot with number, corresponds to the IDs given in Table 81) is shown together with the cross section location (red line) on satellite images (Google Earth/Digital Globe). Below the images, the diagram shows the cross section (elevation along the red line), where the small red dot

in the upper satellite images is marked by the centre of the cross line in the lower diagram. Numbers in the diagram show elevation in mASL (y-Axis) and distance from left in meters (x-axis).

**Table 81. Points of interest, the applied methodology for obtaining the channel cross section and additional channel and cross section properties**

| ID | River | Latitude | Longitude | Channel bathymetry method | Bank width [m] | Ineffective area elevation [mASL] | Slope [m/m] |
|---|---|---|---|---|---|---|---|
| RR9 | MainNile | 19.1831 | 30.4899 | Flood level | 681 | 227 | 0.000068 |

For the Dongola Cross section, buildings are constructed at an elevation of about 227m and higher. During the 1988 floods, flows at Dongola are estimated with 13.000m³/s and a gauge water level of 15.7m, which is equivalent to a 50-100yr RP flood (Sutcliffe *et al*, 1989). This led to “Badan and Maad island near Dongola submerged by Nile and inhabitants evacuated”[5]. The exact location of the islands could not be found, but inhabited Nile islands in proximity to Dongola have a maximum elevation of about 229mASL. It can hence be expected, that inundation at Dongola is mostly below the 227m contour and for the peak discharge of 13.000m³/s at about 229mASL. No survey data is available at Dongola. Using the described data, channel depth was calibrated to 6.5m below the MERIT DEM water surface elevation and to roughness values of 0.03 for the channel and 0.035 for the floodplain (Figure 173; Figure 174)

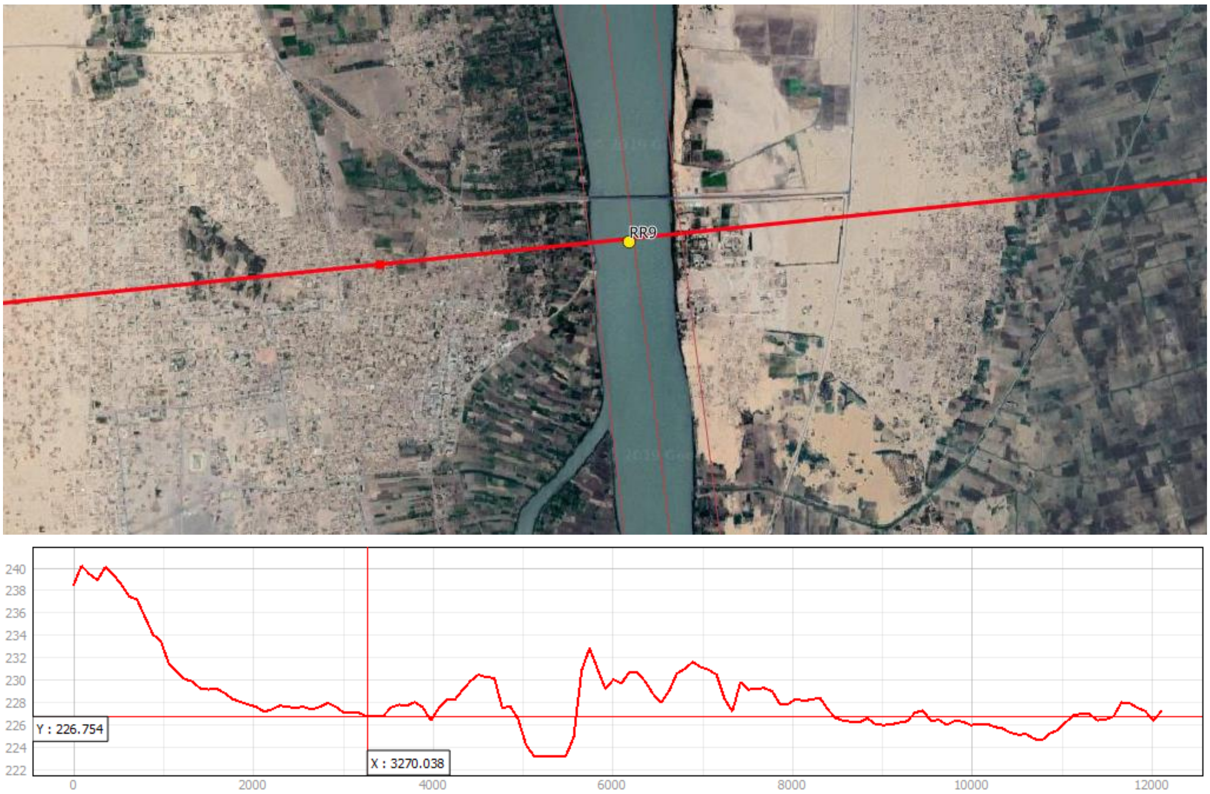


Figure 173. Cross section and elevations at Dongola, Note the buildings at the elevation starting from 227mASL.

---

[5] https://reliefweb.int/report/sudan/sudan-floods-aug-1988-undro-situation-reports-1-13

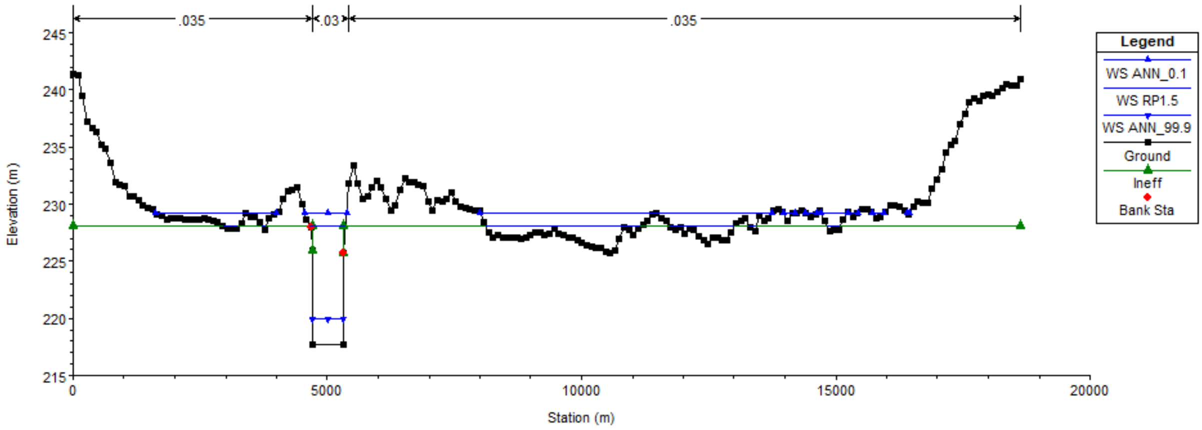


Figure 174: Cross sectional profile of the hydraulic site for RR9

### 4.9.1.3 Vegetation Assessment

This risk region is represented by the Main Nile upstream of Lake Nasser at Dongola with the cross section shown as a red line in Figure 175. Vegetation at this site is restricted to the macro channel associated with the river and farther out vegetation is irrigated. Despite traversing the Sahara Desert the channel supports a clear linear woody riparian zone with several non-woody hydrophytes within the channel confines where it has not been altered for agriculture (Figure 175 and Figure 176). The active channel is wide, averaging 655m. This sub-zone is extensively utilised for agricultural activities, which will include grazing of livestock.

Figure 175: Google Earth © satellite image at Dongola on the Main Nile upstream of Lake Nasser representing risk region 9.

Figure 176: Photograph showing the Main Nile upstream of Lake Nasser and associated vegetation at Dongola (photo courtesy of Google Earth).

Based on the available biological information at cross section sites, and together with hydraulics at each site, the driver components [within the model] were quantified for a B-category (Table 82) as determined by discernible riparian indicators (Table 83). Interpolation was frequently required due to lack of biological data specific to sites.

Table 82: Quantification of driver components for a B-category system (Values are discharge).

| General description | | RR9 |
|---|---|---|
| Bank full for non-woody fringe vegetation | Wet Base | 3780 |
| Wet base less 1m in elevation | Dry Base | 860 |
| Wet base less 1.5m in elevation | Critical Low | 345 |
| Between woody and non-woody limits | Freshette | 4500 |
| To the base of woody vegetation (Tall tree line) | Annual flood | 6900 |

Table 83: Riparian indicators utilized to quantify driver components for a B-category system.

| RR9 | channel width (m) | Discharge | Chan depth | Month | Indicators |
|---|---|---|---|---|---|
| Wet Base | 625 | 3780 | 7.37 | Sep | Base of tree line |
| Dry Base | | 860 | 4.87 | Mar | 2.5m below tree line for phreatophytes |
| Critical Low | | 345 | 3.87 | Mar | Less 1m |
| Freshette | | 4500 | | | |
| Annual flood | | 6900 | | Aug | Used bank full stat |

### Defining Risk to Vegetation

The alteration of driver dynamics, in this case flows and by implication floods, results in risk to the vegetation. Optimal driver state results in low risk to all vegetation endpoints but does not consider the effects of non-flow related impacts, such as ever increasing grazing and trampling pressures, and the impacts of human density and resource use. However, as flows may decline so the risk to vegetation endpoints increases. This risk has been described and quantified for each of the response variables (Table 84), as well as for each of the response variables within different risk regions, and represents declining ecological health or ecosystem wellbeing.

Table 84: Justifications and driver quantification for interaction of vegetation components within the model.

| Bayesian Network variable title, measure - (BN node name) | Rank (score) | Rank definition and measure for variable | RR9 |
|---|---|---|---|
| Aveghab_R_bwet | Zero (25) | 10% higher percentile than B] base | > 3880 |
| | Low (50) | bank full for non-woody vegetation | 3880 - 3480 |
| | Moderate (75) | between [B] dry base and [B] wet base | 3480 - 860 |
| | High (100) | as low as normal (B) dry base | < 860 |
| FPveg_FP_bwet | Zero (25) | 10% higher percentile than B] base | > 3880 |
| | Low (50) | bank full for non-woody vegetation | 3880 - 3480 |
| | Moderate (75) | between [B] dry base and [B] wet base | 3480 - 860 |
| | High (100) | as low as normal (B) dry base | < 860 |
| Aveghab_R_drought | Zero (25) | 95% [B] dry season max month | > 345 |
| | Low (50) | critical low flows for [B] | 345 - 275 |
| | Moderate (75) | 99% dry season max | 275 - 232 |
| | High (100) | | < 232 |
| Aveghab_R_bdry | Zero (25) | wet base | > 1040 |
| | Low (50) | wet base less 1m | 1040 - 860 |
| | Moderate (75) | critical low | 860 - 345 |
| | High (100) | critical low | < 345 |
| FPveg_FP_flood | Zero (25) | to the base of woody vegetation (Tall tree line):annual | > 6900 |
| | Low (50) | between woody and non-woody limits: freshette | 6900 - 4500 |
| | Moderate (75) | no flood: 20% higher than wet base percentile | 4500 - 4000 |
| | High (100) | | < 4000 |
| Subveg_R_bdry | Zero (25) | wet base | > 1040 |
| | Low (50) | wet base less 1m | 1040 - 860 |
| | Moderate (75) | critical low | 860 - 345 |
| | High (100) | critical low | < 345 |
| Subveg_R_bwet | Zero (25) | 10% higher percentile than B] base | > 3880 |
| | Low (50) | bank full for non-woody vegetation | 3880 - 3480 |
| | Moderate (75) | between [B] dry base and [B] wet base | 3480 - 860 |
| | High (100) | as low as normal (B) dry base | < 860 |
| Subveg_FP_bdry | Zero (25) | wet base | > 1040 |
| | Low (50) | wet base less 1m | 1040 - 860 |
| | Moderate (75) | critical low | 860 - 345 |
| | High (100) | critical low | < 345 |
| Subveg_FP_bwet | Zero (25) | 10% higher percentile than B] base | > 3880 |
| | Low (50) | bank full for non-woody vegetation | 3880 - 3480 |
| | Moderate (75) | between [B] dry base and [B] wet base | 195 - 90 |
| | High (100) | as low as normal (B) dry base | < 90 |

#### 4.9.1.4 Fish Assessment

For the determination of instream flow requirements for the Main Nile River (Sudan) four species of fishes that have habitat and or migratory requirements that occur within the river were selected for the assessment (Table 85). Based on the relative size species attains and biology and ecology information the depth and velocity requirements were determined as well as minimum depths to maintain lateral and longitudinal migrations for these indicator species. This information was aligned to the seasonal flows of the system and used to establish flow requirements that were provided to the hydrologist to determine eflow requirements (Figure 177, Figure 178 and Figure 179).

**Table 85: Fishes selected to determine eflows for RR9. Hypothesised preferences for habitats (depth and velocity) and migratory notes provided for each species.**

| Min. Depth (mm) | Min. Vel (m/s) | Weight | Lower Nile River indicator spp. | Details |
|---|---|---|---|---|
| 1000 | 1.2 | 3 | *Labeo sp.* | Good rheophillic species long.↑↑ & lat. Potamodromous migrations. |
| 2000 | 1.2 | | *Labeobarbus spp.* | Good rheophillic species long.↑↑ & lat. Potamodromous migrations. |
| 2000 | 0.8 | 3 | *Hydrocynus sp.* | Good rheophillic species long.↑↑ & lat. Potamodromous migrations. |
| 1200 | 0.8 | 2 | *Bagrus spp.* | Semi-rheophillic species long.↑↑ & lat. Potamodromous migrations. |

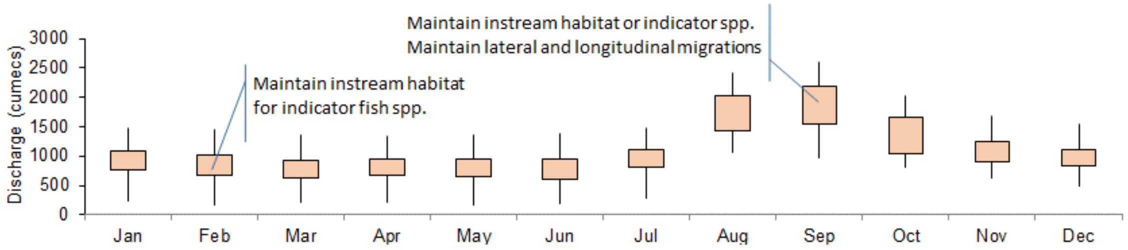


Figure 177: Reference hydrograph from RR9 with key fish biology and ecology requirements.

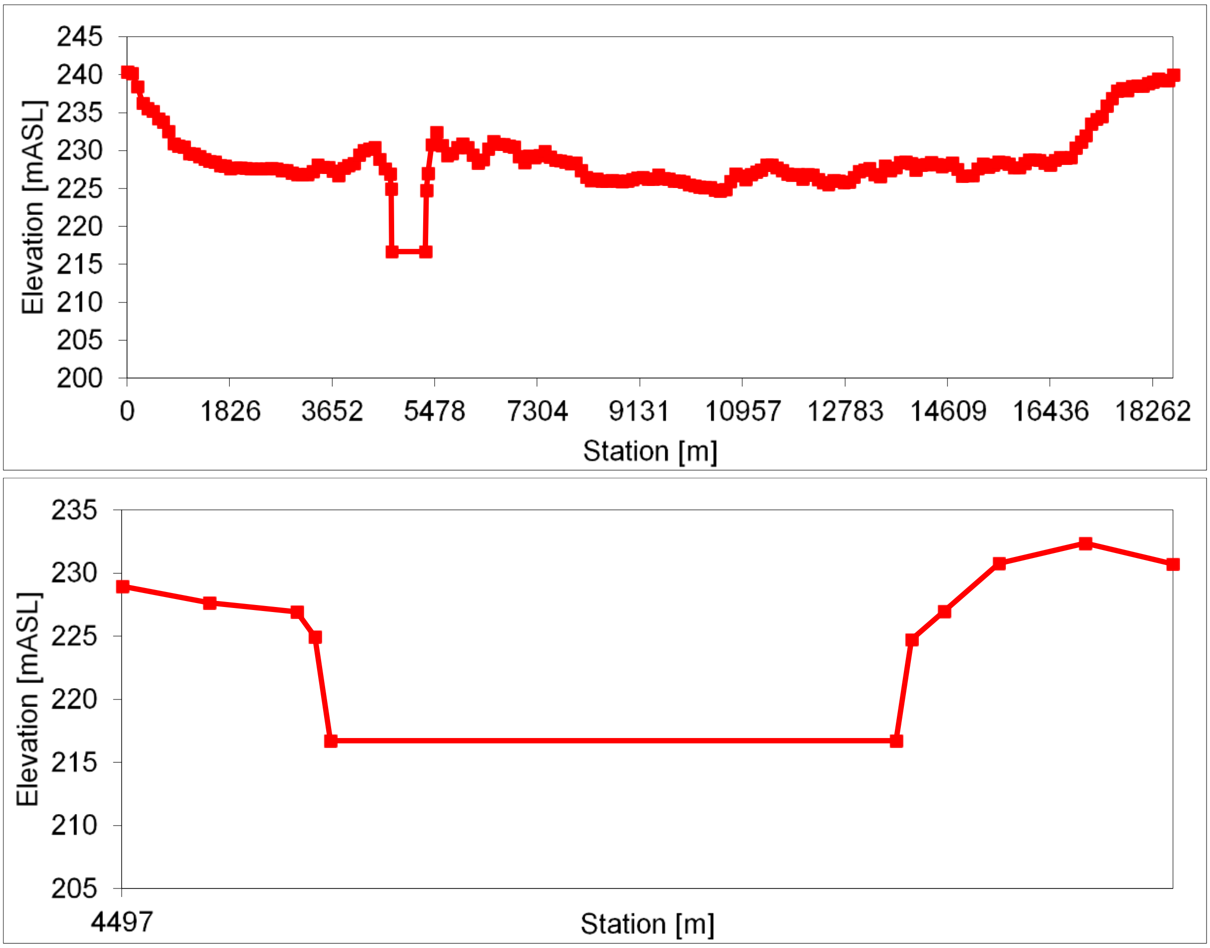


Figure 178: Cross section of RR9 with flow elevations highlighted for key fish biology and ecology events selected in the study for eflow determination.

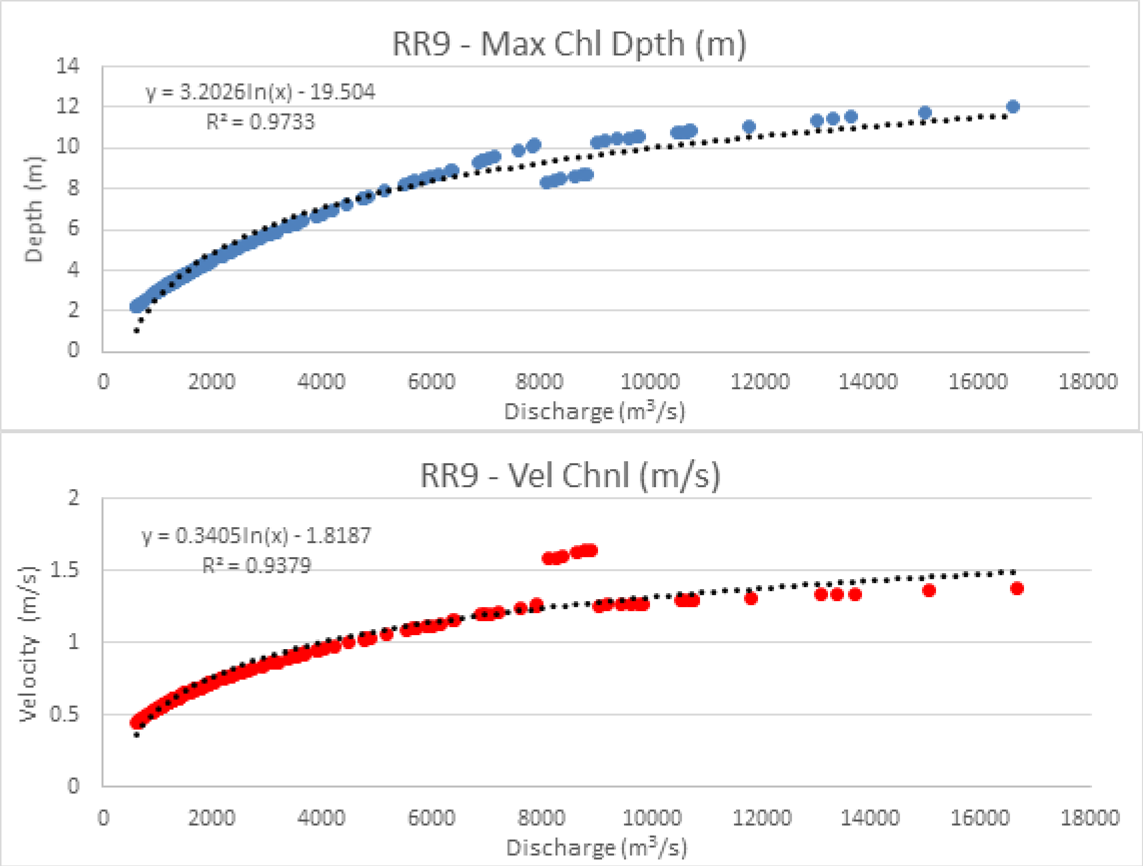


Figure 179: Flow depth (Blue) and Velocity depth (Red) relationships established for the study used to determine flow requirements for fishes.

### 4.9.2 Calculate Risk

Following the determination of flows to maintain the ecosystems associated with each site in each ecological category a summary of the flow requirements associated with these scenarios is generated (Table 86). These hydrographs were used in the risk assessment as scenarios to compare the socio-ecological consequences of altered flows associated with each scenario (ecological category).

Table 86: Summary of the floods required to provide for key socio-ecological processes in the Nile River per ecological category Class considered in the study.

| RR | River | Flow Component | Percentage EFR per Ecological Class | | |
|---|---|---|---|---|---|
| | | | B | C | D |
| 9 | Nile River (Dongola) | Drought flows | 13.2% | 13.2% | 12.6% |
| | | Maintenance (or base) flows Low (or dry) period | 41.3% | 23.4% | 15.7% |
| | | Maintenance (or base) flows high (or wet) period | 13.6% | 8.2% | 5.5% |
| | | **Total** | **55.0%** | **31.6%** | **21.2%** |

The reference hydrographs and median flows for ecological categories B, C and D considered in the risk assessment for RR9 – Main Nile River are graphically presented in Figure 180 and Figure 181. The rank thresholds for indicators selected for this site were used to query this hydrology data and evaluate the socio-ecological consequences of altered flows in the system using PROBFLO.

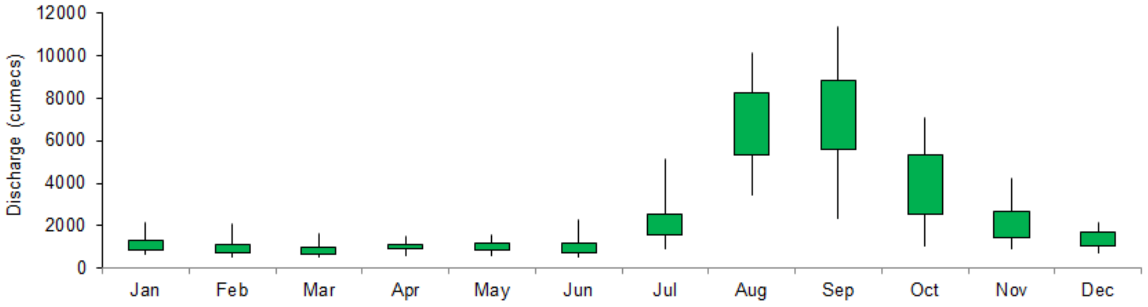


**Figure 180: Box and whisker plot summary of the reference (Class A) average monthly ($m^3/s$) flows observed in RR9 in the study. Whiskers represent 0.01%tiles and 99.9%tiles and box 20%tile and 80%tiles.**

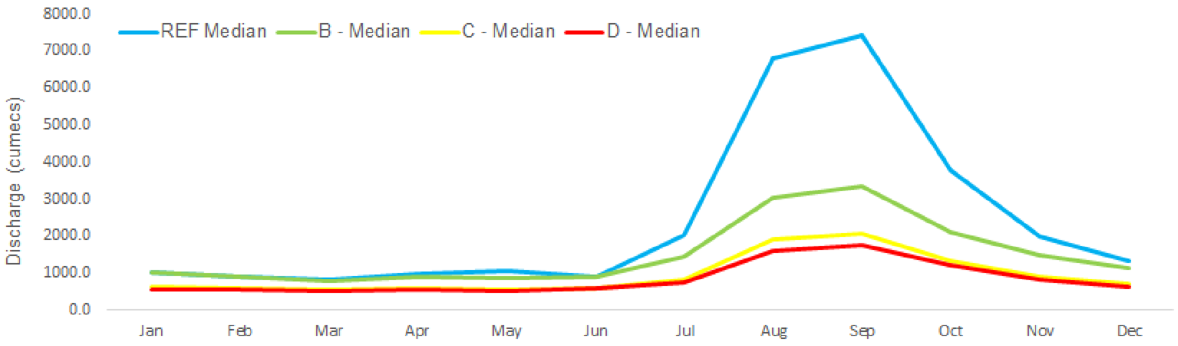


**Figure 181: Relative graphs (medians) of the reference (Class A or pristine), Class B (near natural), Class C (moderately modified) and Class D (largely modified) average monthly flows ($m^3/s$) flows observed in RR9 in the study. Whiskers represent 0.01%tiles and 99.9%tiles and box 20%tile and 80%tiles.**

Risk outcomes directly obtained from the Netica Bayesian Network assessment are presented per RR with averages, standard deviation (SD) and risk rank probability profiles.

### *Floodplain ecosystem services endpoint*

The relative risk to the floodplain ecosystem serves endpoint showed an increasing trend in risk from Class A to Class D (Figure 182). The results for Class A and B revealed low risk with SD extending into the moderate risk range. The results for Class C and D revealed moderate risk with SD extending into the high risk range From Figure 183, no possibility of high (>50%) risk to the floodplain services for this RR.

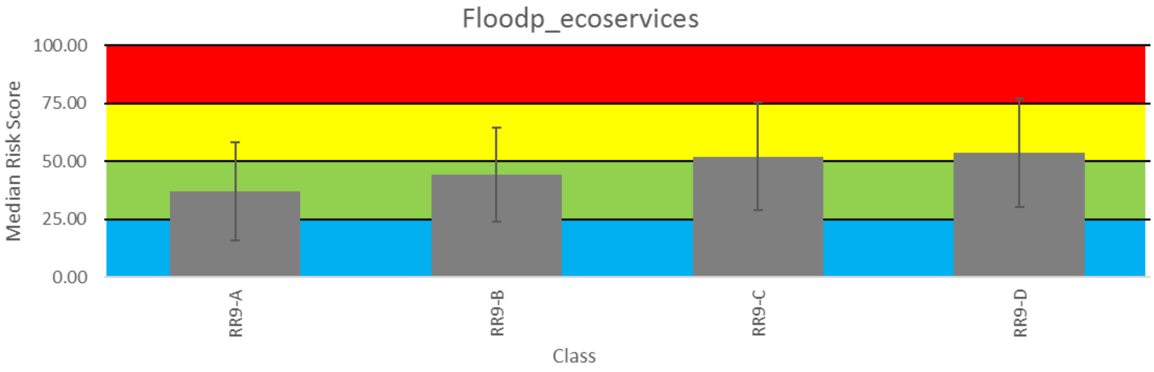


**Figure 182: Relative Risk (median, with standard deviation) of multiple stressors associated with eflow scenarios to Floodplain ecosystem services endpoint considered in the study (Class A (A), Class B (B), Class C (C) and Class (D)). Risk rank ranges for Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) risk included.**

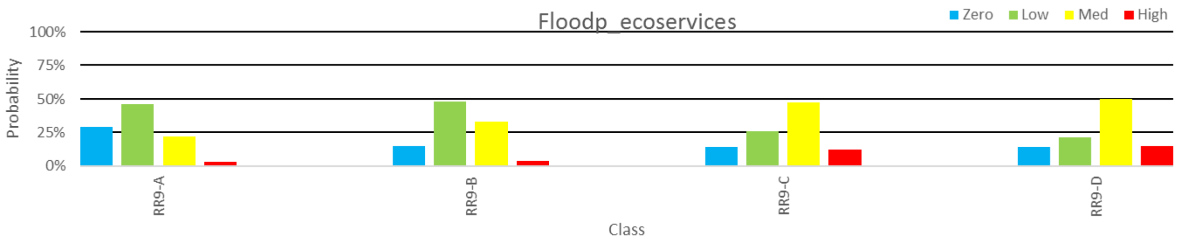


**Figure 183: Probability of risk rank occurrence for ranks Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) of multiple stressors associated with eflow scenarios to Floodplain ecosystem services endpoint considered in the study.**

***River ecosystem services endpoint***

The relative risk to the river ecosystem services endpoint showed an increasing trend in risk from Class A to Class D (Figure 184). The results for Class A to D were dominated by low risk with SD extending into the moderate risk range. Results in Figure 185 includes no probabilities of high risk (>45%) to the RR.

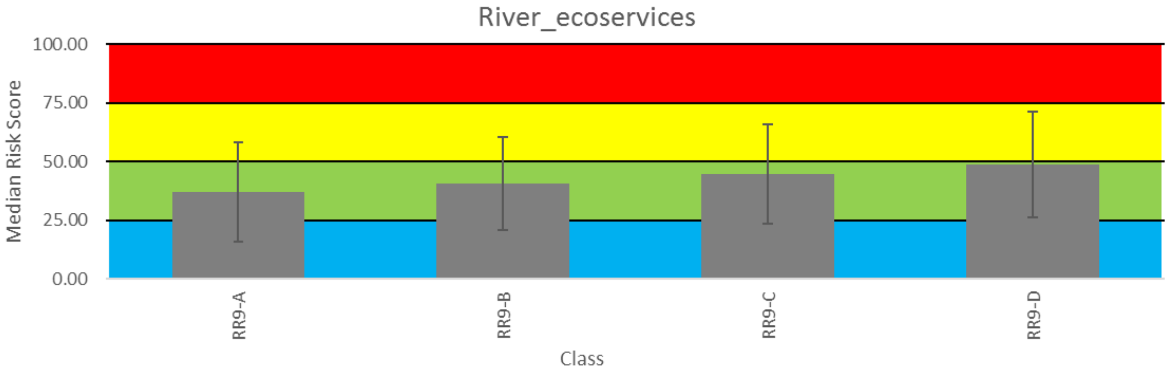


**Figure 184: Relative Risk (median, with standard deviation) of multiple stressors associated with eflow scenarios to River ecosystem services endpoint considered in the study (Class A (A), Class B (B), Class C (C) and Class (D)). Risk rank ranges for Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) risk included.**

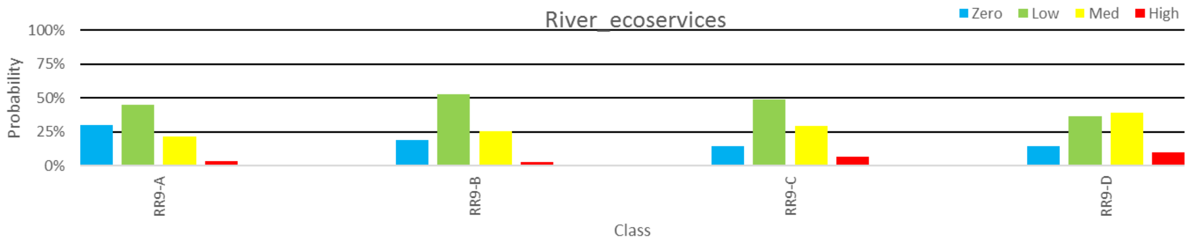


Figure 185: Probability of risk rank occurrence for ranks Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) of multiple stressors associated with eflow scenarios to River ecosystem services endpoint considered in the study.

### *Floodplain biodiversity endpoint*

The relative risk to the floodplain biodiversity endpoint showed an increasing trend in risk from Class A to Class D (Figure 186). The results for Class A revealed low risk with SD staying within the low risk range. The results for Class B to D revealed moderate risk with SD extending into the high risk range. No probability of high risk (>50%) to the endpoint for this RR (Figure 187).

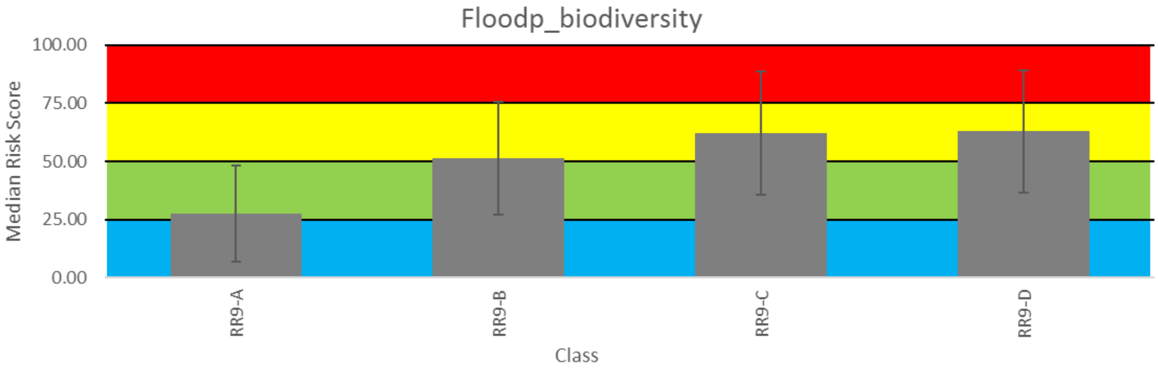


Figure 186: Relative Risk (median, with standard deviation) of multiple stressors associated with eflow scenarios to Floodplain biodiversity endpoint considered in the study (Class A (A), Class B (B), Class C (C) and Class (D)). Risk rank ranges for Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) risk included.

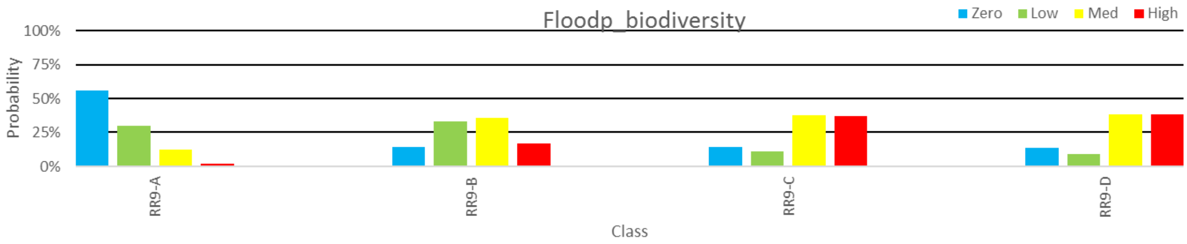


Figure 187: Probability of risk rank occurrence for ranks Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) of multiple stressors associated with eflow scenarios to Floodplain biodiversity endpoint considered in the study.

### *River biodiversity endpoint*

The relative risk to the floodplain biodiversity endpoint showed an increasing trend in risk from Class A to Class D (Figure 188). The results revealed low risk for all the Classes (Classes A to D), with SD often extending into the moderate risk range. No high risk (>50%) to the riverine biodiversity was shown for this RR (Figure 189).

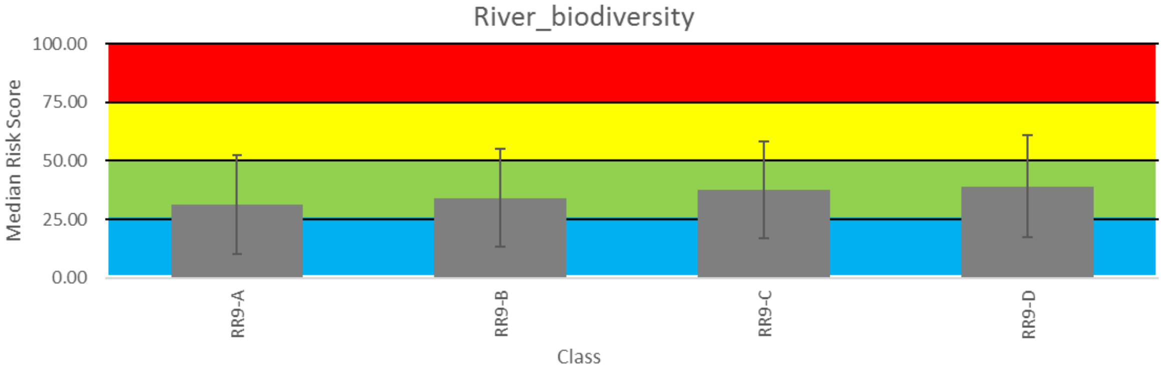


Figure 188: Relative Risk (median, with standard deviation) of multiple stressors associated with eflow scenarios to River biodiversity endpoint considered in the study (Class A (A), Class B (B), Class C (C) and Class (D)). Risk rank ranges for Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) risk included.

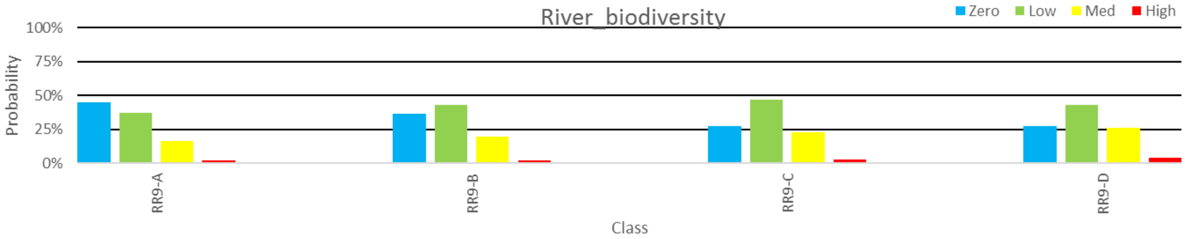


Figure 189: Probability of risk rank occurrence for ranks Zero (Blue), Low (Green), Moderate (Yellow) and High (Red) of multiple stressors associated with eflow scenarios to River biodiversity endpoint considered in the study.

### 4.9.3 Conclusion for RR9

Low flows (dry and wet base flows) are important for the Nile River and should be provided to ensure adequate habitats to maintain the ecology of the river. It is also important to note that the river is perennial and that the 99.9 percentile flow specified for each month provides for non-zero flows. Thus, any future operation of the system or water resource developments should accommodate the minimum flow requirements.

Results include increasing risk to endpoints as the ecological wellbeing of the rivers deteriorate from reference states to Class B, C and D ecological categories. Similarly, there is a high variability in the resilience and associated risk of altered flows to different endpoints. This includes relatively higher risk to the floodplain biodiversity endpoint compared to the riverine biodiversity and the ecosystem services associated with the river and floodplain ecosystems. No probability of high risk (>50%) was recorded for any endpoint.

# 5 RECOMMENDATIONS

The coarse eflows assessment has developed eflow analysis for various river reaches in the Nile basin, focusing on nine representative sites with favourable data situation based on existing datasets. The analysis of these sites comparing the current typical flow envelope against eflow requirements for e.g. "B" status environmental flow requirements shows that already now eflow requirements are not fulfilled under certain low flow conditions for a number of sites. In addition, several reaches face challenges due to future development plans. Before implementing and operationalizing such developments, it is strongly recommended to conduct additional, in-depth environmental flow studies, to ensure holistic consideration of benefits of the developments.

An overview of the sites is provided in Table 86. Detailed descriptions of the conditions of the related segments are provided in the following paragraphs, describing risk aspects and potential measures, considering upstream-downstream relations. In addition to the individual reaches, also the basin wide conditions as well as cumulative, basin wide effects are to be considered.

Table 86: Overview of river reaches

| RR | River | Reach Name | Site/ Weir |
|---|---|---|---|
| RR1 | Kagera | Kagera River | Kyaka Ferry |
| RR2 | Victoria Nile | Victoria Nile downstream of Lake Victoria | Jinja |
| RR3 | Bahr el Jebel | Bahr el Jebel upstream of Sudd inflow | Mongala |
| RR4 | Baro River | Baro River upstream of Machar Marshes | Gambela |
| RR5 | Sobat | Sobat River upstream of mouth (confluence with White Nile) | Hillet Doleib |
| RR6 | White Nile | White Nile upstream of Jebel Aulia | Malakal |
| RR7 | Blue Nile | Blue Nile downstream of GERD | El Diem/Roseires |
| RR8 | Atbara | Atbara River | Kubor, Wad Elhiliew |
| RR9 | Nile | Main Nile upstream of Lake Nasser | Dongola |

RR1 - Kagera

The Kagera is characterized by wetlands and agricultural areas with the latter increasing and encroaching both forested as well as wetland areas, leading to landcover change, and respectively to changed, runoff patterns. In addition, water abstraction for irrigation is leading to a reduction of flows with respective impacts on the environment, especially during low flow conditions. It would be of particular interest here to assess these development scenarios in the Kagera basin to fully understand impacts on the environment and livelihoods. The results of the assessments, same as e.g. in the Mara, would provide a good set of information, that, within limitation, can also be projected to other upper catchment sites in the basin. Flows as compared to environmental flow requirements are shown in Figure 190.

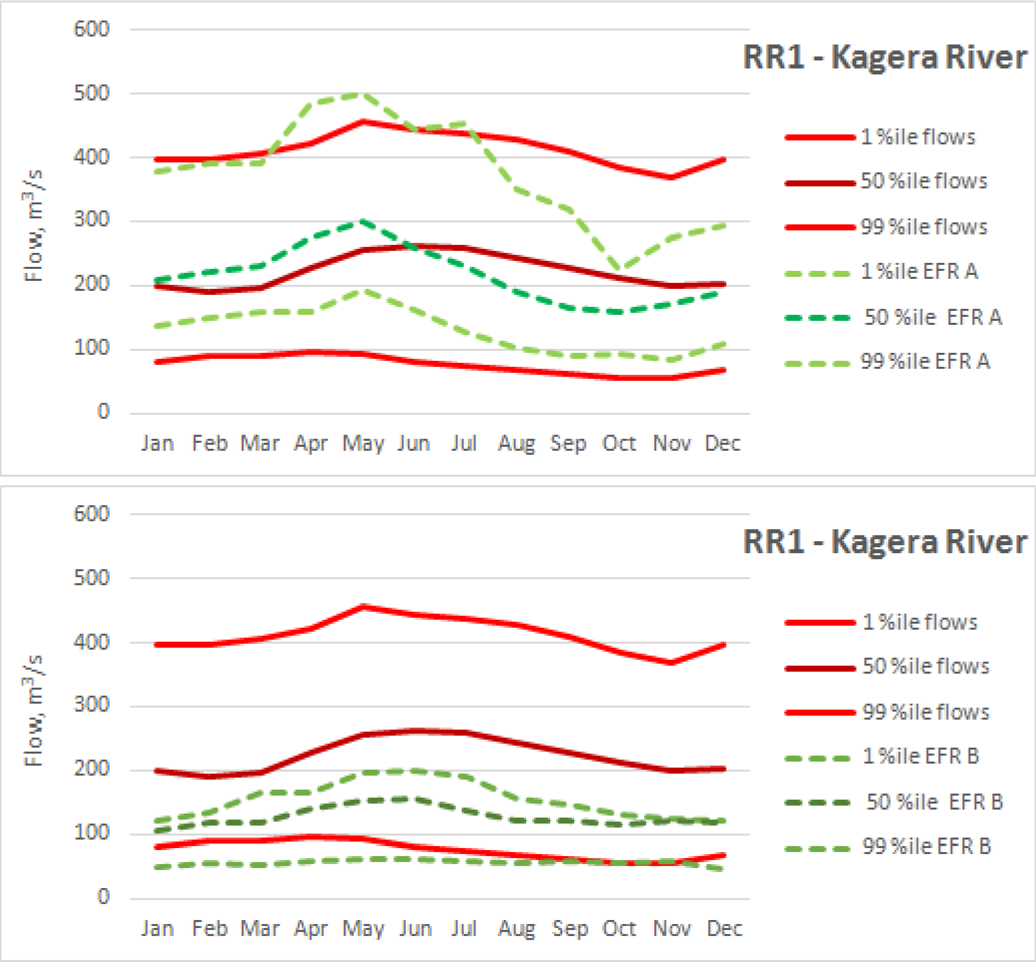


Figure 190: Kagera River environmental flow requirements (EFR) for maintaining "A" (natural) and "B" (good) state conditions, compared with current flow conditions as modelled with the Nile DSS, showing that for most flow conditions EFR A requirements are fulfilled and that only for lower percentiles EFR are not met. B state requirements are always met.

## RR2 - Victoria Nile

The Victoria Nile downstream of Lake Victoria is controlled by the lake outflow and governed by the "Agreed Curve" that mimics natural flow conditions at the hydropower stations that mark the outlet of the lake. Releases are linked to lake water level providing natural, i.e. prehydropower, flow conditions. In recent years it has been observed that releases from the lake have not always been adhering to the "Agreed Curve" for reasons e.g. discussed by Sutcliffe & Petersen (2007) in " Lake Victoria: derivation of a corrected natural water level series ". In addition, lake levels are dependent on inflow and rainfall over the lake area which again are related to climate conditions and landuse practices in the larger Lake Victoria catchment which should be broadly monitored for early knowledge acquisition, also considering cumulative effects. On the Victoria Nile itself there is some further hydropower potential that my lead to changes in the flow patterns. Here eflow aspects need to be considered when designing dam operations. Flows as compared to environmental flow requirements are shown in Figure 191.

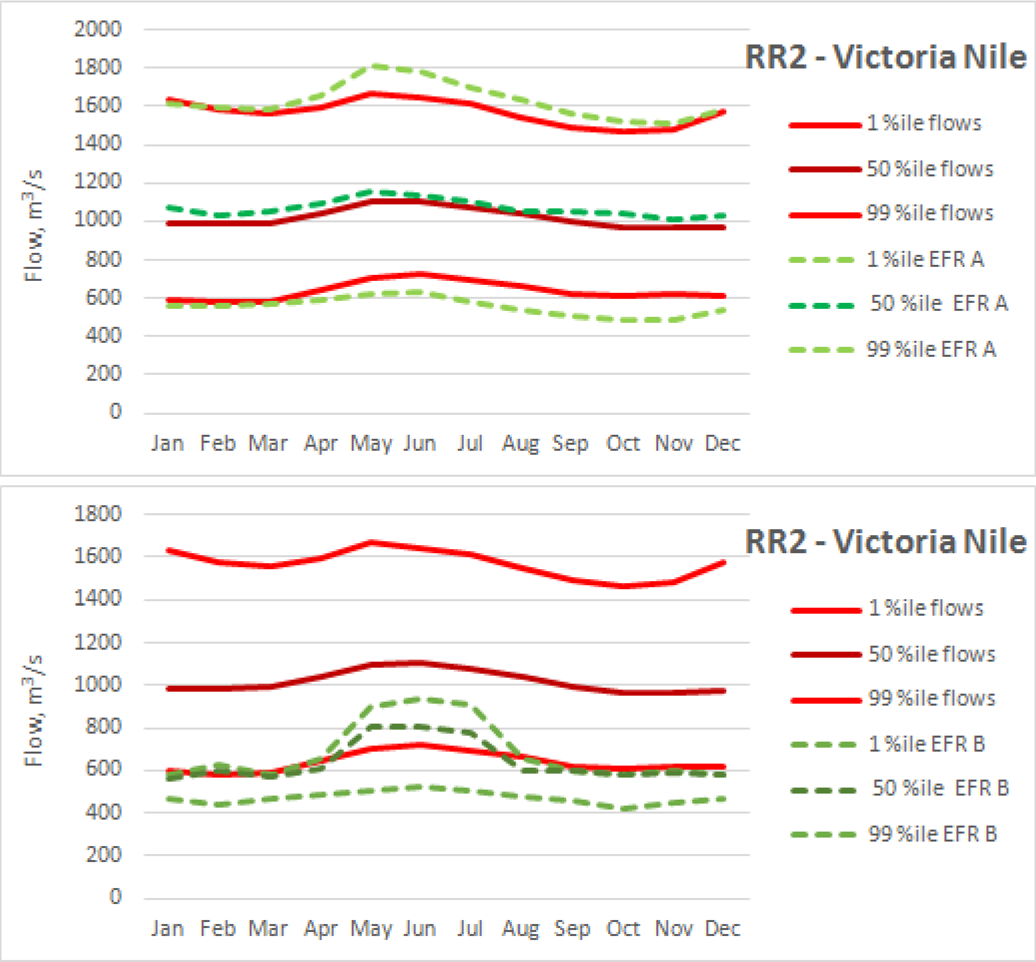


Figure 191: Victoria Nile environmental flow requirements (EFR) for maintaining "A" (natural) and "B" (good) state conditions, compared with current flow conditions as modelled with the Nile DSS, showing that EFR A requirements are fulfilled as it would be expected considering the agreed curve rule.

RR3 - Bahr el Jebel

The Bahr el Jebel upstream of the Sudd inflow at Mongala is dependent of inflowing water from the Equatorial Lakes region and may be affected by changing upstream land use, water consumption and hydropower developments. Changes in the flow patterns at this location would have potentially serious consequences for the downstream Sudd wetlands that are dependent on the flood pulses for the functioning of the permanent swamps as well as the seasonally flooded grasslands. Upstream catchment developments and change therefore should be closely monitored. Flows as compared to environmental flow requirements are shown in Figure 192.

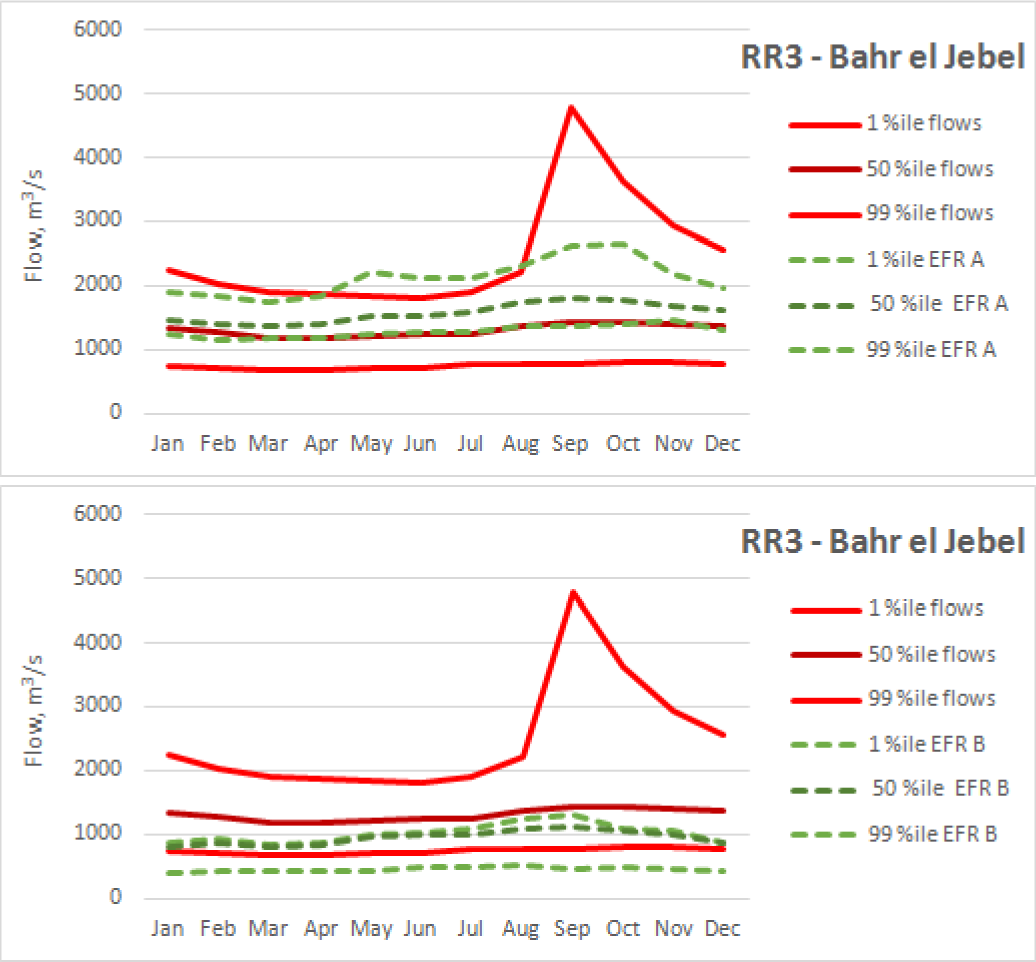


Figure 192: Bahr el Jebel environmental flow requirements (EFR) for maintaining "A" (natural) and "B" (good) state conditions, compared with current flow conditions as modelled with the Nile DSS, showing that EFR A requirements are mostly not met. Targeting for B state, the requirements are met.

RR4 - Baro River

The Baro River upstream of the Machar Marshes at Gambela is fed by runoff from the Ethiopian highlands and as such susceptible to change with changing landcover in the upper catchments caused by deforestation and expanding agricultural areas. In addition, potential hydropower developments as well as water abstractions may increase in the future with these aspects leading to changes in the quantity and timing of flows. These flows are a driver for the Machar Marsh ecosystem that is partly fed by spill from the Baro and may be affected by changing river discharges. Close monitoring of landuse change is respectively recommended. Flows as compared to environmental flow requirements are shown in Figure 193.

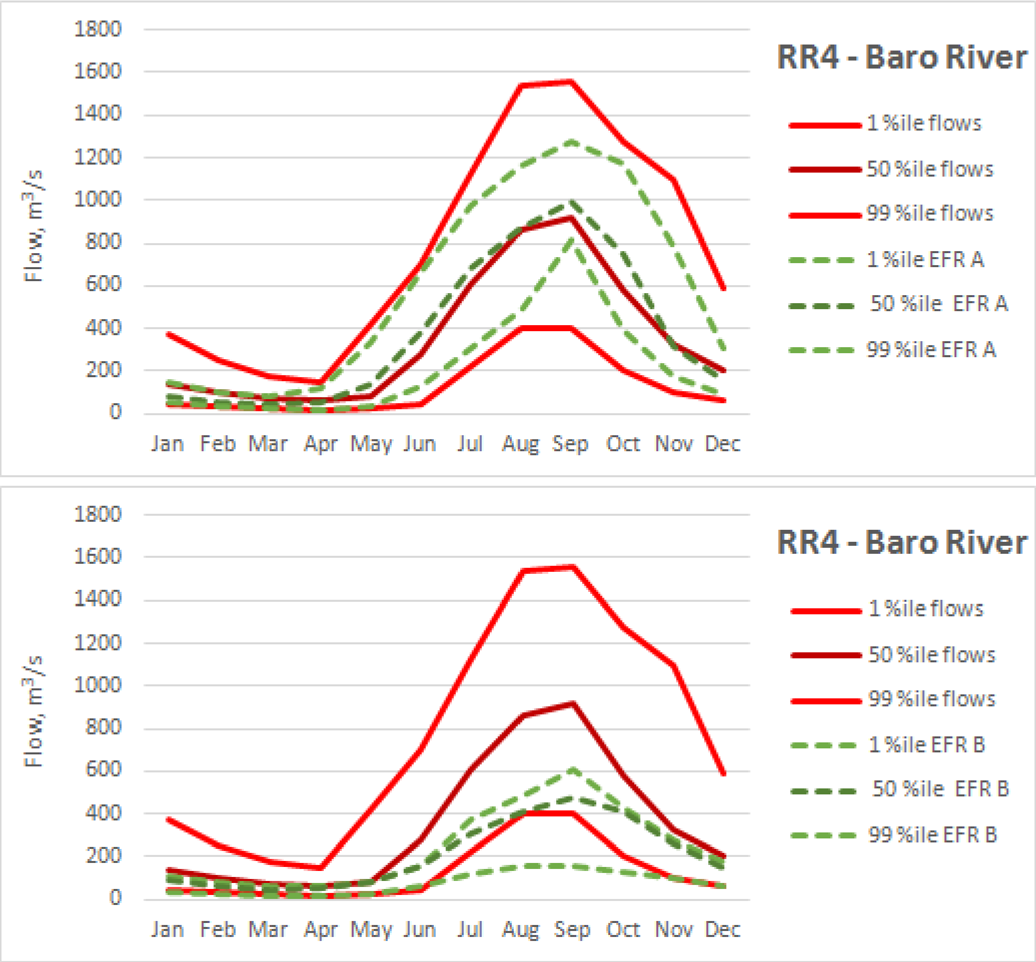


**Figure 193: Baro River environmental flow requirements (EFR) for maintaining "A" (natural) and "B" (good) state conditions, compared with current flow conditions as modelled with the Nile DSS, showing that EFR A requirements are not fulfilled, while B requirements are generally met.**

RR5 - Sobat

The Sobat River is fed by the Baro-Akobo-Sobat basin, draining large parts of South Sudan as well as the Ethiopian escarpment. Flows are rainfall dependent. The system is currently largely unmodified though developments in the Ethiopian upper catchment may lead to modifications of the runoff patterns in the long term. Flows as compared to environmental flow requirements are shown in Figure 194. Deviations may be attributed to limitations in data availability for setting up the hydrological and hydraulic models. Eflow understanding (and modelling results) would strongly benefit from meteorological, hydrological and ecological data acquisition in this area.

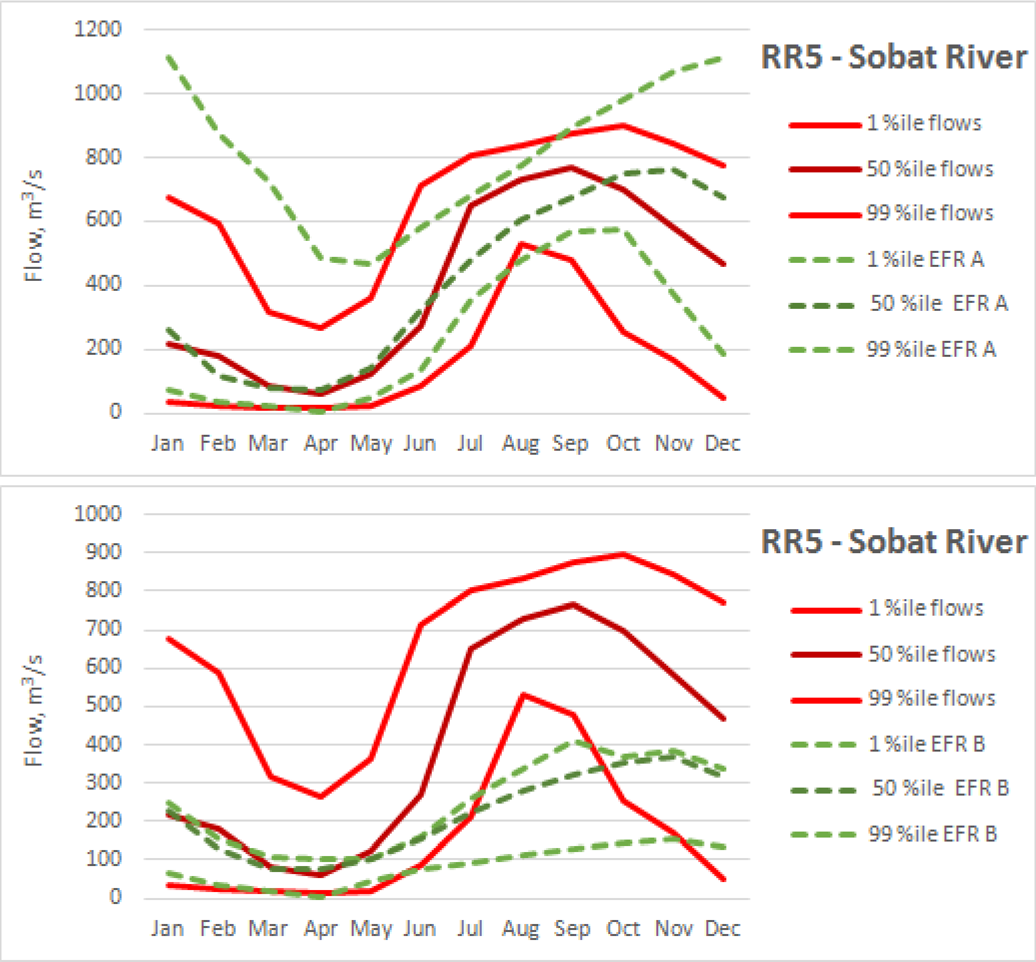


Figure 194: Sobat River environmental flow requirements (EFR) for maintaining "A" (natural) and "B" (good) state conditions, compared with current flow conditions as modelled with the Nile DSS, showing that EFR A requirements are to some extent met while runoff conditions over the year seem modified. Deviations may also be attributed to data limits leading to uncertainties in the modelled flow data.

### RR6 - White Nile

The White Nile drains the large upper Nile basin, receiving its inflow mainly from the Bahr el Jebel and Sobat rivers, and is as such directly dependent on the developments in these basins. Downstream the White Nile is a main contributor to the main Nile and as such modifications in flow, accumulatively, may show effects in the lower basin. Flows as compared to environmental flow requirements are shown in Figure 195. For recommendations see comments to the upstream river sections.

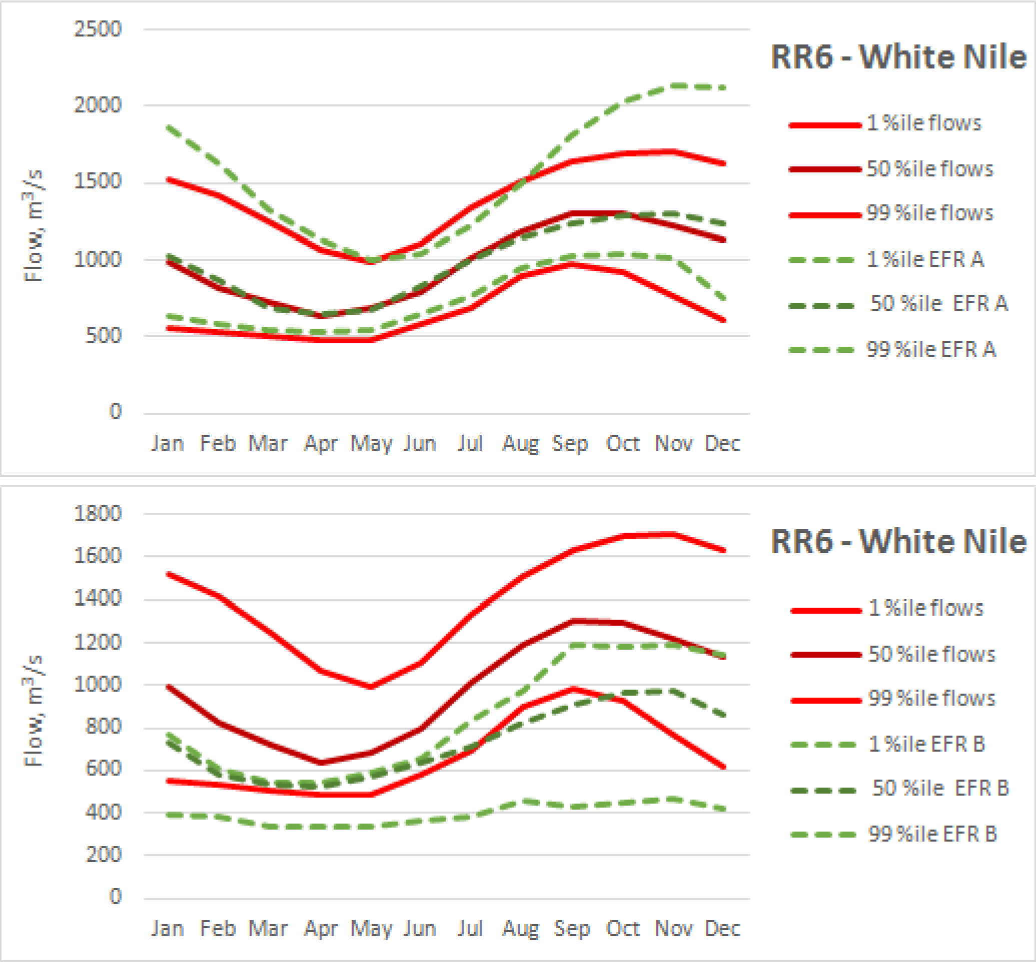


**Figure 195: White Nile River environmental flow requirements (EFR) for maintaining "A" state (natural) conditions, compared with current flow conditions as modelled with the Nile DSS, showing that EFR A requirements are to some extent met, EFR B requirements are always met.**

### <u>RR7 - Blue Nile</u>

The Blue Nile drains the large Ethiopian part of the Nile basin and is directly dependent on rainfall and runoff from there. The basin is undergoing significant developments with agricultural land use change and e.g. the GERD (Grand Ethiopian Renaissance Dam) potentially leading to significant changes in the runoff patterns. Especially the influence of GERD and its operation schedule needs to be carefully investigated as it is influencing the entire downstream Nile basin. Flows as compared to environmental flow requirements are shown in Figure 196.

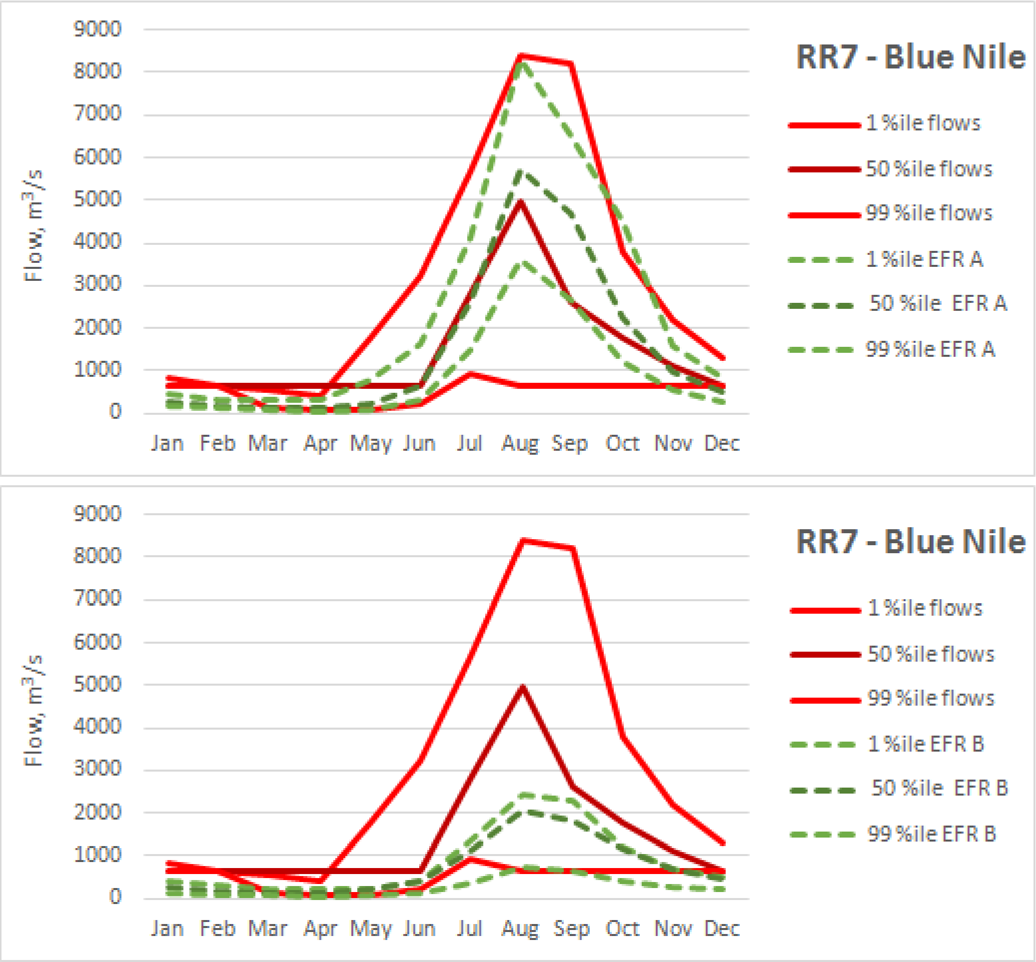


Figure 196: Blue Nile River environmental flow requirements (EFR) for maintaining "A" state (natural) and "B" state conditions, compared with current flow conditions as modelled with the Nile DSS, showing that EFR A requirements are not fulfilled while B requirements are met.

RR8 - Atbara

The Atbara River features highly seasonal flows. The flow regime may be altered by dams and weirs as well as water abstraction for irrigation. Especially cumulative effects are of importance here, considering the irrigation potential along its course. Respective developments should be closely monitored as the Atbara significantly contributes to the Nile flows. Flows as compared to environmental flow requirements are shown in Figure 197.

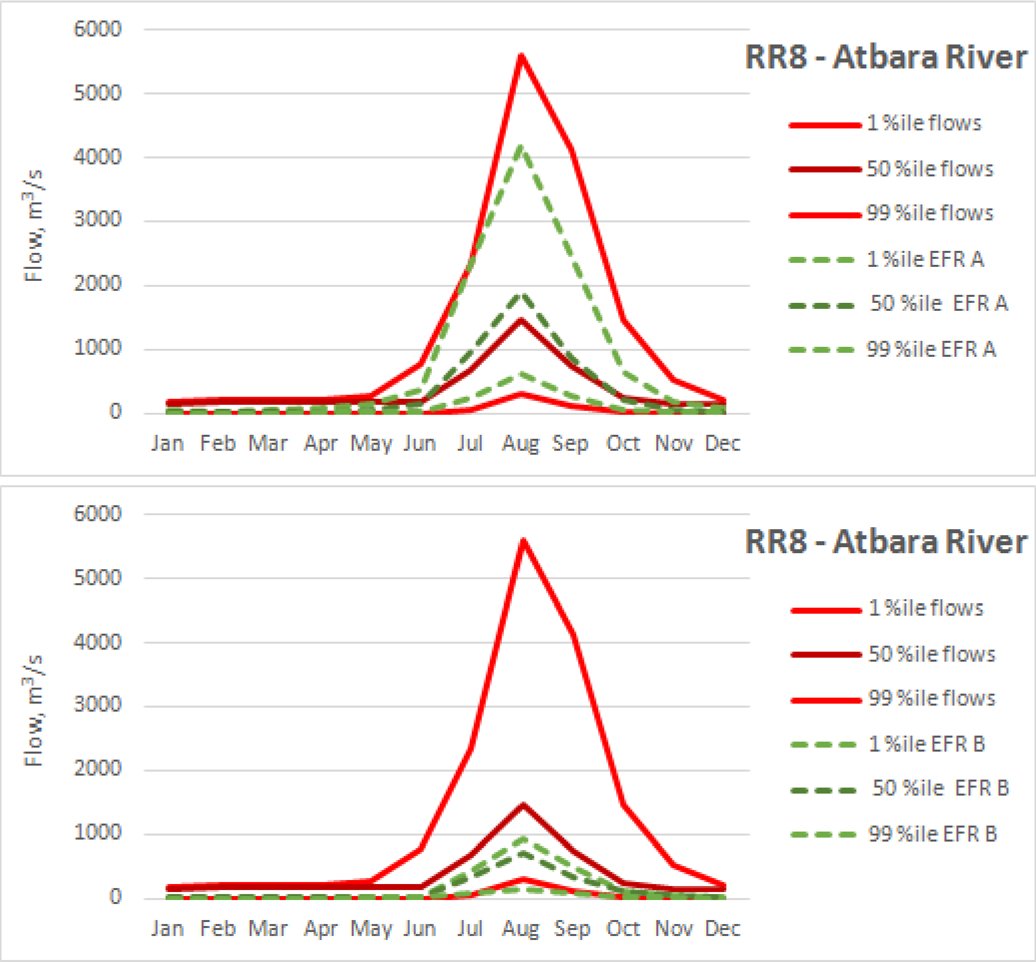


**Figure 197: Atbara River environmental flow requirements (EFR) for maintaining "A" (natural) and "B" state conditions, compared with current flow conditions as modelled with the Nile DSS, showing that EFR A requirements are mostly not achieved. B state conditions on the other hand are achieved.**

RR9 - Nile

The main Nile below the confluence of the Blue and White Nile has been significantly altered through a series of dams that have completely changed the flow regime. In addition, the waters are extensively used for irrigation, leading to significant abstractions. Wetlands along this stretch and in particular the Nile Delta have been significantly modified and converted to agricultural land. In this regard, the Nile Delta is a very vulnerable ecosystem, as under pressure from agricultural practices, a growing population, as well as changed flow patterns as compared to the original Nile flows. Eflow assessments for the Nile Delta or any other reaches of the Nile in Egypt have so far not been conducted but are strongly recommended. Flows as compared to environmental flow requirements are shown in Figure 198.

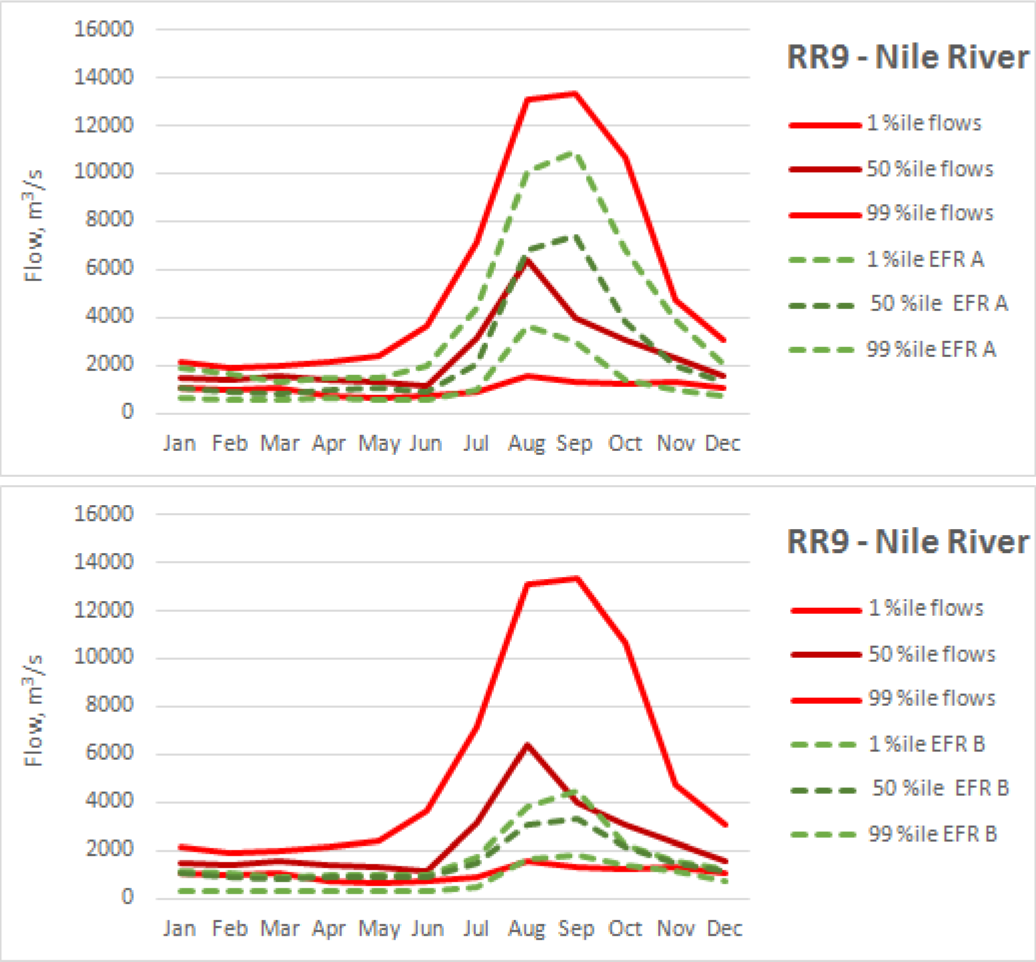


Figure 198: Nile River environmental flow requirements (EFR) for maintaining "A" (natural) and "B" (good) state conditions, compared with current flow conditions as modelled with the Nile DSS, showing that EFR A requirements are only partly achieved. B state conditions on the other hand are nearly always achieved

Further to the situation and developments in the individual reaches of the basin, cumulative effects are of importance and need to be considered in scenario assessments as well as in development planning.

Monitoring

In order to effectively assess the system and conduct future more detailed environmental flow assessments, data is necessary which, at the current stage, is extremely scarce for large stretches of the Nile, in particular considering ecological datasets. Periodical measuring and data collection campaigns as well as the reestablishment of a basin wide hydrometeorological monitoring network would therefore significantly support future efforts. In addition it would be highly beneficial to collect and collate any historic data as currently available only in scattered locations. While such studies can already be called historic, they contain a wealth of valuable and applicable information, especially in parts of the basin that have so far not significantly developed. Parameters that should be collected cover all aspects of importance for environmental flow assessment, ranging from hydraulic conditions to biodiversity and socioeconomic information. Considering the vast scale of the basin and that data collection efforts cannot be started everywhere, areas that may be affected by near-future developments should be prioritized.

Refined environmental flow studies

With more data in place, or data collected through special campaigns, more detailed environmental flow studies are recommended to analyze stretches that have been, or are about to be modified through upstream developments. Scenario analysis can be carried out in order to develop sustainable development plans for catchment management, dam operation, irrigation development, etc. considering downstream eflow requirements. The current coarse eflows assessment can in this way be utilized as a starting point for well refined studies. Eflow studies may be especially interesting for Egypt where so far no eflow studies have been conducted, as well as on other sites, e.g. to assess the impact of GERD, or to assess the cumulative impact of agricultural developments, e.g. in the upper catchments in Rwanda, Burundi, Tanzania, Kenya, and Uganda.

# 6 CONCLUSIONS

This assignment undertook to determine the environmental flow requirements (eflows), for nine river reaches for the Nile basin. This was successfully achieved by implementing the eflow determination and evaluation tool PROBFLO for eight of the nine sites, following the NBI "Strategy for Management of Environmental Flows in the Nile Basin". The eflows for the Atbara River site (RR8) was not determined using PROBFLO but the Desktop Reserve hydrological assessment method by Hughes *et al.* (2014) due to the lack of suitable hydraulic and associated socio-ecological information. For the reaches assessed by the holistic eflows method PROBFLO, the socio-ecological consequences of altered flows have been evaluated by assessing the risk of alterations in water flow, to a number of ecological and social endpoints. Based on the risk posed to these endpoints by each scenario of change, an eflow was determined that would protect the ecosystem and maintain indicator components at a sustainable level. The sustainability of the endpoints were dominated by qualitative measures in the Nile basin rivers. Thus the eflow requirements represent the volume, timing, duration and frequency of flows required to maintain the sustainable quality of the endpoints.

Because no site surveys were conducted, it was not possible to determine the present condition of each riverine ecosystem. This meant that it was not possible to relate the current condition of the system to observed present flows, and thus to characterise the impact of altered flow and non-flow environmental variables. As a result, it has not been possible to determine the eflow requirements to maintain the present condition, but instead eflows have been based on maintain a pristine state (Class A), a largely natural state (Class B), a moderately modified state (Class C) and a largely modified (Class D) ecological category. Although the precise state of the ecosystem associated with these ecological categories could not be determined, this would require field surveys and associated analyses and interpretations for each site, hypothetical requirements were identified for the assessment. This area of uncertainty can be improved with evidence.

Uncertainty in the assessment is associated with the lack of biophysical data for the project. Instead, it was necessary to make use of a combination of evidence from global data sets, including those from Earth Observation, published reports and regional experts. Because none of this data was collected directly for the purpose of an eflows assessment, the nature and quality of the data was generally insufficient to ensure a high confidence eflows assessment. The specialists on the project team were thus forced to use their judgement to interpret what was available, which does mean that the assessment was generally a low confidence one. Recommendations to improve the outcomes include the identification of indicators and measures of the socio-ecological system that should be monitored to: (a) validate the outcomes of this assessment, (b) validate the selection and use of the indicators and measures to represent the system of interest, (c) reduce uncertainty associated with available data and its use.

A number of important recommendations emerge that need to be considered during further planning incorporating the eflows for the region.

- In the absence of a vision for the resource, eflows required to maintain the ecosystems in a Class B, Class C or D were selected for the study. Ideally the vision and objectives would rank the balance between use and protection of the ecosystem in terms of risk, and would provide benchmarks that would enable the eflows to be structured to ensure that the objectives would be met. The greatest uncertainty here, as a result of a lack of a clear vision and objectives, is that any reduction in flow would reduce the ecosystem services to people. At what point does this become a livelihoods problem? This poses the greatest decision to policy makers in the region.

- The data that was available to determine the eflows was only adequate to conduct a low confidence study. It is important thus that the eflows that are presented here are recognised as such, as low confidence, and should not be used for high-cost development decisions without further studies based on additionally collected data. A particular improvement opportunity is in the relation of the inflows to the extent of floodplain inundation using flood modelling. for a higher confidence eflows assessment, all involved datasets would need to be updated and strengthened.
- Relative risk outcomes for all of these development scenarios generally correlate to the proposed integrity Classes selected for the assessment. In some occasions where the risk is proposed to be more severe (>50% high risk) than proposed ecological class descriptions the outcomes should be considered with caution.

# 7 REFERENCES

Arthington, A. H., Bhaduri, A., Bunn, S. E., Jackson, S. E., Tharme, R. E., Tickner, D., ... & Horne, A. C. (2018). The Brisbane declaration and global action agenda on environmental flows (2018). Frontiers in Environmental Science, 6.

Bailey, R. G. (1994). Guide to the fishes of the River Nile in the Republic of the Sudan. Journal of Natural History, 28(4), 937-970.

Baumgartner, L. J., Conallin, J., Wooden, I., Campbell, B., Gee, R., Robinson, W. A., & Mallen-Cooper, M. (2014). Using flow guilds of freshwater fish in an adaptive management framework to simplify environmental flow delivery for semi-arid riverine systems. Fish and Fisheries, 15(3), 410-427.

Boulenger, G. A. (1887). An Account of the Fishes obtained by Surgeon-Major ASG Jayakar at Muscat, East Coast of Arabia. Journal of Zoology, 55(4), 653-667.

Boulenger, G. A. (1912). XIX.—Descriptions of new Batrachians from the Andes of South America, preserved in the British Museum. Journal of Natural History, 10(56), 185-191.Boulenger (1887, 1902, 1912).

Boulenger, G. A. (1965). The fishes of the Nile (Vol. 3). Egyptian government.

Burnett, M. J., O'Brien, G. C., Wepener, V., & Pienaar, D. (2018). The spatial ecology of adult Labeobarbus marequensis and their response to flow and habitat variability in the Crocodile River, Kruger National Park. African Journal of Aquatic Science, 1-10.

Closs, G. P., Krkosek, M., & Olden, J. D. (Eds.). (2015). Conservation of freshwater fishes. Cambridge University Press

Colnar, A. and Landis, W. (2007). Conceptual model development for invasive species and a regional risk assessment case study: the European green crab, Carcinus maenas, at Cherry Point, Hum. Ecol. Risk Assess. [online] Available from: http://www.tandfonline.com/doi/abs/10.1080/10807030601105076 (Accessed 18 August 2016).

Dickens, C, Smakhtin V., McCartney M., O'Brien, G., Pringle K. and L. Dahir (2018 in press) Defining and quantifying national-level targets and indicators for management of natural resources to achieve the Sustainable Development Goals (SDGs).

Dudgeon D, Arthington AH, Gessner MO, Kawabata Z-I, Knowler DJ, Lévêque C, Naiman RJ, Prieur-Richard A-H, Soto D, Stiassny MLJ, Sullivan CA. (2006). Freshwater biodiversity: importance, threats, status and conservation challenges. Biological Reviews of the Cambridge Philosophical Society 81: 163–182.

Goodier, S. A., Cotterill, F. P., O'Ryan, C., Skelton, P. H., & de Wit, M. J. (2011). Cryptic diversity of African tigerfish (Genus Hydrocynus) reveals palaeogeographic signatures of linked Neogene geotectonic events. PloS one, 6(12), e28775.

Greenwood, P. H. (1976). Fish fauna of the Nile. In The Nile, biology of an ancient river (pp. 127-141). Springer, Dordrecht.

Guimarães, A. R. P. (1884). Lista dos peixes da ilha da Madeira, Açores e das possessoes portuguezas d'Africa que existem no Museu de Lisboa.

Hickley, P., & Bailey, R. G. (1987). Food and feeding relationships of fish in the Sudd swamps (River Nile, southern Sudan). Journal of Fish Biology, 30(2), 147-159.

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. Assess.

[online] Available from: http://onlinelibrary.wiley.com/doi/10.1002/ieam.1509/full (Accessed 18 August 2016).

Horne, A. C., Webb, J. A., Stewardson, M. J., Richter, B., & Acreman, M. (2017). Water for the Environment.

Hughes DA & 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.

Jørgensen, S. E., Xu, L., & Costanza, R. (Eds.). (2016). Handbook of ecological indicators for assessment of ecosystem health. CRC press.

King, J. and Pienaar, H. (2011). Sustainable use of South Africa’s inland waters.

King, J., Tharme, RE. and de Villiers, MS (Eds.). (2008). Environmental Flow Assessments for Rivers: Manual for the Building Block Methodology (updated edition). WRC report No TT 354/08.

Kuriqi, A., Rivaes, R., Sordo-Ward, A., Pinheiro, A. N., & Garrote, L. (2017, April). Comparison and validation of hydrological eflow methods through hydrodynamic modelling. In Proceedings of the EGU General Assembly Conference, Vienna, Austria (pp. 24-28).

Landis, W. (2004). Regional scale ecological risk assessment: using the relative risk model. [online] Available from: https://books.google.co.za/books?hl=en&lr=&id=-gdO-NF1bb0C&oi=fnd&pg=PA1&dq=Landis+and+weigers+1997&ots=aUvWeGWe2r&sig=_IgC0f2tB0lJGX2QjJVcORQD8Rc (Accessed 18 August 2016a).

Landis, W. and Wiegers, J. (1997). Design considerations and a suggested approach for regional and comparative ecological risk assessment, Hum. Ecol. Risk Assess. [online] Available from: http://www.tandfonline.com/doi/pdf/10.1080/10807039709383685 (Accessed 18 August 2016).

Landis, W.: Comment on ET & C perspectives , November 2015-A holistic view : Comment on ET & C Perspectives, , (August), doi:10.1002/etc.3378, 2016.

Marcot, 2012;

McCann, R. K., Marcot, B. G. and Ellis, R. (2006). Bayesian belief networks : applications in ecology and natural resource, , (Reckhow 1999).

Mitchell, B. (2005). Integrated water resource management, institutional arrangements, and land-use planning, Environ. Plan. A [online] Available from: http://epn.sagepub.com/content/37/8/1335.short (Accessed 29 August 2016).

Nile Basin Initiative (NBI). (2008). Kagera Rive Basin Monograph. Basin Development Report. Transboundary Integrated Water Resources Management and Development Project.

Nile Basin Initiative (NBI). (2012). State of the River Nile Basin Report.

Nile Basin Initiative (NBI). (2016a). Preparation of NBI Guidance Document on Environmental Flows: Nile Eflows Framework Technical Implementation Manual. Prepared by HYDROC GmbH on behalf of the Nile Basin Initiative and Deutsche Gesellschaft für Internationale Zusammenarbeit.

Nile Basin Initiative (NBI). (2016b). Nile Basin Water Resources Atlas. Nile Basin Initiative, Kampala, Uganda.

Nile Basin Initiative (NBI). (2017). Strategy for management of Environmental Flows in the Nile Basin. GIZ Project Number: 13. 2249.4. Available for download from: www.nilebasin.org

O’Brien GC, Bulfin JB, Husted A and Smit NJ. (2012). A. Comparative behavioural assessment of an established and new Tigerfish (Hydrocynus vittatus) population in two artificial impoundments in the Limpopo catchment, southern Africa. African Journal of Aquatic Sciences 37(3): 253-263.

O'Brien GC, Jacobs FJ, Nel L, Wepener W and Smit NJ. (2013). Habitat use, home ranges, migrations and general behaviour of yellowfishes in the Vaal River, with management considerations for the river. South African Journal of Science. 109:7/8. 1-8.

O'Brien, G. 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), 153–166, doi:10.4314/wsa.v38i2.1.

O'Brien GC, Cambray J, Engelbrecht J and Bills, R. (2017). Labeobarbus polylepis (amended version published in 2017) The IUCN Red List of Threatened Species 2017: e.T63262A111041325. http://dx.doi.org/10.2305/IUCN.UK.2017-1.RLTS.T63262A111041325.en. Downloaded on 21 September 2017.

O'Brien GC, Jacobs F, Evans SW and Smit NJ. (2014). First observation of African tigerfish Hydrocynus vittatus predating on barn swallows Hirundo rustica in flight. Journal of Fish Biology. 84(1): 263–266.

O'Brien, G. C., Dickens, C., Hines, E., Wepener, V., Stassen, R., Quayle, L., & Landis, W. G. (2018). A regional-scale ecological risk framework for environmental flow evaluations. Hydrology and Earth System Sciences, 22(2), 957.

Ogutu-Ohwayo, R. (1990). The decline of the native fishes of lakes Victoria and Kyoga (East Africa) and the impact of introduced species, especially the Nile perch, Lates niloticus, and the Nile tilapia, Oreochromis niloticus. Environmental biology of fishes, 27(2), 81-96.

Økland, F., Thorstad, E. B., Hay, C. J., Næsje, T. F., & Chanda, B. (2005). Patterns of movement and habitat use by tigerfish (Hydrocynus vittatus) in the Upper Zambezi River (Namibia). Ecology of Freshwater Fish, 14(1), 79-86.

Poff, N. L., Richter, B. D., Arthington, A. H., Bunn, S. E., Naiman, R. J., Kendy, E., Acreman, M., Apse, C., Bledsoe, B. P., Freeman, M. C., Henriksen, J., Jacobson, R. B., Kennen, J. G., Merritt, D. M., O'Keeffe, J. H., Olden, J. D., Rogers, K., Tharme, R. E. and Warner, A. (2010). The ecological limits of hydrologic alteration (ELOHA): A new framework for developing regional environmental flow standards, Freshw. Biol., 55(1), 147–170, doi:10.1111/j.1365-2427.2009.02204.x.

Poff, N. L., Tharme, R. E., & Arthington, A. H. (2017). Evolution of environmental flows assessment science, principles, and methodologies. In Water for the environment (pp. 203-236). Academic Press.

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, , doi:10.1016/j.envsoft.2006.03.006.

Ramesh T, Downs CT, & O'Brien GC (2018). Movement response of OrangeVaal largemouth yellowfish (Labeobarbus kimberleyensis) to water quality and habitat features in the Vaal River, South Africa. Environmental Biology of Fishes, 101(6), 997-1009.

Richter et al., 2006;

Samuels PG. (1990). Cross-section location in 1-D models. Intl. Conference on River Flood Hydraulics, Wallingford, UK

Schilthius L (1891) and Pellegrin DJ (1900 and 1901).

Schwartz et al., 2006;

Schwartz, J. D., Pallin, M. J., Michener, R. H., Mbabazi, D., & Kaufman, L. (2006). Effects of Nile perch, Lates niloticus, on functional and specific fish diversity in Uganda's Lake Kyoga system. African Journal of Ecology, 44(2), 145-156.

Siddig, A. A., Ellison, A. M., Ochs, A., Villar-Leeman, C., & Lau, M. K. (2016). How do ecologists select and use indicator species to monitor ecological change? Insights from 14 years of publication in Ecological Indicators. Ecological Indicators, 60, 223-230.

Sissoko K, Keulen H, Verhagen J, Tekken V, Battaglini A (2011) Agriculture, livelihoods and climate change in the West African Sahel. Reg Environ Chang 11:119–125. doi: 10.1007/s10113-010-0164-y

Stiassny, M. L., & Schaefer, S. A. (2005). Rhabdalestes aeratis, new species (Characiformes: Alestidae): first occurrence of the genus from the Middle Congo River basin. Ichthyological Exploration of Freshwaters, 16(3), 271.

Sutcliffe JV, Dugdale G, Milford JR. (1989). The Sudan floods of 1988. Hydrological Sciences Journal 34:3, 355-364.

USEPA, 2003. Generic Ecological Assessment Endpoints (GEAEs) for Ecological Risk Assessment. EPA/630/P-02/004F

Vijverberg, J., Sibbing, F. A., & Dejen, E. (2009). Lake Tana: Source of the Blue Nile. In The Nile (pp. 163-192). Springer, Dordrecht.

Winemiller, K.O. and Adite, A., (1997). Convergent evolution of weakly electric fishes from floodplain habitats in Africa and South America. Environmental Biology of Fishes, 49(2), pp.175-186.

Witte, F., de Graaf, M., Mkumbo, O. C., El-Moghraby, A. I., & Sibbing, F. A. (2009). Fisheries in the Nile system. In The Nile (pp. 723-747). Springer, Dordrecht.

WREM International Inc., (2017): Establishment of a Water Regulation and Management Tool for the River Nile in Uganda, Bathymetry Survey Report. Technical Report under Contract Agreement MWE/CONS/14-15/00210, sponsored by the Ministry of Water and Environment, Republic of Uganda, and developed by WREM International Inc., Atlanta, Georgia, USA, 54pp.

Zhao, C., Yang, S., Liu, J., Liu, C., Hao, F., Wang, Z., & Lim, R. P. (2018). Linking fish tolerance to water quality criteria for the assessment of environmental flows: A practical method for streamflow regulation and pollution control. Water research, 141, 96-108.

# ANNEXURE A: LITERATURE REVIEW OF SOCIO-ECOLOGICAL AND FLOW INFORMATION TO DETERMINE COARSE EFLOWS FOR SELECTED SITES IN THE NILE BASIN.

**Hydro-ecological changes**

| **Information** | **Source** |
|---|---|
| • Stream flow is considered as a master variable shaping many fundamental ecological characteristics of riverine ecosystems. Flow variation is also the most important environmental factor which decides relative succession of different species of the riverine ecosystem. Lack of environmental flows is the major reason behind extinction of riverine species sensitive to nutrient/sediment concentration.<br>• Reduced flows also lower sediment and nutrient transport which increase in-channel sediment deposition and destroy in-channel habitats. It also affects estuarine health by reducing the nutrient supply to estuaries.<br>• Hydro-ecological changes are generally not reversible after they have occurred. The time span over which these changes occur is very difficult to anticipate because the nature of these changes (gradual or abrupt) has not yet been fully explored. Therefore, these changes can happen by surprise. | Patil R. Wei Y. Pullar D. and Shulmeister J. 2018. Understanding hydro-ecological surprises for riverine ecosystem management. Current Opinion in Environmental Sustainability. 33:142–150 |
| • Ecological responses to altered flow regimes in a specific stream or river depend on how the components of flow have changed relative to the natural flow regime for that particular stream or river and how specific geomorphic and ecological processes will respond to this relative change. As a result of variation in flow regime within and among rivers, the same human activity in different locations may cause different degrees of change relative to unaltered conditions and, therefore, have different ecological consequences.<br>• The rearing and refuge functions of shallow shoreline or backwater areas, where many small fish species and the young of large species are found, are severely impaired by frequent flow fluctuations. In these artificially fluctuating environments, specialized stream or river species are typically replaced by generalist species that tolerate frequent and large variations in flow. Furthermore, life cycles of many species are often disrupted and energy flow through the ecosystem is greatly modified.<br>• At the opposite hydrologic extreme, flow stabilization below certain types of dams, such as water supply reservoirs, results in artificially constant environments that lack natural extremes. Although production of a few species may increase greatly, it is usually at the expense of other native species and of systemwide species diversity.<br>• Many lake fish species have successfully invaded (or been intentionally established in) flow-stabilized | Poff NL. Allan JD. Bain MB, Karr JR. Prestegaard KL. Richter BD. Sparks RE and Stromberg JC. 1997. The Natural Flow Regime A paradigm for river conservation and restoration. BioScience, 47(11) 769-784 |

| Information | Source |
|---|---|
| river environments. Often top predators, these introduced fish can devastate native river fish and threaten commercially valuable stocks. | |

**Flow influences on habitat**

<table>
<tr><th colspan="3">Information</th><th>Source</th></tr>
<tr><td colspan="3">• The shape and size of river channels, the distribution of riffle and pool habitats, and the stability of the substrate are all largely determined by the interaction between the flow regime and local geology and landform. In turn this complex interaction between flows and physical habitat is a major determinant of the distribution, abundance, and diversity of stream and river organisms.<br>• In large floodplain rivers, many aquatic species ranging from benthic microorganisms, phytoplankton, zooplankton, and fish are cued to rising flood levels, emerging from resting stages or spawning in response to the cue of rising water levels and inundation.</td><td>Bunn SE and Arthington AH. 2002. Basic Principles and Ecological Consequences of Altered Flow Regimes for Aquatic Biodiversity. Environmental Management Vol. 30, No. 4, pp. 492–507</td></tr>
<tr><td colspan="3">• Over periods of years to decades, a single river can consistently provide ephemeral, seasonal, and persistent types of habitat that range from freeflowing, to standing, to no water. This predictable diversity of in-channel and floodplain habitat types has promoted the evolution of species that exploit the habitat mosaic created and maintained by hydrologic variability. For many riverine species, completion of the life cycle requires an array of different habitat types, whose availability over time is regulated by the flow regime.<br>• Human alteration of flow regime changes the established pattern of natural hydrologic variation and disturbance, thereby altering habitat dynamics and creating new conditions to which the native biota may be poorly adapted.<br>• Belos is a list of the phyological responces to altered flow regimes:</td><td rowspan="4">Poff NL. Allan JD. Bain MB, Karr JR. Prestegaard KL. Richter BD. Sparks RE and Stromberg JC. 1997. The Natural Flow Regime A paradigm for river conservation and restoration. BioScience, 47(11) 769-784</td></tr>
<tr><th>Sources of alteration</th><th>Hydrologic changes</th><th>Geomorphic changes</th></tr>
<tr><td>Dam</td><td>Capture sediment moving downward</td><td>Downstream channel erosion and tributary headcutting<br>Bed armouring</td></tr>
<tr><td>Dam, diversion</td><td>Reduce magnitude and frequency of high flows</td><td>Deposition of fines in gravel<br>Channel stabilization and narrowing<br>Reduced formation of point bars, secondary channels,</td></tr>
</table>

| Information | | | Source |
|---|---|---|---|
| | | oxbows and changes in channel plan form | |
| Urbanization, tiling drainage | Increase magnitude and frequency of high flows<br>Reduced filtration into soil | Bank erosion and channel widening<br>Downward incision and floodplain disconnection<br>Reduced baseflows | |
| Levees and channelization | Reduced overbank flows | Channel restrictions causing downcutting<br>Floodplain deposition and erosion prevented<br>Reduced channel migration and secondary channel formation | |
| Groundwater pumping | Lowered water table levels | Streambank erosion and channel downcutting after the loss of vegetation stability | |

### Influence of Flow and Habitat on Aquatic Plants

| Information | Source |
|---|---|
| • Spatial and temporal variation in plant assemblage structure is influenced by flooding and scouring, desiccation, substrate stability and localized variations in water velocity, turbulence and shear stress.<br>• A regulated relatively stable flow throughout the year can cause excessive growths of submerged aquatic macrophytes eg Norwegian rivers regulated by hydropower stations.<br>• Wider range of water regimes can be beneficial for many plant species, promoting diversity.<br>• Rates of water level fluctuations can impact aquatic macrophyte growth rates and seedling survival. Changes in water regime have a profound effect on the establishment and survival of many aquatic plant species owing to their narrow range of tolerances and inability to regenerate under modified conditions. | Bunn SE and Arthington AH. 2002. Basic Principles and Ecological Consequences of Altered Flow Regimes for Aquatic Biodiversity. Environmental Management Vol. 30, No. 4, pp. 492–507 |
| • Flow stabilization also reduces the magnitude and frequency of overbank flows, affecting riparian plant species and communities. In rivers with constrained canyon reaches or multiple shallow channels, loss of high flows results in increased cover of plant species' that would otherwise be removed by flood scour. Moreover, due to other related effects of flow regulation, including increased water salinity, non-native | Poff NL. Allan JD. Bain MB, Karr JR. Prestegaard KL. Richter BD. Sparks RE and Stromberg JC. 1997. The Natural Flow Regime A paradigm for river |

| Information | Source |
|---|---|
| vegetation often dominates.<br>- In alluvial valleys, the loss of overbank flows can greatly modify riparian communities by causing plant desiccation, reduced growth, competitive exclusion, ineffective seed dispersal, or failure of seedling establishment.<br>- Changes in the duration of flow conditions also have significant biological consequences. Riparian plant species respond dramatically to channel dewatering, which occurs frequently in arid regions due to surface water diversion and groundwater pumping. These biological and ecological responses range from altered leaf morphology to total loss of riparian vegetation cover. Changes in duration of inundation, independent of changes in annual volume of flow, can alter the abundance of plant cover types.<br>- Riparian plant species are also strongly affected by altered flow timing. A shift in timing of peak flows from spring to summer, as often occurs when reservoirs are managed to supply irrigation water, has prevented reestablishment of the Fremont cottonwood (Populus fremontii), the dominant plant species in Arizona, because flow peaks now occur after, rather than before, its germination period. Non-native plant species with less specific germination requirements may benefit from changes in flood timing. | conservation and restoration. BioScience, 47(11) 769-784 |

**Influence of Flow and Habitat on Aquatic Invertebrates**

| Information | Source |
|---|---|
| - Increased stability of baseflow and reduction of flow variability will cause the following biotic response:<br>  ○ Proliferation of nuisance larval blackflies<br>  ○ Increased standing crop and reduced diversity of macroinvertebrates<br>- Erratic (diurnal) patterns in flow below hydroelectric dams will cause the following biotic response:<br>  ○ Reduction in species richness of benthic macroinvertebrates<br>  ○ Reduction in standing crop of benthic macroinvertebrates<br>  ○ Stranding of macroinvertebrates<br>- Conversion of lotic habitat to lentic<br>  ○ Decline of populations of riverine crayfish and snails<br>- Timing of spates can impact survivorship of larval atyid shrimps following early summer spates<br>- Short term fluctuations in flows have an adverse effect on species of stoneflies with long larval development times (autumn/winter). | Bunn SE and Arthington AH. 2002. Basic Principles and Ecological Consequences of Altered Flow Regimes for Aquatic Biodiversity. Environmental Management Vol. 30, No. 4, pp. 492–507 |
| Invertebrate density<br>- Studies have shown that reduced flow can in different cases increase or decrease invertebrate densities | Dewson ZS, James ABW and Death RG. 2007. A review of the consequences of |

| Information | Source |
|---|---|
| and the response to food resources such as algae and organic matter, to low flow can strongly influence invertebrate density responses.<br>• The taxonomic composition of the invertebrate community can cause variable density responses to flow reduction. The severity of flow reduction also can influence the direction of density responses. Studies showed that the mean invertebrate densities increased 57% downstream of mild diversions, whereas invertebrate densities decreased 50% downstream of severe diversions. The direction of the density responses probably differed because the magnitude of change to habitat suitability varied with the severity of flow reduction.<br>Species richness<br>• Low or reduced flows in permanent streams often cause decreases in taxonomic richness. A loss of richness can be attributed to the loss of habitat types (e.g., fast flows, rapids) during reduced flows. water abstraction generally had less effect on the fauna of upland streams than on the fauna of small lowland streams in the UK. Habitat diversity and connectivity decreased in the lowland streams, whereas a diverse range of suitable microhabitats remained available in the upland streams after water abstraction, and the presence of numerous tributaries facilitated recolonization in the upland streams.<br>• Higher than normal summer water temperatures and larger than usual annual temperature ranges at reduced flow sites contributed to lower invertebrate richness.<br>• Species richness was lower in sites with reduced flow than in sites with normal flow because food supply for grazing invertebrates was lower at the sites with reduced flow.<br>• Taxa with preferences for low water velocities and fine sediments characterized sites during drought years, and taxa with preferences for high velocities and gravel substrate characterized sites during nondrought years.<br>• Channel morphology can strongly influence invertebrate community responses to decreases in flow. A homogeneous section of stream probably maintains its range of habitats during extreme decreases in flow, whereas sections that are more heterogeneous are likely to lose a large proportion of the habitat types that are available during high flows. Minor abstractions generally had less effect on biota than major abstractions.<br>Community composition<br>• Invertebrate community composition often changes in response to low or reduced flow. Low flows should favour taxa that prefer slower water velocities<br>• Sediment accumulation also influences habitat suitability. Increased sedimentation and a loss of macrophytes can be responsible for changes in macroinvertebrate community composition | decreased flow for instream habitat and macroinvertebrates. The North American Benthological Society, Vol 26(3): pp. 401–415 |

| **Information** | **Source** |
|---|---|
| Drift behaviour<br>• If low flow creates unsuitable conditions for invertebrates, individuals might seek refuge or leave the stream reach. Drift enables organisms to escape unfavourable conditions and can occur actively or passively<br>• Passive drift decreases in response to low water velocities during periods of low flow, but many studies have shown that active drift increases during periods of low flow<br>• Drift responses to reduced flows differ among taxa. For example, reduced flow increased active drift by some taxa (Baetis spp., Epeorus longimanus, Simuliidae, Brachycentrus americanus) and decreased active drift by other taxa (Paraleptophlebia heteronea, Ephemerella in frequens, Triznaka signata, Lepidostoma ormea)<br>Refugia<br>• Studies suggest that the hyporheic zone is not used as a refuge in permanent streams<br>Predation and competition<br>• Low or reduced flow can alter the direction and strength of predator–prey and competitive interactions by decreasing water velocity and habitat size (wetted area).<br>• Contraction of wetted width as flow decreases can cause invertebrate densities to increase and can lead to increases in predation and competition.<br>• Reduced velocities also could remove velocity-mediated predation refugia when predators and prey normally have different velocity preferences. Species richness and abundance of simuliid larvae were greater than predicted at low flow sites and attributed this result to lower densities of predators and less competition at low flow sites than at high flow sites.<br>• Water velocity controls the rate of food delivery for filter feeders. For instance, hydropsychid caddisfly larvae tend to aggregate in high-velocity water where feeding rates are higher than in low-velocity water. Larvae might react to flow reduction by moving to zones of more rapid flow thereby increasing competition for space and food. Individuals of Hydropsyche morosa are less tolerant of conspecifics at low velocities than at high velocities, possibly because of reduced food delivery rates at low velocities<br>Grazer-periphyton interactions<br>• Water velocity can influence the foraging efficiency of grazers and alter their role in structuring algal assemblages. The velocity differences associated with decreased discharge can influence grazer-periphyton interactions.<br>• The effect of water velocity on grazing efficiency is species-specific. Caddisfly (Glossosoma verdona) was a more effective grazer at higher velocity, whereas the grazing efficiency of two mayflies (Baetis | |

| Information | Source |
|---|---|
| bicaudatus and Drunella grandis) did not change significantly with velocity.<br>- Water velocity also influences the behavioral responses of invertebrates to algal resources. At low velocities, drift of Helicopsyche borealis is greater when periphyton levels are low, whereas at high velocities, passive drift is the predominant source of drift and no relationship exists between drift and periphyton levels | |

**Influence of Flow and Habitat on fish**

| Information | Source |
|---|---|
| - Increased stability of baseflow and reduction of flow variability will cause the following biotic response:<br>  ○ Reduction in fish populations<br>- Erratic (diurnal) patterns in flow below hydroelectric dams will cause the following biotic response:<br>  ○ Stranding of fish<br>- Conversion of lotic habitat to lentic<br>  ○ Elimination of salmonids and pelagic spawning fishes and dominance of generalist fish species<br>  ○ Loss of fishes adapted to turbid river habitats<br>  ○ Loss of fishes due to inundation of spawning grounds<br>- Flow plays a profound role in the lives of fish with critical life events linked to flow regime (e.g., phenology of reproduction, spawning behaviour, larval survival, growth patterns and recruitment). Many of these life events are synchronized with temperature and day length, such that changes in flow regime that are not in natural harmony with these seasonal cycles may have a negative impact on aquatic biota.<br>- Stable low flows required for spawning and recruitment of riverine fish. | Bunn SE and Arthington AH. 2002. Basic Principles and Ecological Consequences of Altered Flow Regimes for Aquatic Biodiversity. Environmental Management Vol. 30, No. 4, pp. 492–507 |
| - Competitive interactions need to be considered as many fishes in small streams are habitat specialists and reductions in flow will decrease the range of habitats available. Consequently, low flows, especially those of unprecedented duration and magnitude, may increase the intensity of competitive interactions. Because fish are crowded into the same limited physical space at low flows, the influence of resource sharing on microhabitat availability must be considered<br>- Consideration of predation risk in instream flow assessments is important because (1) microhabitat utilization may vary due to the presence of predators and their activity pattern (i.e. time of day) and (2) predation pressure, rather than microhabitat availability, may act to regulate population density | Orth DJ. 1987. Ecological considerations in the development and application of instream flow-habitat models. Regulated Rivers: Research & Management, Vol. 1, 171-181 |
| Patterns in population size and assemblage structure associated with flow regimes<br>- In this study, the effects of flow regime alteration were most evident in streams where historically | Rolls RJ. Arthington AH. 2014. How do low magnitudes of hydrologic alteration |

| Information | Source |
|---|---|
| intermittent flow regimes have become more perennial. For example, we detected significant differences in M. duboulayi and P. signifer populations between currently unregulated and regulated reaches that had similar flow regimes under predevelopment conditions. There were significantly lower densities of both species in regulated reaches with more perennial flows compared to reference reaches.<br>• The abundance of G. holbrooki, the dominant non-native species, varied across current flow Classes and was highest in the highly intermit-tent unpredictable summer flow Class. This is consistent with the responses of other non-native species to regulated flow conditions and the ability of G. holbrooki to dominate fish populations under intermittent flow conditions.<br>• The over-whelming importance of flow regime characteristics in structuring the fish assemblages of the study area supports our emphasis on flow regime changes in regulated reaches as the probable impact factor, rather than stresses associated with land-use in surrounding upland catchments or differences in reach habitat structure.<br>Potential processes underlying patterns of association with flow regimes<br>• Studies show that fish abundance, demographic parameters and diversity decrease by at least 50% in response to both decreased (−50% to −100%) and increased (+50% to 100%) flow magnitude. Clear ecological effects of flow alteration have been associated with other marked changes in the flow regime, such as complete reversal of flow seasonality.<br>• Stream ecosystems are structured by, and therefore reflect, the influence of flow patterns over temporal scales ranging from milliseconds to millennia. temporal aspects of changes in river flow regimes (e.g. the length of time that a river has experienced a regulated flow regime) are also critical to interpretation of the effects of flow regime alterations. | impact riverine fish populations and assemblage characteristics? Ecological Indicators Vol 39 pp. 179– 188 |
| • The Mekong, Sekong, Sesan, and Srepok (Mekong-3S) river system, a Ramsar wetlands of international importance and critical fish migration routes, is altered by dams that distort the seasonal flow dynamics, structuring dispersal and reproduction success of fishes.<br>• Water level is also an important ecological determinant that further explains these temporal changes. In the Mekong-3S system, we observe that water levels in the Mekong sites show more seasonal-predictable patterns than those in the 3S sites where the seasonality of flow is disrupted by increasing dam operations in the upper reach of these rivers since 1990s.<br>• Overall, our results support the central hypothesis that fish assemblages in sites with unpredictable flows (3S) exhibit different temporal changes compared to fish assemblages in sites with predictable flow patterns (the Mekong).<br>• Flow perturbation caused by dams in the 3S system has decreased seasonal variation of flow, thus | Ngor PB., Legendre P., Oberdorff T. and Lek S. 2018. Flow alterations by dams shaped fish assemblage dynamics in the complex Mekong-3S river system. Ecological Indicators. Vol 88. Pp 103-114 |

| Information | Source |
|---|---|
| muting the seasonal structure of fish assemblages. The findings are consistent with the seasonality framework, emphasizing that sites with predictable environmental fluctuations are characterized by temporal (seasonal) assemblage change, whereas sites with unpredictable environmental conditions are represented by aseasonal assemblage variability, as exhibited in the 3S.<br>• Sites displaying flow disruptions are generally poorer in species richness and lower in species diversity than sites with more stable seasonal flow patterns. This pattern is most likely due to flow alterations caused by dams.<br>• Lower species richness has also been observed in regulated rivers (i.e., Gam and Mun Rivers) compared to an unregulated one (Sankgram River), and hydrological alterations have also been previously identified to cause changes in fish assemblage structure (i.e., reduced species diversity, shift in compositional and life history structure) in central Amazonian and American rivers.<br>• A general decreasing trend in species abundance, richness and diversity index in the Mekong-3S system was observed since 2010. This temporal variation is coincident with the threefold increase in hydropower dam reservoirs in the 3S sub-basin from 2007 to 2010 and the construction of a new mainstream dam (Xayaburi), which has been underway since 2012.<br>• The decreasing trends in species abundance, richness and diversity index are much stronger in sites of the 3S rivers and are attributed to the increasing river impoundment upstream, which dampens flood pulses, mutes seasonal and inter-annual flow variation, disrupts flow connectivity among fish critical habitats, and alters food web dynamics that support fish diversity and biomass. | |
| • Individual species often have contrasting habitat, spawning and feeding requirements and therefore may have evolved life history strategies specific to different flow regimes. For instance, golden perch (Macquaria ambigua Perchichthyidae) require an increase in both temperature and flow to provide cues for spawning and upstream migration in adult fish. During larval stages, however, flow is more important for downstream dispersal. Thus a flow of similar timing, duration and magnitude could either be used to stimulate upstream dispersal of adults or downstream drift of eggs and larvae depending on time of year. Similar paradoxes could exist among species because a flow which may provide benefits for native fish, may also provide optimal conditions for proliferation of alien species.<br>• Any environmental flow delivery program will be subsequently constrained by the current system configuration both in terms of what delivery method is physically possible and the requirement to balance both human and environmental needs whilst minimizing collateral benefits to alien fish that have a stronger preference for regulated conditions.<br>**How do you meet the flow requirements of many species?** | Baumgartner LJ, Conallin J, Wooden I, Campbell B, Gee R, Robinson WA, Mallen-Cooper M. Using flow guilds of freshwater fish in an adaptive management framework to simplify environmental flow delivery for semi-arid riverine systems. Fish and Fisheries. 2014 Sep;15(3):410-27. |

| Information | Source |
|---|---|
| • Assuming that enough biological information exists for many native riverine fish species, identifying which hydrological conditions may provide ecological benefit should be available to adaptively develop environmental flow programs for fish. Linking hydrological regimes to biological outcomes is difficult, especially when many species have different flow requirements.<br>• Freshwater fish species of the Murray-Darling Basin were therefore divided into four broad groups based on physiological or behavioural similarities that could be linked to flow. Emphasis on single species indicators was removed, but variable flow regimes were maintained to satisfy a range of beneficiaries. In reality, some overlap is likely to exist, but the establishment of four common groups sought to simplify the flow requirements by providing a basis to develop specific hydrographs that may result in benefits to a grouping of biologically similar species. The outcome is a far more nuanced approach to environmental water delivery that can still be practically delivered within the constraints of regulated river operations management.<br>○ **Group 1: long-lived apex predators** – Example Murray cod (Maccullochella peelii Perchichthyidae) and trout cod (Maccullochella macquariensis Perchichthyidae) for instance are known to spawn over a predictable temporal period in response to increasing temperature irrespective of flow. Environmental flow strategies for these species should therefore not focus solely on provision of single flows to create spawning opportunities on an annual basis. To maximize benefits for this species, environmental flow delivery should focus on inundating a large number of potential nest sites regularly, providing additional opportunities for juveniles to connect with off-channel nursery habitat and then allowing recolonization of main channel habitats to promote dispersal.<br>○ **Group 2: flow dependent specialists** These species are commonly referred to as flow recruitment specialists as it is generally observed that pulses are needed to generate a spawning response in these species.<br>○ **Group 3: foraging generalists** Large volume flood pulses are often considered the main flow regime that should be delivered for fish in semiarid systems. For generalist species, low flow periods are equally important and in rivers where most flow is regulated, decreasing water volumes may be more beneficial than a largesustained pulse. Foraging generalists which are generally resilient to prolonged lowflow conditions may have more flexible spawning and recruitment strategies. These species may also spawn more than once annually, so numerous small-scale watering events to inundate spawning habitat may be required to optimize benefits for these species provided that inundation occurs long enough for eggs to develop and hatch. |  |

| Information | Source |
|---|---|
| Increased abundances of these species during low flow periods suggest that these species may benefit in years where environmental water is limited or not delivered at all. Flow releases for this grouping may therefore focus on habitat availability, enhancing spawning conditions or drought refuge connectivity through small increases rather than large bankfull pulses<br>○ **Group 4: floodplain specialists** Connectivity between main channel habitats and floodplains is a main driver for productivity in large rivers. The floodplain can provide a source for nutrient input , nursery habitat for larvae and juveniles or spawning habitat for adult. In the context of flow management in regulated rivers, floodplain inundation is difficult to achieve because it requires large volumes of water to be available on a regular basis. Many floodplain species are short-lived, so even short-term interruptions to wetting and drying cycles can have deleterious effects on fish fauna. Many species of fish have a known requirement to access flood plain habitats to complete essential life history stages. | |

**Influence of Flow and Habitat on birds**

| Information | Source |
|---|---|
| • The elimination of flooding may also affect anima! species that depend on terrestrial habitats. For example, in the flow-stabilized Platte River of the Uni ted States Great Plains, the channel has narrowed dramatically (up to 85%) over a period of decades. This narrowing has been facilitated by vegetative colonization of sandbars that formerly provided nesting habitat for the threatened piping plover (*Charadius melodius*) and endangered least tern (*Sterna antillarum)*. Sandhill cranes (*Grus canadensis*), which made the Platte River famous, have abandoned river segments that have narrowed the most. | Poff NL. Allan JD. Bain MB, Karr JR. Prestegaard KL. Richter BD. Sparks RE and Stromberg JC. 1997. The Natural Flow Regime A paradigm for river conservation and restoration. BioScience, 47(11) 769-784 |

**Flow alterations by dams**

| Information | Source |
|---|---|
| • In many regulated river systems modified flow regimes are accompanied by major shifts in the thermal regime, especially where dams have hypolimnetic water releases leading to the release of cold oxygen-deficient water downstream. Since aquatic insects and fish use the combined cue of day length and the summation of day-degrees to synchronize emergence as adults, the release of cooler water downstream of impoundments can influence the spawning behavior of fish and life history processes of invertebrates.<br>• In the long-term, hypolimnetic releases can cause selective disappearance of susceptible species from downstream reaches. Modified thermal patterns and day length cues have been shown not only to | Bunn SE and Arthington AH. 2002. Basic Principles and Ecological Consequences of Altered Flow Regimes for Aquatic Biodiversity. Environmental Management Vol. 30, No. 4, pp. 492–507 |

| Information | Source |
|---|---|
| disrupt insect emergence patterns but also to reduce population success (Ward and Stanford 1982). Coldwater releases have been found to delay spawning by up to 30 days in some fish species and may cause the elimination of temperature specific species of fish. | |
| • Hydropower dams severely alter flows of a river system, causing recruitment failure and diminishment of fisheries productivity at both local and regional spatiotemporal scales worldwide.<br>• Dams cause environmental filtering of fish because many migratory (specialist) species that depend on seasonal flow dynamics to complete their life cycles are constrained or extirpated by flow disruption of dams, which finally leads to increased faunal homogenization. | Ngor PB., Legendre P., Oberdorff T. and Lek S. 2018. Flow alterations by dams shaped fish assemblage dynamics in the complex Mekong-3S river system. Ecological Indicators. Vol 88. Pp 103-114 |
| • Dams capture all but the finest sediments moving down a river, with many severe downstream consequences. For example, sediment depleted water released from dams can erode finer sediments from the receiving channel. The coarsening of the streambed can, in turn, reduce habitat availability for the many aquatic species living in or using interstitial spaces. In addition, channels may erode or downcut, triggering rejuvenation of tributaries, which themselves begin eroding and migrating headward.<br>• Fine sediments that are contributed by tributaries downstream of a dam may be deposited between the coarse particles of the streambed. In the absence of high flushing flows, species with life stages that are sensitive to sedimentation, such as the eggs and larvae of many invertebrates and fish, can suffer high mortality rates. | Poff NL. Allan JD. Bain MB, Karr JR. Prestegaard KL. Richter BD. Sparks RE and Stromberg JC. 1997. The Natural Flow Regime A paradigm for river conservation and restoration. BioScience, 47(11) 769-784 |

**Loss of longitudinal or lateral connectivity**

| Information | Source |
|---|---|
| • The viability of populations of many species of fully aquatic organisms depends on their ability to move freely through the stream network. Large migratory macroinvertebrates such as shrimps and crabs are an important component of the biota of tropical and subtropical streams because of their direct influence on ecosystem level processes, such as primary production, organic matter processing, sedimentation, and the composition of benthic algal and invertebrate communities.<br>• Water abstraction causes reduction in migrating shrimp larvae.<br>• Presence of instream barriers result in the increased predation of juvenile migrating shrimp and a loss of migratory fish species. | Bunn SE and Arthington AH. 2002. Basic Principles and Ecological Consequences of Altered Flow Regimes for Aquatic Biodiversity. Environmental Management Vol. 30, No. 4, pp. 492–507 |

| Information | Source |
|---|---|
| - Reduced frequency, duration and area of inundation of floodplain wetlands causes:<br>  ○ Reduced spawning areas and/or recruitment success of lowland river fish<br>  ○ Decline in waterbird species richness and abundance<br>  ○ Decline in wetland vegetation | |

**Invasion and success of exotic introduced species**

| Information | Source |
|---|---|
| - Loss of wet-dry cycles and increased stability of water levels causes reduced growth and survival of native aquatic macrophytes and increased invasion of exotics<br>- Reduced flow variability and increased seasonal stability favour populations of exotic fish species (carp, mosquitofish)<br>- Conversion of lotic to lentic habitat results in the proliferation of exotic fish species<br>- Interbasin transfers of water results in the transfer of schistosomiasis; translocation of fish species | Bunn SE and Arthington AH. 2002. Basic Principles and Ecological Consequences of Altered Flow Regimes for Aquatic Biodiversity. Environmental Management Vol. 30, No. 4, pp. 492–507 |

**Selection of target species**

| Information | Source |
|---|---|
| - Species most restricted to fast water and slow water would be the most useful as target species | Orth DJ. 1987. Ecological considerations in the development and application of instream flow-habitat models. Regulated Rivers: Research & Management, Vol. 1, 171-181 |

**Geomorphological effects of flow alteration on rivers**

| Information | Source |
|---|---|
| - Alterations to the flow regime directly modify river morphology and geomorphic functions such as channel shape and sediment transport and distribution. The primary response of altered flow and the secondary response of altered channel morphology both have implications for aquatic ecosystems.<br>- Geomorphic changes to channel form and processes, such as bed and bank erosion, can be related to specific characteristics of flow regime alteration. Important flow characteristics can include: (1) increased frequency of high-magnitude flows or larger overall flow volume (i.e., in urban rivers) that can lead to | Vietz GJ and Finlayson BL. 2017. Chapter 5: Geomorphological effects of flow alteration on Rivers. In Water for the environment. PP 83-100 |

| Information | Source |
|---|---|
| greater channel scour; (2) changes in the rate of flow recession such as rapid flow drawdown below a hydropower dam, leading to increased likelihood of mass failure where saturated riverbanks overcome the strength of the bank material retaining them; and (3) prolonged low flows, such as below an irrigation storage, leading to subaerial preparation of the bank through drying and desiccation, facilitating removal of dislodged sediments during subsequent flow events.<br>• Changes to deposition are equally driven by flow. Floodplain formation through deposition can be reduced below a regulated river through decreases in both the frequency of overbank flows and the lower sediment concentrations.<br>Role of geomorphology in aquatic ecosystems<br>• The form and function, as well as the hydraulics, of river systems are altered by changes to the flow regime, and these in turn impact physical habitat and aquatic ecosystems but it is important to recognize that rivers are naturally dynamic. It is most commonly excessive extents or rates of change that we aim to understand and manage. Instream biota are adaptable to change within natural rates, but may not be able to quickly adapt to sudden changes in-channel characteristics such as morphology or sediment movement.<br>• Examples of physical and hydraulic attributes that may be ecologically important include: the size and diversity of bed sediments and how they influence hyporheic exchange, hydraulic diversity at the reach and patch scale, pools and slow water refuges, sediment deposits such as bars and benches and the role they play in vegetation diversity, erosional niches such as undercut banks and the distribution of large wood.<br>• Flow alters geomorphic conditions, facilitating ecological responses that in turn further alter geomorphic conditions. Examples of this include: the development of benches, islands, or floodplains in aggrading systems that encourage vegetation colonization, encouraging further deposition, with the process repeating itself; or large wood liberated from floodplains through bank erosion, increasing roughness, encouraging deposition within the channel and floodplain, and providing niches for vegetation establishment as a future source of wood.<br>Vegetation change<br>• A common observation in this regard is that stream channels with intact riparian vegetation cover and more wood are wider, less incised, have increased bed roughness and lower average velocity than streams with deforested riparian zones. High-quality geomorphic characteristics of rivers in forested riparian zones led to improved ecosystem attributes such as increased mass of organic matter, improved nutrient dynamics, and a greater abundance of macroinvertebrates. | |

| Information | Source |
|---|---|
| • The clearing of vegetation from a watershed influences stream geomorphology through changes in flow and sediment delivered to the stream.<br>Dams<br>• Dams can affect the geomorphological characteristics of streams in three ways: (1) dams interrupt the continuity of sediment movement down rivers by trapping all but the finest particles; (2) dams can change the magnitude, frequency, duration, and regime of flows released downstream, and hence the way in which stream energy is exerted on the channel; and (3) dams can divert flow out of the river system and into other streams or to consumptive uses, reducing (or sometimes increasing) the overall volume of flow. Factors that determine the magnitude of the geomorphological impact of dams as: the storage capacity of the impoundment in relation to MAR, operational procedures used on the dam, bed materials in the downstream channel, water outlet structures on the dam, and the sediment load of the river prior to dam construction.<br>Common flow alteration scenarios that impact river geomorphology<br>• Vegetation clearing<br>○ Channel incision and enlargement with variable sediment loads<br>• Urbanization<br>○ Channel incision, enlargement and simplication<br>○ Sediment increases then decreases<br>• Large water supply reservoirs<br>○ Channel reduction and simplication<br>○ Variable sediment loads<br>○ Bed sediment armouring<br>• Hydropower<br>○ Channel enlargement<br>○ Reduction in channel sinuosity<br>○ Episodic erosion<br>○ Bed sediment armouring<br>• Flood alleviation dams<br>○ Enlarged low flow channel<br>○ Potentially reduced high-flow channel<br>○ Reduced sediment supply<br>○ Reduced floodplain formation | |

| **Information** | **Source** |
|---|---|
| • Farm dams<br>○ Channel reduction and connectivity interruption<br>○ Potential for clearwater erosion under sediment starvation<br>• Groundwater extraction and depletion<br>○ Minor influence through vegetation or changed salinity<br>• Altered surface drainage networks<br>○ Loss of small-order streams<br>○ Channelization<br>○ Concentrated flow leading to channel enlargement | |

### Nile Delta and estuary

| **Information** | **Source** |
|---|---|
| • The altered riverine sediment and freshwater discharge, and the increasing nutrients from irrigation fields in Egypt, have negatively impacted the eco-health of the Nile Delta coast.<br>• Immediately after the Aswan Dam was built in 1964, fish landing off the western Nile coast decreased in numbers rapidly, and this trend was followed by a gradual recovery in the 1980s and a significant recovery in 1990s. This pattern definitely fit the increasing nutrient delivery to the estuary, here manifested by the parallel increasing N and fish catches in the coastal lagoons. The improved fishing technology in more recent times can be an additional attributor.<br>• Dissolved silicate (DSi) into the delta coast (measured below the dam) decreased after the dam because the dam not only blocks the sediment flux, but also increases the time of water residence in reservoirs, thereby promoting the uptake of Si by algae in the reservoir.<br>• The primary production in the estuarine waters followed the same trend as that of DSi shortly after damming in 1960s and 1970s, however PPR increased dramatically after the 1980s, suggesting a change from silicate algae to nonsilicate algae. In turn, this led to algaegenerated hypoxia events. | Chen Z. 2019. Chapter 13: A Brief Overview of Ecological Degradation of the Nile Delta: What We Can Learn. In: Coasts and Estuaries. Pp233-236 |
| • Since 1964 sediment has not been able to bypass the Aswan High Dam. The two results of this trapping of sediments behind the dam are the filling up of Lake Nasser and severe erosion of the Nile delta's coast.<br>• The advance and retreat of the Nile delta shoreline, about 240 km from west of Abu Quir to Port Said, correlates closely with the quantity of sediment discharged to the sea, a condition affected by the construction of irrigation control structures and dams on the Nile River. This phenomenon has been affected by the climatic changes that have occurred in east Africa. It has been found that major changes | |

| Information | Source |
|---|---|
| prevailed prior and subsequent to 1900. Before 1900, water and sediment discharge was not impeded by artificial structures and were high. After control structures were added to the system, lesser amounts of water and sediment reached the sea and coastal erosion and retreat became common. | |

**Mechanistic Links Between Low Flow and Aquatic Ecosystems**

| | |
|---|---|
| • Principle 1: Low flows control the extent of physical aquatic habitat, thereby influencing the composition and diversity of biota, trophic structure, and carrying capacity<br>• Principle 2: Low flows mediate changes in habitat conditions, which in turn, drive patterns in the distribution and recruitment of biota<br>• Principle 3: Low flows affect the sources and exchange of energy in riverine ecosystems, thereby affecting ecosystem production and biotic composition<br>• Principle 4: Low flow restricts connectivity and diversity of habitat, increases the importance of refugia, and drives multiscale patterns in biotic diversity.<br>• The broad mechanistic links between low flow, processes and patterns in riverine ecosystems do not operate in isolation and many ecological pathways are affected by low flows and are likely to occur simultaneously, potentially resulting in similar or synergistic and complex effects.<br>• The processes and mechanisms by which low flows affect aquatic ecosystems identified in our paper are driven both by the hydrological characteristics of individual flow events (e.g., duration, timing, frequency) and by the context of events within the temporal hierarchy of the long-term low flow regime. Disentangling the relative importance of these different flow disturbance attributes (described above) is necessary to isolate their individual and interacting ecological effects | Rolls JR. Leigh C and Sheldon F. 2012. Mechanistic effects of low flow hydrology on riverine ecosystems: ecological principles and consequences of alteration. Freshwater Science 31(4):1163–1186 |

**Site specific info**

RR2 – Jinja: Victoria Nile downstream of Lake Victoria

| Jinja | Source |
|---|---|
| • The Alliance for Zero Extinctions (AZE) is an initiative led by a group of biodiversity conservation organisations to identify and protect the last remaining habitats for the world's most threatened species (see http:// www.zeroextinction.org). AZE Sites are designated through the and all must be met in order to qualify: Criterion 1 – the site must contain at least one species listed as Critically Endangered or Endangered by the IUCN Red List; Criterion 2 – The site must be the sole location where the Critically Endangered or Endangered species exists, or contain the overwhelming significant | Darwall, W., Smith, K., Lowe, T. and Vié, J.-C. 2005. The Status and Distribution of Freshwater Biodiversity in Eastern Africa. IUCN SSC Freshwater Biodiversity Assessment Programme. IUCN, Gland, Switzerland and |

| | |
|---|---|
| population for one life history segment; and Criterion 3 – the site application of three criteria, must have a definable boundary within which the character of the habitats, biological communities, and/or management issues have more in common with each other than with those in adjacent areas.<br>• The list below provides the candidate AZE sites for fish taxa endemic to Eastern Africa. | Cambridge, UK. viii + 36 pp. |

| **Site No.** | **Species** | **IUCN Red List Status** | **Location** |
|---|---|---|---|
| 1 | *Neochromis simotes* | Critically Endangered | Restricted to Kakindu and Ripon Fall, both on the Victoria Nile in Jinja, Uganda. |
| 2 | *Haplochromis cavifrons* | Critically Endangered | Endemic to the Vesi Archipelago in the Speke Gulf, Lake Victoria, Tanzania. |
| 3 | *Haplochromis* sp. *"amboseli"* | Critically Endangered | Endemic to the Amboseli swamps, Kenya. |
| 4 | *Oreochromis hunteri* | Critically Endangered | Endemic to Lake Chala on the eastern slopes of Mount Kilimanjaro. |
| 5 | *Oreochromis chungruruensis* | Critically Endangered | Endemic to Lake Chungruru, a crater lake north of Lake Malawi which has no water outlet. |

RR4 – Gambela: Baro River upstream of Machar Marshes.

| Gambela | Source |
|---|---|
| **Fish** | |
| • The freshwater fish fauna of Ethiopia contains a mixture of Nilo-Sudanic, East African and endemic forms. The Nilo-Sudanic forms represent a large number of species found in the Baro-Akobo, Omo-Ghibe and Abay drainage basins (the genera *Alestes, Bagrus, Barilius, Catharinus, Hydrocynus, Hyperopisus, Labeo, Malapterurus, Mormyrus, Polypterus* and *Protopterus).* The highlands East African forms are found in the northern Rift Valley lakes, the highland lakes and associated river systems and the Awash drainage basin (genera *Barbus, Clarias, Garra, Oreochromis* and *Varicorhinus*).<br>• Of the cyprinid genera, *Barbus* species are by far the most diverse group found. The group stands second, next to the *Oreochromis niloticus,* in total commercial catches from the countries water bodies. Another important species in small to medium sized stream are members of the cyprinid genus *Garra*. They are highly resilient fish found in large numbers even in streams that hardly flow and where there is light pollution.<br>• The only know loach species in Africa *Nemacheilus abyssinicus* was discovered in the Baro drainage | Getahun, A and Stiassny MLJ. 1998. The freshwater biodiversity crisis: the case of the Ethiopian fish fauna. Ethiopian journal of Science,21(2): 207-230. |

<table>
<tr>
<td>basin from the Sore River near Metu town.</td>
<td></td>
</tr>
<tr>
<td>
<ul>
<li>Baro river at Gambella, turbid muddy substrate 8°14'54''N, 34°34'59''E</li>
<li>Samples were taken during September 24 to October 24, 2008</li>
<li>The following 10 species where collected at Baro at Gambella:
<ul>
<li><i>Polypterus bichir</i></li>
<li><i>Gymnarchus niloticus</i></li>
<li><i>Hippopptamyrus pictus</i></li>
<li><i>Mormyrops anguilloides</i></li>
<li><i>Mormyrus caschive</i></li>
<li><i>Citharinus latus</i></li>
<li><i>Bagrus docmak</i></li>
<li><i>Clarius gariepinus</i></li>
<li><i>Synodontis schall</i></li>
<li><i>Oreochromis niloticus</i></li>
</ul>
</li>
</ul>
</td>
<td>Melaki T abd Getahun A. 2012. Diversity And Relative Abundance Of Fishes In Sometemporary And Perennial Water Bodies Of The Baro Basin,Gambella, Ethiopia. Ethiop. J. Biol. Sci. 11(2):193-206.</td>
</tr>
<tr>
<td>
<ul>
<li>The fish fauna is most diverse in the lowland part of the drainage (the Gambela region). It is not surprising because the reproductive and feeding cycles of most of the local fish species are closely tied to the floodplains inundated during the rainy season (LoweMcConnell, 1977; 1987). Only a few species are found in most of the upper reaches of the system (Fig. 2a): <i>Barbus</i> cf. <i>intermedius, B. paludinosus,</i> two species of <i>Garra</i> and <i>Nemacheflus abyssinicus</i> (Krysanov and Golubtsov, 1996; Abebe Getahun and Stiassny, 1998; our unpublished data).</li>
<li>We should mention also one or two undescribed <i>Garra</i> species and possibly an undescribed species of the annual killifish, <i>Nothobranchius</i> found in the Gambela lowland (Golubtsov <i>et al.</i>, 1995) as potential Ethiopian endemics inhabiting the White Nile system. We have no information about introduced fishes in this system.</li>
<li>Below is a list of the fish diversity in the White Nile system within the limits of Ethiopia (2003)</li>
</ul>
<table>
<tr><th rowspan="2">Family</th><th colspan="2">Genera</th><th colspan="2">Species</th></tr>
<tr><th>2003</th><th>2008</th><th>2003</th><th>2008</th></tr>
<tr><td>Protopteridae - African lungfish</td><td>1</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td>Polypteridae - bichirs</td><td>1</td><td>1</td><td>2</td><td>2</td></tr>
<tr><td>Osteoglossidae - African bonytongue</td><td>1</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td>Notopteridae -African knifefishes</td><td></td><td>1</td><td></td><td>1</td></tr>
<tr><td>Mormyridae - elephantfishes</td><td>8</td><td>8</td><td>15</td><td>15</td></tr>
</table>
</td>
<td>
<ul>
<li>Golubtsov AS and Mina MV. 2003. Fish Species Diversity In The Main Drainage Systems Of Ethiopia: Current State Of Knowledge And Research Perspectives. Ethiopian Journal of Natural Resources. 5 (2): 281-318.</li>
<li>Golubtsov AS and Darkov AA. 2002. A review of fish diversity in the main drainage systems of Ethiopia based on the data obtained by 2008. Research gate publication.</li>
</ul>
</td>
</tr>
</table>

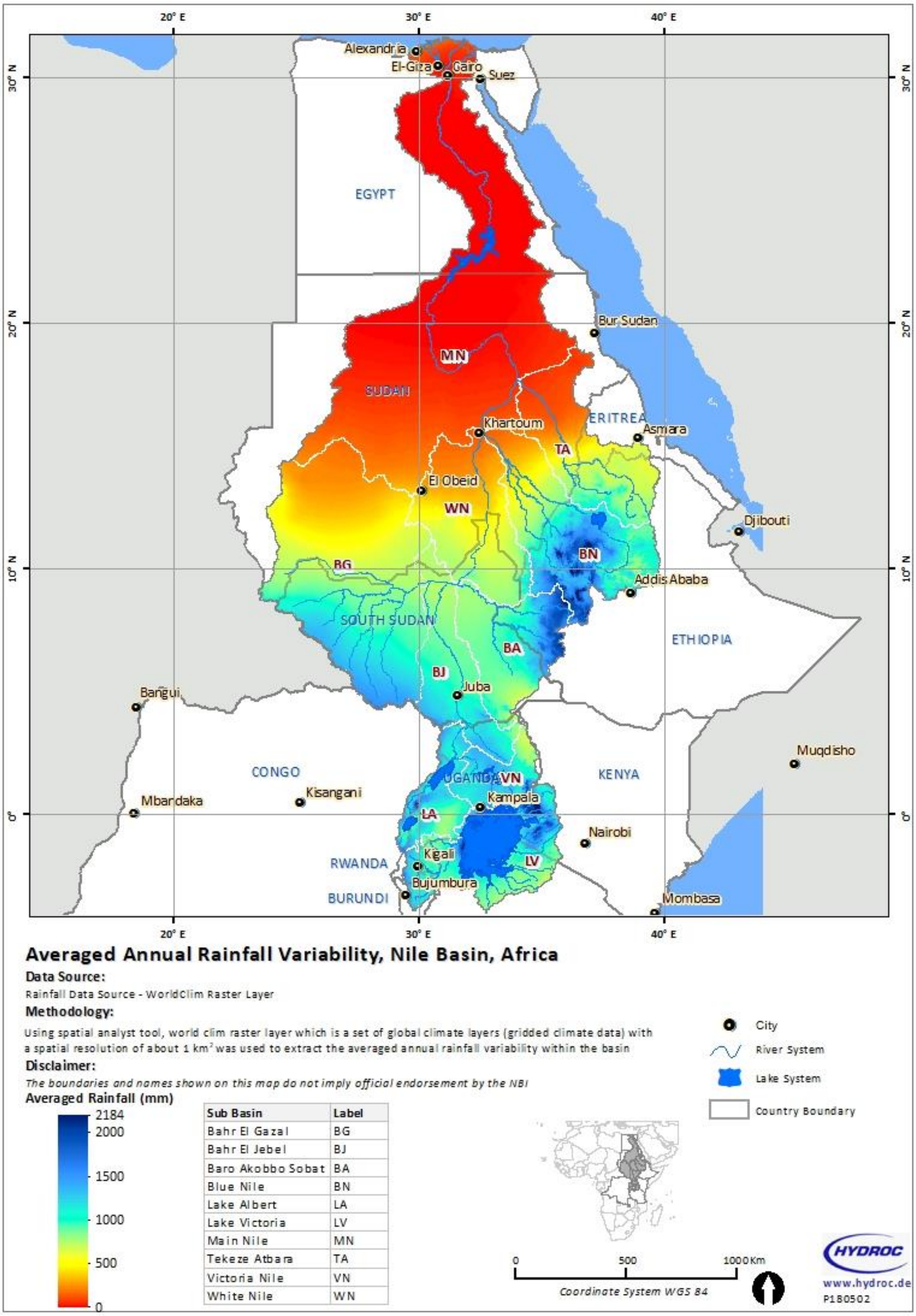
| | | | | | |
|---|---|---|---|---|---|
| Gymnarchidae - aba | 1 | 1 | 1 | 1 | |
| Cromeriidae - naked shellear | 1 | 1 | 1 | 1 | |
| Characidae - characins | 4 | 4 | 7 | 7 | |
| Distichodontidae - purus | 4 | 4 | 9 | 9 | |
| Citharinidae - abeels | 1 | 1 | 2 | 2 | |
| Cyprinidae - carps | 6 | 7 | 19 | 21 | |
| Balitoridae - African stony loach | 1 | 1 | 1 | 1 | |
| Bagridae - bagrid catfishes | 3 | 1 | 5 | 2 | |
| Claroteidae – claroteid catfishes | | 3 | | 4 | |
| Schibeidae - schilbeid catfishes | 2 | 3 | 4 | 5 | |
| Amphiliidae - loach catfishes | 2 | 2 | 2 | 2 | |
| Clariidae - airbreathing catfishes | 2 | 2 | 4 | 5 | |
| Malapteruridae - electric catfishes | 1 | 1 | 2 | 2 | |
| Mochokidae - squeakers | 5 | 5 | 15 | 15 | |
| Nothobranchiidae – African rivulines | | 2 | | 3 | |
| Poeciliidae – poeciliids | | 1 | | 2 | |
| Cyprinodontidae - toothcarps, killifishes | 3 | | 4+ | | |
| Channidae - snakehead | 1 | 1 | 1 | 1 | |
| Centropomidae - Nile perch | 1 | 1 | 1 | 1 | |
| Cichlidae - cichlids | 4 | 4 | 5 | 5 | |
| Anabantidae - climbing gouramies | 2 | 2 | 3 | 3 | |
| Tetraodontidae - puffer | 1 | 1 | 1 | 1 | |
| Totals | 55 | 60 | 106 | 113 | |
| • The glass catfish *Parailia pellucida* from the Baro River at Gambella<br><br>• In December 2006 the glass catfish was sampled from the Baro River just upstream from the bridge at | | | | | Golubtsov AS and Darkov AA. 2002. A review of fish diversity in the main drainage systems of Ethiopia based on the data obtained by 2008. Research gate publication. |

| | |
|---|---|
| the town of Gambella and in 2007 and 2008, six specimens of the African knifefish were collected by fishermen from the Akidi Pond located at the southern bank of the Bar River, 37km west of Gambella.<br>• The African knifefish *Xenomystus nigri* from the Akidi Pond at the southern bank of the Baro River<br> | |
| **Vegetation** | |
| *Acacia* trees and elephant grasses are the dominant vegetation | Melaki T abd Getahun A. 2012. Diversity And Relative Abundance Of Fishes In Sometemporary And Perennial Water Bodies Of The Baro Basin,Gambella, Ethiopia. Ethiop. J. Biol. Sci. 11(2):193-206. |

RR9 – Dongola: Main Nile upstream of Lake Nasser

| Dongola | Source |
|---|---|
| **Vegetation**<br>• From Khartoum downstream, the Nile valley is a broad flat plain over 300 km wide at its narrowest point and almost devoid of vegetation throughout the desert of northern Sudan. However, drought-tolerant plant species, such as *Polygonum* spp. and *Potamogeton* spp., occur in local stands and create narrow fringes along the mainstem Nile. Stands of *Phragmites* proliferate where the Nile flows into Lake Nubia (Dumont 1986; Hughes & Hughes 1992).<br>**Fish**<br>• The lower Nile River provides vital habitat within a desert environment for an array of fish and other wildlife. Over 70 species of fish live in the ecoregion, many belonging to the families Alestiidae, Cichlidae, Citharinidae, Claroteidae, Cyprinidae, Mochokidae, and Mormyridae. | http://www.feow.org/ecoregions/details/lower_nile |

# ANNEXURE B: NILE BASIN THEMATIC MAPS



**Averaged Annual Rainfall Variability, Nile Basin, Africa**

**Data Source:**

Rainfall Data Source - WorldClim Raster Layer

**Methodology:**

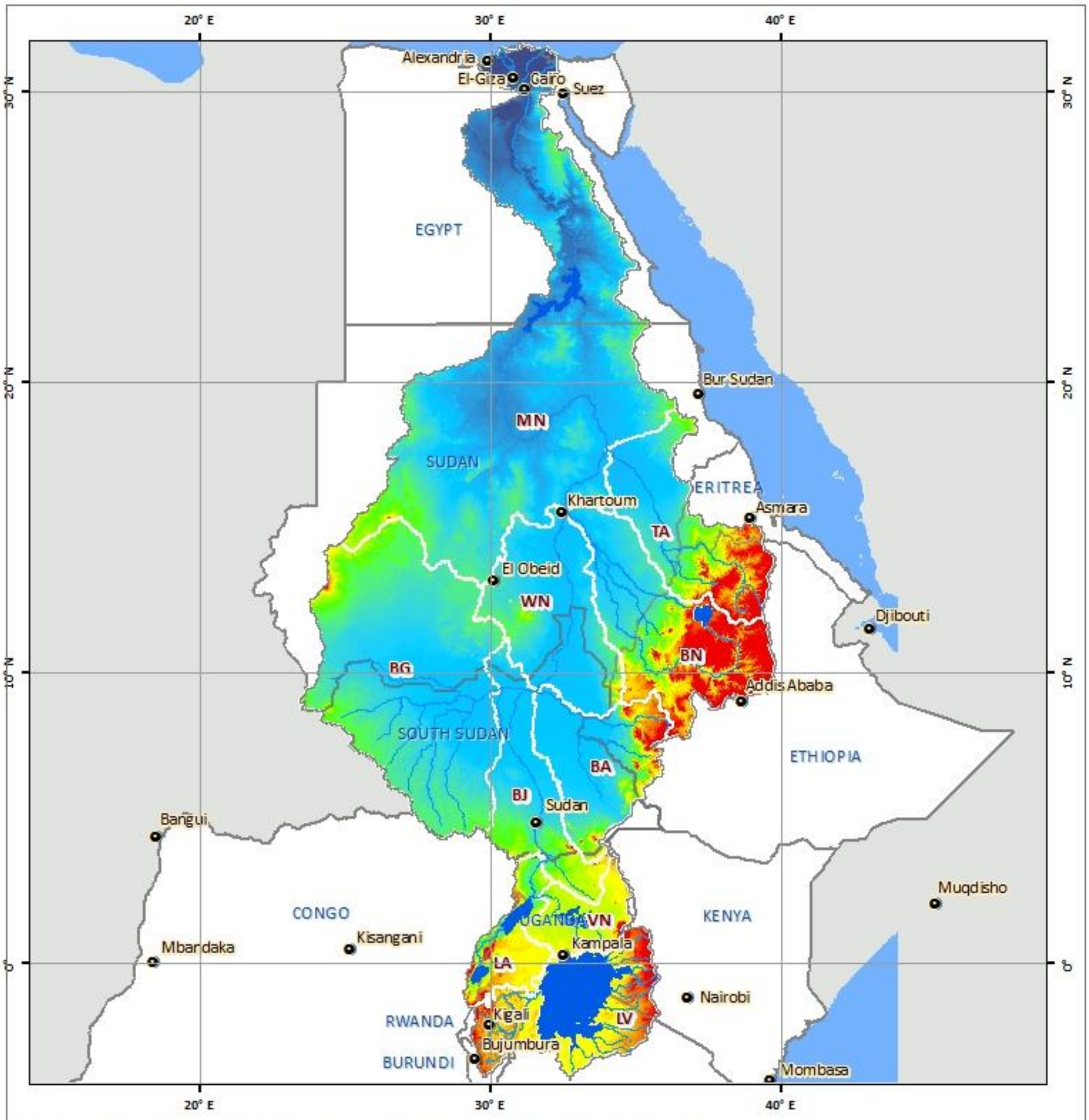
Using spatial analyst tool, world clim raster layer which is a set of global climate layers (gridded climate data) with a spatial resolution of about 1 $km^2$ was used to extract the averaged annual rainfall variability within the basin

**Disclaimer:**

*The boundaries and names shown on this map do not imply official endorsement by the NBI*

**Averaged Rainfall (mm)**

| Sub Basin | Label |
|---|---|
| Bahr El Gazal | BG |
| Bahr El Jebel | BJ |
| Baro Akobbo Sobat | BA |
| Blue Nile | BN |
| Lake Albert | LA |
| Lake Victoria | LV |
| Main Nile | MN |
| Tekeze Atbara | TA |
| Victoria Nile | VN |
| White Nile | WN |



## Basin Boundary and Riparian Countries, Nile Basin, Africa

**Data Source:**

Data provided by Nile Basin Initiative and The Nature Conservacy (TNCMAPS)

**Methodology:**

Using spatial analyst tool,an extraction of the digital elevation model (DEM) was performed to delienate the topographic basin boundary and an overlay of thematic layers of rivers, lakes, ocean system, riparian country boundaries and nile basin cities undetaken

**Disclaimer:**

*The boundaries and names shown on this map do not imply official endorsement by the NBI*

| Sub Basin | Label |
|---|---|
| Bahr El Gazal | BG |
| Bahr El Jebel | BJ |
| Baro Akobbo Sobat | BA |
| Blue Nile | BN |
| Lake Albert | LA |
| Lake Victoria | LV |
| Main Nile | MN |
| Tekeze Atbara | TA |
| Victoria Nile | VN |
| White Nile | WN |

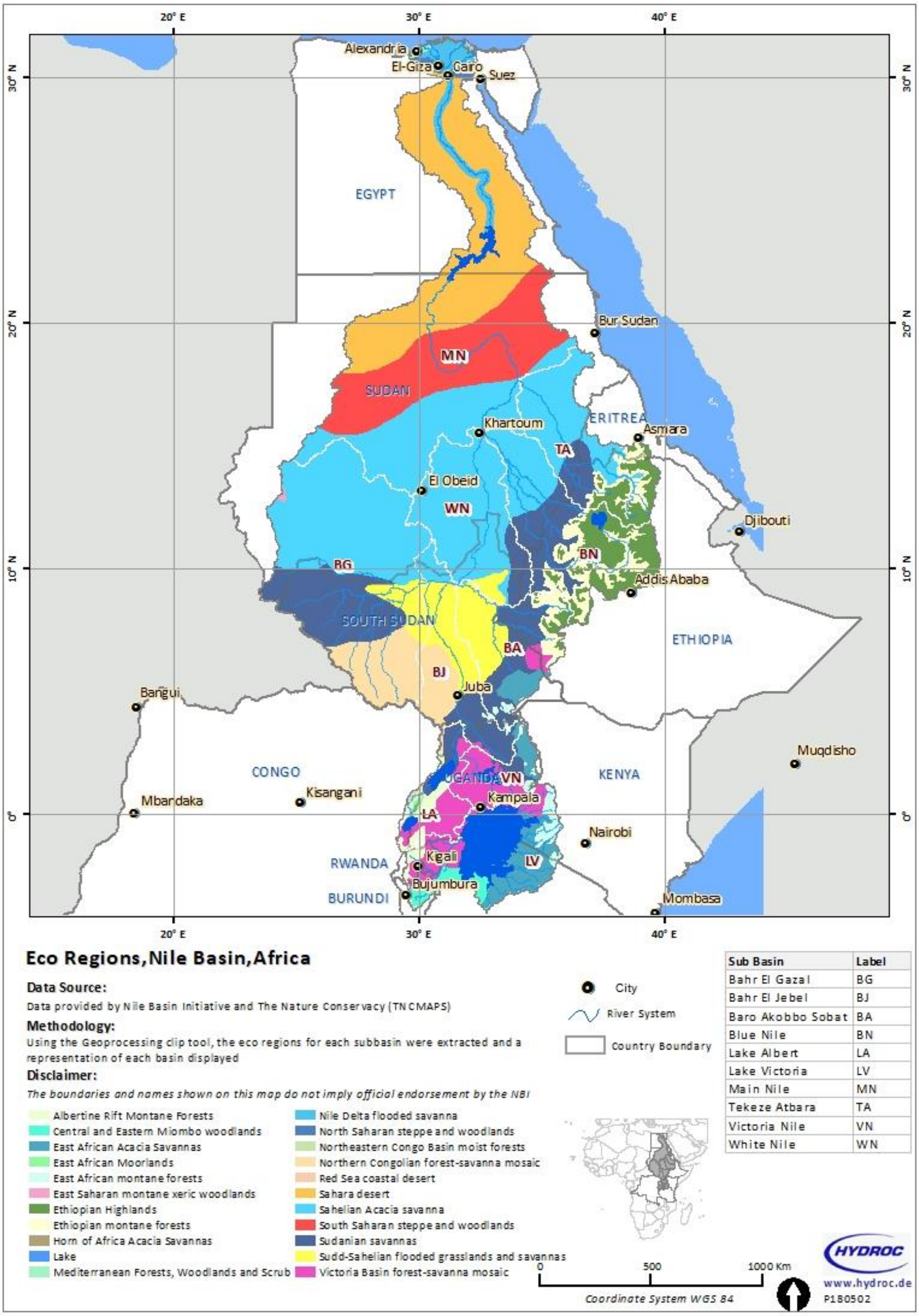
● City
∿ River System
● Lake System
▨ Ocean
☐ Country Boundary

**Elevation (masl)**

🟥 > 2000
🟧 1,600.01 - 2,000
🟨 1,200.01 - 1,600
🟩 800.01 - 1,200
🟦 400.01 - 800
■ 0 - 400

*Coordinate System WGS 84*

HYDROC
www.hydroc.de
P180502



## Eco Regions, Nile Basin, Africa

**Data Source:**

Data provided by Nile Basin Initiative and The Nature Conservacy (TNCMAPS)

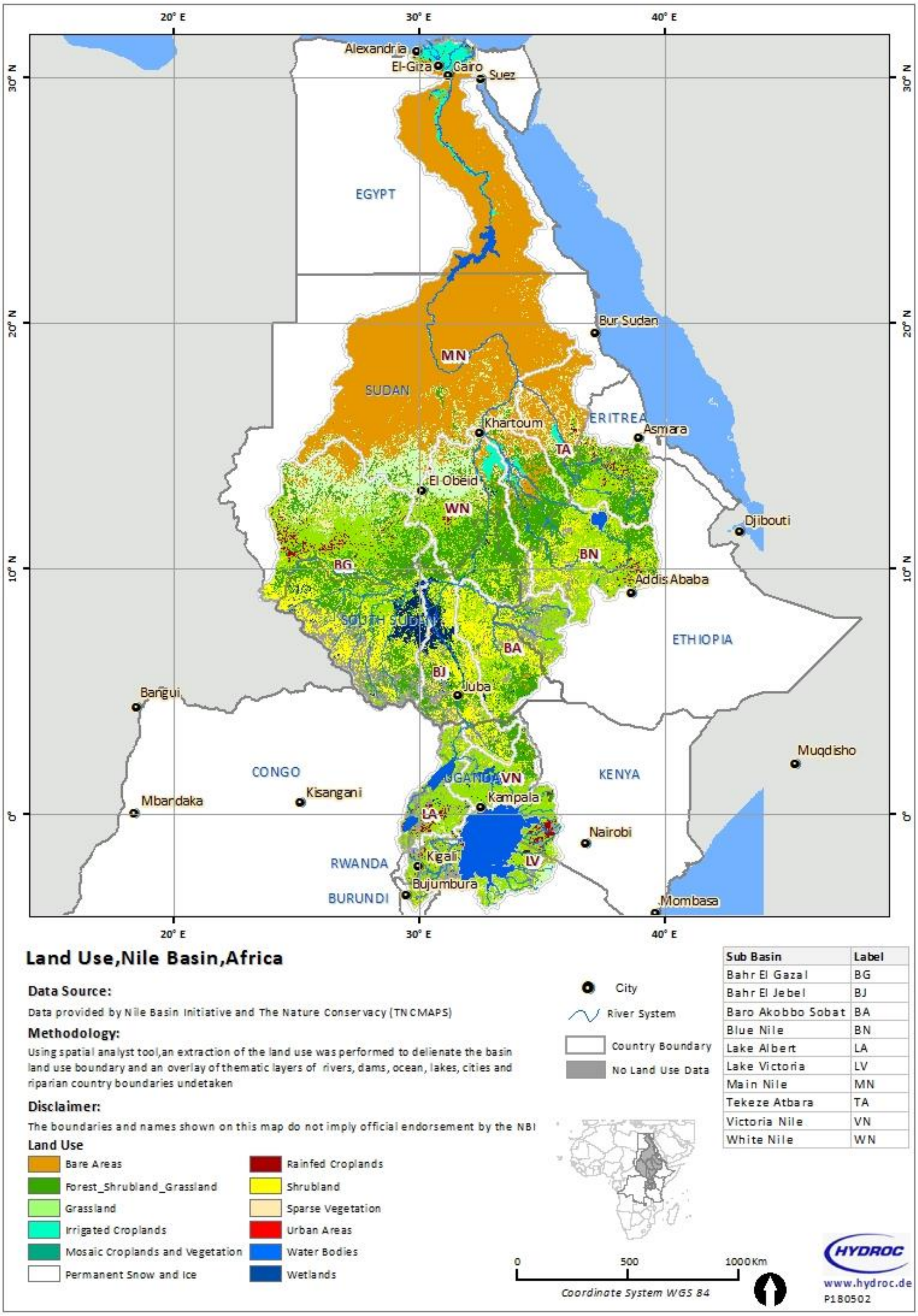
**Methodology:**

Using the Geoprocessing clip tool, the eco regions for each subbasin were extracted and a representation of each basin displayed

**Disclaimer:**

*The boundaries and names shown on this map do not imply official endorsement by the NBI*

| Sub Basin | Label |
|---|---|
| Bahr El Gazal | BG |
| Bahr El Jebel | BJ |
| Baro Akobbo Sobat | BA |
| Blue Nile | BN |
| Lake Albert | LA |
| Lake Victoria | LV |
| Main Nile | MN |
| Tekeze Atbara | TA |
| Victoria Nile | VN |
| White Nile | WN |



## Land Use,Nile Basin,Africa

**Data Source:**

Data provided by Nile Basin Initiative and The Nature Conservacy (TNCMAPS)

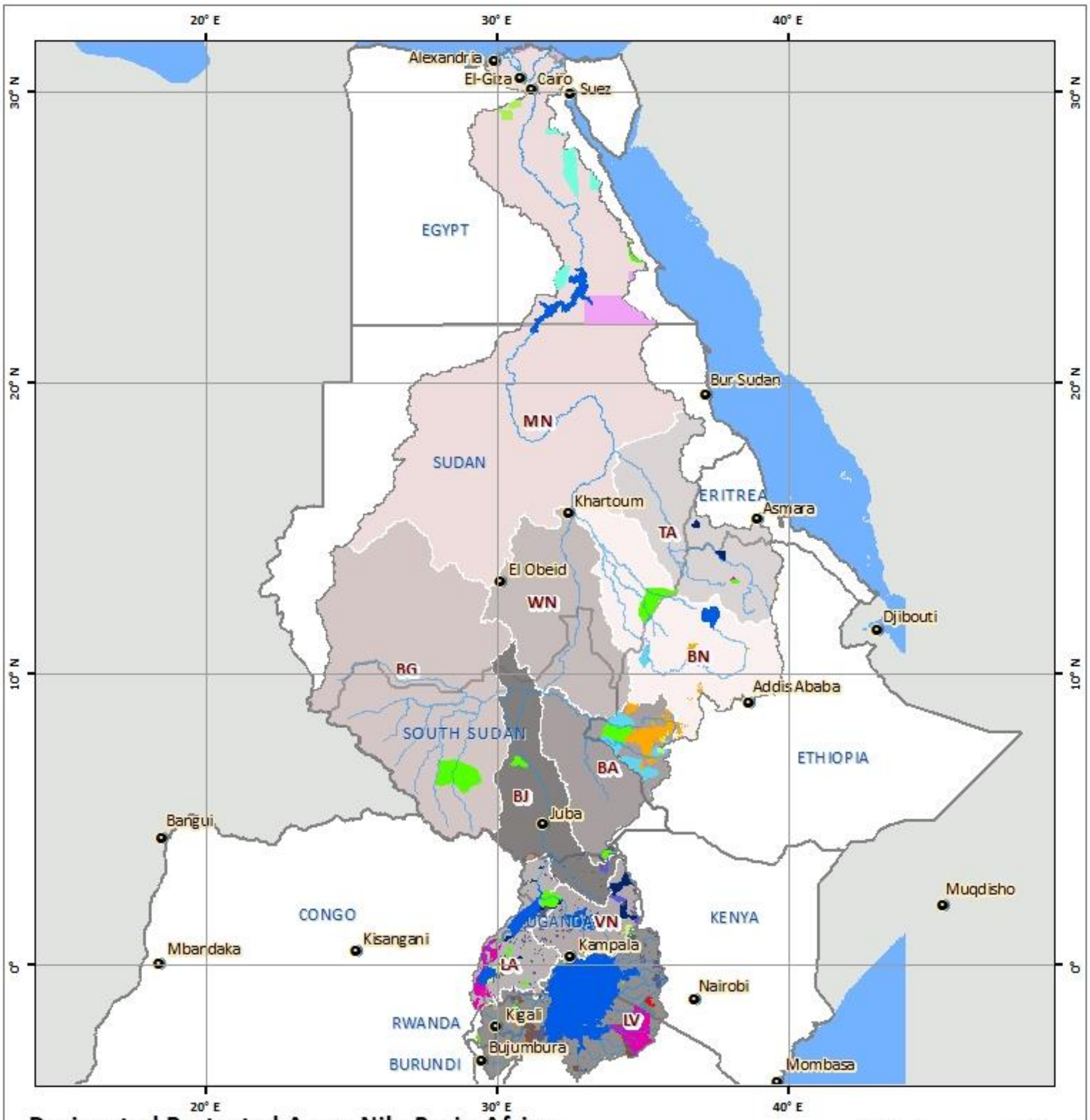
**Methodology:**

Using spatial analyst tool,an extraction of the land use was performed to delienate the basin land use boundary and an overlay of thematic layers of rivers, dams, ocean, lakes, cities and riparian country boundaries undetaken

**Disclaimer:**

The boundaries and names shown on this map do not imply official endorsement by the NBI

| Sub Basin | Label |
|---|---|
| Bahr El Gazal | BG |
| Bahr El Jebel | BJ |
| Baro Akobbo Sobat | BA |
| Blue Nile | BN |
| Lake Albert | LA |
| Lake Victoria | LV |
| Main Nile | MN |
| Tekeze Atbara | TA |
| Victoria Nile | VN |
| White Nile | WN |



## Designated Protected Areas,Nile Basin,Africa

**Data Source:**

Data provided by Nile Basin Initiative and The Nature Conservacy (TNCMAPS)

**Methodology:**

The thematic layer of designated protected areas (DPAs) was overlaid with the Nile Basin boundary to display the DPAs within each sub basin

**Disclaimer:**

*The boundaries and names shown on this map do not imply official endorsement by NBI*

- 🟥 Community Conservancy
- 🟦 Community Wildlife Management Area
- 🟥 Conservation Area
- 🟦 Controlled Hunting Area
- 🟪 Faunal Reserve
- ⬛ Forest Reserve
- 🟫 Game Reserve
- 🟩 Geological Protected Area
- 🟪 Hunting Area
- 🟪 Multiple Use Management Area
- 🟧 National Forest Priority Area
- 🟩 National Park
- 🟦 National Reserve
- 🟪 Nature Reserve
- 🟦 Protected Area
- 🟪 Protected Landscape
- 🟩 Ramsar Site, Wetland of International Importance
- 🟩 Sanctuary
- 🟥 Strict Nature Reserve
- 🟩 UNESCO-MAB Biosphere Reserve
- 🟪 Wildlife Management Area
- 🟦 Wildlife Reserve
- 🟫 Wildlife Sanctuary
- 🟪 World Heritage Site
- 🟨 Not Reported

● City

∿ River System

▭ Country Boundary

| Sub Basin | Label |
|---|---|
| Bahr El Gazal | BG |
| Bahr El Jebel | BJ |
| Baro Akobbo Sobat | BA |
| Blue Nile | BN |
| Lake Albert | LA |
| Lake Victoria | LV |
| Main Nile | MN |
| Tekeze Atbara | TA |
| Victoria Nile | VN |
| White Nile | WN |

0 500 1000Km

*Coordinate System WGS 84*

HYDROC
www.hydroc.de
P180502

# ANNEXURE C: HYDRAULIC FLOW DATA FOR HEC-RAS CALCULATED FROM DAILY SIMULATIONS FROM THE NileDSS (1965-2014)

| | Return Period [m³/s] | |
|---|---|---|
| | 1yr | 1.5yr |
| RR1 | 111 | 249 |
| RR2 | 740 | 1056 |
| RR3 | 859 | 1359 |
| RR4 | 516 | 894 |
| RR5 | 574 | 759 |
| RR6 | 1071 | 1293 |
| RR7 | 3686 | 7569 |
| RR8 | 248 | 1383 |
| RR9 | 6956 | 9023 |

Overall percentiles [m³/s]

| | 0.1 | 1 | 5 | 10 | 15 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 85 | 90 | 95 | 99 | 99.9 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RR1 | 457 | 433 | 393 | 363 | 334 | 314 | 276 | 249 | 223 | 205 | 188 | 164 | 150 | 132 | 112 | 75 | 53 |
| RR2 | 1668 | 1597 | 1482 | 1374 | 1317 | 1276 | 1186 | 1092 | 1033 | 968 | 902 | 848 | 821 | 780 | 700 | 618 | 580 |
| RR3 | 4547 | 2132 | 1834 | 1685 | 1627 | 1583 | 1462 | 1353 | 1260 | 1162 | 1024 | 945 | 902 | 870 | 808 | 710 | 683 |
| RR4 | 1571 | 1390 | 1069 | 893 | 780 | 695 | 487 | 334 | 226 | 156 | 110 | 79 | 68 | 56 | 43 | 28 | 18 |
| RR5 | 899 | 861 | 812 | 772 | 735 | 703 | 641 | 545 | 343 | 228 | 185 | 118 | 82 | 62 | 42 | 25 | 15 |
| RR6 | 1713 | 1581 | 1446 | 1361 | 1304 | 1261 | 1183 | 1096 | 991 | 867 | 782 | 712 | 669 | 618 | 564 | 512 | 481 |
| RR7 | 8865 | 7580 | 5349 | 3989 | 2884 | 2111 | 1261 | 755 | 635 | 635 | 635 | 635 | 635 | 635 | 424 | 121 | 51 |
| RR8 | 5580 | 2952 | 1753 | 1175 | 774 | 514 | 223 | 184 | 172 | 167 | 159 | 144 | 133 | 126 | 0 | 0 | 0 |
| RR9 | 13679 | 10499 | 7874 | 5986 | 4454 | 3529 | 2449 | 1889 | 1650 | 1511 | 1407 | 1300 | 1241 | 1167 | 1038 | 883 | 622 |

January percentiles [m³/s]

| | 0.1 | 1 | 5 | 10 | 15 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 85 | 90 | 95 | 99 | 99.9 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RR1 | 403 | 397 | 348 | 309 | 284 | 271 | 255 | 218 | 198 | 172 | 161 | 148 | 139 | 128 | 111 | 80 | 74 |
| RR2 | 1662 | 1636 | 1380 | 1312 | 1288 | 1267 | 1165 | 1080 | 987 | 932 | 892 | 854 | 828 | 794 | 686 | 595 | 592 |
| RR3 | 2372 | 2247 | 1836 | 1636 | 1587 | 1508 | 1428 | 1370 | 1321 | 1167 | 961 | 917 | 885 | 837 | 785 | 727 | 710 |
| RR4 | 452 | 372 | 231 | 205 | 192 | 183 | 167 | 152 | 136 | 119 | 105 | 94 | 89 | 81 | 69 | 45 | 42 |
| RR5 | 715 | 676 | 598 | 568 | 502 | 467 | 309 | 239 | 219 | 206 | 190 | 173 | 108 | 80 | 57 | 34 | 31 |
| RR6 | 1566 | 1523 | 1351 | 1279 | 1228 | 1174 | 1097 | 1039 | 989 | 914 | 858 | 808 | 752 | 663 | 605 | 555 | 541 |
| RR7 | 987 | 848 | 702 | 635 | 635 | 635 | 635 | 635 | 635 | 635 | 635 | 635 | 635 | 635 | 635 | 635 | 620 |
| RR8 | 196 | 178 | 174 | 171 | 166 | 159 | 154 | 151 | 148 | 147 | 146 | 145 | 144 | 143 | 0 | 0 | 0 |
| RR9 | 2202 | 2127 | 1903 | 1713 | 1670 | 1606 | 1540 | 1498 | 1439 | 1388 | 1346 | 1298 | 1242 | 1171 | 1107 | 1034 | 984 |

February percentiles [m³/s]

|  | 0.1 | 1 | 5 | 10 | 15 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 85 | 90 | 95 | 99 | 99.9 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RR1 | 402 | 397 | 340 | 305 | 285 | 264 | 233 | 201 | 189 | 171 | 164 | 145 | 130 | 123 | 115 | 88 | 86 |
| RR2 | 1594 | 1579 | 1380 | 1283 | 1268 | 1252 | 1147 | 1046 | 986 | 937 | 873 | 842 | 823 | 780 | 676 | 581 | 578 |
| RR3 | 2114 | 2026 | 1780 | 1587 | 1532 | 1440 | 1345 | 1307 | 1265 | 1112 | 923 | 868 | 848 | 811 | 737 | 708 | 708 |
| RR4 | 298 | 253 | 160 | 144 | 134 | 128 | 117 | 107 | 97 | 84 | 75 | 67 | 63 | 58 | 49 | 33 | 31 |
| RR5 | 625 | 590 | 455 | 307 | 276 | 248 | 204 | 190 | 180 | 156 | 140 | 85 | 72 | 57 | 40 | 25 | 24 |
| RR6 | 1462 | 1420 | 1246 | 1121 | 1063 | 1021 | 937 | 867 | 819 | 789 | 758 | 698 | 650 | 597 | 560 | 529 | 519 |
| RR7 | 635 | 635 | 635 | 635 | 635 | 635 | 635 | 635 | 635 | 635 | 635 | 635 | 634 | 630 | 626 | 621 | 621 |
| RR8 | 208 | 206 | 201 | 195 | 185 | 180 | 171 | 166 | 165 | 165 | 164 | 163 | 163 | 162 | 0 | 0 | 0 |
| RR9 | 1919 | 1895 | 1723 | 1677 | 1635 | 1556 | 1489 | 1436 | 1379 | 1329 | 1294 | 1231 | 1184 | 1128 | 1061 | 1000 | 980 |

March percentiles [m$^3$/s]

|  | 0.1 | 1 | 5 | 10 | 15 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 85 | 90 | 95 | 99 | 99.9 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RR1 | 408 | 406 | 354 | 326 | 296 | 271 | 242 | 213 | 196 | 182 | 165 | 152 | 142 | 121 | 107 | 90 | 90 |
| RR2 | 1576 | 1559 | 1413 | 1323 | 1260 | 1245 | 1151 | 1036 | 990 | 931 | 882 | 826 | 810 | 780 | 684 | 584 | 579 |
| RR3 | 1932 | 1911 | 1732 | 1557 | 1500 | 1385 | 1285 | 1258 | 1188 | 1075 | 899 | 852 | 814 | 793 | 714 | 685 | 679 |
| RR4 | 208 | 177 | 121 | 106 | 99 | 94 | 87 | 79 | 71 | 61 | 55 | 49 | 46 | 43 | 36 | 24 | 23 |
| RR5 | 553 | 317 | 279 | 221 | 200 | 181 | 160 | 115 | 83 | 71 | 62 | 46 | 40 | 37 | 30 | 19 | 18 |
| RR6 | 1366 | 1245 | 1024 | 960 | 893 | 850 | 795 | 759 | 725 | 671 | 635 | 585 | 568 | 555 | 531 | 505 | 497 |
| RR7 | 9570 | 8527 | 635 | 635 | 635 | 635 | 635 | 635 | 635 | 635 | 635 | 635 | 635 | 635 | 635 | 102 | 86 |
| RR8 | 219 | 217 | 211 | 203 | 190 | 185 | 174 | 168 | 168 | 167 | 166 | 165 | 165 | 164 | 0 | 0 | 0 |
| RR9 | 10724 | 9605 | 2120 | 1888 | 1816 | 1757 | 1671 | 1605 | 1539 | 1492 | 1437 | 1365 | 1303 | 1270 | 1217 | 1054 | 996 |

April percentiles [m$^3$/s]

|  | 0.1 | 1 | 5 | 10 | 15 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 85 | 90 | 95 | 99 | 99.9 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RR1 | 455 | 421 | 400 | 372 | 335 | 324 | 289 | 251 | 229 | 214 | 195 | 171 | 156 | 126 | 110 | 97 | 90 |
| RR2 | 1613 | 1597 | 1496 | 1428 | 1341 | 1299 | 1200 | 1093 | 1044 | 1000 | 945 | 871 | 839 | 823 | 734 | 643 | 612 |
| RR3 | 1876 | 1868 | 1697 | 1599 | 1508 | 1356 | 1276 | 1246 | 1188 | 1059 | 914 | 862 | 841 | 798 | 712 | 686 | 681 |
| RR4 | 191 | 149 | 118 | 94 | 81 | 78 | 69 | 64 | 58 | 49 | 43 | 40 | 37 | 33 | 27 | 18 | 17 |
| RR5 | 300 | 265 | 199 | 173 | 141 | 121 | 90 | 67 | 59 | 52 | 46 | 35 | 32 | 30 | 25 | 15 | 14 |
| RR6 | 1172 | 1069 | 878 | 804 | 774 | 751 | 717 | 671 | 640 | 614 | 595 | 554 | 540 | 529 | 503 | 484 | 479 |
| RR7 | 8760 | 8387 | 635 | 635 | 635 | 635 | 635 | 635 | 635 | 635 | 635 | 635 | 635 | 635 | 635 | 56 | 47 |
| RR8 | 220 | 218 | 206 | 193 | 188 | 183 | 173 | 172 | 171 | 170 | 169 | 167 | 0 | 0 | 0 | 0 | 0 |
| RR9 | 9803 | 9177 | 1915 | 1715 | 1650 | 1600 | 1524 | 1463 | 1401 | 1349 | 1302 | 1244 | 1213 | 1187 | 1151 | 747 | 667 |

May percentiles [m$^3$/s]

| | 0.1 | 1 | 5 | 10 | 15 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 85 | 90 | 95 | 99 | 99.9 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RR1 | 463 | 458 | 421 | 403 | 388 | 366 | 321 | 294 | 256 | 246 | 220 | 207 | 189 | 153 | 131 | 93 | 87 |
| RR2 | 1675 | 1668 | 1575 | 1530 | 1424 | 1369 | 1282 | 1146 | 1098 | 1064 | 1009 | 927 | 893 | 860 | 812 | 702 | 679 |
| RR3 | 1861 | 1844 | 1712 | 1614 | 1573 | 1434 | 1340 | 1277 | 1212 | 1083 | 991 | 912 | 890 | 877 | 808 | 710 | 707 |
| RR4 | 472 | 417 | 301 | 227 | 190 | 169 | 133 | 102 | 84 | 72 | 60 | 49 | 44 | 39 | 36 | 22 | 18 |
| RR5 | 474 | 362 | 267 | 238 | 223 | 205 | 170 | 146 | 123 | 100 | 79 | 66 | 57 | 48 | 30 | 20 | 14 |
| RR6 | 1006 | 991 | 871 | 815 | 785 | 768 | 746 | 724 | 685 | 663 | 626 | 597 | 566 | 538 | 522 | 483 | 478 |
| RR7 | 6298 | 1754 | 1166 | 841 | 635 | 635 | 635 | 635 | 635 | 635 | 362 | 233 | 189 | 142 | 91 | 53 | 39 |
| RR8 | 356 | 260 | 206 | 198 | 191 | 185 | 178 | 176 | 175 | 174 | 172 | 169 | 0 | 0 | 0 | 0 | 0 |
| RR9 | 7048 | 2357 | 1729 | 1581 | 1529 | 1488 | 1411 | 1325 | 1272 | 1238 | 1182 | 1128 | 1055 | 966 | 892 | 629 | 609 |

June percentiles [m$^3$/s]

| | 0.1 | 1 | 5 | 10 | 15 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 85 | 90 | 95 | 99 | 99.9 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RR1 | 449 | 445 | 417 | 403 | 388 | 374 | 333 | 304 | 261 | 240 | 222 | 205 | 192 | 166 | 139 | 81 | 77 |
| RR2 | 1667 | 1645 | 1572 | 1518 | 1415 | 1375 | 1290 | 1144 | 1106 | 1067 | 1016 | 931 | 908 | 863 | 795 | 723 | 710 |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RR3 | 1820 | 1800 | 1692 | 1621 | 1598 | 1479 | 1367 | 1311 | 1226 | 1161 | 1055 | 976 | 958 | 899 | 875 | 722 | 717 |
| RR4 | 752 | 700 | 600 | 536 | 479 | 430 | 358 | 318 | 276 | 240 | 201 | 168 | 149 | 119 | 84 | 44 | 23 |
| RR5 | 812 | 713 | 661 | 617 | 552 | 496 | 381 | 319 | 271 | 241 | 213 | 188 | 173 | 146 | 114 | 84 | 37 |
| RR6 | 1144 | 1109 | 1027 | 972 | 937 | 897 | 850 | 819 | 793 | 754 | 722 | 693 | 681 | 661 | 618 | 577 | 530 |
| RR7 | 8236 | 3235 | 1857 | 1545 | 1334 | 1184 | 944 | 635 | 635 | 560 | 481 | 422 | 392 | 356 | 287 | 208 | 186 |
| RR8 | 855 | 777 | 362 | 267 | 236 | 217 | 192 | 176 | 172 | 171 | 169 | 108 | 24 | 3 | 0 | 0 | 0 |
| RR9 | 8773 | 3664 | 2298 | 1985 | 1832 | 1708 | 1400 | 1256 | 1168 | 1075 | 1019 | 976 | 959 | 921 | 880 | 695 | 618 |

July percentiles [m³/s]

| | 0.1 | 1 | 5 | 10 | 15 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 85 | 90 | 95 | 99 | 99.9 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RR1 | 441 | 439 | 401 | 391 | 377 | 363 | 313 | 289 | 258 | 231 | 215 | 197 | 189 | 156 | 134 | 73 | 70 |
| RR2 | 1636 | 1614 | 1542 | 1446 | 1394 | 1319 | 1266 | 1108 | 1073 | 1022 | 976 | 891 | 865 | 841 | 766 | 691 | 679 |
| RR3 | 1974 | 1897 | 1678 | 1626 | 1603 | 1542 | 1418 | 1347 | 1253 | 1183 | 1046 | 1009 | 974 | 930 | 887 | 755 | 733 |
| RR4 | 1231 | 1123 | 950 | 865 | 822 | 789 | 722 | 663 | 603 | 535 | 483 | 428 | 397 | 362 | 314 | 221 | 129 |
| RR5 | 819 | 803 | 777 | 763 | 750 | 730 | 696 | 677 | 652 | 616 | 557 | 501 | 462 | 349 | 290 | 213 | 146 |
| RR6 | 1427 | 1334 | 1244 | 1199 | 1169 | 1144 | 1094 | 1059 | 1014 | 958 | 893 | 837 | 809 | 771 | 730 | 692 | 653 |
| RR7 | 6025 | 5681 | 5006 | 4487 | 4138 | 3875 | 3456 | 3127 | 2788 | 2467 | 2158 | 1865 | 1704 | 1516 | 1238 | 919 | 742 |
| RR8 | 2566 | 2328 | 1935 | 1572 | 1338 | 1171 | 949 | 797 | 665 | 532 | 409 | 299 | 239 | 193 | 140 | 38 | 0 |
| RR9 | 8365 | 7180 | 6128 | 5508 | 5145 | 4784 | 4196 | 3660 | 3178 | 2725 | 2190 | 1712 | 1478 | 1246 | 1049 | 921 | 785 |

August percentiles [m³/s]

| | 0.1 | 1 | 5 | 10 | 15 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 85 | 90 | 95 | 99 | 99.9 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RR1 | 431 | 427 | 388 | 376 | 359 | 348 | 305 | 265 | 245 | 224 | 208 | 188 | 179 | 143 | 124 | 66 | 63 |
| RR2 | 1575 | 1547 | 1490 | 1390 | 1354 | 1286 | 1213 | 1080 | 1036 | 974 | 929 | 842 | 818 | 795 | 728 | 660 | 642 |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RR3 | 3350 | 2208 | 1841 | 1681 | 1654 | 1634 | 1576 | 1499 | 1359 | 1218 | 1143 | 1006 | 985 | 960 | 897 | 772 | 771 |
| RR4 | 1579 | 1534 | 1381 | 1197 | 1134 | 1077 | 1010 | 923 | 862 | 814 | 738 | 697 | 663 | 612 | 537 | 404 | 393 |
| RR5 | 846 | 836 | 819 | 806 | 796 | 784 | 768 | 749 | 728 | 711 | 697 | 682 | 673 | 651 | 565 | 529 | 517 |
| RR6 | 1556 | 1507 | 1400 | 1350 | 1322 | 1305 | 1263 | 1224 | 1189 | 1158 | 1122 | 1082 | 1045 | 1005 | 964 | 897 | 821 |
| RR7 | 9311 | 8396 | 7304 | 6601 | 6263 | 6023 | 5618 | 5291 | 4951 | 4423 | 3695 | 1390 | 635 | 635 | 635 | 635 | 635 |
| RR8 | 7865 | 5590 | 3369 | 2782 | 2431 | 2308 | 1939 | 1703 | 1465 | 1300 | 919 | 736 | 626 | 494 | 395 | 308 | 276 |
| RR9 | 16630 | 13058 | 10560 | 9405 | 8628 | 8270 | 7598 | 6954 | 6390 | 5663 | 4855 | 3894 | 3458 | 2931 | 2323 | 1583 | 1444 |

September percentiles [m³/s]

| | 0.1 | 1 | 5 | 10 | 15 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 85 | 90 | 95 | 99 | 99.9 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RR1 | 413 | 409 | 372 | 358 | 341 | 327 | 289 | 246 | 228 | 211 | 197 | 174 | 163 | 131 | 114 | 60 | 57 |
| RR2 | 1513 | 1494 | 1434 | 1340 | 1290 | 1244 | 1157 | 1058 | 995 | 929 | 885 | 795 | 774 | 740 | 685 | 620 | 608 |
| RR3 | 5609 | 4789 | 2037 | 1807 | 1668 | 1635 | 1588 | 1521 | 1441 | 1220 | 1124 | 1053 | 961 | 928 | 875 | 762 | 755 |
| RR4 | 1620 | 1560 | 1419 | 1280 | 1190 | 1119 | 1078 | 984 | 917 | 816 | 756 | 708 | 681 | 637 | 507 | 404 | 398 |
| RR5 | 899 | 877 | 856 | 844 | 833 | 823 | 807 | 795 | 766 | 731 | 710 | 697 | 684 | 671 | 559 | 481 | 470 |
| RR6 | 1687 | 1635 | 1540 | 1488 | 1448 | 1418 | 1372 | 1324 | 1299 | 1266 | 1235 | 1200 | 1165 | 1133 | 1082 | 980 | 975 |
| RR7 | 8568 | 8206 | 7151 | 5751 | 4933 | 4727 | 3776 | 1913 | 635 | 635 | 635 | 635 | 635 | 635 | 635 | 635 | 635 |
| RR8 | 5602 | 4130 | 2631 | 2022 | 1686 | 1501 | 1217 | 975 | 738 | 532 | 377 | 243 | 207 | 186 | 166 | 122 | 93 |
| RR9 | 15034 | 13345 | 10744 | 9744 | 8860 | 8125 | 6875 | 5705 | 4006 | 3165 | 2531 | 2155 | 1972 | 1769 | 1615 | 1338 | 1274 |

October percentiles [m³/s]

| | 0.1 | 1 | 5 | 10 | 15 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 85 | 90 | 95 | 99 | 99.9 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RR1 | 391 | 385 | 352 | 336 | 318 | 307 | 267 | 228 | 212 | 199 | 184 | 163 | 148 | 119 | 107 | 55 | 53 |
| RR2 | 1467 | 1464 | 1378 | 1304 | 1268 | 1220 | 1134 | 1048 | 968 | 901 | 850 | 775 | 757 | 712 | 654 | 609 | 606 |
| RR3 | 4117 | 3615 | 2006 | 1862 | 1794 | 1738 | 1615 | 1547 | 1423 | 1237 | 1122 | 990 | 954 | 917 | 877 | 799 | 759 |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RR4 | 1482 | 1273 | 1059 | 952 | 869 | 827 | 741 | 666 | 581 | 511 | 451 | 383 | 350 | 317 | 280 | 205 | 180 |
| RR5 | 924 | 898 | 870 | 856 | 839 | 823 | 775 | 733 | 697 | 668 | 627 | 589 | 559 | 536 | 367 | 253 | 230 |
| RR6 | 1779 | 1697 | 1584 | 1539 | 1492 | 1454 | 1381 | 1332 | 1295 | 1265 | 1233 | 1190 | 1155 | 1126 | 1022 | 928 | 879 |
| RR7 | 4140 | 3771 | 3122 | 2812 | 2557 | 2428 | 2196 | 1974 | 1764 | 1602 | 1399 | 1171 | 635 | 635 | 635 | 635 | 635 |
| RR8 | 1738 | 1460 | 948 | 743 | 632 | 545 | 425 | 330 | 248 | 191 | 157 | 147 | 141 | 136 | 127 | 6 | 2 |
| RR9 | 11793 | 10675 | 7885 | 6348 | 5640 | 4752 | 3906 | 3514 | 3072 | 2696 | 2368 | 1952 | 1779 | 1667 | 1489 | 1255 | 1234 |

November percentiles [m$^3$/s]

| | 0.1 | 1 | 5 | 10 | 15 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 85 | 90 | 95 | 99 | 99.9 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RR1 | 384 | 370 | 336 | 317 | 297 | 278 | 257 | 226 | 200 | 192 | 179 | 150 | 139 | 114 | 103 | 54 | 52 |
| RR2 | 1530 | 1477 | 1358 | 1306 | 1270 | 1238 | 1143 | 1063 | 968 | 920 | 840 | 795 | 780 | 750 | 662 | 618 | 609 |
| RR3 | 3182 | 2938 | 1952 | 1827 | 1730 | 1697 | 1593 | 1494 | 1392 | 1253 | 1049 | 994 | 924 | 907 | 864 | 803 | 781 |
| RR4 | 1103 | 1096 | 661 | 546 | 483 | 453 | 404 | 361 | 325 | 284 | 247 | 219 | 204 | 189 | 159 | 100 | 91 |
| RR5 | 891 | 846 | 793 | 750 | 722 | 698 | 655 | 615 | 583 | 555 | 519 | 470 | 284 | 248 | 199 | 168 | 139 |
| RR6 | 1732 | 1704 | 1504 | 1458 | 1439 | 1399 | 1312 | 1266 | 1218 | 1194 | 1161 | 1110 | 1077 | 1009 | 874 | 766 | 733 |
| RR7 | 2506 | 2171 | 1876 | 1686 | 1553 | 1456 | 1307 | 1193 | 1091 | 1013 | 926 | 833 | 786 | 703 | 635 | 620 | 620 |
| RR8 | 697 | 524 | 322 | 262 | 220 | 189 | 160 | 147 | 137 | 132 | 127 | 123 | 121 | 119 | 114 | 1 | 0 |
| RR9 | 5898 | 4760 | 3576 | 3361 | 3116 | 2903 | 2647 | 2483 | 2322 | 2179 | 2014 | 1813 | 1704 | 1623 | 1452 | 1325 | 1279 |

December percentiles [m$^3$/s]

| | 0.1 | 1 | 5 | 10 | 15 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 85 | 90 | 95 | 99 | 99.9 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RR1 | 404 | 398 | 357 | 294 | 284 | 278 | 252 | 226 | 201 | 184 | 167 | 150 | 139 | 127 | 105 | 68 | 63 |
| RR2 | 1583 | 1573 | 1350 | 1319 | 1282 | 1263 | 1152 | 1082 | 971 | 917 | 872 | 835 | 823 | 784 | 674 | 613 | 599 |
| RR3 | 2708 | 2543 | 1847 | 1683 | 1636 | 1590 | 1513 | 1425 | 1353 | 1203 | 995 | 974 | 910 | 871 | 841 | 761 | 748 |
| RR4 | 934 | 592 | 364 | 316 | 294 | 278 | 253 | 227 | 202 | 177 | 156 | 139 | 131 | 120 | 101 | 66 | 61 |
| RR5 | 859 | 773 | 687 | 650 | 619 | 586 | 539 | 505 | 469 | 314 | 233 | 209 | 200 | 163 | 109 | 48 | 44 |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RR6 | 1727 | 1632 | 1424 | 1383 | 1345 | 1285 | 1230 | 1175 | 1134 | 1065 | 1013 | 937 | 875 | 802 | 720 | 614 | 575 |
| RR7 | 1607 | 1312 | 1097 | 979 | 892 | 848 | 736 | 635 | 635 | 635 | 635 | 635 | 635 | 635 | 635 | 635 | 625 |
| RR8 | 257 | 196 | 163 | 154 | 151 | 148 | 143 | 139 | 135 | 132 | 131 | 128 | 128 | 127 | 3 | 0 | 0 |
| RR9 | 3392 | 3028 | 2376 | 2166 | 1996 | 1899 | 1735 | 1633 | 1548 | 1485 | 1423 | 1366 | 1335 | 1267 | 1180 | 1075 | 1031 |

# ANNEXURE D: SUMMARY OF THE FISH SPECIES THAT OCCUR IN THE NILE BASIN AND THEIR MIGRATORY REQUIREMENTS, HABITAT REQUIREMENTS AND POTENTIAL POPULATION STATE/TREND.

| Family | Species | Rwanda | Uganda | Sudan & S. Sudan | Ethiopia | Egypt | Longitudinal | Lateral | Other movements | Potamodromous | Anadromous | Catadromous | Amphidromous | Rheophillic | Limnophillic | Status | Pop trend | Mig. Evidence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tetraodontidae | | | | | | | | | | | | | | | | | | |
| | *Tetraodon lineatus* | - | - | 1 | 1 | - | - | - | - | - | - | - | - | - | - | LC | ? | Low |
| Mastacembelidae | | | | | | | | | | | | | | | | | | |
| | *Mastacembelus frenatus* | 1 | 1 | - | - | - | 1 | - | - | - | - | - | - | 1 | - | LC | ? | Mod |
| Amphiliidae | | | | | | | | | | | | | | | | | | |
| | *Amphilius jacksonii* | 1 | 1 | - | - | - | - | - | - | - | - | - | - | - | - | LC | ? | Low |
| | *Andersonia leptura* | - | - | 1 | 1 | - | - | - | - | - | - | - | - | - | - | LC | ? | Low |
| Bagridae | | | | | | | | | | | | | | | | | | |
| | *Bagrus bajad* | - | 1 | 1 | 1 | 1 | - | - | - | - | - | - | - | 1 | 1 | LC | ? | Mod |
| | *Bagrus docmak* | 1 | 1 | 1 | 1 | 1 | 1 | - | - | - | - | - | - | 1 | 1 | LC | ? | Mod |
| Clariidae | | | | | | | | | | | | | | | | | | |
| | *Clarias alluaudi* | - | 1 | 1 | - | - | - | - | - | - | - | - | - | - | 1 | LC | ? | Mod |
| | *Clarias anguillaris* | - | - | 1 | 1 | 1 | - | - | - | - | - | - | - | - | 1 | LC | ? | Mod |
| | *Clarias gariepinus* | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | | | - | - | 1 | LC | ? | Mod |
| | *Clarias liocephalus* | 1 | 1 | 1 | - | - | 1 | - | - | 1 | - | - | - | - | 1 | LC | ? | Mod |
| | *Heterobranchus bidorsalis* | - | - | 1 | 1 | 1 | - | - | - | - | - | - | - | - | - | LC | ? | Low |
| | *Heterobranchus longifilis* | - | - | 1 | 1 | 1 | 1 | 1 | - | 1 | - | - | - | - | 1 | LC | ? | Mod |
| Claroteidae | | | | | | | | | | | | | | | | | | |
| | *Auchenoglanis biscutatus* | - | - | 1 | 1 | 1 | - | - | - | - | - | - | - | 1 | 1 | LC | ? | Mod |
| | *Auchenoglanis occidentalis* | - | - | 1 | 1 | 1 | - | - | - | - | - | - | - | 1 | 1 | LC | ? | Mod |
| | *Chrysichthys auratus* | - | - | 1 | 1 | 1 | - | 1 | - | 1 | - | - | - | - | 1 | LC | ? | Mod |
| | *Chrysichthys rueppelli* | - | - | 1 | - | 1 | - | - | - | 1 | - | - | - | - | 1 | LC | ? | Mod |
| Malapteruridae | | | | | | | | | | | | | | | | | | |
| | *Malapterurus electricus* | - | 1 | 1 | 1 | - | - | - | - | 1 | - | - | - | - | 1 | LC | ? | Mod |
| Mochokidae | | | | | | | | | | | | | | | | | | |
| | *Chiloglanis niloticus* | - | - | 1 | 1 | 1 | - | - | - | - | - | - | - | - | - | DD | ? | Low |

| Family | Species | Rwanda | Uganda | Sudan & S. Sudan | Ethiopia | Egypt | Longitudinal | Lateral | Other movements | Potamodromous | Anadromous | Catadromous | Amphidromous | Rheophillic | Limnophillic | Status | Pop trend | Mig. Evidence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Mochokus niloticus* | - | - | 1 | 1 | - | 1 | - | - | 1 | - | - | - | - | 1 | LC | ? | Mod |
| | *Synodontis afrofischeri* | 1 | 1 | - | - | - | - | - | - | - | - | - | - | - | - | LC | ? | Low |
| | *Synodontis batensoda* | - | - | 1 | 1 | - | 1 | 1 | - | 1 | - | - | - | - | 1 | LC | ? | Mod |
| | *Synodontis caudovittatus* | - | - | 1 | 1 | - | - | - | - | - | - | - | - | - | - | DD | ? | Low |
| | *Synodontis clarias* | - | - | 1 | 1 | - | - | - | - | 1 | - | - | - | - | 1 | LC | ? | Mod |
| | *Synodontis eupterus* | - | - | 1 | 1 | - | - | - | - | - | - | - | - | - | - | LC | ? | Low |
| | *Synodontis filamentosus* | - | - | 1 | 1 | - | - | - | - | - | - | - | - | - | - | LC | ? | Low |
| | *Synodontis frontosus* | - | 1 | 1 | 1 | - | - | - | - | - | - | - | - | - | - | LC | ? | Low |
| | *Synodontis khartoumensis* | - | 1 | 1 | - | - | - | - | - | - | - | - | - | - | - | DD | ? | Low |
| | *Synodontis membranaceus* | - | - | 1 | 1 | - | - | - | - | 1 | - | - | - | - | 1 | LC | ? | Mod |
| | *Synodontis nigrita* | - | - | 1 | 1 | - | - | - | - | - | - | - | - | - | 1 | LC | ? | Mod |
| | *Synodontis schall* | - | 1 | 1 | 1 | - | 1 | - | - | 1 | - | - | - | - | 1 | LC | ? | Mod |
| | *Synodontis serratus* | - | - | 1 | 1 | - | - | - | - | - | - | - | - | - | - | LC | ? | Low |
| | *Synodontis sorex* | - | - | 1 | 1 | - | - | - | - | - | - | - | - | - | - | LC | ? | Low |
| Schilbeidae | | | | | | | | | | | | | | | | | | |
| | *Schilbe intermedius* | 1 | 1 | 1 | 1 | - | 1 | 1 | | 1 | | | - | 1 | 1 | LC | ? | Mod |
| | *Schilbe mystus* | - | 1 | 1 | 1 | - | 1 | - | - | 1 | - | - | - | 1 | 1 | LC | ? | Mod |
| | *Schilbe uranoscopus* | - | - | 1 | 1 | - | 1 | - | - | 1 | - | - | - | 1 | 1 | LC | ? | Mod |
| | *Siluranodon auritus* | - | - | 1 | 1 | - | - | - | - | - | - | - | - | 1 | 1 | LC | ? | Mod |
| Polypteridae | | | | | | | | | | | | | | | | | | |
| | *Polypterus bichir* | - | - | 1 | 1 | - | - | - | - | - | - | - | - | 1 | 1 | LC | ? | Mod |
| | *Polypterus endlicherii* | - | - | 1 | 1 | - | - | - | - | 1 | - | - | - | 1 | 1 | ? | ? | Mod |
| | *Polypterus senegalus* | - | 1 | 1 | 1 | - | - | - | - | 1 | - | - | - | 1 | 1 | ? | ? | Mod |
| Anabantidae | | | | | | | | | | | | | | | | | | |
| | *Ctenopoma petherici* | - | - | 1 | - | 1 | - | - | - | 1 | - | - | - | - | 1 | LC | ? | Mod |
| Channidae | | | | | | | | | | | | | | | | | | |

| Family | Species | Rwanda | Uganda | Sudan & S. Sudan | Ethiopia | Egypt | Longitudinal | Lateral | Other movements | Potamodromous | Anadromous | Catadromous | Amphidromous | Rheophillic | Limnophillic | Status | Pop trend | Mig. Evidence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Parachanna obscura* | - | - | 1 | 1 | - | - | 1 | - | - | - | - | - | - | 1 | ? | ? | Mod |
| Cichlidae | | | | | | | | | | | | | | | | | | |
| | *Astatoreochromis alluaudi* | 1 | 1 | - | - | - | - | - | - | - | - | - | - | - | - | LC | ? | Low |
| | *Coptodon zillii* | - | 1 | 1 | 1 | 1 | - | - | - | - | - | - | - | - | 1 | ? | ? | Mod |
| | *Haplochromis loati* | - | 1 | 1 | - | - | - | 1 | - | - | - | - | - | - | 1 | DD | ? | Mod |
| | *Hemichromis fasciatus* | - | - | 1 | 1 | - | - | - | - | 1 | - | - | - | - | 1 | LC | ? | Mod |
| | *Hemichromis letourneuxi* | - | - | 1 | 1 | 1 | - | - | - | - | - | - | - | - | - | LC | ? | Low |
| | *Oreochromis niloticus* | 1 | 1 | 1 | 1 | - | | | | 1 | | | | - | 1 | LC | ↔ | Mod |
| | *Oreochromis spilurus* | - | 1 | - | 1 | - | - | - | - | - | - | - | - | - | - | ? | ? | Low |
| | *Pseudocrenilabrus multicolor* | 1 | 1 | 1 | - | - | 1 | - | - | - | - | - | - | - | 1 | LC | ? | Mod |
| | *Sarotherodon galilaeus* | - | 1 | 1 | 1 | - | - | - | - | 1 | - | - | - | - | 1 | LC | ? | Mod |
| | *Thoracochromis wingatii* | - | 1 | 1 | - | - | - | - | - | - | - | - | - | - | - | DD | ? | Low |
| Latidae | | | | | | | | | | | | | | | | | | |
| | *Lates niloticus* | - | 1 | 1 | 1 | - | - | - | - | - | - | - | - | - | 1 | LC | ? | Mod |
| Sparidae | | | | | | | | | | | | | | | | | | |
| | *Acanthopagrus berda* | - | - | 1 | - | 1 | - | - | - | - | - | - | - | - | - | LC | ? | Low |
| Arapaimidae | | | | | | | | | | | | | | | | | | |
| | *Heterotis niloticus* | - | - | 1 | 1 | - | - | 1 | - | - | - | - | - | - | 1 | LC | ? | Mod |
| Gymnarchidae | | | | | | | | | | | | | | | | | | |
| | *Gymnarchus niloticus* | - | - | 1 | 1 | 1 | - | 1 | - | - | - | - | - | - | 1 | LC | ? | Mod |
| Mormyridae | | | | | | | | | | | | | | | | | | |
| | *Brevimyrus niger* | - | - | 1 | 1 | - | - | 1 | - | - | - | - | - | - | 1 | LC | ? | Mod |
| | *Gnathonemus longibarbis* | 1 | 1 | - | - | - | - | - | - | - | - | - | - | - | 1 | LC | ? | Mod |
| | *Hippopotamyrus grahami* | 1 | 1 | - | - | - | 1 | - | - | 1 | - | - | - | - | 1 | LC | ? | Mod |
| | *Hippopotamyrus pictus* | - | - | 1 | 1 | - | - | - | - | - | - | - | - | - | - | LC | ? | Low |
| | *Hyperopisus bebe* | - | - | 1 | 1 | - | 1 | - | - | 1 | - | - | - | - | 1 | LC | ? | Mod |

| Family | Species | Rwanda | Uganda | Sudan & S. Sudan | Ethiopia | Egypt | Longitudinal | Lateral | Other movements | Potamodromous | Anadromous | Catadromous | Amphidromous | Rheophillic | Limnophillic | Status | Pop trend | Mig. Evidence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Marcusenius cyprinoides* | - | - | 1 | 1 | - | - | - | - | - | - | - | - | - | 1 | LC | ? | Mod |
| | *Marcusenius victoriae* | 1 | 1 | - | - | - | - | - | - | - | - | - | - | - | 1 | LC | ? | Mod |
| | *Mormyrops anguilloides* | - | 1 | 1 | 1 | - | 1 | - | - | 1 | - | - | - | - | 1 | LC | ? | Mod |
| | *Mormyrus caschive* | - | 1 | 1 | 1 | - | - | - | - | - | - | - | - | - | - | LC | ? | Low |
| | *Mormyrus hasselquistii* | - | - | 1 | 1 | - | - | - | - | 1 | - | - | - | - | 1 | LC | ? | Mod |
| | *Mormyrus kannume* | 1 | 1 | 1 | 1 | - | 1 | - | - | - | - | - | - | - | 1 | LC | ? | Mod |
| | *Petrocephalus bane* | - | - | 1 | 1 | - | - | - | - | - | - | - | - | - | 1 | LC | ? | Mod |
| | *Petrocephalus bovei* | - | - | 1 | 1 | - | - | - | - | - | - | - | - | - | 1 | ? | ? | Mod |
| | *Petrocephalus catostoma* | 1 | 1 | - | - | - | 1 | | | | | | | - | 1 | LC | ? | Mod |
| | *Pollimyrus isidori* | - | - | 1 | 1 | - | - | - | - | - | - | - | - | - | 1 | ? | ? | Mod |
| | *Pollimyrus nigricans* | 1 | 1 | - | - | - | - | - | - | - | - | - | - | - | 1 | LC | ? | Mod |
| | *Pollimyrus petherici* | - | - | 1 | 1 | - | - | - | - | - | - | - | - | - | - | LC | ? | Low |
| Kneriidae | | | | | | | | | | | | | | | | | | |
| | *Cromeria nilotica* | - | - | 1 | 1 | - | - | - | - | - | - | - | - | - | - | LC | ? | Low |
| Cyprinodontidae | | | | | | | | | | | | | | | | | | |
| | *Aphanius dispar* | - | - | 1 | 1 | 1 | - | - | - | - | - | - | - | - | - | LC | ↔ | Low |
| Nothobranchiidae | | | | | | | | | | | | | | | | | | |
| | *Epiplatys spilargyreius* | - | - | 1 | 1 | - | - | - | - | 1 | - | - | - | - | 1 | LC | ? | Mod |
| | *Nothobranchius nubaensis* | - | - | 1 | 1 | - | - | - | - | - | - | - | - | - | - | ? | ? | Low |
| | *Nothobranchius virgatus* | - | - | 1 | 1 | - | - | - | - | - | - | - | - | - | - | DD | ? | Low |
| Poeciliidae | | | | | | | | | | | | | | | | | | |
| | *Lacustricola centralis* | 1 | 1 | - | - | - | - | - | - | - | - | - | - | - | - | ? | ? | Low |
| | *Micropanchax loati* | - | 1 | 1 | - | - | - | 1 | - | - | - | - | - | - | - | LC | ? | Low |
| Cyprinidae | | | | | | | | | | | | | | | | | | |
| | *Chelaethiops bibie* | - | - | 1 | 1 | 1 | - | - | - | - | - | - | - | - | 1 | LC | ? | Mod |
| | *Enteromius anema* | - | - | 1 | 1 | 1 | - | - | - | - | - | - | - | - | - | LC | ? | Low |

| Family | Species | Rwanda | Uganda | Sudan & S. Sudan | Ethiopia | Egypt | Longitudinal | Lateral | Other movements | Potamodromous | Anadromous | Catadromous | Amphidromous | Rheophillic | Limnophillic | Status | Pop trend | Mig. Evidence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Enteromius apleurogramma* | 1 | 1 | - | - | - | 1 | - | - | 1 | - | - | - | - | 1 | LC | ? | Mod |
| | *Enteromius cercops* | 1 | 1 | - | - | - | - | - | - | - | - | - | - | - | - | LC | ? | Low |
| | *Enteromius kerstenii* | 1 | 1 | - | 1 | - | 1 | - | - | 1 | - | - | - | - | 1 | LC | ↓ | Mod |
| | *Enteromius neglectus* | - | - | 1 | 1 | 1 | 1 | - | - | - | - | - | - | - | 1 | LC | ? | Mod |
| | *Enteromius neumayeri* | 1 | 1 | - | - | - | - | - | - | - | - | - | - | - | - | LC | ? | Low |
| | *Enteromius nigeriensis* | - | - | 1 | - | 1 | - | - | - | - | - | - | - | - | - | LC | ? | Low |
| | *Enteromius paludinosus* | 1 | 1 | - | 1 | - | 1 | 1 | | 1 | | | | - | 1 | LC | ? | Mod |
| | *Enteromius pellegrini* | 1 | 1 | - | - | - | - | - | - | - | - | - | - | - | - | LC | ? | Low |
| | *Enteromius perince* | - | 1 | 1 | 1 | 1 | - | - | - | - | - | - | - | - | - | LC | ? | Low |
| | *Enteromius pumilus* | - | - | 1 | 1 | - | - | - | - | - | - | - | - | - | - | DD | ? | Low |
| | *Enteromius stigmatopygus* | - | - | 1 | 1 | - | - | - | - | - | - | - | - | - | 1 | LC | ? | Mod |
| | *Enteromius yeiensis* | - | - | 1 | - | 1 | - | - | - | - | - | - | - | - | - | ? | ? | Low |
| | *Garra blanfordii* | - | - | 1 | 1 | - | - | - | - | - | - | - | - | - | - | LC | ↔ | Low |
| | *Garra dembeensis* | 1 | 1 | 1 | 1 | 1 | - | - | - | 1 | - | - | - | - | - | LC | ? | ? |
| | *Labeo coubie* | - | 1 | 1 | 1 | - | - | - | - | - | - | - | - | 1 | - | LC | ? | Mod |
| | *Labeo forskalii* | - | 1 | 1 | 1 | - | - | - | - | - | - | - | - | - | - | LC | ? | Low |
| | *Labeo horie* | - | 1 | 1 | 1 | - | - | - | - | - | - | - | - | 1 | - | ? | ? | Mod |
| | *Labeo niloticus* | - | - | 1 | 1 | - | - | - | - | - | - | - | - | - | - | LC | ? | Low |
| | *Labeo victorianus* | 1 | 1 | - | - | - | 1 | 1 | - | 1 | - | - | - | 1 | - | CR | ↓ | Mod |
| | *Labeobarbus altianalis* | 1 | 1 | - | - | - | 1 | - | - | 1 | - | - | - | 1 | - | LC | ? | Mod |
| | *Labeobarbus bynni* | - | - | 1 | 1 | - | - | - | - | - | - | - | - | - | - | ? | ? | |
| | *Labeobarbus somereni* | 1 | 1 | - | - | - | - | - | - | - | - | - | - | - | - | ? | ? | Low |
| | *Leptocypris niloticus* | - | - | 1 | 1 | - | - | - | - | 1 | - | - | - | 1 | 1 | LC | ? | Mod |
| | *Raiamas senegalensis* | - | 1 | 1 | 1 | - | - | - | - | 1 | - | - | - | 1 | - | LC | ? | Mod |
| Alestidae | | | | | | | | | | | | | | | | | | |
| | *Alestes baremoze* | - | 1 | 1 | 1 | 1 | 1 | - | - | - | - | - | - | 1 | 1 | LC | ? | Mod |

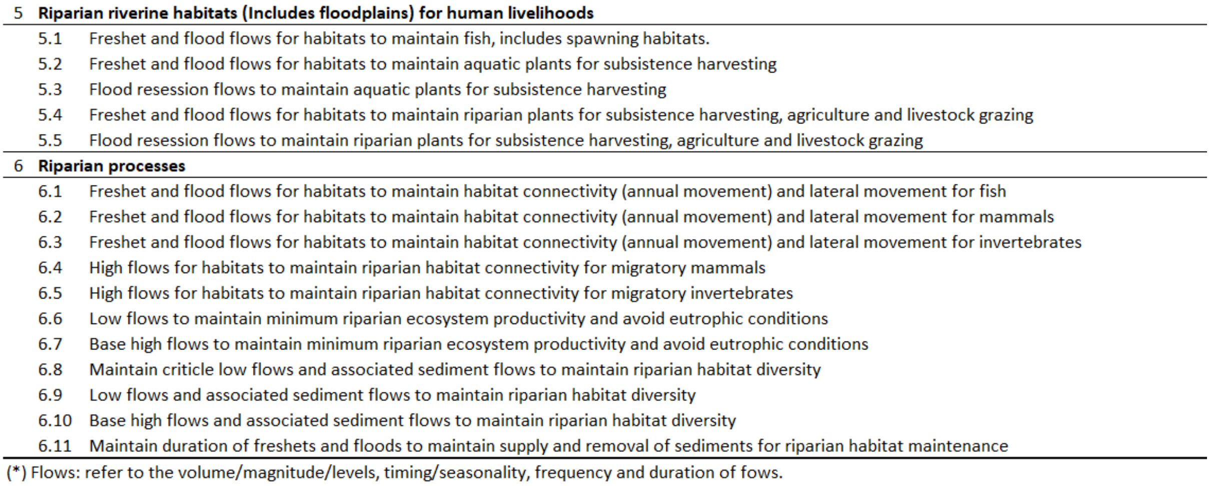
| Family | Species | Rwanda | Uganda | Sudan & S. Sudan | Ethiopia | Egypt | Longitudinal | Lateral | Other movements | Potamodromous | Anadromous | Catadromous | Amphidromous | Rheophillic | Limnophillic | Status | Pop trend | Mig. Evidence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Alestes dentex* | - | 1 | 1 | 1 | 1 | - | - | - | - | - | - | - | 1 | 1 | LC | ? | Mod |
| | *Brycinus jacksonii* | 1 | 1 | - | - | - | - | - | - | - | - | - | - | 1 | 1 | ? | ? | Mod |
| | *Brycinus macrolepidotus* | 1 | 1 | 1 | 1 | 1 | 1 | - | - | 1 | - | - | - | 1 | 1 | LC | ? | Mod |
| | *Brycinus nurse* | - | 1 | 1 | 1 | 1 | - | - | - | - | - | - | - | 1 | 1 | LC | ? | Mod |
| | *Brycinus sadleri* | 1 | 1 | - | - | - | 1 | - | - | 1 | - | - | - | 1 | 1 | LC | ? | Mod |
| | *Hydrocynus brevis* | - | - | 1 | 1 | 1 | - | - | - | - | - | - | - | 1 | 1 | LC | ? | Mod |
| | *Hydrocynus forskahlii* | - | 1 | 1 | 1 | 1 | - | - | - | - | - | - | - | 1 | 1 | LC | ? | Mod |
| | *Hydrocynus vittatus* | - | 1 | 1 | 1 | - | 1 | - | - | 1 | | - | | 1 | 1 | LC | ? | Mod |
| | *Micralestes elongatus* | - | - | 1 | 1 | - | - | - | - | 1 | - | - | - | 1 | 1 | ? | ? | Mod |
| Citharinidae | | | | | | | | | | | | | | | | | | |
| | *Citharinus citharus* | - | 1 | 1 | 1 | - | - | - | - | - | - | - | - | 1 | - | ? | ? | Mod |
| Citharinidae | | | | | | | | | | | | | | | | | | |
| | *Citharinus latus* | - | 1 | - | 1 | 1 | - | - | - | - | - | - | - | - | - | LC | ? | Low |
| Distichodontidae | | | | | | | | | | | | | | | | | | |
| | *Distichodus brevipinnis* | - | - | 1 | 1 | - | - | - | - | - | - | - | - | 1 | - | LC | ? | Mod |
| | *Distichodus engycephalus* | - | - | 1 | 1 | 1 | - | - | - | - | - | - | - | - | - | LC | ? | Low |
| | *Distichodus nefasch* | - | 1 | 1 | 1 | - | - | - | - | - | - | - | - | - | - | ? | ? | Low |
| | *Ichthyborus besse* | - | - | 1 | 1 | - | - | 1 | - | - | - | - | - | 1 | - | ? | ? | Mod |
| | *Neolebias trewavasae* | - | - | 1 | 1 | - | - | - | - | - | - | - | - | - | - | LC | ? | Low |

# ANNEXURE E: LIST OF THE STANDARD SOCIAL AND ECOLOGICAL INDICATORS USED IN A DESKTOP PROBFLO ASSESSMENT.

**Annexure B Table:** List of the standard social and ecological indicators used in a desktop PROBFLO assessment.

| **SOCIO-ECOLOGICAL QUALITATIVE AND/OR QUANTITATIVE INDICATORS OF ALTERED FLOWS*** | |
|---|---|
| 1 | **Instream riverine habitats (Includes floodplains) for fauna and flora** |
| 1.1 | Criticle low flows (infrequent drought periods) habitats to maintain fish |
| 1.2 | Base low flows (annual dry periods) for habitats to maintain fish |
| 1.3 | Base high flows (annual wet periods) for habitats to maintain fish, includes spawning habitats |
| 1.4 | Criticle low flows for habitats to maintain aquatic invertebrates |
| 1.5 | Base low flows for habitats to maintain aquatic invertebrates |
| 1.6 | Base high flows for habitats to maintain aquatic invertebrates |
| 1.7 | Criticle low flows (infrequent drought periods) for habitats to maintain aquatic mammals |
| 1.8 | Base low flows for habitats to maintain aquatic mammals |
| 1.9 | Base high flows for habitats to maintain aquatic mammals |
| 1.10 | Criticle low flows for habitats to maintain aquatic / riparian vegetation |
| 1.11 | Base low flows for habitats to maintain aquatic / riparian vegetation |
| 1.12 | Base high flows for habitats to maintain aquatic / riparian vegetation |
| 1.13 | Criticle low flows for instream habitats to maintain resident and migratory birds |
| 1.14 | Base low flows for instream habitats to maintain resident and migratory birds |
| 1.15 | Base high flows for instream habitats to maintain resident and migratory birds |
| 2 | **Instream riverine habitats (Includes floodplains) for human livelihoods** |
| 2.1 | Criticle low flows for habitats to maintain fish for subsistence fisheries |
| 2.2 | Base low flows for habitats to maintain fish for subsistence fisheries |
| 2.3 | Base high flows for habitats to maintain subsistence fisheries, includes spawning habitats |
| 2.4 | Criticle low flows for habitats to maintain aquatic / riparian plants for long-term subsistence harvesting |
| 2.5 | Base low flows for habitats to maintain aquatic / riparian plants for long-term subsistence harvesting |
| 2.6 | Base high flows for habitats to maintain aquatic / riparian plants for long-term subsistence harvesting |
| 3 | **Instream processes** |
| 3.1 | Base high flows for habitats to maintain river connectivity for migratory fish |
| 3.2 | Wet base flows for habitats to maintain river connectivity for migratory mammals |
| 3.3 | Base high flows for habitats to maintain river connectivity for migratory invertebrates |
| 3.4 | Maintain criticle base low flows (includes sediment flows) to maintain minimum ecosystem productivity and avoid eutrophic conditions |
| 3.5 | Maintain criticle low flows and associated sediment flows to maintain instream habitat diversity |
| 3.6 | Base low flows (includes sediment flows) to maintain minimum ecosystem productivity and avoid eutrophic conditions |
| 3.7 | Base high flows (includes sediment flows) to maintain minimum ecosystem productivity and avoid eutrophic conditions |
| 3.8 | Base low flows and associated sediment flows to maintain instream habitat diversity |
| 3.9 | Base high flows and associated sediment flows to maintain instream habitat diversity |
| 3.10 | Maintain duration of freshets and floods to maintain supply and removal of sediments for habitat maintenance |
| 4 | **Riparian riverine habitats (Includes floodplains) for fauna and flora** |
| 4.1 | Freshet and flood flows for habitats to maintain fish, includes spawning habitats. |
| 4.2 | Freshet and flood flows for habitats to maintain aquatic mammals. |
| 4.3 | Freshet and flood flows for habitats to maintain aquatic vegetation |
| 4.4 | Freshet and flood flows for instream habitats to maintain resident and migratory birds |
| 4.5 | Criticle low flows for habitats to maintain specialist riparian invertebrates |
| 4.6 | Base low flows for habitats to maintain specialist riparian invertebrates |
| 4.7 | High flows for habitats to maintain specialist riparian invertebrates |
| 4.8 | Criticle low flows for habitats to maintain specialist riparian mammals |
| 4.9 | Base low flows for habitats to maintain specialist riparian mammals |
| 4.10 | Base high flows for habitats to maintain specialist riparian mammals |
| 4.11 | Criticle low flows for habitats to maintain riparian vegetation |
| 4.12 | Base low flows for habitats to maintain riparian vegetation |
| 4.13 | Base high flows for habitats to maintain riparian vegetation |
| 4.14 | Freshet and flood flows for habitats to maintain specialist riparian vegetation |
| 4.15 | Freshet and flood habitats to maintain riparian vegetation |
| 4.16 | Criticle low flows for instream habitats to maintain specialist riparian birds |
| 4.17 | Base low flows for habitats to maintain specialist riparian birds |
| 4.18 | Base high flows for habitats to maintain specialist riparian birds |
| 4.19 | Freshet and flood flows for habitats to maintain specialist riparian birds |

**Annexure B Table (Continued):** List of the standard social and ecological indicators used in a desktop PROBFLO assessment.



| | |
|---|---|
| 5 | **Riparian riverine habitats (Includes floodplains) for human livelihoods** |
| 5.1 | Freshet and flood flows for habitats to maintain fish, includes spawning habitats. |
| 5.2 | Freshet and flood flows for habitats to maintain aquatic plants for subsistence harvesting |
| 5.3 | Flood resession flows to maintain aquatic plants for subsistence harvesting |
| 5.4 | Freshet and flood flows for habitats to maintain riparian plants for subsistence harvesting, agriculture and livestock grazing |
| 5.5 | Flood resession flows to maintain riparian plants for subsistence harvesting, agriculture and livestock grazing |
| 6 | **Riparian processes** |
| 6.1 | Freshet and flood flows for habitats to maintain habitat connectivity (annual movement) and lateral movement for fish |
| 6.2 | Freshet and flood flows for habitats to maintain habitat connectivity (annual movement) and lateral movement for mammals |
| 6.3 | Freshet and flood flows for habitats to maintain habitat connectivity (annual movement) and lateral movement for invertebrates |
| 6.4 | High flows for habitats to maintain riparian habitat connectivity for migratory mammals |
| 6.5 | High flows for habitats to maintain riparian habitat connectivity for migratory invertebrates |
| 6.6 | Low flows to maintain minimum riparian ecosystem productivity and avoid eutrophic conditions |
| 6.7 | Base high flows to maintain minimum riparian ecosystem productivity and avoid eutrophic conditions |
| 6.8 | Maintain criticle low flows and associated sediment flows to maintain riparian habitat diversity |
| 6.9 | Low flows and associated sediment flows to maintain riparian habitat diversity |
| 6.10 | Base high flows and associated sediment flows to maintain riparian habitat diversity |
| 6.11 | Maintain duration of freshets and floods to maintain supply and removal of sediments for riparian habitat maintenance |

(*) Flows: refer to the volume/magnitude/levels, timing/seasonality, frequency and duration of fows.

# ANNEXURE F: HYDROGRAPH OUTCOMES FOR SCENARIOS MODELLED IN THE STUDY.

Nile Coarse EFlow determinations flow duration (time series) summary flows in monthly average m$^3$/s.: **RR1 - Reference (CLASS A) FLOWS**. Colour conditional formatting highlights high (RED) to low (GREEN) values, and does not represent the suitability of the flows.

| %tile | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.1 | 405.8 | 409.7 | 406.9 | 494.2 | 501.9 | 443.5 | 460.6 | 352.7 | 357.6 | 228 | 282.8 | 308.6 |
| 1 | 377.6 | 391.6 | 391.2 | 485.6 | 498.8 | 442.9 | 453.6 | 351.3 | 317.8 | 224.1 | 275 | 293.9 |
| 5 | 314.6 | 344.8 | 360.5 | 446 | 473.6 | 430.8 | 355.5 | 284.3 | 240.5 | 194.1 | 256.3 | 265.2 |
| 10 | 278.2 | 319.2 | 326.9 | 397.4 | 448.5 | 398.8 | 318 | 242.8 | 209.3 | 189 | 214.8 | 254.8 |
| 15 | 259.7 | 296 | 320.5 | 369.7 | 424 | 362.3 | 303.1 | 229.1 | 201.6 | 188.5 | 209.3 | 248.7 |
| 20 | 251.7 | 288.8 | 295.3 | 362.4 | 403.8 | 342.1 | 280.3 | 227.8 | 192.7 | 184.2 | 206.7 | 238.9 |
| 30 | 240.5 | 244.5 | 290.4 | 319 | 337.3 | 293.4 | 261.1 | 209.5 | 182.5 | 173.9 | 198.7 | 228.4 |
| 40 | 229.6 | 226.5 | 245.5 | 284.5 | 316.1 | 267.6 | 238.8 | 196 | 169.1 | 167.9 | 185.3 | 201 |
| 50 | 207.6 | 219.8 | 229.1 | 275.8 | 300 | 259 | 230.1 | 189.2 | 164.9 | 159 | 172.4 | 189.5 |
| 60 | 197.8 | 214.6 | 208.4 | 248.6 | 292.6 | 245.2 | 201.8 | 167.2 | 151 | 147.3 | 165.5 | 177.3 |
| 70 | 189.8 | 199.6 | 205 | 223 | 237.1 | 213.1 | 173.5 | 147 | 140.3 | 139.3 | 137.3 | 158.8 |
| 80 | 180.3 | 173.9 | 176.7 | 208.3 | 221.1 | 200.8 | 166.9 | 139.2 | 135 | 136.1 | 130.9 | 150.2 |
| 85 | 149.5 | 164.5 | 172 | 186.5 | 217.9 | 189.4 | 164.4 | 130.7 | 118.5 | 106.8 | 120.4 | 136.5 |
| 90 | 146.9 | 153.1 | 163.2 | 181.6 | 211.6 | 179.1 | 156.4 | 119.5 | 101.8 | 97.3 | 119.6 | 124.5 |
| 95 | 138.9 | 151.9 | 158.2 | 164.9 | 198.2 | 164.6 | 138.7 | 107.4 | 91.6 | 92.9 | 110.6 | 115.8 |
| 99 | 137.9 | 148.1 | 157.3 | 159.9 | 191.7 | 160.3 | 127.3 | 102.6 | 89.8 | 92.2 | 83.1 | 108.7 |
| 99.9 | 137.6 | 147.3 | 156.9 | 159.8 | 188.5 | 159.6 | 126.9 | 102.3 | 88.9 | 92 | 73.5 | 108.7 |

Nile Coarse EFlow determinations flow duration (time series) summary flows in monthly average m$^3$/s.: **RR1 - CLASS B FLOWS**. Colour conditional formatting highlights high (RED) to low (GREEN) values, and does not represent the suitability of the flows.

| %tile | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.1 | 120.1 | 134.1 | 164.3 | 165.5 | 197.1 | 198.6 | 189.1 | 155.5 | 144.6 | 131.8 | 122.8 | 120.8 |
| 1 | 120.1 | 134.1 | 164.3 | 165.5 | 197.1 | 198.6 | 189.1 | 155.5 | 144.6 | 131.8 | 122.8 | 120.8 |
| 5 | 120.1 | 134.1 | 164.2 | 165.3 | 197.0 | 198.3 | 188.5 | 155.3 | 144.6 | 131.7 | 122.8 | 120.8 |
| 10 | 119.9 | 134.0 | 160.1 | 164.8 | 196.4 | 197.6 | 187.7 | 154.9 | 144.1 | 131.5 | 122.8 | 120.7 |
| 15 | 119.7 | 133.5 | 157.9 | 164.0 | 195.1 | 196.1 | 186.4 | 153.7 | 143.5 | 131.1 | 122.7 | 120.6 |
| 20 | 119.1 | 133.1 | 152.3 | 163.0 | 193.8 | 194.2 | 183.4 | 152.0 | 142.8 | 130.0 | 122.6 | 120.6 |
| 30 | 117.2 | 130.2 | 147.7 | 157.8 | 187.5 | 187.1 | 175.1 | 147.5 | 139.8 | 127.3 | 122.3 | 120.3 |
| 40 | 114.1 | 125.1 | 137.7 | 145.6 | 180.5 | 169.3 | 160.4 | 138.7 | 131.2 | 122.1 | 121.9 | 119.5 |
| 50 | 105.9 | 118.8 | 116.8 | 139.1 | 153.4 | 154.5 | 138.0 | 122.3 | 122.0 | 113.3 | 121.1 | 119.0 |
| 60 | 97.3 | 106.4 | 97.2 | 110.7 | 136.8 | 124.9 | 108.6 | 113.4 | 115.1 | 109.8 | 119.5 | 117.8 |
| 70 | 79.2 | 93.8 | 85.6 | 92.5 | 102.3 | 98.6 | 94.1 | 102.1 | 108.1 | 107.2 | 116.3 | 115.3 |
| 80 | 67.5 | 75.1 | 65.4 | 76.1 | 84.3 | 73.5 | 70.4 | 86.5 | 101.8 | 104.7 | 112.2 | 111.2 |
| 85 | 58.1 | 65.5 | 60.8 | 66.9 | 70.3 | 68.5 | 66.6 | 77.4 | 89.2 | 98.0 | 106.8 | 106.7 |
| 90 | 53.9 | 60.0 | 56.6 | 62.0 | 64.7 | 65.0 | 61.1 | 68.9 | 81.0 | 90.5 | 102.0 | 100.0 |
| 95 | 50.1 | 55.6 | 53.3 | 58.1 | 61.1 | 62.0 | 58.9 | 58.0 | 66.6 | 78.7 | 84.7 | 79.3 |
| 99 | 48.7 | 54.0 | 52.4 | 56.7 | 59.8 | 61.1 | 57.9 | 53.6 | 57.0 | 55.8 | 58.1 | 46.9 |
| 99.9 | 48.3 | 53.7 | 52.0 | 56.7 | 59.2 | 60.9 | 57.9 | 53.4 | 52.0 | 48.6 | 48.9 | 46.9 |

Nile Coarse EFlow determinations flow duration (time series) summary flows in monthly average m$^3$/s.: **RR1 - Reference (CLASS C) FLOWS**. Colour conditional formatting highlights high (RED) to low (GREEN) values, and does not represent the suitability of the flows.

| %tile | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.1 | 84.7 | 93.8 | 117.6 | 117.0 | 147.2 | 144.7 | 138.6 | 118.9 | 118.5 | 120.8 | 109.1 | 106.6 |
| 1 | 84.7 | 93.8 | 117.6 | 117.0 | 147.2 | 144.7 | 138.6 | 118.9 | 118.5 | 120.8 | 109.1 | 106.6 |
| 5 | 84.7 | 93.8 | 117.6 | 116.8 | 147.1 | 144.5 | 138.2 | 118.7 | 118.5 | 120.7 | 109.1 | 106.6 |
| 10 | 84.6 | 93.8 | 114.2 | 116.5 | 146.6 | 143.9 | 137.6 | 118.4 | 118.1 | 120.5 | 109.0 | 106.5 |
| 15 | 84.4 | 93.4 | 112.4 | 115.9 | 145.6 | 142.8 | 136.6 | 117.4 | 117.5 | 120.1 | 108.9 | 106.4 |
| 20 | 84.0 | 93.1 | 108.0 | 115.2 | 144.7 | 141.4 | 134.3 | 116.1 | 116.9 | 119.0 | 108.8 | 106.3 |
| 30 | 82.6 | 91.1 | 104.4 | 111.5 | 139.8 | 136.1 | 128.1 | 112.4 | 114.2 | 116.2 | 108.5 | 106.1 |
| 40 | 80.4 | 87.5 | 96.9 | 102.6 | 134.4 | 122.8 | 117.1 | 105.3 | 106.6 | 110.8 | 108.1 | 105.3 |
| 50 | 74.6 | 83.0 | 81.4 | 98.0 | 113.5 | 111.7 | 100.2 | 91.7 | 98.4 | 101.9 | 107.3 | 104.8 |
| 60 | 68.4 | 74.2 | 67.7 | 77.6 | 100.7 | 89.6 | 78.1 | 82.2 | 91.2 | 98.3 | 105.7 | 103.6 |
| 70 | 55.5 | 65.3 | 59.4 | 64.5 | 74.1 | 70.0 | 67.2 | 73.6 | 85.2 | 95.6 | 102.5 | 101.1 |
| 80 | 47.2 | 52.1 | 45.2 | 52.7 | 60.3 | 51.2 | 49.4 | 61.7 | 79.7 | 93.0 | 98.4 | 97.0 |
| 85 | 40.5 | 45.3 | 42.0 | 46.1 | 49.5 | 47.5 | 46.5 | 54.7 | 68.8 | 86.1 | 92.9 | 92.5 |
| 90 | 37.4 | 41.4 | 39.0 | 42.5 | 45.2 | 44.9 | 42.4 | 48.3 | 61.7 | 78.3 | 88.1 | 85.8 |
| 95 | 34.7 | 38.4 | 36.7 | 39.7 | 42.4 | 42.6 | 40.7 | 40.0 | 49.2 | 66.2 | 70.7 | 65.2 |
| 99 | 33.7 | 37.2 | 36.0 | 38.7 | 41.4 | 41.9 | 40.0 | 36.8 | 40.9 | 42.3 | 44.0 | 32.9 |
| 99.9 | 33.4 | 37.0 | 35.8 | 38.7 | 40.9 | 41.8 | 40.0 | 36.7 | 36.5 | 34.8 | 34.7 | 32.9 |

Nile Coarse EFlow determinations flow duration (time series) summary flows in monthly average m$^3$/s.: **RR1 - Reference (CLASS D) FLOWS**. Colour conditional formatting highlights high (RED) to low (GREEN) values, and does not represent the suitability of the flows.

| %tile | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.1 | 70.5 | 78.0 | 80.5 | 92.3 | 114.5 | 107.3 | 95.9 | 80.5 | 89.5 | 97.3 | 101.9 | 99.7 |
| 1 | 70.5 | 78.0 | 80.5 | 92.3 | 114.5 | 107.3 | 95.9 | 80.5 | 89.5 | 97.3 | 101.9 | 99.7 |
| 5 | 70.5 | 78.0 | 80.5 | 92.2 | 114.4 | 107.2 | 95.6 | 80.4 | 89.5 | 97.1 | 101.9 | 99.7 |
| 10 | 70.4 | 78.0 | 79.2 | 92.0 | 114.1 | 106.8 | 95.3 | 80.2 | 89.2 | 97.0 | 101.9 | 99.6 |
| 15 | 70.3 | 77.7 | 78.4 | 91.5 | 113.3 | 106.0 | 94.6 | 79.6 | 88.8 | 96.7 | 101.8 | 99.5 |
| 20 | 70.0 | 77.5 | 76.5 | 91.0 | 112.7 | 105.1 | 93.3 | 78.9 | 88.4 | 95.8 | 101.7 | 99.5 |
| 30 | 68.9 | 75.9 | 74.8 | 88.3 | 109.1 | 101.5 | 89.4 | 76.8 | 86.6 | 93.7 | 101.4 | 99.2 |
| 40 | 67.2 | 73.2 | 70.8 | 82.0 | 105.1 | 92.5 | 82.7 | 72.7 | 81.9 | 90.0 | 101.1 | 98.5 |
| 50 | 62.8 | 69.8 | 62.2 | 78.6 | 89.9 | 85.0 | 72.4 | 67.3 | 78.6 | 89.3 | 100.3 | 98.0 |
| 60 | 58.2 | 63.2 | 53.4 | 63.9 | 80.6 | 70.1 | 58.9 | 63.7 | 76.2 | 87.5 | 98.9 | 96.9 |
| 70 | 48.3 | 56.4 | 48.1 | 54.5 | 61.3 | 56.8 | 52.2 | 58.1 | 71.5 | 85.2 | 95.8 | 94.6 |
| 80 | 42.0 | 46.4 | 39.0 | 46.0 | 51.2 | 44.1 | 41.3 | 50.3 | 67.3 | 82.9 | 92.1 | 90.8 |
| 85 | 36.9 | 41.3 | 36.9 | 41.2 | 43.3 | 41.6 | 39.5 | 45.8 | 58.9 | 76.9 | 87.0 | 86.6 |
| 90 | 34.7 | 38.4 | 35.0 | 38.7 | 40.2 | 39.9 | 37.0 | 41.6 | 53.5 | 70.2 | 82.5 | 80.4 |
| 95 | 32.6 | 36.0 | 33.6 | 36.6 | 38.1 | 38.3 | 36.0 | 36.0 | 43.9 | 59.7 | 66.3 | 61.2 |
| 99 | 31.9 | 35.2 | 33.1 | 35.9 | 37.4 | 37.9 | 35.5 | 33.3 | 37.0 | 38.5 | 41.5 | 31.2 |
| 99.9 | 31.6 | 35.0 | 33.0 | 35.9 | 37.1 | 37.8 | 35.5 | 33.1 | 33.3 | 31.8 | 32.9 | 31.2 |

Nile Coarse EFlow determinations flow duration (time series) summary flows in monthly average m$^3$/s.: **RR2 - Reference (CLASS A) FLOWS**. Colour conditional formatting highlights high (RED) to low (GREEN) values, and does not represent the suitability of the flows.

| %tile | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.1 | 1626.2 | 1653.5 | 1637.2 | 1758.4 | 1893.7 | 1857.8 | 1767.7 | 1715.2 | 1662.1 | 1638.8 | 1600.7 | 1594.6 |
| 1 | 1612 | 1596.8 | 1580.2 | 1659 | 1809.8 | 1780.6 | 1702 | 1632.5 | 1566.7 | 1525 | 1514.5 | 1582.7 |
| 5 | 1402.6 | 1434.1 | 1459.3 | 1535 | 1631.8 | 1638.6 | 1563.5 | 1485.8 | 1439.8 | 1387 | 1378.7 | 1393 |
| 10 | 1344.9 | 1344 | 1403 | 1475.1 | 1602.2 | 1574.9 | 1501.1 | 1427 | 1361 | 1309.4 | 1318.2 | 1357.1 |
| 15 | 1317.9 | 1333.1 | 1349.3 | 1423.9 | 1544.2 | 1513.8 | 1426.1 | 1358.4 | 1313.6 | 1278 | 1305.7 | 1302.8 |
| 20 | 1273.8 | 1288.6 | 1287.5 | 1328.2 | 1392.7 | 1360.6 | 1299.6 | 1240 | 1222.6 | 1197.2 | 1199.6 | 1270.6 |
| 30 | 1179.3 | 1165.5 | 1171.4 | 1198.8 | 1294.5 | 1318.5 | 1253.8 | 1187.3 | 1138 | 1130.5 | 1139 | 1143.1 |
| 40 | 1121.9 | 1111.2 | 1103 | 1132.3 | 1189.6 | 1181.2 | 1143.4 | 1119 | 1101.4 | 1085.1 | 1110.8 | 1104.2 |
| 50 | 1069.2 | 1027.1 | 1050.8 | 1088 | 1158.6 | 1139.2 | 1106.6 | 1052.8 | 1048.1 | 1043.1 | 1013.8 | 1032.3 |
| 60 | 998.8 | 972.3 | 974.8 | 1037 | 1102.8 | 1096.3 | 1054.1 | 994.9 | 957.3 | 924.2 | 952.8 | 971.9 |
| 70 | 923.9 | 948.7 | 948.4 | 963.2 | 1050.9 | 1051.8 | 1011.2 | 943.6 | 913.7 | 891.8 | 873.4 | 919.1 |
| 80 | 858.1 | 854.8 | 838.6 | 906.6 | 1000 | 978.5 | 931.5 | 878.3 | 832.4 | 795.5 | 817.2 | 874 |
| 85 | 805.5 | 781.1 | 772.2 | 826.7 | 904.1 | 893.7 | 857.3 | 806.4 | 779.7 | 756.8 | 780.9 | 819.8 |
| 90 | 722.2 | 728.5 | 732.1 | 771.6 | 847.2 | 838.5 | 762.2 | 720 | 698.4 | 712.9 | 729.3 | 728.6 |
| 95 | 695.3 | 690.3 | 690.4 | 707.5 | 740.9 | 748.1 | 715.2 | 682.8 | 672.3 | 651.2 | 659.2 | 683.6 |
| 99 | 559.2 | 554.9 | 574.8 | 586.7 | 625 | 633.4 | 579.4 | 543.9 | 508.6 | 482 | 491.2 | 535.6 |
| 99.9 | 476.4 | 448.6 | 496.9 | 523.2 | 579.2 | 580.1 | 526.6 | 496.4 | 457.6 | 425.8 | 449.7 | 507.6 |

Nile Coarse EFlow determinations flow duration (time series) summary flows in monthly average m$^3$/s.: **RR2 - CLASS B FLOWS**. Colour conditional formatting highlights high (RED) to low (GREEN) values, and does not represent the suitability of the flows.

| %tile | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.1 | 583.2 | 626.0 | 577.5 | 651.3 | 902.5 | 933.0 | 904.1 | 654.9 | 600.2 | 579.7 | 595.8 | 581.3 |
| 1 | 583.2 | 626.0 | 577.5 | 651.3 | 902.5 | 933.0 | 904.1 | 654.9 | 600.2 | 579.7 | 595.8 | 581.3 |
| 5 | 583.2 | 625.9 | 577.4 | 651.2 | 902.3 | 932.3 | 903.2 | 654.6 | 600.2 | 579.7 | 595.7 | 581.3 |
| 10 | 583.0 | 625.1 | 577.4 | 650.5 | 901.5 | 931.0 | 902.0 | 654.2 | 600.1 | 579.5 | 595.6 | 581.3 |
| 15 | 582.5 | 624.9 | 576.9 | 649.4 | 899.0 | 927.3 | 897.8 | 652.4 | 599.9 | 579.3 | 595.5 | 581.1 |
| 20 | 581.6 | 623.9 | 576.5 | 646.5 | 891.5 | 916.3 | 886.8 | 648.2 | 599.6 | 579.0 | 595.1 | 580.8 |
| 30 | 579.6 | 619.6 | 575.4 | 642.8 | 881.8 | 903.3 | 873.4 | 642.2 | 599.1 | 578.4 | 594.7 | 580.3 |
| 40 | 574.4 | 610.8 | 573.0 | 631.4 | 854.1 | 864.5 | 834.7 | 625.5 | 598.2 | 577.3 | 593.8 | 579.9 |
| 50 | 564.6 | 594.4 | 568.7 | 611.6 | 806.2 | 801.8 | 773.3 | 598.6 | 596.8 | 576.0 | 591.8 | 578.2 |
| 60 | 547.6 | 558.3 | 558.1 | 594.7 | 721.5 | 694.3 | 675.7 | 582.9 | 593.5 | 572.4 | 589.8 | 576.2 |
| 70 | 516.5 | 530.3 | 547.0 | 590.1 | 649.1 | 625.4 | 611.1 | 578.5 | 589.4 | 568.5 | 584.1 | 573.4 |
| 80 | 500.0 | 490.0 | 526.4 | 584.4 | 574.6 | 593.0 | 574.9 | 572.8 | 581.4 | 559.4 | 576.9 | 567.0 |
| 85 | 485.5 | 464.9 | 509.1 | 574.6 | 564.2 | 583.2 | 566.9 | 564.5 | 571.3 | 547.0 | 563.1 | 558.7 |
| 90 | 477.8 | 454.5 | 494.6 | 566.3 | 555.7 | 574.3 | 556.7 | 554.8 | 558.9 | 535.1 | 554.2 | 549.6 |
| 95 | 470.4 | 441.5 | 473.5 | 531.5 | 529.9 | 543.7 | 527.2 | 522.3 | 519.5 | 498.1 | 520.9 | 520.5 |
| 99 | 467.3 | 437.3 | 463.8 | 486.0 | 501.4 | 518.4 | 502.5 | 477.0 | 452.2 | 420.2 | 445.7 | 466.2 |
| 99.9 | 467.1 | 436.8 | 463.8 | 486.0 | 501.4 | 518.4 | 502.5 | 477.0 | 451.8 | 419.7 | 445.3 | 466.2 |

Nile Coarse EFlow determinations flow duration (time series) summary flows in monthly average m$^3$/s.: **RR2 - CLASS C FLOWS**. Colour conditional formatting highlights high (RED) to low (GREEN) values, and does not represent the suitability of the flows.

| %tile | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.1 | 446.8 | 477.4 | 486.3 | 633.6 | 836.3 | 864.5 | 837.7 | 635.5 | 592.0 | 572.0 | 464.0 | 573.2 |
| 1 | 446.8 | 477.4 | 486.3 | 633.6 | 836.3 | 864.5 | 837.7 | 635.5 | 592.0 | 572.0 | 464.0 | 573.2 |
| 5 | 446.8 | 477.4 | 486.2 | 633.5 | 836.0 | 863.7 | 836.6 | 635.0 | 592.0 | 572.0 | 464.0 | 573.2 |
| 10 | 446.6 | 476.8 | 486.1 | 632.2 | 835.1 | 862.1 | 835.1 | 634.2 | 591.8 | 571.6 | 463.9 | 573.1 |
| 15 | 446.1 | 476.6 | 485.5 | 630.2 | 832.0 | 857.6 | 830.0 | 631.2 | 591.5 | 571.4 | 463.8 | 572.7 |
| 20 | 445.2 | 476.0 | 484.9 | 625.0 | 822.9 | 844.3 | 816.7 | 624.1 | 590.9 | 570.9 | 463.4 | 572.1 |
| 30 | 443.0 | 473.1 | 483.3 | 618.4 | 811.1 | 828.5 | 800.4 | 613.9 | 590.2 | 570.0 | 463.1 | 571.0 |
| 40 | 437.6 | 467.3 | 479.9 | 598.2 | 777.6 | 781.5 | 753.6 | 585.7 | 588.6 | 568.3 | 462.4 | 570.1 |
| 50 | 427.5 | 456.3 | 473.8 | 585.4 | 719.5 | 705.5 | 679.2 | 573.2 | 586.2 | 566.3 | 460.6 | 566.5 |
| 60 | 409.8 | 432.3 | 458.6 | 580.9 | 617.0 | 594.2 | 576.4 | 568.2 | 580.5 | 560.7 | 458.8 | 562.3 |
| 70 | 377.4 | 413.6 | 442.8 | 571.0 | 562.1 | 579.7 | 563.0 | 558.9 | 573.3 | 554.7 | 453.9 | 556.1 |
| 80 | 360.3 | 386.8 | 413.5 | 558.7 | 547.8 | 565.9 | 548.3 | 546.8 | 559.5 | 540.6 | 447.7 | 542.5 |
| 85 | 345.1 | 370.1 | 388.7 | 537.8 | 527.7 | 545.3 | 531.5 | 529.0 | 542.0 | 521.4 | 435.7 | 524.6 |
| 90 | 337.2 | 363.1 | 368.1 | 519.9 | 509.7 | 526.3 | 509.8 | 508.6 | 520.6 | 503.0 | 428.0 | 505.2 |
| 95 | 329.5 | 354.5 | 338.0 | 443.8 | 453.0 | 453.7 | 440.3 | 438.1 | 452.5 | 445.7 | 399.1 | 442.8 |
| 99 | 326.4 | 352.1 | 324.1 | 340.1 | 350.3 | 362.1 | 351.0 | 333.9 | 337.1 | 325.7 | 334.3 | 326.4 |
| 99.9 | 326.4 | 352.1 | 324.1 | 340.1 | 350.3 | 362.1 | 351.0 | 333.9 | 337.1 | 325.7 | 334.3 | 326.4 |

Nile Coarse EFlow determinations flow duration (time series) summary flows in monthly average m$^3$/s.: **RR2 - CLASS D FLOWS**. Colour conditional formatting highlights high (RED) to low (GREEN) values, and does not represent the suitability of the flows.

| %tile | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.1 | 322.1 | 374.1 | 441.9 | 556.2 | 783.5 | 809.9 | 784.7 | 560.7 | 509.7 | 492.6 | 329.9 | 493.5 |
| 1 | 322.1 | 374.1 | 441.9 | 556.2 | 783.5 | 809.9 | 784.7 | 560.7 | 509.7 | 492.6 | 329.9 | 493.5 |
| 5 | 322.1 | 374.1 | 441.8 | 556.1 | 783.3 | 809.0 | 783.5 | 560.2 | 509.7 | 492.5 | 329.9 | 493.5 |
| 10 | 321.9 | 373.5 | 441.7 | 554.7 | 782.3 | 807.3 | 781.8 | 559.3 | 509.5 | 492.2 | 329.8 | 493.4 |
| 15 | 321.6 | 373.3 | 440.9 | 552.5 | 778.9 | 802.4 | 776.2 | 556.1 | 509.1 | 491.9 | 329.7 | 492.9 |
| 20 | 320.8 | 372.7 | 440.1 | 547.0 | 769.0 | 787.9 | 761.8 | 548.4 | 508.6 | 491.4 | 329.5 | 492.3 |
| 30 | 319.2 | 369.8 | 438.0 | 539.9 | 756.1 | 770.7 | 744.0 | 537.5 | 507.8 | 490.4 | 329.2 | 491.2 |
| 40 | 315.0 | 363.9 | 433.5 | 518.1 | 719.5 | 719.4 | 692.9 | 507.2 | 506.1 | 488.6 | 328.7 | 490.2 |
| 50 | 307.3 | 352.9 | 425.5 | 502.9 | 656.2 | 636.5 | 611.8 | 491.8 | 503.5 | 486.5 | 327.4 | 486.4 |
| 60 | 293.7 | 328.7 | 405.5 | 498.1 | 544.3 | 512.1 | 497.5 | 486.4 | 497.4 | 480.5 | 326.1 | 481.9 |
| 70 | 268.9 | 309.9 | 384.7 | 487.5 | 479.8 | 494.5 | 480.3 | 476.5 | 489.7 | 474.2 | 322.5 | 475.3 |
| 80 | 255.7 | 282.9 | 346.2 | 474.4 | 464.5 | 479.8 | 464.7 | 463.6 | 475.0 | 459.0 | 318.0 | 460.8 |
| 85 | 244.1 | 266.1 | 313.6 | 452.1 | 443.2 | 457.9 | 446.8 | 444.7 | 456.4 | 438.5 | 309.2 | 441.7 |
| 90 | 238.0 | 259.1 | 286.5 | 433.0 | 424.0 | 437.7 | 423.7 | 423.0 | 433.5 | 419.0 | 303.6 | 421.0 |
| 95 | 232.1 | 250.3 | 246.9 | 351.7 | 363.6 | 360.3 | 349.7 | 347.9 | 360.9 | 357.7 | 282.5 | 354.4 |
| 99 | 229.7 | 248.0 | 228.7 | 240.9 | 253.3 | 261.9 | 253.8 | 236.9 | 237.8 | 229.8 | 235.3 | 230.2 |
| 99.9 | 229.7 | 248.0 | 228.7 | 240.9 | 253.3 | 261.9 | 253.8 | 236.9 | 237.8 | 229.8 | 235.3 | 230.2 |

Nile Coarse EFlow determinations flow duration (time series) summary flows in monthly average m$^3$/s.: **RR3 - Reference (CLASS A) FLOWS**. Colour conditional formatting highlights high (RED) to low (GREEN) values, and does not represent the suitability of the flows.

| %tile | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.1 | 1956.5 | 1870.2 | 1782.3 | 1846.4 | 2253.8 | 2171.5 | 2134.8 | 2354.5 | 2644.7 | 2732 | 2218.4 | 1965.1 |
| 1 | 1903.3 | 1834.1 | 1754.2 | 1831.9 | 2204.9 | 2131.2 | 2120.4 | 2318.9 | 2627.5 | 2659.3 | 2184.1 | 1952.6 |
| 5 | 1666.9 | 1673.9 | 1629.3 | 1767.4 | 1987.9 | 1952.4 | 2056.5 | 2160.6 | 2551.3 | 2336.4 | 2031.6 | 1897.3 |
| 10 | 1650.7 | 1615 | 1614.1 | 1742.3 | 1791.4 | 1784.3 | 1788.6 | 2075.2 | 2098.4 | 1926.1 | 1979.9 | 1814 |
| 15 | 1643.9 | 1574.5 | 1599 | 1697.3 | 1761.7 | 1717.8 | 1742.8 | 2014.2 | 1956.8 | 1882.5 | 1939.2 | 1749.3 |
| 20 | 1638.9 | 1564.3 | 1554.1 | 1612.7 | 1738.8 | 1678.2 | 1722.2 | 1930.9 | 1931.3 | 1881 | 1898.9 | 1709.6 |
| 30 | 1602.9 | 1511.5 | 1462 | 1519.7 | 1619.3 | 1608 | 1703.4 | 1847 | 1907.4 | 1860.8 | 1792.4 | 1657.8 |
| 40 | 1529 | 1443.4 | 1395.2 | 1432.1 | 1566.5 | 1569.4 | 1655.2 | 1804.6 | 1824.8 | 1810 | 1754.6 | 1632.2 |
| 50 | 1465.4 | 1405.2 | 1361.6 | 1383.1 | 1519.2 | 1516.2 | 1581.2 | 1731.1 | 1792.1 | 1775.5 | 1684 | 1616.8 |
| 60 | 1437.1 | 1381.8 | 1341.5 | 1334.9 | 1461.6 | 1466.1 | 1552.4 | 1692.9 | 1709.9 | 1686.5 | 1654.3 | 1602.8 |
| 70 | 1383.9 | 1328.4 | 1297.6 | 1305.6 | 1404.9 | 1412.8 | 1524.6 | 1680.2 | 1691.4 | 1650.8 | 1606.5 | 1506.5 |
| 80 | 1349.2 | 1292.5 | 1256.4 | 1287.8 | 1334.5 | 1361.9 | 1363.4 | 1651.5 | 1630.4 | 1513.9 | 1530.1 | 1437 |
| 85 | 1341.9 | 1272.8 | 1248.1 | 1250.4 | 1294.3 | 1328.1 | 1321.5 | 1642.3 | 1585.8 | 1501.6 | 1521 | 1429.2 |
| 90 | 1315.6 | 1265.3 | 1226.4 | 1228.4 | 1280.4 | 1310.2 | 1305 | 1573.4 | 1527 | 1491.4 | 1501.2 | 1402.7 |
| 95 | 1286 | 1247.1 | 1222.5 | 1205.8 | 1257.4 | 1295.7 | 1282.1 | 1378.4 | 1381 | 1476 | 1468.4 | 1390.4 |
| 99 | 1254.8 | 1140 | 1173.4 | 1179.4 | 1245.5 | 1286.9 | 1281.2 | 1371.6 | 1378 | 1409.6 | 1444.9 | 1310.6 |
| 99.9 | 1247.8 | 1115.9 | 1162.4 | 1173.5 | 1242.8 | 1284.9 | 1281 | 1370 | 1377.4 | 1394.7 | 1439.6 | 1292.7 |

Nile Coarse EFlow determinations flow duration (time series) summary flows in monthly average m$^3$/s.: **RR3 - CLASS B FLOWS**. Colour conditional formatting highlights high (RED) to low (GREEN) values, and does not represent the suitability of the flows.

| %tile | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.1 | 858.5 | 923.1 | 841.6 | 870.6 | 981.4 | 1023.9 | 1086.2 | 1228.2 | 1308.0 | 1092.0 | 1051.1 | 862.7 |
| 1 | 858.5 | 923.1 | 841.6 | 870.6 | 981.4 | 1023.9 | 1086.2 | 1228.2 | 1308.0 | 1092.0 | 1051.1 | 862.7 |
| 5 | 858.5 | 923.1 | 841.6 | 870.6 | 981.4 | 1023.9 | 1086.2 | 1228.2 | 1308.0 | 1092.0 | 1051.1 | 862.7 |
| 10 | 858.5 | 923.1 | 841.6 | 870.6 | 981.4 | 1023.9 | 1074.5 | 1210.3 | 1282.8 | 1092.0 | 1051.1 | 862.7 |
| 15 | 858.5 | 923.1 | 841.6 | 870.6 | 981.4 | 1023.9 | 1062.9 | 1192.7 | 1258.3 | 1092.0 | 1051.1 | 862.7 |
| 20 | 856.8 | 921.3 | 840.3 | 869.3 | 979.7 | 1022.5 | 1051.0 | 1175.0 | 1234.2 | 1090.1 | 1049.3 | 862.2 |
| 30 | 849.3 | 913.1 | 834.8 | 863.6 | 972.7 | 1017.4 | 1027.2 | 1140.7 | 1195.3 | 1082.1 | 1036.6 | 860.7 |
| 40 | 836.5 | 890.0 | 822.4 | 848.9 | 962.4 | 1010.3 | 999.7 | 1112.9 | 1137.9 | 1064.5 | 1024.3 | 858.5 |
| 50 | 816.8 | 872.4 | 810.7 | 836.4 | 942.6 | 998.1 | 981.8 | 1084.8 | 1111.6 | 1047.5 | 983.8 | 856.5 |
| 60 | 769.7 | 832.3 | 788.3 | 803.3 | 904.4 | 978.1 | 946.9 | 1025.7 | 1006.5 | 991.3 | 935.6 | 852.6 |
| 70 | 696.0 | 747.5 | 726.1 | 751.2 | 833.7 | 923.9 | 885.7 | 980.7 | 938.0 | 923.5 | 870.2 | 839.7 |
| 80 | 591.5 | 634.6 | 637.2 | 659.2 | 720.0 | 835.9 | 802.3 | 867.6 | 808.0 | 852.6 | 842.4 | 808.2 |
| 85 | 534.4 | 573.0 | 580.6 | 600.7 | 647.6 | 771.0 | 740.8 | 798.7 | 725.3 | 846.4 | 815.3 | 782.2 |
| 90 | 480.0 | 514.2 | 518.8 | 536.8 | 568.7 | 689.3 | 663.2 | 712.0 | 635.0 | 833.9 | 766.3 | 735.0 |
| 95 | 433.7 | 464.2 | 457.1 | 473.0 | 489.7 | 590.6 | 569.7 | 607.3 | 542.7 | 786.3 | 660.7 | 632.8 |
| 99 | 406.9 | 435.2 | 414.1 | 428.5 | 434.7 | 502.2 | 485.8 | 513.5 | 449.3 | 487.3 | 468.2 | 437.0 |
| 99.9 | 400.8 | 428.6 | 404.4 | 418.4 | 422.3 | 482.3 | 466.9 | 492.4 | 428.3 | 420.1 | 424.9 | 392.9 |

Nile Coarse EFlow determinations flow duration (time series) summary flows in monthly average m$^3$/s.: **RR3 - CLASS C FLOWS**. Colour conditional formatting highlights high (RED) to low (GREEN) values, and does not represent the suitability of the flows.

| %tile | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.1 | 460.7 | 493.9 | 463.6 | 479.6 | 565.4 | 609.7 | 642.2 | 733.2 | 765.5 | 701.9 | 727.4 | 578.5 |
| 1 | 460.7 | 493.9 | 463.6 | 479.6 | 565.4 | 609.7 | 642.2 | 733.2 | 765.5 | 701.9 | 727.4 | 578.5 |
| 5 | 460.7 | 493.9 | 463.6 | 479.6 | 565.4 | 609.7 | 642.2 | 733.2 | 765.5 | 701.9 | 727.4 | 578.5 |
| 10 | 460.7 | 493.9 | 463.6 | 479.6 | 565.4 | 609.7 | 634.4 | 721.5 | 749.0 | 701.9 | 727.4 | 578.5 |
| 15 | 460.7 | 493.9 | 463.6 | 479.6 | 565.4 | 609.7 | 626.8 | 710.0 | 733.0 | 701.9 | 727.4 | 578.5 |
| 20 | 460.2 | 493.4 | 463.1 | 479.2 | 564.7 | 609.2 | 619.2 | 698.7 | 717.6 | 700.9 | 726.3 | 578.3 |
| 30 | 458.1 | 491.1 | 461.4 | 477.4 | 561.8 | 606.9 | 604.6 | 677.4 | 693.9 | 696.6 | 718.8 | 577.5 |
| 40 | 454.5 | 484.6 | 457.6 | 472.9 | 557.7 | 603.9 | 589.2 | 661.1 | 661.4 | 687.3 | 711.5 | 576.4 |
| 50 | 448.9 | 479.6 | 454.0 | 469.0 | 549.7 | 598.6 | 579.8 | 645.5 | 647.6 | 678.3 | 687.6 | 575.3 |
| 60 | 435.6 | 468.3 | 447.0 | 458.7 | 534.3 | 589.8 | 561.3 | 612.8 | 593.6 | 648.5 | 659.1 | 573.2 |
| 70 | 414.7 | 444.3 | 427.7 | 442.5 | 505.7 | 566.3 | 533.2 | 590.3 | 565.1 | 612.6 | 604.3 | 566.5 |
| 80 | 385.2 | 412.4 | 400.0 | 413.9 | 459.8 | 528.0 | 498.9 | 541.4 | 512.3 | 574.4 | 573.9 | 550.0 |
| 85 | 369.1 | 395.0 | 382.4 | 395.7 | 430.5 | 499.8 | 473.7 | 511.7 | 478.7 | 571.1 | 559.7 | 536.3 |
| 90 | 353.7 | 378.4 | 363.3 | 375.9 | 398.6 | 464.3 | 441.8 | 474.2 | 442.0 | 564.6 | 534.0 | 511.6 |
| 95 | 340.6 | 364.3 | 344.1 | 356.0 | 366.7 | 421.4 | 403.4 | 428.9 | 404.5 | 539.5 | 478.6 | 458.1 |
| 99 | 333.0 | 356.1 | 330.7 | 342.2 | 344.5 | 383.0 | 369.0 | 388.4 | 366.5 | 381.3 | 379.3 | 355.5 |
| 99.9 | 331.3 | 354.2 | 327.7 | 339.1 | 339.5 | 374.3 | 361.2 | 379.2 | 358.0 | 345.7 | 357.0 | 332.4 |

Nile Coarse EFlow determinations flow duration (time series) summary flows in monthly average m$^3$/s.: **RR3 - CLASS D FLOWS**. Colour conditional formatting highlights high (RED) to low (GREEN) values, and does not represent the suitability of the flows.

| %tile | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.1 | 378.6 | 404.7 | 453.8 | 352.7 | 408.7 | 492.8 | 574.2 | 644.8 | 625.3 | 589.3 | 611.0 | 497.7 |
| 1 | 378.6 | 404.7 | 453.8 | 352.7 | 408.7 | 492.8 | 574.2 | 644.8 | 625.3 | 589.3 | 611.0 | 497.7 |
| 5 | 378.6 | 404.7 | 453.8 | 352.7 | 408.7 | 492.8 | 574.2 | 644.8 | 625.3 | 589.3 | 611.0 | 497.7 |
| 10 | 378.6 | 404.7 | 453.8 | 352.7 | 408.7 | 492.8 | 568.5 | 636.1 | 613.1 | 589.3 | 611.0 | 497.7 |
| 15 | 378.6 | 404.7 | 453.8 | 352.7 | 408.7 | 492.8 | 562.9 | 627.7 | 601.3 | 589.3 | 611.0 | 497.7 |
| 20 | 378.3 | 404.4 | 453.3 | 352.5 | 408.4 | 492.4 | 557.2 | 619.2 | 590.0 | 588.5 | 610.2 | 497.5 |
| 30 | 377.0 | 402.9 | 451.4 | 351.8 | 407.0 | 490.8 | 546.1 | 603.1 | 572.5 | 585.2 | 604.2 | 496.8 |
| 40 | 374.6 | 398.7 | 446.9 | 350.1 | 404.9 | 488.7 | 533.8 | 590.5 | 548.3 | 577.8 | 598.4 | 495.9 |
| 50 | 371.0 | 395.6 | 442.7 | 348.6 | 400.9 | 484.9 | 526.0 | 578.0 | 538.0 | 570.6 | 579.4 | 495.1 |
| 60 | 362.4 | 388.3 | 434.5 | 344.6 | 393.2 | 478.8 | 510.8 | 551.7 | 497.6 | 547.0 | 556.8 | 493.4 |
| 70 | 348.9 | 373.0 | 412.0 | 338.3 | 378.9 | 462.1 | 485.9 | 532.7 | 475.9 | 518.6 | 515.4 | 487.9 |
| 80 | 329.8 | 352.6 | 379.9 | 327.2 | 355.9 | 435.1 | 453.5 | 487.6 | 435.5 | 494.9 | 495.6 | 474.4 |
| 85 | 319.4 | 341.4 | 359.4 | 320.1 | 341.3 | 415.2 | 429.6 | 460.1 | 409.8 | 492.2 | 484.0 | 463.3 |
| 90 | 309.5 | 330.8 | 337.1 | 312.4 | 325.3 | 390.1 | 399.5 | 425.6 | 381.7 | 486.9 | 462.9 | 443.1 |
| 95 | 301.0 | 321.8 | 314.7 | 304.7 | 309.4 | 359.9 | 363.2 | 383.9 | 353.1 | 466.3 | 417.6 | 399.4 |
| 99 | 296.1 | 316.5 | 299.2 | 299.3 | 298.3 | 332.7 | 330.6 | 346.5 | 324.1 | 336.4 | 335.8 | 315.7 |
| 99.9 | 295.0 | 315.3 | 295.7 | 298.1 | 295.8 | 326.6 | 323.2 | 338.0 | 317.5 | 307.2 | 317.3 | 296.9 |

Nile Coarse EFlow determinations flow duration (time series) summary flows in monthly average m$^3$/s.: **RR4 - Reference (CLASS A) FLOWS**. Colour conditional formatting highlights high (RED) to low (GREEN) values, and does not represent the suitability of the flows.

| %tile | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.1 | 155 | 98.9 | 78 | 125.6 | 349.5 | 670 | 999.5 | 1192.8 | 1301.8 | 1194.4 | 822.6 | 332.9 |
| 1 | 147.6 | 97.6 | 77.8 | 119.3 | 332.1 | 668.1 | 976.2 | 1158.6 | 1276.9 | 1171.3 | 785.5 | 310.1 |
| 5 | 121.3 | 91.9 | 75.6 | 96.7 | 272.4 | 639.2 | 870.3 | 1063.5 | 1209.2 | 1103.2 | 585.7 | 240 |
| 10 | 113.3 | 69.6 | 70.5 | 83.3 | 256.6 | 570.5 | 811.5 | 1060.9 | 1167.2 | 1084.2 | 461.5 | 214.7 |
| 15 | 112.6 | 66.1 | 65.5 | 75.9 | 233.8 | 537.4 | 797.5 | 1040.3 | 1089.1 | 965.9 | 454.1 | 200.7 |
| 20 | 111.8 | 64.9 | 58.8 | 74.1 | 211.8 | 494.6 | 776.6 | 1023.8 | 1079.1 | 887.5 | 428.8 | 184.6 |
| 30 | 106.1 | 63.6 | 53.5 | 61.9 | 193.4 | 450.8 | 754.8 | 963.4 | 1060 | 835.5 | 373.5 | 169 |
| 40 | 98.2 | 60.1 | 50.8 | 56.4 | 159.4 | 428.1 | 699.6 | 922.7 | 1033.9 | 751.9 | 335.8 | 157.8 |
| 50 | 83.3 | 56.3 | 45 | 54.9 | 138.3 | 382.6 | 680.9 | 873.9 | 991.9 | 746 | 314.9 | 153.8 |
| 60 | 77.9 | 52.2 | 43.4 | 52.7 | 125.2 | 342.2 | 665.1 | 839.2 | 964.1 | 698.8 | 265.1 | 144.8 |
| 70 | 69.7 | 45.6 | 40.1 | 42.6 | 98.4 | 311.7 | 612.6 | 799.9 | 929.3 | 630.9 | 237.5 | 131.7 |
| 80 | 68 | 43.3 | 39.4 | 38.2 | 78.2 | 292.2 | 566.1 | 769.3 | 882.4 | 574.5 | 221.2 | 115.9 |
| 85 | 60.4 | 42.1 | 38.8 | 35.3 | 67.3 | 267 | 551.4 | 725.7 | 868.9 | 526.2 | 220.7 | 113.2 |
| 90 | 55.7 | 35.6 | 38.5 | 34.8 | 51.8 | 234.3 | 528 | 679.5 | 858.3 | 489.4 | 202.9 | 109.2 |
| 95 | 53.7 | 34 | 32.3 | 27.4 | 41.9 | 215.3 | 497.2 | 576.6 | 819.2 | 449 | 187.6 | 97.9 |
| 99 | 50 | 31.2 | 23.9 | 15.8 | 36.6 | 127.8 | 309.8 | 483.5 | 815.3 | 389.6 | 172.1 | 92 |
| 99.9 | 49.3 | 30.2 | 22.5 | 12.8 | 35 | 100.1 | 249.1 | 470.7 | 815.2 | 378.2 | 166.7 | 91.8 |

Nile Coarse EFlow determinations flow duration (time series) summary flows in monthly average $m^3$/s.: **RR4 - CLASS B FLOWS**. Colour conditional formatting highlights high (RED) to low (GREEN) values, and does not represent the suitability of the flows.

| %tile | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.1 | 112.2 | 82.1 | 65.5 | 65.9 | 84.2 | 157.1 | 369.6 | 487.5 | 608.7 | 426.0 | 277.2 | 177.0 |
| 1 | 112.2 | 82.1 | 65.5 | 65.9 | 84.2 | 157.1 | 369.6 | 487.5 | 608.7 | 426.0 | 277.2 | 177.0 |
| 5 | 112.2 | 82.1 | 65.5 | 65.9 | 84.2 | 157.1 | 369.6 | 487.5 | 608.7 | 426.0 | 277.2 | 177.0 |
| 10 | 112.2 | 74.8 | 65.5 | 65.9 | 84.2 | 157.1 | 363.3 | 479.4 | 595.8 | 426.0 | 277.2 | 177.0 |
| 15 | 112.2 | 70.4 | 64.6 | 65.9 | 84.2 | 157.1 | 356.2 | 471.6 | 575.2 | 426.0 | 277.2 | 177.0 |
| 20 | 112.0 | 69.4 | 56.4 | 65.8 | 84.2 | 157.0 | 348.9 | 460.8 | 567.1 | 425.6 | 277.0 | 174.6 |
| 30 | 106.7 | 67.6 | 53.2 | 64.7 | 83.7 | 156.3 | 335.2 | 443.2 | 540.4 | 423.0 | 273.9 | 162.2 |
| 40 | 100.1 | 65.2 | 50.8 | 59.0 | 82.5 | 154.9 | 322.1 | 425.5 | 512.6 | 417.2 | 271.9 | 152.3 |
| 50 | 88.3 | 59.6 | 45.0 | 56.7 | 80.2 | 152.4 | 308.0 | 413.1 | 480.0 | 408.0 | 257.0 | 148.0 |
| 60 | 78.7 | 55.3 | 43.3 | 54.8 | 74.4 | 145.2 | 273.9 | 362.1 | 420.7 | 376.0 | 238.2 | 134.8 |
| 70 | 70.2 | 49.0 | 40.5 | 45.7 | 66.2 | 135.2 | 253.1 | 336.3 | 373.2 | 334.5 | 213.8 | 125.7 |
| 80 | 59.9 | 45.2 | 39.6 | 38.9 | 54.7 | 118.7 | 220.5 | 293.5 | 307.2 | 276.4 | 172.4 | 94.1 |
| 85 | 51.5 | 41.4 | 33.7 | 31.1 | 50.6 | 106.1 | 184.8 | 245.5 | 279.2 | 241.5 | 152.6 | 83.4 |
| 90 | 43.0 | 33.0 | 31.4 | 30.0 | 40.7 | 93.5 | 170.6 | 227.8 | 226.8 | 205.4 | 119.7 | 69.7 |
| 95 | 39.3 | 25.7 | 23.0 | 23.9 | 29.9 | 78.6 | 143.2 | 186.7 | 170.0 | 151.2 | 104.1 | 63.8 |
| 99 | 35.5 | 24.1 | 18.9 | 17.4 | 24.8 | 64.5 | 114.2 | 151.6 | 152.5 | 125.0 | 95.3 | 58.9 |
| 99.9 | 34.9 | 23.7 | 18.3 | 16.3 | 23.9 | 60.1 | 105.0 | 141.3 | 150.7 | 120.7 | 92.7 | 58.1 |

Nile Coarse EFlow determinations flow duration (time series) summary flows in monthly average $m^3$/s.: **RR4 - CLASS C FLOWS**. Colour conditional formatting highlights high (RED) to low (GREEN) values, and does not represent the suitability of the flows.

| %tile | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.1 | 69.6 | 49.6 | 38.8 | 38.8 | 47.5 | 80.1 | 150.2 | 189.4 | 227.0 | 170.2 | 108.6 | 86.4 |
| 1 | 69.6 | 49.6 | 38.8 | 38.8 | 47.5 | 80.1 | 150.2 | 189.4 | 227.0 | 170.2 | 108.6 | 86.4 |
| 5 | 69.6 | 49.6 | 38.8 | 38.8 | 47.5 | 80.1 | 150.2 | 189.4 | 227.0 | 170.2 | 108.6 | 86.4 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 69.6 | 49.6 | 38.8 | 38.8 | 47.5 | 80.1 | 148.6 | 187.5 | 224.0 | 170.2 | 108.6 | 86.4 |
| 15 | 69.6 | 49.6 | 38.8 | 38.8 | 47.5 | 80.1 | 146.8 | 185.7 | 219.2 | 170.2 | 108.6 | 86.4 |
| 20 | 69.5 | 49.5 | 38.8 | 38.7 | 47.5 | 80.0 | 144.9 | 183.1 | 217.3 | 170.1 | 108.6 | 86.3 |
| 30 | 69.1 | 49.3 | 38.6 | 38.5 | 47.3 | 79.8 | 141.3 | 178.8 | 210.9 | 169.4 | 107.7 | 85.8 |
| 40 | 68.2 | 48.6 | 38.2 | 38.0 | 46.8 | 79.3 | 137.7 | 174.4 | 204.1 | 167.7 | 107.2 | 84.9 |
| 50 | 66.8 | 46.9 | 37.3 | 37.1 | 45.8 | 78.4 | 133.7 | 171.2 | 195.5 | 165.0 | 103.1 | 81.9 |
| 60 | 61.0 | 43.6 | 35.5 | 34.6 | 43.4 | 75.8 | 124.1 | 157.6 | 179.7 | 155.8 | 98.0 | 74.7 |
| 70 | 54.7 | 38.6 | 32.4 | 31.0 | 39.9 | 72.3 | 117.3 | 149.7 | 165.4 | 143.8 | 91.3 | 68.9 |
| 80 | 44.9 | 34.3 | 30.0 | 26.1 | 35.0 | 66.3 | 106.7 | 136.4 | 145.7 | 127.0 | 80.0 | 58.2 |
| 85 | 40.9 | 30.9 | 24.6 | 21.7 | 33.3 | 61.8 | 95.1 | 121.6 | 137.3 | 116.9 | 74.6 | 54.5 |
| 90 | 36.9 | 27.0 | 23.4 | 21.2 | 29.0 | 57.3 | 90.5 | 116.1 | 121.6 | 106.5 | 65.7 | 49.9 |
| 95 | 35.1 | 23.6 | 19.6 | 18.2 | 24.5 | 52.0 | 81.6 | 103.4 | 104.7 | 90.8 | 61.4 | 47.9 |
| 99 | 33.4 | 22.9 | 17.8 | 15.0 | 22.3 | 46.9 | 72.2 | 92.6 | 99.4 | 83.2 | 59.0 | 46.2 |
| 99.9 | 33.1 | 22.7 | 17.5 | 14.5 | 21.9 | 45.4 | 69.2 | 89.4 | 98.9 | 81.9 | 58.3 | 45.9 |

Nile Coarse EFlow determinations flow duration (time series) summary flows in monthly average m$^3$/s.: **RR4 - CLASS D FLOWS**. Colour conditional formatting highlights high (RED) to low (GREEN) values, and does not represent the suitability of the flows.

| %tile | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.1 | 43.2 | 39.3 | 32.5 | 32.3 | 40.8 | 59.6 | 108.0 | 137.7 | 149.1 | 118.5 | 76.2 | 51.5 |
| 1 | 43.2 | 39.3 | 32.5 | 32.3 | 40.8 | 59.6 | 108.0 | 137.7 | 149.1 | 118.5 | 76.2 | 51.5 |
| 5 | 43.2 | 39.3 | 32.5 | 32.3 | 40.8 | 59.6 | 108.0 | 137.7 | 149.1 | 118.5 | 76.2 | 51.5 |
| 10 | 43.2 | 39.3 | 32.5 | 32.3 | 40.8 | 59.6 | 107.1 | 136.7 | 147.6 | 118.5 | 76.2 | 51.5 |
| 15 | 43.2 | 39.3 | 32.5 | 32.3 | 40.8 | 59.6 | 106.2 | 135.8 | 145.2 | 118.5 | 76.2 | 51.5 |
| 20 | 43.2 | 39.3 | 32.5 | 32.3 | 40.7 | 59.6 | 105.2 | 134.5 | 144.2 | 118.4 | 76.2 | 51.5 |
| 30 | 43.1 | 39.1 | 32.4 | 32.2 | 40.6 | 59.5 | 103.4 | 132.3 | 141.0 | 118.0 | 75.9 | 51.4 |
| 40 | 42.8 | 38.7 | 32.0 | 31.8 | 40.2 | 59.2 | 101.5 | 130.0 | 137.5 | 117.2 | 75.6 | 51.2 |
| 50 | 42.3 | 37.5 | 31.4 | 31.1 | 39.4 | 58.7 | 99.3 | 128.2 | 133.4 | 115.9 | 73.9 | 50.6 |
| 60 | 40.3 | 35.3 | 30.0 | 29.2 | 37.5 | 57.3 | 94.0 | 120.8 | 125.7 | 111.5 | 71.7 | 49.1 |
| 70 | 38.3 | 32.0 | 27.7 | 26.5 | 34.7 | 55.3 | 89.9 | 115.9 | 119.2 | 105.7 | 68.9 | 47.9 |
| 80 | 35.0 | 29.1 | 25.8 | 22.8 | 30.9 | 52.0 | 83.5 | 107.8 | 110.1 | 97.6 | 64.0 | 45.6 |
| 85 | 33.6 | 26.8 | 21.8 | 19.5 | 29.5 | 49.5 | 76.5 | 98.8 | 106.2 | 92.7 | 61.7 | 44.9 |
| 90 | 32.3 | 24.2 | 20.9 | 19.1 | 26.2 | 46.9 | 73.8 | 95.4 | 99.0 | 87.7 | 57.9 | 43.9 |
| 95 | 31.7 | 22.0 | 18.0 | 16.9 | 22.6 | 44.0 | 68.4 | 87.7 | 91.2 | 80.1 | 56.1 | 43.5 |
| 99 | 31.1 | 21.5 | 16.7 | 14.4 | 20.9 | 41.2 | 62.7 | 81.1 | 88.8 | 76.5 | 55.0 | 43.1 |
| 99.9 | 31.0 | 21.3 | 16.4 | 14.0 | 20.6 | 40.3 | 60.9 | 79.1 | 88.5 | 75.9 | 54.7 | 43.1 |

Nile Coarse EFlow determinations flow duration (time series) summary flows in monthly average m$^3$/s.: **RR5 - Reference (CLASS A) FLOWS**. Colour conditional formatting highlights high (RED) to low (GREEN) values, and does not represent the suitability of the flows.

| %tile | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.1 | 1199 | 1201.3 | 1041.9 | 592.3 | 586.6 | 606.9 | 687 | 827.7 | 952.4 | 1028.4 | 1093.6 | 1165.6 |
| 1 | 1116.4 | 875.1 | 722.3 | 488.8 | 469.5 | 579.6 | 683.7 | 774.3 | 891.7 | 983.4 | 1071.7 | 1115 |
| 5 | 844.2 | 555.9 | 270 | 247.4 | 328.6 | 486.5 | 573.9 | 680.7 | 785.1 | 877 | 974.7 | 1003.4 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 757.9 | 404.2 | 192.2 | 187.7 | 267.5 | 417 | 562.8 | 653.4 | 763.8 | 837 | 864.7 | 869.5 |
| 15 | 712 | 286.2 | 136.5 | 158.2 | 229.9 | 399 | 542.6 | 644.4 | 761.8 | 812.5 | 837.7 | 843.9 |
| 20 | 594.4 | 205.8 | 114.6 | 131.8 | 207.8 | 390.4 | 526.1 | 637.2 | 735.1 | 799.9 | 826.9 | 807.9 |
| 30 | 469.1 | 158.2 | 96.9 | 108.5 | 186.4 | 366 | 507 | 626.9 | 720.2 | 780 | 802.8 | 747.2 |
| 40 | 338.2 | 137 | 85.6 | 97.1 | 159.4 | 334.9 | 497.1 | 609 | 698 | 772 | 773.7 | 724.4 |
| 50 | 263.7 | 119 | 78.3 | 72.2 | 140.5 | 321 | 483.1 | 602.9 | 677.1 | 749.4 | 760.4 | 673.4 |
| 60 | 218.9 | 97.3 | 69.3 | 60.8 | 126.7 | 293.6 | 474.1 | 587.1 | 663 | 718.7 | 738.6 | 580.3 |
| 70 | 183.6 | 87.8 | 59.6 | 50.8 | 113.6 | 280.5 | 460.3 | 572.1 | 652.8 | 701.6 | 715.7 | 527.3 |
| 80 | 138.9 | 71.3 | 48.5 | 42.3 | 101.5 | 257.3 | 439.4 | 554.5 | 633.3 | 671.8 | 687.3 | 475.9 |
| 85 | 126.6 | 68.2 | 41.6 | 39.7 | 95.3 | 250.2 | 428.6 | 545.8 | 615.2 | 661.9 | 673.1 | 433.5 |
| 90 | 118.7 | 62 | 37.4 | 36.3 | 84.9 | 229.9 | 418.7 | 534.6 | 602.7 | 645.1 | 648.5 | 306.7 |
| 95 | 106.8 | 51.6 | 34 | 29.2 | 61.5 | 175.8 | 409.2 | 519.3 | 596.2 | 626.2 | 596.9 | 220.6 |
| 99 | 71 | 37.9 | 24.4 | 6.5 | 50.3 | 136.3 | 354.5 | 479.5 | 567.9 | 571.9 | 376.5 | 188.5 |
| 99.9 | 61.1 | 31.9 | 19.4 | 1.3 | 49.6 | 134.1 | 278.6 | 467.9 | 565.5 | 491.3 | 349.5 | 133.1 |

Nile Coarse EFlow determinations flow duration (time series) summary flows in monthly average m$^3$/s.: **RR5 - CLASS B FLOWS**. Colour conditional formatting highlights high (RED) to low (GREEN) values, and does not represent the suitability of the flows.

| %tile | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.1 | 246.9 | 155.8 | 107.7 | 100.4 | 104.0 | 160.8 | 260.9 | 337.7 | 410.5 | 367.3 | 384.0 | 335.8 |
| 1 | 246.9 | 155.8 | 107.7 | 100.4 | 104.0 | 160.8 | 260.9 | 337.7 | 410.5 | 367.3 | 384.0 | 335.8 |
| 5 | 246.9 | 155.8 | 107.7 | 100.4 | 104.0 | 160.8 | 260.9 | 337.7 | 410.5 | 367.3 | 384.0 | 335.8 |
| 10 | 246.9 | 155.8 | 107.7 | 100.4 | 104.0 | 160.8 | 260.2 | 333.7 | 405.8 | 367.3 | 384.0 | 335.8 |
| 15 | 246.9 | 155.8 | 107.7 | 100.4 | 104.0 | 160.8 | 254.4 | 328.7 | 396.8 | 367.3 | 384.0 | 335.8 |
| 20 | 246.8 | 155.7 | 107.7 | 100.4 | 104.0 | 160.8 | 249.9 | 321.6 | 383.6 | 367.2 | 384.0 | 335.7 |
| 30 | 244.8 | 154.3 | 99.0 | 100.1 | 103.8 | 160.1 | 237.8 | 305.9 | 361.4 | 365.0 | 381.6 | 332.8 |
| 40 | 239.6 | 146.6 | 85.1 | 99.2 | 103.5 | 159.0 | 231.2 | 293.3 | 340.1 | 360.8 | 376.5 | 327.1 |
| 50 | 228.3 | 126.2 | 78.4 | 74.5 | 103.1 | 156.6 | 222.1 | 280.8 | 320.9 | 351.2 | 367.5 | 315.0 |
| 60 | 208.1 | 104.5 | 69.4 | 62.3 | 102.3 | 152.2 | 205.5 | 255.1 | 285.3 | 333.1 | 348.4 | 285.8 |
| 70 | 176.7 | 93.3 | 60.2 | 51.6 | 100.9 | 142.9 | 192.2 | 238.6 | 256.5 | 295.9 | 318.0 | 250.9 |
| 80 | 128.0 | 74.7 | 47.6 | 43.7 | 92.3 | 129.5 | 161.7 | 204.4 | 214.1 | 244.8 | 258.0 | 215.2 |
| 85 | 104.6 | 60.4 | 41.1 | 40.4 | 86.5 | 126.6 | 148.4 | 186.6 | 192.9 | 215.3 | 230.0 | 209.7 |
| 90 | 87.7 | 45.7 | 33.6 | 37.4 | 76.6 | 120.8 | 141.5 | 181.0 | 186.8 | 201.8 | 221.8 | 200.3 |
| 95 | 71.4 | 37.3 | 23.5 | 30.2 | 55.9 | 104.9 | 126.2 | 173.2 | 168.6 | 182.3 | 197.8 | 174.8 |
| 99 | 64.9 | 33.8 | 19.1 | 1.2 | 45.5 | 74.6 | 93.2 | 112.9 | 130.1 | 143.6 | 155.5 | 131.3 |
| 99.9 | 60.6 | 33.2 | 18.7 | 0.8 | 45.2 | 74.6 | 93.2 | 112.9 | 130.1 | 143.6 | 155.5 | 123.7 |

Nile Coarse EFlow determinations flow duration (time series) summary flows in monthly average m$^3$/s.: **RR5 - CLASS C FLOWS**. Colour conditional formatting highlights high (RED) to low (GREEN) values, and does not represent the suitability of the flows.

| %tile | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.1 | 93.7 | 58.2 | 39.0 | 43.0 | 44.9 | 61.0 | 102.6 | 130.6 | 157.0 | 147.3 | 155.1 | 137.8 |
| 1 | 93.7 | 58.2 | 39.0 | 43.0 | 44.9 | 61.0 | 102.6 | 130.6 | 157.0 | 147.3 | 155.1 | 137.8 |
| 5 | 93.7 | 58.2 | 39.0 | 43.0 | 44.9 | 61.0 | 102.6 | 130.6 | 157.0 | 147.3 | 155.1 | 137.8 |
| 10 | 93.7 | 58.2 | 39.0 | 43.0 | 44.9 | 61.0 | 102.4 | 129.4 | 155.6 | 147.3 | 155.1 | 137.8 |
| 15 | 93.7 | 58.2 | 39.0 | 43.0 | 44.9 | 61.0 | 100.6 | 127.9 | 152.9 | 147.3 | 155.1 | 137.8 |
| 20 | 93.7 | 58.2 | 39.0 | 43.0 | 44.9 | 61.0 | 99.3 | 125.8 | 148.9 | 147.3 | 155.1 | 137.8 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 30 | 93.2 | 57.9 | 38.8 | 42.9 | 44.8 | 60.9 | 95.5 | 120.9 | 142.1 | 146.4 | 154.1 | 136.6 |
| 40 | 91.8 | 57.1 | 38.3 | 42.7 | 44.7 | 60.8 | 93.4 | 116.9 | 135.2 | 144.7 | 152.1 | 134.3 |
| 50 | 88.9 | 55.6 | 37.6 | 42.3 | 44.6 | 60.5 | 90.3 | 112.8 | 128.7 | 141.0 | 148.6 | 129.6 |
| 60 | 83.7 | 52.9 | 35.8 | 41.8 | 44.3 | 60.2 | 84.7 | 104.2 | 116.5 | 133.8 | 141.0 | 118.1 |
| 70 | 75.6 | 48.0 | 33.3 | 40.8 | 43.7 | 59.4 | 79.3 | 97.5 | 104.9 | 119.2 | 128.9 | 104.4 |
| 80 | 63.1 | 41.7 | 27.3 | 38.4 | 42.4 | 57.3 | 68.5 | 85.3 | 92.4 | 100.1 | 109.1 | 99.4 |
| 85 | 57.1 | 38.7 | 24.6 | 35.5 | 41.1 | 56.0 | 65.7 | 83.3 | 87.9 | 97.6 | 105.8 | 96.7 |
| 90 | 52.7 | 35.7 | 22.1 | 32.6 | 38.8 | 53.3 | 63.3 | 82.5 | 84.8 | 92.0 | 101.5 | 92.2 |
| 95 | 48.5 | 34.0 | 19.8 | 23.6 | 34.2 | 45.8 | 55.9 | 78.5 | 75.5 | 82.0 | 89.0 | 79.7 |
| 99 | 47.2 | 33.3 | 18.8 | 1.0 | 22.0 | 30.7 | 38.8 | 46.8 | 53.9 | 59.3 | 64.3 | 58.2 |
| 99.9 | 47.2 | 33.2 | 18.7 | 0.8 | 22.0 | 30.7 | 38.8 | 46.8 | 53.9 | 59.3 | 64.3 | 58.2 |

Nile Coarse EFlow determinations flow duration (time series) summary flows in monthly average m$^3$/s.: **RR5 - CLASS D FLOWS**. Colour conditional formatting highlights high (RED) to low (GREEN) values, and does not represent the suitability of the flows.

| %tile | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.1 | 45.0 | 27.1 | 17.6 | 18.5 | 19.6 | 27.4 | 49.4 | 63.9 | 85.0 | 82.2 | 86.5 | 76.5 |
| 1 | 45.0 | 27.1 | 17.6 | 18.5 | 19.6 | 27.4 | 49.4 | 63.9 | 85.0 | 82.2 | 86.5 | 76.5 |
| 5 | 45.0 | 27.1 | 17.6 | 18.5 | 19.6 | 27.4 | 49.4 | 63.9 | 85.0 | 82.2 | 86.5 | 76.5 |
| 10 | 45.0 | 27.0 | 17.5 | 18.5 | 19.6 | 27.4 | 49.3 | 63.2 | 84.2 | 82.2 | 86.5 | 76.5 |
| 15 | 45.0 | 26.9 | 17.5 | 18.5 | 19.6 | 27.4 | 48.3 | 62.4 | 82.7 | 82.2 | 86.5 | 76.5 |
| 20 | 45.0 | 26.8 | 17.4 | 18.5 | 19.6 | 27.4 | 47.6 | 61.3 | 80.6 | 82.1 | 86.5 | 76.5 |
| 30 | 44.9 | 26.7 | 17.3 | 18.5 | 19.6 | 27.4 | 45.7 | 58.8 | 77.0 | 81.8 | 86.1 | 76.1 |
| 40 | 44.6 | 26.5 | 17.2 | 18.4 | 19.6 | 27.4 | 44.7 | 56.9 | 73.6 | 81.1 | 85.2 | 75.1 |
| 50 | 44.1 | 26.4 | 17.2 | 18.3 | 19.6 | 27.4 | 43.5 | 55.1 | 70.5 | 79.5 | 83.8 | 73.2 |
| 60 | 43.0 | 26.4 | 17.2 | 18.0 | 19.5 | 27.3 | 41.1 | 51.3 | 64.9 | 76.4 | 80.6 | 68.5 |
| 70 | 41.4 | 26.4 | 17.1 | 17.6 | 19.5 | 27.2 | 39.7 | 49.5 | 60.4 | 70.2 | 75.5 | 62.9 |
| 80 | 38.9 | 26.3 | 17.1 | 16.6 | 19.3 | 27.0 | 36.5 | 45.6 | 53.8 | 61.6 | 65.5 | 55.6 |
| 85 | 37.7 | 26.3 | 17.1 | 15.4 | 19.2 | 26.8 | 34.7 | 43.1 | 50.0 | 56.7 | 60.4 | 54.8 |
| 90 | 36.9 | 26.3 | 17.1 | 14.2 | 18.9 | 26.4 | 33.3 | 40.7 | 49.0 | 53.5 | 58.8 | 53.5 |
| 95 | 36.0 | 26.3 | 17.1 | 10.4 | 18.3 | 25.5 | 30.9 | 38.6 | 46.3 | 50.5 | 55.1 | 49.8 |
| 99 | 35.8 | 26.3 | 17.1 | 0.9 | 16.8 | 23.6 | 29.4 | 35.3 | 40.7 | 44.7 | 48.5 | 44.1 |
| 99.9 | 35.8 | 26.3 | 17.1 | 0.8 | 16.8 | 23.6 | 29.4 | 35.3 | 40.7 | 44.7 | 48.5 | 44.1 |

Nile Coarse EFlow determinations flow duration (time series) summary flows in monthly average m$^3$/s.: **RR6 - Reference (CLASS A) FLOWS**. Colour conditional formatting highlights high (RED) to low (GREEN) values, and does not represent the suitability of the flows.

| %tile | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.1 | 2142.7 | 1838.8 | 1502.1 | 1249.6 | 1066 | 1049.9 | 1251.8 | 1546.5 | 1989.5 | 2250.2 | 2369.7 | 2371.6 |
| 1 | 1862.6 | 1621.6 | 1327 | 1128.3 | 1001.2 | 1042.7 | 1222.5 | 1499.7 | 1804.8 | 2034.8 | 2134.4 | 2123.7 |
| 5 | 1403.1 | 1223.7 | 896.5 | 784.5 | 871.5 | 1007.7 | 1164.7 | 1319.3 | 1497.7 | 1626.1 | 1685.5 | 1665.3 |
| 10 | 1378 | 1140.9 | 857.7 | 750.3 | 792.2 | 973.8 | 1123.6 | 1236.5 | 1347.9 | 1487.9 | 1521.2 | 1524.6 |
| 15 | 1332.8 | 1034 | 840.8 | 737.3 | 777 | 932.3 | 1099.7 | 1211.4 | 1330.4 | 1441.9 | 1461.3 | 1440.2 |
| 20 | 1286.2 | 1025.9 | 823.3 | 723.8 | 763.8 | 927.5 | 1080.7 | 1205.4 | 1317.1 | 1411.1 | 1431.7 | 1419.8 |
| 30 | 1232.5 | 944.8 | 789.4 | 706.6 | 728.9 | 905.2 | 1064.2 | 1173.2 | 1279.7 | 1347.9 | 1380.7 | 1371.7 |
| 40 | 1113.4 | 896.3 | 722.8 | 676.4 | 706.9 | 866.9 | 1025.3 | 1155.7 | 1260.5 | 1311.4 | 1325 | 1311.6 |
| 50 | 1022.8 | 872.6 | 687.6 | 652.4 | 672.6 | 829.7 | 998.7 | 1142.8 | 1229.4 | 1286.9 | 1301.5 | 1241.6 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 60 | 957.3 | 758 | 663.6 | 623.8 | 655.7 | 800.5 | 987.5 | 1114.6 | 1210.5 | 1258.5 | 1287.1 | 1187.1 |
| 70 | 884.5 | 726.3 | 637.9 | 596.6 | 639 | 789.8 | 952.6 | 1092.4 | 1188.3 | 1244.1 | 1246.3 | 1146.4 |
| 80 | 790.6 | 675.5 | 623.6 | 584.6 | 596.4 | 743.3 | 904.5 | 1060.3 | 1153.4 | 1194.8 | 1191.2 | 1088.2 |
| 85 | 768.1 | 664.7 | 609 | 580 | 591 | 731.6 | 887.4 | 1018.6 | 1113 | 1163.5 | 1171.2 | 1058.7 |
| 90 | 731.8 | 636.5 | 592.6 | 571.2 | 575.5 | 713.1 | 874.1 | 996.1 | 1083.4 | 1126.9 | 1144.3 | 980.3 |
| 95 | 672.6 | 611.5 | 580.7 | 551.2 | 567.5 | 677.8 | 844.5 | 976.3 | 1056.2 | 1096.4 | 1101.9 | 922.9 |
| 99 | 633.7 | 580.2 | 546.9 | 533.9 | 541 | 651.1 | 768.5 | 953.9 | 1025 | 1040.9 | 1016.3 | 752.7 |
| 99.9 | 626.9 | 569.9 | 546.9 | 532.1 | 536.4 | 645.1 | 738.1 | 940.4 | 1021.9 | 1026.7 | 985.4 | 749.2 |

Nile Coarse EFlow determinations flow duration (time series) summary flows in monthly average m$^3$/s.: **RR6 - CLASS B FLOWS**. Colour conditional formatting highlights high (RED) to low (GREEN) values, and does not represent the suitability of the flows.

| %tile | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.1 | 769.5 | 605.3 | 545.0 | 540.2 | 587.2 | 652.5 | 836.9 | 976.8 | 1186.7 | 1290.1 | 1301.7 | 1296.4 |
| 1 | 769.5 | 605.3 | 545.0 | 540.2 | 587.2 | 652.5 | 836.9 | 976.8 | 1186.7 | 1182.2 | 1188.9 | 1144.2 |
| 5 | 769.5 | 605.3 | 545.0 | 540.2 | 587.2 | 652.5 | 836.9 | 976.8 | 1186.7 | 1023.4 | 1022.7 | 920.0 |
| 10 | 769.5 | 605.3 | 545.0 | 540.2 | 587.2 | 652.5 | 833.7 | 962.6 | 1152.0 | 1023.4 | 1022.7 | 920.0 |
| 15 | 769.5 | 605.3 | 545.0 | 540.2 | 587.2 | 652.5 | 820.1 | 950.6 | 1145.7 | 1023.4 | 1022.7 | 920.0 |
| 20 | 769.3 | 605.2 | 544.6 | 540.2 | 587.1 | 652.4 | 803.7 | 929.8 | 1109.8 | 1023.4 | 1022.7 | 920.0 |
| 30 | 763.8 | 600.5 | 543.0 | 538.1 | 583.2 | 650.3 | 780.1 | 894.2 | 1044.2 | 1018.2 | 1017.5 | 912.5 |
| 40 | 753.9 | 595.3 | 538.5 | 532.9 | 579.0 | 646.2 | 755.8 | 861.3 | 983.4 | 1005.2 | 1002.9 | 899.1 |
| 50 | 729.6 | 580.3 | 529.0 | 524.3 | 567.2 | 636.5 | 714.3 | 820.2 | 909.1 | 968.8 | 969.4 | 863.3 |
| 60 | 668.1 | 548.2 | 509.7 | 500.4 | 545.5 | 622.5 | 675.7 | 749.0 | 809.5 | 924.6 | 917.6 | 796.8 |
| 70 | 606.0 | 508.2 | 481.2 | 474.4 | 505.5 | 590.1 | 642.2 | 714.8 | 751.7 | 835.6 | 842.1 | 704.9 |
| 80 | 498.2 | 442.5 | 430.1 | 425.6 | 444.8 | 527.7 | 574.9 | 620.0 | 636.7 | 700.0 | 682.7 | 582.7 |
| 85 | 458.8 | 422.8 | 395.1 | 389.1 | 410.3 | 492.3 | 512.6 | 582.2 | 563.3 | 593.3 | 616.7 | 568.1 |
| 90 | 429.3 | 405.3 | 377.9 | 370.0 | 380.4 | 454.9 | 477.6 | 567.0 | 551.9 | 548.7 | 575.8 | 550.2 |
| 95 | 402.5 | 385.8 | 354.0 | 347.0 | 346.7 | 397.9 | 410.9 | 551.2 | 508.5 | 507.2 | 525.4 | 510.0 |
| 99 | 390.3 | 379.9 | 339.1 | 333.6 | 332.0 | 363.3 | 380.1 | 456.6 | 425.7 | 443.0 | 461.6 | 418.7 |
| 99.9 | 388.2 | 378.2 | 339.1 | 332.3 | 329.7 | 355.3 | 368.6 | 394.9 | 417.3 | 427.0 | 439.5 | 416.8 |

Nile Coarse EFlow determinations flow duration (time series) summary flows in monthly average m$^3$/s.: **RR6 - CLASS C FLOWS**. Colour conditional formatting highlights high (RED) to low (GREEN) values, and does not represent the suitability of the flows.

| %tile | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.1 | 548.7 | 472.6 | 434.5 | 428.1 | 466.3 | 531.6 | 664.1 | 779.4 | 945.5 | 1285.3 | 1297.5 | 1292.8 |
| 1 | 548.7 | 472.6 | 434.5 | 428.1 | 466.3 | 531.6 | 664.1 | 779.4 | 945.5 | 1133.7 | 1146.0 | 1108.4 |
| 5 | 548.7 | 472.6 | 434.5 | 428.1 | 466.3 | 531.6 | 664.1 | 779.4 | 945.5 | 910.4 | 922.9 | 836.7 |
| 10 | 548.7 | 472.6 | 434.5 | 428.1 | 466.3 | 531.6 | 662.6 | 771.4 | 926.0 | 910.4 | 922.9 | 836.7 |
| 15 | 548.7 | 472.6 | 434.5 | 428.1 | 466.3 | 531.6 | 656.3 | 764.6 | 922.5 | 910.4 | 922.9 | 836.7 |
| 20 | 548.6 | 472.5 | 434.2 | 428.1 | 466.2 | 531.5 | 648.5 | 752.7 | 902.2 | 910.4 | 922.9 | 836.7 |
| 30 | 545.0 | 468.9 | 432.9 | 426.5 | 463.1 | 529.7 | 636.4 | 731.5 | 863.5 | 905.4 | 917.7 | 829.1 |
| 40 | 538.6 | 464.9 | 429.2 | 422.4 | 459.6 | 526.2 | 622.9 | 711.0 | 825.0 | 892.7 | 903.1 | 815.5 |
| 50 | 522.8 | 453.4 | 421.5 | 415.5 | 450.1 | 517.9 | 596.6 | 683.2 | 772.4 | 857.2 | 869.7 | 778.9 |
| 60 | 482.7 | 428.8 | 405.9 | 396.4 | 432.6 | 506.0 | 570.8 | 632.4 | 696.6 | 814.2 | 817.9 | 711.1 |
| 70 | 442.3 | 398.2 | 382.8 | 375.7 | 400.4 | 478.4 | 539.8 | 601.1 | 641.7 | 727.5 | 742.5 | 619.9 |
| 80 | 372.1 | 347.8 | 341.4 | 336.7 | 351.4 | 425.1 | 477.5 | 543.9 | 584.9 | 595.9 | 601.6 | 583.7 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 85 | 346.4 | 332.7 | 313.1 | 307.6 | 323.5 | 394.9 | 419.8 | 541.2 | 557.0 | 557.4 | 583.5 | 567.0 |
| 90 | 327.2 | 319.3 | 299.1 | 292.4 | 299.3 | 363.0 | 387.4 | 536.9 | 541.4 | 538.9 | 562.3 | 541.4 |
| 95 | 309.7 | 304.3 | 279.8 | 274.1 | 272.1 | 314.3 | 325.6 | 521.0 | 480.0 | 480.4 | 497.6 | 483.6 |
| 99 | 301.8 | 299.8 | 267.7 | 263.3 | 260.2 | 284.8 | 297.1 | 393.9 | 338.4 | 361.4 | 383.1 | 326.6 |
| 99.9 | 300.4 | 298.5 | 267.7 | 262.3 | 258.4 | 278.0 | 286.4 | 310.9 | 324.0 | 331.2 | 342.6 | 323.4 |

Nile Coarse EFlow determinations flow duration (time series) summary flows in monthly average m$^3$/s.: **RR6 - CLASS D FLOWS**. Colour conditional formatting highlights high (RED) to low (GREEN) values, and does not represent the suitability of the flows.

| %tile | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.1 | 441.5 | 376.2 | 363.4 | 355.8 | 449.1 | 552.1 | 642.8 | 751.6 | 858.2 | 865.6 | 879.8 | 804.0 |
| 1 | 441.5 | 376.2 | 363.4 | 355.8 | 449.1 | 552.1 | 642.8 | 751.6 | 858.2 | 865.6 | 879.8 | 804.0 |
| 5 | 441.5 | 376.2 | 363.4 | 355.8 | 449.1 | 552.1 | 642.8 | 751.6 | 858.2 | 865.6 | 879.8 | 804.0 |
| 10 | 441.5 | 376.2 | 363.4 | 355.8 | 449.1 | 552.1 | 641.9 | 745.9 | 843.9 | 865.6 | 879.8 | 804.0 |
| 15 | 441.5 | 376.2 | 363.4 | 355.8 | 449.1 | 552.1 | 634.4 | 741.3 | 841.4 | 865.6 | 879.8 | 804.0 |
| 20 | 441.4 | 376.1 | 363.2 | 355.8 | 449.0 | 551.8 | 627.6 | 728.3 | 826.5 | 865.5 | 879.3 | 803.5 |
| 30 | 439.3 | 374.5 | 362.3 | 354.8 | 446.4 | 549.2 | 616.3 | 711.0 | 788.7 | 858.9 | 874.6 | 794.1 |
| 40 | 435.5 | 372.6 | 360.2 | 352.7 | 443.5 | 545.4 | 607.7 | 698.5 | 760.1 | 846.4 | 852.8 | 781.5 |
| 50 | 425.2 | 366.5 | 355.5 | 348.1 | 432.0 | 534.8 | 574.3 | 671.0 | 710.1 | 803.9 | 818.1 | 743.0 |
| 60 | 397.5 | 351.5 | 343.9 | 338.1 | 415.7 | 522.9 | 558.4 | 626.7 | 650.9 | 770.3 | 772.4 | 673.8 |
| 70 | 369.0 | 333.9 | 328.7 | 323.8 | 378.8 | 486.1 | 522.2 | 593.5 | 604.2 | 679.7 | 704.9 | 600.2 |
| 80 | 325.9 | 307.2 | 301.3 | 300.5 | 335.1 | 426.7 | 462.5 | 573.8 | 581.9 | 582.3 | 596.1 | 582.2 |
| 85 | 312.0 | 301.1 | 282.3 | 286.7 | 308.6 | 395.8 | 401.2 | 571.1 | 549.5 | 552.5 | 580.6 | 564.9 |
| 90 | 300.7 | 293.7 | 274.4 | 269.7 | 284.2 | 358.0 | 372.8 | 565.8 | 536.7 | 535.8 | 558.1 | 538.4 |
| 95 | 289.4 | 286.1 | 261.5 | 264.6 | 258.1 | 303.0 | 310.7 | 546.6 | 471.1 | 472.0 | 489.1 | 474.9 |
| 99 | 284.8 | 283.7 | 254.1 | 249.5 | 247.0 | 271.5 | 281.9 | 392.4 | 319.6 | 342.9 | 365.0 | 307.3 |
| 99.9 | 283.9 | 283.1 | 254.1 | 248.9 | 245.3 | 264.0 | 271.3 | 294.9 | 304.4 | 310.4 | 321.6 | 303.9 |

Nile Coarse EFlow determinations flow duration (time series) summary flows in monthly average m$^3$/s.: **RR7 - Reference (CLASS A) FLOWS**. Colour conditional formatting highlights high (RED) to low (GREEN) values, and does not represent the suitability of the flows.

| %tile | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.1 | 444.7 | 332.9 | 300 | 357.9 | 1021 | 1706.9 | 4253.4 | 9290.4 | 6875.7 | 5192.4 | 1657.2 | 854.8 |
| 1 | 443.8 | 307.2 | 288.7 | 318.6 | 771.1 | 1640.2 | 4105.5 | 8314.1 | 6500.4 | 4481.2 | 1589.7 | 832.6 |
| 5 | 412.7 | 294.6 | 255.2 | 268.1 | 497.7 | 1310.9 | 3768.1 | 7125 | 6250.8 | 4009.5 | 1501.5 | 737.4 |
| 10 | 395.9 | 259.3 | 225.5 | 225.3 | 407 | 1063.3 | 3587.3 | 7038.1 | 5882.7 | 3669.1 | 1365.8 | 699.9 |
| 15 | 353.3 | 245.2 | 183.3 | 199.1 | 351.1 | 987.4 | 3337.8 | 6752.8 | 5742.7 | 3331.5 | 1300.1 | 633.1 |
| 20 | 346.8 | 223.6 | 171.6 | 187.9 | 315 | 877.4 | 3274.5 | 6591.7 | 5432.2 | 2960.3 | 1246.4 | 610.3 |
| 30 | 333.4 | 207.2 | 156 | 159.9 | 278.6 | 767.4 | 3090.1 | 6408.8 | 5295.5 | 2665.4 | 1124.2 | 577.3 |
| 40 | 298.5 | 196.9 | 143.6 | 138.5 | 251 | 695.1 | 2800.2 | 6147.4 | 4948.3 | 2500.1 | 1007.7 | 533.5 |
| 50 | 285.1 | 184.9 | 134.9 | 119.6 | 212.1 | 655.1 | 2628.8 | 5724.3 | 4672.1 | 2229.6 | 944.4 | 497.3 |
| 60 | 263.9 | 174.4 | 127.5 | 108.3 | 185.1 | 607.1 | 2382.3 | 5620.7 | 4450.6 | 2135 | 880.6 | 469.9 |
| 70 | 254.1 | 166 | 120.8 | 96.1 | 163.5 | 557.6 | 2256.5 | 5396.3 | 4182.9 | 1951.2 | 838.5 | 435.1 |
| 80 | 230.3 | 149.9 | 105.4 | 92.9 | 141.8 | 524.3 | 2049.9 | 4813.1 | 3875.8 | 1762.8 | 728.8 | 388.5 |
| 85 | 219 | 140.8 | 100.3 | 85.9 | 130.4 | 468.2 | 1903.6 | 4705.1 | 3635 | 1680.2 | 703.4 | 375 |
| 90 | 209.2 | 129.4 | 96.1 | 81.6 | 114.4 | 431.8 | 1796.8 | 4577.1 | 3447.5 | 1545.3 | 666.7 | 363.4 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 95 | 192 | 125.7 | 87.2 | 70.9 | 103.2 | 401.4 | 1670.3 | 4315.6 | 3115.9 | 1427.5 | 637 | 337 |
| 99 | 174 | 110.2 | 65.7 | 49 | 82.1 | 331.9 | 1496 | 3608 | 2667.2 | 1185.3 | 526 | 272 |
| 99.9 | 125.1 | 83.7 | 57.2 | 48.3 | 74.9 | 312.3 | 1474.9 | 3294.9 | 2631.3 | 950.6 | 387.7 | 218.6 |

Nile Coarse EFlow determinations flow duration (time series) summary flows in monthly average m$^3$/s.: **RR7 - CLASS B FLOWS**. Colour conditional formatting highlights high (RED) to low (GREEN) values, and does not represent the suitability of the flows.

| %tile | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.1 | 411.9 | 310.0 | 237.6 | 221.4 | 237.1 | 416.8 | 1331.1 | 2425.3 | 2263.8 | 1213.7 | 703.8 | 474.9 |
| 1 | 411.9 | 305.6 | 237.6 | 221.4 | 237.1 | 416.8 | 1331.1 | 2425.3 | 2263.8 | 1213.7 | 703.8 | 474.9 |
| 5 | 411.9 | 295.3 | 237.6 | 221.4 | 237.1 | 416.8 | 1331.1 | 2425.3 | 2263.8 | 1213.7 | 703.8 | 474.9 |
| 10 | 396.7 | 255.2 | 222.4 | 216.2 | 237.1 | 416.8 | 1329.5 | 2423.8 | 2240.6 | 1213.7 | 703.8 | 474.9 |
| 15 | 356.5 | 243.1 | 182.7 | 196.7 | 237.1 | 416.8 | 1296.1 | 2374.6 | 2198.0 | 1213.7 | 703.8 | 474.9 |
| 20 | 346.0 | 220.8 | 170.9 | 185.8 | 237.0 | 416.6 | 1272.1 | 2327.4 | 2129.7 | 1213.5 | 703.6 | 474.8 |
| 30 | 332.2 | 206.5 | 154.9 | 159.4 | 235.5 | 414.8 | 1217.0 | 2235.3 | 2023.1 | 1204.5 | 699.6 | 471.5 |
| 40 | 298.1 | 196.8 | 143.1 | 138.3 | 231.6 | 411.2 | 1167.5 | 2151.8 | 1918.5 | 1189.4 | 687.3 | 463.9 |
| 50 | 285.2 | 184.8 | 134.8 | 119.6 | 210.6 | 401.9 | 1103.4 | 2061.3 | 1815.1 | 1149.0 | 661.9 | 446.2 |
| 60 | 264.0 | 174.5 | 126.9 | 108.6 | 183.6 | 386.5 | 1011.5 | 1882.9 | 1617.8 | 1076.6 | 628.1 | 406.7 |
| 70 | 254.6 | 166.4 | 120.5 | 96.3 | 162.0 | 361.1 | 934.3 | 1753.2 | 1437.9 | 966.4 | 559.8 | 350.3 |
| 80 | 217.7 | 149.4 | 105.3 | 93.0 | 140.2 | 302.8 | 794.7 | 1465.5 | 1158.5 | 765.0 | 447.3 | 281.6 |
| 85 | 182.2 | 128.8 | 100.0 | 85.6 | 126.6 | 273.4 | 704.1 | 1332.8 | 1010.1 | 662.7 | 400.4 | 255.1 |
| 90 | 153.4 | 106.5 | 90.9 | 80.7 | 105.0 | 232.2 | 599.5 | 1136.9 | 862.5 | 561.8 | 342.1 | 227.1 |
| 95 | 130.4 | 88.3 | 67.3 | 59.2 | 84.3 | 177.1 | 447.8 | 858.0 | 696.1 | 458.6 | 285.3 | 204.8 |
| 99 | 121.5 | 82.0 | 57.4 | 48.9 | 74.9 | 143.9 | 367.9 | 723.4 | 637.9 | 412.7 | 260.4 | 196.6 |
| 99.9 | 120.0 | 80.8 | 56.5 | 48.3 | 74.0 | 143.9 | 367.9 | 723.4 | 637.9 | 412.7 | 260.4 | 196.6 |

Nile Coarse EFlow determinations flow duration (time series) summary flows in monthly average m$^3$/s.: **RR7 - CLASS C FLOWS**. Colour conditional formatting highlights high (RED) to low (GREEN) values, and does not represent the suitability of the flows.

| %tile | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.1 | 205.6 | 150.0 | 112.5 | 103.4 | 112.3 | 189.6 | 566.0 | 1063.2 | 973.3 | 544.1 | 332.2 | 239.1 |
| 1 | 205.6 | 150.0 | 112.5 | 103.4 | 112.3 | 189.6 | 566.0 | 1063.2 | 973.3 | 544.1 | 332.2 | 239.1 |
| 5 | 205.6 | 150.0 | 112.5 | 103.4 | 112.3 | 189.6 | 566.0 | 1063.2 | 973.3 | 544.1 | 332.2 | 239.1 |
| 10 | 205.6 | 150.0 | 112.5 | 103.4 | 112.3 | 189.6 | 565.5 | 1062.8 | 966.4 | 544.1 | 332.2 | 239.1 |
| 15 | 205.6 | 150.0 | 112.5 | 103.4 | 112.3 | 189.6 | 555.5 | 1048.0 | 953.6 | 544.1 | 332.2 | 239.1 |
| 20 | 205.5 | 149.9 | 112.4 | 103.3 | 112.2 | 189.6 | 548.3 | 1033.9 | 933.1 | 544.1 | 332.2 | 239.1 |
| 30 | 204.4 | 148.9 | 111.9 | 102.8 | 111.8 | 189.0 | 531.8 | 1006.2 | 901.1 | 541.4 | 331.0 | 238.1 |
| 40 | 201.4 | 147.0 | 110.8 | 101.7 | 110.8 | 188.0 | 516.9 | 981.1 | 869.6 | 537.0 | 327.4 | 235.8 |
| 50 | 196.8 | 142.3 | 108.5 | 98.2 | 108.9 | 185.3 | 497.6 | 953.7 | 838.4 | 525.3 | 319.8 | 230.5 |
| 60 | 185.9 | 134.4 | 103.1 | 94.3 | 105.0 | 180.8 | 470.0 | 899.9 | 778.8 | 504.2 | 309.8 | 218.7 |
| 70 | 169.5 | 120.9 | 94.9 | 85.9 | 97.9 | 173.5 | 446.6 | 860.4 | 724.0 | 472.1 | 289.7 | 201.8 |
| 80 | 148.6 | 103.2 | 82.4 | 73.8 | 87.7 | 156.6 | 404.4 | 772.7 | 639.0 | 413.4 | 256.4 | 181.2 |
| 85 | 138.2 | 95.2 | 74.5 | 66.1 | 82.7 | 148.1 | 377.0 | 732.3 | 593.9 | 383.6 | 242.5 | 173.3 |
| 90 | 129.7 | 88.5 | 67.1 | 59.6 | 76.9 | 136.2 | 345.4 | 672.6 | 549.0 | 354.3 | 225.3 | 164.9 |
| 95 | 122.9 | 83.0 | 59.8 | 51.7 | 71.3 | 120.3 | 299.6 | 587.6 | 498.4 | 324.2 | 208.5 | 158.3 |
| 99 | 120.3 | 81.1 | 56.7 | 48.5 | 68.8 | 110.7 | 275.4 | 546.6 | 480.7 | 310.9 | 201.1 | 155.8 |
| 99.9 | 119.9 | 80.8 | 56.4 | 48.3 | 68.8 | 110.7 | 275.4 | 546.6 | 480.7 | 310.9 | 201.1 | 155.8 |

Nile Coarse EFlow determinations flow duration (time series) summary flows in monthly average m$^3$/s.: **RR7 - CLASS D FLOWS**. Colour conditional formatting highlights high (RED) to low (GREEN) values, and does not represent the suitability of the flows.

| %tile | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.1 | 154.5 | 109.3 | 92.5 | 83.8 | 92.3 | 142.8 | 374.8 | 703.2 | 648.6 | 346.2 | 201.1 | 139.6 |
| 1 | 154.5 | 109.3 | 92.5 | 83.8 | 92.3 | 142.8 | 374.8 | 703.2 | 648.6 | 346.2 | 201.1 | 139.6 |
| 5 | 154.5 | 109.3 | 92.5 | 83.8 | 92.3 | 142.8 | 374.8 | 703.2 | 648.6 | 346.2 | 201.1 | 139.6 |
| 10 | 154.5 | 109.3 | 92.5 | 83.8 | 92.3 | 142.8 | 374.4 | 702.9 | 642.9 | 346.2 | 201.1 | 139.6 |
| 15 | 154.5 | 109.3 | 92.5 | 83.8 | 92.3 | 142.8 | 366.2 | 690.7 | 632.4 | 346.2 | 201.1 | 139.6 |
| 20 | 154.4 | 109.2 | 92.5 | 83.8 | 92.2 | 142.8 | 360.3 | 679.2 | 615.7 | 346.2 | 201.1 | 139.6 |
| 30 | 153.8 | 108.7 | 92.1 | 83.4 | 91.9 | 142.4 | 347.3 | 657.5 | 590.7 | 345.0 | 200.7 | 139.4 |
| 40 | 152.1 | 107.7 | 91.4 | 82.7 | 91.0 | 141.7 | 336.2 | 638.9 | 568.0 | 343.1 | 199.5 | 138.9 |
| 50 | 149.4 | 105.3 | 89.8 | 80.4 | 89.4 | 139.8 | 323.0 | 620.6 | 547.9 | 338.1 | 197.1 | 137.9 |
| 60 | 143.1 | 101.3 | 86.1 | 77.9 | 86.0 | 136.7 | 304.4 | 585.0 | 510.7 | 329.0 | 193.9 | 135.5 |
| 70 | 133.6 | 94.5 | 80.6 | 72.6 | 79.8 | 131.5 | 294.0 | 567.9 | 486.7 | 315.2 | 187.3 | 132.1 |
| 80 | 121.4 | 85.5 | 72.1 | 64.7 | 70.9 | 119.7 | 275.2 | 530.0 | 449.5 | 289.9 | 176.6 | 128.1 |
| 85 | 115.4 | 81.5 | 66.7 | 59.7 | 66.5 | 113.8 | 263.0 | 512.5 | 429.7 | 277.1 | 172.1 | 126.5 |
| 90 | 110.5 | 78.1 | 61.7 | 55.6 | 61.5 | 105.4 | 249.0 | 486.7 | 410.0 | 264.5 | 166.5 | 124.8 |
| 95 | 106.6 | 75.3 | 56.7 | 50.5 | 56.7 | 94.2 | 228.5 | 449.9 | 387.8 | 251.5 | 161.1 | 123.5 |
| 99 | 105.1 | 74.3 | 54.7 | 48.4 | 54.5 | 87.5 | 217.8 | 432.2 | 380.1 | 245.8 | 158.7 | 123.0 |
| 99.9 | 105.1 | 74.3 | 54.7 | 48.2 | 54.5 | 87.5 | 217.8 | 432.2 | 380.1 | 245.8 | 158.7 | 123.0 |

Nile Coarse EFlow determinations flow duration (time series) summary flows in monthly average m$^3$/s.: **RR8 - Reference (CLASS A) FLOWS**. Colour conditional formatting highlights high (RED) to low (GREEN) values, and does not represent the suitability of the flows.

| %tile | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.1 | 48.9 | 33.8 | 75.8 | 82 | 174.9 | 361 | 2398.5 | 4541.1 | 3393 | 782.3 | 221.3 | 82.8 |
| 1 | 48.2 | 32.4 | 55.9 | 73.2 | 138 | 352.2 | 2331.4 | 4200.2 | 2474.9 | 631.7 | 160.8 | 81.4 |
| 5 | 35 | 24.9 | 36 | 51 | 91 | 256 | 1904.3 | 3667.7 | 1743.1 | 483.2 | 134.1 | 67.2 |
| 10 | 34 | 24 | 34.8 | 48.8 | 88.6 | 251.6 | 1723.6 | 3175.6 | 1567.4 | 376.8 | 111.8 | 58.8 |
| 15 | 31 | 21.7 | 31 | 43.1 | 76.5 | 225.1 | 1564.7 | 2949.6 | 1436.4 | 359.1 | 105.1 | 53.4 |
| 20 | 30.2 | 19.6 | 29 | 39.6 | 68 | 207.2 | 1504.6 | 2861.2 | 1297.8 | 320 | 101.6 | 49.2 |
| 30 | 23.4 | 17 | 23 | 32 | 56.8 | 180.4 | 1187.4 | 2467.8 | 1164.4 | 260.2 | 82.4 | 40 |
| 40 | 21.2 | 15 | 22 | 28.2 | 51.2 | 158.4 | 1091.2 | 2123.4 | 1014 | 228.6 | 70.6 | 36 |
| 50 | 19 | 13 | 19 | 26 | 46 | 138 | 972 | 1898 | 858 | 192 | 63 | 32 |
| 60 | 16 | 10.8 | 15.8 | 22 | 40.8 | 124.2 | 860.6 | 1713.2 | 775.6 | 185.6 | 53.8 | 27 |
| 70 | 14.6 | 10 | 13.6 | 19 | 34 | 110.4 | 800.2 | 1571 | 728.6 | 171 | 46 | 24 |
| 80 | 12 | 8 | 8.4 | 13.2 | 21.2 | 92 | 684.4 | 1368.4 | 590 | 130.2 | 36 | 20 |
| 85 | 8.3 | 5.3 | 7 | 10 | 16.3 | 86.3 | 654.5 | 1229 | 546 | 114.4 | 31.3 | 14.9 |
| 90 | 6.2 | 4.2 | 6 | 8 | 14 | 60.2 | 506.4 | 1056.6 | 516.4 | 95.6 | 27.4 | 12.2 |
| 95 | 6 | 3 | 3.1 | 5.1 | 6.1 | 35.3 | 405.7 | 894.3 | 423.6 | 70.4 | 21.1 | 9.1 |
| 99 | 1.8 | 1.8 | 1.8 | 2.8 | 4.6 | 17.6 | 230 | 598.5 | 274.7 | 50.8 | 14.2 | 5.3 |
| 99.9 | 1.1 | 1.1 | 1.1 | 2.1 | 3.2 | 16.2 | 221.9 | 366.7 | 220.1 | 50.1 | 6.8 | 2.3 |

Nile Coarse EFlow determinations flow duration (time series) summary flows in monthly average m$^3$/s.: **RR8 – CLASS B FLOWS**. Colour conditional formatting highlights high (RED) to low (GREEN) values, and does not represent the suitability of the flows.

| %tile | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.1 | 18.2 | 14.2 | 13.8 | 15.2 | 17.7 | 32.0 | 432.2 | 928.0 | 482.4 | 104.5 | 50.3 | 31.0 |
| 1 | 18.2 | 14.2 | 13.8 | 15.2 | 17.7 | 32.0 | 432.2 | 928.0 | 482.4 | 104.5 | 50.3 | 31.0 |
| 5 | 18.2 | 14.2 | 13.8 | 15.2 | 17.7 | 32.0 | 432.2 | 928.0 | 482.4 | 104.5 | 50.3 | 31.0 |
| 10 | 18.2 | 14.2 | 13.8 | 15.2 | 17.7 | 32.0 | 430.5 | 924.8 | 473.0 | 104.5 | 50.3 | 31.0 |
| 15 | 18.2 | 14.2 | 13.8 | 15.2 | 17.7 | 32.0 | 413.6 | 872.4 | 460.6 | 104.5 | 50.3 | 31.0 |
| 20 | 18.2 | 14.2 | 13.7 | 15.2 | 17.7 | 31.9 | 402.5 | 854.2 | 436.1 | 104.5 | 50.3 | 30.9 |
| 30 | 18.0 | 14.0 | 13.6 | 15.0 | 17.6 | 31.8 | 376.9 | 802.8 | 406.2 | 103.9 | 49.9 | 30.6 |
| 40 | 17.5 | 13.9 | 13.5 | 14.8 | 17.3 | 31.6 | 353.1 | 749.5 | 374.8 | 102.3 | 48.5 | 29.8 |
| 50 | 16.4 | 12.8 | 12.8 | 14.2 | 16.6 | 31.0 | 330.2 | 698.4 | 344.0 | 99.1 | 47.2 | 28.0 |
| 60 | 14.4 | 9.8 | 11.8 | 13.1 | 15.4 | 29.9 | 285.8 | 599.7 | 290.2 | 92.7 | 42.7 | 24.5 |
| 70 | 10.3 | 9.8 | 9.6 | 11.1 | 13.2 | 27.7 | 261.8 | 548.6 | 252.2 | 81.3 | 35.6 | 17.0 |
| 80 | 9.0 | 7.0 | 7.0 | 8.1 | 9.8 | 24.8 | 218.5 | 455.9 | 194.8 | 66.2 | 26.7 | 11.7 |
| 85 | 4.8 | 3.7 | 5.2 | 6.2 | 7.8 | 21.8 | 186.2 | 388.0 | 160.0 | 53.3 | 20.5 | 8.1 |
| 90 | 3.0 | 2.3 | 3.5 | 4.4 | 5.7 | 20.0 | 147.0 | 304.6 | 124.9 | 42.7 | 14.4 | 5.1 |
| 95 | 3.0 | 1.3 | 1.9 | 2.8 | 3.9 | 13.6 | 102.7 | 210.5 | 94.6 | 33.6 | 9.0 | 2.9 |
| 99 | 1.2 | 0.9 | 1.2 | 2.0 | 3.1 | 11.0 | 73.9 | 149.4 | 80.0 | 29.1 | 6.4 | 2.0 |
| 99.9 | 1.1 | 0.8 | 1.1 | 1.9 | 3.0 | 11.0 | 73.9 | 149.4 | 80.0 | 29.1 | 6.2 | 1.9 |

Nile Coarse EFlow determinations flow duration (time series) summary flows in monthly average m$^3$/s.: **RR8 – CLASS C FLOWS**. Colour conditional formatting highlights high (RED) to low (GREEN) values, and does not represent the suitability of the flows.

| %tile | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.1 | 16.3 | 12.2 | 12.3 | 13.6 | 16.3 | 31.7 | 326.6 | 688.5 | 357.2 | 92.1 | 49.2 | 28.8 |
| 1 | 16.3 | 12.2 | 12.3 | 13.6 | 16.3 | 31.7 | 326.6 | 688.5 | 357.2 | 92.1 | 49.2 | 28.8 |
| 5 | 16.3 | 12.2 | 12.3 | 13.6 | 16.3 | 31.7 | 326.6 | 688.5 | 357.2 | 92.1 | 49.2 | 28.8 |
| 10 | 16.3 | 12.2 | 12.3 | 13.6 | 16.3 | 31.7 | 325.6 | 686.5 | 351.6 | 92.1 | 49.2 | 28.8 |
| 15 | 16.3 | 12.2 | 12.3 | 13.6 | 16.3 | 31.7 | 315.5 | 655.1 | 344.1 | 92.1 | 49.2 | 28.8 |
| 20 | 16.3 | 12.2 | 12.3 | 13.6 | 16.3 | 31.7 | 308.8 | 644.2 | 329.4 | 92.1 | 49.2 | 28.8 |
| 30 | 16.1 | 12.1 | 12.2 | 13.5 | 16.1 | 31.6 | 293.1 | 612.8 | 311.1 | 91.6 | 48.8 | 28.5 |
| 40 | 15.7 | 11.9 | 12.1 | 13.3 | 15.9 | 31.3 | 278.3 | 579.6 | 291.4 | 90.3 | 47.4 | 27.8 |
| 50 | 14.7 | 11.0 | 11.5 | 12.8 | 15.3 | 30.8 | 263.3 | 546.6 | 271.1 | 87.5 | 46.1 | 26.1 |
| 60 | 12.9 | 8.7 | 10.5 | 11.8 | 14.2 | 29.7 | 234.3 | 482.8 | 235.2 | 82.1 | 41.7 | 22.8 |
| 70 | 9.3 | 8.7 | 8.6 | 10.1 | 12.2 | 27.5 | 215.4 | 443.2 | 205.9 | 72.4 | 34.8 | 15.9 |
| 80 | 8.2 | 6.1 | 6.3 | 7.4 | 9.1 | 24.7 | 181.3 | 371.6 | 161.6 | 59.5 | 26.1 | 11.0 |
| 85 | 4.4 | 3.3 | 4.7 | 5.7 | 7.3 | 21.7 | 155.8 | 319.0 | 134.8 | 48.5 | 20.2 | 7.7 |
| 90 | 2.8 | 2.1 | 3.2 | 4.1 | 5.5 | 19.9 | 124.9 | 254.6 | 107.8 | 39.4 | 14.2 | 4.9 |
| 95 | 2.8 | 1.2 | 1.8 | 2.7 | 3.8 | 13.5 | 90.0 | 181.8 | 84.4 | 31.6 | 9.0 | 2.9 |
| 99 | 1.2 | 0.9 | 1.2 | 2.0 | 3.1 | 11.0 | 67.3 | 134.5 | 73.1 | 27.8 | 6.4 | 2.0 |
| 99.9 | 1.1 | 0.8 | 1.1 | 1.9 | 3.0 | 11.0 | 67.3 | 134.5 | 73.1 | 27.8 | 6.2 | 1.9 |

Nile Coarse EFlow determinations flow duration (time series) summary flows in monthly average m$^3$/s.: **RR8 – CLASS D FLOWS**. Colour conditional formatting highlights high (RED) to low (GREEN) values, and does not represent the suitability of the flows.

| %tile | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.1 | 10.6 | 7.6 | 8.1 | 9.0 | 11.0 | 23.8 | 261.4 | 521.2 | 278.5 | 71.8 | 35.4 | 19.5 |
| 1 | 10.6 | 7.6 | 8.1 | 9.0 | 11.0 | 23.8 | 261.4 | 521.2 | 278.5 | 71.8 | 35.4 | 19.5 |
| 5 | 10.6 | 7.6 | 8.1 | 9.0 | 11.0 | 23.8 | 261.4 | 521.2 | 278.5 | 71.8 | 35.4 | 19.5 |
| 10 | 10.6 | 7.6 | 8.1 | 9.0 | 11.0 | 23.8 | 260.6 | 519.7 | 273.9 | 71.8 | 35.4 | 19.5 |
| 15 | 10.6 | 7.6 | 8.1 | 9.0 | 11.0 | 23.8 | 252.3 | 496.6 | 267.8 | 71.8 | 35.4 | 19.5 |
| 20 | 10.6 | 7.6 | 8.1 | 9.0 | 11.0 | 23.8 | 246.8 | 488.6 | 255.7 | 71.8 | 35.4 | 19.5 |
| 30 | 10.5 | 7.5 | 8.0 | 9.0 | 11.0 | 23.7 | 234.0 | 465.6 | 240.9 | 71.4 | 35.1 | 19.3 |
| 40 | 10.2 | 7.5 | 8.0 | 8.8 | 10.8 | 23.6 | 222.1 | 441.4 | 225.3 | 70.5 | 34.1 | 18.8 |
| 50 | 9.6 | 6.9 | 7.6 | 8.5 | 10.4 | 23.2 | 210.3 | 417.5 | 209.7 | 68.6 | 33.3 | 17.7 |
| 60 | 8.5 | 5.5 | 7.0 | 7.9 | 9.8 | 22.5 | 187.4 | 371.3 | 182.4 | 64.8 | 30.3 | 15.6 |
| 70 | 6.2 | 5.5 | 5.8 | 6.9 | 8.6 | 21.2 | 173.5 | 343.7 | 162.3 | 58.1 | 25.6 | 11.0 |
| 80 | 5.5 | 4.0 | 4.3 | 5.2 | 6.7 | 19.4 | 148.6 | 293.6 | 131.9 | 49.2 | 19.7 | 7.8 |
| 85 | 3.2 | 2.3 | 3.4 | 4.2 | 5.6 | 17.6 | 130.0 | 257.0 | 113.4 | 41.6 | 15.7 | 5.7 |
| 90 | 2.2 | 1.6 | 2.4 | 3.2 | 4.5 | 16.4 | 107.4 | 212.0 | 94.9 | 35.3 | 11.6 | 3.8 |
| 95 | 2.2 | 1.1 | 1.6 | 2.4 | 3.5 | 12.5 | 81.9 | 161.2 | 78.8 | 29.9 | 8.1 | 2.5 |
| 99 | 1.2 | 0.9 | 1.2 | 2.0 | 3.0 | 10.9 | 65.3 | 128.2 | 71.0 | 27.3 | 6.3 | 2.0 |
| 99.9 | 1.1 | 0.8 | 1.1 | 1.9 | 3.0 | 10.9 | 65.3 | 128.2 | 71.0 | 27.3 | 6.2 | 1.9 |

Nile Coarse EFlow determinations flow duration (time series) summary flows in monthly average m$^3$/s.: **RR9 - Reference (CLASS A) FLOWS**. Colour conditional formatting highlights high (RED) to low (GREEN) values, and does not represent the suitability of the flows.

| %tile | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.1 | 2118.9 | 2050.9 | 1601.5 | 1476.7 | 1546.4 | 2250.8 | 5141.8 | 10131.7 | 11351.9 | 7076.1 | 4243.8 | 2170.5 |
| 1 | 1874.7 | 1617.9 | 1309.3 | 1438.1 | 1459.6 | 1928.5 | 4359.1 | 10089.9 | 10946.2 | 6834.4 | 3863.6 | 2039.8 |
| 5 | 1515.2 | 1310.4 | 1056.5 | 1366.8 | 1345.3 | 1473.4 | 2908 | 9392.4 | 10639.5 | 6322.6 | 3327.5 | 1909.8 |
| 10 | 1400.4 | 1248.8 | 975.5 | 1223.4 | 1240.6 | 1346.7 | 2688.1 | 8905.4 | 10034 | 5778.6 | 3121.6 | 1795 |
| 15 | 1385 | 1144.4 | 954.7 | 1153.7 | 1206.8 | 1242 | 2612 | 8435.4 | 9376.8 | 5671.7 | 2850.4 | 1708.3 |
| 20 | 1310.8 | 1098.5 | 946 | 1136 | 1177.2 | 1187.8 | 2539 | 8229.4 | 8836.6 | 5304.8 | 2676.6 | 1687.6 |
| 30 | 1223 | 990.2 | 923.2 | 1067.4 | 1129.8 | 1074.6 | 2206.2 | 7540 | 8111.2 | 4850.2 | 2422.6 | 1532.4 |
| 40 | 1163.2 | 937.6 | 865 | 1030.4 | 1084.8 | 963.4 | 2131.9 | 7285.8 | 7712.4 | 4226.4 | 2225.2 | 1398.4 |
| 50 | 1031 | 910.7 | 812 | 990 | 1040 | 908 | 2027.7 | 6813 | 7423 | 3776 | 1983 | 1316 |
| 60 | 992.4 | 784.2 | 757.2 | 952.7 | 955.4 | 829.2 | 1899.4 | 6458.2 | 7012.3 | 3363.6 | 1743.4 | 1220.6 |
| 70 | 930.2 | 754.4 | 708.1 | 927.8 | 898.4 | 770.8 | 1778.8 | 5979.4 | 6338.2 | 2977.5 | 1624.2 | 1126.8 |
| 80 | 863.6 | 712.4 | 651.8 | 879.8 | 820.4 | 708.6 | 1556.4 | 5355.3 | 5580.6 | 2551.2 | 1400.8 | 1033.6 |
| 85 | 840.5 | 675.6 | 619.1 | 849.6 | 763.1 | 623.8 | 1464.4 | 5093.4 | 5172 | 2349.9 | 1295.6 | 986.5 |
| 90 | 768.6 | 628.2 | 599.9 | 816 | 683.2 | 601.9 | 1366.9 | 4816 | 4121.8 | 2170 | 1244 | 886.4 |
| 95 | 750.3 | 615.2 | 544.8 | 706.1 | 606.6 | 578.2 | 1273.5 | 4163.1 | 3638.8 | 1914.4 | 1095 | 842.8 |
| 99 | 652.3 | 556.2 | 511.2 | 606.4 | 562.6 | 536 | 973.3 | 3613.1 | 3006.9 | 1367.7 | 937 | 709.6 |
| 99.9 | 647.5 | 498.4 | 502.7 | 564.7 | 558.5 | 504.5 | 937 | 3473.5 | 2314.9 | 1017.8 | 910.9 | 697.4 |

Nile Coarse EFlow determinations flow duration (time series) summary flows in monthly average m$^3$/s.: **RR9 – CLASS B FLOWS**. Colour conditional formatting highlights high (RED) to low (GREEN) values, and does not represent the suitability of the flows.

| %tile | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.1 | 1150.3 | 1038.0 | 908.9 | 963.5 | 932.7 | 935.0 | 1711.7 | 3822.9 | 4497.6 | 2257.1 | 1574.6 | 1224.8 |
| 1 | 1150.3 | 1038.0 | 908.9 | 963.5 | 932.7 | 935.0 | 1711.7 | 3822.9 | 4497.6 | 2257.1 | 1574.6 | 1224.8 |
| 5 | 1150.3 | 1038.0 | 908.9 | 963.5 | 932.7 | 935.0 | 1711.7 | 3822.9 | 4497.6 | 2257.1 | 1574.6 | 1224.8 |
| 10 | 1150.3 | 1038.0 | 908.9 | 963.5 | 932.7 | 935.0 | 1707.1 | 3787.8 | 4473.3 | 2257.1 | 1574.6 | 1224.8 |
| 15 | 1150.3 | 1038.0 | 908.9 | 963.5 | 932.7 | 935.0 | 1675.0 | 3683.2 | 4309.5 | 2257.1 | 1574.6 | 1224.8 |
| 20 | 1149.7 | 1036.8 | 907.7 | 962.5 | 932.1 | 934.3 | 1644.6 | 3585.4 | 4156.2 | 2254.4 | 1573.4 | 1224.6 |
| 30 | 1140.4 | 1017.9 | 901.6 | 953.3 | 926.0 | 928.2 | 1580.8 | 3405.2 | 3868.3 | 2240.1 | 1562.9 | 1213.3 |
| 40 | 1114.6 | 937.3 | 862.6 | 936.9 | 907.3 | 913.3 | 1518.4 | 3218.7 | 3533.8 | 2199.7 | 1535.5 | 1187.6 |
| 50 | 1030.8 | 910.8 | 803.1 | 911.9 | 878.1 | 897.2 | 1453.5 | 3056.0 | 3332.6 | 2118.1 | 1464.9 | 1130.0 |
| 60 | 966.8 | 785.8 | 742.1 | 845.8 | 817.1 | 829.4 | 1318.0 | 2706.8 | 2861.9 | 1956.0 | 1361.2 | 1087.9 |
| 70 | 801.2 | 694.3 | 693.5 | 743.2 | 700.9 | 774.5 | 1164.9 | 2483.9 | 2493.7 | 1682.7 | 1239.0 | 1065.8 |
| 80 | 585.5 | 520.4 | 533.6 | 574.5 | 557.2 | 661.3 | 993.5 | 2104.9 | 1964.2 | 1450.6 | 1227.9 | 1021.2 |
| 85 | 458.2 | 400.7 | 427.6 | 469.6 | 438.0 | 526.1 | 824.6 | 1783.3 | 1887.3 | 1434.1 | 1210.9 | 968.1 |
| 90 | 374.8 | 337.6 | 345.3 | 362.9 | 343.2 | 419.5 | 645.2 | 1721.3 | 1855.4 | 1395.2 | 1180.5 | 855.8 |
| 95 | 322.7 | 292.8 | 273.7 | 290.3 | 286.2 | 325.2 | 462.9 | 1642.6 | 1780.6 | 1350.8 | 1137.4 | 747.0 |
| 99 | 289.6 | 267.3 | 231.4 | 247.1 | 239.2 | 237.8 | 325.6 | 645.9 | 706.7 | 495.0 | 373.7 | 308.8 |
| 99.9 | 289.6 | 267.3 | 231.4 | 247.1 | 239.2 | 237.8 | 325.6 | 645.9 | 706.7 | 495.0 | 373.7 | 308.8 |

Nile Coarse EFlow determinations flow duration (time series) summary flows in monthly average m$^3$/s.: **RR9 – CLASS C FLOWS**. Colour conditional formatting highlights high (RED) to low (GREEN) values, and does not represent the suitability of the flows.

| %tile | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.1 | 648.2 | 649.5 | 582.2 | 619.5 | 599.6 | 619.9 | 985.7 | 2360.5 | 2773.3 | 1416.3 | 973.8 | 749.4 |
| 1 | 648.2 | 649.5 | 582.2 | 619.5 | 599.6 | 619.9 | 985.7 | 2360.5 | 2773.3 | 1416.3 | 973.8 | 749.4 |
| 5 | 648.2 | 649.5 | 582.2 | 619.5 | 599.6 | 619.9 | 985.7 | 2360.5 | 2773.3 | 1416.3 | 973.8 | 749.4 |
| 10 | 648.2 | 649.5 | 582.2 | 619.5 | 599.6 | 619.9 | 982.9 | 2339.4 | 2758.7 | 1416.3 | 973.8 | 749.4 |
| 15 | 648.2 | 649.5 | 582.2 | 619.5 | 599.6 | 619.9 | 963.7 | 2276.7 | 2660.4 | 1416.3 | 973.8 | 749.4 |
| 20 | 648.0 | 649.0 | 581.6 | 618.9 | 599.3 | 619.5 | 945.4 | 2218.1 | 2568.5 | 1414.9 | 973.2 | 749.3 |
| 30 | 644.0 | 644.6 | 578.4 | 614.1 | 596.1 | 616.2 | 908.2 | 2110.9 | 2397.1 | 1407.1 | 967.8 | 743.8 |
| 40 | 633.1 | 632.3 | 571.3 | 605.5 | 586.4 | 608.0 | 872.9 | 2001.2 | 2201.0 | 1385.3 | 953.7 | 731.2 |
| 50 | 610.6 | 607.9 | 552.6 | 592.5 | 571.1 | 599.1 | 838.0 | 1906.9 | 2085.0 | 1341.0 | 917.6 | 703.0 |
| 60 | 570.4 | 553.4 | 522.4 | 557.9 | 539.2 | 580.6 | 765.5 | 1704.8 | 1814.8 | 1253.2 | 864.4 | 667.1 |
| 70 | 500.1 | 478.0 | 470.1 | 504.3 | 478.5 | 540.4 | 694.8 | 1584.5 | 1614.9 | 1105.1 | 780.3 | 656.7 |
| 80 | 408.7 | 391.2 | 386.8 | 416.1 | 403.4 | 469.1 | 615.8 | 1380.3 | 1318.2 | 915.1 | 760.4 | 635.8 |
| 85 | 354.7 | 331.4 | 331.6 | 361.3 | 341.0 | 394.7 | 537.9 | 1195.7 | 1225.5 | 907.1 | 752.3 | 610.7 |
| 90 | 319.3 | 300.0 | 288.7 | 305.5 | 291.5 | 335.9 | 455.1 | 1108.9 | 1197.1 | 888.3 | 737.8 | 557.8 |
| 95 | 297.2 | 277.6 | 251.4 | 267.5 | 261.7 | 284.0 | 371.0 | 1070.2 | 1160.2 | 866.8 | 717.3 | 506.6 |
| 99 | 283.2 | 264.9 | 229.4 | 245.0 | 237.2 | 235.8 | 307.6 | 593.9 | 646.7 | 461.6 | 358.3 | 301.7 |
| 99.9 | 283.2 | 264.9 | 229.4 | 245.0 | 237.2 | 235.8 | 307.6 | 593.9 | 646.7 | 461.6 | 358.3 | 301.7 |

Nile Coarse EFlow determinations flow duration (time series) summary flows in monthly average m$^3$/s.: **RR9 – CLASS D FLOWS**. Colour conditional formatting highlights high (RED) to low (GREEN) values, and does not represent the suitability of the flows.

| %tile | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.1 | 570.8 | 578.5 | 538.4 | 575.0 | 556.6 | 608.3 | 855.6 | 1910.1 | 2213.4 | 1274.6 | 881.3 | 688.1 |
| 1 | 570.8 | 578.5 | 538.4 | 575.0 | 556.6 | 608.3 | 855.6 | 1910.1 | 2213.4 | 1274.6 | 881.3 | 688.1 |
| 5 | 570.8 | 578.5 | 538.4 | 575.0 | 556.6 | 608.3 | 855.6 | 1910.1 | 2213.4 | 1274.6 | 881.3 | 688.1 |
| 10 | 570.8 | 578.5 | 538.4 | 575.0 | 556.6 | 608.3 | 853.7 | 1896.1 | 2203.7 | 1274.6 | 881.3 | 688.1 |
| 15 | 570.8 | 578.5 | 538.4 | 575.0 | 556.6 | 608.3 | 841.0 | 1854.3 | 2138.3 | 1274.6 | 881.3 | 688.1 |
| 20 | 570.6 | 578.0 | 537.8 | 574.5 | 556.4 | 607.9 | 828.8 | 1815.2 | 2077.1 | 1273.3 | 880.8 | 688.0 |
| 30 | 567.3 | 574.3 | 534.9 | 570.1 | 553.4 | 604.6 | 803.2 | 1742.7 | 1961.2 | 1266.5 | 876.1 | 683.1 |
| 40 | 558.3 | 563.9 | 528.4 | 562.3 | 544.6 | 596.4 | 778.1 | 1666.7 | 1824.4 | 1247.1 | 863.6 | 671.8 |
| 50 | 539.6 | 543.3 | 511.6 | 550.4 | 530.6 | 587.5 | 751.8 | 1599.5 | 1740.7 | 1207.8 | 831.6 | 646.4 |
| 60 | 506.4 | 497.1 | 484.2 | 519.0 | 501.6 | 569.1 | 696.9 | 1455.0 | 1544.0 | 1130.0 | 784.6 | 614.6 |
| 70 | 448.3 | 433.2 | 436.8 | 470.0 | 446.2 | 529.0 | 633.7 | 1356.8 | 1381.7 | 998.6 | 713.1 | 605.3 |
| 80 | 372.7 | 359.6 | 361.4 | 389.7 | 377.8 | 457.9 | 563.0 | 1189.7 | 1190.4 | 866.7 | 707.3 | 586.5 |
| 85 | 328.0 | 309.0 | 311.4 | 339.7 | 320.9 | 383.6 | 493.3 | 1088.7 | 1167.5 | 859.2 | 699.9 | 564.1 |
| 90 | 298.8 | 282.3 | 272.6 | 288.9 | 275.8 | 325.0 | 419.2 | 1064.9 | 1152.3 | 841.5 | 686.8 | 516.7 |
| 95 | 280.5 | 263.3 | 238.8 | 254.3 | 248.6 | 273.2 | 344.0 | 1027.6 | 1116.6 | 821.3 | 668.1 | 470.9 |
| 99 | 268.9 | 252.6 | 218.9 | 233.8 | 226.3 | 225.2 | 287.3 | 546.2 | 593.2 | 427.9 | 336.7 | 286.4 |
| 99.9 | 268.9 | 252.6 | 218.9 | 233.8 | 226.3 | 225.2 | 287.3 | 546.2 | 593.2 | 427.9 | 336.7 | 286.4 |

# ANNEXURE G UNCERTAINTY ANALYSES SECTION: SENSITIVITY ANALYSIS OF THE BAYESIAN NETWORK

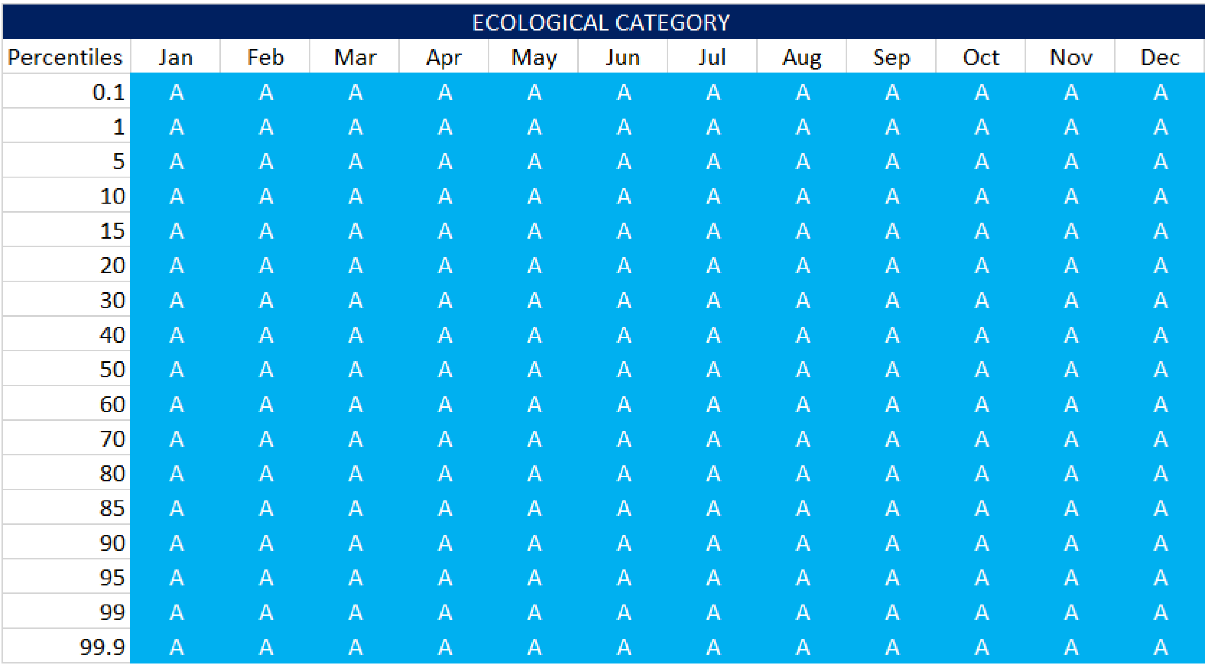
| Node | Variance | Percent | Mutual | Percent | Variance of |
|---|---|---|---|---|---|
| RIVER BIODIVERSITY | Reduction | | Info | | Beliefs |
| Aveghab_R_bwet | 48.71 | 17.2 | 0.18382 | 13.9 | 0.0357984 |
| River_biodiversity | 24.49 | 8.65 | 0.12044 | 9.08 | 0.012145 |
| Aveghab_R_drought | 18.23 | 6.44 | 0.06164 | 4.65 | 0.0094346 |
| Aveghab_R_bdry | 9.056 | 3.2 | 0.02898 | 2.18 | 0.0046992 |
| River_hab_fish | 0 | 0 | 0 | 0 | 0 |
| Fishhab_R_drought | 0 | 0 | 0 | 0 | 0 |
| Fishhab_R_bdry | 0 | 0 | 0 | 0 | 0 |
| Fishhab_R_bwet | 0 | 0 | 0 | 0 | 0 |
| River_biod_potential | 0 | 0 | 0 | 0 | 0 |

| Node | Variance | Percent | Mutual | Percent | Variance of |
|---|---|---|---|---|---|
| FLOODPLAIN BIODIVERSITY | Reduction | | Info | | Beliefs |
| Floodp_hab_fish | 9.001 | 4.79 | 0.0439 | 4.92 | 0.0133761 |
| Floodp_biodiversity | 0.8065 | 0.429 | 0.00416 | 0.466 | 0.0012036 |
| Floodp_biod_potential | 0 | 0 | 0 | 0 | 0 |
| Fishhab_FP_flood | 0 | 0 | 0 | 0 | 0 |
| FPveg_FP_flood | 0 | 0 | 0 | 0 | 0 |
| Floodp_hab_veg | 0 | 0 | 0 | 0 | 0 |
| River_Eserv_potential | 0 | 0 | 0 | 0 | 0 |
| Fish_migrations | 0 | 0 | 0 | 0 | 0 |
| FPveg_FP_bwet | 0 | 0 | 0 | 0 | 0 |

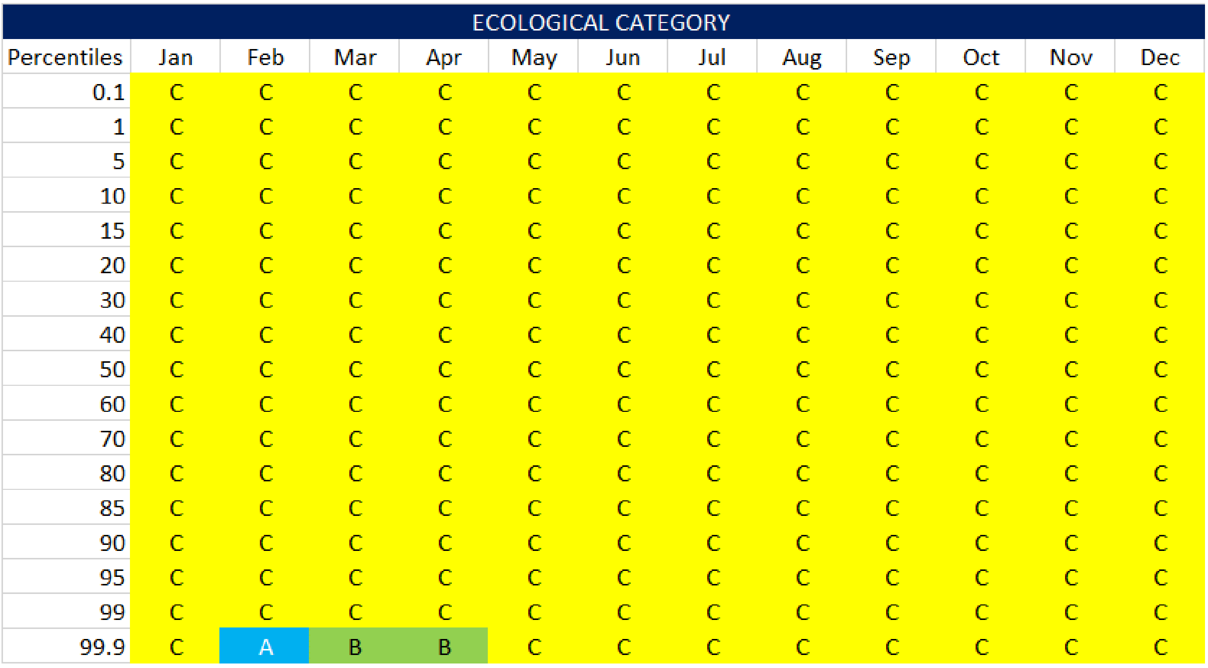
| Node | Variance | Percent | Mutual | Percent | Variance of |
|---|---|---|---|---|---|
| RIVER ECOSYSTEM SERVICES | Reduction | | Info | | Beliefs |
| River_subsfish | 4.47 | 2.92 | 0.03009 | 4.11 | 0.0070222 |
| River_ecoservices | 0.8284 | 0.542 | 0.00585 | 0.798 | 0.0012993 |
| Subveg_R_bwet | 0 | 0 | 0 | 0 | 0 |
| Subveg_R_bdry | 0 | 0 | 0 | 0 | 0 |
| River_Eserv_potential | 0 | 0 | 0 | 0 | 0 |
| River_veg_products | 0 | 0 | 0 | 0 | 0 |
| Subfish_R_bwet | 0 | 0 | 0 | 0 | 0 |

| Node | Variance | Percent | Mutual | Percent | Variance of |
|---|---|---|---|---|---|
| FLOODPLAIN ECOSYSTEM SERVICES | Reduction | | Info | | Beliefs |
| Floodp_subsfish | 9.001 | 4.79 | 0.0439 | 4.92 | 0.0133761 |
| Floodp_ecoservices | 1.101 | 0.586 | 0.00575 | 0.644 | 0.0016412 |
| Subveg_FP_bwet | 0 | 0 | 0 | 0 | 0 |
| Subveg_FP_bdry | 0 | 0 | 0 | 0 | 0 |
| Subfish_FP_flood | 0 | 0 | 0 | 0 | 0 |
| Floodp_veg_products | 0 | 0 | 0 | 0 | 0 |
| Floodp_Eserv_potential | 0 | 0 | 0 | 0 | 0 |

# ANNEXURE H: APPLICATION OF THE EFLOW DATA QUERY TOOL.



| | ECOLOGICAL CATEGORY | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Percentiles | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| 0.1 | A | A | A | A | A | A | A | A | A | A | A | A |
| 1 | A | A | A | A | A | A | A | A | A | A | A | A |
| 5 | A | A | A | A | A | A | A | A | A | A | A | A |
| 10 | A | A | A | A | A | A | A | A | A | A | A | A |
| 15 | A | A | A | A | A | A | A | A | A | A | A | A |
| 20 | A | A | A | A | A | A | A | A | A | A | A | A |
| 30 | A | A | A | A | A | A | A | A | A | A | A | A |
| 40 | A | A | A | A | A | A | A | A | A | A | A | A |
| 50 | A | A | A | A | A | A | A | A | A | A | A | A |
| 60 | A | A | A | A | A | A | A | A | A | A | A | A |
| 70 | A | A | A | A | A | A | A | A | A | A | A | A |
| 80 | A | A | A | A | A | A | A | A | A | A | A | A |
| 85 | A | A | A | A | A | A | A | A | A | A | A | A |
| 90 | A | A | A | A | A | A | A | A | A | A | A | A |
| 95 | A | A | A | A | A | A | A | A | A | A | A | A |
| 99 | A | A | A | A | A | A | A | A | A | A | A | A |
| 99.9 | A | A | A | A | A | A | A | A | A | A | A | A |



| | ECOLOGICAL CATEGORY | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Percentiles | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| 0.1 | C | C | C | C | C | C | C | C | C | C | C | C |
| 1 | C | C | C | C | C | C | C | C | C | C | C | C |
| 5 | C | C | C | C | C | C | C | C | C | C | C | C |
| 10 | C | C | C | C | C | C | C | C | C | C | C | C |
| 15 | C | C | C | C | C | C | C | C | C | C | C | C |
| 20 | C | C | C | C | C | C | C | C | C | C | C | C |
| 30 | C | C | C | C | C | C | C | C | C | C | C | C |
| 40 | C | C | C | C | C | C | C | C | C | C | C | C |
| 50 | C | C | C | C | C | C | C | C | C | C | C | C |
| 60 | C | C | C | C | C | C | C | C | C | C | C | C |
| 70 | C | C | C | C | C | C | C | C | C | C | C | C |
| 80 | C | C | C | C | C | C | C | C | C | C | C | C |
| 85 | C | C | C | C | C | C | C | C | C | C | C | C |
| 90 | C | C | C | C | C | C | C | C | C | C | C | C |
| 95 | C | C | C | C | C | C | C | C | C | C | C | C |
| 99 | C | C | C | C | C | C | C | C | C | C | C | C |
| 99.9 | C | A | B | B | C | C | C | C | C | C | C | C |

| ECOLOGICAL CATEGORY | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Percentiles | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| 0.1 | D | E/F | E/F | D | B | A | A | A | A | A | B | D |
| 1 | D | E/F | E/F | E/F | B | A | A | A | A | A | B | D |
| 5 | E/F | E/F | E/F | E/F | C | A | A | A | A | A | B | E/F |
| 10 | E/F | E/F | E/F | E/F | E/F | A | A | A | A | A | B | E/F |
| 15 | E/F | E/F | E/F | E/F | E/F | A | A | A | A | A | B | E/F |
| 20 | E/F | E/F | E/F | E/F | E/F | B | A | A | A | A | B | E/F |
| 30 | E/F | E/F | E/F | E/F | E/F | B | A | A | A | A | B | E/F |
| 40 | E/F | E/F | E/F | E/F | E/F | B | A | A | A | A | B | E/F |
| 50 | E/F | E/F | E/F | E/F | E/F | B | A | A | A | A | C | E/F |
| 60 | E/F | E/F | E/F | E/F | E/F | C | A | A | A | A | C | E/F |
| 70 | E/F | E/F | E/F | E/F | E/F | C | A | A | A | A | C | E/F |
| 80 | E/F | E/F | E/F | E/F | E/F | C | A | A | A | A | B | E/F |
| 85 | E/F | E/F | E/F | E/F | E/F | C | A | A | A | A | B | E/F |
| 90 | E/F | E/F | E/F | E/F | E/F | C | A | A | A | A | B | E/F |
| 95 | E/F | E/F | E/F | E/F | E/F | B | A | A | A | A | B | E/F |
| 99 | E/F | E/F | E/F | E/F | E/F | C | A | A | A | A | B | E/F |
| 99.9 | E/F | E/F | E/F | E/F | E/F | C | A | A | A | B | C | E/F |

| ECOLOGICAL CATEGORY | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Percentiles | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| 0.1 | D | D | D | E/F | E/F | E/F | E/F | C | B | B | B | D |
| 1 | D | D | D | E/F | E/F | E/F | E/F | C | B | B | B | D |
| 5 | D | D | D | E/F | E/F | E/F | E/F | C | B | B | B | D |
| 10 | D | D | D | E/F | E/F | E/F | E/F | C | B | B | B | D |
| 15 | D | D | D | E/F | E/F | E/F | E/F | D | B | B | B | D |
| 20 | D | D | D | E/F | E/F | E/F | E/F | D | D | B | B | D |
| 30 | D | D | D | E/F | E/F | E/F | E/F | D | D | B | B | D |
| 40 | D | D | D | E/F | E/F | E/F | E/F | C | D | B | B | D |
| 50 | D | D | D | E/F | E/F | E/F | E/F | C | D | C | C | D |
| 60 | D | D | D | E/F | E/F | E/F | D | D | D | D | C | D |
| 70 | D | D | D | E/F | E/F | E/F | D | D | E/F | D | C | D |
| 80 | D | D | D | E/F | E/F | E/F | E/F | D | E/F | D | C | D |
| 85 | D | D | D | E/F | E/F | E/F | E/F | D | E/F | D | C | D |
| 90 | D | D | D | E/F | E/F | E/F | E/F | D | E/F | D | C | D |
| 95 | D | D | D | E/F | E/F | E/F | D | D | E/F | C | C | D |
| 99 | D | D | D | D | D | D | D | C | D | C | C | D |
| 99.9 | D | D | D | D | D | D | D | C | D | D | D | D |

ONE RIVER
ONE PEOPLE
ONE VISION

Nile Basin Initiative Secretariat
P.O. Box 192
Entebbe – Uganda
Tel: +256 414 321 424
+256 414 321 329
+256 417 705 000
Fax: +256 414 320 971
Email: nbisec@nilebasin.org
Website: http://www.nilebasin.org

/Nile Basin Initiative
@nbiweb

Eastern Nile Technical Regional Office
Dessie Road
P.O. Box 27173-1000
Addis Ababa – Ethiopia
Tel: +251 116 461 130/32
Fax: +251 116 459 407
Email: entro@nilebasin.org
Website: http://ensap.nilebasin.org

ENTRO

Nile Equatorial Lakes Subsidiary Action Program Coordination Unit
Kigali City Tower
KCT, KN 2 St, Kigali
P.O. Box 6759, Kigali Rwanda
Tel: +250 788 307 334
Fax: +250 252 580 100
Email: nelsapcu@nilebasin.org
Website: http://nelsap.nilebasin.org

NELSAP-CU