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NBI Technical Reports: Wetlands and Biodiversity series

Environmental Flows Assessment Methodology for Nile Basin Wetlands

WRM/WBS-2022-03

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Document Sheet

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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.

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E-FLOW DETERMINATION AND MANAGEMENT FOR WETLANDS OF THE NILE BASIN.

Nile basin wetlands of transboundary significance: inventory, baseline study and framework management

Guidance for setting water allocation targets (e-flows) for wetlands.

Preparation of NBI Guidance Document on Environmental Flows for Wetlands

Photo: African wetland: by Stephen Robinson

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1 Executive summary

The Nile E-flows Framework was developed in 2016 by the Nile Basin Initiative to contribute to the trans-boundary regional and basin scale management of riverine e-flows in the Nile basin. The framework includes a step by step methodology for the management of e-flows in the context of best practice e-flow assessment methodologies. The framework was established to direct e-flows of riverine environments, and although the general phases within the framework are applicable to wetlands, wetland environments are distinctly different, and these differences need to be considered when determining e-flows guidelines for wetlands. Wetland ecosystems in the Nile basin can generally be differentiated from the riverine ecosystems by a range of characteristics including; slow flowing (<0.2 m/s) lentic habitats that are usually shallow <2 m and well vegetated. They can be linked to rivers (e.g. floodplains) and/or due to flat topography rivers may flow into large depressions that form extensive wetland habitats, technically referred to as palustrine ecosystems. Other wetlands can be disconnected from rivers and be associated with seeps and depressions throughout the Nile basin landscape. Wetland ecosystems in the Nile basin have a high ecological, social and economic value and need to be used and protected in a sustainable manner. This requires the integration of wetland ecosystems into the Nile E-flows Framework with rivers, but also requires specific consideration of the unique attributes, values and processes of the Nile basin wetlands. In addition, while river ecosystems can be evaluated in a qualitative manner, where representative features can be considered and maintained at various locations along the length of the river, entire wetland ecosystems features need to be evaluated in a quantitative manner. This difference in approach needs to be considered for e-flow assessments of wetlands in the Nile basin.

Recognised wetlands of importance in the Nile basin include; Nile Delta, Dinder floodplain wetlands, Lake Tana wetlands, Baro/Akobo Sobat floodplain wetlands (with specific focus on the Machar Marshes), the Sudd (Bahr el Jebel), Bahr el Ghazal wetlands, Lake Kyoga wetlands, Semliki wetlands incl. Lake Albert / George / Edward in Uganda and the Democratic Republic of Congo, Lake Victoria wetlands, Kagera wetlands, Mara wetland in Tanzania and the Sio Nzoia Yala Nyando wetlands.

This document provides context to the framework for wetlands and the application of the PROBFLO EFA methodology specifically aimed at assessing e-flows for transboundary wetlands of importance in the Nile basin. The seven procedural steps of the E-flows Framework include:

Phase 1: Situation Assessment and Alignment Process, aligns existing wetland and regional scale information and the plan for the new e-flows 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 e-flow governance requirements are considered/applied in the wetland e-flow assessments, and describes the vision and Resource Quality Objectives determination procedures.

Phase 3: Hydrological Foundation in the wetland, this phase includes the baseline evaluation/modelling of hydrology data for the site/regional wetland e-flows 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 in the wetland and potentially describe any differences between these baseline flows and current flows.

Phase 4: Wetland Ecosystem Type Classification. Although no two wetland ecosystems are exactly the same, wetland 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 wetland ecosystem type being considered for e-flow assessments in an effort to assist with future assessments. *The dynamics of wetland ecosystems in the context of regional e-flow management must be addressed in Phase 4. Wetland ecosystems may or may not have direct relationships to river and/or groundwater ecosystems. Those that do not have any linkages can be managed independently but the majority that do have connections need to be considered in the context of the connections that drive the dynamics of those ecosystems. Estuaries and floodplain ecosystems have direct relationships with rivers for example and these relationships contribute to the dynamics of the wetlands. In this phase of the framework the wetland types are clearly identified and considered in the context of regional ecosystems and flow-ecosystem and flow-ecosystem service relationships that include connections to other ecosystems. This knowledge of the types of systems and their dynamics will contribute to the selection of and use of EFMs and the application of the Nile E-flows Framework.*

Phase 5: Flow Alterations, here alterations in wetland 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 in wetlands 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 e-flow assessment methods.*

Phase 7: E-flows Setting and Monitoring, in this phase the flows required to maintain the socio-ecological wetland system in the desired condition established in the Framework is detailed for implementation. Within these e-flow requirements many uncertainties associated with the availability of evidence used in the assessment, the understanding of the wetland 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.

Sudd environmental flow case study

Environmental flows are described as 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. In this case study the PROBFLO holistic, regional scale ecological risk assessment based e-flow method that has been implemented as a part of the Nile e-flows Framework (2016) will be adapted and implemented to address the requirements of e-flow assessments for wetlands and to demonstrate its application. The case study that will be used for the demonstration of the method is the Sudd wetland, South Sudan, in the Nile basin. The application of the PROBFLO approach for the Sudd wetland will include:

- utilization of detailed datasets as generated by the other study workpackages, including e.g. detailed modelled wetland hydraulics and wetland biodiversity information
- review available socio-ecological, bio-physical and water resource use characteristics of the Sudd wetland, and characterise features (habitats and ecological indicators for example) and ecosystem processes of the wetland;
- select socio-ecological endpoints to represent the management problem for the case study;
- establish a conceptual model representing risk pathways that describe causal pathways of risk between stressors, receptors and endpoints selected for the study that conform to the regional scale ecological risk assessment;
- characterise additional bio-physical and social evidence required for the assessment;
- calculate the risk of multiple stressors to these endpoints and established the e-flows,
- evaluate the risk of multiple stressors to endpoints for a range of resource use and protection scenarios, and
- present the uncertainty associated with the outcomes and propose and adaptive management plan to reduce uncertainty.

Within the first phase of the PROBFLO assessment for the Sudd wetland the establishment of a vision (step 1) for the Sudd wetland will be evaluated. In the Sudd wetland case study, e-flow requirements to maintain the ecosystem in a range of ecological categories including a Largely Natural state (Class B), moderately modified state (Class C) and Largely Natural but sustainable state (Class D). This approach will also result in the selection of social and ecological endpoints that represent what is important to stakeholders in the Sudd wetland. This will be based on the evaluation of the values of the wetland and may include the maintenance of the livelihoods of local communities and ecological endpoints that address biodiversity and ecosystem processes of the wetland resources. Thereafter a literature review will be undertaken for the study area and maps will be established of water resources and associated ecosystem services of the wetland (step 2). The study area will be divided into spatially explicit risk regions, or areas of the wetland ecosystem that generally consists of uniform social and/or ecological land use scenarios. These risk regions allow stakeholders to consider relative risk to endpoints between these spatial areas (step 3). In step 4 conceptual models that demonstrate the causal risk pathways from identified sources (including anthropogenic and natural activities/events) to stressors (water quality, flow and habitat modifications for example), socio-ecological receptors in multiple habitats to endpoints, will be developed. During this phase a hydrodynamic model of the Sudd wetland as developed in the project will be used in combination with the known habitat characteristics (mapping and biodiversity study results) of the wetland to evaluate the flow of water into the wetland, the retention capacity of the wetland and the effect of altered volumes, duration and frequency of flows entering the wetland on the habitats within the wetland. A ranking scheme will be established for the study to represent the condition of each variable of the study and risk to endpoints (step 5) and then the risk will be calculated (step 6) using Microsoft ® Excel and Netica™ to generate Bayesian Networks and Oracle® Crystal Ball™ software to randomise and integrate risk probabilities. Some important aspects of uncertainty will be included in this assessment. Available data will be used to identify social and ecological indicators to represent the Sudd wetland ecosystem in the assessment. This assessment will also result in the establishment of a monitoring plan/programme that can be used to reduce uncertainty in the assessment (step 8). Hypotheses associated with the uncertainty reduction will then be tested by revising the risk assessment/ learning from and improving relationships and risk assessment results (step 9). The last step of the approach is to communicate the outcomes so that the e-flows can achieve acceptability but also to ensure that all relevant stakeholders are familiar with the details and are implementing what is needed (step 10).

In this case study, knowledge of the hydrodynamics, habitat dynamics and associated biodiversity, and ecosystem services of the Sudd wetland will be incorporated. Knowledge of the characteristic longitudinal and lateral flows of the Sudd wetland will be evaluated, in the context of the control features that cause flow to move in multiple directions. This is used to consider the alterative directions of flows associated with habitats and control features in the wetlands, and associated habitats. Importantly these flow dynamics of the Sudd wetlands, affect the formation of habitats and their associated provision of ecosystem services and processes including: flow dynamics that drive the timing of flows in the wetland, delaying flows through the ecosystem, and volumes of flows including evaporation factors, duration of flows in different habitats and frequency of flows usually associated with flood attenuation. In addition any information on the affect of sediment transport and deposition relationships will be evaluated in the study. These processes drive wetland succession and major cyclic shifts in habitat characteristics across the wetland. This natural variability can be associated with long-term hydrological phases extended over many flow cycles (± 10 - 50yr). Although e-flows are usually established to maintain/provide suitable instream, floodplain and/or riparian habitats within wetlands, due to the dynamics of the flows within wetlands themselves, e-flow requirements that consider the volume, timing, frequency and duration of flows required to maintain wetland habitats are usually established for rivers or dam releases etc. upstream of the wetland. Habitats within wetlands and the ecosystem services and processes that are important for a range of ecological and social management objectives (or endpoints) of e-flow management are not uniformly distributed in space and time.

Contents

Abbreviations:

BBM	Building Block Methodology
BHN	Basin Human Needs
BN	Bayesian Network
CPT	Conditional Probability Tables
DRIFT	Downstream Response to Imposed Flow Transformations
E-flow	Environmental Flows
EFA	Environmental Flow Assessment
EFM	Environmental Flow Methods
EFR	Environmental Flow Requirements
ELOHA	Ecological Limits of Hydrologic Alteration
ESP	Environmental and Social Policy
GIS	Geographical Information Systems
HGM	Hydrogeomorphic
IFIM	Instream Flow Incremental Methodology
IWMI	International Water Management Institute
NBI	Nile Basin Initiative
NBSF	Nile basin Sustainability Framework
RQO	Resource Quality Objectives
RRM	Relative Risk Model
SUMHA	Sustainable Management of Hydrological Alterations
WUA	Weighted Usable Area

2 Introduction

The Nile Basin Initiative (NBI) recognises that the sustainable management of the shared Nile basin water resources requires the establishment of relevant transboundary policy instruments (within the Nile Basin Sustainability Framework (NBSF)). A Nile E-flows Framework (NBI, 2016a) was thus developed to contribute to the trans-boundary regional and basin scale management of riverine environmental flows (e-flows) in the Nile basin. *This general approach does not describe how wetland specific ecosystems can be evaluated and integrated into the framework.* The Nile E-flows Framework also included a manual that provides a step by step methodology for the management of e-flows in the context of best practice e-flow assessment methodologies (EFMs). *The E-flow Framework (NBI, 2016a) was established to direct e-flows of riverine environments, and although the general phases within the Nile E-flows Framework are applicable to wetlands, wetland environments are distinctly different, and these differences need to be considered when determining e-flows guidelines for wetlands.* This document provides context to the Nile E-flow Framework (NBI, 2016), for wetlands and the application of the PROBFLO Environmental Flow Assessment (EFA) methodology specifically aimed at assessing e-flows for transboundary wetlands of importance in the Nile basin. The first section of the report details the consideration of wetland specific ecosystems in the Nile E-flow Framework and the second describes the application of PROBFLO for a range of important transboundary wetlands in the Nile basin including, but not limited to:

- Nile Delta including estuary in Egypt.
- Dinder wetlands in Ethiopia and Sudan
- Lake Tana wetlands in Ethopia.
- Baro/Akobo Sobat Wetlands (specific focus on the Machar Marshes) in Ethiopia and South Sudan.
- Sudd (Bahr el Jebel) in South SIdan
- Bahr el Ghazal wetlands in South SIdan
- Lake Kyoga wetlands in Uganda influenced by rivers from Kenya.
- Semliki wetlands incl. Lake Albert / George / Edward in Uganda and the Democratic Republic of Congo.
- Lake Victoria wetlands in Kenya, Tanzania and Uganda.
- Kagera wetlands in Rwanda
- Mara wetland in Tanzania
- Sio Nzoia Yala Nyando wetlands (lumped together) in Kenya and Uganda.

3 Study Overview

The framework was established to direct e-flows of riverine environments, and although the general phases within the framework are applicable to wetlands, wetland environments are distinctly different, and these differences need to be considered when determining e-flows guidelines for wetlands. Wetland ecosystems in the Nile basin can generally be differentiated from the riverine ecosystems by a range of characteristics including; slow flowing (<0.2 m/s) lentic habitats that are usually shallow <2 m and well vegetated. They can be linked to rivers (e.g. floodplains) and/or due to flat topography rivers may flow into large depressions that form extensive wetland habitats, technically referred to as palustrine ecosystems. Other wetlands can be disconnected from rivers and be associated with seeps and depressions throughout the Nile basin landscape. Wetland ecosystems in the Nile basin have a high ecological, social and economic value and need to be used and protected in a sustainable manner. This requires the integration of wetland ecosystems into the Nile E-flows Framework with rivers, but also requires specific consideration of the unique attributes, values and processes of the Nile basin wetlands. In addition, while river ecosystems can be evaluated in a qualitative manner, where representative features can be considered and maintained at various locations along the length of the river, entire wetland ecosystems features need to be evaluated in a quantitative manner. This difference in approach needs to be considered for e-flow assessments of wetlands in the Nile basin. Guidance for the determination of e-flows for significant wetlands in the Nile basin must be undertaken in the context of the Nile E-flow Framework and must conform to the existing NBI Environmental and Social Policy (ESP), which includes the following established objectives (NBI, 2013a and b):

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.
4. To demonstrate commitment of the NBI and Nile countries to international best practices with regard to environmental and social management of development activities.

The sustainable use of these socio-ecologically important water resources of the Nile basin requires the coordinated management of the e-flows on meaningful spatial scales (Figure 3.1). Environmental flows describe the quantity, quality and timing of water flows required to sustain freshwater (including wetlands) and estuarine ecosystems and the human livelihoods and wellbeing that depend on these ecosystems (Arthington et al., 2018). The Nile E-flows Framework provides general standards and norms for riverine e-flows in the Nile basin for establishing e-flow requirements and managing flows in the Basin for transboundary water resources planning purposes (NBI, 2016a).

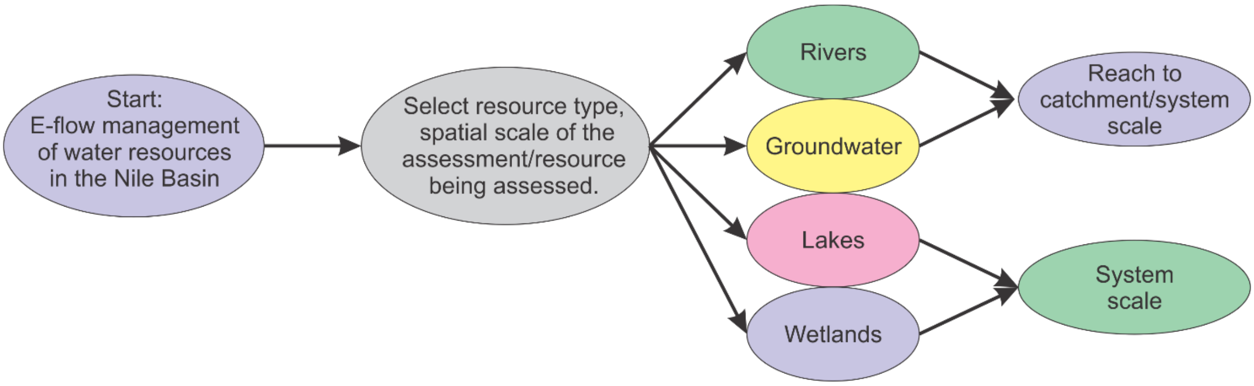


Figure 3.1: Schematic representation of spatial scope consideration for e-flow assessments in the context of the Nile E-flows Framework.

This technical manual expands on the principles of the Nile E-flows Framework, to include guidance for the application of the Nile E-flows Framework for determining e-flows for wetlands (Figure 3.2)*. The manual additionally provides a step by step methodology for the determination of e-flows for wetlands in this case study using the holistic regional scale EFM called PROBFLO (O'Brien et al., 2018).*

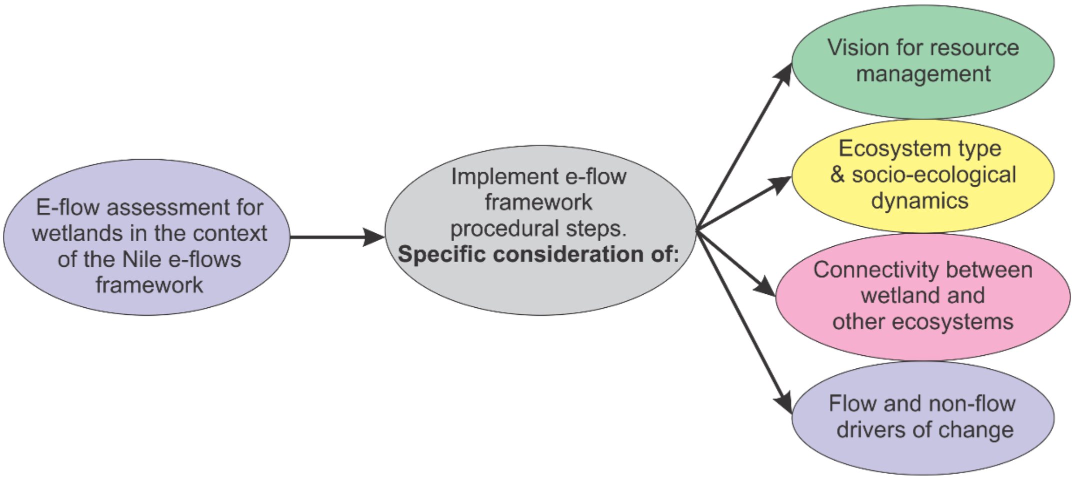


Figure 3.2: Schematic representation of important considerations for application of Nile e-flows framework for wetlands.

4 Review of the Nile E-flows Framework and considerations for wetlands

The Nile E-flows Framework has been designed to address the requirements of a suitable e-flows framework for the Nile basin and current best practice e-flows management frameworks and e-flows assessment methods into an adaptable, scientifically valid e-flows management framework for the Nile basin (summarised in Figure 4.1). *The purpose of the framework is to: (a) provide a structured approach for the determination of e-flows for important water resources (rivers, groundwater, lakes and wetland ecosystems) in the Nile basin, and (b) collate and apply existing e-flows information for water resources in the basin to contribute to the determination of e-flows throughout the basin*.

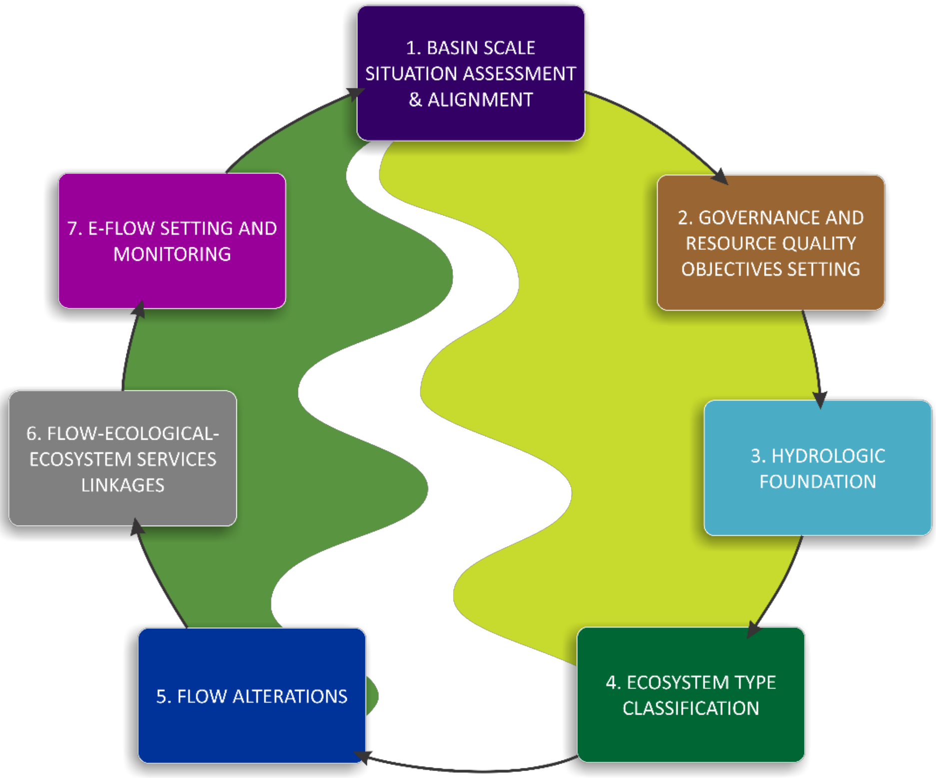


Figure 4.1: Summary of the seven phases of the Nile E-flows Framework established to direct the management of e-flows in the Nile basin.

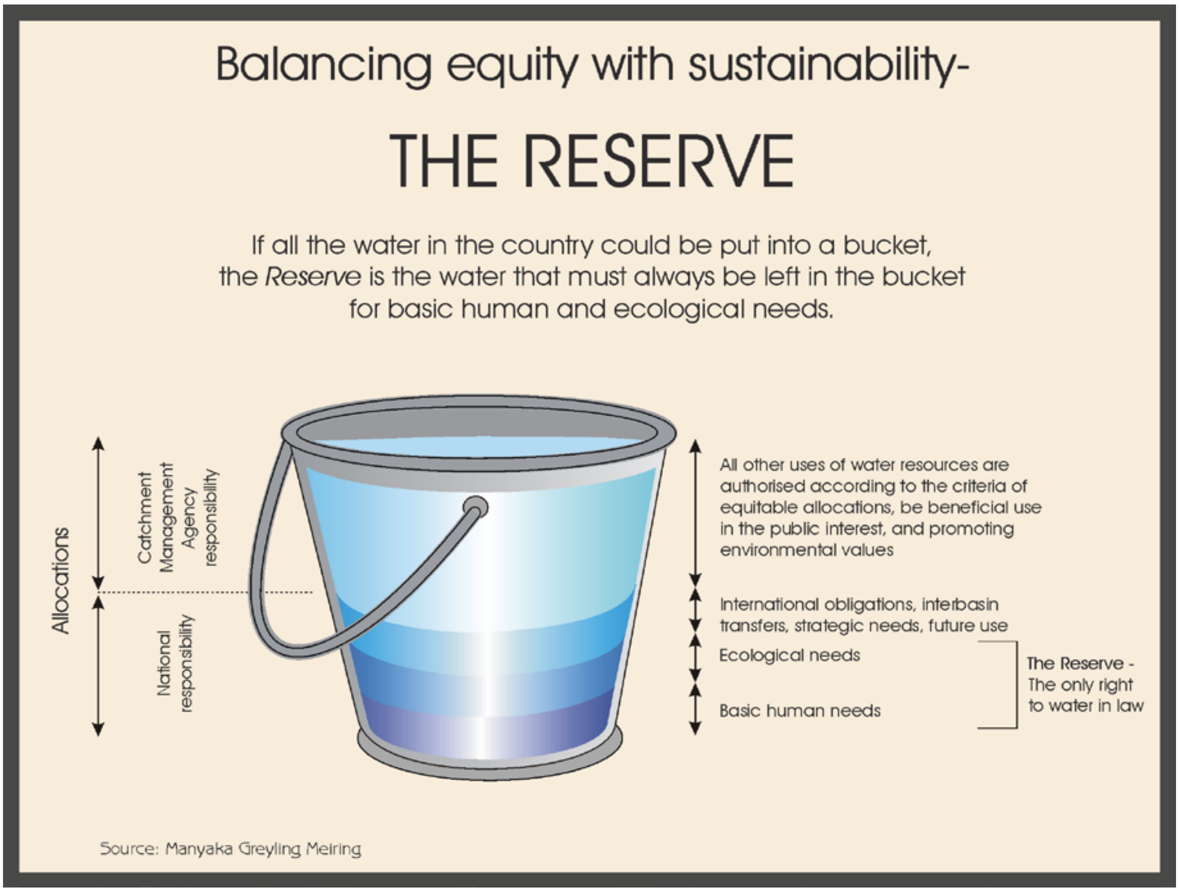
The principles of best e-flows management practice should be embraced for assessments of wetlands including (please refer to the NBI 2016a for more information):

- **Collaboration**: the principle of collaboration promotes the participation of stakeholders of the protection and use of water resources and e-flow management activities.
- **Sharing benefits**: the principle of the equitable allocation of allocable (*may exclude ecological type flows for example*) water resources to stakeholders in the Nile basin through a negotiation process is recognised as another fundamental principle of e-flows management. Some regional best e-flows management practices make provision for the protection of e-flows required to meet Basic Human Needs (BHNs) and ecosystem wellbeing as a legal right. These flows are often referred to as the “Reserve” (Figure 4.2). In addition, international obligations, strategic needs and future use may be protected as a national responsibility with legal implications. All flows

thereafter should be allocated equitably in an effective, efficient manner which promotes social upliftment and ecosystem protection.

- **Sustainability**: the ultimate aim of water resource management is to achieve the sustainable use of water for the benefit of all users. This must be considered in the context of the existing Nile cooperative framework that describes the right of all Nile basin States to reliable access and use the Nile River system for health, agriculture, livelihoods, production and environment**.** Sustainability necessitates the efficient, effective use of water resources and adequate consideration of water resource protection (Millennium Ecosystem Assessment, 2003, 2005).
- **Evidence based**: the principle of using available evidence in the decision making process is strongly recommended in e-flow management activities (Poff *et al.* 1997; Baron *et al.* 2002; Dudgeon *et al.* 2006; Calder and Aylward 2006). Sometimes referred to as a "science-based" approach, this principle promotes the use of available local and regional data and the generation of additional evidence required to make e-flow management decisions in the context of existing uncertainty. The principle also recognises that lack of certainty should not be the basis for lack of action and that in these cases the "precautionary principle" (O'Riordan 1994), should be adopted with suitable adaptive management actions (Richter *et al.* 2006).
- **Requisite simplicity**: requisite simplicity or the principle here of keeping an e-flow management activity "as simple as necessary" is strongly encouraged. Thus e-flows should be kept as simple as possible, but cannot avoid a necessary amount of complexity. The requisite simplicity concept recognises that although there are no simple answers and/or single solutions to all e-flows management challenges, a view of choosing not to indulge details or complexity, while retaining conceptual clarity and scientific rigor is recommended so that information can be used at an appropriate scale of implementation. It is recognised that on occasion, too much or too little information limits action, so good communication is required to identify what is important and understand how available information should be used (Mander *et al.* 2011).
- **Transparency**: transparency, and the principle of explicitly presenting limitations or uncertainties associated with e-flows management, is a fundamental part of best e-flows management practices. Transparency should be evident in all aspects of; stakeholder negations and consultative processes, decision making processes, the generation of and use of evidence and in e-flow methods and e-flow models and tools. Transparency allows true adaptive management where lessons learnt can be evaluated and mistakes corrected/avoided in future assessments.
- **Adaptability**: the principles of adaptive and/or flexible management can generally be defined as "learning from doing". This implies post-implementation activities that consider lessons learnt from the implementation in an attempt to achieve either; the original objectives of the activity or

new objectives, and associated actions, in accordance with new information learnt from the implementation of the activity.



Balancing equity with sustainability-

THE RESERVE

If all the water in the country could be put into a bucket, the *Reserve* is the water that must always be left in the bucket for basic human and ecological needs.

Source: Manyaka Greyling Meiring

Figure 4.2: Schematic description of the Ecological Reserve adapted from Manyaka Greyling Meiring (DWAF 1999; NBI 2016a).

The Nile E-flows Framework is based on these core principles of best e-flow management practices, and has been aligned with existing international frameworks namely the ELOHA and SUMHA frameworks and considers new best e-flow management practices such as PROBFLO (Poff *et al.* 2010; Pahl-Worstl *et al.* 2013; O'Brien et al., 2018). The existing framework has been established and largely directed towards river ecosystems. Here we direct the use of the framework and demonstrate an application of the PROBFLO EFM for wetlands to direct the application of the framework for wetlands and how PROBFLO can contribute to the application of the e-flows process for wetlands specifically.

5 Wetlands in the Nile E-flows Framework

The Ramsar Convention defines wetlands as "areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres" (cited by Ramsar Convention Secretariat 2011). The definition identifies five categories of wetlands including:

1. marine (coastal wetlands including coastal lagoons, rocky shores, and coral reefs);
2. estuarine (including deltas, tidal marshes, and mangrove swamps);
3. lacustrine (wetlands associated with lakes);
4. riverine (wetlands along rivers and streams); and
5. palustrine (meaning "marshy" - marshes, swamps and bogs).

For this Nile basin guideline on the determination of and management of e-flows for wetland, we have excluded marine ecosystem, which may be a receiving ecosystem of the effects of suitable and/or unsuitable e-flows, and river ecosystems, the latter of which is considered in NBI (2016a). Coastal and marine wetlands are often highly dependent on inputs of freshwater and associated nutrients and sediments from rivers. *In this report we will refer to the term "wetland" to represent estuarine, lacustrine and palustrine ecosystems and "river" to specifically represent these wetlands.* Wetlands are adapted to the prevailing hydrological regime and determined by the spatial and temporal variation in water depth, flow patterns through the ecosystem and water quality, this includes the frequency and duration of inundation.

The estuarine, lacustrine and palustrine wetlands that this guidance document has been designed specifically for includes:

- Nile Delta including estuary in Egypt.
- Dinder wetlands in Ethiopia and Sudan
- Lake Tana wetlands in Ethopia.
- Baro/Akobo Sobat Wetlands (specific focus on the Machar Marshes) in Ethiopia and South Sudan.
- Sudd (Bahr el Jebel) in South SIdan
- Bahr el Ghazal wetlands in South SIdan
- Lake Kyoga wetlands in Uganda influenced by rivers from Kenya.
- Semliki wetlands incl. Lake Albert / George / Edward in Uganda and the Democratic Republic of Congo.
- Lake Victoria wetlands in Kenya, Tanzania and Uganda.
- Kagera wetlands in Rwanda
- Mara wetland in Tanzania
- Sio Nzoia Yala Nyando wetlands (lumped together) in Kenya and Uganda.

6 Framework for environmental flow assessments of wetlands in the Nile basin

The Nile E-flows framework that is applicable for the application of all important water resources in the Nile basin (incl. rivers, groundwater, lakes and wetlands) integrates seven best e-flows management practice principles into seven procedural steps (Figure 4.1 and Figure 6.1):

- **Phase 1**: Situation Assessment and Alignment Process, aligns existing site and regional scale information and the plan for the new e-flows 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 e-flow governance requirements are considered/applied in e-flow 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 e-flows 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 ecosystems 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 e-flow assessments in an effort to assist with future assessments.

The dynamics of wetland ecosystems in the context of regional e-flow management must be addressed in Phase 4. Wetland ecosystems may or may not have direct relationships to river and/or groundwater ecosystems. Those that do not have any linkages can be managed independently but the majority that do have connections need to be considered in the context of the connections that drive the dynamics of those ecosystems. Estuaries and Floodplain ecosystems have direct relationships with rivers for example and these relationships contribute to the dynamics of the wetlands. In this phase of the Nile E-flows Framework the wetland types are clearly identified and considered in the context of regional ecosystems and flow-ecosystem and flow-ecosystem service relationships that include connections to other ecosystems. This knowledge of the types of systems and their dynamics will contribute to the selection of and use of EFMs and the application of the Nile E-flows Framework.

- **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 e-flow assessment methods.*
- **Phase 7:** E-flows 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 e-flow 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.

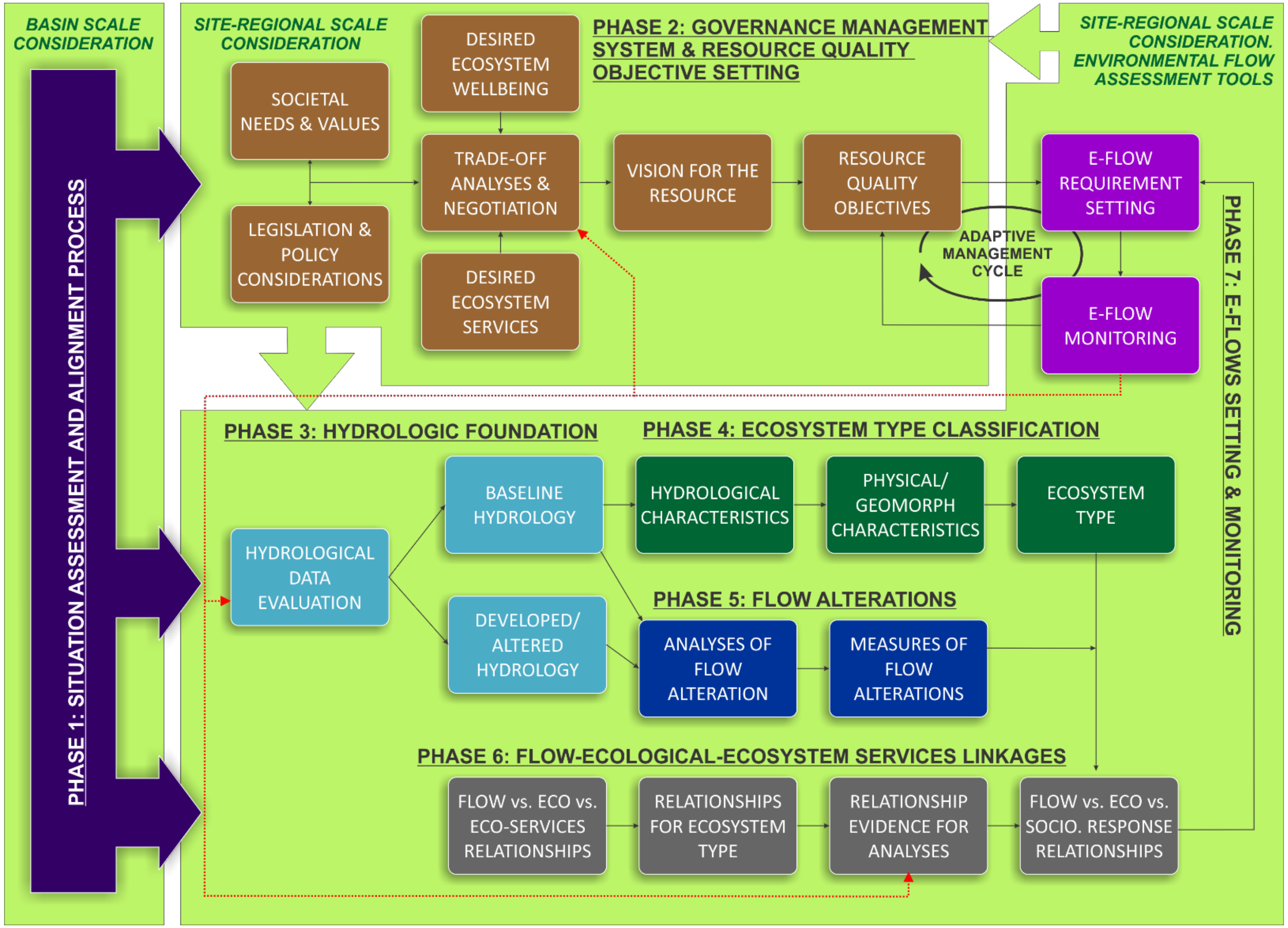


Figure 6.1: Expanded seven phase Nile E-flows Framework for the coordinated assessment of e-flows on multiple spatial scales in the Nile basin with the adaptive management cycle emphasised (from NBI, 2016a).

6.1 Theoretical Overview of the Nile E-flows Framework procedure for significant wetlands

In this section the application of the Nile E-flows Framework for evaluation of wetlands is considered. The dynamics of wetland ecosystems and associated endpoints or objectives for wetlands are addressed. More detail on the framework is available in NBI (2016a).

6.1.1 Phase 1: Situation Assessment and Alignment Process

The Nile E-flows Framework will contribute to the future aim of managing e-flows on a regional and ultimately Nile basin scale, where consideration for all of the water resources, including wetlands are considered, using information derived from past/existing sub-basin scale e-flow management activities. This includes e-flow information from other wetlands in the basin and/or e-flow information from rivers, groundwater and lake ecosystems that may be linked to the wetland of interest. Due to the hydrological dynamics of wetlands e-flows for wetlands are generally provided by upstream flows (volume, timing and duration) into the wetland. To integrate the requirements of wetlands into basin management plans of the Nile, the requirements of these ecosystem must be synchronised with e-flow requirements in rivers. This will ensure that the requirements of the wetlands are provided by the rivers that connect them.

Basin scale e-flows assessments require knowledge of future spatial scale relevant e-flow management objectives of important water resources, including wetlands and linkages between ecosystems, and an understanding of the flow-ecology and flow-ecosystem service relationships on a basin scale. Here consideration of resource availability in relation to use dynamics and linkages between systems including rivers and wetlands in the Nile basin is considered. The application of the framework allows for larger regional scale assessments to be undertaken and highlights information needs for larger regional/basin scale assessments. This necessitates the establishment of a coordinated basin wide water balance and e-flow management plan that integrates and synchronises the ecological requirements and BHN requirements as the “Reserve” (Figure 4.2), and associated international obligations to achieve the Reserve throughout the Basin (refer to NBI, 2016a).

The Nile E-flows Framework has proposed a top-down (using transboundary – basin scale requirements to propose management objectives in regions) and bottom-up (using existing site to regional scale objectives and e-flow requirements to establish regional objectives) approach to establishing regional scale e-flow management objectives and plans. This includes reviewing existing local and transboundary governance structures relevant to e-flows management activities on suitable spatial scales (local, regional, national and international) measures. In addition, available site and regional scale e-flow assessment objectives and outcomes should be reviewed and adopted directly into regional scale e-flow assessment until a basin scale alignment or synchronisation assessment of e-flow objectives and e-flow requirements can be carried out. Basin wide plans should include the evaluation of impaired wetland (and other) ecosystems caused by flow alterations, in the context of non-flow related stressors, on multiple spatial scales that will ultimately result in basin wide evaluation of e-flows threats to water resources. Not only must all other e-flows assessments/management plans be established with this basin scale objective in consideration, all other assessments should strive where possible to contribute to the basin wide understanding of e-flow requirements and threats. For example, sub-basin e-flow assessments in the Mara River in Kenya and Tanzania, can contribute to the e-flows assessment of the Lake Victoria Nile River Sub-Basin which in turn can contribute to the Nile basin assessment.

The Nile E-flows Framework conforms to the ELOHA Framework by promoting the determination of e-flow requirements for important aquatic ecosystems (including wetlands) simultaneously on a regional Nile Sub-Basin scale. This approach includes an assessment of priority ecosystems or those with a high social and/or ecological value which should urgently either be managed to achieve sustainability or protected to maintain conservation features that may offset use in other areas of the Basin. *This may include the initial low confidence assessments of rivers and wetlands for which little hydrologic or ecological information exists and the explicit presentation of uncertainty associated with these assessments.* This is achieved through the use of available regional information and directing scientific experimentation to provide general information for multiple river and wetland ecosystems in the Basin. For the Nile E-flows Framework to include a synthesis of knowledge and experience gained from individual case studies into a basin scale assessment, a dedicated alignment process has been established in the Framework.

The Nile E-flows Framework conforms with best international regional scale e-flow frameworks for the determination of e-flows for water resources (including wetlands) on meaningful scales, such as basin scales. This can be achieved by inferring requirements for ecosystems that have similar characteristics within the regional area being considered if information for those types of ecosystems is available. For unique, large and socio-ecologically important wetland ecosystems this approach is limited. When e-flow data for these unique wetlands is obtained however that information can effectively be used in the framework to contribute to the determination of low confidence e-flow requirements for other wetlands. This is the principle of regional scale e-flow frameworks. Take note that the framework advocates an adaptive management approach to mitigate the uncertainty of inferred e-flow requirements established using the e-flows framework.

To facilitate this process in the Nile E-flows Framework the establishment of a database that can store this information that should easily be accessed by, and contributed to by stakeholders for future regional and basin scale e-flows assessment is required. The alignment process then aligns available information from site and regional scale assessments for use in basin scale assessments into this database. The Nile E-flows Framework advocates consideration of minimum ecological and social information requirements to undertake e-flow requirements in this phase to direct the type of data needed for the database.

6.1.2 Phase 2: Resource Quality Objectives Setting

The governance system proposed for the Nile E-flows Framework promotes stakeholders to analyse and synthesize available scientific information into ecologically based and socially acceptable objectives and targets for management of e-flows of wetlands that will then direct the rest of the e-flow management process. These relationships serve as the basis for the societally driven process of developing regional and basin scale flow standards (sensu Pahl-Wostl *et al*., 2013). The Governance Management System and Resource Quality Objectives (RQO) setting phase of the Nile E-flows Framework includes the characterisation of the needs and values of society effected by e-flow management. This includes the establishment of a vision for the water resource which describes society's aspirations for the resource, which necessarily includes the level of use and/or protection that should be afforded to the resource. This process is usually carried out on a regional or basin scale at which level trade-offs between use and protection requirements can be established in a negotiated process in a meaningful regional context (sensu Pahl-Wostl *et al*., 2014). Along with ecosystem wellbeing requirements, ecosystem service requirements are considered not only to raise awareness of the importance of ecosystem functions for the resilience of social-ecological systems (Pahl-Wostl *et al*., 2014), but to support negotiation of trade-offs and development of strategies for adaptive implementation.

Through the application of the Nile E-flows Framework acceptable ecological conditions for each water resources including rivers, wetlands and the Nile Delta should be established, according to societal values. This can be accomplished through a well-vetted stakeholder process of identifying and agreeing on the ecological and cultural values to be protected or restored through resource management, all of which fits within the vision that is set for the water resources of the basin as a whole. *The goal of the Nile E-flows Framework is not to maintain or attempt to restore pristine conditions in all rivers and wetlands; rather, it is to understand the trade-offs that need to be made between human uses of water and ecological degradation.* Stakeholders might decide that some ecosystems, particularly wetlands should be protected from development, but other ecosystems such as river reaches for example and/or lake ecosystems could be managed for fair to good conditions, rather than excellent, ecological condition. This gradational approach lends flexibility to governments overseeing variable levels of water development within their jurisdictions. The Nile E-flows Framework, following the example of the ELOHA Framework, establishes a scientifically credible, legally defensible basis for this public discussion (Poff *et al.*, 2010). Once the ecological goals are decided, scientists can develop flow alteration - ecological response relationships based on flow statistics that are relevant to those goals. All stakeholders need to understand the process and uncertainties involved in developing these flow alteration-ecological response relationship

The e-flows implementation phase is enhanced by an adaptive management process, where e-flow requirements aligned to RQOs are established and implemented. Throughout the implementation phase monitoring data or targeted field sampling data is collected which allows for testing of the proposed flow alteration-ecological response relationships in the assessment. This experiential validation process allows for a fine-tuning of environmental flow management objectives (Poff *et al.*, 2010). This information is then available for stakeholders to either accept the achieved balance between the use and protection of water resources in the assessment or amend the RQOs or e-flow requirements using the new information. *Consider additional legislation and policy considerations available in NBI (2016a).*

Vision for the resource

There is the old saying that “if you don’t know where you are going, then any road will take you there” (Alice in Wonderland – Lewis Carroll). This caution translates into the management of water resources, that unless there is a picture of the desired state of a resource, then it is impossible to implement management activities that have any focus or purpose. Visioning is a process documenting society’s aspirations for the future, which could include its aspirations for the future of the Nile River and all its associated resources. But a vision statement must be converted into and explicitly linked with objectives that are useful at the operational level. This is where RQOs are relevant.

What is the context in which a vision needs to be described? The resources of the world, including those of the Nile basin, are at risk from overexploitation, which if it becomes a reality, will deprive society of the many services that are presently obtained from the Nile River and its wetland ecosystems. The vision thus needs to describe the resources of the Nile River as it continues to provide its beneficent supply of good and services to the people of the Nile Bain. In that process it needs to describe the reality that there are users of the resource who have present and probably future desires for the resources being provided. However, their desires need a level of restraint as well, as the resource cannot provide an unlimited supply of these resources, thus the vision needs to be aware of the limits of the river and wetlands to provide services. Yet it is society that manages this resource, so the process of setting the vision is as important as the final outcome because it requires stakeholders to develop an understanding of what the resource can provide together with the needs of other users and the impacts of their use on the resource.

The shared vision that forms the beginning of the NBSF notes: *"to achieve sustainable socio-economic development through equitable utilization of, and benefit from, the common Nile basin water resources."* There are two main components of this vision:

1. Equitable allocation of water resources
2. Water resources for sustainable development

What constitutes "equitable allocation" is a matter outside of the ambit of this report as this is a largely socio-political process that would entail the collaboration and agreement between all the countries of the Nile on how the allocable resources are shared for the benefit of those countries. However, the second component of sustainable development is less subjective despite the abuse the term has suffered over the years. The question is, how may water resources be used for *sustainable* development, and what does sustainable really imply? According to the Bruntland Commission (1987) sustainable development is *"development that meets the needs and aspirations of the present without compromising the ability of future generations to meet their own needs"*. Sustainable development requires consideration of three vital aspects required to ensure sustainability, the so called triple bottom line of social, economic and environmental all linked together and made possible by a governance system.

Resource Quality Objectives

Early thinking on the setting of objectives for the water resource emerged in the extensive 1999 South African publication of guidelines for resource directed measures (DWAF, 1999) which noted that "Resource Quality Objectives for a water resource are a numerical or descriptive statement of the conditions which should be met in the receiving water resource, in terms of resource quality, in order to ensure that the water resource is protected." This manual also states that RQOs are scientifically derived criteria based on best available scientific knowledge and that they should be set for each Resource Unit for instream and riparian habitat and aquatic biota. The National Water Resources Strategy of South Africa (DWA, 2013) took this further and stipulated that "Resource Quality Objectives might describe, among other things, the quantity, pattern and timing of instream flow; water quality; the character and condition of riparian habitat, and the characteristics and condition of the aquatic biota". In Box 1 (below), a description of these resource components is provided. These are numerical and narrative descriptors of conditions that need to be met in order to achieve the required management scenario as provided during the resource classification.

Box 1: Description of the resource components considered for Resource Quality Objectives for Wetlands.

Water resource can be divided into a number of components each of which needs consideration during implementation of resource management via the setting of objectives. The relevant aspects of these components are as follows:

- Quantity
  - Water inputs (the function and habitat of wetlands are dependent on amount of water entering the wetland from the upstream catchment as well as the pattern or timing of the inputs).
  - Water distribution and retention patterns (the way in which water is distributed and retained within a wetland as changes in water distribution can affect the biological processes and the vegetation patterns).
- Quality
  - Nutrients (those chemicals that promote growth of plants and animals – sometimes resulting in nuisance conditions).
  - Salts (dissolved salts).
  - System variables (a collection of water quality parameters not elsewhere considered including pH, turbidity or suspended solids, temperature, dissolved oxygen.
  - Toxics (chemicals present in the water that are potentially toxic to both the ecosystem as well as to people making use of the water. This includes metals as well as organic chemicals).
  - Pathogens (particularly human gut bacteria and viruses).
- Habitat
  - Geomorphology (the processes of weathering, erosion, and deposition that affects the three-dimensional structure of the wetland surface).
  - Wetland vegetation (provides the compositional and structural characteristics that provide specialised habitats for a range of important wetland dependant species).
- Biota
  - Fish (which may be considered both from a social use and ecosystems point of view).
  - Riparian plants (both the biodiversity as well as the functionality of the vegetation in securing the river banks).
  - Mammals (water living mammals eg. Hippopotamus – excluding those just drinking from the wetland).
  - Birds (birds associated with the wetland including migrants and resident species).
  - Amphibians and reptiles (frogs and lizards associated with the wetland).
  - Periphyton (algae growing on the substrate of the wetland).
  - Aquatic benthic macroinvertebrates (small invertebrates that live on the wetland substrate, whether on stones, gravel of sand, or on submerged vegetation).
  - Diatoms (small algae that coat all the substrates under water – forming an important part of the food-chain).

Determination of RQOs, targets and indicators

It has above been made clear that there is a need to quantify various aspects of the water resource so that management of the water resource, for the benefit of society, is possible. These objectives have associated with them various targets and quantitative indicators (Figure 6.2).

Description of RQOs, targets and indicators

The output of this process will be the generation of RQOs, targets and the definition of indicators for each Resource Unit or basin area that is relatively homogeneous from an ecological point of view (i.e. Ecoregions). Refer to Background Document 2 (NBI, 2015).

Resource Quality Objectives

These are essentially narrative and qualitative but sometimes broadly quantitative statements that describe the overall objectives for the catchment or Resource Unit. For example, an RQO for a river may state *"e.g. the quantity of water in the river is sufficient to keep the ecosystem in good condition providing the local people with an abundant source of fish as food"*. These RQOs are aligned with the vision for the resource, and as they are essentially narrative, are less subject to change as the understanding of the ecosystem changes. Because they are descriptive, and generally easy to understand, they are also meaningful to stakeholders, as well as the responsible managers, and give direction for whatever action is necessary to achieve the vision for the resource.

Targets

Targets describe the RQOs in relation to the components of the ecosystem that need to be managed i.e. quantity, quality, habitat and biota but may also include other characteristics. The targets thus state in narrative (or quantitative) terms the detail on how the RQO is to be achieved. Hence, where the above example RQO was that the quantity of water was sufficient to keep the ecosystem in good condition and that it would provide abundant fish for consumption, the target now details this by saying that e-flows are provided according to the month of the year and wet/dry cycles and that these flows should keep the river and wetlands in a good condition (measurable condition). A biological target could include that fish will be provided in sufficient quantities for a sustainable fishery.

Indicators

The indicators give a quantitative measure of the targets that need to be achieved if the water resource is going to comply with the vision e.g. following the examples given above, the indicators would be the actual flows in m^3/s that must be in the river or wetland in each month of the year according to seasonal variation and wet/dry cycles i.e. the e-flows. Indicators would also state the statistics of what constitutes a sustainable fishery – the species, number and size of fish that must be found following a fixed sampling procedure, if the vision for the ecosystem is to be achieved.

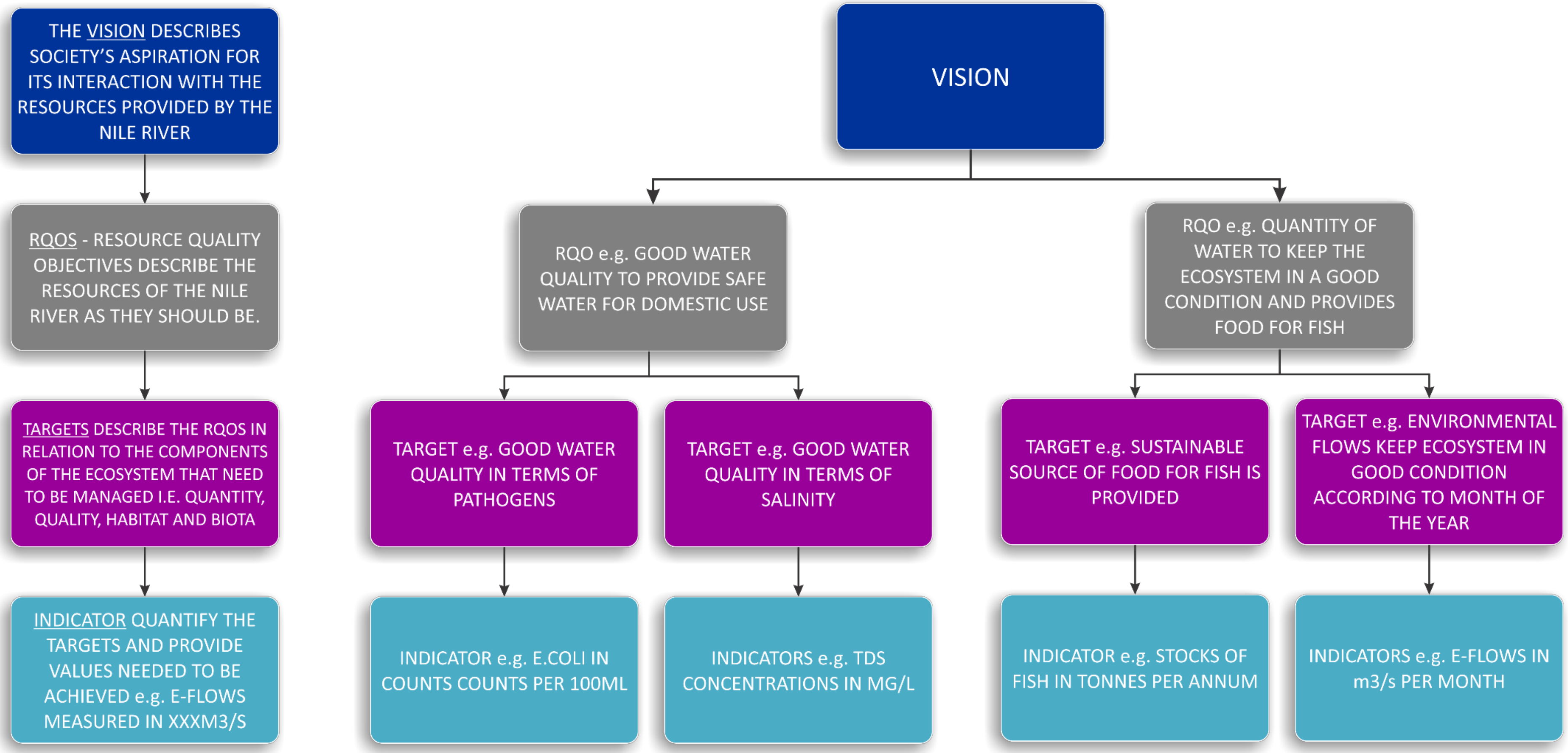


Figure 6.2: Illustration of how the hierarchy of the Vision, Resource Quality Objectives and the eventual Indicators are structured. *(Note that the use of the words Target and Indicator here is aligned with the recent Sustainable Development Goal documentation)*

Adaptive management

The fundamentals of adaptive management, or learning while doing, established by Holling (1978) and Walters (1986) is based on revisiting outcomes, re-evaluating approaches and learning from past experiences. The approach expels the concept of postponing action until "enough" is known, but acknowledges that time and resources are too limited to defer some form of action, particularly to address urgent problems such as maintaining ecosystem processes or ecosystems service provision which people depend on. Adaptive management principles accept that our knowledge of ecosystem structure and function is not uniform and to address this unevenness, management policies should be selected to test specific assumptions, so that the most important uncertainties are tested rigorously and early. Adaptive management responds to problems and opportunities, which differs from pure experimental science which explores a phenomenon systematically. Consider that there are still advantages and disadvantages to both adaptive management and traditional experimental approaches.

In the adaptive management phase of the Nile e-flows process, e-flow requirements aligned to RQOs are initially established and implemented. Here the precautionary approach to environmental management (Wynne, 1992), is advocated. This includes the selection of a high protection vision for e-flows management for sites, regions where very little information is available, which requires that use is minimised and ecosystem protection is prioritised. With limited understanding of e-flow requirements, this approach directs managers to regulate use, and monitor the response of the ecosystem to existing uncertainties and variability in flows. With some information on the ecosystem, user requirements and responses of ecosystems to e-flow variability management, RQOs should be established which provide direction for the attainment of e-flows. With these requirements an EFA can be undertaken which implements the rest of the procedural steps of the Nile E-flows Framework. The EFA culminates in an Environmental Flow Requirement (EFR) with associated socio-ecological consequences to altered flows. In the adaptive management phase, a monitoring programme is developed to test the modelled socio-ecological responses to altered flows during the implementation phase of e-flows management. Should the e-flows requirement implementation be hampered, monitoring the socio-ecological response of ecosystem components to altered flows is still important as the EFA outcomes usually describe the response of the system to a range of flows. This monitoring data is required to validate and update the objectives for e-flows in the system and the EFA assessments. This experiential validation process allows for a fine-tuning of environmental flow management objectives (Poff *et al*., 2010). This information is then available for stakeholders to either accept the achieved balance between the use and protection of water resources in the assessment or amend the RQOs or EFRs using the new information.

The Framework promotes an adaptive management process that is (1) informed by iterative learning about the ecosystem, (2) earlier management successes and failures and (3) increase present day resilience that can improve the ability of e-flows management, to respond to the threats of increasing resource use. This type of adaptive managementcan be used to pursue the dual goals of greater ecological stability and more flexible institutions for resource management.

6.1.3 Phase 3: Hydrological Foundation

In this step hydrological modelling is usually used to model long term (period long enough to represent climate variability) baseline or reference flows on a daily or monthly time interval to build the 'hydrologic foundation'. These reference flows refer to natural or minimally impacted flows at certain points (important tributaries, Environmental Flow Requirement sites, and gauging weirs) 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 output from this modelling is usually presented as hydrographs (monthly or daily) and hydrological statistics (mean, median, 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 and geomorphological 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 regime types 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 water managers may want to make allocation or other water management decisions, as well as sites where biological data have been collected. Figure 6.3 illustrates schematically the approach to develop the hydrological foundation, adapted from Poff, *et al.* (2010).

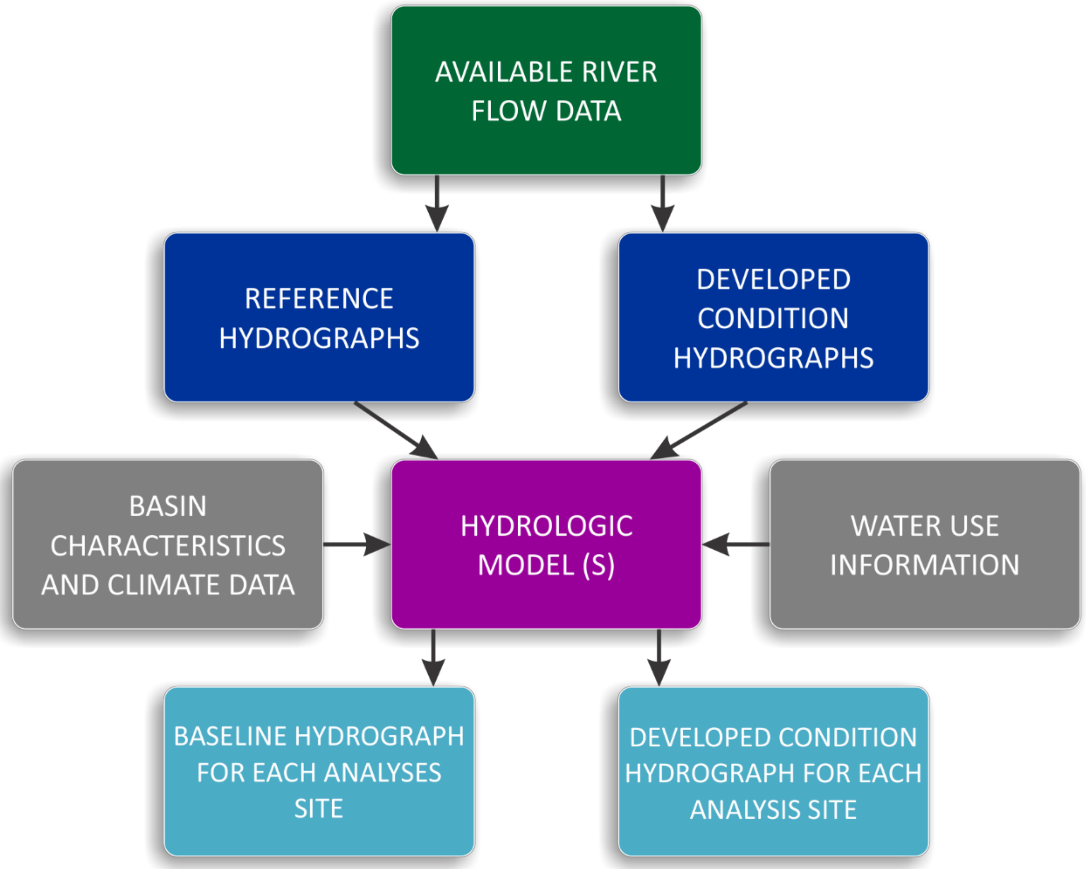


Figure 6.3: Schematic illustration of the approach to develop the hydrological foundation (adapted from Poff *et al*., 2010).

Outcomes of the hydrological assessment usually include a series of statistical data describing the historical and developed hydrographs from the study area. Additional information includes flow duration statistics of various scenarios for e-flow assessments.

6.1.4 Phase 4: Ecosystem Type Classification

Current best practice e-flow frameworks recognise the importance of describing the aquatic ecosystems considered in an e-flow assessment from which future assessments can use/benefit from case studies that have evaluated similar ecosystems. The Nile E-flows Framework has been aligned to these best practice frameworks and currently incorporates a river classification system (Pahl-Wostl *et al.*, 2013), and allows for expansion of the system to consider other ecosystems in the future (NBI, 2015b) (Ollis *et al.* 2014). The wetland, *including rivers here*, type characterisation process involves the characterisation of variations (usually natural) in measured characteristics of riverine ecosystems in the present Framework. With these river type characterisations, the responses of similar ecosystems can be compared and commonalities applied to other ecosystems within the Basin. This approach will direct cost effective e-flow assessments on regional scales throughout the Basin. The range of natural hydrologic variation that regulates habitat characteristics and ecological processes will be described for each wetland type evaluated using a standard river type classification system. This information details the current baseline states of many physical environmental variables against which ecological responses to future alterations can be compared and measured. With this approach numerous river segments along a gradient of hydrological alteration can be characterised and the ecological repose to any changes can be compared in the context of river typology. In addition, efficient environmental monitoring and water resource protection research design can be facilitated by combining the regional hydrologic model with a river wetland information. This will enable the strategic placing of monitoring sites throughout a region to optimise the range of ecological responses across a gradient of hydrological alteration for different river types. The Framework focuses mainly on hydrological and geomorphic characterisation of rivers segments to determine river types. Wetland types can be further sub-classified according to important geomorphic features that define hydraulic habitat features. The ELOHA Framework (Poff *et al*., 2010), builds on the wealth of available information obtained from decades of river-specific studies, and allows for the application of that knowledge to large regional and basin scale geographic areas. River segments and wetlands can be classified into a categories based on similarity of flow regimes. Each type of ecosystem can be sub-classified using key geomorphic characteristics that define physical habitat features. The number of ecosystem types that may occur in a region will depend on the region’s inherent heterogeneity and size. The wetland classification component of this Framework recognises that apart from Nile River itself which is one of the world’s most iconic natural features, the Basin contains many ecologically important wetlands that are globally recognised and should be incorporated into the Framework.

6.1.5 Phase 5: Flow Alterations

In the Nile E-flows Framework for wetlands the deviation of current condition flows from baseline-condition flow is then determined. Here suitable hydrologic evaluation tools are used to describe the hydrologic alteration for each river or wetland segment, (usually expressed as the percentage deviation of developed-condition flows from baseline-condition flows). There after a range of flow statistics can be produced to describe the flow scenarios (historical vs. current vs. altered flows for example) developed for the site being assessed. These statistics are then used to establish flow-ecological responses so that the socio-ecological consequences of altered flows can be established. In this section e-flows required to maintain a selected range of ecosystem features for example, can be generated from established flow-ecological relationships or flow-ecosystem service and social requirement relationships.

6.1.6 Phase 6: Flow-Ecological-Ecosystem Services Linkages

The Nile E-flows Framework conforms to the ELOHA Framework (Poff *et al*., 2010), here by including a synthesis of existing hydrologic and ecological databases from many rivers and wetlands within a user-defined region to develop scientifically defensible and empirically testable relationships between:

- flow alteration and ecological responses, and
- flow alterations and ecosystem service and social relationships

This information is required to link the use and protection aspects of water resources to the measures of flow alterations so that the changes in flows can be evaluated. These relationships should be developed for each river type and wetland, based on a combination of existing information, expert knowledge and field studies across gradients of hydrologic alteration. Many methods have been established to contribute to this process. Best practice principles of scientific validity, transparency and where relevant the use probabilistic modelling techniques should be used. Uncertainty associated with the description of these relationships will exist, potentially due to the complex nature of ecosystems and the attempts to use indicator relationships components to describe complex relationships and the synergistic effect of non-flow variability. It is important here to address uncertainty explicitly and discuss the implications of the uncertainty and how to reduce uncertainty. The approach synthesizes existing hydrologic and ecological databases from many rivers and wetlands within a region to generate flow alteration-ecological response relationships for rivers and wetlands with different types of hydrological regimes (sensu Poff *et al*., 2010). These relationships correlate measures of ecological condition, which can be difficult to manage directly, to river and wetlands conditions, which can be managed through water use strategies and policies for example. Although detailed flow-ecology and flow-ecosystem service and social relationships may be limited an adaptive management approach should be adopted with an emphasis on monitoring these relationships to generate a better understanding of the socio-ecological consequences of altered flows during adaptive e-flow management cycles.

Although it is acknowledged that the socio-ecological relationships are complex and that not all aspects of the relationships can be characterised, ecosystem components that are widely used to describe these relationships should be considered as core components. This includes for example:

- the characterisation of flow dependent habitat requirements/preferences of aquatic animals,
- flows required to maintain river and wetland substrate types to maintain habitat requirements for indicator aquatic animals,
- flows required to provide access for aquatic animals to move between important habitat types such as the flows required to allow animals to move between different river reaches, this

includes flows requires to establish linkages between important aquatic ecosystems such as rivers and their floodplains,

- the flows required to inundate different zones of riparian ecosystem to maintain the wellbeing of this component,
- flows (including floods) required to maintain aquatic biodiversity, and population wellbeing specifically considering the wellbeing of fish, invertebrates and riparian ecosystems,
- the flow associated movement to fine and course particulate organic matter to maintain ecosystem productivity and energy processes,
- shape of flows required to suspend or deposit material across ecological important reaches of the ecosystems, and
- flows required to dilute water quality constituents that may accumulate or concentrate and drive non-flow related impacts.

Many scientifically valid methods or lines of evidence including numerous biological indices are available to be applied in EFA case studies. Indicator ecological components selected for EFAs are usually linked to the endpoints or objectives considered in case studies, the types of flow alterations and threats to socio-ecological objectives.

Flow-ecology or ecosystem services hypotheses

Although flow-ecological, and flow-ecosystem service relationships are dynamic and difficult to characterise, relationships that are used to evaluate the socio-ecological consequences of altered flows, should can be established and used as hypotheses to base decision on. These hypotheses should be based on available evidence, uncertainties associated with these hypotheses should be presented explicitly, and these relationships should be tested through e-flow implementation and environmental monitoring. In an adaptive management process, hypotheses should be amended or validated and if required refined to represent a better understanding of the flow-ecological, and flow-ecosystem service relationships.

6.1.7 Phase 7: E-flows Setting and Monitoring

Through the application of the suitable EFM, the flow-ecological, and flow-ecosystem service relationships are used in the context of the ecosystem types and flow alteration information (may include scenarios) to establish suitable EFRs in the context of the RQOs (or EFA endpoints) for a site/region. The selection of suitable EFRs ultimately depends on the desired balance between the use and protection of the ecosystem being evaluated and the amount of risk associated with the RQOs being achieved, stakeholders and decision makers are willingness to accept. Some EFMs facilitate this process and can contribute to the trade-off decision making process and then provide information pertaining to the socio-ecological consequences associated with these decisions. These EFRs can then be converted into hydrologic rules that can be communicated to regional managers and then implemented and monitored.

Monitoring plan and recommendations for adaptive management

Environmental Flow Assessments only provide predictions of the likely effects of modified flow regimes (Pahl-Wostl *et al*., 2013). Only when the flows are implemented can these predictions be tested and verified. Once flow recommendations are defined, an associated monitoring program must be implemented alongside the flows to test and verify/challenge the original predictions given in the initial EFA. As implementation occurs, monitoring and evaluation provides information to inform the adaptive management cycle where the information is then used to refine the initial recommendations.

The purpose of establishing and implementing an e-flow monitoring plan within the Nile E-flows Framework is to identify and direct monitoring activities to test the successes and failures associated with the EFA and socio-economic consequences associated with the e-flows selected for a system. This is especially important in case studies with high uncertainty associated with available evidence. In addition, the purpose of the monitoring programme is to assess the achievement of EFRs, as well as to monitor whether the achievement of EFRs result in the expected outcomes in terms of socio-ecological responses. Ecological responses are difficult to monitor due to their variability in space and time, and the monitoring programme must be designed such that it addresses the complex relationship between biological responses and physical parameters such as flow, channel morphology and water quality considered in the EFA. The Nile Framework advocates the implementation of the monitoring programme by regulators as a key part of the water resource management activities.

7 Wetland ecosystems of the Nile River Basin

The Nile basin Wetland Management Strategy (2013) states that: *Wetlands are key natural environmental assets providing crucial ecosystem services that support livelihoods and socio-economic development in the basin. Their role in mitigating climate change and supporting climate resilience as well as safeguarding water, food and energy security is currently threatened through their insufficient protection and management*. Within the Nile basin, wetlands and other water bodies represent at least four percent of the total area with more than 70 major wetlands of relevance for the Nile system having been identified by the riparian countries (Table 7.1). 17 Nile basin wetlands are also designated as "Ramsar wetlands of international importance" (Table 7.2; Figure 7.1) as they provide wintering grounds for migratory birds and important biodiversity hot spots (NBI, 2013).

Table 7.1: Major Nile basin Wetlands (NTEAP Wetland Inventory) (NBI, 2013)

Country	Name	River/Lake	Town (near)
Burundi	Lake Cohoha	Akanyaru River	Bujumbura, Gitega
	Lake Gacamirinda	Akanyaru River	Muyinga, Gitega
	Lake Rwihinda	Akanyaru River	Muyinga,Gitega
	Lake Rweru	Nyawarungu River	Bujumbura, Muyinga
	Lake Kanzigiri	Lake Rugwero	Muhinga, Gitega
	Luivironza/ Kayongonzi/ Ruvubu System	Luvironza/ Kayongozi/ Ruvubu System	Muyinga
	Akanyaru River	Akanyaru River	Muyinga
DRC	Lake Albert Swamps	Lake Albert	Bunia
	Lake Edward	Kazinga Channel	Lubero
	Semliki River	Semliki River	Bunia
Egypt	Lake Manzala	Nile	Alexandria
	Lake Nasser	Nile	Aswan
	The Delta Proper	Nile	Alexandria
	Lake Maryut	Nile	Alexandria
	Lake Idku	Nile	Alexandria
	Lake Burullus	Nile Delta	Kafr El Sheikh
	Lake Bardawil	Nile Delta	Port Said
Ethiopia	Lake Tana	Lake Tana	Amhara Region
	Fogera floodplain marsh and swamps	Gumera River, Lake Tana Eastern shore	Fogera Woreda, South Gondar
	Dembia floodplain marsh and swamps	Dembia River, L Tana, northern valley	Dembia Woreda, North Gondar
	Bahir Dar Zuria marsh and swamps	Lake Tana, southern valley	Bahir Dar Woreda, West Gojam
	Dangela floodplain marsh and swamps	Kilti River, (L. Tana's tributary)	Awi Zone, Dangela Wereda
	Gambela marsh and swamps	Baro, Akobo, Alwero and Gilo Rivers	Gambela Region
	Fincha'a-Chomen Lake marsh	Finch'a- Chomen Reservoir	Fincha'a, Shambu, E Wellega
	Dabus River marsh and swamps	Dabus River floodplain	Nejo, W.Wellega, Oromiya Region
	Illubabor marsh and swamps	Valley bottom along numerous highland small streams	Illubabor Zone, Oromiya Region
	Abay and Beles River floodplains	Abay and Beles River (lower)	Benishangul-Gumuz Region
Kenya	Winam Gulf swamps	Lake Victoria	Kisumu
	Lake Vicrotia East Shore	Lake Victoria	Kisumu
	Sio-Siteko Wetland System	Lake Victoria	Nambobato
	Lotakipi (Lotagipi) Swamp	Lake Turkana	Loropio
	Mara river basin wetlands	Mara River	Migori
	Lake Jipe wetlands	Lake Jipe	Voi
	Lake Chala wetlands	Lake Chala	Voi
Rwanda	Kamiranzovu Swamp	Rukarara River	Rusizi
	Lake Muhazi	Nyabugogo River	Kigali, Kibungu
	Rugezi Swamp	Ruhondo Lake	Gicumbi, Musanze

Country	Name	River/Lake	Town (near)
	Mugesera Rweru Swamp Complex	Nyabarongo River	Kigali, Kibungu
Sudan	Lake Nubia/ Nasser	Nile	Dongola
	El Roseires	Blue Nile	El Roseires
	Sennar	Blue Nile	Sennar
	Kashm el Girba	Atbara	Kassala
	Dinder Floodplains	Dinder River	Dinder Town
	Gebel Aulia	White Nile	Khartoum
South Sudan	Sudd swamp	Bahr el Jebel	Bor
	Lake Yirol	Yei River	Yirol, Shambe
	Lake Anyi	Yei River	Shambe
	Lake Nyiropo	Lau River	Shambe
	Kenamuke/ Kobowen Swamp	Kangen River, Sobat River	Juba
	Lotilla Swamps	Lotilla River	Pibor
	Badigeru Swamp	Kenyenti River	Juba, Bor
	Nile Valley below Malakal	White Nile	Malakal
	Veveno/ Adiet/ Lilebook Swamps	Lotilla River	Bor, Pibor Post
	Lake Ambadi	Bahr el Ghazal	Rumbek
	Bahr el Ghazal Swamps	Bahr el Ghazal	Wau
	Machar marshes (Sobat Marches)	Sobat River	Daga Post, Malakal
Tanzania	Kagera swamps	Kagera River	Mwanza
	Lake Vie, south shore swamps	Lake River	Mwanza, Kagera
	Mara wetlands	Kafu River	Mara
Uganda	Kafu System	Kafu River	Masindi
	Lake Wamala	Kibimba River	Kampala
	Lake Bisina & Opeta	Lake Kyoga	Junja
	Kijanebalola Lake	Ruizi River	Mbarara
	Bunyoni Lake	Kabirita River	Mbarara
	Lake Albert	Albert Nile	Masindi, Hoima
	Lake Edward	Kazinga Channel	Fort Portal
	Lake Vie, north shore swamps	Lake Victoria	Entebbe, Jinja, Kampala, Masaka
	Lake Kyoga Kwani Swamps	Lake Kyoga	Lira, Soroti, Mbale, Nakasongola
	Lake George swamps	Lake George	Kasese
	Albert Nile swamp	Albert Nile	Arua

Table 7.2: Wetlands of International Importance within the Nile basin (NBI, 2016b)

Name	Country	Sub-basin	Area (km^2)	Dominant type
Virunga National Park	DRC	Lake Albert	8,000	Permanent freshwater lakes
Rugezi- Bulera Ruhondo	Rwanda	Lake Victoria	85	Permanent freshwater marshes
Lake Bisina Wetland System	Uganda	Victoria Nile	542	Permanent freshwater lakes
Lake George	Uganda	Lake Albert	150	Permanent freshwater lakes
Lake Mburo- Nakivali Wetland System	Uganda	Lake Victoria	268 - 837	Permanent freshwater lakes

Name	**Country**	**Sub-basin**	**Area (km^2)**	**Dominant type**
Lake Nabugabo	Uganda	Lake Victoria	220	Permanent freshwater lakes
Lake Nakuwa	Uganda	Victoria Nile	911	Permanent freshwater marshes or pools
Lake Opeta	Uganda	Victoria Nile	689	Permanent freshwater marshes or pools
Mbamba Bay	Uganda	Lake Victoria	24	Permanent freshwater marshes or pools
Murchison Falls-Albert Delta	Uganda	Victoria Nile	172	Permanent freshwater marshes or pools
Nabajjuzi	Uganda	Lake Albert	17	Permanent freshwater marshes or pools
Rwenzori Mountains	Uganda	Lake Victoria	995	Seasonal/intermittent freshwater lakes/rivers
Sango Bay- Musambwa island	Uganda	Lake Albert	551	Seasonal/intermittent freshwater lakes
Sudd	South Sudan	Bahr El Jebel	57,000	Permanent/seasonal rivers
Dinder National Park	Sudan	Blue Nile	10,846	Seasonal/intermittent freshwater lakes/rivers
Lake Burullus	Egypt	Main Nile	426	Permanent freshwater marshes or pools
Bahr El Ghazal swamps	South Sudan	Bahr El Ghazal		Permanent/seasonal rivers
Sobat/Machar Marches	South Sudan	Baro Akobbo Sobat	4,041	Permanent/seasonal rivers

Ramsar site information is available for three of the abovementioned wetlands, these include Rugezi-Bulera Ruhondo, Lake Nabugabo and Murchison Falls-Albert Delta. This information includes an overview of the characteristics and supporting description of these systems. No information is provided for the Lake Nakuwa and Sudd systems, whereas information for the Lake Bisina Wetland System is in preparation.

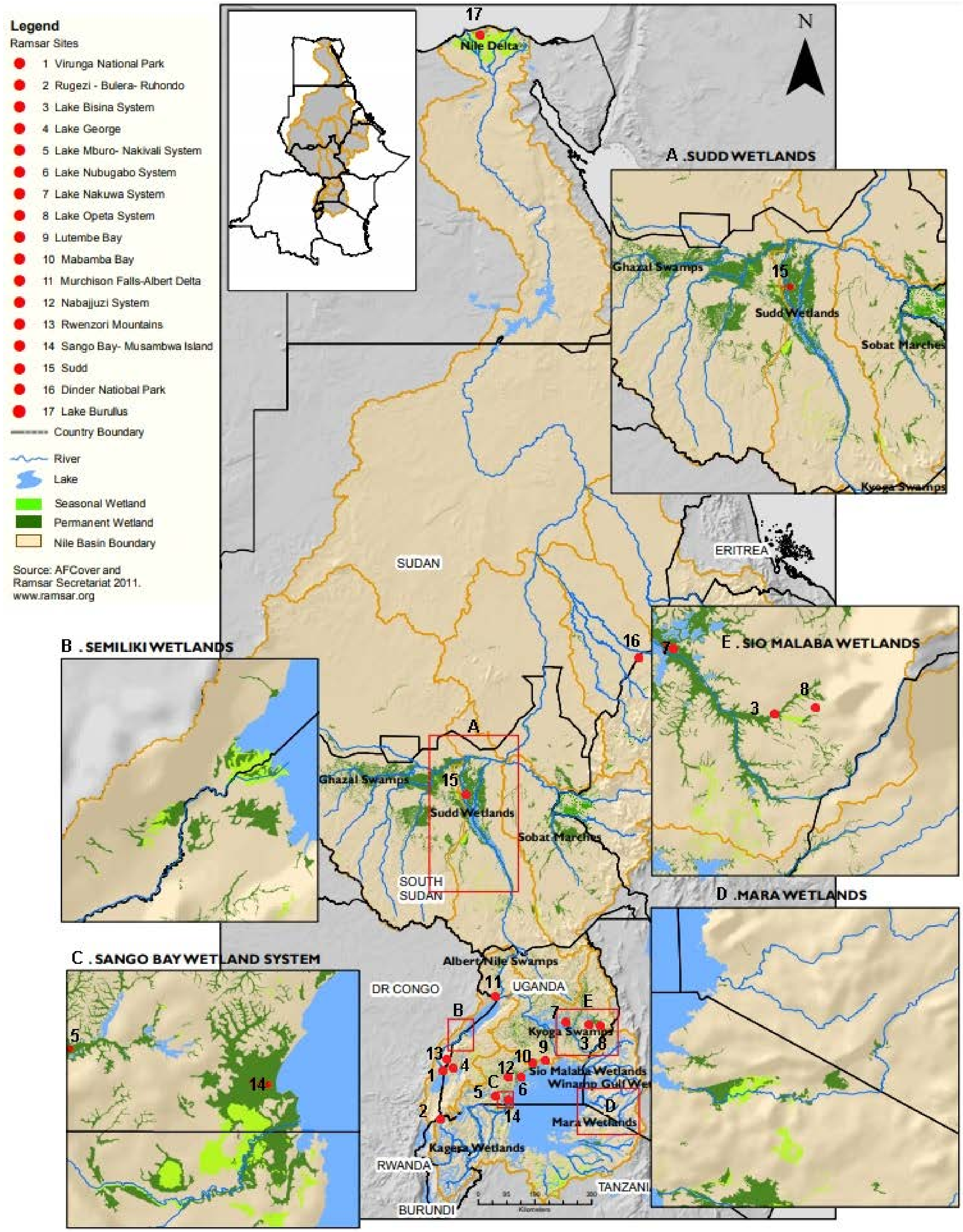


Figure 7.1: Wetlands and Ramsar sites in the Nile basin (NBI, 2012)

The characteristics and function of any wetland is determined by climate, hydrology, substrate and position and dominance in the landscape (National Research Council, 1995). Hydrology is the driving force that controls the abiotic and biotic characteristics of wetlands (Figure 7.2) and the temporal pattern of water levels (hydroperiod) for an individual wetland is its ecological signature. The thresholds (direct indicators) for the hydrologic criterion are normally defined in terms of the frequency or duration of continuous flooding or saturation within a given distance of the surface during the growing season. The long-term threshold for hydrology of a wetland is that which, at minimum, is necessary to maintain the vegetation or other organisms of wetlands as well as characteristic physical and chemical features of wetland substrate, such as hydric soils. Unfortunately, there is much uncertainty about the duration and frequency of saturation that define this threshold, especially because the threshold can be expected to vary from one region to another (National Research Council, 1995).

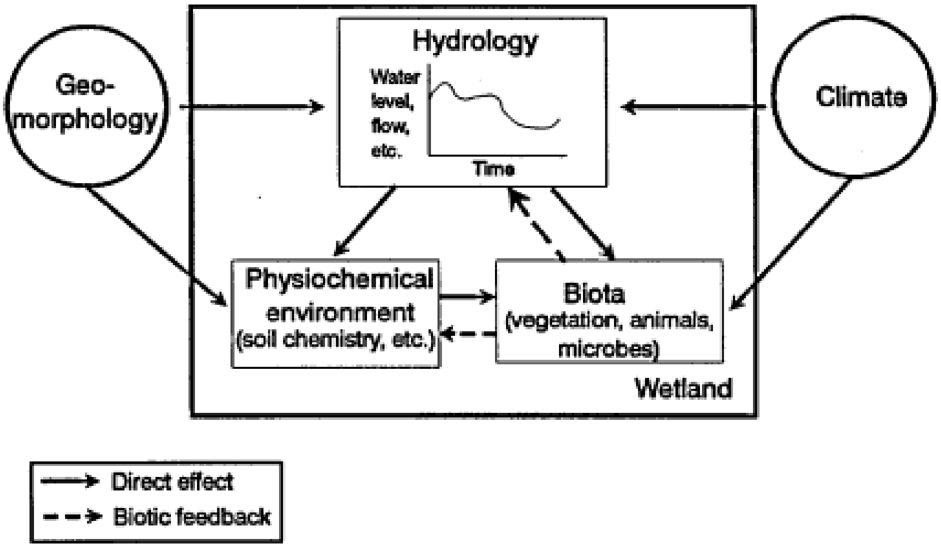


Figure 7.2: The relationships among hydrology, physicochemical environment, and biota in wetlands (National Research Council, 1995).

Efforts have been taken to identify and classify various wetland types as a basis for wetland conservation, management, and ecosystem service inventories (Finlayson and van der Valk, 1995; Sieben et al., 2011, 2018; Junk et al., 2013). According to The Wetlands in Drylands Research Network, (2014) and Tooth et al. (2015b) wetlands in drylands is a collective term that includes shallow lakes, floodplains, marshes, swamps, pans and oases that occur in subhumid through hyperarid environments. There is a need for more robust approaches to characterise wetland systems that takes into account of the variable and dynamic nature of many drylands and their constituent wetland landscapes (Lisenby et al., 2019). For the purposes of this framework the hydrogeomorphic (HGM) wetland classification system has been implemented and is one of the most widely implemented approaches for classifying wetlands (Sieben et al., 2018).

According to Ollis et al. (2013) wetlands are considered to be a type of aquatic ecosystem which is classified according to characteristics such as function, regional setting and landscape. Wetlands include transitional land between terrestrial and aquatic systems, but aquatic ecosystems such as rivers, lakes, ponds, dams and other open waterbodies are included. This ecosystem classification is also in accordance with the Ramsar Convention which defines wetlands as "areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres" (Ramsar Convention Secretariat 2011).

A system which is part of a water course that is connected to the ocean and is characterised by a permanent of periodically opening to the sea, tidal influences and where salinity is measurably higher is classified as an estuarine system (Ollis et al.,2013). The remaining system, not including marine systems are referred to as inland systems with no existing connection to the ocean with the absence of marine exchange and/or tidal influences. Most rivers are indirectly connected to the ocean by means of an estuary. According to Ollis et al (2013) many coastal lakes could have had a historical connection with the ocean and thus retain the saline characteristics and faunal assemblages of an estuary, but these systems do not have an existing connection to the ocean and are referred to as an inland system.

The definition of a wetland as per the Ramsar Convention makes does not distinguish between inland systems, but for the purposes of the framework these inland systems have been classified into three broad types (Ollis et al., 2013). The wetlands of the Nile basin are classified according to the dominant type of system represented.

River systems are described as 'lotic' system with either permanently or periodically flowing water within a defined channel. According to Ollis et al. (2013) a river represents a linear landform with clearly discernible riverbed and embankments, which comprises both the active channel and the riparian area. According to Brinson (1993) rivers are linear throughout the landscape with a predominantly unidirectional flow. The hydrological regimes of these systems vary from short / flashy In the headwaters to long / steady periods in the high order systems. The dominant hydrological inputs for these systems include surface flow from upstream channels and the associated tributaries (Ollis et al., 2013). According to Ollis et al. (2013) floodplains are characterised by predominantly flat or gently sloping land adjacent to river which has formed by an alluvial channel which is subject to periodic inundation by overtopping of the channel bank. Water and sediment inputs into a floodplain are mainly by means of over topping of embankments from a river channel during flood events. Floodplains may contribute to groundwater recharge if sufficiently saturated during wet periods (Brinson, 1993).

According to Ollis et al. (2013) lakes form in a valley due to inundation of the area caused by an obstruction. Lakes are characterised by closed elevation contours and the system increases in depth from the perimeter to an area of greatest depth in the centre. These open waterbodies are permanently inundated and are classified as 'lentic' systems. The dominant hydrological inputs for lakes include overland flow (or run-off) and also channelled inflow.

Brinson (1993) distinguishes between tidal salt and freshwater marshes with the setting a direct result of the position of the system in relation to sea level and the influence of tides. The United States Environmental Protection Agency defines marshes are as wetlands that are frequently or continually inundated with water and characterised by emergent soft-stemmed vegetation adapted to saturated soil conditions. Tidal and non-tidal marshes are distinguished from one another, with tidal marshes influenced by estuarine tides. Non-tidal marshes are typically freshwater systems, although some are brackish or alkaline. These systems are often associated with poorly drained depressions and in shallow areas adjacent to lakes, ponds and rivers. The prevalence of a salt or freshwater marsh is determined by the salinity of the adjacent estuary. The hydroperiods of these systems are characterised by frequent and predictable tides, this is particular for the regularly inundated areas. The areas less characterised by estuarine tides and floods are more influenced by precipitation which also influences salinity (Brinson et al, 1991).

The hydrological function of some of the major wetlands within the Nile basin is provided in Table 7.3.

Table 7.3: Hydrological function of major wetlands in the Nile basin (IWMI, 2012)

Wetland	**Hydrological function**
Wetlands of Uganda	Most of the individual wetlands link to other wetlands through a complex network of permanent and seasonal streams, rivers. and lakes, making them an essential Part of the entire drainage system of the country
Headwater wetlands of the Baro Akobo	Regulate flow in the Baro Akobo River while believed to play an important role in maintaining downstream dry-season river flows
Lake Albert	Critical link between the White Nile and its headwaters; without the flow regulation of this lake the White Nile would be reduced to a seasonal stream and could play no significant role in maintaining the base flow of the main Nile
Sudd, Machar Marshes and wetlands of the Bahr Ghazal	Significantly attenuate flows of the White Nile and its tributaries reducing flood peaks and supporting dry-season river flows, thereby minimizing the seasonal variation in the flow of the White Nile
Nile Delta	Limits saline intrusion from the Mediterranean Sea, thereby protecting coastal freshwater sources

Freshwater marsh / Floodplains

Floodplains provide major environmental benefits that support local and regional economies, mainly through flood-risk management, fisheries, recreation and seasonal agriculture (Opperman et. al., 2017). They support complex physical, biological and social systems and are created through the interaction between the flow of water and sediment. These in turn are influenced by physical structures and biological processes. Floodplain ecosystems are largely influenced by the hydrograph of the river and are often comparable to the ecosystems of riparian wetlands or “bottomland” forests. The floodplain ecosystems are also shaped by the timing and predictability of flooding and the ecosystems can be divided into three basic categories; namely:

- Tropical seasonal floodplain ecosystems – massive rainy-season floods occur predictably for a month at a time.
- Temperate seasonal floodplain ecosystems – flooding occurs predictably within a specific season but the exacting timing and extent varies.
- Temperate aseasonal floodplain ecosystems – large rainstorms occur in any month of the year but often have long periods between floods.

Hydrology is the most driving variable in floodplains as river flows control the processes of erosion and deposition that create floodplain topography. Hydrology also structures floodplain ecosystems by controlling connectivity, residence time and the exchange of organisms, carbon and nutrients between different sections of the floodplain (Opperman et. al., 2017).

The Sudd wetland

The Sudd wetland in South Sudan is the largest freshwater wetland in the Nile basin, one of the largest floodplains in Africa and one of the largest tropical wetlands in the world and is also the most important wetland to the hydraulics of the downstream river (IWMI, 2012; Rebelo et. al, 2012). It varies in width from 10 to about 40 km and is approximately 650 km long. The permanent swamp area covers about 30 000 km^2 but the degree of seasonal inflows effects the latent extent. Historical data has shown that in times of low flow and rainfall (1921, 1923 and 1984) even the permanent swamps dried up. The Sudd comprises of various ecosystems with the habitat varying from open water and submerged vegetation to floating fringe vegetation, seasonally flooded grasslands, rain-fed grasslands and floodplain woodlands. The diverse range of habitats supports a rich array of aquatic and terrestrial fauna including over 400 bird and 100 mammal species (IWMI, 2012). Many fish species also migrate from the surrounding rivers to the nutrient-rich floodplains to feed and breed during the seasonal floods making the wetlands an important source of fish for the surrounding communities (Rebelo et. al, 2012). A core area of 57 000 km^2 of the Sudd was designated as a Ramsar wetlands site of international importance in 2006 (IWMI, 2012; Rebelo et. al, 2012).

Flow into the Sudd comes from the Bahr el Jebel system that originates in the African Lakes Plateau and outflows specifically from Lake Victoria is important to the function of the Sudd (IWMI, 2012; Rebelo et. al, 2012). The annual flood pulse is essential to the functioning of the wetland as the seasonal inundation drives the hydrologic, geomorphological and ecological processes. Proposed hydroelectric dams on the main stem of the Bahr el Jebel will not reduce flows but will affect seasonal flows which in turn will affect the Sudd (Rebelo et. al, 2012).

Additional threats to the Sudd wetland include the discovery and extraction of oil in the Sudd which threatens the diversity of the wildlife, aquatic macrophytes, and floodplains, as well as the hydrology of the complex ecosystem. The completion of the Jonglei Canal will also divert inflows to the Sudd resulting in approximately 4700 Mm^3 of water for downstream use due to the reduction in evaporation from the wetland. Approximately 100 000 ha of land will also be reclaimed for agriculture through the completion of the canal but these reductions in flow to the Sudd will have significant impacts on siltation, water quality, loss of biodiversity, fish habitats and important grazing area (Rebelo et. al, 2012).

Table 7.4: Basin-wide functions, services and benefits of transboundary wetlands (NBI, 2013)

Function	**Services / benefit**
Livelihoods and food security	Sustenance of livelihoods and food provision for the largely rural population (up to 70-80%) of the Nile basin. Production of water, food, fuel wood, medicinal resources and raw materials for construction. Sustenance of wetland agriculture, including crop production and fishing, both for food production and income generation. Carrier of stock farming (grazing). Base for other economic activities, such as tourism and recreation
Water quality and quantity	Water production and storage, used for irrigation and domestic water supply. Basis for hydropower capacities for energy production. Groundwater discharge and recharge. Recycling of nutrients, human and organic waste, and water treatment Water purification through filtering capacity, urgently needed as almost 70% of effluents are not treated sufficiently before their discharge into surface waters. This is critical for quality of surface water and groundwater across the basin.
Biodiversity	Habitat and reservoir for endemic species. Ecological stepping-stones within a network of ecosystems across the basin necessary for adaptive capacity of species in times of climate change and unusual weather events (droughts). Maintenance of biological and genetic diversity. Breeding grounds and habitat during seasonal changes and annual climatic changes (migration of great mammals in parts of the basin, e.g. Dinder National Park).

Function	**Services / benefit**
	Provide ecological refugee for animals (e.g. Sudd, dry-season refuge). Stopover and wintering grounds for birds of international conservation importance (e.g. Sudd, etc.).
Climate change	Wetlands are important carbon sinks, particularly tropical wetlands. Climatic stabilization. The stabilizing effect of wetlands on the water flow enhances resilience of landscapes and people to droughts and floods.
Environmental stabilization	Natural flood control and flow regulation. Erosion and salinity control. Maintenance of ecosystem stability and integrity of other sub ecosystems. Shoreline stabilization and storm protection. Sediment and nutrient retention and export
Other	Socio-cultural significance. Information functions in education, science and research.

7.1 Types of aquatic ecosystems in the Nile basin

The Nile River is the longest river in the world and its basin is one of the largest (Figure 7.4), and although socially, economically and ecologically important to millions of Africans, little is known about the aquatic ecosystems in the basin together with the dynamics of their biodiversity, apart from the main Nile River and associated tributaries. In addition, where data is available, different classification techniques have been used to classify the smaller aquatic ecosystems in particular. Here available information and spatial data has been used to classify aquatic ecosystem types in the Nile basin on a coarse, desktop scale using the classification system of Ollis et al., 2013. The Nile basin contains two main aquatic ecosystems types including the Nile Delta and associated estuarine ecosystem, and the freshwater or inland portion of the Nile River and the associated basin. (Refer to Background Document 2 (NBI, 2015).)

1. **Estuarine ecosystems** i.e.. the Nile Delta, is defined as a body of surface water that is (a) part of a water course that is permanently or periodically open to the sea, (b) in which a rise and fall of the water level as a result of the tides is measurable at spring tides when the water course is open to the sea, or (c) in respect of which the salinity is measurably higher as a result of the influence of the sea (after the Integrated Coastal Management Act; Act No. 24 of 2008) (Figure 7.3).

2. **Inland ecosystems**: an inland aquatic ecosystem is defined as a surface (excludes groundwater ecosystems) aquatic ecosystem upstream of the estuary. These ecosystems are characterised by the complete absence of marine exchange and/or tidal influence. Inland aquatic ecosystems broadly include lakes, rivers, wetlands and open water bodies (Figure 7.4).

Figure 7.4: The Nile River

On a regional scale (Level II,) the Nile basin consists of three main sub-basins including the White Nile, the Blue Nile and the lower Nile below the confluence of the White and Blue Nile. In addition, the Nile Equatorial Lakes region has been demarcated to include the White Nile and Blue Nile River regions dominated by large natural lakes including; Burundi, Democratic Republic of Congo, Kenya, Rwanda, Tanzania and Uganda, South Sudan and parts of Sudan. In the Nile Equatorial sub basin there are many open waterbodies (lakes) and wetlands, while in Eastern Nile Sub-basin (dominated by the Blue Nile), the highland influences the nature of the slope which influence the rains and runoff, makes the Nile more fluvial and more river dominated. The geographical location is a key factor (coupled with the geomorphologic terrains), in influencing the ecosystem type and also determines the location to which the jurisdiction of the ecosystem falls in terms of regional and transboundary managed ecosystems. Within the Landscape setting of the Nile basin the location of the ecosystem being considered is used to demarcate ecosystem types on Level III (Table 7.5).

Table 7.5: Landscape Unit (Level III) summary of the aquatic ecosystem classification system used for the Nile basin (adapted from Ollis et al., 2013).

Landscape Units	**Definition**	**Sub-categories**
Valley floor	Base of valley which lies between two side-slopes	
Slope	Inclined section of ground, usually occurring on the side of a mountain	Can include: o Steep (scarp) slopes o Mid-slopes o Foot-slopes
Plain	Large area of low relief, with subtle undulations and a uniform gradient	
Bench	Discrete area of level or relatively level of land, in relation to the broader surroundings	Types: o Hilltop o Saddle o Shelf

Following the consideration of the position of the ecosystem within the landscape, the hydrogeomorphic (HGM) characteristics of the ecosystem are considered. Here the landform, hydrological characteristics and hydrodynamics of the ecosystem are considered (Table 7.6, Figure 7.5).

Table 7.6: Hydrogeomorphic characteristics unit (Level IV) summary of the aquatic ecosystem classification system used for the Nile basin (adapted from Ollis et al., 2013).

HGM Type	Longitudinal zonation/ landform/ outflow drainage	Landform/inflow drainage
River	o Mountain headwater stream o Mountain stream o Transitional o Upper foothills o Lower foothills o Lowland river o Rejuvenated bedrock fall o Rejuvenated foothills o Upland floodplain	o Active channel or riparian zone
Channelled Valley-Bottom Wetland		
Unchannelled Valley-Bottom Wetland		
Floodplain Wetland	o Floodplain depression o Floodplain flat	
Depression (includes open waterbodies including lakes (Important for Nile basin).	o Exorheic (one or more outlets) o Endorheic (no outlets) o Dammed	o With channelled inflow or without channelled inflow
Seep	o With channelled inflow or without channelled inflow	
Wetland Flat		

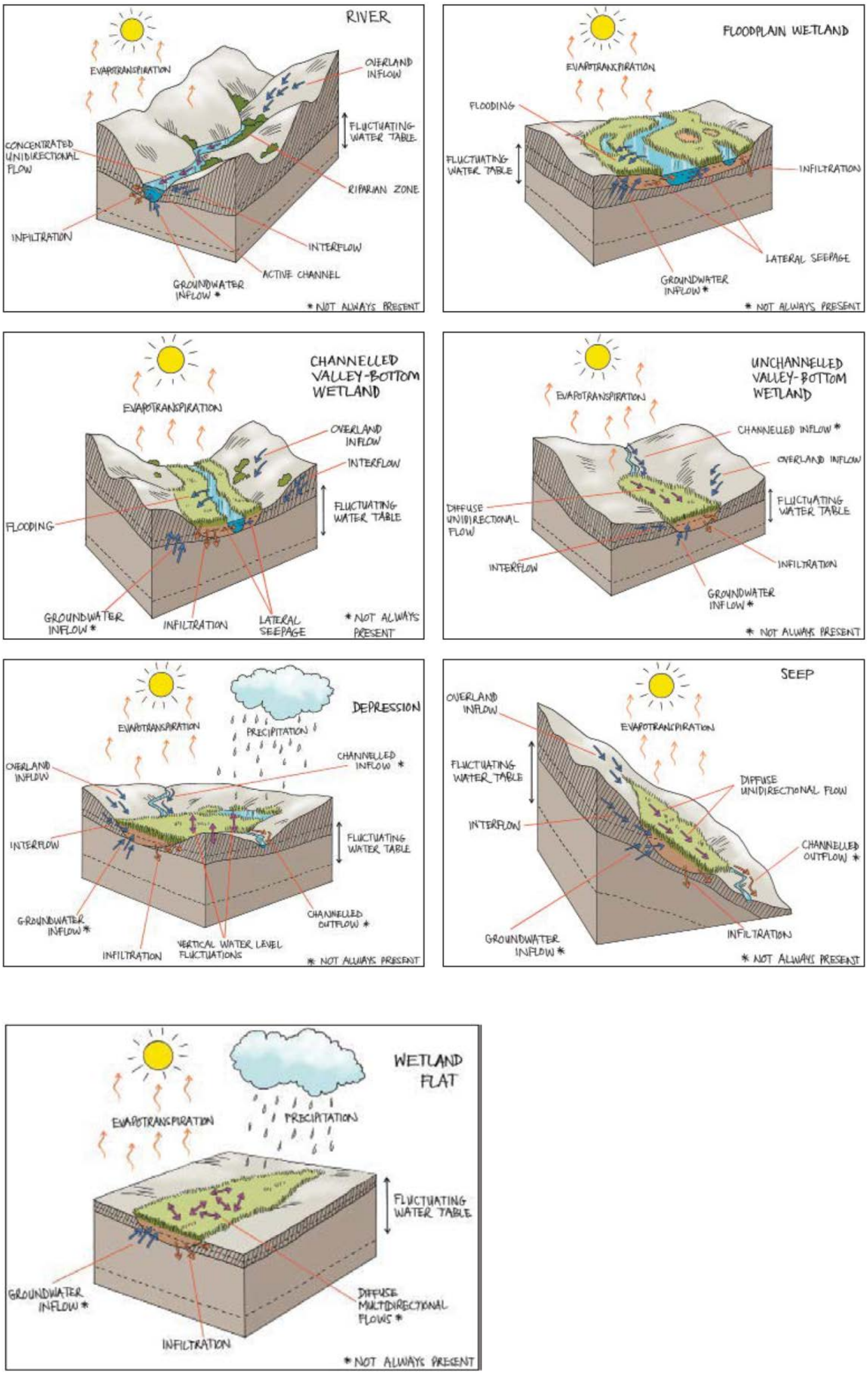


Figure 7.5: Drawing of the types of hydrogeomorphic ecosystems that may occur in the Nile basin. Hydrological flow dynamics highlighted by blue (input), yellow (output) and pink (throughput) arrows.

The hydroperiod of the ecosystem is then considered as a part of the Level V tier of the classification system proposed for the Nile basin. Here the perennial (flows continuously) versus non-perennial (does not flow continuously) nature of the ecosystem is evaluated based on the period of inundation, saturation and depth classes of the ecosystem (Table 7.7).

Table 7.7: Hydroperiod categories for Level V tier of the classification system proposed for the Nile basin including period of inundation, saturation and depth classes (adapted from Ollis et al. (2013)).

Inundation periodicity (A)	**Saturation periodicity (within 0.5 m of soil surface) (B)**	**Inundation depth-class (C)**
Permanently inundated	NA	Limnetic Littoral Unknown
Seasonally inundated	Permanently saturated Seasonally saturated Unknown	
Intermittently inundated	Permanently saturated Seasonally saturated Intermittently saturated Unknown	
Never inundated	Permanently saturated Seasonally saturated Intermittently saturated Unknown	
Unknown	Permanently saturated Seasonally saturated Intermittently saturated	

On the Level VI tier descriptors of the ecosystem type are introduced into the classification system so that ecosystem variability can be considered as a component of an environmental flow assessment for example. The effect of human development on the ecosystems in considered here as a primary descriptor including **natural** (produced by nature – not made/caused by humans) vs. **artificial** (produced by human being, not naturally occurring) ecosystems. Thereafter some board water quality descriptors can be used including salinity and pH:

- Salinity
    - **Fresh** (electrical conductivity (EC) range <500 mS/m or Total Dissolved Salts (TDS) <3g/l)
    - **Brackish** (EC range 500-3000 mS/m or TDS 3-18g/l)
    - **Saline** (EC range 500-8000 mS/m or TDS 18-48g/l)
    - **Hypersaline** (EC range >8000mS/m or TDS >48g/l)
- pH
    - **Acidic** (pH <6)
    - **Circum-neutral** (pH 6-8)
    - **Alkaline** (>8)

Additional descriptors include consideration of substratum type which may include different portion of many of the following substrate types; bedrock, boulder, cobbles, gravel, sand, clay soils, loam soils, silt (mud), organic matter, salt crust and other substrates.

Finally the vegetation cover, form and status should be characterised (Table 7.8).

Table 7.8: Level VI vegetation cover, form and status component of descriptor component of ecosystem type classification system for the Nile basin, adapted from Ollis et al. (2013).

	Vegetation form (B)	**Vegetation status (C)**
	Aquatic	o Floating o Submerged o Algal mat
	Herbaceous	o Geophytes o Grasses o Herbs/Forbs o Sedges/Rushes o Reeds o Restios o Palmiet
	Shrubs/thicket	N/A
	Forest	o Riparian Forest o Forested Wetland (swamp forest)
	N/A	N/A

7.2 Major types of Aquatic Ecosystems of the Nile

The aquatic ecosystems that dominate the Nile basin can be differentiated on a hydrogeomorphic classification tier (Level IV). This includes depressions (open waterbodies), wetlands, rivers, floodplains, valley-bottom, seeps, etc.

Depressions (open waterbodies): these lacustrine or lentic ecosystems include lakes, wetlands and meres. They are permanently inundated aquatic ecosystems where standing water is the principal medium within which the dominant biota live. Open water bodies with a maximum depth greater than 2 m are also called limnetic (lake-like) systems. They occur on locations within the basin where geomorphological features allow establishment of basins, which either through flow of an inflowing river or runoff are filled with water. Their physical conditions modify the habitats for example they can be shallow or deep, have small or large surface area. The geomorphological conditions coupled with climatic factors govern the characteristics that drive resilience and adaptation. These ecosystems include:

Figure 7.6: Lake Victoria

- **Large Shallow Basins** of the Nile include Lake Victoria (Figure 7.6), the world's second largest freshwater lake and the largest in the Nile basin with a surface area of 69,000 km^2, followed by the three other major lakes of the East African Rift Valley including Lake Albert, Kyoga and Edward. The existence of these lakes and associated ecosystems depend on flow. Fluctuations in their surface levels has been reported in the past and is associated by changing seasons and alterations in their incoming or outgoing flows. The basins of Lake Victoria and the three smaller lakes to the west Lake George, Edward and Albert are continguos with floodplains, wetlands and smaller satellite lakes that support an abundant diversity of animals and plants and many water-dependent ecosystems. Lake Tana within the Blue Nile basin is another great lake of the Nile basin and has a surface area of 3,200 km^2.

LARGE SHALLOW BASIN LAKES with lentic characteristics, shallow depths and large surface areas are usually eutrophic with high productivity and associated with rich content of nutrients. The total area of open water in the Nile basin is about 90,000 km^2 (Nile Information System). The Common large basins associated with the Nile basin located at the Nile equatorial lakes include Lakes Victoria, Kyoga, Edward, George, Albert, White Nile. And in the Blue Nile Lake Tana occurs. These large shallow basins depend on flows and provide the basis of socio-economic benefits to local communities including the fisheries industry, hydro electricity generation, transport and recreation.

Box 2: Large Shallow Basin Lakes

- **Large Deeper Basins:** These include the rift valley lakes which have been named due to their location in the Western Rift Valley. They are associated with deep waters with zones deep enough to cause pseudo - meromixis (failure for deeper waters to mix with surface waters) e.g.. Lake Edward, Albert, and George. These lakes have a large volume due to their extraordinary depths.

- **Small lake Basins** which include lakes of relatively smaller sizes usually not larger than 25km^2 and characterise many areas of the great lakes region of the Equatorial Nile basin. These include:

- **Satellite lakes**: Large lakes like Victoria form satellite lakes like Lake Nabugabo (Figure 7.7) and Lake Kanyaboli which are connected during rare high lake level periods. These lakes are of particular importance as the flow of species from these lakes and the greater lakes is of great ecological importance. During periods of low levels species diverge from parent stocks in isolated lakes. When the lake levels rise, satellite lakes are connected to the main lake and populations mix. If some mechanisms prevent interbreeding, two distinct species may be recognised from one common ancestor. Therefore natural flow is important in this phenomenon in large lakes.

Figure 7.7: Lake Nabugabo in Uganda.

- **High Altitude Lakes:** These are specific in small basins that occur in high altitudes and mountainous areas. These are exemplified by Lakes Kitandara, Bujuku and Mahoma occur above 2500m above sea level on Mount Rwenzori.

- **Crater Lakes:** are basins caused by volcanic activities. When they contain water they become crater lakes. Usually their water flows into them from the surrounding catchments. Some are seasonal and saline e.g.. Lake Katwe (Figure 7.8) and Lake Kasenyi in Eastern Uganda.

Figure 7.8: Lake Katwe in Uganda.

- **Oases:** occur in the desert ecosystems. An oasis forms when shallow sub-surface waters interact with the surface in desert ecosystems in the form of springs. These features are usually associated with bedrock features close to the surface where rain fed aquifers interacts with the surface. In some occasions wind action can cause erosion that causes depressions or opens depressions that are filled with water.

SMALL BASIN LAKES – these smaller basin lakes also have socio-ecological importance as they provide food for the Nile riparian communities. For example in the Kagera Sub basin, there are a number of small lakes such as Lakes Mburo, Mutukula, Kabandate, Mishera, Nakivali, which have a surface area of less than 15km^2 and are situated in western Uganda. Others like Karunga, Kijanebalola, Kachira, Mutanda, Muleke, Bunyonyi, Chafari and Kayumbu are all depended on flow and support small but important artisanal fisheries. The small lakes of Rwanda, like Lakes Cyohoha North, Cyohoha South, Rweru, Bugesera, Ihema, Hogo, and Rwanyakizinga all depend on the flow of the Nile and despite their smallness support livelihood to a large population of human dependants in addition to their roles in maintaining

Box 3: Small Basin Lakes

- **Artificial/man-made aquatic ecosystem**
  These exist so long as there is human intervention to hold flow, or alter the distribution of water (Figure 7.9). They include:
    - Irrigated ecosystems
    - Reservoirs or dams and manmade lakes. Man-made lakes are a significant feature of the lower reaches of the Nile, where Lake Nasser (Lake Nubia) has a potential area of 4,200 km^2, making it the world‘s second largest artificial lake.
    - Aquaculture ponds for fish, crocodiles etc.

Figure 7.9: Lake Nasser in Egypt.

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  Artificial ecosystem are important in addressing demands for livelihood support especially food and energy. It is therefore important that flow regulations that do not compromise ecosystems’ wellbeing are put in place so that water is available for irrigation, aquaculture as well as production of energy through hydro-power generation.

- **Wetlands ecosystems**
  The wetlands of the Nile basin consist of habitats which support a number of globally threatened species and restricted range species, such as water turtles, crocodiles, monitor lizards, snakes, otters and a large variety of water birds including herons, egrets, ducks, warblers and weavers. Their other biodiversity including vegetation types together with their soils support a wide range of livelihood, agriculture and construction industries (NBI State of

Basin report 2009; 2012). A great amount of evaporation attributed to great losses of water is reported to occur particularly in the Sudd area (Figure 7.10) (by many reports including the NBI MSOIA report of 2014). However, evaporation is a naturally hydrological process through which other ecosystems receive water through the hydrological pathway. This role performed by the wetlands is of much value and could be considered as a process that require considerable flow to balance water between the wetlands functions and other uses.

Figure 7.10: The Sudd wetland in the Nile basin.

8 Application of PROBFLO for e-flow assessment of wetlands in the Nile basin

PROBFLO is a holistic, regional scale ecological risk assessment based e-flow method that has been implemented as a part of the Nile e-flows Framework (O'Brien et al., 2018). The approach includes a ten step process to:

- review available information and characterise the ecosystem being evaluated;
- establish a conceptual model representing risk pathways that conform to the regional scale ecological risk assessment;
- select socio-ecological endpoints to represent the management problem for the case study;
- collect additional essential bio-physical and social evidence required for the assessment;
- calculate the risk of multiple stressors to these endpoints and established the e-flows,

- evaluate the risk of multiple stressors to endpoints for a range of resource use and protection scenarios, and
- present the uncertainty associated with the outcomes and propose and adaptive management plan to reduce uncertainty.

The steps implemented in the first phase of the PROBFLO assessment include the establishment of a vision (step 1) for the water resources being evaluated that resulted in the selection of social endpoints associated with the maintenance of the livelihoods of local communities, and ecological endpoints that address biodiversity and ecosystem processes of the resources. Thereafter a literature review will be undertaken for the study area and maps will be established of water resources and associated ecosystem services (step 2). The study area will then be divided into spatially explicit risk regions, or areas of the ecosystem that generally consists of uniform social and/or ecological land use scenarios. These risk regions allow stakeholders to consider relative risk to endpoints between these spatial areas (step 3). In step 4 conceptual models that demonstrate the causal risk pathways from identified sources (including anthropogenic and natural activities/events) to stressors (water quality, flow and habitat modifications for example), socio-ecological receptors in multiple habitats to endpoints, will be developed. A ranking scheme will be established for the study to represent the condition of each variable of the study and risk to endpoints (step 5) and then the risk will be been calculated (step 6) using Microsoft ® Excel and Netica™ to generate Bayesian Networks and Oracle® Crystal Ball™ software to randomise and integrate risk probabilities. Some important aspects of uncertainty will be included in this assessment. A series of field surveys and the testing of a monitoring plan/programme established to reduce uncertainty in the assessment will be established to evaluate uncertainty (step 8). Hypotheses associated with the uncertainty reduction will then be tested by revising the risk assessment/ learning from and improving relationships and risk assessment results (step 9). The last step of the approach is to communicate the outcomes so that the e-flows can achieve acceptability but also to ensure that all relevant stakeholders are familiar with the details and are implementing what is needed (step 10).

Environmental Flows are described as 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 (Arthington *et al.*, 2018). Numerous methods are available for the determination of e-flows for a wide range of water resource types on a multiple spatial scales (NBI, 2016a). Although EFAs are dominated by riverine ecosystem methods, some methods allow for the consideration of estuaries, wetlands, lakes ecosystems and ground water ecosystems for example

(O'Keeffe *et al.*, 2002; King, Brown and Sabet, 2003;; Hughes and Louw 2010; O'Brien et al., 201). A summary of available methods, their scope and application as well as some advantages and disadvantages relevant to the application in the Nile E-flows Framework is presented in the Appendix.

For this study the dynamics of wetlands have been considered in the context of EFAs. Primarily knowledge of the hydrodynamics, habitat dynamics and associated biodiversity, and ecosystem services of wetlands must be incorporated into the EFA. Wetland ecosystems have characteristic longitudinal and lateral flows, and contain control features that cause flow to move in multiple directions. This requires consideration of the alterative directions of flows associated with habitats and control features in the wetlands, and associated habitats. Importantly these flow dynamics of wetlands, affect the formation of habitats and their associated provision of ecosystem services and processes. In some case studies flow dynamics in wetlands drive flow timing, delaying flows through the ecosystem, volumes including evaporation factors, duration of flows in different habitats and frequency of flows usually associated with flood attenuation. Wetland flows are highly variable and affected by a sediment transport and deposition relationships. This drives wetland succession and major cyclic shifts in habitat characteristics across wetlands. This natural variability can be associated with long-term hydrological phases extended over many flow cycles (± 10 - 50yr). Although e-flows are usually established to maintain/provide suitable instream, floodplain and/or riparian habitats within wetlands, due to the dynamics of the flows within wetlands themselves, e-flow requirements that consider the volume, timing, frequency and duration of flows required to maintain wetland habitats are usually established for rivers or dam releases etc. upstream of the wetland. Habitats within wetlands and the ecosystem services and processes that are important for a range of ecological and social management objectives (or endpoints) of e-flow management are not uniformly distributed in space and time. This requires consideration of the determinants of habitat features and their socio-ecological values. For many water resource types including rivers in large regional scales for example, the qualitative maintenance of social and/or ecological endpoints are adequate for e-flow determination. Examples can include the maintaining of viable populations of species for biodiversity, or successful recruitment of fish species preferred for subsistence fisheries to contribute to the livelihoods of communities. In wetland ecosystems, the extent of habitats that have social and ecological importance, and their confinement within the boundaries of the wetlands, requires more of a quantitative assessment of the endpoints for e-flow management/assessments. For example the known population of people depending on a minimum production of a natural product may require a know abundance of fish or plant to be produced by the wetland. Or the known minimum abundance of an important habitat may be required to maintain viable populations of species indicative of the biodiversity of a wetland. To demonstrate how variable the hydrodynamics of an estuary and floodplain wetland ecosystem can be, two schematic diagrams representing the hydrodynamics of the systems have been included (Figure 8.1 and Figure 8.2). The diagrams demonstrate how in estuaries (Figure 8.1), river flows that are less dense that salt water can flow above sea water before mixing either inland or off shore. And to increase dynamism tidal influences shift this mixing zone inland and off shore. As a result estuaries are considered to be some of the most variable ecosystems on earth and the organisms that lie in these systems must be resilient to these rapid changes. Estuaries types are aggraded into groups according to their size and hydrodynamics and include single channel systems and multi-channel deltas, permanently open and temporarily open-closed systems. Estuaries provide a range of ecosystem services including provisioning services, regulating services and cultural services in particular. They also provide habitat for a high diversity of plants and animal life. In e-flow assessments habitat and associated biodiversity and services produced by the estuaries are usually selected as endpoints for assessments. The characteristics of these habitats required to meet the endpoints can be established, and then a suitable understanding of the hydrodynamics, water quality and geomorphology is required to determine the flows needed to meet endpoint requirements.

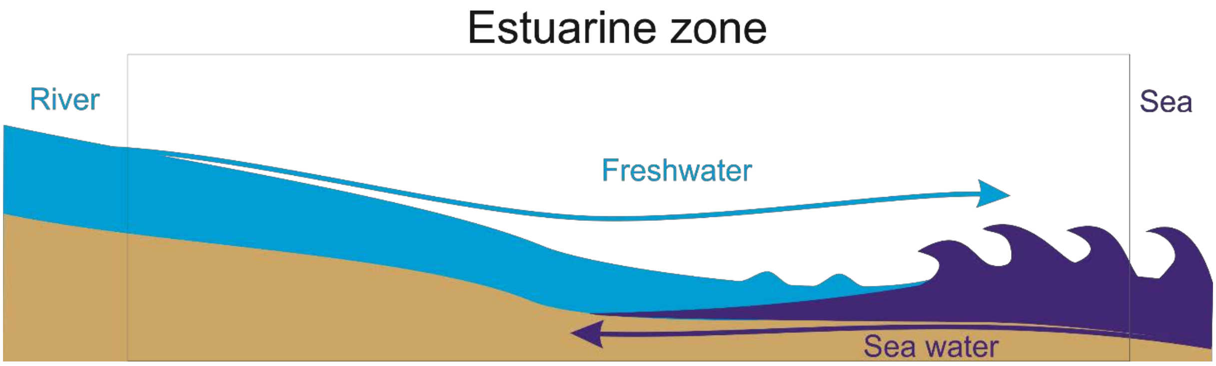

Figure 8.1: Schematic diagram of the hydrodynamics of an estuary with flows from river and flows from the sea that due to different densities can flow across each other.

Similarly in floodplain wetlands (Figure 8.2) longitudinal, lateral, reverse flows and vertical flows characterise these ecosystems. Again without knowledge of the variability of these hydrodynamic and associated water quality and geomorphological processes determining the requirements of the system is only half of the challenge. Meeting the requirements in the context of the dynamic hydrodynamic variability is required to achieve the objectives of an e-flow determination study. For wetlands specific information pertaining to the retention capacity, storage capacity and water balance is required to maintain habitats and the socio-ecological components and processes associated with the wetland habitats.

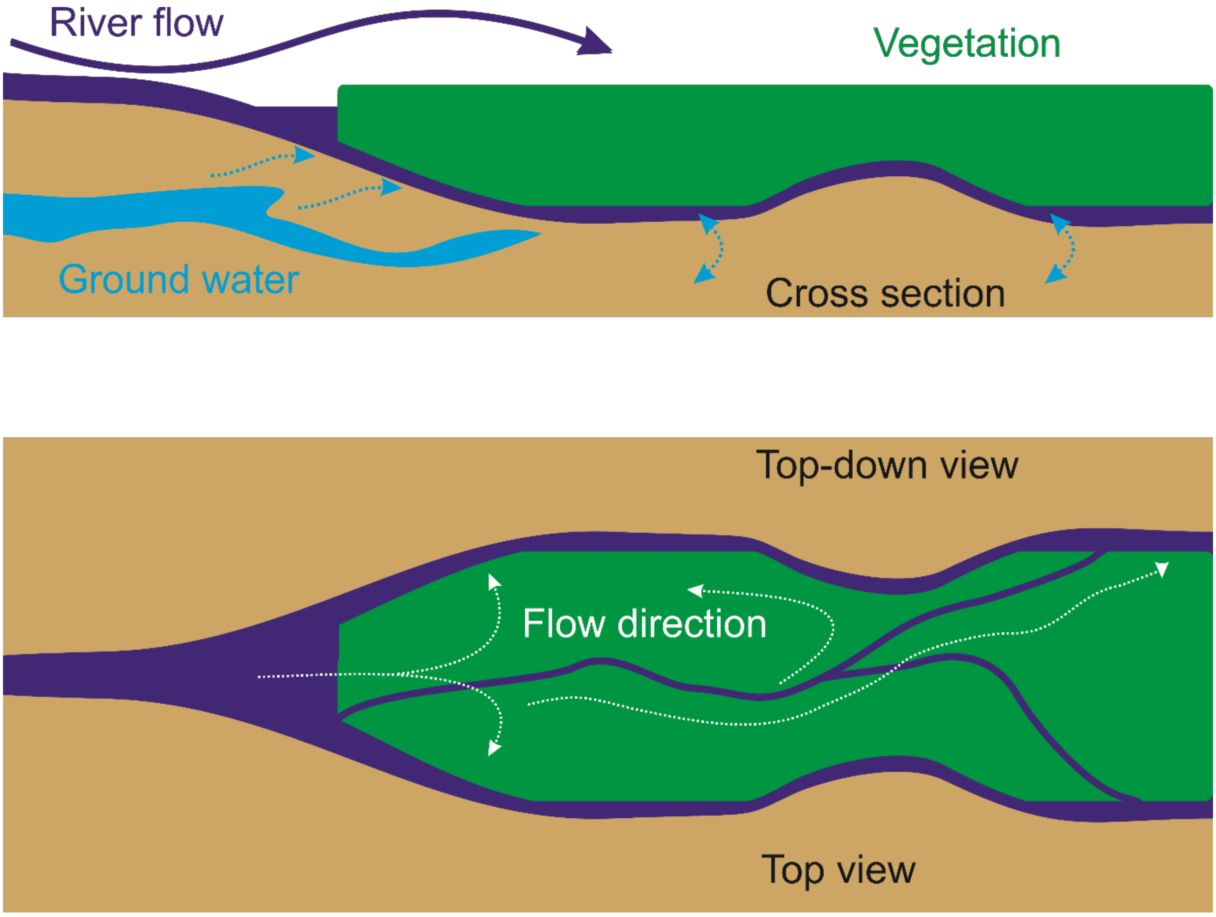

Figure 8.2: Schematic diagram of a cross section and top-down view of a floodplain wetland ecosystem with vertical, longitudinal and lateral flows.

For holistic assessments of wetlands in the Nile basin, the wetlands themselves and connecting marine, freshwater and other driving ecosystems (such as ground water) will be considered. For this, PROBFLO assessments are undertaken by a teams of specialist scientists who work in close collaboration with stakeholders who represent society and resource managers and their needs and aspirations. Good-practice e-flow principles require establishment of ecological and social endpoints that the livelihoods that human communities depend on. In addition, visions for e-flow assessments usually involve consideration of trade-offs between social and ecological endpoints and the selection of protection of use priorities for ecosystems within the range of sustainability, and the context of the rest of the basin. For *holistic* e-flow assessments of wetlands consideration of the riverine and/or marine environments that drive the wetlands should be included. Take note that EFAs of rivers are usually evaluated in a qualitative context to meet socio-ecological requirements within the ecosystems, the precise location where these endpoints are achieved may not necessarily be known, and this is not necessarily needed to be known. In e-flow assessments of wetlands where the entire ecosystem is considered in a holistic context, a quantitative approach is necessary. The challenge is to ensure not only are the socio-ecological requirements achieved, but that the minimum portion of the wetland measured as a percentage of the wetland that can be converted into hectares or km^2, will provide the requirements. When river focused EFAs consider wetland ecosystems, they may describe the requirements of the endpoints in a qualitative manner, similar to the approach applied for rivers in holistic assessments of rivers. However, the hydrodynamic connections between rivers and those ecosystems are usually not adequately addressed. This results in limited ability of these EFAs to provide or meet the e-flows for the ecosystems. Good practice e-flow assessments, and the principles of the Nile E-flows Framework, require not only the endpoints can be achieved but that the means to achieve them are provided/recommended. The approach established here to use PROBFLO for wetlands addresses these requirements.

In this case study the ten procedural steps of PROBFLO listed above is implemented in a wetland specific manner as follows:

Step 1: Vision exercise that will incorporate a workshop with specialists from other components of the assessment (Biodiversity Assessment, Ecosystem Services Assessment and Wetland Management Policies / management scenario section) and stakeholders of the study.

The importance of having clear water resource management and wetland management objectives for a regional scale risk assessment study is imperative as this directs all of the components of the study. Good practice e-flow assessments include trade-off decisions between resource use and protection. There are some EFA examples that consider a range of trade-off options (rather than decisions) between resource use and protection. This includes the determination of e-flows to meet an ecological class “B, or largely natural state’, “C, or moderately modified state” and/or “D, and largely modified by sustainable state”. For a PROBFLO assessment, you initially need to have an understanding of what managers/stakeholders care about in the landscape and what should be considered in a study. Integrated Water Resource Management and wetland management strategies, regional management plans and frameworks, national legislation, and established E-flow 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; 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.

It is necessary to characterise the social and environmental character of the wetlands being evaluated to provide a context for the decisions that are made by policy makers. It is a combination of the context of the region, the environment and its people, together with the policies of the decision-makers and the aspirations of the people that will ultimately frame the ideas for the kind of situation that society would accept, the vision for the wetland. This vision can then be used to frame the endpoints of management. Key to the continued supply of ecosystem services to those farmers, herders and fishers in the Sudd, is the continued provision of water, and in particular, the flooding of the Sudd that is the main driver of the ecosystem and the benefits that accrue to the people. This provision of water, and the amounts that are required. There are two key components of this definition:

- E-flows are about the quantity (and variability) of water flow as well as the quality
- The objective is to sustain ecosystems and the livelihoods that depend on them.

To ensure that e-flows are provided, resource managers need to manage all of those activities that would impact negatively on the quantity and quality of the water in the wetland system. This would include the construction of dams, the offtake of water for irrigation, domestic use and sources of pollution. When making decisions on what needs to be done to secure the E-flows, it is important to understand the impact that those actions will have on the quantity and quality of water, so that management activities are most efficiently implemented not only to optimise the use of water, but also to ensure that the E-flows are sustained.

For EFAs of significant wetlands using PROBFLO, ecological and social endpoints that represent what stakeholders care about and where they are in relation to e-flows must be established. This will in effect establish the scope of the e-flow assessment. For this, it is necessary to establish the vision for the resource, and then to give this detail by describing the objectives for each part of the resource that will lead to the attainment of various endpoints. For wetlands the vision will be an aspirational description of the condition of the resources, what they should contain and what the people should derive from them. The Vision serves as a guide for directing management actions to achieve the Vision. Endpoints have been defined as “specific entities and their attributes that are at risk and that are expressions of a management goal” (USEPA, 2003). In the absence of a detailed stakeholder consultation process during the determination of e-flows, and following the recommendation of Horne et al (2017), the following approach to clarifying the Vision and setting the endpoints are recommended:

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 E-flows, 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 wetlands. 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.

Step 2: Evaluation of existing data and spatial mapping of information

PROBFLO assessments of wetlands include a review of existing information to provide data and context for the assessment. During this phase the minimum data requirements for EFAs is evaluated. If this data is not available it can be collected to ensure that the uncertainty associated with an assessment is acceptable. Available data evaluations includes considerations of water resource use information affecting trends in hydrology and water quality, and geomorphology and hydraulic information that together address habitat conditions. Thereafter specialist ecologists and ecosystem service scientists will characterise and analysed indicators of the socio-ecological system and established flow-ecosystem and flow-ecosystem service relationships to represent the wetland in a PROBFLO probabilistic adaptive model. This will all be available for future adaptive management process. *The minimum data requirements for holistic and regional EFAs includes:*

Hydrology and Hydrodynamics: For wetland EFAs hydrology data that describes the present, past and future use and/or protection scenarios must be provided. This data must be supported with a specialist report to (i) summarise the primary sources of hydrological data and information available for the wetland per selected spatial area selects for the relative assessment, (ii) select specific hydrological datasets for use during the e-flows assessment, (iii) provide an overview of the catchment and its developments, and, (iv) select initial spatial areas for the assessments referred to as Risk Regions and (v) provide the e-flow requirements and simulated flows under various management scenarios for the selected Risk Regions. Ideally, flow (discharge) variability should be provided in standard flow duration tables and include daily flow variability information. Additional timing, duration, frequency statistics should be provided. In addition for wetlands in particular, hydrodynamic and hydraulic information of the system is required to describe the flow associated habitat characteristics of the ecosystem, and flow retention, storage capacity and connection information. This should include the depth, channel shape, velocity of water flow, wetted areas etc. Consider the example of summarised hydrodynamic data outputs provided from a hydrodynamic model generated for the Inner Niger Delta floodplain wetland (Appendix 2 and Figure 8.3). The data includes information on the availability of habitats (associated with areas of the delta (km^2)) inundated by a range of depths (0.1m to 10m). And in addition, the timing and duration of flows that describe the retention and storage capacity of the wetland. This data was successfully used to establish the flow-dependent habitat requirements of a range of indicators included in a PROBFLO assessment of the Inner Niger Delta.

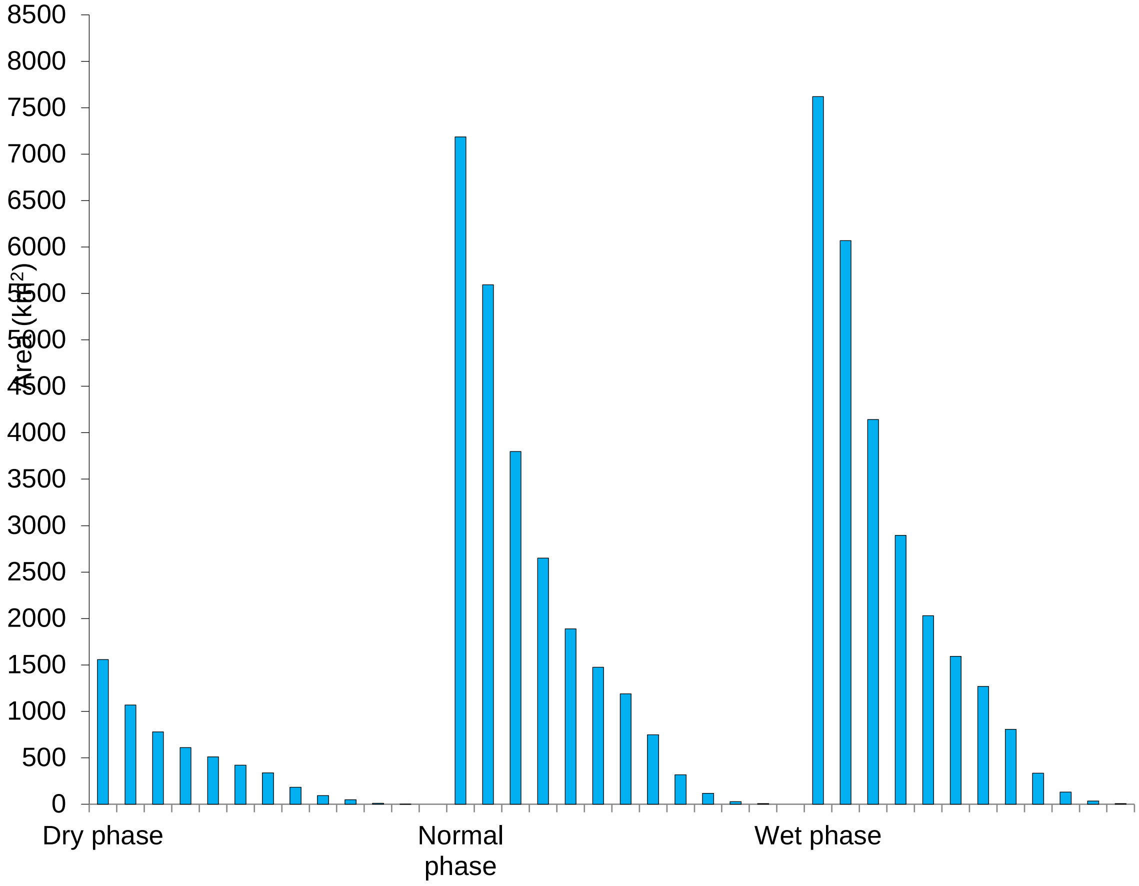

Figure 8.3: Hydrodynamic model results of an assessment of the Inner Niger Delta (West Africa), including availability of wetland habitat

For hydraulic evaluations, the main driver here is the flow of water, which is contextualised by the slope of the river, the sediments and substrate, and important in this study, the floodplain nature of the wetlands. For this bathymetry and associated hydraulic analyses of the wetland is required and will be used in the assessment. From this information simulations of habitat available associated with known wet and dry periods of the region and possible drought phases can be considered. The key point for investigation here, will be the relationship between flow (the discharge of water entering the wetland) and the amount of flooded area.

Water quality: Very limited data describing the water quality or significant wetlands in the Nile basin is available. This is understandable as there have been limited drivers of water quality alteration, and the assimilative capacity of wetlands are considered to be high. However, for some wetlands such as the Sudd, several reports have highlighted the increasing use of chemicals in agricultural projects within the wetland may now be a cause for concern. Furthermore, increasing concentrations of toxins, heavy metals, nutrients and microbial pollutants are anticipated as a result of the increasing population size, urbanisation and agricultural activity within the Sudd itself, in conjunction with mining and industrial activity increasing in the upper catchments. Greatest impacts of these parameters are expected to occur in the low flow season when dilution potential is at its lowest. So while water quality information for the Sudd may be limited, numerous reports provide qualitative and anecdotal evidence of activities, threats and impacts to the health, integrity and management of both the natural systems and the human livelihoods which rely on the maintenance of water quality within the Sudd. For the purpose of this project these resources were augmented by aerial imagery sourced from Google Earth in conjunction with a first-principals approach to aquatic ecology and available Geographical Information Systems (GIS) data/layers for area. The main objective of the report was to develop the foundations for establishing an integrated water quality scoring system for the identified risk regions that can be used in the Bayesian Models for different endpoints.

Sediments and geomorphology: The purpose of this part of the EFA will be to provide descriptions of the geomorphology of the wetlands and inferences concerning impacts on the riverine ecology through habitat availability and quality. This includes both instream and floodplain habitat. This will be limited to available information and other components of the study, using a mixture of literature, maps, Earth Observation (Google Earth) to estimate the geomorphological situation.

Step 3: Study area and risk region delineation by specialist team providing feedback to the client/stakeholders.

Many wetlands, such as the Sudd region ae 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 that must be considered in EFAs include the excessive use of 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 PROBFLO approach includes the relative evaluation of multiple sources of stressors to endpoints on regional scales that will be spatially and temporally referenced for regional comparisons/evaluations. In this study the spatial extent of the Sudd will be described, and the locations of potential sources, habitats and impacts will be identified and spatially referenced to direct the delineation of risk regions for the assessment. In addition, source-stressor exposure and habitat/receptor to endpoint pathways/relationships will be defined for each region and spatially referenced. In addition for this assessment, available data will be used to describe the socio-ecological ecosystem of concern. For the selection of risk regions in wetland EFAs, combinations of the management objectives, source information, and available habitat data will be used to establish geographical risk regions for the relative risk assessment. 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.

Scenario selection: In this risk assessment a range of water resource use and/or protection scenarios will be 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 will be evaluated. In the PROBFLO approach a pre-anthropogenic development scenario (“natural condition”) and present day scenario (“present”) are usually selected as initial scenarios to: (1) set up the models that are largely based on present day understandings of ecosystem relationships because they can be tested, and (2) calibrate the model using historical information.

Step 4: Conceptual model that will be established by the PROBFLO team with feedback from specialists from other components of the study.

In this step, following the evaluation of available evidence to characterise the socio-ecological system of concern, conceptual models that will describe hypothesised relationships between multiple sources, stressors, habitats and impacts to endpoints selected for the study will be generated. This includes the holistic (consider flow and non-flow related variables in spatial-temporal context), best practice characterisation of flow-ecosystem and flow-ecosystem service relationships in the context of a regional scale E-flows framework (Poff et al., 2010), with relevant non-flow (water quality and habitat) relationships in the models. Conceptual models will be constructed through an expert stakeholder workshop specialists after the completion of the literature review. The workshop will include hydrologists, geomorphologists, ecologists and ecosystem services scientists. They will be 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 E-flow 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. The detailed conceptual models will be used to develop risk models for each endpoint in the study that in turn will be used to generate Bayesian Network models for each endpoint, and an Integrated Bayesian Network for the assessment (Figure 8.4 to Figure 8.9).

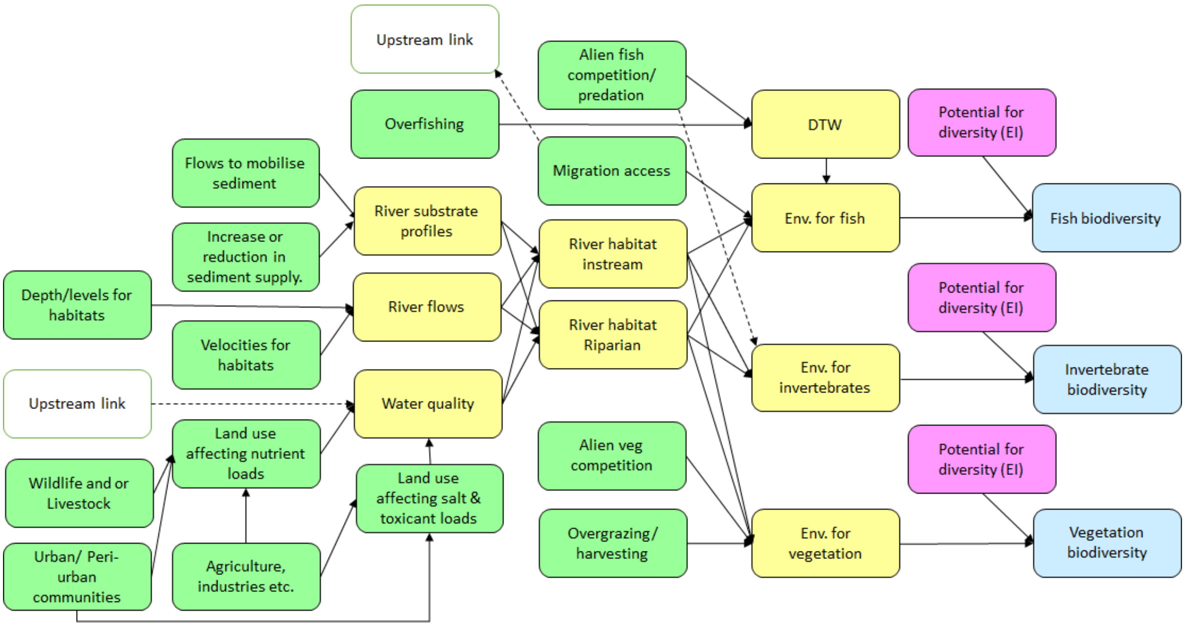

Figure 8.4: Example of a conceptual model for ecological endpoints for an assessment of the river and wetland in the Mara River including the risk pathways (arrows) from bio-physical components of the ecosystems that describe the threats of multiple stressors in the river (green (parent) and yellow (daughter) nodes) to endpoints (blue (daughter) nodes) with effects potential included (pink (parent) nodes). *Input nodes require information describing the state of a variable and daughter nodes require rule tables or conditional probability tables to represent how the variables interact.*

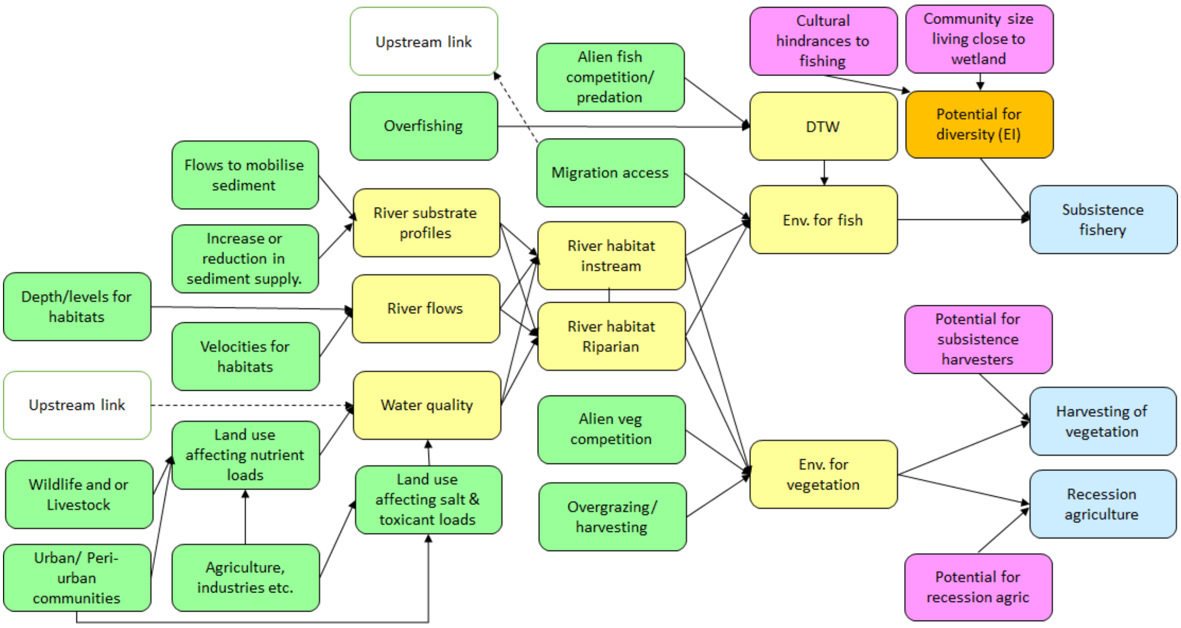

Figure 8.5: Example of a conceptual model for social endpoints for an assessment of the river and wetland in the Mara River including the risk pathways (arrows) from bio-physical components of the ecosystems that describe the threats of multiple stressors in the river (green (parent) and yellow (daughter) nodes) to endpoints (blue (daughter) nodes) with effects potential included (pink (parent) and orange (daughter) nodes). *Input nodes require information describing the state of a variable and daughter nodes require rule tables or conditional probability tables to represent how the variables interact.*

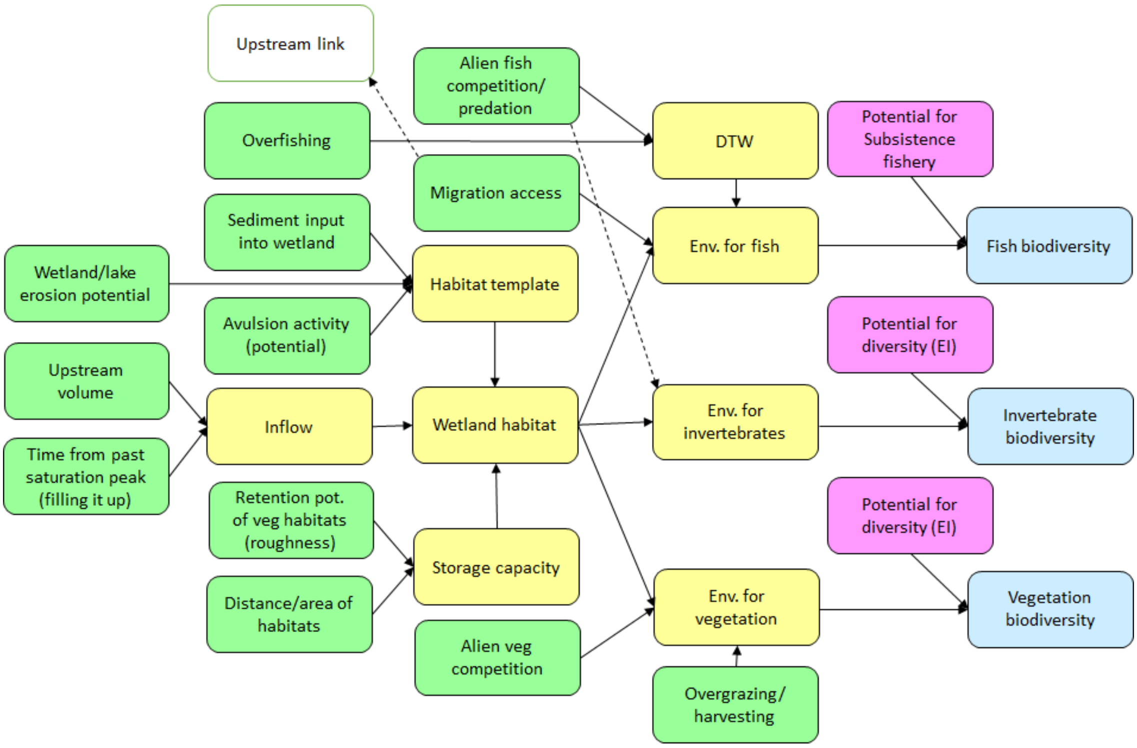

Figure 8.6: Example of a conceptual model for ecological endpoints for an assessment of the river and wetland in the Mara River including the risk pathways (arrows) from bio-physical components of the ecosystems that describe the threats of multiple stressors in the wetland (green (parent) and yellow (daughter) nodes) to endpoints (blue (daughter) nodes) with effects potential included (pink (parent)

nodes). *Input nodes require information describing the state of a variable and daughter nodes require rule tables or conditional probability tables to represent how the variables interact.*

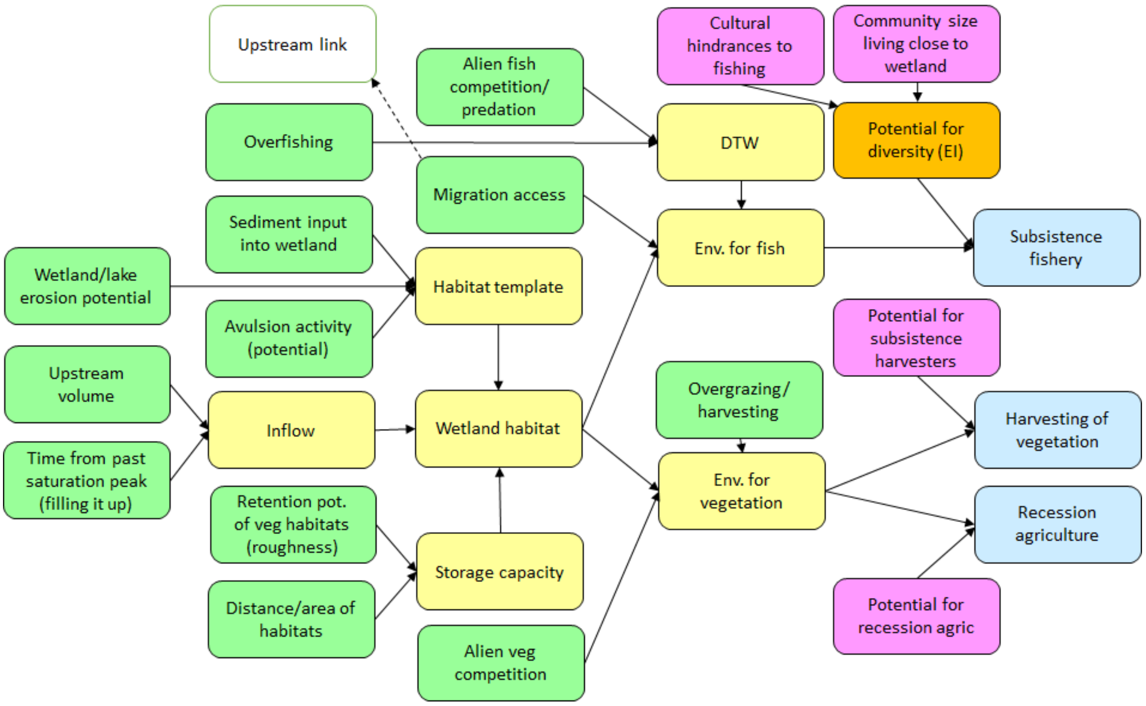

Figure 8.7: Example of a conceptual model for social endpoints for an assessment of the river and wetland in the Mara River including the risk pathways (arrows) from bio-physical components of the ecosystems that describe the threats of multiple stressors in the wetland (green (parent) and yellow (daughter) nodes) to endpoints (blue (daughter) nodes) with effects potential included (pink (parent) and orange (daughter) nodes). *Input nodes require information describing the state of a variable and daughter nodes require rule tables or conditional probability tables to represent how the variables interact.*

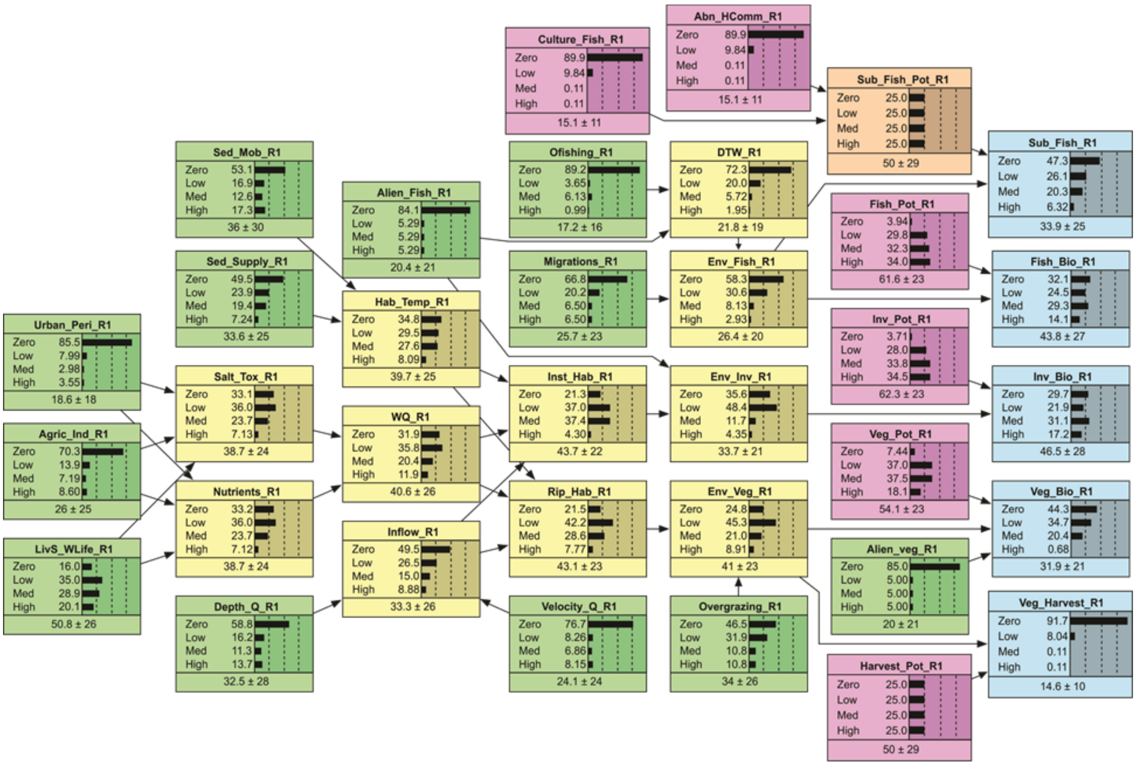

Figure 8.8: Example of a Bayesian Network established to represent the conceptual model for the social and ecological endpoints for an assessment of the river and wetland in the Mara River including the risk pathways (arrows) from bio-physical components of the ecosystems that describe the threats of multiple stressors in the river (green (parent) and yellow (daughter) nodes) to endpoints (blue (daughter) nodes) with effects potential included (pink (parent) nodes). *Input nodes require information describing the state of a variable and daughter nodes require rule tables or conditional probability tables to represent how the variables interact.*

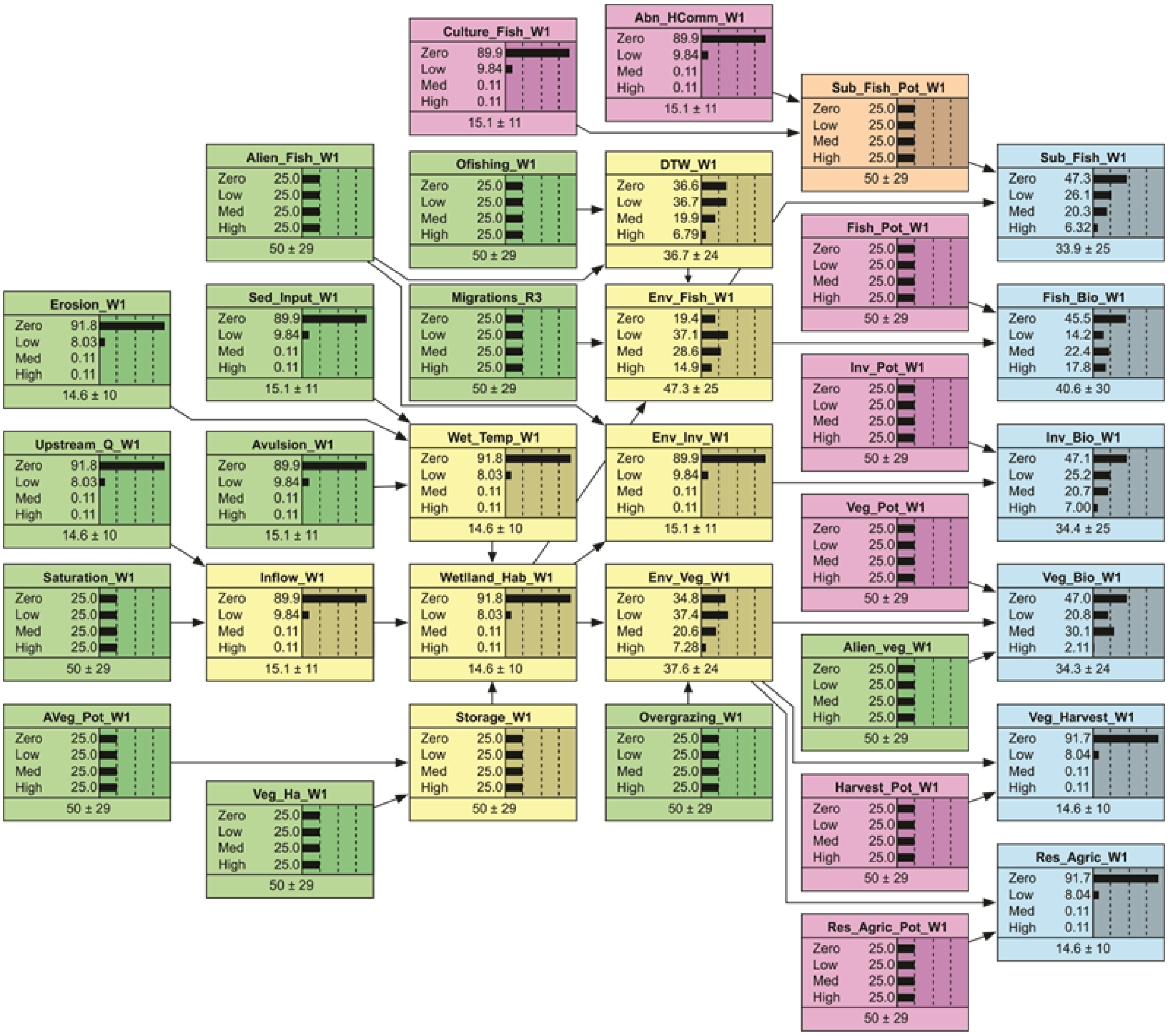

Figure 8.9: Example of a Bayesian Network established to represent the conceptual model for the social and ecological endpoints for an assessment of the river and wetland in the Mara River including the risk pathways (arrows) from bio-physical components of the ecosystems that describe the threats of multiple stressors in the wetland (green (parent) and yellow (daughter) nodes) to endpoints (blue (daughter) nodes) with effects potential included (pink (parent) nodes). *Input nodes require information describing the state of a variable and daughter nodes require rule tables or conditional probability tables to represent how the variables interact.*

Step 5: Ranking scheme by the PROBFLO team,

Ranking schemes will be used to represent the state of variables, with unique measures and units to be comparable as non-dimensional ranks and combined in Bayesian Network Relative Risk Model (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 pre-anthropogenic 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 will 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 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.

- ***Step 6: Calculate risks by the PROBFLO team***

From the Bayesian Network models including indicators of the socio-ecological system being evaluated, measures and interactions of variables will initially be set up, justified, tested and then applied. 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 will make use of the NeticaTM BN software by Norsys Software (http://www.norsys.com/) to perform the assessments.

The BNs will initially be 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 (see annexures).

To evaluate the socio-ecological consequences of alternative water resource use scenarios, trade-offs of acceptable risk to social and ecological endpoints will initially be established for each risk region by specialist stakeholders, usually within a legislative context. These trade-offs of acceptable risk, comparable with the vision of sustainable use for the resources of the study area, will be 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, trade-offs of acceptable risk for E-flow determination should only dominate the “moderate” risk range when there is certainty that the E-flow requirements can be provided, such as in the case of E-flow releases from a dam. In case studies where there is high uncertainty associated with the ability to provide E-flow requirements, such as the management of multiple water resource users to cumulatively maintain E-flows, then a buffer should be provided according to the definition of ranks and the “low” risk range should be selected. After the selection of trade-offs 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 will be spatially and temporally referenced and be provided to a hydrologist to describe the e-flow requirements which can be presented in various formats, such as daily or monthly water (usually m3/s) discharge percentiles with associated ecological categories. During the E-flow determination procedures the state of non-flow variable nodes, which contribute to the risk to endpoints, associated with flow variables will be either be maintained to represent the current state, and described as such or they will be amended with available water resource use information.

- ***Step 7: Uncertainty evaluation and way forward by PROBFLO team.***

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 wetlands including objectives and endpoint selection for the assessment, availability and use of evidence, expert solicitations and model uncertainty for example, will 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 will 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 e-flow assessment studies.

Step 8: Hypothesis establishment, the testing of hypotheses step 9 and communication of results will all be achieved as a part of the development of a monitoring plan for the study and the management and communication of the study with stakeholders and the client.

In a PROBFLO assessment it is necessary to conduct a sensitivity and uncertainty analysis. In this step any uncertainty associated with the data used (or lack thereof), modelling processes and integration processes are defined and presented. This allows managers to consider the amount of uncertainty associated with a risk profile to facilitate decision making processes. This step allows examination of what management decisions could be made to optimize riverine ecosystem services by identifying the key drivers which are the inputs that most influence the model output. By evaluating uncertainty, data gaps may be identified to direct future research and refine the model to reduce uncertainty where possible. This step can fit well within the adaptive management framework.

Step 9: Hypotheses generation and testing phase (adaptive management component)

PROBFLO assessments result in the establishment of EFRs and are used to evaluate the socio-ecological consequences of altered flows in aquatic ecosystems. Managers use these outcomes to make resource use and/or protection decisions. There will always be a level of uncertainty associated with the outcomes of a PROBFLO assessment. The PROBFLO includes two strategies to address this uncertainty; initially the process includes explicit descriptions of the uncertainty and possible implications to the outcomes and then the approach incorporates hypotheses generation steps to identify and test aspects of uncertainty in the process (Figure 8.10). In this process indicators of the models are identified that can be used to test the relationships are established (Figure 8.10). This may include for example from a hypothetical model to evaluate the effects of flow alterations by sources (Figure 8.10). This process is used to:

- Generate data to reduce uncertainty pertaining to the state of input components,
- Generate evidence to reduce uncertainty associated with the use of CPTs to define the relationships between variables,
- Generate evidence to reduce uncertainty associated with the outcomes of the PROBFLO assessment.

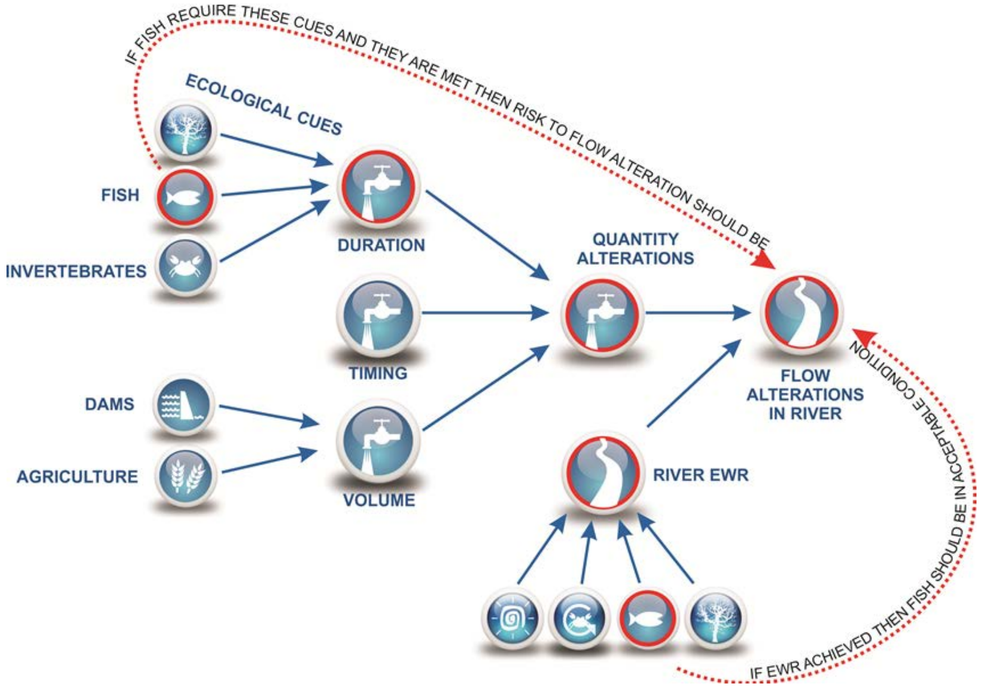

Figure 8.10: Graphical representation of the selection of indicators identified in a PROBFLO assessment which can be used to establish hypotheses and test them to reduce uncertainty.

The implementation process requires the establishment of a PROBFLO implementation data management system to receive and interpret data, update existing PROBFLO assessments and produce outcomes to compare historical and current PROBFLO assessment results. Although this process can be automated, it is recommended that a risk assessor review the outcomes of an implementation process to ensure that they are representative of the new information. To implement the PROBFLO process the following procedural steps are followed:

- Indicators of the model that can be used to test the uncertainty and/or the outcomes of a PROBFLO assessment are identified.
- A monitoring plan is designed to collect data that describes the state of selected indicator components and/or describes the relationships between variables. In this example a range of ecosystem driver components (water quality, discharge and habitat states) and response

components (fish, riparian vegetation and invertebrate data) were selected for a monitoring plan with multiple levels of details for surveys (annual rapid surveys and comprehensive three yearly surveys for example).

- The monitoring plan is implemented and the results are captured into a data management system which then:
    - Updates available evidence and immediately provides descriptive analyses of the new data,
    - Converts the information into a format which the PROBFLO process can use/query,
    - Populates the PROBFLO models and integrates the outcomes.
- The automated outputs of the data management system include:
    - descriptive analyses of the new sampling data,
    - outcomes of the PROBFLO assessment with comparisons to the original assessment,
    - a description of the results of the hypotheses testing to reduce uncertainty, and
    - information on PROBFLO uncertainty mitigation measures, and model refinement recommendations which can be agreed to for automatic amendments or refused for testing etc.
- PROBFLO outcomes can be compared with original modelling outcomes to update the socio-ecological consequence assessment of reduced flows based on measured data, and provide scenario amendment information to evaluate alternative management implications.

These procedural steps will reduce the uncertainty associated with the original PROBFLO assessment, and allow the approach to be used in an adaptive management framework as advocated as best scientific practice. This will allow managers to constantly update the assessment with new information and consider the refined socio-ecological implications of water resource use decisions. The approach also allows for later add-on components which can be used in the future to evaluate the cumulative impacts of additional stressors to the endpoints considered etc.

PROBFLO Step 10: Communicate outcomes

Throughout the PROBFLO process, communication needs to occur so that relative risk and uncertainty in response to management goals is effectively portrayed using a range of tools (reports, presentations etc.). The graphical display outputs by BNs and Monte Carlo clearly portray the risk given in probability distributions which can serve as useful communication tools to managers and stakeholders. In this step the reporting phase for the whole study.

8.1 Closing Remarks

The importance of the establishment of a holistic e-flows management framework in the Nile basin is greater than ever, due to the continued demand for water resource use that is affecting e-flows throughout the Basin. Historically, many nations have used and/or managed flows in the Basin in isolation with many advantages (usually for that nation) and disadvantages (usually for other nations). The Nile E-flows Framework offers stakeholders of the Nile basin with a structured, scientifically valid system to; establish basin wide objectives and apply suitable EFM to sustainably use the resources of the Nile basin and to coordinate e-flow management efforts. The approach also offers stakeholders an approach to review available e-flow management information and apply the information on a regional and basin scale. Although e-flows are not managed on a regional scale at the moment in the Nile basin, this Framework should make a noticeable contribution to the establishment of regional efforts to sustainably the water resources of the Nile basin.

With the existence of the Nile E-flows Framework all e-flow management considerations in the Basin should consider the Framework and strive to make the case study as useful as possible, to the management of e-flows on a sub-basin and basin scale in the Nile basin. The water resources of the Nile basin and the people who depend on them, urgently need management plans to manage water resources to ensure sustainability.

This brief describes the PROBFLO method and how to apply it to evaluate e-flows for wetlands of significance in the Nile basin. For this to be achieved the minimum data requirements for a PROBFLO assessment describe in this brief must be provided by other components (work packages) of the study.

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APPENDIX 1: Comparison between e-flow methods.

Table 0.1: Advantages and disadvantages of different e-flow methods taken from Horne et al (Eds.). (2017).

Method Type	River Ecosystem Attributes/ Components Addressed	Knowledge and Expertise Required	Resource Intensity	Resolution of Output (Environmental Flow)	Appropriate Level(s)
Hydrological	Whole ecosystem condition/ health, or nonspecific. Some include effects to specific components (e.g., physical habitat, fish).	Primarily desktop, with low data needs. Use virgin/naturalized (or other reference state) historical flow records (daily, monthly, or annual). Single flow indices (often low flow metrics), or more commonly multiple ecologically relevant flow metrics characterizing flow regime/whole hydrograph. Some use historical ecological data, hydraulic habitat data, or meta-analysis of results of multiple environmental water assessments to derive rules. Require expertise of a hydrologist. Few require ecological or geomorphological expertise, but such expertise is highly.	Low time and cost, and low or moderate technical capacity.	Mostly simple, flow targets for maintaining river health, based on estimates of the percentage of annual, seasonal, or monthly volume (often termed the minimum flow) that should be left in a river to maintain acceptable habitat or varying levels of river condition. Often expressed as % of monthly or annual flow (median or mean); or as limits to change in vital flow parameters, commonly low flow indices. Low resolution, complexity, flexibility and confidence, or moderate and dynamic in a few more recent regime focused methods.	Reconnaissance/planning level of water resource developments. *Unsuitable for high-profile, negotiated cases, or where whole flow regime dynamics are critical*. As a tool within habitat simulation or holistic methods. For highly data-deficient systems with limited ecological information. Regionalization potential for different river ecotypes.
	Used widely in many developed and developing countries/basins. Simple single index, rule-of-thumb, and look-up table approaches (e.g., Montana method, Tennant, 1976; flow percentiles derived from Flow Duration Curve Analysis; Tharme, 2003, provides examples) becoming less common. Shift toward ecologically relevant flow metrics addressing multiple aspects of hydrological regime (e.g., Range of Variability approach, Richter et al., 1996; Environmental Flow Duration Curve, Smakhtin and Anputhas, 2006) and use of desktop models derived from meta-analyses of multiple environmental flows assessments (e.g., Desktop Reserve Model, Hughes and Hannart, 2003; Hughes et al., 2014).				
Hydraulic rating	Aquatic (instream) physical habitat for	Low to moderate data needs. Desktop analysis and limited field surveys.	Mostly low, sometimes moderate	Hydraulic variables (e.g., wetted perimeter, depth) used as	Water resource developments where

Method Type	River Ecosystem Attributes/ Components Addressed	Knowledge and Expertise Required	Resource Intensity	Resolution of Output (Environmental Flow)	Appropriate Level(s)
	target species or assemblages.	Historical flow records. Discharge linked to hydraulic variables, typically single river cross-section/transect. Single or multiple hydraulic variables. Require moderate expertise (hydrologist, field hydraulic habitat assessment, and modeling). Few require ecological or geomorphological expertise.	time, cost, and technical capacity	surrogate for habitat flow needs of target species or assemblages. Low, sometimes moderate, resolution, complexity, flexibility, and confidence.	little negotiation is involved. As a tool within habitat simulation or holistic methods.
	Used widely historically, mostly in developed countries (see Annear et al., 2004; Arthington, 2012; Tharme, 2003), but nowadays largely superseded or used as one of several integrated habitat modeling tools in habitat simulation or holistic methods (e.g., used within DRIFT, Arthington et al., 2003; King et al., 2003).				
Habitat simulation	Primarily instream physical habitat for target species, guilds, or assemblages. Some also consider channel form, sediment transport, water quality, riparian vegetation, wildlife, recreation, and aesthetics.	Moderate to high data needs. Desktop, and field surveys. Historical flow records, typically average daily discharge. Few to many hydraulic variables are modelled at a range of discharges at multiple river cross-sections. Physical habitat availability, utilization, and preference data, or similar models, for target biota. A few use statistical summary methods based on results of multiple physical habitat studies.	High to sometimes moderate time, cost, and technical capacity.	Output in the form of weighted usable area (WUA) or similar habitat metrics for target biota (fish, invertebrates, plants). Often includes comparative analyses of time series of habitat availability, and duration and use. Moderate to high resolution, complexity, and confidence, moderate flexibility.	Water resource developments, often large scale, involving rivers of moderate to high strategic importance, often with complex, negotiated trade-offs among users. Commonly used as a method within holistic approaches and frameworks. Useful to examine a variety of

<table>
<tr><th>Method Type</th><th>River Ecosystem Attributes/ Components Addressed</th><th>Knowledge and Expertise Required</th><th>Resource Intensity</th><th>Resolution of Output (Environmental Flow)</th><th>Appropriate Level(s)</th></tr>
<tr><td rowspan="2"></td><td></td><td>High level of expertise, with hydrologist, hydraulic habitat modeller. May use hydrodynamic modelling, GIS/remote sensing, ecological or geomorphological expertise.</td><td></td><td></td><td>alternative environmental water regime scenarios for several species/life stages/ assemblages.</td></tr>
<tr><td colspan="5">Move away from single-species focus to increasing use for needs of species, guilds, and assemblages (IFIM, Bovee, 1982; see examples in Annear et al., 2004; Arthington, 2012; Tharme, 2003). Primarily applied in developed countries, using increasingly sophisticated and multidimensional (eco)hydraulic habitat modelling (e.g., Lamouroux and Jowett, 2005). Less commonly used in developing countries/basins, and then tending to be one of a suite of tools used to set environmental water within holistic approach (e.g., USAID, 2016).</td></tr>
<tr><td>Holistic (ecosystem) methods and frameworks</td><td>Entire ecosystem, all or several ecological components. Most consider instream and riparian components, some also consider groundwater, wetlands, floodplains, deltas, estuaries, lagoons, coastal waters. Few consider geomorphic processes (e.g., sediment dynamics, channel</td><td>Typically, moderate to high knowledge and expertise, but several used in data-poor contexts. Desktop and often field studies (seasonal or more intensive). Many reliant on mix of data and expert judgment, using expert panels. Some use both scientific and traditional knowledge to develop or infer flow ecology social relationships. Use virgin/naturalized historical flow records, or rainfall records/ other data for ungauged sites. Several use hydraulic habitat variables from multiple cross-sections. Typically use biological data on flow ecology relationships for</td><td>Moderate to high time, cost, and technical capacity.</td><td>Recommended hydrological regime linked to explicit quantitative or qualitative ecological, geomorphological, and sometimes, social and economic responses and consequences. Some address environmental water regimes for dry or wet years. Moderate to high complexity and confidence. Typically, high resolution and flexibility. Several with potential to generate outputs for multiple scenarios (past, future). Some explicitly address probabilities, interaction effects, risk, and/or uncertainty. A few incorporate climate change.</td><td>Water resource developments, typically large scale, involving rivers of high conservation and/or strategic importance, and/or with complex, negotiated trade-offs among stakeholders. Simpler approaches (e.g., expert panels) often used in basin contexts where flow ecology knowledge is limited, and limited trade-offs exist among users, and/ or time, resources, and</td></tr>
</table>

Method Type	River Ecosystem Attributes/ Components Addressed	Knowledge and Expertise Required	Resource Intensity	Resolution of Output (Environmental Flow)	Appropriate Level(s)
	adjustments), or ecological functions/processes (e.g., nutrient dynamics, food web structure). Several explicitly address social and economic (e.g., livelihoods of rural subsistence users, human health) dependencies on species, ecosystem resources, and processes (i.e., ecosystem services, e.g., fisheries).	lifecycle stages of aquatic and riparian species, assemblages and components (e.g., fish migration and spawning cues, riparian water quality tolerances, exotic species requirements).			capacity constraints exist. Used in planning stage of new developments to protect high conservation values. Also used in highly modified or novel ecosystems, with focus on flow regime to deliver specific restoration objectives, or to address socio-ecological values and services in novel ecosystems.
Regional and landscape-level holistic approaches.	As for other holistic methods, but for large-scale system(s).	Range of experts from different disciplines, including ecologists, hydrologists, and often a geomorphologist. Several include social scientists, other specialists (e.g., water chemistry, health), water managers. Designed to use existing data sets and knowledge. In some cases, includes collection	As for other holistic methods.	Quantified environmental water release rules or standards for rivers of contrasting hydrological type or ecotype and points of management interest, at user defined regional scale(s). Flow alteration-ecological/ social response relationships by river type. As for other holistic methods.	As for other holistic methods. Large systems/basins or aggregations of smaller ones, regions, entire states, or multiple projects. May be integrated with water management systems.

Method Type	River Ecosystem Attributes/ Components Addressed	Knowledge and Expertise Required	Resource Intensity	Resolution of Output (Environmental Flow)	Appropriate Level(s)
		of new data, or modelling for system locations of interest for which hydrological and/or ecological data are absent.			
	Increasingly common in developing and developed countries (e.g., BBM, King and Louw, 1998; Benchmarking, Brizga et al., 2002). Recent attention in developed regions focused on in-depth analysis of ecosystem components and, less commonly, functions/processes. Used regularly in developing countries, including for capacity development, and in complex basins with development pressures and, in many cases, communities with clear dependencies on aquatic systems (e.g., DRIFT, Arthington et al., 2003, 2007; Blake et al., 2011; King and Brown, 2010; King et al., 2000, 2014; Lokgariwar et al., 2014; McClain et al., 2014; Speed et al., 2011; Thompson et al., 2014; USAID, 2016). At regional scale, most applications are adaptations of a single framework, the Ecological Limits of Hydrologic Alteration (ELOHA, Poff et al., 2010; e.g., Arthington et al., 2012; James et al., 2016; McManamay et al., 2013; Rolls and Arthington, 2014; Solans and de Jalo´n, 2016) or similar approaches (e.g., Kendy et al., 2012). Expansion underway from applications in a few developed countries, to pilots in several developing countries, and increasing numbers of applications in large developed basins, with explicit links to water management tools and decision support systems (e.g., PROBFLO, O'Brien et al., 2018).				

APPENDIX 2: Example of hydrodynamic model results.

APPENDIX 2: Hydrodynamic model output for the Inner Niger Delta presenting the availability of habitat (km^2) in the wetland for a given range of flows (m^3/s).

	0.1-D	0.5-D	1-D	1.5-D	2-D	2.5-D	3-D	4-D	5-D	6-D	8-D	10-D
1-Jul	394.6	332	184.2	151.7	116.6	77.9	56	17.1	6	1.8	0	0
2-Jul	389.6	337.4	188.1	151.5	115.7	72.8	56.2	17.3	5.9	0.7	0	0
3-Jul	385.9	335.1	189	150.6	105	77.4	56.5	17.4	5.8	0.6	0	0
4-Jul	384.5	335.5	187.8	149.2	101.7	77.9	56.6	17.4	5.6	0.5	0	0
5-Jul	382.1	335.6	185.8	145.2	101.8	77.8	56.9	17.3	5.5	0.5	0	0
6-Jul	381.7	334.5	184.8	136.4	101.9	78.6	57.2	17.3	5.4	0.3	0	0
7-Jul	380.5	333.5	189.5	134.7	102.2	79.3	57.5	17.3	5.3	0.3	0	0
8-Jul	381	333.9	203.3	134.6	102.7	81.3	58.3	17.7	5.2	0.2	0	0
9-Jul	382.2	334.8	219.5	134.7	103.8	83.6	59.2	18.1	5.1	0.2	0	0
10-Jul	384.6	335.4	248.5	135.8	104.9	85.3	61.2	18.6	5.1	0.2	0	0
11-Jul	386.6	337.3	261.4	136.9	110.9	87.5	63	18.9	5.1	0.2	0	0
12-Jul	387.5	339	270.7	137.6	112.6	88.9	65.4	19.8	5	0.2	0	0
13-Jul	388.2	340.7	277.7	141.7	114.3	89.9	67.1	20.7	4.6	0.2	0	0
14-Jul	389.8	341.8	280.6	150.5	114.9	90.7	68.4	21.5	4.6	0.2	0	0
15-Jul	390.1	342.7	282.2	157.4	115.4	91.4	73.3	21.6	4.5	0.2	0	0
16-Jul	391.1	343.4	283.5	161.3	116	92	74	21.8	4.7	0.2	0	0
17-Jul	390.9	344.4	285.7	165	116.4	92.5	74.2	21.8	4.8	0.3	0	0
18-Jul	391.7	345.7	288.8	166.6	116.9	92.9	74.5	21.8	5	0.3	0	0
19-Jul	392.9	346.3	295	168.7	116.9	93	75.2	21.8	4.8	0.5	0	0
20-Jul	393	346.5	302.1	168.8	117.1	93.3	75.8	22.1	4.7	1.3	0	0
21-Jul	394.1	347.5	302.9	169.2	117.7	95.6	76.8	22.5	5	1.3	0	0
22-Jul	396.8	349.8	303.8	181.5	119.3	99.6	78.6	24.1	5.3	1.3	0	0
23-Jul	399.9	352.7	305.7	206.6	121.5	101.3	81.6	28.4	6.5	1.3	0	0
24-Jul	404.4	355.2	309.2	233.2	126.5	104.2	83.5	32.2	7.4	1.4	0	0
25-Jul	409.6	359	313.9	245	142.9	106.5	85.6	35.3	7.8	1.6	0	0
26-Jul	414.5	362.1	317.3	252.5	159.7	109	87.7	37.7	8.2	1.9	0	0
27-Jul	423.7	364.7	321.3	259.5	166	113.5	89	40.4	8.8	2.3	0	0
28-Jul	432.8	369.7	325	264.3	171.2	117.2	90.2	42.7	9.2	2.3	0	0
29-Jul	440.6	377.2	328	268.8	181.5	119.2	95.9	47	10.1	2.3	0	0
30-Jul	447.3	381	332	275.9	185.8	121.2	98.3	49.6	10.9	2.3	0	0
31-Jul	454	387	335.4	285.5	189.4	124.2	100.6	53.7	12.2	2.3	0	0
1-Aug	462.8	392.4	339.3	295	193.3	131.5	103.3	56.9	13.4	2.3	0	0
2-Aug	471.9	397	342.4	298.9	197.5	139.3	105.8	63	15.5	2.6	0	0
3-Aug	482.6	402.2	345.6	302.4	207.9	148.3	107.2	65.8	16.8	2.9	0	0
4-Aug	491.1	408.6	350	306.1	219.9	159.6	108.8	68.3	17.4	2.9	0	0
5-Aug	502.1	414	352.2	308.3	226.6	165.8	111.6	69.6	17.4	2.9	0	0
6-Aug	515.1	418.4	354.8	311.1	227.6	169.1	114	70.8	17.3	2.9	0	0
7-Aug	523.9	422.2	357.9	312.7	228.5	171	120.6	71.6	17.2	2.9	0	0
8-Aug	535.6	426.2	361.6	313.8	235.3	173.5	121.4	72.3	17.4	2.1	0	0
9-Aug	549.9	430	365.3	316.2	247.6	180.1	122.3	73.5	17.8	2.1	0	0
10-Aug	564.4	435	367.8	318.4	264.3	187.4	123.6	75.2	18.3	2.1	0	0
11-Aug	581.2	439.6	370.6	320.9	282.5	194.7	129	80.3	18.8	2.3	0	0
12-Aug	599.5	446.5	375.7	326.4	288.9	207.8	142.6	85.6	21.8	2.5	0	0
13-Aug	621.1	455.1	383.1	331.7	294.1	234.2	155	88.7	29.7	3	0	0
14-Aug	651.4	465.6	390	338.7	301.2	264.7	168.4	92.3	38.6	5.3	0	0
15-Aug	692.4	484.7	401.3	346.8	307.8	272.4	198.4	94.9	45.8	7.9	0	0
16-Aug	730.5	511.5	413.1	359.6	315	280.1	219.2	99.4	50.5	12.4	0	0
17-Aug	765.8	540.2	425.3	369.9	324.6	289.6	240.7	124	55.5	14.8	0	0
18-Aug	809.1	564.9	437.4	380.7	333.9	295.8	253.7	133.9	60.8	17.8	0	0

19-Aug	853.5	590.9	449.7	390.2	341.9	300.2	260.5	137	67.1	20.6	0	0
20-Aug	901.2	620.6	464.9	396.3	347.7	305.8	266.2	142.6	70.7	25.9	0	0
21-Aug	937.2	649.5	486.6	406.5	353.9	311.8	270.6	148.4	73.5	28.2	0	0
22-Aug	967.6	674.3	503.7	414.6	361.5	317.4	274.5	150.5	74.1	30.2	0	0
23-Aug	998.1	696.5	518.8	423.9	366.8	321.1	276.6	152.3	75	31.9	0	0
24-Aug	1028.3	712.7	528.9	432.5	373.5	324.5	276.5	153.6	81.8	33	0	0
25-Aug	1055	728.5	536	438.3	376.7	327.2	266.6	152.9	82	33.7	0	0
26-Aug	1072.8	736.5	543.9	443.7	379.1	328.5	255.1	151.1	81.3	33	0	0
27-Aug	1088.9	745.7	549.9	447.6	380.8	330.2	252.2	149.4	80.7	33.7	0	0
28-Aug	1100	751	554.5	450.6	385	330.3	251.9	147.8	80.1	33.5	0	0
29-Aug	1108.8	755.4	561.6	457.9	386.5	330.9	250.4	147.1	79.6	33.6	0.6	0
30-Aug	1118.4	760.8	564.2	460.5	390.9	331.8	248.2	146.5	79.2	33.6	1.5	0
31-Aug	1132.2	763.6	565.9	462.5	392	334.8	247.8	146	78.8	33.3	2.7	0
1-Sep	1144.5	768.8	569.1	465	393.1	335.3	248.2	145.7	78.9	33.1	3.6	0
2-Sep	1153.4	775.1	576.3	468.5	395.4	336	251.6	146.1	79	32.8	4.1	0
3-Sep	1164.5	785	583.4	472.5	398.8	338.7	254.5	146.7	79.6	32.8	4.2	0
4-Sep	1173	794.6	590.7	480	402.4	340.6	256.1	147.5	80	33.2	4.5	0
5-Sep	1184.9	798	595.1	486	408.4	343.5	256.7	148.4	79.9	34.5	4.7	0
6-Sep	1191.1	801.9	598.7	488.4	412.1	345.3	257.1	149.1	79.6	36.5	4.8	0
7-Sep	1199.5	803.3	600.3	490.2	414.3	347.3	256	148.4	79.1	37.3	4.8	0
8-Sep	1203.5	800.4	601.6	492	413.3	346.9	252.3	147.7	78.1	37.1	4.8	0
9-Sep	1203.8	797.4	602.5	493.1	412.7	343.5	248.7	144.9	77.2	36.1	4.9	0
10-Sep	1200.6	792.3	600.8	492.3	411.1	341.5	246	142.5	76	33.9	4.9	0
11-Sep	1201	790.9	597.8	492.9	411.5	346.6	247.2	139.9	75.2	31.2	4.9	0
12-Sep	1202.3	791	595.6	493.7	411.2	347.7	250.3	139.6	75.2	29.1	4.8	0
13-Sep	1206.7	792.7	596.1	495.1	411.5	349.4	251.3	140.9	75.8	28.9	4.8	0
14-Sep	1209.9	793.9	596.7	496.3	411.9	350.1	251.7	141.2	76	29	4.8	0
15-Sep	1213.5	797.4	598.3	497.2	413	350	252.5	141.4	76.1	29	4.8	0
16-Sep	1216.4	798.8	599.4	498	413.8	352.1	253	141.5	76.2	29.2	4.8	0
17-Sep	1220.2	800.7	601.3	498.7	414.8	352.7	253.5	141.4	76.1	29.1	4.8	0
18-Sep	1221.4	800.5	602.8	498.9	414.1	352.5	252.8	140.9	76	29.1	4.8	0
19-Sep	1223.8	799.4	603	499.9	414.5	348.4	250.9	139	75.5	28.7	4.9	0
20-Sep	1226.2	797	603.8	499.5	413.1	336.5	247.4	137	74.8	28.3	5	0
21-Sep	1226.2	795.1	603.6	499.4	413	330.8	243.3	134.6	74.2	27.7	5.3	0
22-Sep	1223.4	792.8	605	500	413.3	329.1	240.6	130.9	73.4	27.6	5.4	0
23-Sep	1223	794.8	606.2	499.7	413.1	329.3	239.2	127.7	72.9	27.4	5.5	0
24-Sep	1222.9	795.7	605.8	499.5	412.9	329.4	238.3	126.1	72.6	27.5	5.7	0
25-Sep	1223.3	797.6	608.4	501.5	413.1	327.9	237.6	124.3	72	27.2	6.2	0
26-Sep	1222.3	796.3	608.5	502.8	414.9	326.5	236.7	123.2	71.7	26.9	6.2	0
27-Sep	1221.5	797.4	608.7	503.6	415.5	326.1	236.4	121.8	71.4	26.8	5.9	0
28-Sep	1221.5	797.9	609.3	504.8	415.4	330	236.4	120.9	71	26.7	5.9	0
29-Sep	1223.1	798	611.4	505.7	416.3	340.8	237.9	121	70.9	26.7	5.9	0
30-Sep	1228.1	804.6	614.8	509.1	419	352	246.4	123.5	71.5	26.8	6	0
1-Oct	1235.3	814.3	618.1	512.6	421.6	354.9	253.8	129.7	73.1	26.9	6.2	0
2-Oct	1248.5	831.2	623.5	518.3	426.6	358	266	139.2	74.6	27.8	6.7	0
3-Oct	1258.2	847.3	630.8	523.4	431.9	361	276.9	146.8	77.8	30.1	6.9	0
4-Oct	1271.4	866.6	639.5	527.2	436.8	365.9	284	150.1	80	34.6	7.2	0
5-Oct	1289.6	880.4	649.6	532.5	443.3	370	291.7	152.9	81.3	37.4	7.7	0
6-Oct	1305.8	896.1	659.7	539.5	448.8	374.2	297.1	154.4	82.6	39.5	8	0
7-Oct	1324.9	908.4	669.1	545.5	454.3	378.6	298.3	156.9	83.4	40.8	8.3	0
8-Oct	1339.5	921.4	680.2	550.7	459.3	382.3	296.8	158.3	83.8	41.3	8.6	0
9-Oct	1357.5	930	687.2	555.8	464.7	386.7	296.7	160.3	84.4	41.5	9.1	0.9
10-Oct	1376.3	936.7	693	559.3	469.5	389.9	303.9	161.4	85.2	41.6	9.6	1.9
11-Oct	1393.7	949.4	698.7	564.9	474.2	393.8	314.5	163.3	86.5	42.9	10.4	2.4
12-Oct	1409	960.2	708.3	568.5	479	397.7	320.3	167	88	43.7	10.7	2.3
13-Oct	1422.9	971.9	718.3	573.3	483.2	401.1	325.4	171.1	89.9	44.4	11	2
14-Oct	1436.1	986	727.9	577.5	488.3	404.6	329.2	175.1	91.3	45	11	1.9
15-Oct	1456.7	1003	740.1	583.8	493.1	409.2	333.1	178.7	92.8	45.6	11.1	1.6

16-Oct	1479.4	1019	753.5	590.8	496.6	412.1	336.1	180.4	93.7	46.8	11.3	1.5
17-Oct	1501.4	1036.4	763.6	594.7	500.9	414.6	338.1	181.8	94	47.3	11.3	1.4
18-Oct	1517.2	1049.7	770.1	599.1	504	417.3	339.2	182	94.2	47.5	11.4	1.3
19-Oct	1531.6	1059.8	773.2	602.2	507	419.8	339.6	181.9	94.3	47.2	11.4	1.2
20-Oct	1541.9	1067.5	777.6	605.7	509	421.9	336.4	181.2	94.3	46.7	11.4	1.1
21-Oct	1552.8	1072.2	781.1	610.6	510.2	421.8	327.2	179.1	93.8	46.4	11.4	0.8
22-Oct	1558.8	1070.8	780.3	612.5	510.2	421.3	316.3	177.2	93	44.9	11.4	0.5
23-Oct	1563	1066	777.8	613.1	508.2	420.1	310.8	175.2	91.7	43.7	11.3	0.4
24-Oct	1563.3	1055.4	774.1	609.8	506.8	417.6	305.6	172.6	90.3	42.9	11.2	0.4
25-Oct	1558.4	1042.7	769.1	604.5	504.8	404.7	298.7	165.9	88.5	42.2	11	0.1
26-Oct	1541.5	1027.8	760.3	598.4	500.9	385.3	291.2	157.6	86.7	41	10.5	0
27-Oct	1521.9	1011.5	747.3	594	495.9	377.5	280.8	152.4	84.6	39.2	10.3	0
28-Oct	1503.8	999.4	739.8	588.8	489.4	369.1	274.4	149	81.5	37.1	9.3	0
29-Oct	1487	984.3	732.4	584.9	481.9	364.6	270.2	139.3	77.5	34.4	8.9	0
30-Oct	1466.7	969	722.9	578.8	475.2	357.2	265.8	133.4	74.1	33.9	8.8	0
31-Oct	1450.7	955.3	715.4	573.7	467.9	349.3	259.6	128	71.7	33	8.5	0
1-Nov	1430.9	937.6	709.2	566.8	457.8	341.5	252.5	126.7	69.4	32.2	7.9	0
2-Nov	1411.7	921.8	700.8	560.1	441.4	331.9	246.9	124.1	64.4	31.5	7	0
3-Nov	1396	900.7	694	552.4	422.5	323.1	240.3	122.4	60	30.9	6.2	0
4-Nov	1372.9	886.8	687.3	544.7	410	314.9	231.6	120.3	56.3	30.9	6	0
5-Nov	1354.7	875.7	679.8	536.3	400.1	308.2	222.6	118.1	52.9	30.7	5.3	0
6-Nov	1328.1	863.8	673.4	528.3	392.2	300.1	212.9	115.6	49.6	27	5.2	0
7-Nov	1307.9	852.3	666.8	520.7	384.5	291.9	204.7	112.9	46.9	22.8	5	0
8-Nov	1288.1	840.2	658.2	515.2	368.8	285.5	193.7	109.1	45.3	22.1	3.9	0
9-Nov	1264.2	829.6	649.5	496.8	360.5	276.4	184.2	106.6	44.1	21.2	2.9	0
10-Nov	1239.7	820.2	642.1	475.3	350.3	265.4	178.7	103.9	43.3	20.8	1.4	0
11-Nov	1216.4	811.2	631.7	468.7	343.5	253.2	176.1	101.2	36	20.1	0.8	0
12-Nov	1191.7	800.6	624	463.7	338.9	240.3	173.5	98.3	34.5	19.3	0.4	0
13-Nov	1170.6	791.5	618.5	451.9	333.2	225.5	170.2	96.5	33.9	17.6	0	0
14-Nov	1146.2	783.6	613.5	439	326.7	218.1	166.3	94	33.5	16.9	0	0
15-Nov	1124.8	773.8	609.9	428.5	318.8	213	163.9	91	31.8	15.9	0	0
16-Nov	1103.5	764.6	604.7	424.3	310.6	210.6	160.6	83.4	30.7	13.9	0	0
17-Nov	1086.6	757.4	598.8	418.1	303.7	207.7	158.6	80	29.6	12.7	0	0
18-Nov	1071.4	752	593.9	413	297.6	205.2	156.8	78.1	28.5	12.4	0	0
19-Nov	1053.6	747.4	588.6	410.2	287.9	202.4	154	75.2	27.5	11.7	0	0
20-Nov	1035.2	742.3	583.5	406.4	279.9	199.4	151.8	73.3	26.4	7.4	0	0
21-Nov	1016.6	737.8	579.7	403.4	275.5	196.1	147.6	71.2	25.6	6.6	0	0
22-Nov	1000.6	734.2	575.1	400.1	272.9	194.1	143	69.4	24.9	5.8	0	0
23-Nov	988	729.9	570.7	394.5	267.8	192.1	139	68.4	24.6	4.9	0	0
24-Nov	977.1	726.1	565.2	389.9	265.1	190.3	136.6	67.1	24	4.2	0	0
25-Nov	968.4	723.2	559.1	383.6	260.2	188.5	134.3	65.7	23.7	3.8	0	0
26-Nov	960.8	719.1	552.5	378.6	253.2	187.4	132.1	64.1	20.4	3.5	0	0
27-Nov	952.6	714.6	548.4	375.4	250.1	186.5	131.2	62	18.5	3.2	0	0
28-Nov	943.4	712.6	543.6	371.8	248.6	184.9	129.5	57.9	18.5	3.2	0	0
29-Nov	935.2	709.9	539.5	368.2	246.4	184	128.4	55.6	18.1	3.1	0	0
30-Nov	930.3	707.6	539.3	363.6	244.7	182.7	127.4	54.1	17.9	3.1	0	0
1-Dec	923.2	705.7	548	360.7	243.4	181.7	127	53.1	17.4	3	0	0
2-Dec	917.1	704.7	547.6	360.8	241.3	181.4	127.3	52.9	16.9	2.9	0	0
3-Dec	911.7	704.1	545.9	367.1	239.3	181.4	128.3	54.2	16.4	2.9	0	0
4-Dec	907	701.2	545.5	371.1	239	181.9	129.3	49.7	16.6	2.9	0	0
5-Dec	902.8	699.7	544.7	373.3	238.9	181.7	129.7	51.1	16.7	2.9	0	0
6-Dec	897.6	696.7	542.3	373.3	240.1	182.5	129.6	50.4	16.7	2.9	0	0
7-Dec	892.1	694.7	540.4	371.3	239.9	181.8	129.1	50.2	16.8	2.9	0	0
8-Dec	884.8	691.6	528.1	367.4	236.6	180	127.8	49.3	16.6	2.9	0	0
9-Dec	879.1	688.6	513.7	360.4	234.1	178.1	125.9	47.7	16.2	2.9	0	0
10-Dec	874.4	686	496.5	352	232.4	174.9	124.1	43.6	15.4	2.7	0	0
11-Dec	866.8	683	480.9	344.6	230.3	171.4	121.4	41.5	14.1	2.6	0	0
12-Dec	860.2	679.8	473.8	330.4	227.6	169.3	119	40.1	13.3	2.5	0	0

13-Dec	855.3	675.3	468	321.6	225.7	167.7	116.9	39.4	12.5	2.5	0	0
14-Dec	849.9	672.2	462.1	315.6	223.7	165.8	110.5	38.4	12.2	2.3	0	0
15-Dec	845.2	670.6	456.8	310.1	221.8	164.3	108.2	37.4	11.6	2.3	0	0
16-Dec	841.3	666.5	450.9	307.4	220.5	163.2	106	36.1	11.2	2.2	0	0
17-Dec	837.5	664.1	445.4	304	219.1	160.6	104.3	35.2	11	1.9	0	0
18-Dec	834.8	661.7	439.3	301.4	217.6	159.1	102.6	34	10.9	1.8	0	0
19-Dec	829.2	658.8	431.2	297.5	215.2	156.9	100.9	32.7	10.7	1.8	0	0
20-Dec	824.4	655.8	421.3	293.9	213.9	154.9	99.8	31.9	6.7	1.6	0	0
21-Dec	819.3	653	407.8	289.6	210.1	153.6	98.7	31.2	6.6	1.6	0	0
22-Dec	814.6	650.3	401.2	287.7	207.2	152.3	97.6	30.6	6.5	1.6	0	0
23-Dec	811.1	646.1	397.2	284.9	205.6	150.7	96.9	30.3	6.5	1.5	0	0
24-Dec	806.4	644	395.1	283.4	204.8	149.2	96.3	30.2	6.4	0.8	0	0
25-Dec	803.7	641.8	393	281.5	203.8	148.2	95.8	25.3	6.2	0.6	0	0
26-Dec	800.9	639.2	392.3	280.3	203.1	143.4	95.5	25	6.2	0.6	0	0
27-Dec	796.4	637	395.4	278.2	202.3	143.5	95.2	25	6.1	0.5	0	0
28-Dec	792.9	635	393.3	275.2	202.7	143.9	95.3	25.1	5.8	0.5	0	0
29-Dec	788.6	632.4	400.6	274.1	203.1	144.4	95.8	25.1	5.6	0.5	0	0
30-Dec	784.2	629.2	400.9	273.1	202.5	143.6	95	25.2	5.4	0.5	0	0
31-Dec	780.8	622.1	398.2	271.8	200.8	141.5	93.7	25.1	5.4	0.5	0	0
1-Jan	777.2	592.2	386.4	270	199	140.2	85.8	24.9	5.4	0.3	0	0
2-Jan	773.3	568.5	380.5	266.8	196	137.5	80.5	24.3	5.2	0.3	0	0
3-Jan	769	557.3	372.4	261.7	192.6	134.2	78	23.9	5.2	0.3	0	0
4-Jan	765.5	551.5	370.5	258.9	190.1	130.5	75.9	23.4	5.2	0.2	0	0
5-Jan	762.3	550.1	369.2	255	187.1	126.5	72.9	23	5.2	0.2	0	0
6-Jan	759.1	552.5	366.9	252.5	182.8	123.8	69.8	22.8	5.2	0.9	0	0
7-Jan	754.4	550.9	364.4	251.2	176.9	122.7	66.6	22.5	5.2	0.9	0	0
8-Jan	749.5	545.9	361	249.7	177	124.2	64.6	22.1	5.1	0.9	0	0
9-Jan	745.5	542.6	357.2	248.9	177.6	124.3	62.8	21.6	5.1	0.9	0	0
10-Jan	742.2	548	355.5	247.6	176.8	124.7	62.8	21.2	5.1	0.9	0	0
11-Jan	738.8	554	351.9	247.7	176.4	124.8	63.6	21.1	5	0.9	0	0
12-Jan	736.9	554.1	347.5	247.1	176.4	117.5	64.7	17.1	5	0.3	0	0
13-Jan	734.8	548.3	343.4	246.1	176.5	117.7	66.4	17.1	5	0.1	0	0
14-Jan	731.2	528.7	341.1	245.7	175.3	116.9	66.7	17.2	4.9	0.1	0	0
15-Jan	728.9	516.3	339.1	244.7	173.1	116.2	65.9	17.3	4.9	0.1	0	0
16-Jan	726.5	510.8	337	242.6	171.3	114.6	62.5	17.3	4.9	0.1	0	0
17-Jan	723.7	503.8	334.8	240.9	169.7	109.3	58.4	17	4.9	0.1	0	0
18-Jan	721.3	492.6	332.1	239.5	167.5	106.5	56.2	16.6	4.9	0.1	0	0
19-Jan	718.1	482.1	329.6	237.5	164.8	104.8	54.9	16.3	4.8	0.1	0	0
20-Jan	714.3	474.4	326.5	235.4	162.3	101.9	53.9	16.2	4.8	0.1	0	0
21-Jan	709.3	468.5	323	228.3	160.9	99.1	48.5	16.1	4.6	0.1	0	0
22-Jan	706.4	462.9	320.1	226.2	159.3	96.3	47	15.8	4.3	0.1	0	0
23-Jan	704.2	456.3	318.6	224.1	157.8	92.8	45.3	15.7	4.1	0.1	0	0
24-Jan	702.2	451.5	317	222.1	155.9	90.4	43.7	15.7	3.9	0.1	0	0
25-Jan	698.8	445.9	315.3	220.8	154.2	88.7	42.5	15.5	3.8	0.1	0	0
26-Jan	696.6	441	314.3	219.4	152.4	87.1	42	15.3	3.7	0.1	0	0
27-Jan	692.3	435.8	313.6	218	144.6	85.7	41.4	15.3	3.6	0.1	0	0
28-Jan	689	431.4	311.4	215.9	142.8	83.6	41.2	14.3	3.5	0.1	0	0
29-Jan	686.8	424.8	310.5	215	141.4	82.4	41.1	14.3	3.2	0	0	0
30-Jan	683.8	420.7	309.2	214	139.5	81.8	40.7	14.4	3.2	0	0	0
31-Jan	681.5	417.6	307.3	212.6	138.2	81.3	40.2	14.1	3.1	0	0	0
1-Feb	677.4	414.8	306.2	211.6	136.9	79.7	40	14.1	3.1	0	0	0
2-Feb	675.1	412.7	301.8	210.4	134.4	73.5	39.6	14.1	3	0	0	0
3-Feb	671.4	411.4	299.9	209.3	131.7	71.9	39.3	14	3	0	0	0
4-Feb	668	408.9	298.3	207.6	129.5	70.5	38.9	13.9	3	0	0	0
5-Feb	664.1	407.4	296.9	205.7	127.1	70	38.6	13.9	3	0	0	0
6-Feb	660.8	405.7	295.8	204.5	125.4	69.6	38.5	13.7	2.7	0	0	0
7-Feb	658.7	403.5	294.7	203.7	123.5	68	38.1	13.7	2.7	0	0	0
8-Feb	654.8	401.9	293.2	202.7	121.4	67	38.1	13.5	2.7	0	0	0

9-Feb	653.7	399.8	292.2	195.5	119.7	67.1	33.5	13	2.7	0	0	0
10-Feb	651.1	399	291.7	194.1	118.3	66.1	33.3	12.4	2.7	0	0	0
11-Feb	647.2	397.2	291.1	192.9	117.5	65.6	33.1	12.2	2.6	0.8	0	0
12-Feb	644.5	395.2	290.4	191.9	116.7	65.2	32.5	12.6	2.4	0.8	0	0
13-Feb	641.7	393.7	288.7	191.6	115.7	64.6	32.4	12.6	2.4	0.8	0	0
14-Feb	638.2	391.8	287.1	190.4	113.9	64.3	32.2	12.6	2.4	0.8	0	0
15-Feb	634.2	389.9	285.5	189	112.4	63.2	32.2	12.5	2.4	0.8	0	0
16-Feb	629.9	384.4	283.2	187.8	106.5	62.2	32	12	2.4	0.8	0	0
17-Feb	626.9	382.1	281.2	187	105.8	61.3	31.8	12	2.4	0.8	0	0
18-Feb	623.2	379.7	280.8	185.2	104.9	61	31.7	11.8	2.4	0.8	0	0
19-Feb	621.2	379.2	278.7	183.1	104.4	60.7	31.6	11.4	2.4	0.8	0	0
20-Feb	619.2	377.3	277.8	182.2	104.3	60.3	31.5	11.3	2.4	0.8	0	0
21-Feb	616.7	375.7	276.3	181.1	104.1	60.2	31.3	11.2	2.4	0.8	0	0
22-Feb	614.4	374.7	275.2	178.8	103.4	59.9	31.1	11.1	2.2	0.8	0	0
23-Feb	612.5	372.8	274.7	175.1	103	59.1	30.5	11	2	0.8	0	0
24-Feb	611.3	370.7	273.6	170.6	102.5	58.9	30.5	11	2	0.8	0	0
25-Feb	609.7	369.6	266.1	167.2	101.5	54.7	30.4	10.7	2	0.8	0	0
26-Feb	607.9	368.2	265.9	165.9	101.3	54.4	30.4	10.6	2.1	0.8	0	0
27-Feb	606.4	366.8	265.2	165.9	101.4	54.1	30.4	10.2	2.1	0.8	0	0
28-Feb	605.6	366.2	265.7	167.8	101.6	53.5	30.4	10.1	2.1	0.8	0	0

ONE RIVER
ONE PEOPLE
ONE VISION

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