Joule Africa Limited

Bumbuna Reservoir II, Sierra Leone

Ecological Flow Assessment

ecotone
Freshwater Consultants

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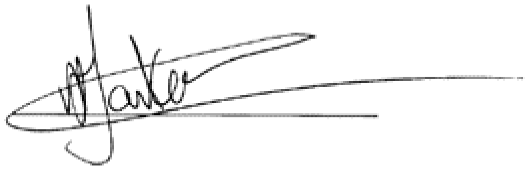

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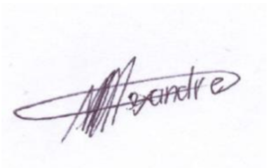

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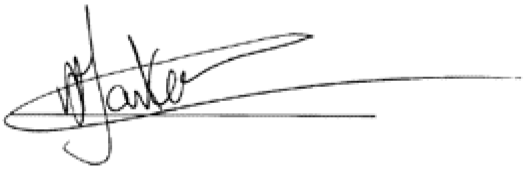
Declaration of Independence

I, Michiel Jonker, as duly authorised representative of Ecotone Freshwater Consultants CC (Ecotone), hereby confirm my independence (as well as that of Ecotone, its members, employees and sub-consultants) as a specialist and declare that neither I nor Ecotone have any interest, be it business, financial, personal or other, in any proposed activity, application or appeal in respect to the proposed Bumbuna Reservoir II project, Sierra Leone, other than fair remuneration for work performed.



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ABBREVIATIONS AND ACRONYMS

ASPT	Average Score per Taxa
AAO	Area of Occurrence
BDI	Biological Diatom Index
DLIFR	Drought low flow
EC	Ecological Category
EFA	Environmental Flow Assessment
EWA	Environmental Water Assessment
EFR	Environmental Flow Requirement
EWR	Environmental Water Requirement
EIS	Ecological Importance and Sensitivity
EOO	Extent of Occurrence
EWR	Ecological Water Requirement
FD	Fast Deep
FDC	Flow Duration Curves
FI	Fast Intermediate
FRAI	Fish Response Assessment Index
FROC	Frequency of Occurrence
FS	Fast Shallow
FVS	Fast Very Shallow
IHI	Index of Habitat Integrity
LSR	Large semi-rheophilic fish species
MAR	Mean Annual Runoff
MIRAI	Macro-Invertebrate Response Assessment Index
MCM	Million Cubic Meters
MV	Marginal vegetation
MVI	Marginal vegetation macroinvertebrate
PES	Present Ecological State
%PTV	Percentage Pollution Tolerant Valves
RDM	Resource Directed Measures
RDRM	Revised Desktop Reserve Model
REC	Recommended Ecological Category
SADI	South African Diatom Index
SASS	South African Scoring System
SD	Slow Deep
SPI	Specific Pollution Sensitivity Index

SS	Slow Shallow
SVS	Slow Very Shallow
TDI	Trophic Diatom Index
Veg	Vegetation

KEY TERMINOLOGY DEFINED

Key ecological terms that should be explained at this point for the meaningful reading of the text.

Active channel	The portion of a river that conveys flowing water at sufficiently regular intervals to maintain channel form (i.e. the presence of distinct bed and banks) and keep the channel free of established terrestrial vegetation.
Alkaline	Where the pH of water is greater than 8.
Amphidromous	Migrating from fresh to salt water or from salt to fresh water at some stage of the life cycle other than the breeding period.
Aquatic vegetation	Plants that grow principally on or below the water surface.
Bass flow	The portion of stream flow that is not runoff and results from slow seepage of water from the ground into a channel over time. The New RDRM completes a baseflow separation for wet and dry seasons. While the dry season separation is consistent with the formal definition of baseflow, the wet season separation, for larger systems such as the Zambezi, does not necessarily conform to the definition. For this reason, reference is made to 'low flows' for both wet and dry periods. The maximum 'low flows' separation for the wet season is consistent with the point at which instream habitat is optimised and additional flows will not translate into meaningful changes in channel width and depth. This point is considered an ecological low stress point.
Bedrock channel	A channel formed in solid (consolidated) rock, though there may be loose (unconsolidated) material present locally.
Bench	(As relating to landscape setting): a relatively discrete area of mostly level or nearly level high ground (relative to the broad surroundings), including hilltops, saddles and shelves. Benches are significantly less extensive than plains, typically being less than 50ha in area
Benthic	The ecological region at the lowest level of a body of water such as an ocean or a lake, including the sediment surface and some sub-surface layers. Organisms living in this zone are called benthos.
Benthopelagic	Living and feeding near the bottom as well as in midwaters or near the surface. Feeding on benthic as well as free swimming organisms. Many freshwater fish are opportunistic feeders that forage on the bottom as well as in midwater and near the surface.
Brackish	(As relating to salinity/conductivity): slightly salty. For purposes of the Classification System, brackish water is categorised as having a salinity (or TDS concentration) of 3 to 18g/l, and/or a conductivity of 500 to 3000mS/m

Circum-neutral	Where the pH of water is between 6 and 8
Conductivity	A measure of the ability of a sample of water to conduct an electrical current, providing an indication of the concentration of Total Dissolved Salts (TDS) in water: Conductivity can be used as a surrogate measure of salinity.
Data Deficient	A species categorised by the IUCN as offering insufficient information for a proper assessment of conservation status to be made.
Demersal	Sinking to or lying on the bottom; living on or near the bottom and feeding on benthic organisms.
Dystrophic	Rich in organic matter, usually in the form of suspended plant colloids, but of a low nutrient content.
EcoClassification	The term used for Ecological Classification - refers to the determination and categorisation of the Present Ecological State (PES; health or integrity) of various biophysical attributes of rivers compared to the natural or close to natural reference condition. The purpose of EcoClassification is to gain insights into the causes and sources of the deviation of the PES of biophysical attributes from the reference condition. This provides the information needed to derive desirable and attainable future ecological objectives for the river. The EcoClassification process also supports a scenario-based approach where a range of ecological endpoints must be considered.
EcoStatus	The incorporation of different PES categories for the varies biophysical attributes into an overall ecological status.
Endangered	A species categorised by the IUCN as being seriously at risk of extinction.
Endemic	Species that exist only in one geographic region. Species can be endemic to large or small areas of the earth. Some are endemic to a continent, some to part of a continent, and others to a single island.
Eupotamonic benthic guild	Benthic species that occupy the centre of the main channel. They are generally intolerant of lowered dissolved oxygen concentrations, although they may have to resist periodic lowering of oxygen tensions during the hot, dry season. They can adapt behaviourally to altered hydrographs, existing in a quasi-lacustrine condition and generally increase in number as other species decline. They are impacted negatively by modifications that change deposition–siltation processes and alter the nature of the substratum and may also be sensitive to deoxygenated conditions in the deeper, refuge areas of the channel during the dry season. They are predominantly psammophils and lithophils.
Eupotamonic lithophilic guild	Species in this guild are often longitudinal migrants, including many anadromous species. They differ from the eupotamonic pelagophilic species in that they are predominantly lithophils and psammophils with a single breeding season. They may be semelparous, having one breeding season only. Fry may be resident at

upstream sites for a certain period and may occupy upstream floodplains. These species are also vulnerable to damming and to lowered water quality that prevents migration, although they may respond favourably to appropriately designed fish passes. They are also adversely affected by changes in the timing of high flow events that are inappropriate to their breeding seasonality, as well as to changes in the quality of upstream breeding habitats, which may become choked with silt or have insufficient flow to aerate the developing eggs. The species may be recovered by ensuring longitudinal connectivity by fish passage facilities or removal of cross channel dams, or by ensuring the timing and quantity of flows are adequate to promote migration and ensure the development of eggs and larvae by providing aerating flows in the spawning gravels.

Eupotamonic phytophilic guild Species in this guild are long distance or short distance longitudinal migrants that also undertake lateral migrations onto and off the floodplain, which they use for breeding, nursery grounds and feeding by juvenile and adult fish. Adult and juvenile populations may be found in floodplain lagoons as dry season residents. They are predominantly phytophils or phytolithophils, spawning at floodplain margins, in inflowing channels or on the floodplain itself. Eggs and larvae of some species are semi-pelagic and are carried onto the floodplain by passive drift with the rising flood. Species in this guild tend to disappear or become greatly diminished in abundance when the river is dammed and prevents migration, or when access to the floodplain is denied to developing fry and juveniles because flow levels are inadequate to flood riparian lands, or these are cut off by levees.

Eupotamonic riparian This guild occupies the riparian zone and particularly the vegetation of the main channel and floodplain waterbodies; and may move onto the floodplain to occupy similar habitats during flooding. Populations may have lateral migratory or semi-migratory components, with resident elements that become dominant in controlled conditions. These species usually tolerate low dissolved oxygen. They show a wide range of breeding behaviour but are predominantly phytophils although they also include species showing various degrees of nest building and parental care. They can adapt behaviourally to altered hydrographs, are extremely flexible and may adopt other habitats as river conditions change and increase in number as other species decline. This guild is especially well represented in most rivers. Species in this guild are colonizers of regulated systems and often increase to pest levels following control of flooding and stabilization of river hydrographs or declines in water quality through eutrophication.

Eutrophic High primary productivity, rich in mineral nutrients required by plants.

Froth nesters Bubble nests, also called foam nests, are created by some fish and frog species as floating masses of bubbles blown with an oral secretion, saliva bubbles, and

	occasionally aquatic plants, or an area for egg deposit attached at the bottom. Fish that build and guard bubble nests are known as aphrophils.
Hydrological regime	The typical cycle of water movement in an aquatic ecosystem.
Hypereutrophic	Very high primary productivity, constantly elevated supply of mineral nutrients required by plants.
Least Concern	A species categorized by the IUCN as evaluated but not qualified for any other category. As such they do not qualify as threatened, near threatened, or conservation dependent.
Lentic	Of or relating to standing (still) waters.
Lithopelagophils	A reproductive guild of rock and gravel spawners with pelagic larvae. After hatching free embryos are pelagic by positive buoyancy or active movement. The young are not photophobic, and there is a limited respiratory structure.
Lithophils	Breeding is associated with a stony substrate.
Lotic	Of or relating to running (flowing) waters.
Lower foothills	Lower gradient, mixed-bed alluvial channel with sand and gravel dominating the bed, locally may be bedrock-controlled. Reach types typically include pool-riffle or pool-rapid, sand bars common in pools. Pools of significantly treater extent than rapids or riffles. Floodplain often present. Characteristic gradient 0.001-0.005.
Mesotrophic	Intermediate levels of primary productivity, with intermediate levels of mineral nutrients required by plants.
Mineral content	Classes and thresholds as applied in the diatom assessment:

Very electrolyte poor	<50µS/cm
Electrolyte-poor (low electrolyte content)	50-100µS/cm
Moderate electrolyte content	100-500µS/cm
Electrolyte-rich (high electrolyte content)	>500µS/cm
Brackish (very high electrolyte content)	>1000µS/cm
Saline	6000µS/cm

Mouth brooders	Fish which broods or protects the eggs (ovophile) or young (larvophile) by taking them into the mouth.
Natural Habitat	“Natural habitats are areas composed of viable assemblages of plant and/or animal species of largely native origin, and/or where human activity has not essentially modified an area’s primary ecological functions and species composition” – IFC PS6.
Near Threatened	A species categorized as by the IUCN that may be considered threatened with extinction soon, although it does not currently qualify for the threatened status.
Non-perennial	Does not flow continuously throughout the year, although pools may persist.

Oligotrophic Low levels or primary productivity, containing low levels of mineral nutrients required by plants.

Paleopotamonic guild This guild consists of species tolerant of complete anoxia that are found in isolated floodplain pools and wetlands. They are usually sedentary and sometimes show extremes of parental care with nest building and viviparity. In slightly modified systems they persist in residual floodplain water bodies isolated from the main river and may resist complete desiccation (xerophils). They may also survive in low numbers in deoxygenated backwaters and marginal and floating vegetation and form important components in rice field and ditch faunas. Some of these species have been used for intensive aquaculture because of the readiness with which they adapt to pond conditions and extremely dense populations. The guild is impacted negatively by floodplain reclamation schemes that drain or fill the marginal waterbodies and wetlands in which component species live.

Parapotamonic guild Species in this guild may be termed semi-lotic in that their behaviour is intermediate between the long-distance migrants of the other three lotic guilds and the lentic groupings. They are sometimes sedentary but also show semi-migratory behaviour. They include lithophils, phytophils, phytolithophils and psammophils. They prefer slow-flowing anabranches of the main river or backwaters with low or seasonal flows. They can also use tributary creeks, blind backwaters or slacks downstream of point bars as breeding grounds and nurseries. The parapotamon is also used as a refuge for many rheophilic species during times of excessive main channel flow. Species in this guild are usually fairly resistant to change and as such could be considered eurytopic (generalist). However, they are sensitive to river straightening and bank revetments that suppress main channel diversity and bank structure. Species can be recovered by rehabilitating main channel diversity, particularly by reconnection of abandoned side arms and active backwaters.

Pelagic The pelagic ecosystem is a deep-water habitat largely dependent on the phytoplankton inhabiting the upper, sunlit regions, where most ocean organisms live.

Perennial Flows continuously throughout the year, in most years.

Phytolithophils Non-obligatory plant spawners that deposit eggs on submerged items.

Phytophils Breeding is associated with a vegetation.

Plant material nesters Constructing a nest out of plant material.

Plant tenders Parental care is taking place around plant material.

Plesiopotamonic guild This guild consists of species that are tolerant to reduced dissolved oxygen concentrations but cannot resist complete anoxia. They usually inhabit relatively well-oxygenated water bodies that are regularly connected to the main river by

	flooding, where they may be found in open waters as well as in the riparian vegetation. Some species may also occupy riparian vegetation of still-water channels and canals. They are often sedentary but may show a limited amount of lateral migration that permits them to escape the worst of deoxygenated conditions. They include guarding and non-guarding phytophilic and nest building species. Species in this guild tend to disappear when the floodplain is disconnected from the main channel and desiccated through levee construction. Limited populations may continue in riparian vegetation in the main channel or in backwaters whose upper end is silted. They may also increase in number in shallow, isolated wetlands, and drainage ditches.
Pollution (Saprobity)	classes and thresholds as applied in the diatom assessment:

Unpolluted to slightly polluted	BOD <2, O_2 deficit <15%	oligosaprobic
Moderately polluted	BOD <4, O_2 deficit <30%	mesosaprobic
Critical level of pollution	BOD <7, O_2 deficit <50	mesosaprobic
Strongly polluted	BOD <13, O_2 deficit <75%	mesosaprobic
Very heavily polluted	BOD <22, O_2 deficit <90%	polysaprobic

Potamon	That part of a river in which the water is typically slow-moving, still-surfaced, deep, and relatively warm, favouring organisms that are thrifty in their use of dissolved oxygen.
Pouch brooder	Brooding eggs or young fry from a pouch.
Psammophils	Require sand for reproduction.
Rheophilic	All life staged require flowing water.
Rhithron-pool guild	Species in this guild are slightly more limnophilic in habit and generally seek to inhabit the slack regions of back eddies where emergent and floating vegetation may occur. Other species inhabit the deeper waters. They tend to be insectivorous, feeding on the drift dislodged from the riffles or on insects falling into the river from riparian vegetation. They may be either limnophilic, breeding in the riffles, or phytophilic, attaching their eggs to vegetation. The various species inhabiting rhithronic pools usually have well-defined home ranges, and appear to have defined habitats delimited by depth, current strength and the distribution of vegetation. As with the riffle guild, variations may occur resulting from the lessening gradient and widening of the channel. These species are also disturbed by changes to the flow regime that desiccate the pools or leave them for long periods without flow, so they become anoxic. They also generally rely on the delicate balance between pool and riffle of the rhithron and respond negatively to any influence that changes this balance. Again, this guild can be affected by the loss of longitudinal connectivity.

Rhithron-riffle guild	Species in this guild are rheophilic, main channel residents that inhabit rapids and riffle areas. They are generally sedentary, of small size and are equipped with suckers or spines to enable them to grip rocks and other submersed objects. They may also have elongated or laterally flattened forms that allow them to live in the interstitial spaces of the rock and cobble substrate. Riffle species are generally non-guarding and guarding lithophils with extended breeding seasons depositing their eggs among the rocky riffles where they live. They are generally insectivorous or specialists such as algal scrapers or filter feeders. Species inhabiting riffles usually require very well oxygenated water.
Rhithron	That part of a river in which the water is typically fast-moving, broken-surfaced, shallow, and relatively cold, favouring rheophilous, cold-water stenothermous organisms with a high demand for dissolved oxygen.
Rock tenders	Parental care taking place around rocky substrate.
Sand nester	Fish constructing nests with sand or gravel.
Serial spawner	A fish species spawning in multiple bursts within a given period, typically in response to some environmental stimulus or cue.
Silt (mud)	Soil dominated by mineral particles with diameters of less than 0.06 mm (i.e. very fine material).
Synchronous spawning	Also, called broadcast spawning. Synchronous spawning takes place when animals release their eggs and sperm into the water at the same time, where fertilization occurs externally.
Total dissolved solids	A measure of the total amount of material dissolved in water, including all material that is both organic and inorganic, and both ionized and un-ionized.
Vulnerable	A species categorized by the IUCN as likely to become endangered unless the circumstances threatening its survival and reproduction improve.
Whetted Width/Perimeter	The wetted perimeter is the perimeter of the cross sectional area that is "wet". in the context if this assessment it directly relates to available instream habitat.

EXECUTIVE SUMMARY

Ecotone Freshwater Consultants (CC) was appointed to conduct a baseline freshwater assessment of aquatic habitat and associated ecology for the Seli/Rokel River. In addition, the study aimed to predict the changes that the Bumbuna Extension activities may have on receiving aquatic resources. The assessment took an integrated driver (water quality, flow, sediment) and responder (diatoms, aquatic macroinvertebrates and fish) approach to define baseline conditions. The approach is represented as part of a water resource management framework that is consistent with the IFC PS 6 standard, in that it classifies the aquatic resources on a continuum of modification (ranging from Natural to Modified), while the ecological relevance of the aquatic habitat was expressed in terms of its ecological importance and sensitivity.

The study determined four main aquatic habitat units, based on longitudinal slope which included: Source zone, Upper foothills and Lowland (or floodplain) and Rejuvenated foothill. Sites representing these different habitat units were assessed during April 2018. The Source zone represents the start of the Seli/Rokel River, while the Upper foothills habitat extends from the end of the Source zone to the Bumbuna Settlement, where the Lowland river starts. Intermittent slope adjustments within the Lowland reaches results in Rejuvenated foothill habitat.

Figure 0-1 provides a spatial summary of the results in relation to the proposed Bumbuna Expansions. Each site is represented by a red dot and two overall EcoStatus boxes. The top box reflects baseline conditions while the bottom box indicates the anticipated change during operations. The overall EcoStatus is expressed on a continuum from *Good* to *Very Poor* and is the product of integrating different ecological components (habitat integrity, diatoms, aquatic macroinvertebrates and fish). The overall EcoStatus of the Source zone and upper parts of the Upper foothills habitat were assessed as *Good* or *Largely Natural*. The ecology of these reaches retained a high degree of functionality, although some impacts related to artisanal goldmining and deforestation for agriculture were present which may have some influence on the ecological integrity. The lower parts of the Upper foothills habitat and the Lowland habitat revealed a *Moderate* loss within the overall EcoStatus under baseline conditions. The spatial variations within the ecological components suggest an impact gradient along the longitudinal profile of the Rokel River, most likely associated with changes within the hydrological regime due to existing Bumbuna HEP operations.

The Expansions will result in: (i) a modification of a portion of the Upper foothills habitat associated with the new inundation zone. (ii) Flow reduction within the 'dry reach' within a portion of Upper foothills habitat (between the existing Bumbuna Reservoir and the Extension HEP tailrace. (iii) An increase in dry season baseflows extending over the length of the downstream river and a delay in the onset of the wet season functional flows. These operational changes will result in a decrease in EcoStatus for a portion of the Upper foothills habitat associated with the inundation zone, from *Good* to *Poor* (or *Largely modified*). The overall EcoStatus for the lower parts of the Upper foothills (associated with the 'dry reach') and Lowland habitat will remain the same during operations, although some decrease is expected for the habitat and fish assemblage integrity within the downstream reaches (**Figure 0-1**).

All the defined habitat units potentially qualify as Critical Habitat (CH) under Tier 2 of Criteria 1 (habitat of importance to Endangered- EN or Critically Endangered- CR species) and Criteria 2 (habitat of importance to endemic or range restricted species). Other aspects that contribute towards the ecological importance of the different habitats include (i) the relative species richness of the Lowland habitat. (ii) The structural diversity of the Upper foothills (providing suitable habitat for rheophilic and semi-rheophilic species). (iii) Spawning habitat downstream of Bumbuna Falls. (iv) The occurrence of taxa sensitive to changes in water quality and flow regime. (v) The flood storage and energy dissipation capacity associated with the lower parts of the Lowland unit.

Potential impacts are summarised accordingly:

Inundation Zone (Upper foothills)

- The functional integrity of habitat within the inundation zone will decrease. However, Upper foothills species are likely to recruit and utilise marginal habitat while migrating along the sides of the reservoir and breeding at the inflow and upstream thereof.
- Rheophilic (flow loving) and semi-rheophilic species within the inundation zone will be displaced and replaced with lacustrine (lake loving) species. Overall species richness is likely to remain relatively comparable to pre-impoundment conditions although a small decrease is possible.

'Dry Reach' (Upper foothills)

- The decrease in temporal variation will leave less habitat for wet season spawners and less seasonal nursery areas. This may influence the breeding success of dry season spawners and the recruitment of rheophilic species which prefer Fast Intermediate (FI) and Fast Shallow (FS) habitat. However, currently the ecology of the 'dry reach' is dominated by peaking generation and an improvement in fish and invertebrate assemblages for resident species is possible during the proposed operational flows. This may offset the lack of seasonal variation during the proposed operations.
- The 'dry reach' encompasses a portion of the area downstream of the Bumbuna Falls, which may be important for spawning. Some of this habitat will be available for spawning during operational flows but will be notably reduced from baseline conditions. Many of the expected riffle and rapid spawners (*Labeo* and *Labeobarbus* species) and the rheophilic species *(Amphilius and Chiloglanis* species) have been lost within this reach, due to the current operations of the existing Bumbuna HEP. An additional impact is therefore not expected.

- It is likely that the aquatic invertebrates will respond positively to the stable habitat template, specifically to the relative increase in FS and FI habitat units under the proposed operational flow of 6 m^3s^{-1} within the 'dry reach'. It is also likely that there will be some new recruitment of resident rheophilic species (particularly in the absence of any pulsing/peaking within the reach).

Downstream of the Bumbuna Extension HEP Tailrace (Lowland and Rejuvenated foothill)

- The instream habitat requirements for the Lowland endemics and species of conservation concern will not be negatively affected, but functional flows related to dry season breeding and early wet season migration and breeding will be impacted. The former may extend to the entire downstream river, while the latter will be pronounced between Bumbuna Town and Magburaka. A subsequent decrease in the reproductive success of some species is expected:
    - A decrease in Lowland species with a requirement to breed during the dry season (such as *Heterotilapia buttikoferi*- LC and *Sarotherodon caudomarginatus*- LC) might occur.
    - While the breeding success of species sensitive to the onset of the rainy season (mainly represented by species of the genera *Chrysichthys*, *Marcusenius* and *Synodontis*) may occur for a portion of the Lowland habitat downstream of the Extensions. It is unlikely that these species will be completely lost, rather a decrease in their proportional representation within the fish assemblages may occur.
- Floodplains within the lower parts of the Lowland unit are likely to be activated less frequently and for shorter periods. However, the rate and duration of floodplain activation is lower under present day conditions compared to natural conditions due to substantial channel incision within the lower parts of the Lowland habitat. It is also likely that any residual requirements for floodplain habitat will be met by the presence of annual flood benches (terraces) that will not be affected during operations.

Estuary

Given that there will be an annual flood regime during the operation of the Bumbuna Extensions and that variations from the natural regime will be corrected by the normal annual cycle through the lower catchment there is no reason to think that the Estuarine functionality will be significantly affected.

Some operational flows are suggested for the 'dry reach' and for the Lowland habitat which will mitigate the anticipated impacts associated with the loss of some functional flows and improve the general quality of instream habitat.

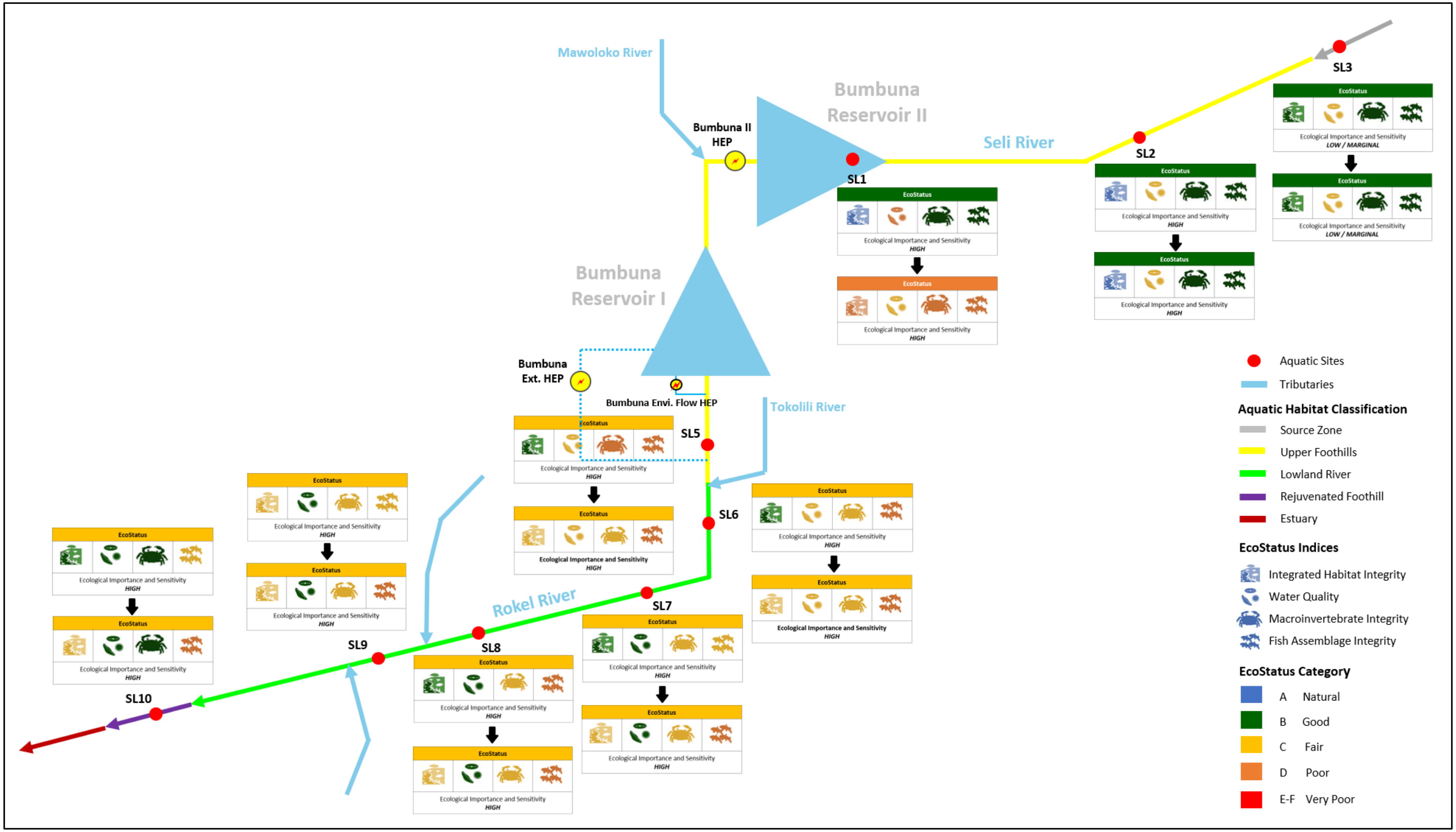

Figure 0-1: Map illustrating the proposed HEP releases and the EcoStatus classification for each site assessed during the April 2018 assessment, as well as the modelled EcoStatus during operation.

1. INTRODUCTION

1.1. BACKGROUND

Joule Africa in partnership with the Government of Sierra Leone is proposing a Bumbuna II Project. This is a hydroelectric scheme which will have a generation capacity of 143 MW of electricity for supply to the regional grid system of Sierra Leone. A schematic diagram of the proposed Bumbuna Extension is provided in **Figure 1-1**. The project will build upon the existing Bumbuna I which consists of a 50 MW dam power generation facility located on the Upper Rokel/Seli River in the Northern Province of Sierra Leone. The Bumbuna II scheme comprises of two developments, including Bumbuna Extension and Yiben Dam (**Figure 1-1**).

The Bumbuna Extension is located on the western bank of the Bumbuna Reservoir, upstream of the existing dam and will generate 88 MW of power. An underground tunnel will take water from the Bumbuna Reservoir to the new turbines and a concrete tailrace channel will return the water to the river after it has been through the turbines. This will bypass approximately 4 km of the Rokel River between the existing dam wall and the new tailrace. The Yiben Reservoir (Bumbuna II) is located 30 km north of the Bumbuna Extension forming a reservoir of approximately 115 km^2 and will generate 55 MW of additional power. A tunnel will take the water from the dam to the turbines and a channel will return the water to the river once it has been through the turbines.

Ecotone was appointed to conduct a baseline freshwater assessment of aquatic habitat and associated ecology for the Seli/Rokel River. In addition, the study aimed to determine the predicted change the Bumbuna Extension activities may likely have on receiving aquatic resources. The assessment took an integrated driver (water quality, flow, sediment) and responder (diatoms, aquatic macroinvertebrates and fish) approach to define baseline conditions. The approach is represented as part of a water resource management framework that is consistent with the IFC PS 6 (Biodiversity Conservation and Sustainable Management of Living Natural Resources) standard, in that it classifies the aquatic resources on a continuum of modification (ranging from Natural to Modified), while the ecological relevance of the aquatic habitat is expressed in terms of its ecological importance and sensitivity.

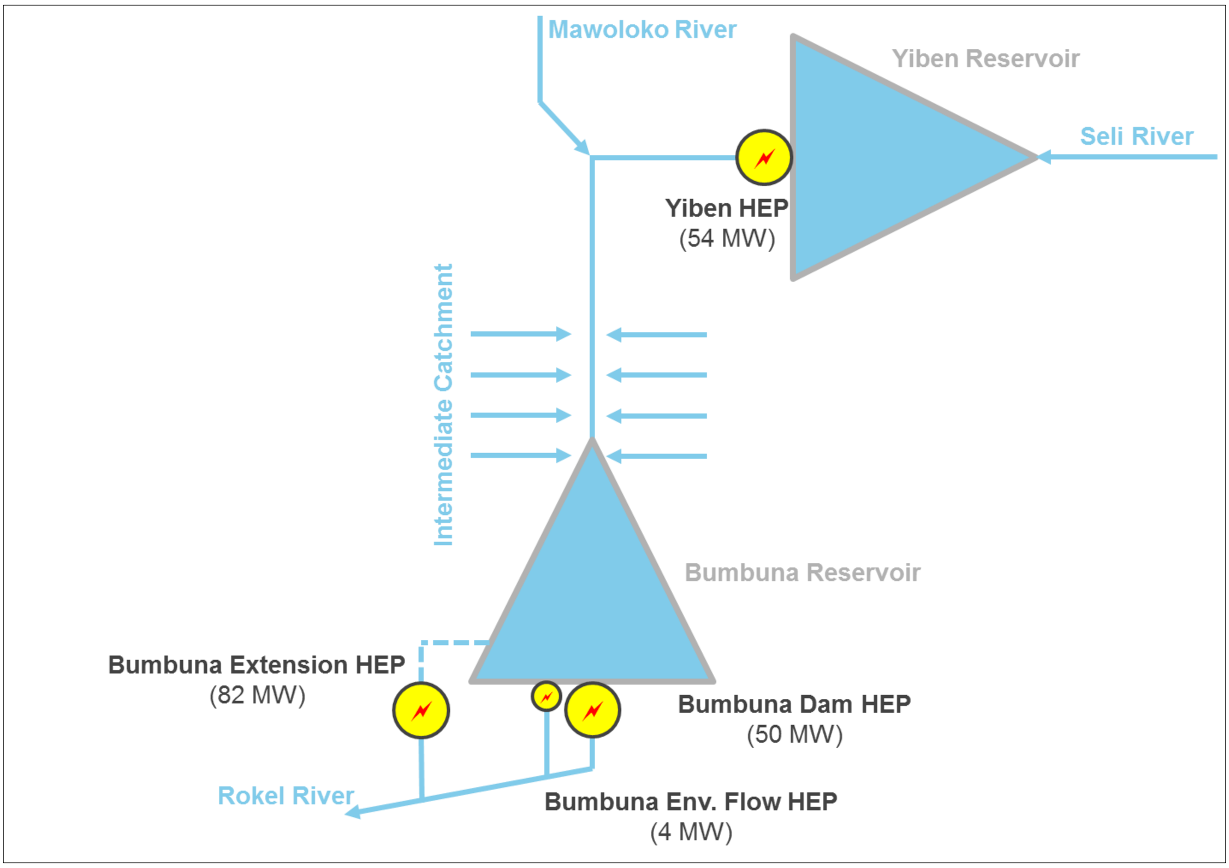

Figure 1-1: Schematic layout of the proposed Yiben Reservoir and Bumbuna Extension HEP with the Bumbuna Environmental Flow HEP (taken from Lahmeyer International GmbH 2017).

1.2. RATIONALE

The proposed Bumbuna Extensions may influence the aquatic habitat associated with the Rokel/Seli River in the following ways:

(i) The inundation of the Yiben reservoir will transform a portion of the Seli River into lake habitat. The extent of this habitat modification is consistent with the inundation zone.

(ii) The reach of the Rokel/Seli River between the Bumbuna Reservoir and the Bumbuna Extension HEP (82 MW) will be subjected to flow reduction measured from natural flows for large parts of the year (i.e. less flow than natural for most or all the time) (see **Figure 1-1**).

(iii) The hydrology of the Rokel River downstream of the Bumbuna Extension HEP tailrace will change. The degree of the hydrological alteration in relation to the natural hydrology is illustrated in **Figure 1-2 A** and **B**. The longitudinal extent of the hydrological change will be naturally mitigated further downstream. An approximation of the natural recovery in downstream flow is provided and discussed in **Section 4.3.3**.

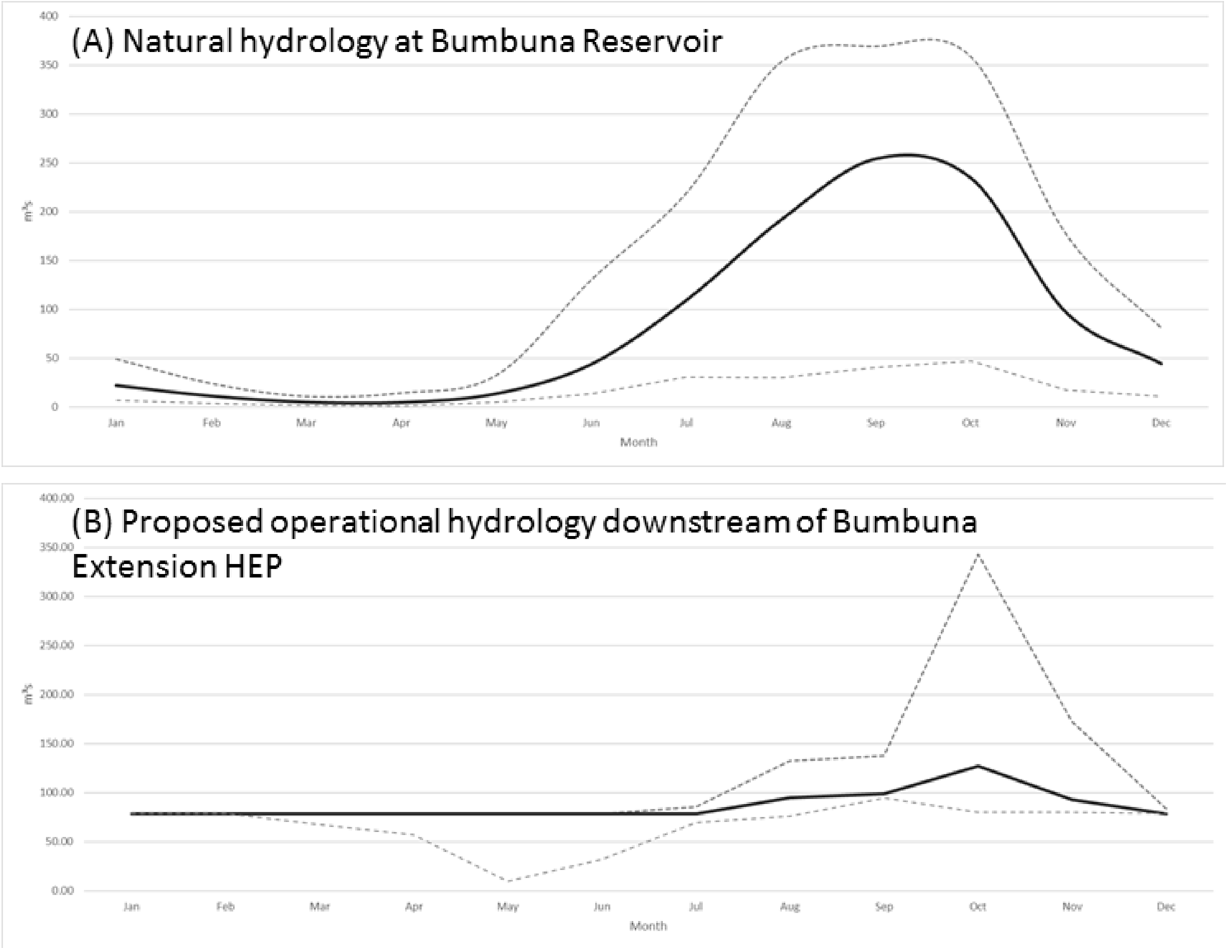

Figure 1-2: (A) Model of the natural flow regime for the Rokel/Seli River at Bumbuna Reservoir. The top line represents maximum monthly flows, the middle line represents median flows and the bottom line represents minimum monthly flows. (B) The change in hydrology that will be experienced downstream of the Bumbuna Extension HEP. The top line represents maximum monthly flows, the middle line represents median flows and the bottom line represents minimum monthly flows.

The implications of the proposed Bumbuna Extensions (and most notably the change in hydrology) on aquatic habitat and associated ecology requires the following context:

(i) Large parts of Seli/Rokel catchment have been subjected to deforestation extending as far back as 200 years (Payne, 2018).

(ii) Direct impacts on instream habitat within the upper reaches (i.e. reaches upslope of the Bumbuna Reservoir) include channel bed and bank modification due to historical and present artisanal gold mining activity.

(iii) The existing Bumbuna Reservoir has modified aquatic habitat from flowing habitat to lake habitat for approximately 30 km upstream of the reservoir.

(iv) The downstream river is historically affected by commercial mining (such as the iron ore mining in the Tonkolili catchment) and floodplain agriculture (for the reach of the coastal plain).

(v) Larger urban centres (such as Bumbuna, Magburaka and Lunsar) are near the Rokel River and may impact on aquatic habitat through changes in flow (abstraction), water quality (polluted runoff) and high sediment loads (bed and bank instability).

(vi) The operations of the existing Bumbuna HEP has altered the downstream hydrology of the Seli/Rokel River. More notably, the existing Bumbuna HEP has been operating with large daily flow changes (peaking) (**Figure 1-3**). From an ecological perspective peaking events act as a major driver of change on the receiving environment.

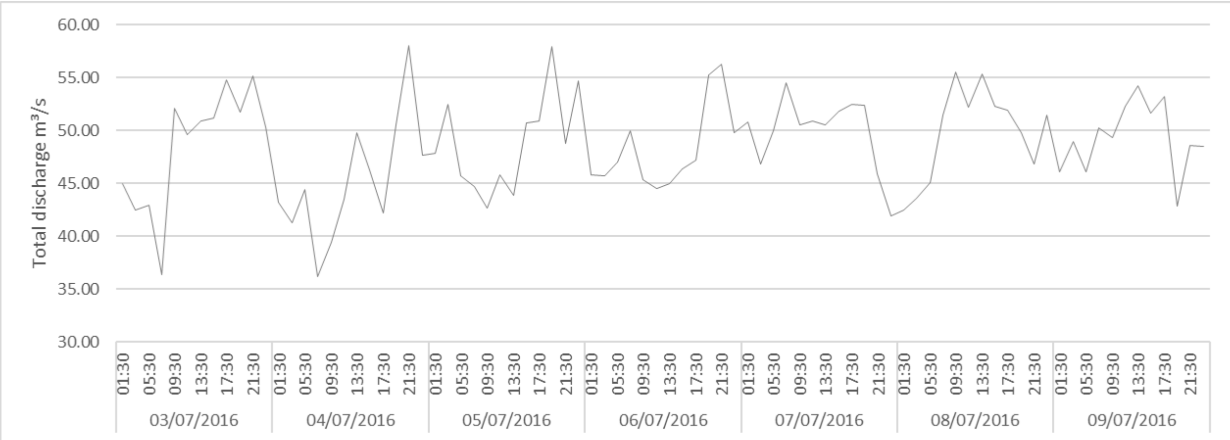

Figure 1-3: Hourly flow releases through the existing Bumbuna HEP for 3-9 July 2016.

The Project therefore requires an understanding of the potential implications of the proposed operational activities on the aquatic habitat for the Seli/Rokel River, considering the existing habitat modifications. The main objectives thus relate to measuring the degree of modification under baseline (pre-implementation of the proposed Bumbuna Extensions) and post implementation conditions. And to determine the ecological importance and sensitivity of the aquatic resource, irrespective of the degree of modification. Aspects of the aquatic habitat and associated ecology (i.e. the degree of modification and the ecological importance and sensitivity) constitute primary considerations for the management of the resource.

1.3. APPROACH

The approach followed was adopted from Louw e*t al*. (2005) and are outlined below in **Figure 1-5**. The report structure roughly follows the approach outlined in **Figure 1-5**.

The approach focusses on two main aspects, which are discussed below:

(i) Determining the degree of habitat modification before and after the implementation of the Project.
(ii) Ascertaining the conservation importance and the ecological sensitivity of the aquatic resources that may be affected by the proposed Bumbuna Extensions.

Baseline conditions can be defined in terms of the ecological status (or Present Ecological State- PES) and Ecological Importance and Sensitivity (EIS) of the water resource. The PES is simply a measure to indicate the degree of modification or residual ecological integrity within the resource and is measured by the digression from a natural state (**Figure 1-4**). The value of the resource lies with its ecological integrity, which gives a water resource its resilience and enables it to function properly. This principle is recognized universally to enable a balance between the protection and use of a water resource. A standardised approach assessing and classifying baseline conditions is pertinent in determining potential ecological risks linked to the Project. The approach applied in this study assessed most of the features and characteristics of the river and reflects the ability of the system to support natural biota and its capacity to provide a variety of ecological goods and services. This approach is termed EcoStatus determination and is widely applied in a South-African context (Kleynhans and Louw, 2007). The EcoStatus represents an ecological integrated state for drivers (hydrology, geomorphology, physico-chemical) and responses (fish, aquatic invertebrates etc.). Standardised indices for drivers and responses provide respective PES categories, which are integrated to ascertain an EcoStatus. The principle followed here is that the biological responses integrate the effect of the modification of the drivers and that results in an ecological endpoint (Louw, Kleynhans and Thirion, 2006). A critical consideration for measuring the impact on any ecosystem is the use of holistic ecosystem endpoints (Mackay, 2000).

The EIS of the resource is an expression of its importance to the maintenance of biological diversity and ecological functioning on local and wider scales (Kleynhans and Louw, 2007). Ecological sensitivity (or fragility) refers to the system's ability to resist disturbance and its capability to recover from disturbance once it has occurred (resilience) (Resh *et al*. 1988; Milner, 1994). Both abiotic and biotic components of the system are taken into consideration in the assessment of ecological importance and sensitivity. The EcoStatus and the EIS informs recommendations regarding future resource management objectives.

The flow requirements for different levels of ecological endpoints were determined through integrating hydrological, hydraulic (channel cross-sections) and ecological habitat data to establish a modified flow regime that is expected to achieve some level of ecological functioning relative to the natural condition.

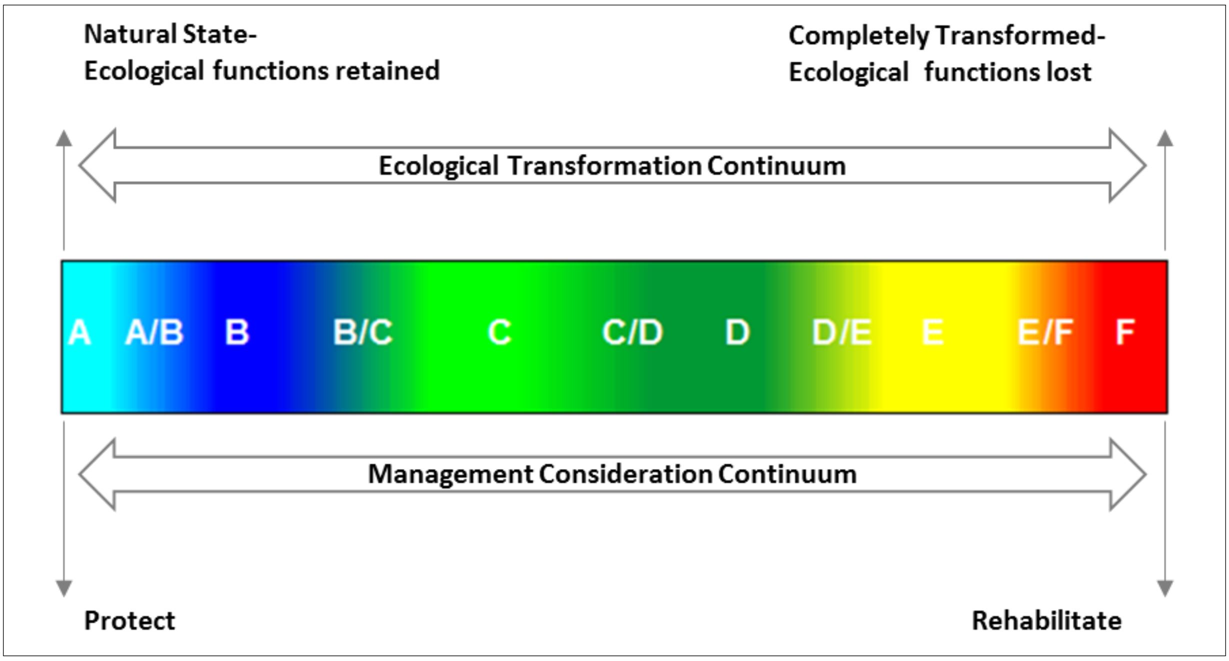

Figure 1-4: Illustration of the distribution of Ecological Categories in a continuum and the link between the Ecological Categories and resource management consideration.

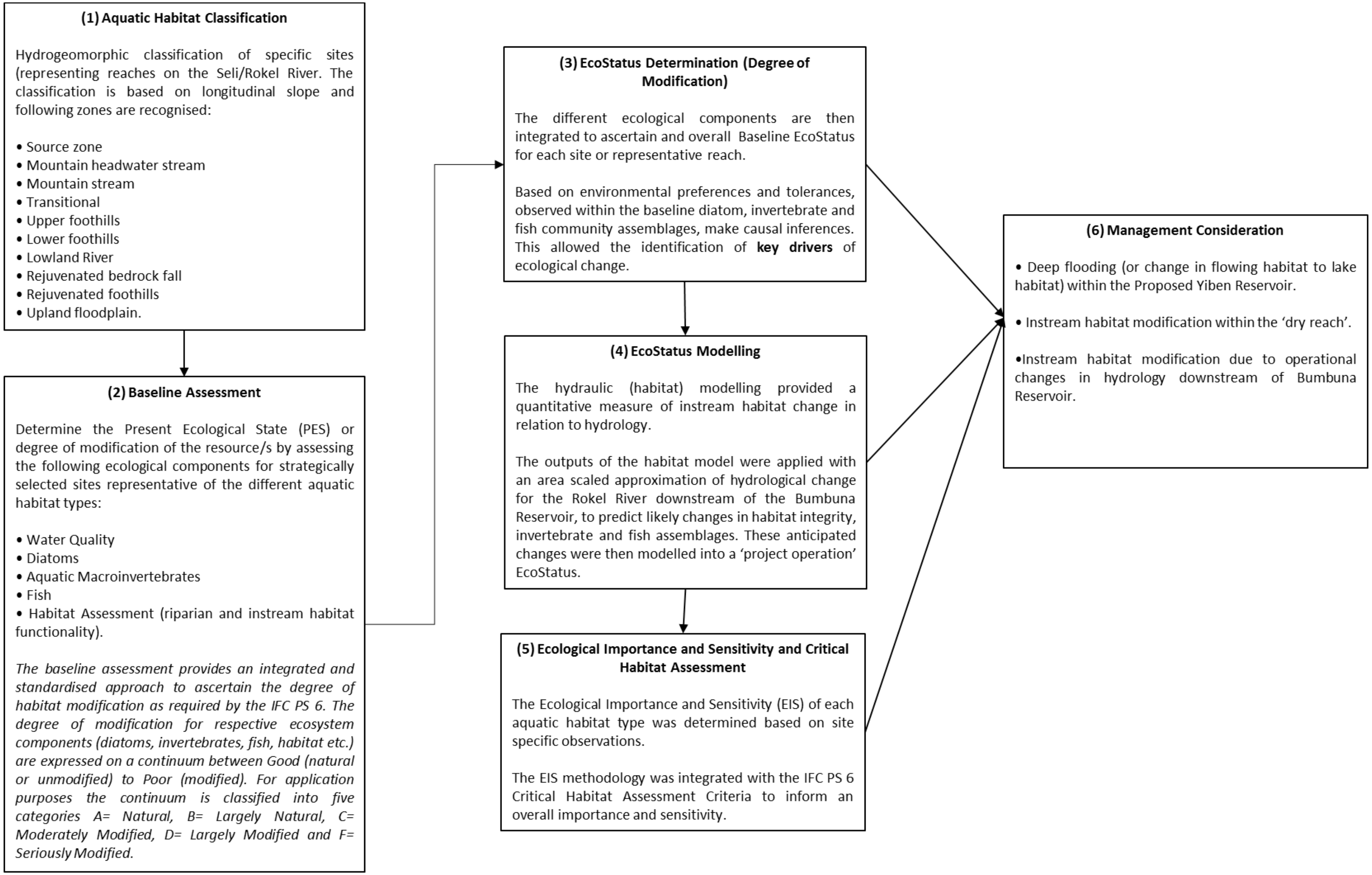

Figure 1-5: Flow diagram outlining the approach applied to reach the objectives of the assessment.

2. GENERAL NOTES, ASSUMPTIONS AND LIMITATIONS

2.1. THE STUDY AREA

The Seli/Rokel River is the main stem of river relevant to this study. Tributaries were not assessed, and the resource quality classification provided in this assessment may not necessarily be applicable to tributaries of the Seli/Rokel River. It is possible and even likely that many of tributaries may reflect a large degree of ecological intactness.

An assessment of the ecological functions and associated flow requirements for the Sierra Leone Estuary was not included in this study. Such a study would be constrained by data availability (freshwater and salt water dynamics, nutrient loads, hydrology etc.). However, the contribution of the Seli to the whole Rokel discharge into the Estuary is likely to be in the order of 40% (approximated from catchment size and rainfall). Given that there will be an annual flood cycle during the operation of the Bumbuna Extensions and that variations from the natural regime will be corrected by the normal annual regime through the lower catchment there is no reason to think that the Estuarine functionality will be notably affected.

2.2. LEVEL OF THE ASSESSMENT

The resource quality classifications (EcoStatus) were determined for the resource units (reaches) represented by the sampling locations. The EcoStatus modelling was undertaken at am Intermediate level, with the inclusion of 10 strategically selected sites with dry season ecological observations and modelled monthly hydrology (**Table 2-1**). Ecological attributes considered within the study include detailed water quality, diatoms, aquatic macroinvertebrates, fish and habitat integrity. This level of assessment is considered enough in the context of the anticipated impact. However, the confidence of the assessment can be improved by augmenting it with seasonal observations

Table 2-1: Different levels for the application of the EcoStatus modelling and associated confidence

Level	Terminology	Confidence	Significance of anticipated Impact
1	Desktop	Very low	Low
2	Rapid	Low to medium	Low to Moderate
3	Intermediate	Medium	Moderate to High
4	Comprehensive	High	High

2.3. ECOCLASSIFICATION MODELS

The rule-based models (i.e. habitat, diatom, invertebrate and fish response models) adopted for this assessment are theoretical and requires local validation. No national water resource classification system exists. The rule-based models have been extensively applied in Southern Africa and the general approach are considered relevant for application in a local context. Any uncertainty in this regard, can be managed through operational monitoring and adaptive management.

2.4. CRITICAL HABITAT ASSESSMENT

As part of determining the conservation importance associated with the different instream habitat units assessed, an IFC Performance Standard (PS) 6 habitat classification was completed with a Critical Habitat (CH) assessment. The CH assessment only considered fish sampled or potentially occurring based on references from Leveque and Paugy (1984), Daget *et al.,* (1991), Paugy *et al*., (1990 and 2003), Payne *et al.,* (2010) and Payne (2018). Specific reference to individual locations sampled within the Seli/Rokel River could be made from Payne *et al.,* (2010). Conservation status (Least Concern- LC, Near Threatened- NT, Endangered- EN, Critically Endangered-CR and Data Deficient- DD) of expected and sampled fish is referenced from the IUCN Red List.

2.5. HYDROLOGY AND ECOLOGICAL WATER REQUIREMENTS

The study augmented and revised aspects of the EWA completed by Ecotone during 2016. The most notable aspects pertain to the revision of a more relevant hydraulic cross section located within the 'dry reach' (reach between the existing Bumbuna Reservoir and the proposed Bumbuna Extension tailrace. And the application of scaled hydrology which was considered more appropriate (personal communication with Lahmeyer, 2018).

In terms of the hydrology, the natural time series provided to Ecotone represents an 80% scaling of the 100% hydrology. The mean annual runoff (MAR) of the 80% scaled hydrology is some 2 789 *106 m^3, while the MAR of the Bumbuna Extensions releases are some 2 806 *106 m^3. The negative difference suggests that a greater amount of water can be released from the reservoir (on average) than the natural inflow, even though some losses (evaporation, seepage, etc.) are inevitably going to occur. The conclusion is that the natural flow time series recommended for use in the EWA are uncertain. A key concern is that while a simple percentage scaling factor might be considered adequate for the estimation of reservoir yield (and the hydro-power operation), it may not be adequate to represent the full range of natural flow conditions. For example, the main error may be in the estimation of high flows, while the 80% reduction will also substantially affect the low flow estimations that were used in the estimation of the EFRs.

2.6. OPERATIONAL FLOWS

Daily operating variables such as, tripping, maximum discharge ratio, maximum ramping rate and the degree to which discharge will be regulated, all have ecological risk implications. The total discharge associated with the Project may well be within the broad EFR given a mean daily or monthly view, but daily ramping rates or discharge control may be intolerable to instream biota. The effectiveness of mitigating impacts related to these daily operational variables has not been well studied and is poorly documented. Operational releases (discharge, regime etc.) are not addressed in this study.

3. MATERIALS AND METHODS

This section describes the study approach and is divided into three main sections. The first section deals with the site selection and the field assessment. The second section describes the water resource classification applied. This relates to defining the ecological integrity, importance and sensitivity of each river reach included in the study. The third section describes the methodology applied for determining the EFRs for different levels of ecological protection.

The future relevance of the EcoStatus is that it provides a framework in which the resource units can be managed. Details regarding the methods applied for the components included within this assessment can be found in the respective appendices and is crossed-referenced below:

- Water Quality **Appendix A – Water Quality**
- Diatoms **Appendix B – Diatoms**
- Intermediate Index of Habitat Integrity **Appendix C - Intermediate Index of Habitat Integrity**
- Aquatic Macroinvertebrates **Appendix D - Aquatic Macroinvertebrates**
- Fish **Appendix E - Fish**

3.1. SITE SELECTION AND FIELD ASSESSMENT

The names and coordinates of the nine instream sites that were used during the April 2018 baseline assessment are provided in **Table 3-1** and **Figure 3-1**. Sites were selected to represent hydrogeomorphic reaches associated with the longitudinal profile of the Seli/Rokel River (**Table 3-2**).

To determine the relationship between flow and habitat three hydraulic cross-sections were surveyed and are highlighted in **Table 3-2**. The cross section associated with SL1 represents the upper foothills aquatic habitat, while SL5 represents a transition zone between upper foothills and lowland habitat. Site SL9 represents lowland habitat. The SL5 and SL6 cross sections were applied with modelled hydrology provided to Ecotone, while the SL6 hydrology had to be scaled to determine an approximation of the flow-habitat relationship with the Lowland (SL9) zone. The method for determining the flow-habitat relationship is outlined in **Section 4.3.2**.

The habitat-flow relationship was applied in conjunction with the operational hydrology to model anticipated changes within the EcoStatus of the different representative sites assessed. The EcoStatus determination is discussed in **Section 3.2**.

Table 3-1: Names and coordinated for sites assessed during the April 2018 assessment

Site Names	Location in Relation to Bumbuna Reservoir I	Latitude	Longitude
SL3	Upstream	9.716164°	-11.128206°
SL2	Upstream	9.473199°	-11.337025°
SL1	Upstream	9.308250°	-11.580914°
SL5	Downstream	9.052838°	-11.737818°
SL6	Downstream	8.978954°	-11.866412°
SL7	Downstream	8.862510°	-11.882063°
SL8	Downstream	8.740423°	-11.931327°
SL9	Downstream	8.613622°	-12.180896°
SL10	Downstream	8.593571°	-12.688260°

Table 3-2: Hydrogeomorphic classification of aquatic riverine habitat adopted from Ollis *et al*., 2013

Zone	Gradient	Description
Source zone	not specified	Low gradient, upland plateau or upland basin able to store water. Spongy or peaty hydromorphic soils.
Mountain headwater stream	> 0.1	Very steep gradient streams dominated by vertical flow over bedrock with waterfalls and plunge pools. Normally first or second order. Reach types include bedrock fall and cascades.
Mountain stream	0.04 - 0.99	Steep gradient stream dominated by bedrock and boulders, locally cobble or coarse gravels in pools. Reach types include cascades, bedrock fall, step-pool, Approximate equal distribution of 'vertical' and 'horizontal' flow components.
Transitional	0.02 - 0.039	Moderately steep stream dominated by bedrock or boulder. Reach types include plain-bed, pool-rapid or pool riffle. Confined or semi-confined valley floor with limited flood plain development.
Upper Foothills	0.005 - 0.019	Moderately steep, cobble-bed or mixed bedrock-cobble bed channel, with plain-bed, pool-riffle or pool-rapid reach types. Length of pools and riffles/rapids similar. Narrow flood plain of sand, gravel or cobble often present.
Lower Foothills	0.001 - 0.005	Lower gradient mixed bed alluvial channel with sand and gravel dominating the bed, locally may be bedrock controlled. Reach types typically include pool- riffle or pool-rapid, sand bars common in pools. Pools of significantly greater extent than rapids or riffles. Flood plain often present.
Lowland river	0.0001- 0.001	Low gradient alluvial fine bed channel, typically regime reach type. May be confined, but fully developed meandering pattern within a distinct flood plain develops in unconfined reaches where there is an increased silt content in bed or banks.
Rejuvenated bedrock fall/cascades	>0.02	Moderate to steep gradient, confined channel (gorge) resulting from uplift in the middle to lower reaches of the long profile, limited lateral development of alluvial features, reach types include bedrock fall, cascades and pool-rapid.

Zone	Gradient	Description
Rejuvenated foothills	0.001 - 0.02	Steepened section within middle reaches of the river caused by uplift, often within or downstream of gorge; characteristics similar to foothills (gravel/cobble bed rivers with pool-riffle/ pool-rapid morphology) but of a higher order. A compound channel is often present with an active channel contained within a macro channel activated only during infrequent flood events. A limited flood plain may be present between the active and macro-channel.
Upland floodplain	< 0.005	An upland low gradient channel often associated with uplifted plateau areas as occur beneath the eastern escarpment.

The tasks undertaken during the field assessment included:

- The selection of representative sites. The selection of a suitable sites was determined by the suitability of the river channel for accurate hydraulic modelling and flow assessment, as well as the presence of sensitive habitats important for ecosystem functioning, such as riffles and rapids. The sites were also representative of the hydrological reach to allow extrapolation of the results to the resource unit.
- The specialists assessed the present condition of their study component in relation to the considered reference conditions. Relevant specialist assessments included:
    - A qualitative assessment of instream and riparian habitat integrity through the application of the Intermediate Index of Habitat Integrity (IHI).
    - The water quality was assessed at all sites for *in situ* variables, main cat- and anions and nutrients.
    - Inferences regarding water quality were made from the diatom community assessment at each site assessed for each assessment.
    - An aquatic macroinvertebrate assessment. The invertebrate specialist surveyed the aquatic macroinvertebrates occurring within the range of habitats at each locality using the South African Scoring System version 5 (SASS5) methodology and sampling equipment and techniques, including a comprehensive assessment of the frequency distribution of different flow-depths and substrate units associated with each reach assessed.
    - A fish assessment. The fish specialist sampled fish in all suitable aquatic habitats associated with each site using an electro-fish shocker and nets.
- Cross-sectional profiles for the Upper foothills (SL5) and for the Lowland habitat (SL6), were surveyed, hydraulic data for calibration purposes was collected and the river flow determined.

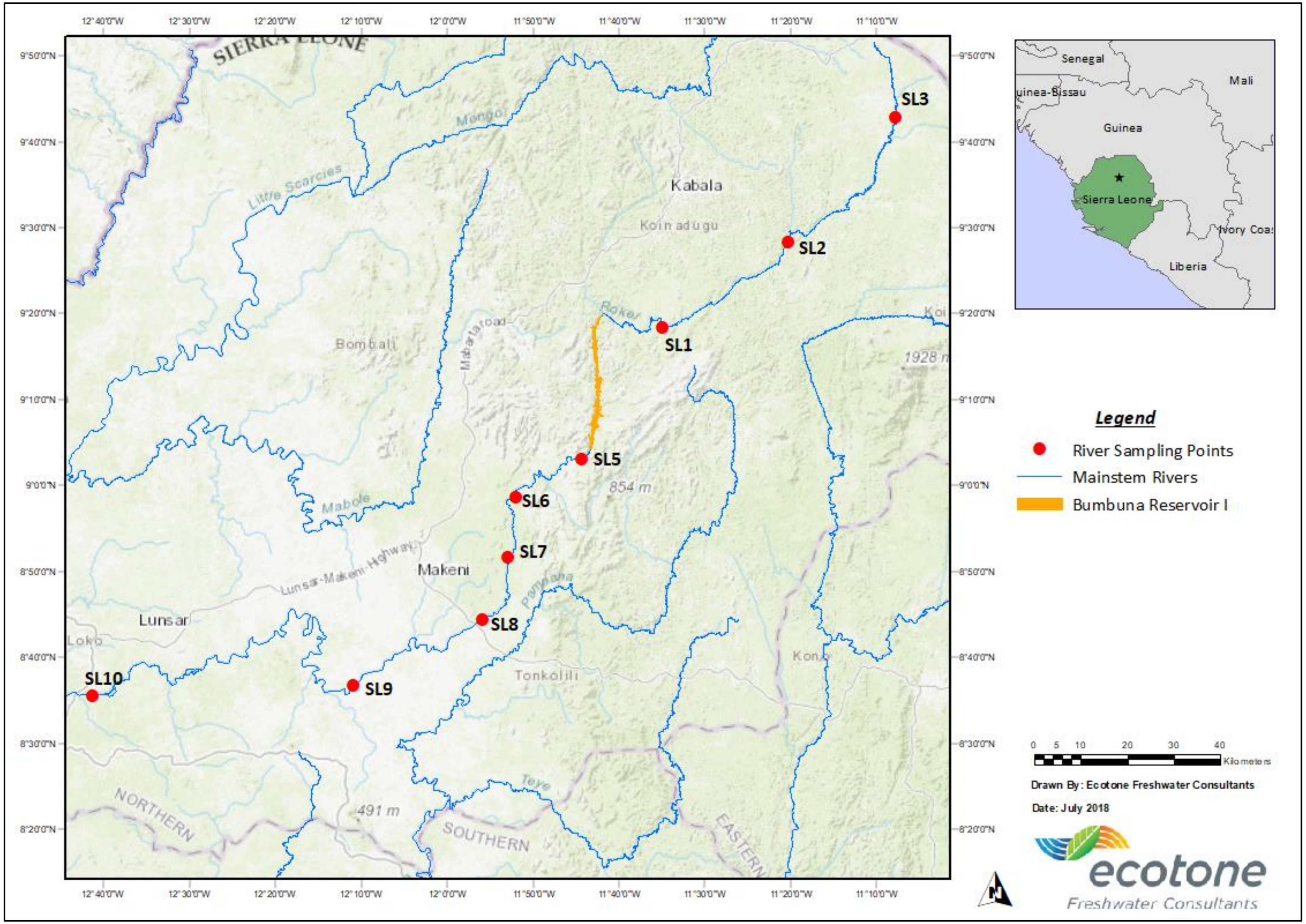

Figure 3-1: Aquatic ecology sites assessed during the April 2018 field assessment.

3.2. INDICES OF SENSITIVITY, INTEGRITY AND HABITAT AVAILABILITY

A range of ecological indices were calculated for the various proxies of ecological condition (diatoms, macroinvertebrates and fish) used in the ecological baseline assessment. The indices used in this study are discussed in **Table 3-3**. The results of each of the components are provided in the respective appendices and integrated into the overall Ecostatus (see **Section 3.3**).

Table 3-3: The indices and categories used in this study

Index (acronym)	Index (name)	Categories	Description
SPI	Specific Pollution Index	A (High) to F (Bad)	• The SPI is an inclusive index and takes factors such as salinity, eutrophication and organic pollution into account. • This index comprises 2035 taxa and is recognised as the broadest species base of any index currently in use and has been adapted to include taxa endemic to and commonly found in South Africa, thus increasing the accuracy of diatom-based water quality assessments and is known as the South African Diatom Index (SADI)
%PTV	Percentage Pollution Tolerant Values	<20 (free from organic pollution) –>60% (heavily contaminated with organic pollution)	• The Percentage Pollution Tolerant Valves (%PTV) is part of the UK Trophic Diatom Index (TDI) and was developed for monitoring organic pollution (sewage outfall- orthophosphate-phosphorus concentrations), and not general stream quality.
IHI	Index of Habitat Integrity	A (*Natural*) to F (*Critically Modified*)	• IHI is a tool for assessing instream and riparian habitat by incorporating driver aspects (changes in water quality, hydrology, erosion rates etc) and potential impacts. The IHI is thus a surrogate for ecological drivers and considers instream and riparian aspects. • The severity of impact of the modifications is based on six categories which comprise of ratings ranging from 0 to 25: 0 (no impact), 1 to 5 (small impact), 6 to 10 (moderate impact), 11 to 15 (large impact), 16 to 20 (serious impact) and 21 to 25 (critical impact).
IHAS	Invertebrate Habitat Assessment Score	Good, adequate and poor	• The IHAS assesses the quantity and quality of various sampling biotopes in terms of potential habitat for invertebrates. It is expressed as a percentage score. The scores for each biotope are then summed up to give a total habitat score and class. • The IHAS is not a measure of functionality but assesses availability. A poor IHAS score does not translate into the loss of habitat functions, it simply means the habitat is not divers in structure and type.
ASPT	Average Score Per Taxa	A high ASPT score indicates a high overall sensitivity.	• The ASPT index is based on the principle that different aquatic macroinvertebrates have different tolerances to pollutants. • The ASPT and SASS scores provide an indication of the overall sensitivity based in the sensitivity scores of taxa.
SASS	South African Scoring System	A low SASS score indicates poor habitat	

Index (acronym)	**Index (name)**	**Categories**	**Description**
		diversity and low biotic diversity; whereas, a high score indicates the converse.	• The SASS score is a simple sum of the total sensitivity scores for each site, while the ASPT is a function of the total sensitivity score and the number of taxa sampled.
%EPT	Percentage Ephemeroptera Plecoptera and Trichoptera	Relative to other sampling locations, but the higher the % score the more sensitive the ecology.	• The EPT model is based on the premise that rivers/streams with good water quality will typically have a greater species richness since EPT taxa are pollution sensitive taxa, using the %EPT will therefore be a good indication of impacts related to land use activities on the diversity and abundance of macroinvertebrates and changes in community structure.
MIRAI	Macro-Invertebrate Response Assessment Index	A (*Natural*) to F (*Critically Modified*)	• The MIRAI is a rule-based index that makes use of a rating approach comprised of four different metric groups that measure the change in present macroinvertebrate assemblages from the reference assemblage. • The MIRAI approach is based on rating the degree of change from natural on a scale of 0 (no change from reference condition) to 5 (maximum change from reference condition) for a variety of different metrics.
FAII (Modified)	Fish Assemblage Integrity Index	A (*Natural*) to F (*Critically Modified*)	• The FAII model uses the referenced fish communities that have been modelled based on the available habitat for each site and the habitat requirements for expected fish.
EIS	Ecological Importance and Sensitivity	Very High: National/International Importance with sensitive taxa. High: Regional importance with sensitive taxa. Moderate: Local importance with or without sensitive taxa. Low: not important or sensitive at any scale.	• Ecological importance is a water resource's ability to maintain the ecological diversity and functioning on local and wider scales. The ecological sensitivity refers to the river's ability to recover from disturbance. • The EIS considers rare and endangered species, species richness, habitat diversity, migration, breeding and feeding importance, species sensitive to water quality and flows, indirect ecosystem services (flood storage, water purification etc.) baseflow augmentation and the degree of modification. These aspects are integrated to ascertain and overall EIS score which informs the conservation importance of each habitat unit.

3.3. ECOCLASSIFICATION

EcoClassification refers to the determination and categorisation of the Present Ecological State (PES) of various biophysical attributes of rivers in relation to a perceived reference condition (Kleynhans and Louw, 2007). The integration of the various PES categories (riparian, aquatic macroinvertebrates and fish) results in the EcoStatus. The EcoClassification process followed in the current study is based on an EcoStatus Level III (refer to **Section 2.2**) assessment (Kleynhans and Louw, 2006) (**Table 3-4**). The EcoClassification involved the following steps:

- Determination of the PES for the aquatic macroinvertebrates and fish components using rule-based EcoStatus models (undertaken during baseline aquatic ecology study- refer to **Appendix B - F**).
- Determination of the EcoStatus which involves integration of the individual ecological category values of the abovementioned components to obtain an overall EcoStatus category.
- Determination of the anticipated trend of the EcoStatus during implementation of the Bumbuna Extensions.

Table 3-4: Metrics applied within different EcoStatus Levels. N= No and Y= Yes

Site	Water Quality	Hydrology	Invertebrates	Fish	Habitat Integrity	Level of EcoClassification
SL3	Y	N	Y	Y	Y	III
SL2	Y	N	Y	Y	Y	III
SL1	Y	Y	Y	Y	Y	III
SL5	Y	Y	Y	Y	Y	III
SL6	Y	Y	Y	Y	Y	III
SL7	Y	N	Y	Y	Y	III
SL8	Y	N	Y	Y	Y	III
SL9	Y	N	Y	Y	Y	III
SL10	Y	N	Y	Y	Y	III

3.3.1. ECOSTATUS

Results for each response component were provided as ecological categories and percentages ranging from *Natural* (Category A) to *Critically* Modified (Category E or F) (**Table 3-5**). The individual results were then combined according to Kleynhans and Louw (2007) to provide a single integrated EcoStatus per reach assessed. Detailed methodology for the response and driver metrics used is provided in **Appendix C - Intermediate Index** of Habitat Integrity.

Table 3-5: Ecological Integrity Categories (Thirion, 2016 - modified from Kleynhans, 1996 and Kleynhans, 1999)

Ecological Category	Generic Description of Ecological Conditions	Arbitrary Guideline Score (% of Maximum Theoretical Total)
A (Natural)	Unmodified/natural, close to natural or close to pre-development conditions within the natural variability of the system drivers: hydrology, physico-chemical and geomorphology. The habitat template and biological components can be considered close to natural or to pre-development conditions. The resilience of the system has not been compromised.	>92 - 100
A/B (Natural)	The system and its components are in a close to natural condition most of the time. Conditions may rarely and temporarily decrease below the upper boundary of a B category.	>88 - ≤ 92
B (Good)	Largely natural with few modifications. A small change in the attributes of natural habitats and biota may have taken place in terms of frequencies of occurrence and abundance. Ecosystem functions and resilience are essentially unchanged.	>82 - ≤88
B/C (Good)	Close to largely natural most of the time. Conditions may rarely and temporarily decrease below the upper boundary of a C category.	>78 - ≤82
C (Modified)	Moderately modified. Loss and change of natural habitat and biota have occurred in terms of frequencies of occurrence and abundance. Basic ecosystem functions are still predominantly unchanged. The resilience of the system to recover from human impacts has not been lost and it is ability to recover to a moderately modified condition following disturbance has been maintained.	>62 - ≤78
C/D (Modified	The system is in a close to moderately modified condition most of the time. Conditions may rarely and temporarily decrease below the upper boundary of a D category.	>58 - ≤62
D (Poor)	Largely modified. A large change or loss of natural habitat, biota and basic ecosystem functions have occurred. The resilience of the system to sustain this category has not been compromised and the ability to deliver ecological goods and services has been maintained.	>42 - ≤58
D/E (Poor)	The system is in a close to largely modified condition most of the time. Conditions may rarely and temporarily decrease below the upper boundary of an E category. The resilience of the system is often under severe stress and may be lost permanently if adverse impacts continue.	>38 - ≤42
E (Very Poor)	Seriously modified. The change in the natural habitat template, biota and basic ecosystem functions are extensive. Only resilient biota may survive, and it is highly likely that invasive and problem (pest) species may dominate. The resilience of the system is severely compromised as is the capacity to provide ecological goods and services. However, geomorphological conditions are largely intact but extensive restoration may be required to improve the system's hydrology and physico-chemical conditions.	>20 - ≤38
E/F (Very Poor)	The system is in a close to seriously modified condition most of the time. Conditions may rarely and temporarily decrease below the upper boundary of an F category. The resilience of the system is frequently under severe stress and may be lost permanently if adverse impacts continue.	>18 - ≤20
F (Critical)	Critically/Extremely modified. Modifications have reached a critical level and the system has been modified completely with an almost complete change of the natural habitat template, biota and basic ecosystem functions. Ecological goods and services have largely been lost This is likely to include severe catchment changes as well as hydrological, physico-chemical and geomorphological changes. In the worst instances the basic ecosystem functions have been destroyed and the changes are irreversible. Restoration of the system to a synthetic but sustainable condition acceptable for human purposes and to limit downstream impacts is the only option.	≤18

3.3.2. Conservation Significance

3.3.2.1. Ecological Importance and Sensitivity

The Ecological Importance and Sensitivity (EIS) scores were calculated using the Resource Directed Measures (RDM - Kleynhans, 1999a) method (**Table 3-6; Table 3-7**). Information from the baseline aquatic ecology assessment was considered when populating the EIS scores. The EIS was used in conjunction with the integrated EcoStatus category to set the Recommended Ecological Category (REC).

Table 3-6: Scoring guidelines for each attribute considered in determining the Ecological Importance and Sensitivity (Kleynhans, 1999b)

EIS Scores	
Very High	4
High	3
Moderate	2
Marginal/Low	1
None	0
Confidence Score	
Very high confidence	4
High confidence	3
Moderate confidence	2
Marginal/low confidence	1

Table 3-7: Scoring guidelines for each attribute considered in determining the Ecological Importance and Sensitivity (Kleynhans, 1999a)

EIS Categories	**Range of EIS score**
Very high: Rivers that are considered ecologically important and sensitive on a national or even international level. The biodiversity of these systems is usually very sensitive to flow and habitat modifications. They play a major role in moderating the quantity and quality of water of major rivers.	>3 and <=4
High: Rivers that are ecologically important and sensitive. The biodiversity of these systems may be sensitive to flow and habitat modifications. They play a role in moderating the quantity and quality of water of major rivers.	>2 and <=3
Moderate: Rivers that are ecologically important and sensitive on a provincial or local scale. The biodiversity of these systems is not usually sensitive to flow and habitat modifications. They play a small role in moderating the quantity and quality of water of major rivers.	>1 and <=2

EIS Categories	Range of EIS score
Low/marginal: Rivers that are not ecologically important and sensitive at any scale. The biodiversity of these systems is ubiquitous and not sensitive to flow and habitat modifications. They play an insignificant role in moderating the quantity and quality of water of major rivers.	>0 and <=1

The EIS was also informed by sensitive species. These species are particularly responsive to changes in river flow. Fluctuations in flow cause depth and velocity fluctuations, and a subsequent change in habitat. Usually, the first habitat to be impacted with a flow reduction is the fast-shallow (FS), white water (rheophilic) habitat, which will cause a decrease in rheophilic fish and macroinvertebrate taxa. Data on the aquatic community composition was used to pin-point sensitive taxa that may be used as proxies for ecological functioning within the EWA. Flow sensitive species were selected based on a combination of scores assigned in the FRAI and MIRAI (Macro-Invertebrate Response Assessment Index) EcoStatus models (Thirion, 2007; Kleynhans, 2007), ecological information collected for each fish species (Skelton, 2001; IUCN, 2014) and expert opinion.

3.3.2.2. IFC PS6 Habitat Classification

The IFC PS6 defines Critical Habitats as representing the highest levels of biodiversity sensitivity. Critical habitats are a subset of either modified or natural habitats, and five specific criteria are specified for their recognition. The higher levels of protection of protected areas, based on the IUCN Management Categories, can also define critical habitat. These criteria are outlined in the following section.

The PS6 (paragraph 16) defines the following criteria for recognition of critical habitat:

- (i) Habitat of significant importance to Critically Endangered (CR) and/or Endangered (EN) species;
- (ii) Habitat of significant importance to endemic and/or restricted-range species;
- (iii) Habitat supporting globally significant concentrations of migratory species and/or congregatory species;
- (iv) Highly threatened and/or unique ecosystems; and/or
- (v) Areas associated with key evolutionary processes.

Critical habitats, specified by criteria (i), (ii) and (iii), are separated into Tier 1 and Tier 2 levels based on various thresholds (**Table 3-8**), with Tier 1 representing the highest possible levels of sensitivity.

Table 3-8: Thresholds for the separation of Tier 1 and Tier 2 Critical Habitat in terms of PS6

Criterion	Tier 1	Tier 2
(i) Critically Endangered (CR)/ Endangered (EN) Species	(a) Habitat required to sustain ≥ 10 percent of the global population of an IUCN Red-listed CR or EN species where there are known, regular occurrences of the species and where that habitat could be considered a discrete management unit for that species. (b) Habitat with known, regular occurrences of CR or EN species where that habitat is one of 10 or fewer discrete management sites globally for that species.	(c) Habitat that supports the regular occurrence of a single individual of an IUCN Red-listed CR species and/or habitat containing regionally-important concentrations of an IUCN Red-listed EN species where that habitat could be considered a discrete management unit for that species. (d) Habitat of significant importance to CR or EN species that are wide-ranging and/or whose population distribution is not well understood and where the loss of such a habitat could potentially impact the long-term survivability of the species. (e) As appropriate, habitat containing nationally/regionally-important concentrations of an EN, CR or equivalent national/regional listing.
(ii) Endemic/ Restricted Range Species	(a) Habitat known to sustain ≥ 95 percent of the global population of an endemic or restricted-range species where that habitat could be considered a discrete management unit for that species (e.g., a single-site endemic).	(b) Habitat known to sustain ≥ 1 percent but < 95 percent of the global population of an endemic or restricted-range species where that habitat could be considered a discrete management unit for that species, where adequate data are available and/or based on expert judgment.
(iii) Migratory / Congregatory Species	(a) Habitat known to sustain, on a cyclical or otherwise regular basis, ≥ 95 percent of the global population of a migratory or congregatory species at any point of the species' life-cycle where that habitat could be considered a discrete management unit for that species.	(b) Habitat known to sustain, on a cyclical or otherwise regular basis, ≥ 1 percent but < 95 percent of the global population of a migratory or congregatory species at any point of the species' life-cycle and where that habitat could be considered a DMU for that species, where adequate data are available and/or based on expert judgment. (c) For birds, habitat that meets Birdlife International's Criterion A4 for congregations and/or Ramsar Criteria 5 or 6 for Identifying Wetlands of International Importance. (d) For species with large but clumped distributions, a provisional threshold is set at ≥5 percent of the global population for both terrestrial and marine species. (e) Source sites that contribute ≥ 1 percent of the global population of recruits.

3.4. ECOLOGICAL WATER REQUIREMENTS

The method used for estimating the EWRs is a recently revised version of the Desktop Reserve model (RDRM: Hughes *et al.,* 2014). A detailed method statement is provided in **Appendix G – Environmental Water Requirements Assessment**. The recent revisions in the model were focused on improved methods for estimating the low flow requirements for different levels of ecological protection; from close to natural (A category) to highly modified (D category) and a different approach to estimating the high flow requirements based on the channel hydraulics.

4. RESULTS AND DISCUSSION

4.1. AQUATIC HABITAT CLASSIFICATION

The study area falls within the Northern Upper Guinea aquatic ecoregion. The Northern Upper Guinea ecoregion lies on the western side of the Guinean range, extending from the foothills of the Fouta Djalon in Guinea southeast to Sierra Leone's southern border and encompasses a small portion of Guinea-Bissau and Liberia. The relatively short rivers of the ecoregion descend from the Guinean Dorsale and cross the coastal plain adjacent to the Atlantic Ocean. The climate of the ecoregion is tropical and wet, with rainfall influenced by the moist southwest trade winds. The ecoregion receives heavy but seasonal precipitation with concentrated rain during August to September.

The Seli/Rokel River drains the uplands of northern Sierra Leone at altitudes of 300-400 m amsl. The river drains a total catchment of approximately 10 500 km^2. Payne *et al.* (2010) highlights the Bumbuna Falls as an important feature marking the transition from the upper to the lower parts of the river. This notion was verified during our assessment (**Figure 4-1**). A view of the longitudinal profile of the river identifies five primary aquatic habitat types. A summary description of each habitat type is provided below (refer to **Table 3-2** for a description of the different habitat types):

- *Source Zone* – represented by a single site **SL3**, which is located approximately 17 km from the source of the Seli River upstream of the Bumbuna Reservoir I (**Figure 3-1**).
- *Upper Foothills* – represented by two sites upstream of Bumbuna Reservoir I **SL2** and **SL1** respectively, and one site **SL5** downstream of the reservoir (**Figure 3-1**). Site SL1, will fall within the inundation zone of Bumbuna Reservoir II (**Figure 3-1**) and will therefore experience deep flooding.
- *Lowland River (Floodplain)* – presented by a total of four sites; **SL6, SL7, SL8** and **SL9** downstream of the reservoir, within a reach of approximately 67 km (**Figure 3-1**).
- *Rejuvenated Foothill* – represented by a single site **SL10** downstream of the reservoir, approximately 100 km downstream of site **SL9** (**Figure 3-1**).

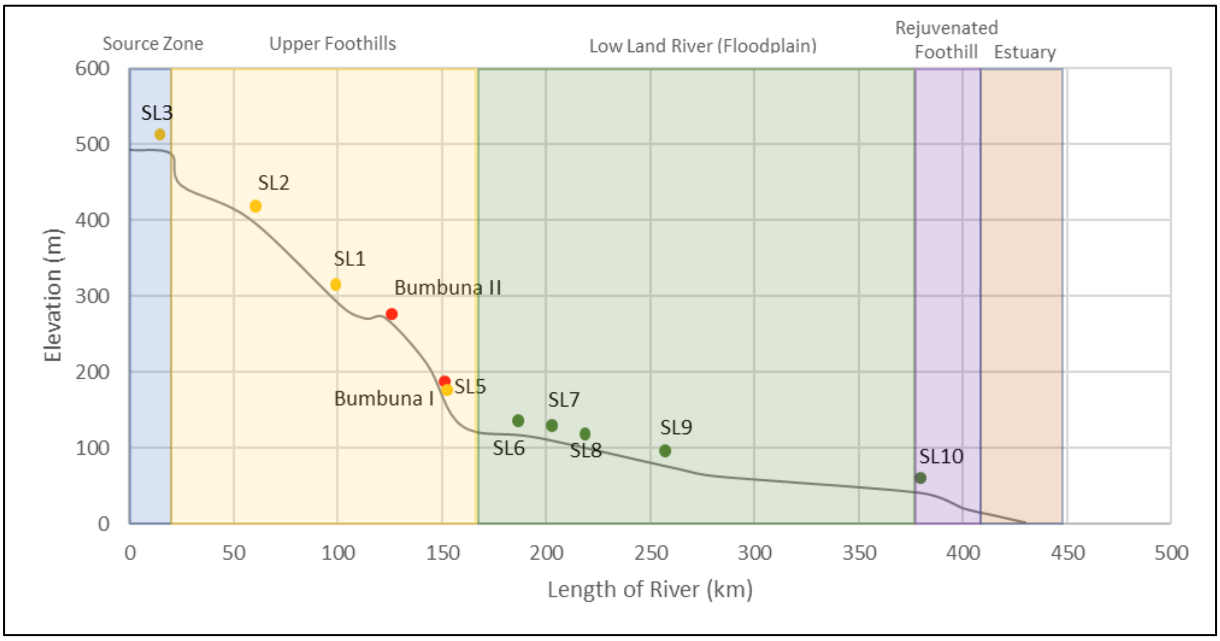

Figure 4-1: Different aquatic habitat types associated with the study area.

4.2. Site Descriptions

For a spatial orientation of cross sections refer to **Figure 3-1**, while the different aquatic habitats and the associated sites are shown in **Figure 4-1.** Details on the channel morphology, velocity depth classes and substrate composition at each are provide from **Table 4-1** to **Table 4-9**.

4.2.1. Source Zone

The source zone is defined as "Low gradient, upland plateau or upland basin able to store water. Spongy or peaty hydromorphic soils" – Rowntree and Wadeson (2000). An aerial view and a bank photograph illustrating the location and general bank features for site SL3, are provided in **Table 4-1:**

Table 4-1: Site description for the river reach associated with site SL3


General Features	
Location	Located furthest upstream, approximately 17 km from the source of the Seli River, upstream of Bumbuna Reservoir I.
Channel dimensions	
Macro-channel width (m)	50-100
Active-channel width (m)	10-20
Water surface width (m)	5-10
Active-channel bank height: left bank (m)	> 3
Active-channel bank height: right bank (m)	> 3
Cross Sectional Features	
Left Bank	***Right Bank***
Flood bench (annual flood)	Flood bench (annual flood)
High terrace (rarely inundated)	High terrace (rarely inundated)
Side bar	Side bar
Substrate Composition	
Bedrock	Common
Boulder (>256 mm)	Absent
Cobble (100-256 mm)	Absent
Pebble (16-100 mm)	Absent
Gravel (2-16 mm)	Sparse
Sand (0.06-2 mm)	Abundant
Silt/mud/clay (<0.06 mm)	Rare
Dominant Physical Biotope	
Cover Unit	Leaf Litter, substrate and overhanging vegetation.
Velocity depth classes	Slow Deep and Slow Shallow

4.2.2. Upper Foothills

The upper foothills are defined as "Moderately steep, cobble-bed or mixed bedrock-cobble bed channel, with plane bed, pool-riffle or pool-rapid reach types. Length of pools and riffles/rapids similar. Narrow floodplain of sand, gravel or cobble often present" – Rowntree and Wadeson, (2000). An aerial view and a bank photograph illustrating the location and general bank features for sites SL2, SL1 and SL5 are provided in **Table 4-2, Table 4-3** and **Table 4-4** respectively.

Table 4-2: Site description for the river reach associated with site SL2


General Features	
Location	Located on the Seli River upstream of Bumbuna Reservoir I, approximately 40 km downstream of site SL3.
Channel dimensions	
Macro-channel width (m)	20-50
Active-channel width (m)	2-5
Water surface width (m)	5-10
Active-channel bank height: left bank (m)	1-3
Active-channel bank height: right bank (m)	1-3
Cross Sectional Features	
Left Bank	***Right Bank***
Secondary or lateral channel	Flood bench (annual flood)
Substrate Composition	
Bedrock	Abundant
Boulder (>256 mm)	Abundant
Cobble (100-256 mm)	Abundant
Pebble (16-100 mm)	Common
Gravel (2-16 mm)	Common
Sand (0.06-2 mm)	Abundant
Silt/mud/clay (<0.06 mm)	Sparse
Dominant Physical Biotope	
Cover Unit	Substrate and overhanging vegetation
Velocity depth classes	Fast Deep, Fast Intermediate and Fast Shallow

Table 4-3: Site description for the river reach associated with site SL1

General Features	
Location	Located upstream of Bumbuna Reservoir I on the Seli River. This reach will fall within the inundation zone of Bumbuna Reservoir II.
Channel dimensions	
Macro-channel width (m)	50-100
Active-channel width (m)	20-50
Water surface width (m)	20-50
Active-channel bank height: left bank (m)	1-3
Active-channel bank height: right bank (m)	1-3
Cross Sectional Features	
Left Bank	***Right Bank***
High terrace (rarely inundated)	High terrace (rarely inundated)
Substrate Composition	
Bedrock	Abundant
Boulder (>256 mm)	Abundant
Cobble (100-256 mm)	Common
Pebble (16-100 mm)	Common
Gravel (2-16 mm)	Spare
Sand (0.06-2 mm)	Abundant
Silt/mud/clay (<0.06 mm)	Rare
Dominant Physical Biotope	
Cover Unit	Substrate
Velocity depth classes	Slow Deep, Fast Deep and Fast Intermediate

Table 4-4: Site description for the river reach associated with site SL5


General Features	
Location	Located downstream from Bumbuna Dam on the Rokel River, approximately 2.5 km downstream of the dam wall.
Channel dimensions	
Macro-channel width (m)	>100
Active-channel width (m)	>100
Water surface width (m)	50-100
Active-channel bank height: left bank (m)	>3
Active-channel bank height: right bank (m)	>3
Cross Sectional Features	
Left Bank	***Right Bank***
Flood bench (annual flood)	Flood bench (annual flood)
Substrate Composition	
Bedrock	Abundant
Boulder (>256 mm)	Abundant
Cobble (100-256 mm)	Common
Pebble (16-100 mm)	Common
Gravel (2-16 mm)	Common
Sand (0.06-2 mm)	Common
Silt/mud/clay (<0.06 mm)	Rare
Dominant Physical Biotope	
Cover Unit	Substrate and overhanging vegetation
Velocity depth classes	Slow Deep, Fast Deep and Fast Intermediate

4.2.3. Lowland River (Floodplain)

Lowland Rivers are defined as “Low gradient alluvial sand bed channel, typically regime type. Often confined, but fully developed meandering pattern within a distinct floodplain in unconfined reaches where there is increased silt content in bed or banks" - Rowntree and Wadeson (2000). An aerial view and bank photograph illustrating the location and general bank features for sites SL6, SL7, SL8 and SL9 are provided in **Table 4-5, Table 4-6, Table 4-7** and **Table 4-8** respectively:

Table 4-5: Site description for the river reach associated with site SL6


General Features	
Location	Located downstream from Bumbuna Dam on the Rokel River, approximately 23 km downstream of the dam wall.
Channel dimensions	
Macro-channel width (m)	>100
Active-channel width (m)	>100
Water surface width (m)	>100
Active-channel bank height: left bank (m)	>3
Active-channel bank height: right bank (m)	>3
Cross Sectional Features	
Left Bank	***Right Bank***
Flood bench (annual flood) Mid-channel bar (no vegetation)	Flood bench (annual flood) Mid-channel bar (no vegetation) Secondary or lateral channel
Substrate Composition	
Bedrock	Abundant
Boulder (>256 mm)	Abundant
Cobble (100-256 mm)	Abundant
Pebble (16-100 mm)	Abundant
Gravel (2-16 mm)	Abundant
Sand (0.06-2 mm)	Abundant
Silt/mud/clay (<0.06 mm)	Sparse
Dominant Physical Biotope	
Cover Unit	Substrate and overhanging vegetation
Velocity depth classes	Slow Deep, Fast Deep, Fast Intermediate and Fast Shallow

Table 4-6: Site description for the river reach associated with site SL7

General Features	
Location	Located downstream from Bumbuna Dam on the Rokel River, approximately 38 km downstream of the dam wall.
Channel dimensions	
Macro-channel width (m)	>100
Active-channel width (m)	>100
Water surface width (m)	50-100
Active-channel bank height: left bank (m)	>3
Active-channel bank height: right bank (m)	>3
Cross Sectional Features	
Left Bank	***Right Bank***
Flood bench (annual flood)	Flood bench (annual flood)
Substrate Composition	
Bedrock	Abundant
Boulder (>256 mm)	Common
Cobble (100-256 mm)	Common
Pebble (16-100 mm)	Sparse
Gravel (2-16 mm)	Common
Sand (0.06-2 mm)	Abundant
Silt/mud/clay (<0.06 mm)	Sparse
Dominant Physical Biotope	
Cover Unit	Substrate
Velocity depth classes	Slow Deep and Fast Deep

Table 4-7: Site description for the river reach associated with site SL8

General Features	
Location	Located downstream from Bumbuna Dam on the Rokel River, approximately 56 km downstream of the dam wall.
Channel dimensions	
Macro-channel width (m)	>100
Active-channel width (m)	>100
Water surface width (m)	50-100
Active-channel bank height: left bank (m)	>3
Active-channel bank height: right bank (m)	>3
Cross Sectional Features	
Left Bank	***Right Bank***
Flood bench (annual flood)	Flood bench (annual flood)
Substrate Composition	
Bedrock	Abundant
Boulder (>256 mm)	Abundant
Cobble (100-256 mm)	Common
Pebble (16-100 mm)	Sparse
Gravel (2-16 mm)	Sparse
Sand (0.06-2 mm)	Common
Silt/mud/clay (<0.06 mm)	Sparse
Dominant Physical Biotope	
Habitat	Substrate, leaf litter and overhanging vegetation
Velocity depth classes	Fast Deep and Slow Deep

Table 4-8: Site description for the river reach associated with site SL9

General Features	
Location	Located downstream from Bumbuna Dam on the Rokel River, approximately 96 km downstream of the dam wall.
Channel dimensions	
Macro-channel width (m)	50-100
Active-channel width (m)	50-100
Water surface width (m)	50-100
Active-channel bank height: left bank (m)	>3
Active-channel bank height: right bank (m)	>3
Cross Sectional Features	
Left Bank	***Right Bank***
	Flood bench (annual flood)
	High terrace (rarely inundated)
Substrate Composition	
Bedrock	Absent
Boulder (>256 mm)	Absent
Cobble (100-256 mm)	Absent
Pebble (16-100 mm)	Absent
Gravel (2-16 mm)	Sparse
Sand (0.06-2 mm)	Abundant
Silt/mud/clay (<0.06 mm)	Sparse
Dominant Physical Biotope	
Habitat	Substrate and leaf litter
Velocity depth classes	Fast Deep and Slow Deep

4.2.4. Rejuvenated Foothill

Rejuvenated foothills are defined as "Steepened section within middle reaches of the river caused by uplift, often within or downstream of a gorge. Characteristics similar to foothills (gravel/cobble-bed rivers with pool-riffle/

pool-rapid morphology) but of a higher order. A compound channel is often present with an active channel contained within a macro channel activated only during infrequent flood events. A floodplain may be present between the active and macro-channel" - Rowntree and Wadeson (2000). An aerial view and bank photograph illustrating the location and general bank features for site SL3, are provided in **Table 4-9**:

Table 4-9: Site description for the river reach associated with site SL10

General Features	
Location	Located downstream from Bumbuna Dam on the Rokel River, approximately 200 km downstream of the dam wall.
Channel dimensions	
Macro-channel width (m)	>100
Active-channel width (m)	>100
Water surface width (m)	>100
Active-channel bank height: left bank (m)	1-3
Active-channel bank height: right bank (m)	1-3
Cross Sectional Features	
Left Bank	***Right Bank***
Flood bench (annual flood)	Flood bench (annual flood)
Substrate Composition	
Bedrock	Common
Boulder (>256 mm)	Abundant
Cobble (100-256 mm)	Abundant
Pebble (16-100 mm)	Abundant
Gravel (2-16 mm)	Abundant
Sand (0.06-2 mm)	Abundant
Silt/mud/clay (<0.06 mm)	Rare
Dominant Physical Biotope	
Habitat	Substrate and overhanging vegetation
Velocity depth classes	Slow Deep, Fast Deep and Fast Intermediate

4.3. Baseline Information (PES Assessment)

4.3.1. EcoStatus

This section summarises the results obtained during the April 2018 aquatic ecology assessment for the different ecological aspects included within the overall EcoStatus assessment (**Table 4-10**; **Table 4-11**). Concurrently, the results for the anticipated change in each ecological component are also summarised in **Table 4-10**. The detailed results for each component are provided in the appendices from **Section 8** to **Section 13**, while a synopsis of each appendix is provided in **Section 4.3.1** to **Section 4.3.7**.

The aquatic ecology in the Source zone (represented by SL3) and Upper foothills, upslope of the Bumbuna Reservoir (represented SL1 and SL2), retains a large degree of ecological integrity. Most of the ecological components, except for diatoms, fell in 'A' and 'B' categories and represent *Natural* to *Largely Natural* conditions.

Site SL1 is located within the inundation zone. The resulting change in habitat will change the individual ecological components for the reach associated with this zone. The Habitat Integrity will subsequently drop to a 'D' category, while the macroinvertebrate and fish assemblages will drop from a 'B' to a 'D' category respectively. A 'D' category translates into a *Largely modified* state.

The baseline conditions for the Rokel River (downstream of the Bumbuna Reservoir) revealed a hydrological impact zone characterised by an improvement in habitat integrity; diatoms; and macroinvertebrates along the longitudinal profile of the river (sites SL5 to SL10). The diatom assemblages improved from a 'B/C' category at SL5 and SL6 to a 'B' category at SL7 to SL10. Similarly, macroinvertebrate assemblages improved from a 'D' category at SL5 to a 'C' category at SL6 to SL10. A slight improvement in fish assemblages were observed albeit lower down in the river at sites SL9 and SL10, where the improvement went from a 'D' category at site SL5, SL6 and SL8 to a 'C' category at site SL9 and SL10.

The implications of the Bumbuna Extensions for the different ecological components for the reach downstream of the Bumbuna Extensions reflect the following:

- The instream habitat for the 'dry reach' (represented by SL5- between the dam wall and the Bumbuna Extension tailrace) will receive less water compared to natural. The 'environmental flow' HEP will discharge at a homogenous rate of 6 m^3s^{-1} for eight months of the year with some variability during August to November. The change in hydrology will result in a decrease in Habitat Integrity, from a 'B' category to a 'C' category. The invertebrate assemblages are likely to improve from a 'D' to a 'C' category, due to an increase in preferred habitat at flows of about 6 m^3s^{-1}. Fish assemblages may improve slightly (as peaking associated with the current operations are likely to stop) but will not change from the 'D' category.

- The reach downstream for the Bumbuna Extension HEP tailrace (downstream of SL5 to SL10) will be affected by an increase in baseflows, a later onset of wet season flows, a decrease in flood magnitude, frequency and duration (i.e. the variation in habitat availability and the associated ecological functions will occur). Operational flows will increase to about 79 m^3s^{-1} for eight months of the year with some flood variability during August to November. The hydrological alteration will result in a decrease in Habitat Integrity from a 'B' category to a 'C' category for the downstream extent of the Rokel River, while the macroinvertebrate and diatom assemblages will remain in the same baseline categories. However, a decrease in fish assemblages is predicted for sites SL7, SL9 and SL10.

A Level III EcoClassification was completed for all the study sites assessed during the April 2018 Baseline assessment (Kleynhans and Louw, 2006)**.** The individual ecological components were integrated into the overall EcoStatus. **Table 4-11** shows the EcoStatus categories for each site before and after the proposed Bumbuna Extensions. The baseline EcoStatus for the sites located upstream of Bumbuna Reservoir fell into 'B' categories. Site SL1 will drop to a 'D' category after the project implementation as it will be inundated by the proposed Yiben Reservoir. Sites located downstream of Bumbuna Reservoir will remain in baseline categories.

Table 4-10: Summary of baseline information collected during April 2018 and modelled outcomes following the construction of Bumbuna Reservoir II

Site	Habitat Integrity		Diatoms		Macroinvertebrates		Fish	
	Baseline	Bumbuna Extensions	Baseline	Bumbuna Extensions	Baseline	Bumbuna Extensions	Baseline	Bumbuna Extensions
SL3	B	B	C	C	B	B	B	B
SL2	A	A	C	C	B	B	B	B
SL1	A	D	C/D	C	B	D	B	D
SL5	B	C	B/C	B/C	D	C	D	D
SL6	B	C	B/C	B/C	C	C	D	D
SL7	B	C	B	B	C	C	C	D
SL8	B	C	B	B	C	C	D	D
SL9	C	C	B	B	B/C	B/C	C	D
SL10	B	C	B	B	B	B	C	D

Table 4-11: Summary of integrated baseline EcoStatus results (April 2018) and modelled outcomes following the construction of Bumbuna Reservoir II

Site	EcoStatus % Baseline	EcoStatus Category Baseline	EcoStatus % Baseline Bumbuna Extension	EcoStatus Category Bumbuna Extension
SL3	83.56	B	83.56	B
SL2	85.58	B	85.58	B
SL1	84.49	B	40.23	D
SL5	60.25	C	69.79	C
SL6	66.93	C	63.44	C
SL7	68.25	C	71.26	C
SL8	69.83	C	65.66	C
SL9	72.19	C	65.99	C
SL10	77.66	C	71.13	C

4.3.2. Discharge Flow Habitat Relationship

The main objective of this assessment was to determine the likely changes within the riverine ecology due to the incremental flow changes introduced by the Bumbuna Extensions. Three areas of change have been identified and include: (i) the Yiben inundation zone (represented by SL1), (ii) the 'dry reach' (represented by SL5) and (iii) the river downstream of the Bumbuna Extension tailrace (represented by SL6) (see **Section 1.2**).

A key consideration in predicting likely ecological responses to flow alteration is habitat availability and the temporal change within the habitat relative to baseline conditions. The different habitats are defined as slow very shallow (SVS), slow shallow (SS), slow deep (SD), fast very shallow (FVS), fast shallow (FS), fast intermediate (FI) and fast deep (FD). The reach within the inundation zone (SL1) will change from riverine habitat (consisting of a range of habitat types from SVS to FD) to lake habitat dominated by SD conditions. Predicting the ecological implications of this is relatively simple and are discussed in more detail in **Sections 4.3.6** to **Section 4.3.8**.

To determine the likely ecological change for the reach downstream of the Bumbuna Extensions the habitat-flow relationship was determined for two cross-sections representing Upper foothills- and Lowland habitat respectively (see **Figure 4-1**). **Figure 4-2** and **Figure 4-3** show the distribution of different habitat units over a range of flows for the representative cross-sections.

The interpretation of the natural hydrology is limited to the available hydrological data and is relevant to the confluence of the Tonkolili River. Approximations regarding hydrology further downstream are made and discussed in **Section 4.3.2**. It is apparent that natural low flows during the driest month varies between about 2 m^3s^1 and 13 2 m^3s^{-1} while wettest month varies between 50 m^3s^{-1} and 370 m^3s^{-1}. The composition of the instream habitat under these flow ranges was determined for upper foothills and lowland habitat types respectively (**Figure 4-2** and **Figure 4-3)**.

During operation the 'dry reach' (represented by **Figure 4-2**) will receive a constant flow of 6 m^3s^{-1}. At this discharge the active channel will be approximate 18 m wide of which more than 50% will be occupied by FD, FI and FS habitat units. The representation of fast habitat units is typically more important for sustaining sensitive rheophilic invertebrate and fish species.

The reach downstream of the Bumbuna Extension tailrace will receive a constant discharge of about 78 m^3s^{-1} for most of time. At this discharge the Upper foothills and lowland units are likely to be dominated by FD and SD habitat. The anticipated change in habitat due to operational flows have been applied to the individual ecological components (Habitat Integrity, diatoms, invertebrates and fish) to predict likely changes within the sections below.

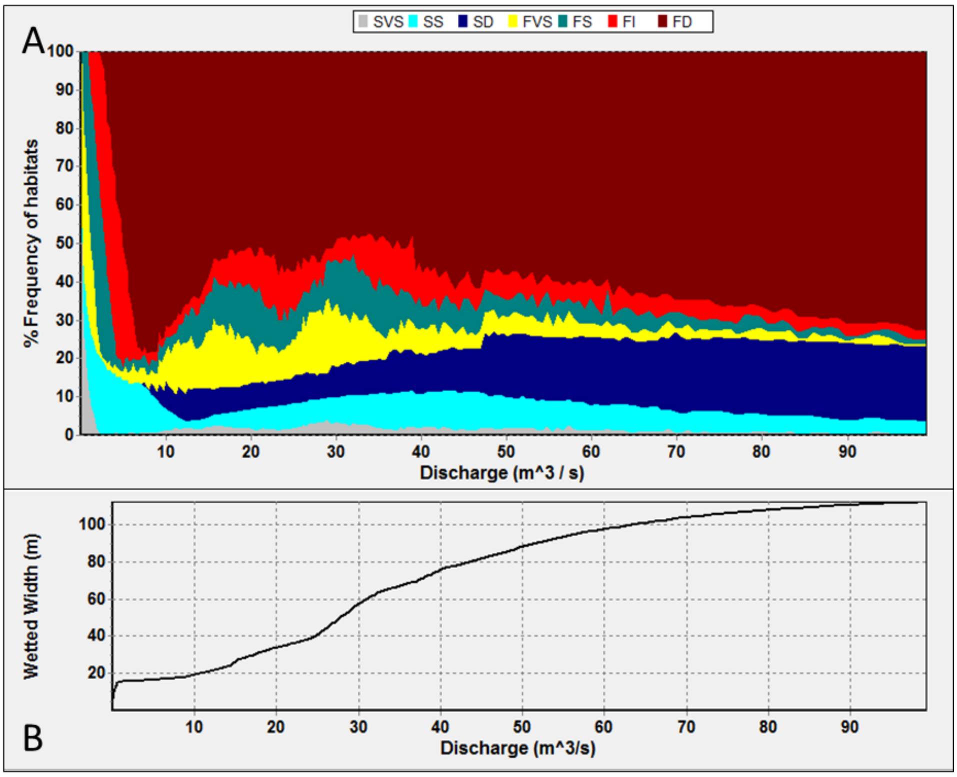

Figure 4-2: Discharge habitat relationship for the reach associated with SL5 representative of Upper foothills.

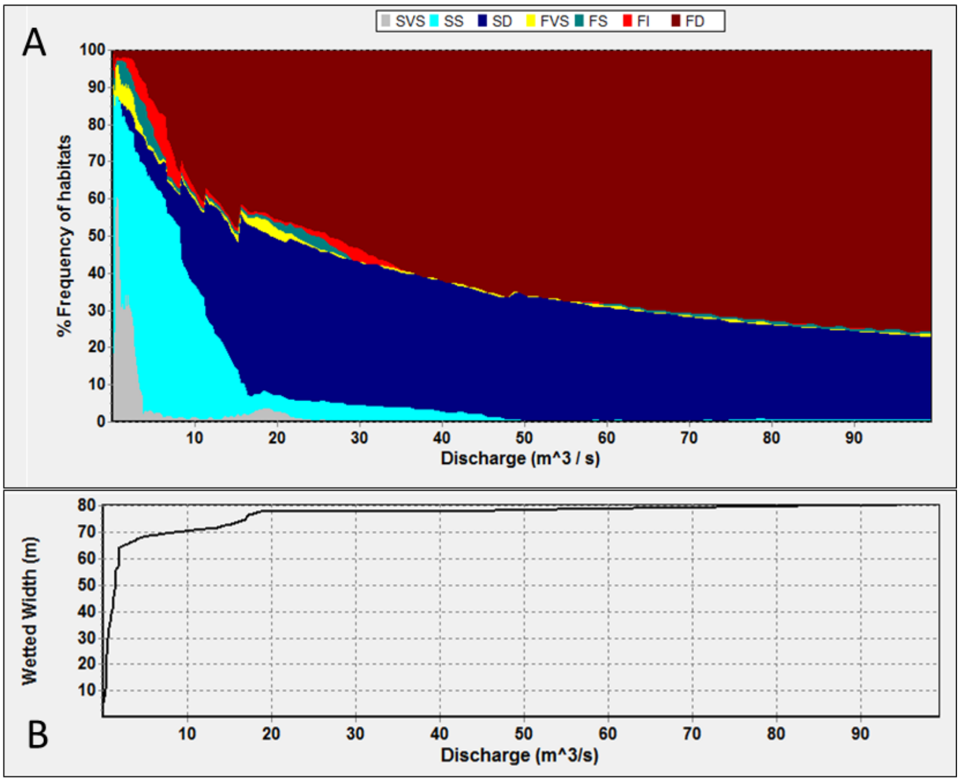

Figure 4-3: Discharge habitat relationship for the reach associated with SL6 and representative of lowland habitat.

4.3.3. Hydrology and Hydrological Alteration During Operation

A second consideration to meeting habitat requirements under different flow scenarios, is meeting other ecological requirements (i.e. functional flows such as; migration cues, longitudinal and lateral connectivity, spawning habitat etc.) associated with the natural flow regime. The natural flow variation of a river influences aquatic biodiversity via several, inter-related mechanisms that operate over different spatial and temporal scales (Bun and Arthington, 2002). Eight generic ecological requirements relating to the natural flow regime are illustrated and discussed in **Figure 4-5 A**, which represents the variation in median, maximum and minimum monthly natural flows for the Rokel River at SL5. The relevance of these requirements to baseline habitat, diatom, invertebrate and fish assemblages are discussed in **Sections 4.3.4** to **Section 4.3.7**.

The relationship between biodiversity and the physical nature of the aquatic habitat is likely to be driven by large events that influence channel form and shape (indicated by point 2 and 8 in **Figure 4-5 A**). However, droughts and low flow events also play a role by limiting overall habitat availability (point 7 and 8 in **Figure 4-5 A**). Many features of the flow regime influence life history patterns, especially the seasonality and predictability of the overall pattern (points 1 to 8). Some flow events trigger longitudinal dispersal of migratory aquatic organisms (point 1) and other large events allow access to otherwise disconnected floodplain habitats (point 2). The aquatic ecology has evolved in response to the overall flow regime.

For comparison to the natural flows, the operational flows downstream of Bumbuna Extension HEP are represented in **Figure 4-5 B**. The flow regime will be attenuated and characterised by: (i) an increase in baseflows, (ii) a delayed onset of wet season and (iii) a decrease in magnitude, frequency and duration of wet flows (**Figure 4-4**). The impact of these flow changes will be mitigated along the longitudinal profile of the Rokel River. To illustrate the 'recovery' the available hydrology was scaled at catchment level to obtain approximate flows at downstream locations SL9 and SL10 (**Figure 4-5 C** and **Figure 4-5 D**). Except for increased baseflows, the majority of the eight ecological flow requirements are likely to be present at site SL9 and further downstream. The ecological consequences of the temporal and spatial changes in the operational flows have been expressed in terms of specific requirements for the diatoms, macroinvertebrates and fish **Sections 4.3.4** to **Section 4.3.7**.

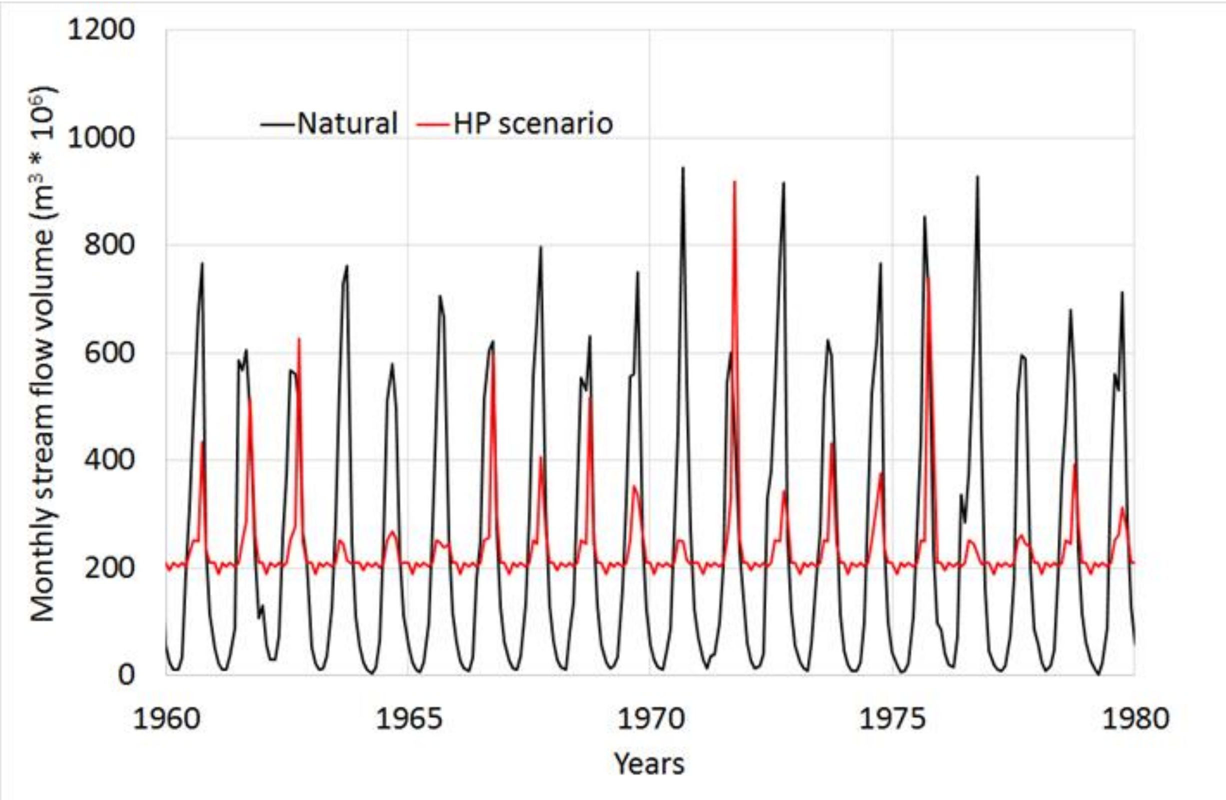

Figure 4-4: Time series of monthly stream flow data used as input to the model.

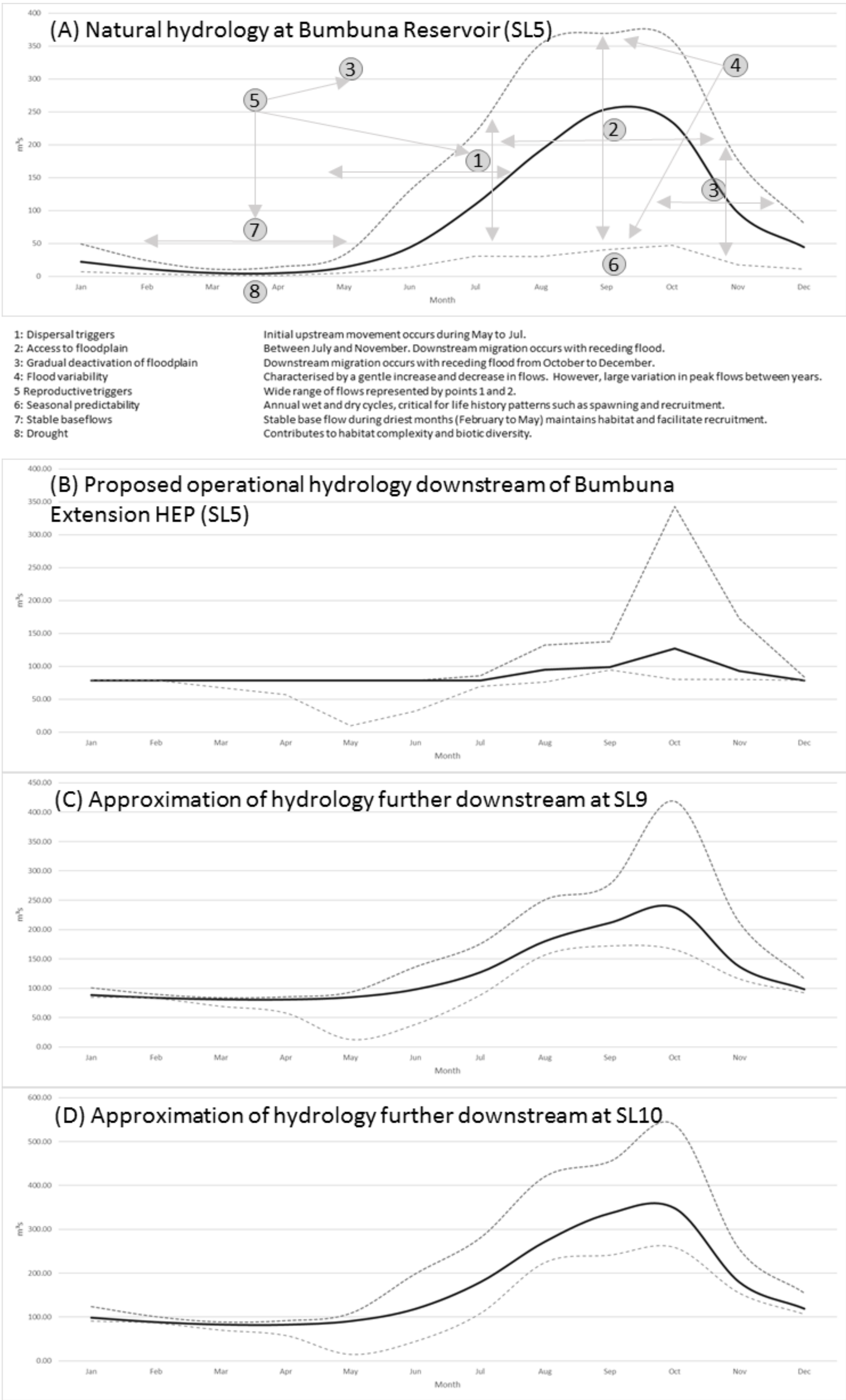

Figure 4-5: Hydrographs showing the natural regime (A) with specific functional flows numbered 1 to 8 in relation to the proposed hydrological releases downstream Bumbuna Extension HEP (B). Figures C and D represents an approximate correction in hydrology at location SL9 (C) and again at SL10 (D).

4.3.4. WATER QUALITY

Water quality at all sites was good during the April 2018 assessment and the water quality at all the river sites was characterised by circumneutral pH values with low salt loads:

- These values fell within the benchmark criteria for aquatic freshwater systems. Spatially, the sites located downstream of Bumbuna Reservoir I (SL5-SL10), showed a slight increase in salt loads, with less variation in the pH values.
- Despite the SO_4 values falling within benchmark criteria, the value recorded at site SL1 was higher when compared to the upstream sites (SL2 and SL3).
- Except for site SL1, the sites obtained a water signature reflecting Calcium Bicarbonate ($Ca(HCO_3)_2$), which is typical of shallow fresh waters, while none of the constituents fell outside the threshold criteria for the maintenance of freshwater aquatic ecosystems.
- Site SL1, is an outlier and indicated a Calcium Sulphate ($CaSO_4$) water signature, which is typical of gypsum ground water and potential mine drainage. Low primary nutrient levels were measured, which indicated an oligotrophic classification (nutrient deficient) (**Appendix A – Water Quality**).

4.3.5. DIATOMS

The diatom assemblages were generally comprised of species characteristic of fresh brackish (<500 µS/cm), circumneutral (pH 7) to alkaline (pH >7) waters and eutrophic conditions. The pollution levels indicated that there was some form of pollution evident at all the sites (ranging from β-mesosaprobic- moderately polluted waters to α-meso-polysaprobic- heavily polluted waters).

Based on diatom community analyses, the ecological water quality ranged from *Good* to *Moderate* (**Table 4-10**). The %PTV scores was relatively low for all the sites indicating that there was a very low impact associated with organic pollution (**Appendix B – Diatoms**). The impacts at these sites may be associated with some form of organic matter input from the surrounding land-use.

A total of 61 diatom species were recorded at the nine Yiben sites and the dominant diatom species recorded at all sites included, *Nitzschia sp*., *Achnanthidium sp., Gomphonema sp*. and *Navicula sp*. (**Figure 4-6**).

According to temporal diatom analysis trends, the ecological water quality appeared to show a slight improvement and the level of organic pollution appeared to decrease compared to the previous survey.

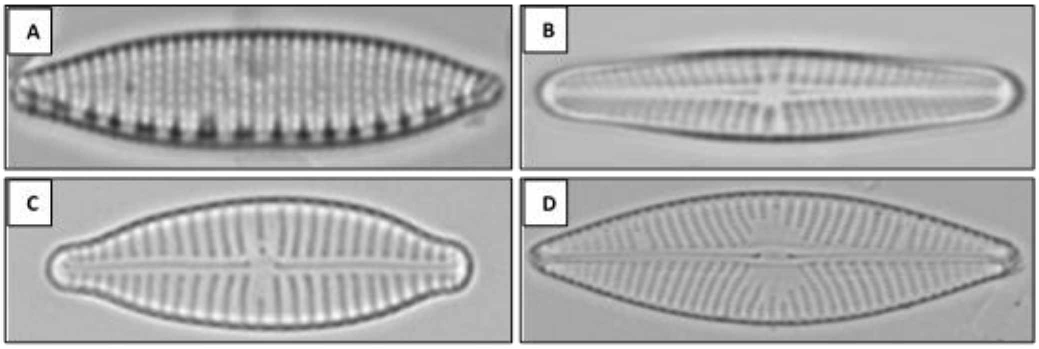

Figure 4-6: Photo plate showing some of the dominant diatom species sampled, including: (A) *Nitzschia sp.*, (B) *Achnanthidium sp.*, (C) *Gomphonema sp.*, and (D) *Navicula sp.* (Kelly *et al.*, 2005).

Table 4-12: The predicted change in the diatom assemblage associated with Bumbuna Reservoir II

Sampling points	Location in Relation to Bumbuna Reservoir I	%PTV	SPI	Ecological Category	Predicted change - Bumbuna Reservoir II	Remarks on change in Diatom assemblage
SL3	Upstream	2.2	13.9	Moderate	Moderate	The upstream sites will still receive allochthonous material from the closed canopy and riparian zone resulting in the presence of organic matter and *Moderate* water quality. The diatom assemblage will be classified into a *Prostrate* ecological guild which thrives in high disturbance (high velocity).
SL2	Upstream	4	13.1	Moderate	Moderate	
SL1	Upstream	5.6	11.8	Moderate	Poor	This site will be inundated by Bumbuna II which will lead to higher organic matter resulting in a slight decline from *Moderate* to *Poor* water quality. The diatom assemblage will shift to a *Filamentous* ecological guild which thrives in nutrient enriched systems with low disturbance (low velocity).
SL5	Downstream	1.3	14.6	Good	Good	The diatom assemblages at the downstream sites may shift but will reflect the same ecological water quality. These sites had low levels of organic pollution and are expected to remain this way. The unenriched sites result in a *Prostrate* ecological guild which thrive in low nutrient and high disturbance (high velocity). The water quality at these downstream sites will remain *Good*.
SL6	Downstream	0	14.7	Good	Good	
SL7	Downstream	0.7	16.4	Good	Good	The diatom assemblages at the downstream sites may shift but will reflect the same ecological water quality. These sites had low levels of organic pollution and are expected to remain this way. The unenriched sites result in a *Prostrate* ecological guild which thrive in low nutrient and high disturbance (high velocity). The water quality at these downstream sites will remain *Good*.
SL8	Downstream	2	15.8	Good	Good	
SL9	Downstream	1.1	16.2	Good	Good	
SL10	Downstream	0.7	15.7	Good	Good	

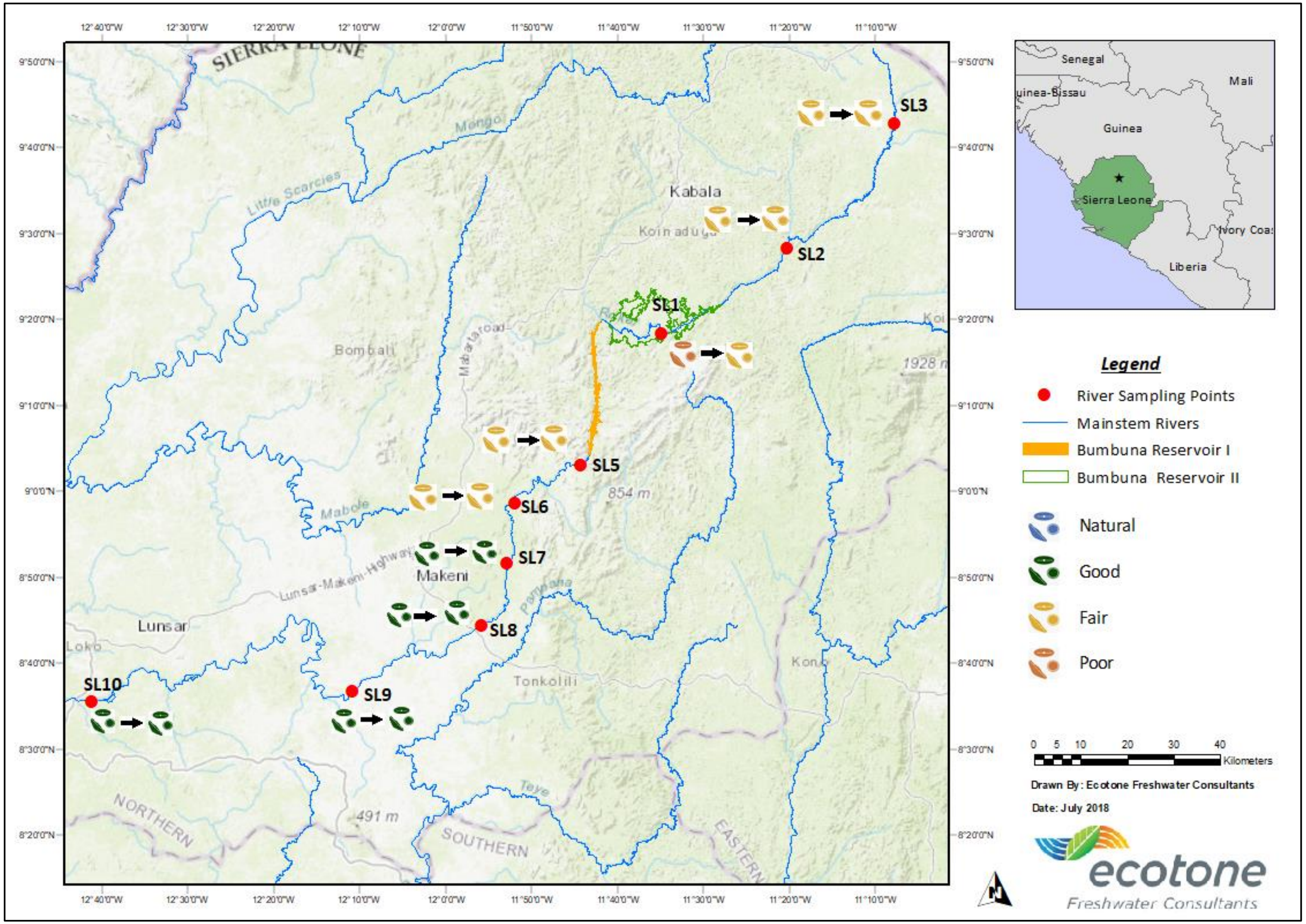

Figure 4-7: Map illustration of the baseline ecological water quality associated with the study area, up- and downstream of Bumbuna Reservoir I.

4.3.6. HABITAT INTEGRITY

The intermediate Index of Habitat Integrity (IHI) was applied on a site level basis to ascertain the change of instream and riparian habitat from natural conditions (Kemper, 1999). The habitat integrity assessment provides a tool for assessing instream and riparian habitat by incorporating factors and potential impacts (Kleynhans, 1996). The IHI was applied as a surrogate to inform impacts related to hydrology, water quality and sedimentation. These three components were assessed based on the following aspects, water abstraction, water quality, bed modification, channel modification, flow modification, alien vegetation, alien fauna, solid waste disposal, bank erosion and vegetation removal:

- At present, all the upstream sites fell in A – B categories and relate to *Natural* and *Largely Natural* conditions (**Table 4-13**). These reaches were largely free of hydrological, geomorphological and water quality impacts, however, some marginal spatial variation was measured at site SL3. The decline in habitat integrity measured at site SL3 was mainly due to slightly reduced water quality, bed modification and vegetation removal (**Appendix C - Intermediate Index of Habitat Integrity**).
- Larger spatial variation was measured downstream of the Bumbuna Reservoir I, where the habitat integrity ranged from *Largely Natural* to *Moderately* modified conditions (**Table 4-13**). The reach associated with site SL9 obtained the lowest IHI score, while SL5 obtained the highest IHI score for the downstream reaches. The decrease in habitat integrity at reach SL9 relates mainly to localised increases in vegetation removal and bank erosion within the riparian zone and the subsequent increase in surface flows l (**Appendix C - Intermediate Index of Habitat Integrity**).
- Overall, the remaining sites classed in a B category, despite sites SL6, SL7 and SL8 scoring lower than the other sites assessed.
- With regards to the anticipated change in the habitat integrity based on the construction of Bumbuna Reservoir II and the new proposed hydrological regime, the ecological categories should remain unchanged at reaches SL2 and SL3 (**Figure 4-8**) as the extent of inundation for the proposed Bumbuna Reservoir II will not infringe on these reaches (**Figure 4-9**).
- However, a decrease in habitat integrity is anticipated at site SL1, as it falls within the inundation zone and the site is anticipated to drop to a D category, inferring a *Largely* modified state. The main impact within this reach will be as a result of deep flooding. A decrease is also anticipated at sites SL6-SL10, mainly due to further alteration to the hydrological regime, which will alter the extent of inundation, potential increases in erosional features and

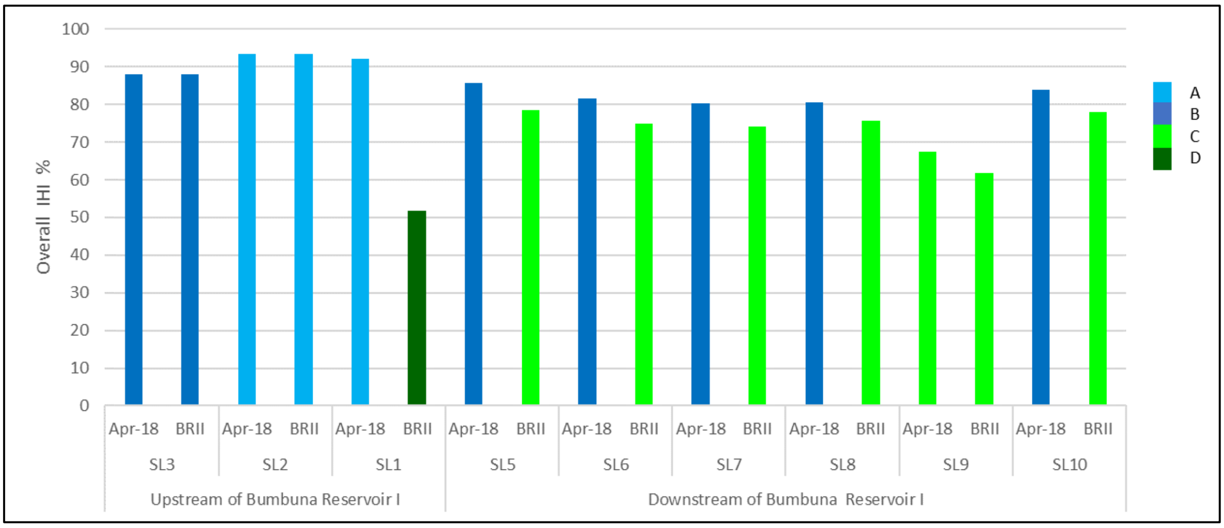

Figure 4-8: Column graph indicating the overall IHI % scores for all the study sites post the construction on Bumbuna Reservoir II.

Table 4-13: Summary table showing the baseline and anticipated change in habitat integrity

Sampling points	Location in Relation to Bumbuna Reservoir I	Baseline (Apr-18)	Predicted Change - Bumbuna Reservoir II	Remarks on change in Habitat Integrity
SL3	Upstream	B	B	The ecological categories should remain unchanged at reaches SL2 and SL3 as the extent of inundation for the proposed Bumbuna Reservoir II will not infringe on these reaches.
SL2	Upstream	A	A	
SL1	Upstream	A	D	A decrease in habitat integrity is anticipated as this reach falls within the inundation zone. The habitat template will change considerably because of deep flooding and the main driving variables will be flow modification, changes in the extent of inundation, bed modification and the subsequent removal of riparian vegetation
SL5	Downstream	B	C	The downstream reaches are anticipated to experience a decrease in habitat integrity, but the basic ecosystem functions will remain predominantly unchanged. The driving variables responsible for the anticipated drop in ecological integrity will be flow modification, changes in the extent of inundation, channel modification within the riparian zone and erosion.
SL6	Downstream	B	C	
SL7	Downstream	B	C	
SL8	Downstream	B	C	
SL9	Downstream	C	C	
SL10	Downstream	B	C	

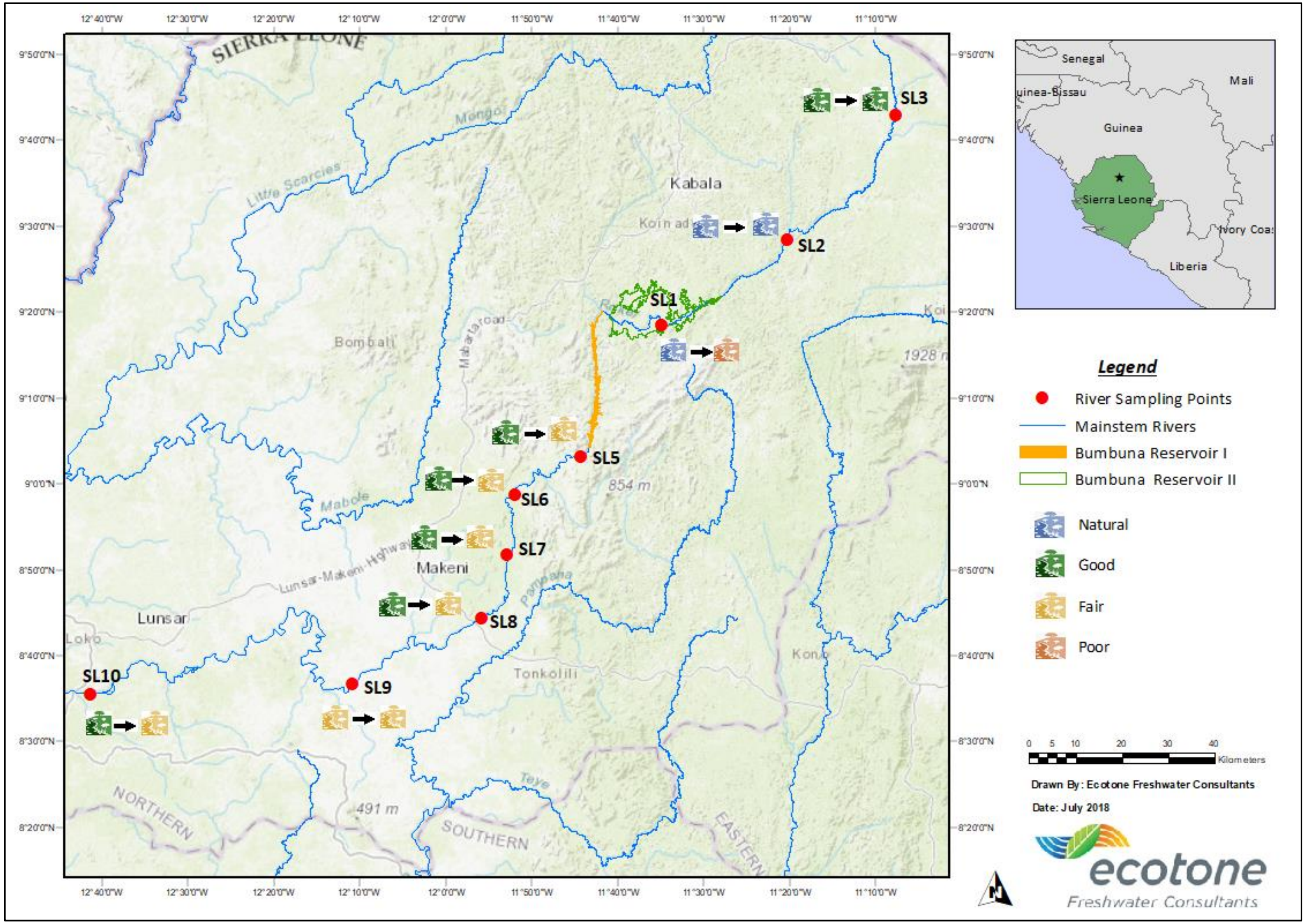

Figure 4-9: Map illustrating the baseline and anticipated ecological categories for the habitat integrity following the construction of Bumbuna II and the new hydrological regime.

4.3.7. AQUATIC MACROINVERTEBRATES

The Macroinvertebrate Response Assessment Index (MIRAI) provides a measure of the residual ecological integrity of a system based on the deviation of the present community in relation to an expected (reference) invertebrate community. The variation in the preferences and the tolerances between the expected and the sampled community also indicates the likely contribution of different drivers (changes in flow, substrate and water quality) to the decrease in ecological integrity. The main aspects with regards to the aquatic macroinvertebrate assemblages under the existing hydrological regime are briefly discussed below:

- A total of 38 taxa were sampled both up- and downstream of the Bumbuna Reservoir I, following the April 2018 assessment, despite six sites (SL4 - SL10) being sampled downstream, opposed to the three sampled upstream (SL1 - SL3). One would expect a slightly higher overall macroinvertebrate diversity over a greater study area.
- Based on instream macroinvertebrate assemblages sampled during the April 2018 assessment, the upstream resource unit at the three reaches (SL3, SL2 and SL1) fell in B category, inferring a *Largely Natural* State (**Figure 4-10**). The ecological categories should remain unchanged at sites SL2 and SL3 as the extent of inundation for the proposed Bumbuna Reservoir II location will not infringe on these reaches However, a decrease in ecological integrity is anticipated at site SL1, as it falls within the inundation zone.
- The main change to the habitat template at site SL1 will be the loss of Stones-in-Current (SIC) habitat, which will result in the absence of taxa with this presence. The subsequent result is that site SL1 will potentially drop to an E category, inferring a *Seriously* modified state (**Figure 4-10**).
- Spatially, the baseline ecological integrity downstream of Bumbuna Reservoir increased along the longitudinal profile of the Rokel River. Sites SL6, SL7 and SL8 indicated an increased in ecological integrity and classed in a C category, translating into a *Moderately* modified (**Figure 4-10**). These sites are anticipated to show a slight increase in ecological integrity but should remain in the same ecological categories.
- Sites SL9 and SL10 obtained similar scores to that of the upstream sites, and classed in B categories, inferring a *Largely Natural* state and were not adjusted as the sites are anticipated to remain in the same ecological categories following the construction of Bumbuna Reservoir II (**Figure 4-10**).
- With the exception of sites SL3, SL5 and SL9, the invertebrate community assemblages were well represented by taxa with specific flow (**Figure 4-12 A**) and water quality (**Figure 4-12 B**) requirements. The taxa with a preference for fast (>0.6 ms^{-1}) and moderately fast (>0.3 ms^{-1}) flowing water included Oligoneuridae (Brushleg mayflies), Heptageniidae (Flathead mayflies), Perlidae (Stoneflies), Tricorythidae (Stout crawlers) and Elmidae (riffle beetles) (**Figure 4-13**). Similarly, these taxa reflected no or little tolerance for water pollution.
- The macroinvertebrate assessment showed that the current flow alterations associated with Bumbuna Reservoir I has resulted in a large alteration to the macroinvertebrate assemblage at site SL5, with

residual impacts shown at sites SL6, SL7 and SL8. The system has however, recovered within the reaches associated with sites SL9 and SL10.

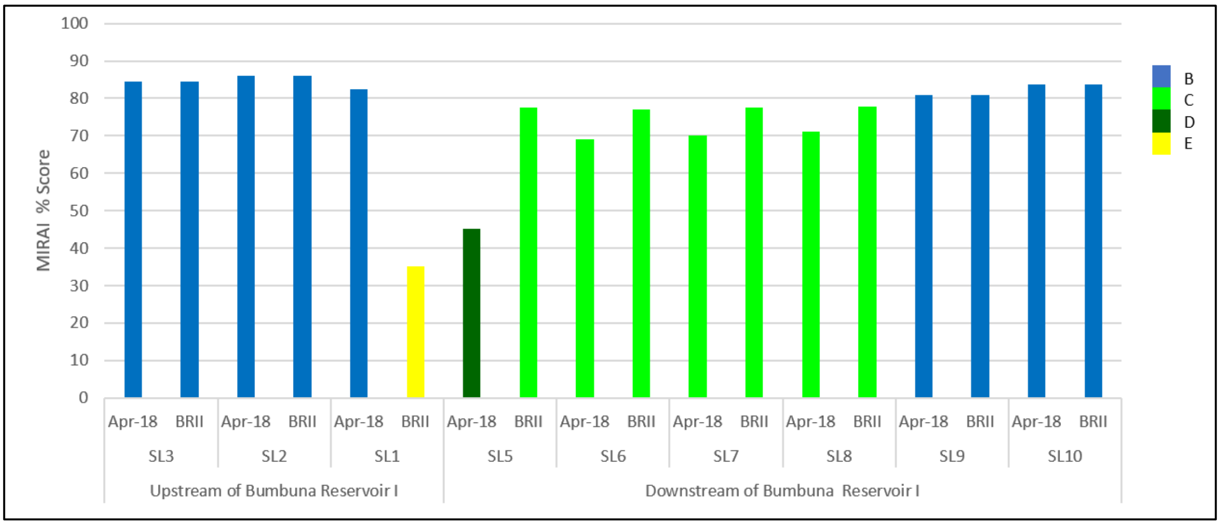

Figure 4-10: Column graph indicating the overall MIRAI % scores for all the study sites post the construction on Bumbuna Reservoir II.

Table 4-14: Summary table showing the baseline and anticipated change in the macroinvertebrate assemblages

Sampling points	Location in relation to Bumbuna Reservoir I	IHAS	SASS Score	ASPT	%EPT	Baseline MIRAI	Predicted change -Bumbuna Reservoir II	Remarks on change in macroinvertebrate assemblage
SL3	Upstream	POOR	54	4.50	0	B	B	The ecological categories obtained for these sites should remain unchanged as the extent of inundation for the proposed Bumbuna Reservoir II location will not infringe on these reaches
SL2	Upstream	POOR / ADEQUATE	175	7.00	40.0	B	B	
SL1	Upstream	POOR	121	6.37	42.1	B	E	A considerable decrease in ecological integrity is anticipated within this reach, as it falls within the inundation zone. The main alteration to the habitat template will be the loss of SIC habitat, which will result in the absence of taxa with this presence. The subsequent result is that this reach will reflect a significant drop in ecological integrity.
SL5	Downstream	POOR	74	4.93	33.3	D	C	With the removal of daily pulses, macroinvertebrate sensitive to alterations in flow are expected to return within this reach. Furthermore, the proposed flows release within this reach (6 m^3/s) will provide adequate FI habitat. Despite the increase in habitat availability the reach will lose seasonal variation, which may alter the community assemblage and potentially result in the dominance of certain families at the expense of others.
SL6	Downstream	POOR / ADEQUATE	141	6.41	36.4	C	C	As fast intermediate habitat is expected to occur within the activated fringes at a mean discharge of 82 m^3/s (year 1) (**Figure 11-7**) and with the daily pulses no longer anticipated, the downstream reach is expected to show an overall increase in ecological integrity, but should remain in the same categories.
SL7	Downstream	POOR / ADEQUATE	140	6.36	31.8	C	C	
SL8	Downstream	POOR	127	5.77	40.9	C	C	
SL9	Downstream	POOR	49	5.44	33.3	C/B	C/B	The reaches located furthest downstream were not adjusted and are anticipated to remain in the same ecological categories following the construction of Bumbuna Reservoir II.
SL10	Downstream	ADEQUATE	178	6.85	42.3	B	B	

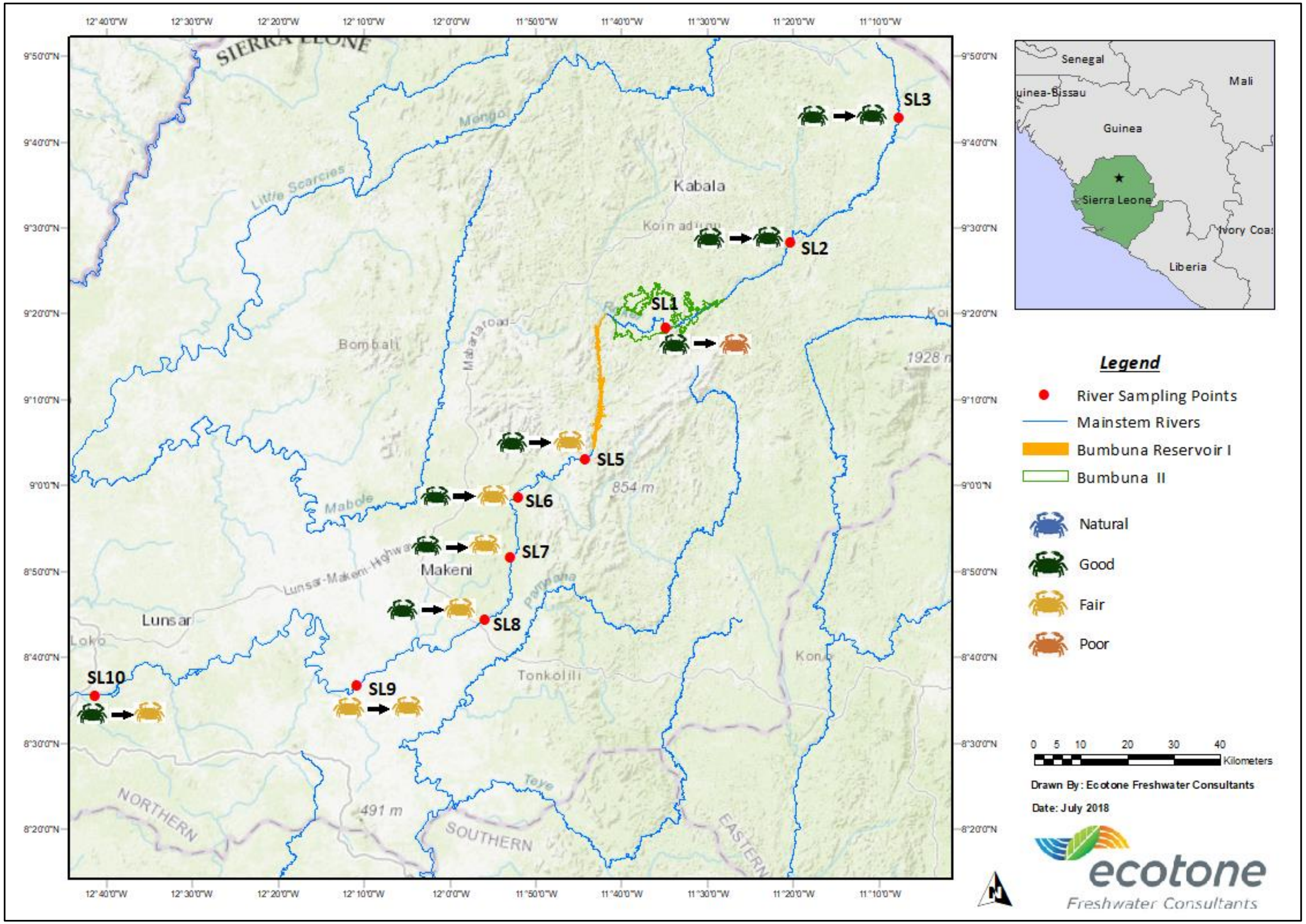

Figure 4-11: Map illustrating the baseline and anticipated ecological categories macroinvertebrate community assemblages following the construction of Bumbuna II and the new hydrological regime.

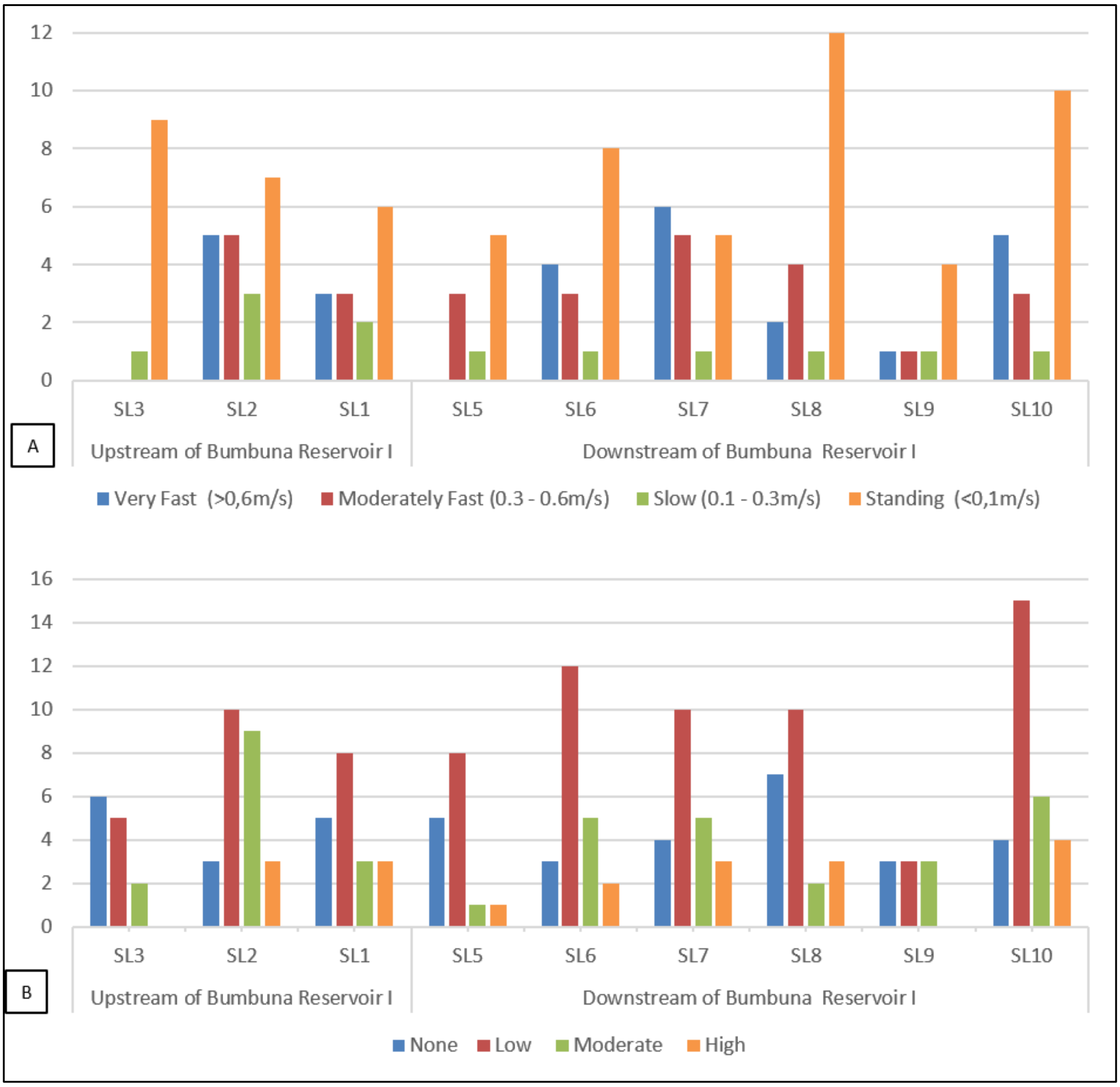

Figure 4-12: Bar graphs showing (A) the number of individual invertebrate taxa with a specific flow requirement and (B) the number of individual taxa with a specific intolerance to water pollution. None= No tolerance to pollution. High= very High tolerance to pollution.

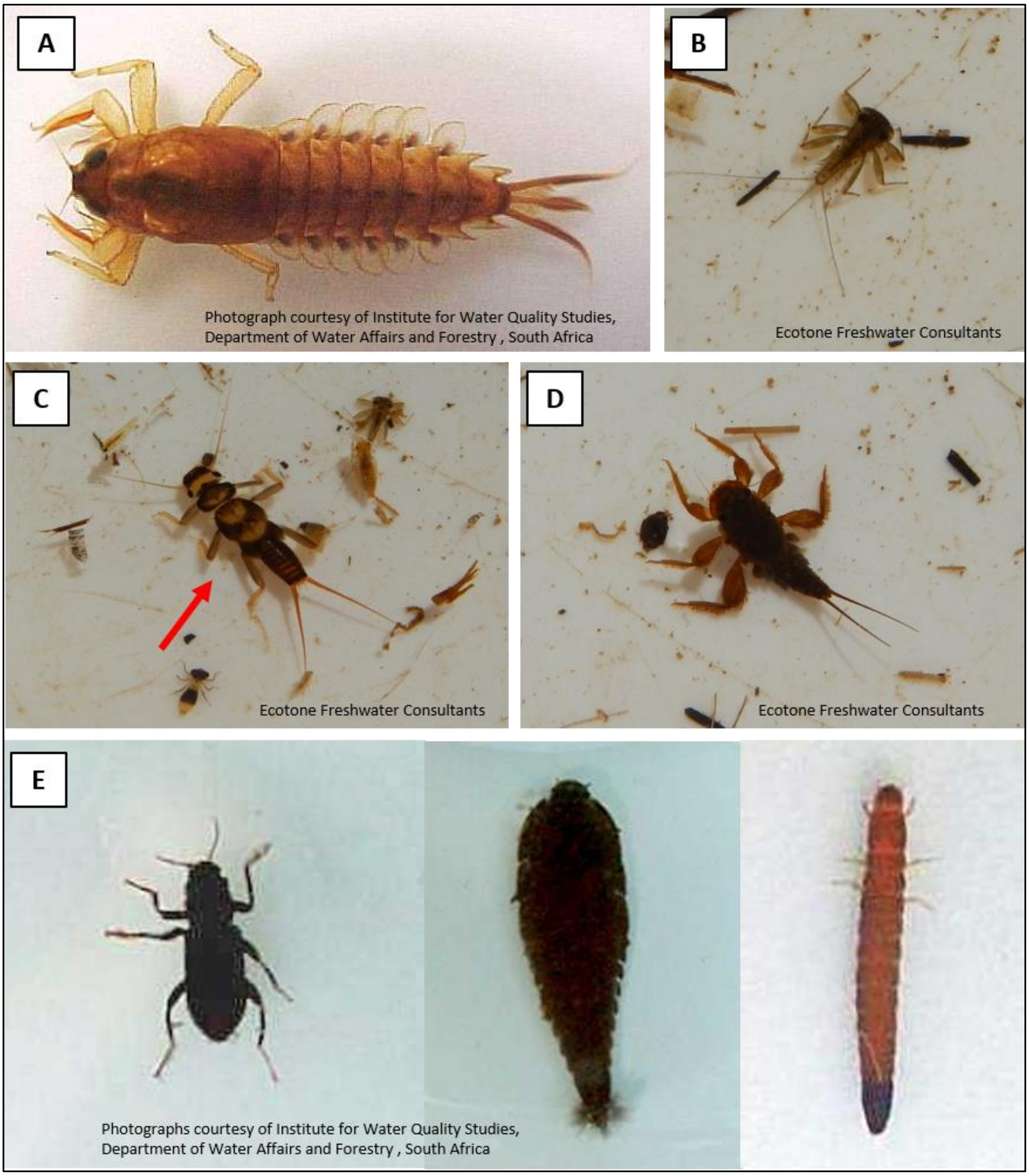

Figure 4-13: Aquatic macroinvertebrate indicator taxa selected for setting flow requirements and for biomonitoring: (A) Oligoneuridae, (B) Heptageniidae, (C) Perlidae, (D) Tricorythidae and (E) Elmidae.

4.3.8. FISH

4.3.8.1. REVIEW OF THREATENED STATUS AND ENDEMISM

The Seli/Rokel River provides habitat for approximately 20 genera representing about 82 known species. Of the expected and sampled species, three are listed by the IUCN Red List as Endangered (EN), nine are Near Threatened (NT) and two are Data Deficient (DD) (**Table 4-15**). A summary of the IUCN Red List data is provided in **Table 4-16**. Details on the IUCN classification justification, habitat requirement and threats are outlined in **Appendix E - Fish Section 12.2.1**.

The Seli/Rokel fish are characteristic of the Northern Upper Guinea ecoregion. The area has a moderate to high regional level of endemism (estimated at 42%- Payne 2018). The most notable regional endemics relate to the Cichlids, with seven endemic species. In addition, four freshwater genera (*Prolabeo*, *Anomolochromis*, *Heterotilapia* and *Coelotilapia*) are endemic to region. Although the endemic species are represented in the Seli/Rokel River they also occur in the neighbouring rivers (i.e. the Seli/Rokel River reflects a high degree of similarity with other rivers within the ecoregion). Overall taxonomic resolution is moderate to good for the main stem Seli/Rokel, and it is unlikely that new species will be described from the main stem. However, tributaries are likely to yield new species.

Table 4-15: Summary Count of IUCN Red Listed Fish Species Known to be Present in the Rokel/Seli River

Row Labels	Count of IUCN Red List Status
Data Deficient (DD)	2
Endangered (EN)	3
Least Concern (LC)	55
Near Threatened (NT)	9
Not Evaluated (NT)	12
Vulnerable (VU)	0
Grand Total	82

Table 4-16: List of sampled and expected fish species for the Rokel/Seli River, with IUCN Red List conservation status

Genus & Species	Common Names	IUCN Red List	Ecotone Jun 15	Ecotone Apr 18	Payne *et al.*, 2006, 2018
Epiplatys njalaensis	NA	EN			X
Sarotherodon occidentalis	Perche Africaine	NT		X (SL10)	X
Enteromius bigornei	Carp	NT		X (SL1, SL2, SL3)	
Enteromius macrops	Blackstripe Barb	NT			X
Enteromius liberiensis	Carp	EN			X
Leptocypris guineensis	NA	NT	X		X
Prolabeo batesi	NA	DD	X (SL5)	X (SL1, SL2, SL3)	
Raiamas nigeriensis	NA	NT	X		X
Raiamas scarciensis	NA	DD			X
Ichthyborus quadrilineatus	NA	NT		X (SL9)	X
Synodontis levequei	Squeaker	NT			X
Synodontis tourei	Squeaker	NT	X (SL5)		X
Marcusenius meronai	NA	EN	X (SL5)	X (SL1, SL2, SL5)	X
Petrocephalus levequei	Elephantfish	NT		X (SL2, SL9)	

4.3.8.2. PRESENT ECOLOGICAL STATE

The PES assessment was completed to determine baseline modification in fish assemblages by measuring the digression in the representation of expected ecological fish guilds and the sampled representation during the April 2018 assessment. The environmental requirements, as defined by the guild classifications, were applied with a more in-depth analyses of breeding and migration requirements to predict the potential change in fish assemblages that may occur during the operation of the Bumbuna Extensions. Refer to **Appendix E - Fish Section 12.2.2** for a detailed review of the ecological fish guilds applied and to **Section 12.2.3** for a discussion of breeding and migration requirements applied within the PES assessment.

The flow-habitat analyses outlined in **Section 4.3.1**, **Figure 4-2** and **Figure 4-3** informed the interpretation of operational flow related habitat changes on fish assemblages. While, **Figure 4-5** conceptualised the degree and extent of flow related change to the river downstream of the Bumbuna Extensions. The degree to which functional flows will be met for the different reaches downstream of the Bumbuna Extensions are summarised in **Table 4-17**. The subsequent results of the ecological classification for baseline conditions and for the Bumbuna Extensions are provided in **Table 4-18** and **Figure 4-14**.

Table 4-17: Summary of impacts on functional flow requirements for the Rokel River downstream of the Bumbuna Extensions

Functional Flow Requirement	Conclusion and Comment	SL5 ('dry reach')	SL6, SL7, SL8	SL9, SL10
Dispersal triggers	Relate to the onset of the wet season (April-June) and is cued by a proportional increase in flow and a change in water temperature. The delayed onset of wet season flows will be pronounced during operations within the lowland section represented by SL6, SL7 and SL8 (compare **Figure 4-5 A** and **B**). Wet season dispersal triggers will recover downstream of site SL9 (**Figure 4-5 C** and **D**).	NA	✗	✔
Longitudinal access	Floodplain features only really develop within the coastal plain downstream of Magburaka. Some expected species will opportunistically exploit floodplain habitat but are not expected to be affected by a decrease in the frequency and duration of floodplain activation. These flood features are likely to still be present (or improved) lower down at sites SL9 and SL10.	NA	NA	✔
Gradual deactivation of high flows	During operations the Bumbuna Extension, the wet season flows will peak during October and will reside until December. This is approximately the same as for the natural deactivation of the high flows. No ecological effects are expected within any of the reaches assessed.	✔	✔	✔
Flood variability	The natural hydrology is characterised by large but relatively predictable seasonal variation. The Bumbuna Extensions operational flows have some variability for September, October and November (**Figure 4-4**). An important consideration for the 'dry reach' is weather the operational flood variability will be enough to maintain channel shape and form. This reach bedrock dominated with riffle and rapid habitat, important for rhithronic and eupotamonic lithophilic species and might experience some sedimentation due to reduced flood variability.	✓	✓	✔
Reproductive triggers	Relate to a wide range of flow variation, but will most notably be affected by the delayed onset of the wet season flows. During the Bumbuna Extensions operational flows the wet season reproductive triggers will only occur from July, a six-week delay from natural conditions. This is likely to affect the reproductive success of fish breeding between May and August (**Figure 12-7**). The sections of the river that will be affected are represented by SL5, SL6, SL7 and SL8. **Figure 4-5 C** and **D** predicts a recovery in reproductive triggers associated with the onset of the wet season downstream of SL9.	✗	✗	✔
Seasonal predictability	Seasonal predictability relates to the annual wet and dry cycles and are important for life history patterns such as spawning and recruitment. During the Bumbuna Extensions operational flows will result in an attenuation of flows (i.e. less variability) but will retain a predictable wet and dry cycle (**Figure 4-4**). The seasonal flows relate to specific instream habitat conditions, which in turn select for species with preferences or tolerances	✓	✓	✓

Functional Flow Requirement	Conclusion and Comment	SL5 ('dry reach')	SL6, SL7, SL8	SL9, SL10
	for these conditions (**Figure 4-2** and **Figure 4-3**). It follows that even if seasonal predictability is retained some habitat constraints associated with decreased or increased flows may impact on fish assemblages. For example, the prevailing habitat under the Bumbuna Extension operational flows may not consist of enough FI, FS and FVS habitat to accommodate the requirement of rhithronic or smaller eupotamonic lithophilic species during the dry season, while the permanent increase in FD and SD habitat may also impact on dry season spawners or specialised cichlids such as *Coelotilapia joka.* The permanent increase in baseflows will affect the entire downstream reach, but the effects of the attenuated flow variability will improve downstream of site SL9.			
Change in baseflows	Baseflow during the dry season (February to May) maintains habitat and facilitate recruitment. For the 'dry reach' operational flow of 6 m^3s^{-1} will remain within the natural dry season baseflow variation (2 to 13 m^3s^{-1}). This functional flow requirement will thus be met for the 'dry reach'. The river downstream of the Bumbuna Extension tailrace will experience a permanent increase in dry season baseflow (to 78 m^3s^{-1}) well outside the natural flow variation for this period. Most of the ecological implications of this are discussed under *Seasonal Predictability* above, but an additional implication of increase baseflows relate to the dry season breeders (**Figure 12-7**). The main consideration relates to habitat suitability for dry season spawners associated with increased baseflows. Of which *Heterotilapia buttikoferi*- LC (a regional endemic genus) is the most notable. With a preference for slow relatively shallow flowing water over rocky substrate.	✓	✗	✗
Droughts	Droughts contribute to habitat complexity and biotic diversity. although the relationship between drought intensity, frequency and duration and aquatic biodiversity is poorly defined and it is highly uncertain how the large decrease in droughts under future operational flows will influence fish assemblages. The entire river downstream of the existing Bumbuna Reservoir will not experience flows resembling natural droughts. However, this have presumably been occurring (to some extent), due to the existing operation of Bumbuna I and the implication of this on the instream ecology is accounted for in the baseline EcoStatus assessment.	✗	✗	✗
✓	Functional flow present			
✓	Functional flow partially present			
✗	Functional flow abcent			

Table 4-18: Fish Assemblage Integrity

Sampling points	Location in Relation to Bumbuna Reservoir I	Baseline Apr-18	Predicted change - Bumbuna Reservoir II	Remarks on change in Fish assemblage
SL3	Upstream	B	B	Will remain unchanged.
SL2	Upstream	B	B	
SL1	Upstream	B	E	Some digression from the reference fish assemblages were observed for the Paleopotamonic (*Clarias anguillaris, C. buettikoferi* and *Ctenopoma kingsleyae*) and Plesiopotamonic guilds (*Epiplatys fasciolatus* and *Heterobranchus isopterus*) under baseline conditions. The digression may be attributed to sampling effort. Fish representing the eupotamonic lithophilic (*Labeobarbus sacratus*, and *Labeo parvus*), parapotamonic (*Enteromius* species of which *Enteromius liberiensis* is EN) and rhithronic (*Amphilius* species and *Chiloglanis occidentalis*) guild are expected to decrease during operations, due to the inundation. Eupotamonic riparian, eupotamonic benthic and paleopotamonic species are likely to dominate the fish assemblages under inundated conditions. These most notably represent Cichlids such as *Coptodon louka* and Alestids such as *Brycinus longipinnis*. The subsequent predicted change in fish assemblage integrity is a drop from a 'B' category to an 'E'.
SL5	Downstream	D	D	During operation the 'dry reach' (represented by SL5) will receive a constant flow of 6 m^3s^{-1}. At this discharge the active channel will be approximately 18 m wide of which more than 50% will be occupied by FD, FI and FS habitat units (**Figure 4-2**). The representation of fast habitat units is typically more important for sustaining sensitive rheophilic invertebrate and fish species. These conditions will be enough to maintain some feeding and breeding habitat for rhithronic species. But may not be enough to provide spawning habitat for more sensitive migrating fish belonging to the eupotamonic lithophilic guild. The baseline fish assemblage integrity for this reach is a 'D' category. A review of the environmental preferences of the sampled and expected species indicate hydrology as the main reason for the decrease in fish assemblage integrity under baseline conditions. Most of the flow sensitive fish were absent, despite ample structural habitat (cover) available. The proposed operational flows will provide more constant habitat for rhithronic species but will not provide enough spawning habitat for lithophils or feeding habitat for some of the expected demersal species. If the predicted fish assemblages are corrected for the anticipated change in flow the ecological integrity remains in a 'D' category during operations.

Sampling points	Location in Relation to Bumbuna Reservoir I	Baseline Apr-18	Predicted change - Bumbuna Reservoir II	Remarks on change in Fish assemblage
SL6	Downstream	D	D	The change within instream habitat associated with the reach downstream of the Bumbuna Extension HEP can roughly be approximated for the Upper foothills and transitional sections from **Figure 4-2**. Similarly, the flow-habitat relationship for the lowland sections can be estimated form **Figure 4-3**. The operational flow of 78 m^3s^{-1} will results in a channel width of about 110 m wide over the Upper foothill habitat, of which 65% will be FD and 15% will SD. At this discharge availability of FI and FS (required for smaller rhithronic species) are constraint to about 10% of the channel. Although expected, most of the more sensitive rhithronic and eupotamonic lithophilic species were absence during the April 2018 baseline assessment within the river reach downstream of the existing Bumbuna operations. Sites SL5 and SL6 reflected the largest digression from refence assemblages and fell in a 'D' category. Site SL7 improved to a 'C' category indicating a recovery in hydrological impacts associated with the existing Bumbuna operations. Site SL8 decreased again to a 'D' category, but this may be related to sampling constraints or possible impacts associated with the large Magburaka settlement. Sites SL9 and SL10 recovered to a 'C' category. As a broad trend, the baseline fish assemblages were consistent with the invertebrate results and reflected a greater hydrological impact within the Upper foothills and lowland aquatic habitats represented by SL5, SL6, SL7 and SL8 and improved assemblages at SL9 and SL10. The fish assemblages during operations of the Bumbuna Extensions are expected to reflect a similar recovery based on the correction in functional flow requirements approximated in **Section 4.3.3**, **Figure 4-4 C** and **D**. The predicted changes within fish guild assemblages were informed by the degree to which functional flows and habitat requirements will be met during future operational flows. Functional flows related to dispersal and reproductive triggers will be affected for the lowland habitat represented by SL6, SL7 and SL8, while dry season baseflows will increase with the entire length of river downstream of the Extensions. The disparity between observed and predicted fish integrity scores are greater for sites SL6, SL7 and SL8 compared to that of SL9 and 10, as more of the functional flow requirements will be altered during future operations. However, it is likely that residual fish assemblage integrity categories for the entire downstream reach will fall into a 'D' category.
SL7	Downstream	C	D	
SL8	Downstream	D	D	
SL9	Downstream	C	D	
SL10	Downstream	C	D	

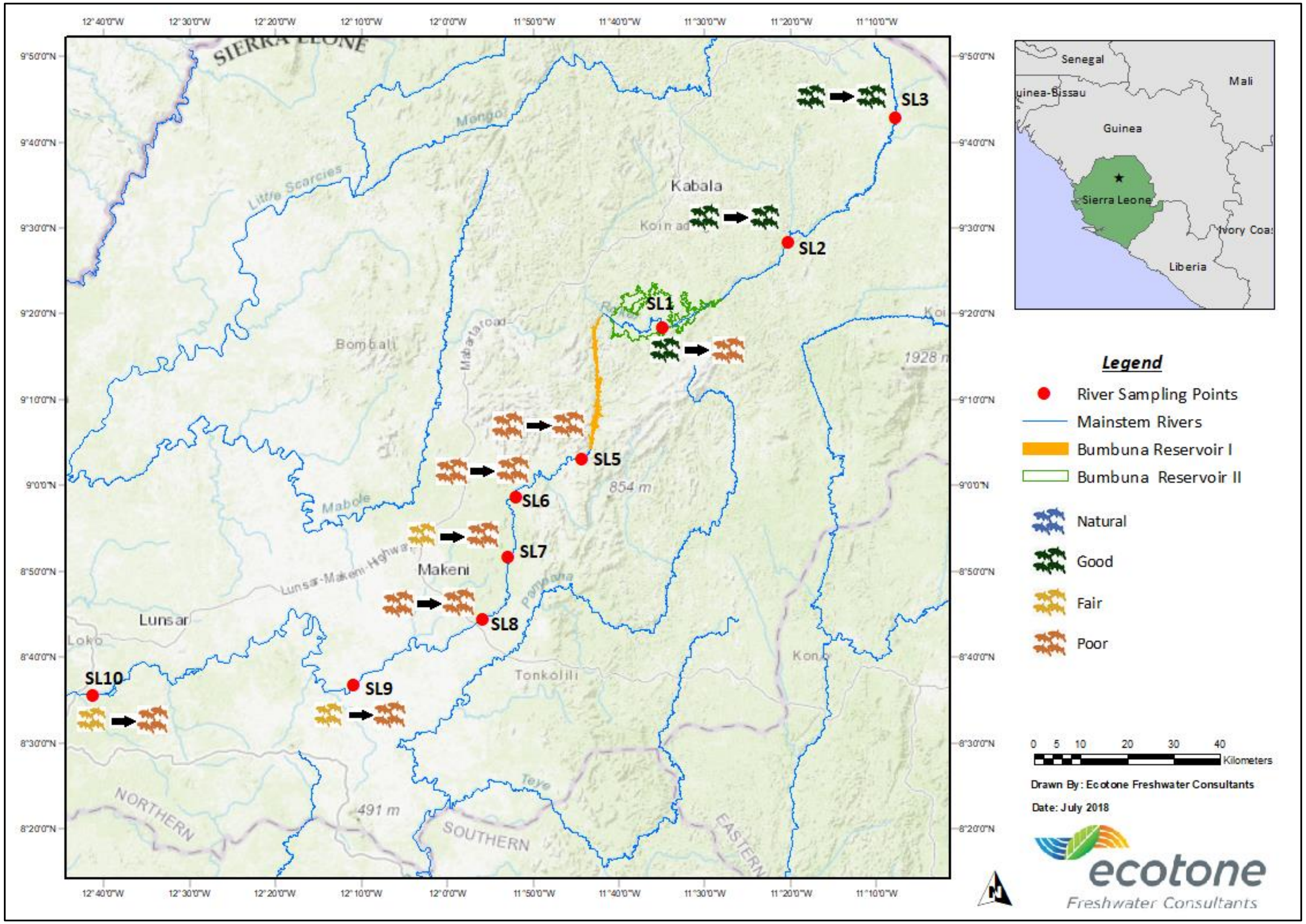

Figure 4-14: Map illustrating the baseline and modelled ecological categories for the fish community assemblages following the construction of Bumbuna II and the new hydrological regime.

4.4. CONSERVATION SIGNIFICANCE

Conservation significance was assessed in terms of the EIS and the IFC PS 6 Critical Habitat Assessment for instream conditions. **Table 4-19** provides a comparison of the criteria associated with each method for determining conservation significance. The EIS scores additional aspects are not considered within the Critical Habitat (CH) assessment (**Table 4-19**). The implications of the proposed Project in relation to both metrics need to be considered.

Table 4-19: Comparison between the IFC PS6 Critical Habitat Assessment and the Ecological Importance and Sensitivity Assessment

Ecological Importance and Sensitivity	IFC PS6 Critical Habitat
Habitat for rare or Endangered species	Habitat of significant importance to CE and/or EN species
Habitat for population of unique species	Habitat of significant importance to endemic and/or restricted-range species
Species/taxon richness	NA
Diversity of habitat types and features	Highly threatened and/or unique ecosystems
Habitat important for migration/breeding	Habitat supporting globally significant concentrations of migratory species and/or congregatory species
Habitat with species sensitive to water quality	NA
Habitat with species sensitive to changes the natural hydrological regime	NA
Habitat with specific flood storage, energy dissipation and water quality improvement functions	NA
Legally protected habitat	Legally protected habitat
Functional ecological integrity	NA
NA	Areas associated with key evolutionary processes

4.4.1. ECOLOGICAL IMPORTANCE AND SENSITIVITY

The ecological importance of a river is an expression of its importance to the maintenance of biological diversity and ecological functioning on both a local and wider scale (Kleynhans, 1999). Ecological sensitivity refers to the capacity to which a system can resist disturbance and its ability to recover from disturbances once they have occurred (Resh *et al.,* 1988; Milner, 1994). Both abiotic and biotic components of the system are taken into consideration in the assessment of ecological importance and sensitivity. **Table 4-19** provides details of the different components included within the EIS and a justification for the scores assigned to each component.

Table 4-20: Ecological Importance and Sensitivity scores and confidence levels associated with each site assessed. RATINGS VARY from 1 (low) to 4 (high)

Determinant	Score				Reason
	Source Zone (SL3)	Upper Foothills (SL1, SL2, SL5)	Lowland (SL6, SL7, SL8, SL9) and Rejuvenated Foothills (SL10)	Confidence	
Rare and endangered species	4	4	4	3	*Epiplatys njalensis* is (EN) and restricted to the lowland tributaries. *Epiplatys njalensis* have not been sampled during the April 2016 Assessment. *Marcusenius meronai (*EN) is known from two rivers (Bagbé and Rokel rivers). This species has been sampled by Payne at Upper Foothills and Lowland habitat reaches. *Marcusenius meronai* was sampled at sites SL1, SL2 and SL5 during the April 2018 assessment (**Table 12-7**). *Enteromius liberiensis* (EN) associated with the tributaries of the Seli River within the Upper foothill and Source zones. *Enteromius liberiensis* have not been observed within the main stem Seli River during the April 2018 assessment, but are considered here as tributaries within the inundation zone of the proposed Yiben Reservoir might be affected. This assessment did not include aquatic macrophytes, but in the context of the EIS *Ledermanniella yiben* (CR) is considered. *L. yiben* is known from a single location (SL1) within the Upper foothills habitat unit of the Seli/Rokel River and contribute notably to the overall EIS of this reach. Several translocations and seeding programmes are being conducted as part of the EMP for *L. yiben*.
Populations of unique species	2	2	2	2	The Seli/Rokel aquatic biota are characteristic of the Northern Upper Guinea ecoregion. The area has a moderate to high regional level of endemism estimates it at 42% (refer to **Section 12.2.1** in **Appendix 12**). The endemic species are represented in the Upper Foothills and Lowland habitat units of the Seli/Rokel River, but are not endemic to the river.
Species / taxon richness	1	3	3	2	The Upper foothills and the lowland habitat units share a large portion of the fish assemblages. However, the contribution of the exclusively Upper foothills species to the overall species richness of the Seli/Rokel Rivers are notably less compared to the lowland unit. The invertebrate taxon richness did not reflect meaningful differences between the upper and lower reaches (except for the source zone). Within a larger context, the species richness of the Seli/Rokel River is comparable to that of similar rivers within the ecoregion.
Diversity of habitat types or features	1	3	3	3	Diversity of habitat types and features relate to the distribution of geomorphological structure, vegetation and flow in each habitat unit. The Upper foothills reflect a more diverse distribution of different velocity depth classes compared to the Lowland units (refer to figure and figure- habitat graphs). However, the Lowland section intermittently expresses channel slope adjustments (characterised by riffle rapid sections) comparable to the Upper foothills habitat. The lowland reaches also reflects well development floodplain features on areas associated with the coastal plain (downstream of Magburaka). The habitat features associated with the different aquatic habitat units are not unique on a local or larger scale.
Migration/breeding and feeding site for wetland species	1	2	3	2	A large portion of the expected fish assemblages have some breeding requirement relating to migration. However, longitudinal migration is more pronounced then lateral (floodplain migration) for the Upper foothills and the Lowland habitats. Some variation in migration/breeding importance

Determinant	Score: Source Zone (SL3)	Score: Upper Foothills (SL1, SL2, SL5)	Score: Lowland (SL6, SL7, SL8, SL9) and Rejuvenated Foothills (SL10)	Confidence	Reason
					between the different habitats relate to the spawning ground immediately downstream of Bumbuna Falls. Seasonal migrators moving upstream will be forced to breed downstream of the falls as it is a natural barrier. The structure of the habitat is suitable for lithophils (and more importantly eupotamonic lithophilic species such as *Labeobarus wurtzi* (LC) and *Labeo coubie* (LC), *Labeo parvus* (LC) and *Prolabeo batesei* (DD). Of these expected species L. *parvus* and *P. batesei* have been sampled within the Lowland unit during the April 2018 assessment. The structure of the instream habitat in the reach below the falls is not unique and can also be found further downstream, particularly at areas where there are steeper slope adjustments within the Lowland habitat unit. However, migrating fish will follow the main flow path until suitable habitat is reached, and it is thus unlikely the fish moving upstream will return to more suitable spawning habitat once passed. Even a small annual decrease in breeding success may compound over time to have a sizable impact on fish assemblages. For this reason, the Lowland habitat is assigned a higher importance score for the migration/breeding aspect.
Sensitivity to changes in natural hydrological regime	1	4	3	2	The Upper foothills and Lowland units consist of fish and aquatic macroinvertebrates sensitive to flow changes. A near equal representation of expected fish intolerant or moderate intolerant to hydrological changes occur between the Upper and Lowland habitats. The more sensitive species include *Amphilius rheophilus* (LC), *A. atesuensis* (LC), *Amphilius platychir** (LC), *Chiloglanis occidentalis** (LC), *Leptocypris guineensis* (NT), *Mastacembelus liberiensis** (LC), *Prolabeo batesi** (DD), *Raiamas nigeriensis* (NT), *R. scarciensis* (DD) and *R. steindachneri** (LC). Species marked with an * have been sampled during the April 2018 assessment. Most of the sampled species were located within the Upper Foothills habitat upstream of the existing Bumbuna Reservoir (represented by SL1 and SL2). Overall, the Upper foothills are assigned a higher sensitivity score due to the specific hydraulic requirements associated with *Ledermanniella yiben* (CR).
Sensitivity to water quality changes	2	3	2	2	The flow and water quality sensitive fish and invertebrates reflect a high degree of similarity. Three additional species that have been sampled are intolerant to changes in water quality. These include *Hemichromis bimaculatus* (LC), *H. fasciatus* (LC) and *Hepsetus odoe* (LC). The Upper hillslope habitat retained more of the invertebrate and fish species sensitive to changes water quality and is subsequently assigned a higher sensitivity score for this aspect.

Determinant	Score			Confidence	Reason
	Source Zone (SL3)	Upper Foothills (SL1, SL2, SL5)	Lowland (SL6, SL7, SL8, SL9) and Rejuvenated Foothills (SL10)		
Flood storage, energy dissipation and particulate/element removal	1	2	4	2	The Upper foothills are relatively entrenched. The Lowland habitat express more defined floodplain features and are likely to play a more important role in flood storage, energy dissipation and water purification.
Baseflow augmentation; dilution	1	4	2	3	The longitudinal discharge measurements during the April 2018 assessment reflected no augmentation of baseflow associated with the catchment between the existing Bumbuna Reservoir and SL10 (located near the estuary). Discharges were measured from the top to the bottom at SL2= $0.8 m^3s^{-1}$, SL1= $1.7 m^3s^{-1}$, SL5= $32.8 m^3s^{-1}$, SL7= $31.6 m^3s^{-1}$, SL8= $23.1 m^3s^{-1}$ and SL9= $29.6 m^3s^{-1}$. This implies that the Upper foothills play an important role dry season baseflow proportional to the Lowland contribution.
Protected Status Area	0	0	4	4	Neither Source, Upper foothills or Lowland habitat of the Seli/Rokel is associated with Protected areas. However, the Rokel River along with the Bankasoka River feeds into the Sierra Leone Estuary which is a Ramsar wetland. In line with the precautionary principle we increase in the conservation importance of the Lowland habitat unit as it contributes to the functional integrity of the Ramsar estuary (see **Section 2.1**).
Ecological Integrity	4	4	2	3	The Source zone and Upper foothills (upslope of the existing Bumbuna Reservoir) retain a high degree of ecological functionality and falls in 'B' EcoStatus categories. These sites are *Largely Natural*. Conversely, the Lowland reaches retain less functional integrity mainly due to the exciting Bumbuna I operations.
TOTAL	***18***	***31***	***32***		
Average	***1.6***	***2.8***	***2.9***		
MEDIAN	**1**	**3**	**3**		

Box 1: Interpretation of Median EIS scores

Ecological Importance and Sensitivity categories (Median)

Very high >3 and <=4

River habitat that is ecologically important and sensitive on a **national or even international** level. The biodiversity of these systems is usually very sensitive to flow and habitat modifications. They play a major role in moderating the quantity and quality of water of major rivers.

High 2 and <=3

River habitat that is ecologically important and sensitive. The biodiversity of these systems may be sensitive to flow and habitat modifications. They play a role in moderating the quantity and quality of water of major rivers.

Moderate >1 and <=2

River habitat that is ecologically important and sensitive on a provincial or local scale. The biodiversity of these systems is not usually sensitive to flow and habitat modifications. They play a small role in moderating the quantity and quality of water of major rivers.

Low/marginal >0 and <=1

4.4.2. Instream Critical Habitat Assessment

Note that the CH assessment only pertained to fish and the habitat units described within this assessment (see **Section 2.3**). **Table 4-21** provides the IFC Habitat Classification, the main considerations are outlined below:

- Of the expected and sampled species, *Enteromius liberiensis, Marcusenius meronai, Epiplatys njalaensis* have an IUCN Red List status of EN. These species are relevant to Criteria 1 (EN and or CR species) and Criteria 2 (endemic and range restricted species) of the CH assessment and are discussed in **Table 4-21**.
- Sampled endemics potentially qualifying under the Tier 2 Threshold for Criteria 2 include: *M. meronai*. *Prolabeo bates* (DD) (Upper foothills and Lowland), *Petrocephalus levequei* (NT) (Lowland) and *Synodontis tourei* (NT) (Lowland). Although the latter two requires taxonomic verification. Several other fish endemic to the Upper Guinean region have also been sampled, but in general rivers in this ecoregion share a high degree of similarity in fish distribution and subsequently do not conform do the thresholds set out under Criteria 2.
- There is no evidence of congregatory species (Criteria 3), or highly threatened and/or unique ecosystems (Criterion 4).
- The Upper Guinean ecoregion appears to be important for speciation with five regional endemic genera and 42% of its total fish fauna also regional endemics. The exact drivers of this evolutionary process are not defined but likely dates to the isolation of this region from the Nile and Congo basins. The relatively wide distribution of endemic species also suggests that there are not key isolated features that drives speciation, but a rather broad regional nexus of drivers. It follows that the habitat units associated within the study area do not meet the conditions of key evolutionary processes under Criteria 5.

Table 4-21: Instream habitat classification in terms of the IFC PS 6 for habitat units assessed.

Habitat Unit/Type	IFC Classification	Remarks
Source Zone (SL3)	*Largely* Unmodified, Potential CH, Tier 2, Criterion 1	*Enteromius liberiensis* (EN) is known in Sierra Leone and Liberia, but exact limits are yet to be confirmed. Payne (2018) associated the species with upper tributaries of the Seli River. The species have not been observed during the field assessment, but the reach of river represented by SL3 is suitable for *E. liberiensis*. Subsequently the Source zone may potentially be classified under Tier 2 of criterion 1.
Upper foothills (SL1, SL2, SL5)	SL1 & SL2: *Largely* Unmodified, Potential CH Tier 2 Criteria 1 and 2 SL5: *Moderately* Modified, Potential CH, Tier 2 Criteria 1 and 2	*Marcusenius meronai*-EN have been observed at sites SL1, SL2 and SL5 in low abundances. This species is known from the Bagbé and Rokel rivers in Sierra Leone. The species qualifies as EN as the EOO and AOO are less than 5,000 km^2 and 500 km^2 respectively. The sampling effort was not sufficiently quantitative to infer with confidence the proportional representation of Seli/Rokel *M. meronai* population. Accordingly, this habitat unit is classified as potential CH under Tier 2 of Criteria 1 and 2.
Lowland (floodplain) (SL6, SL7, SL8, SL9)	*Moderately* modified Potential CH Tier 2 Criteria 1 and 2	Payne (2010) recorded *M. meronai* near Magburaka at site SL8. This species has a low background frequency of occurrence and may have been missed during the April 2018 assessment. *Petrocephalus levequei* (NT): extent of occurrence and area of occupancy are close to meeting the thresholds for Vulnerable (at less than 20,000 km^2 and 2,000 km^2 respectively) and is found in fewer than 10 locations. In line with the precautionary principle the habitat unit is classified as potential CH under Tier 2 of Criteria 1 and 2.
Rejuvenated foothills (SL10)	*Moderately* modified Potential CH Tier 2 Criteria 1 and 2	*Epiplatys njalaensis*-EN included in this report. However, this species is restricted to fewer than five locations, in small lowland streams associated with Little Scarcies, Mabola/Tabai and Rokel system (Payne 2018). Small Lowland streams will not be affected by the proposed operations. The species is thus not included in this CH assessment. *Marcusenius meronai* have not been observed during the April 2018 assessment, but may potentially occur within the Rejuvenated foothills associated with SL10 and this habitat unit is assessed as potential CH under Tier 2 of Criteria 1 and 2.

5. MANAGEMENT CONSIDERATIONS

5.1. INUNDATION ZONE

The inundation zone will affect a large portion of the Upper foothills habitat. This habitat is in a *Largely unmodified* state and have a relatively high conservation importance. The change in habitat will result in a change in fish assemblages from reference conditions. The species of conservation importance include *M. meronia*- EN and *E. liberiensis* EN. The habitat preferences associated with these species are not restricted to the Upper foothills and they may occur well outside the range of the inundation zone. The expected changes within the habitat template after inundation is also not inconsistent with the habitat preferences associated with these species and it is possible that they may occur within the inundation zone. Payne *at al*. (2010) sampled *M. meronia* within the existing Bumbuna Reservoir.

The anticipated change within baseline fish assemblages is summarised below:

- A shift from riverine migratory species towards more resident substrate spawners (*Sarotheodon* and *Coptodon*).
- An increase in microphagous herbivores and omnivores (*Sarotheodon*, *Clarias* and *Brycinus*).
- The leaf-chewing tilapias (*Sarotherodon occidentalis*) depend upon marginal vegetation or leaves falling into the water from the fringing forest and will recruit around the margins of the inundation zone.
- *Coptodon louka* and *Hemichromis fasciatus* (substrate nest builders) will be able to exploit reservoir margins and inlet areas provided shallow sandy habitat is available. However, these areas may be sensitive to the drawdown, which may leave the nests dry.
- Migrating species such as *Barbus sacratus*, and mormyrids, will be confined to the shallow benthic areas around the rim of the reservoir and will retreat to the tail of the reservoir and up into the headwaters or side streams to spawn. The reproductive and spawning areas are likely to be reduced and they will also be very vulnerable to fishing.
- The lake environment will provide habitat for *Oreochromis niloticus*. This species is an invader that is likely to outcompete species occupying the same trophic position. *Oreochromis niloticus* is often favoured in aquaculture for its rapid growth and has been sampled in an aquaculture pool near the existing Bumbuna Reservoir.

The drawdown will be the most important fish habitat management consideration during operations. A large, rapid or variable drawdown will influence the recruitment of vegetation along the margins of the reservoir or may impact on spawning success of fish utilising the marginal zone. Successful recruitment and exploitation of the new lake environment by some of the species mentioned above should translate into some fisheries potential. Generally, reservoirs are l more productive compared to their pre-impounded conditions.

Payne *et al* (2006) also note that a further positive benefit of the environmental changes will be a reduced exposure to Onchocerciasis. The blackfly, Simulium, however is closely associated with what water turbulence and rocky conditions for its larvae to exist in rivers. The elimination of these by flooding the reservoir should reduce or eliminate blackfly occurrence in the vicinity.

5.2. ‘Dry Reach’

The ‘dry reach’ represents a portion of the Upper foothills habitat unit. This portion of the Upper foothills habitat is *Moderately* modified and potential CH. Additionally, the ‘dry reach’ also provide potential spawning ground for some of the migrating species (*Labeobarbus* and *Labeo*) as well as the rheophiles (*Amphilius and Chiloglanis*). Under the proposed discharge during operations the overall EcoStatus is likely to remain comparable to baseline conditions. However, **Table 5-1** represents an assurance table for a modified flow series based on habitat availability (**Figure 4-2**), and different functional flows (**Figure 4-5**) to manage the ‘dry reach’ in a higher ecological state, from a baseline EcoStatus of *Moderate* to an proposed operational status of *Good*. For details on the ‘dry reach’ EWA see **Section 13.2.1.**

Provided the assurance table for ‘B’ level of ecological protection can be feasibly achieved within the operational design, the ecological benefits will include:

- A net increase in Upper foothill habitat downstream of the Bumbuna Extensions. A large portion of the Upper foothills habitat will be modified as it falls within the inundation zone of the Yiben Reservoir. Improving the condition of similar habitat associated with the ‘dry reach’ provides the opportunity to retain some proportional representation of Upper foothills habitat in compensation for the decrease in similar habitat within the inundation zone.
- A gain in ecological goods and services associated with a higher level of ecological functioning. This will most notably be expressed in maintaining the biodiversity associated with this habitat unit.
- Providing additional spawning ground and refuge for the obligate migrators will benefit the proportional representation of these species within the fish assemblages for the entire downstream reach.
- Maintaining a hydrological regime comparable to the natural regime, is likely to improve the hydraulic conditions required for the successful translocation of *L. yiben*.

Table 5-1: Assurance table for managing the 'dry reach' one category up into a *Good* ('B') EcoStatus. Values are provided in m^3s^{-1}

	B Category									
Percentile	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**99**
Oct	43.756	40.764	38.609	36.735	35.159	33.859	32.798	31.937	31.237	30.719
Nov	29.603	28.591	27.154	26.164	24.696	23.687	22.616	22.181	22.171	21.753
Dec	23.903	23.505	22.256	21.523	20.063	19.119	17.973	17.470	17.466	16.884
Jan	19.210	19.207	18.648	18.090	16.687	15.759	14.455	14.314	14.291	13.892
Feb	8.442	7.373	7.248	6.937	6.297	5.859	5.436	5.424	5.412	5.373
Mar	5.762	5.234	5.175	4.867	4.284	3.840	3.252	2.889	2.879	2.834
Apr	5.372	5.011	4.606	4.135	3.616	3.157	2.719	2.378	1.927	1.277
May	7.340	6.833	6.177	5.784	5.129	4.610	3.835	3.196	2.737	2.324
Jun	15.304	14.110	12.589	10.749	9.221	8.172	7.241	6.605	6.047	4.778
Jul	22.320	22.279	21.372	20.246	18.461	17.073	15.231	14.162	13.109	11.355
Aug	31.278	31.269	30.427	29.249	27.787	26.902	25.824	25.069	25.032	24.098
Sep	39.040	38.329	36.697	35.235	34.568	34.556	34.545	34.534	34.243	30.969

5.3. DOWNSTREAM OF BUMBUNA EXTENSION HEP

The River downstream of the Bumbuna Extensions represent Lowland habitat, and Rejuvenated foothills. The upper part of the habitat unit (from Bumbuna to Magburaka) is relatively entrenched. Floodplain features become more prominent downstream of Magburake. The EcoStatus of the downstream river is *Moderate*, but reflect an improvement in habitat integrity, invertebrate assemblages and diatoms along a longitudinal gradient. Although *Modified* both habitat units are considered ecologically important and sensitive **(Section 4.4.1**).

The anticipated impact during operational flows will have a longitudinal gradient of intensity, with most of the functional flows recovered downstream of SL9. One exception is an increase in dry season baseflows which will be experienced for the length of the Rokel River. During operations the overall EcoStatus will remain comparable to that of baseline conditions, although functional habitat integrity and fish assemblages will be affected more notably and over a greater extent than other ecological components such as diatoms and invertebrates. The flow alteration is not likely to impact the specific species of conservation concern discussed in **Section 0**.

As with the 'dry reach' it is possible to improve the ecological integrity within these habitat units through managing the hydrology. **Figure 5-1** provide an example time series period of 'Higher Flows EWR' compared to natural and the proposed Bumbuna Extension flows (note that where the red lines cannot be seen they are in the same place as the green lines). By constraining releases, to varying degrees, during the natural dry period (from February to May) the following functional ecological flows can be retained:

- Dry season habitat diversity will improve for the entire downstream reach. This will allow for the recruitment of species with specific habitat requirements (such as *Amphilius atesuensis*-LC, *Chiloglanis occidentalis*- LC *Labeo coubie*- LC, *Labeobarbus wurtzi*- NE, *Leptocypris guineensis*- NT, *Mastacembelus liberiensis*- LC, *Prolabeo batesi*- DD, *Raiamas nigeriensis*- NT).
- Retaining a more defined dry season will also benefit the dry season breeders such as *Brycinus macrolepidotus*- LC, *Coptodon louka*- LC, *Heterotilapia buttikoferi*- LC and *Sarotherodon occidentalis*- NT.
- Dispersal and reproductive triggers will be retained by the more pronounced difference in discharge between the dry and wet periods. Similarly, negative impacts associated with a delay in the onset of the wet season will be mitigated. Genera likely to benefit from this include *Brienomyrus*, *Chrysichthys, Clarias anguillaris, Leptocypris, Marcusenius, Petrocephalus, Raiamas, Synodontis.*

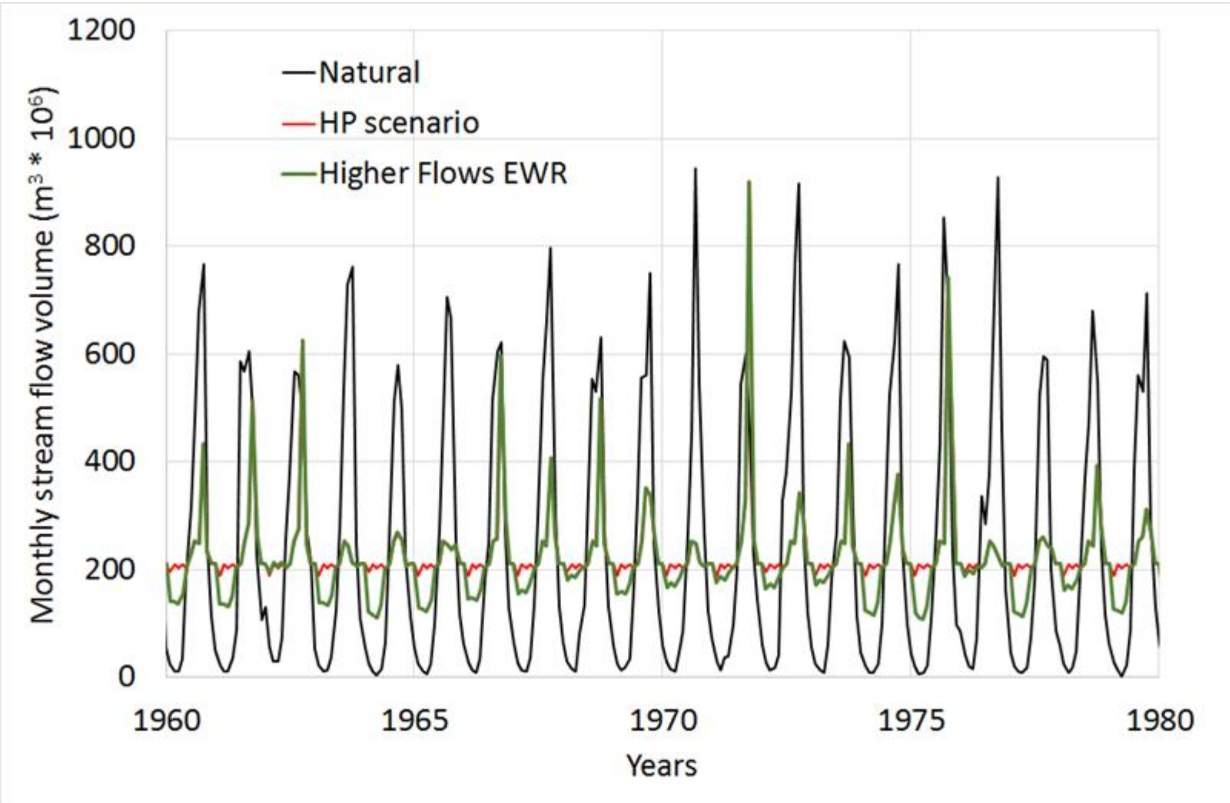

Figure 5-1: Example time series period of 'Higher Flows EWR' compared to natural and Bumbuna Extensions downstream hydro-power releases (note that where the red lines cannot be seen they are in the same place as the green lines).

6. CONCLUSION

The aim of the assessment was to define instream aquatic habitat associated with the study area and to ascertain how these habitats relate to 'natural' conditions. In addition, the assessment aimed to illustrate the conservation significance of the different habitat units regardless of modification. Four main habitat units were defined, these included the Source zone, Upper foothills, Lowland and Rejuvenated foothills. **Table 6-1** provides conclusions for this assessment in relation to the conservation importance of the potential impacts that may result during the proposed operations.

Table 6-1: Conclusions and impacts in relation to the Ecological Importance and Sensitivity and the instream Critical Habitat Analysis

Ecological Importance and Sensitivity	IFC PS6 Critical Habitat	Conclusion	Impact
Habitat for rare or EN species	Habitat of significant importance to CE and/or EN species	All the habitat units provide habitat or potential habitat for species of conservation importance: • *Epiplatys njalaensis*- EN (not sampled, but potentially associated with tributaries of the Lowland unit) • *Enteromius liberiensis*- EN (not sampled, but potentially occurring in the Source zone and tributaries associated with the Upper foothills) • *Marcusenius meronai*-EN (sampled Upper foothills and Lowland units).	At risk is *M. meronai*-, which was sampled within the inundation zone and above it as well as downstream of the existing Bumbuna Reservoir. The expected changes in flow does not violate habitat requirements associated with the species of conservation concern. The habitat requirements associated *M. meronai* will be met during operations within parts of the inundation zone and within the downstream reaches. However, a delay in the functional flow required for a migrating and breeding cue will be experienced within a portion of the Lowland habitat (between SL5 and SL9). The degree to which this may influence the breeding success of this species within this reach is not known, but the habitat will remain suitable for refuge and feeding. *M Marcusenius meronai* is not restricted to the Lowland habitat unit.
Habitat for population of unique species	Habitat of significant importance to endemic and/or restricted-range species	Sampled endemics qualifying under the Tier 2 Threshold for Criteria 2 include: • *M. meronai* • *Prolabeo bates*- DD (Upper foothills and Lowland) • *Petrocephalus levequei*- NT (Lowland, sampled but taxonomic verification required)	The functional integrity of habitat within the inundation zone will decrease. However Upper foothill species are likely to recruit and utilise marginal habitat while migrating along the sides of the reservoir and breeding at the inflow and upstream thereof.

Ecological Importance and Sensitivity	IFC PS6 Critical Habitat	Conclusion	Impact
		• *Synodontis tourei*-NT (Lowland, sampled but taxonomic verification required) Potentially occurring endemics potentially qualifying under Tier 2 Threshold for Criteria 2: • *Enteromius liberiensis*-EN • *Leptocypris guineensis*-NT (Lowland) • *Raiamas scarciensis*-NT (Upper foothills and Lowland) • *Synodontis levequei*-NT.	The instream habitat requirements for the Lowland endemics will not be negatively affected, but functional flows related to migrating and breeding cues will be impacted for the reach between SL5 and SL9. Actual breeding habitat within the affected reach will not be affected.
Species/taxon richness	NA	Invertebrate and fish assemblages reflect some overlap between the different habitat units. However certain fish species only occur within the Upper foothills: • *Amphilius rheophilus*- LC • *Amphilius platychir*- LC • *Enteromius leonensis*-LC • *Enteromius liberiensis*-EN • *Labeobarbus sacratus*-NE. While approximately 45 fish species only occur within the Lowland area. The most notable Lowland species are listed below. • *Ichthyborus quadrilineatus*-NT (sampled) • *Leptocypris guineensis*-NT • *Synodontis levequei*- NT • *Synodontis tourei*-NT (sampled).	Rheophilic and semi-rheophilic species will be displaced within the inundation zone and replaced with lake loving species. Overall species richness is likely to remain relatively comparable to pre-impoundment conditions although a small decrease is possible. A possible decrease in Lowland species with a requirement to breed during the dry season (*Heterotilapia buttikoferi*-LC *and Sarotherodon caudomarginatus*- LC). And species that are sensitive to the onset of the rainy season (mainly species representing the *Chrysichthys*, *Marcusenius* and *Synodontis* genera). The former may experience some decrease in occurrence for the entire extent of the habitat unit, while the latter may be influenced in the reach between SL5 and SL9. It is unlikely that these species will be completely lost, but a decrease in their proportional representation within the fish assemblages may occur.

Ecological Importance and Sensitivity	IFC PS6 Critical Habitat	Conclusion	Impact
Diversity of habitat types and features	Highly threatened and/or unique ecosystems	None of the habitat units are considered highly threatened or unique ecosystems. The inundation zone will result in a decrease of Upper foothill habitat features specifically riffle rapid habitat. Increased baseflows will reduce dry season habitat diversity within the Lowland unit downstream of the Bumbuna Extension. The 'dry reach' will reflect a narrow-wetted perimeter, but with a diverse proportional distribution of different hydraulic units. However, temporal variation within instream habitat will be reduced.	The decrease in habitat diversity will not result in a loss of threatened or unique ecosystems. Decrease in riffle-rapid habitat will influence rheophilic and semi-rheophilic species within the inundation zone. This may influence the breeding success of dry season spawners and the recruitment of rheophilic species which prefer FI and FS habitat. The decrease in temporal variation will leave less habitat for wet season spawners and less seasonal nursery areas. The extent of the 'dry reach' is limited to about 4 km. Currently the ecology of the 'dry reach' is dominated by peaking generation and an improvement in fish and invertebrate assemblages is likely if peaking stops. This may offset the lack of seasonal variation during the operations.
Habitat important for migration/breedi ng	Habitat supporting globally significant concentrations of migratory species and/or congregatory species	None of the habitat units support globally significant concentrations of migratory or congregatory fish species. However, most of the fish and some invertebrates (members from the family Corbiculidae) require seasonal upstream migration. The bulk of these species occur within the Lowland unit. The Bumbuna Falls is expected to be a natural migration barrier and because of this the reach below the Falls provide spawning grounds for riffle and rock spawning migrants as well as for resident rheophiles.	Longitudinal migration will not be impacted within the Lowland unit (i.e. no additional physical obstruction will occur during operation). While a few of the Upper foothill migrators are expected to migrate and spawn up the Mawoloko River. Note that the steep slope adjustments at site SL1 is also considered a natural migration barrier. The 'dry reach' encompasses a portion of the area downstream of the Falls, which may be important for spawning. Some of this habitat will be available for spawning, but it will be notably reduced from baseline conditions. Many of the expected riffle rapid spawners (*Labeo* and *Labeobarbus* species) and the rheophilic species *(Amphilius and Chiloglanis* species) have been lost, within this reach, due the current operations of Bumbuna 1

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Ecological Importance and Sensitivity	IFC PS6 Critical Habitat	Conclusion	Impact
		Lateral migration (i.e. movement into floodplain zones) is not expected as an important consideration as the Upper foothills and a large part of the Lowland units do not have well developed floodplain features. Some of the sampled and expected invertebrate and fish fauna are facultative floodplain spawners (such *Enteromius*, *Synodontis* and *Hydrocynus* species), but no obligate floodplain spawners occur within the Seli/Rokel River.	HEP. An additional impact is thus not expected, but some recommendations are made to improve the baseline ecology of the reach during Bumbuna Extensions operations Floodplains within the lower parts of the Lowland unit are likely to be activated less frequently and for shorter periods. However, a large digression from this has already been observed during the baseline assessment with substantial channel incision within the lower parts of the Lowland unit (SL9). In addition, it is highly likely that any residual requirements for floodplain habitat will be met by the presence of annual flood benches (terraces) that will not be affected during operations.
Habitat with species sensitive to water quality	NA	General water quality is *Fair* to *Good* for the entire system. Several diatoms, invertebrates and fish have been sampled within all reaches that are sensitive to water quality. However, the expected richness of taxa sensitive to water quality is greater for the Lowland unit.	The eutrophication risk assessment along with baseline observations of water quality downstream of the existing Bumbuna Reservoir did not indicate an additional risk to species sensitive to water quality. Some initial nutrient releases are expected for a short period after inundation. However, these releases will be well below the thresholds for changing the trophic classification downstream habitat. The Bumbuna Extension HEP intake will be a surface intake with water temperatures and dissolved oxygen levels expected to be within thresholds for maintaining downstream species sensitive to changes in water quality.
Habitat with species sensitive to changes the natural hydrological regime	NA	Baseline observations indicate that the portion of the invertebrate and fish assemblages, sensitive to changes within the hydrological regime are largely intact for the Upper foothills represented by SL1 and SL2.	The inundation zone associated with the Bumbuna Extensions will result in the complete displacement of flow sensitive taxa within the inundation zone, most notably: *Amphilius rheophilus* (LC), *A. atesuensis* (LC), *A. platychir* (LC), *Chiloglanis occidentalis* (LC) and *Mastacembelus liberiensis* (LC). While other species such *Labeobarbus sacratus* (DD) may be partially displaced but will still

Ecological Importance and Sensitivity	IFC PS6 Critical Habitat	Conclusion	Impact
			be able to occupy reservoir margins and migrate upstream and into tributaries.
		Conversely, assemblages downstream of the existing infrastructure reflect a *Moderate* to *Large* decrease in species sensitive to flow alteration. The diatoms are less flow dependant and thus controlled for water quality. The conclusion is that changes from the natural hydrological regime, due to the existing Bumbuna operations, dominate the downstream ecology and resulted in a decrease (and in some instances a loss) of flow sensitive species.	For the reach downstream of the Bumbuna Extension tailrace a decrease in the frequency of occurrence is expected for the dry season breeders, most notably (*Sarotherodon occidentalis*- NT). And species dependent on the early wet season flows (some of which are NT and have been sampled: *Petrocephalus levequei* and *Synodontis tourei*). This impact will be naturally mitigated along a longitudinal profile. The instream habitat requirements for the latter species will still be met, but the functional cues for migration and breeding will be set back by about six weeks.
		The 'dry reach' will experience a more constant discharge with subsequently less temporal variation within instream habitat during the proposed operations.	It is likely that the aquatic invertebrates will respond positively to the stable habitat template, specifically to relatively increase in FS and FI habitat units under the proposed operational flow of 6 m^3s^{-1} within the 'dry reach'. It is also likely that there will be some new recruitment of resident rheophilic species (particularly in the absence of any pulsing/peaking within the reach). Conversely, the occurrence of migrating riffle/rapid spawners is likely to decrease within this reach due to a decrease in suitable spawning grounds.
Habitat with specific flood storage, energy dissipation and water quality improvement functions	NA	The indirect ecosystem services related to flood storage, energy dissipation and water purification is more pronounced for the Lowland unit than for the Upper foothills	The proposed Bumbuna Expansions will not influence the habitat capacity to retain floods, dissipate energy or purify water.

Ecological Importance and Sensitivity	IFC PS6 Critical Habitat	Conclusion	Impact
Legally protected habitat	Legally protected habitat	The habitat units assessed are not directly associated with legally protected areas. However, the Rokel and Bankasoka rivers feed into a Ramsar wetland (the Sierra Leone Estuary).	Given that there will be an annual flood regime during the operation of the Bumbuna Extensions and that variations from the natural regime will be corrected by the normal annual cycle through the lower catchment there is no reason to think that the Estuarine functionality will be significantly affected.
Functional ecological integrity	(Habitat modification (Natural to Modified)	The integrated EcoStatus indicates the degree of ecological modification and thus the residual ecological functionality. The integrated baseline assessment showed that the Source zone and the Upper foothills (upslope of the existing Bumbuna Reservoir) are *Largely natural* (*Good*). The lower parts of the Upper foothills, the Lowland and the Rejuvenated foothills are in a *Moderately modified* (*Fair*) condition. The upper parts experience some localised channel bed and bank modification through artisanal gold mining and agricultural disturbances within the riparian areas. The modification within the Lowland reach may be attributed to flow alteration from the existing Bumbuna HEP, while lower parts are affected by commercial floodplain agriculture. Large settlements such as Magburaka on the banks of the Rokel, may also contribute to the observed ecological digression.	The portion of the Upper foothills habitat associated with the proposed Expansion inundation zone (Yiben Reservoir) will experience a decrease in EcoStatus from *Largely Natural* to *Moderately modified*. This will result in a net loss of natural habitat. The consequences for the individual ecological components relate to the transformation of riverine species to lake species and are discussed in other section of this table. The ecological functioning of the Upper foothill and Source zone habitat, upslope of the proposed inundation zone, will remain in a *Largely Natural* state. The reaches downstream of the Bumbuna Extensions will remain in an overall *Moderately modified* state. Some of the individual ecological components such as the habitat and fish assemblages' integrities are expected to decrease for most of the downstream area, while invertebrate assemblages may improve along the longitudinal profile of the Rokel River. A flow regime is provided for managing the 'dry reach' into a *Good* status. This will retain a more functional representation of the Upper foothills, downstream of the existing infrastructure. Similarly, the expected decrease in fish assemblage integrity for the River downstream of the Bumbuna Extension can be mitigated through constraining some of the proposed dry season

Ecological Importance and Sensitivity	IFC PS6 Critical Habitat	Conclusion	Impact
			flows (with varying degrees between February and May) to levels that will optimise dry season habitat diversity, and reinstate functional flows associated with early wet season migration and breeding cues. The ecological benefits of these constraints need to be contextualised with the financial and operational feasibility of the proposed Expansions.
NA	Areas associated with key evolutionary processes	A large portion (42%) of the expected fish species are regional endemics, many of which have been sampled. This suggests that the ecoregion drives speciation. However, the homogenous regional distribution of endemics indicates large regional processes such as regional isolation as the main driver of speciation rather than localised isolating features such as the Bumbuna Falls.	The proposed Project will impact on key evolutionary processes associated with fish speciation.

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8. Appendix A – Water Quality

8.1. Materials and Methods

8.1.1. *In situ* Analysis

In situ physico-chemical variables were measured during the aquatic surveys using a pre-calibrated multi-parameter water quality meter (**Table 8-1**). The water quality results were compared to benchmark criteria compiled by Kotze (2002) consisting of Target Water Quality Ranges (TWQRs - DWAF, 1996) and source water quality guidelines used by Rand Water (Steynberg *et al.*, 1996; Rand Water, 1998) (**Table 8-2**).

Table 8-1: In situ water quality parameters measured

***In situ* parameters**	**Abbreviation**	**Units**
pH	pH	[H^1+ ions]
Temperature	Temp	°C
Electrical Conductivity	EC	µS-cm^{-1}
Total Dissolved Solids	TDS	ppm
Time	T	24h

Table 8-2: Benchmark criteria for Ideal, Tolerable and Intolerable values for major ions (Kotze, 2002)

Parameter	**Ideal**	**Tolerable**	**Intolerable**
EC	< 450*	450 - 1000*	>1000*
pH	6.5-8.5#	5-6.5 & 8.5-9#	<5 & >9#
* = µS-cm^{-1}; # = [H^1+ ions]			

8.1.2. Laboratory Analysis

Water samples were collected at each site during the April 2018 survey and were transported to a South African National Accreditation System (SANAS) accredited laboratory (X Lab Earth [1]) for analyses (**Table 8-3**). The water quality laboratory results were compared to benchmark criteria compiled by Kotze (2002) consisting of Target

[1] **X LAB EARTH**, 259 Kent Ave, Ferndale, Johannesburg, 2194. South Africa. Telephone: + 27 (0)11 590 3000 and e-mail: christopher@xlab.earth. SANAS Accredited Laboratory, No. TO775

Water Quality Ranges (TWQRs - DWAF, 1996) and source water quality guidelines used by Rand Water (Steynberg *et al.*, 1996; Rand Water, 1998) (**Table 8-4**).

Table 8-3: Laboratory water quality constituents, abbreviations, and units used for the November 2017 assessment

Analyte Name	Units	Reporting Limit
Acidity as CO_2	mg/l	10
Bicarbonate Alkalinity as $CaCO_3$	mg/l	12
Bicarbonate Alkalinity as HCO_3	mg/l	12
Bicarbonate as $CaCO_3$	mg/l	12
Carbonate Alkalinity as $CaCO_3$	mg/l	12
Carbonate Alkalinity as CO_3	mg/l	12
M Alkalinity as $CaCO_3$	mg/l	12
P Alkalinity as $CaCO_3$	mg/l	12
Total Alkalinity as $CaCO_3$	mg/l	12
Conductivity in mS/m @ 25ºC	mS/m	2
TDS (0.7µm) @ 105ºC	mg/l	21
TSS (0.7µm) @ 105ºC	mg/l	21
Calcium	mg/l	0.5
Ca hardness as $CaCO_3$	mg/l	1.4
Iron	mg/l	0.05
Potassium	mg/l	0.2
Magnesium	mg/l	0.01
Mg hardness as $CaCO_3$	mg/l	0.05
Sodium	mg/l	0.5
Sulphur	mg/l	0.07
Total hardness as $CaCO_3$	mg/l	1.5
Chloride	mg/l	0.05
Nitrite	mg/l	0.5
Nitrite as N	mg/l	0.2
Nitrate	mg/l	0.1
Nitrate as N	mg/l	0.03
Sulphate	mg/l	0.05
Orthophosphate (Total Reactive Phosphorous or PO_4)	mg/l	0.25
Orthophosphate as P	mg/l	0.08
Mercury	µg/l	0.001
Ammonia	mg/l	0.012
Ammonia as N	mg/l	0.01

Table 8-4: Benchmark criteria for Ideal, Tolerable and Intolerable values for major ions (Kotze, 2002)

Parameter	Ideal mg/L	Tolerable mg/L	Intolerable mg/L
Ca	<150	-	>150
Cl	<50	50-150	>150
Mg	<70	-	>70
K	<50	50-400	>400
Na	<50	50-100	>100
SO_4	<80	80-500	>500

* = $\mu S\text{-}cm^{-1}$; # = [H^1+ ions]

8.2. RESULTS AND DISCUSSION

8.2.1. *IN SITU* ANALYSIS

The *in situ* water quality variables measured during the April 2018 assessment for the river and dam sites are shown in **Table 8-5** and **Figure 8-1** respectively, with the main points listed below:

- In general, the *in-situ* water quality at all the river sites was characterised by circumneutral pH values with low salt loads. The values recorded at all the sites fell within the benchmark criteria for aquatic freshwater systems (DWAF, 1996; Kotze, 2002).
- There was very little variation in both pH and salt loads between the sites on the Seli River (SL1-SL3 - **Table 8-5; Figure 8-1**). Site SL1, located furthest downstream, indicated slightly higher salt loads when compared to sites SL2 and SL3 (**Figure 8-1**). However, this value was still well within benchmark criteria (**Table 8-2**).
- The Rokel sites, downstream of Bumbuna Reservoir I (SL5-SL10) also reflected minimal variation between the six sites (**Table 8-5; Figure 8-1**) and all the values were within the benchmark criteria for aquatic freshwater systems (DWAF, 1996; Kotze, 2002).
- Spatially, the sites located downstream of Bumbuna Reservoir I(SL5-SL10), showed a slight increase in salt loads, with less variation in the pH values (**Table 8-5; Figure 8-1**). The Bumbuna Reservoir I showed slightly elevated salt loads and pH in the alkaline range, when compared to the upstream sites on the Seli River (SL1-SL3). This variation is expressed in the downstream sites (**Figure 8-1).**

Table 8-5: Water quality values for sites located on the Seli / Rokel River, April 2018

Variable	Unit	Upstream of Bumbuna Dam			Downstream of Bumbuna Dam					
		SL3	SL2	SL1	SL5	SL6	SL7	SL8	SL9	SL10
pH	[H^1+ ions]	7.30	7.32	7.24	7.32	7.73	7.60	7.62	7.20	7.67
EC	µS-cm^{-1}	82.7	82.4	98.3	124.7	120.7	120.8	116.4	118.8	117.5
TDS	ppm	41.4	41.2	49.2	62.4	60.4	60.4	58.2	59.4	58.8
Temperature	°C	28.6	27.5	22.7	25.2	29.4	29.4	31.2	29.8	30.0
Time	00:00	11:20	11:59	11:34	16:26	14:48	15:50	16:03	10:37	16:24

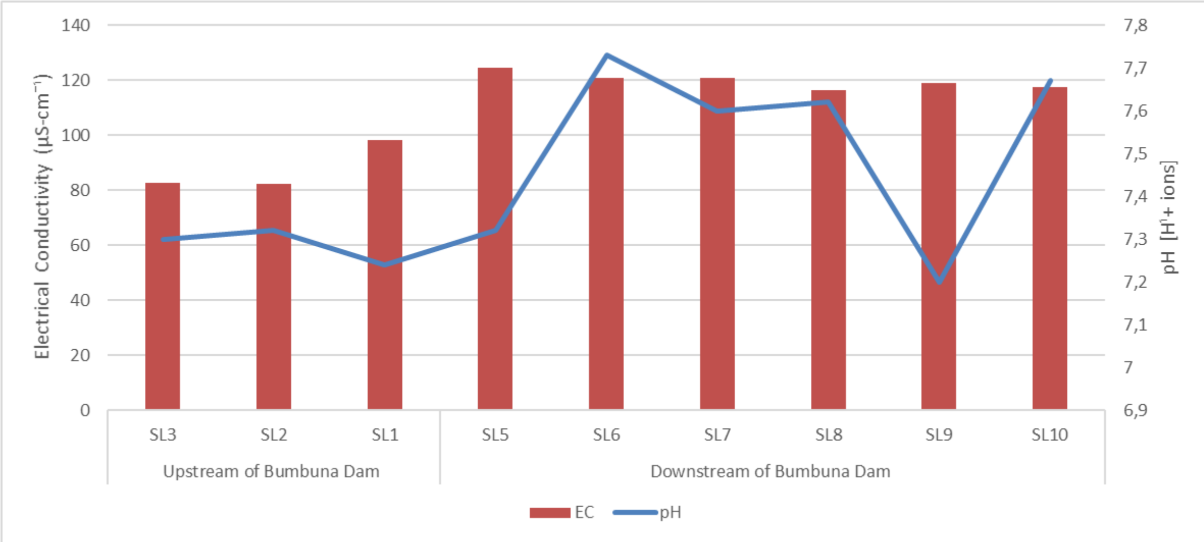

Figure 8-1: **The pH and EC values for sites located on the Rokel / Seli river, April 2018.**

8.2.2. Laboratory Analysis

The results from the laboratory analysis for all nine of the study sites are provided in **Table 8-6**, with the piper diagram illustrated in **Figure 8-2**. The main aspects are briefly discussed below:

- All the water quality samples ordinated to the left quadrant, reflecting a Calcium Bicarbonate – Ca $(HCO_3)_2$ water signature, which is typical of shallow fresh waters (**Figure 8-2**). Furthermore, low primary nutrient levels were measured.
- There was very little variation between the water quality parameters at all the sites with several of the parameters below the instrument detection limit (**Table 8-6**). The values recorded at all the sites fell within the benchmark criteria for aquatic freshwater systems (DWAF, 1996; Kotze, 2002).
- Despite the SO_4 values falling within benchmark criteria, the value recorded at site SL1 was considerably higher when compared to the upstream sites (SL2 and SL3). Sulphates themselves are not toxic, however in excess concentrations they form sulphuric acid (H_2SO_4) which is a strong acid that reduces pH (Dallas & Day, 2004). This was however not observed within this reach as the pH value was comparable and only slightly lower than the upper reaches (refer to **Table 8-5**).
- Site SL1, is an outlier, ordinating towards the Calcium Sulphate – $CaSO_4$ quadrant (**Figure 8-2**) which is typical of gypsum ground water and potential mine drainage.
- Low primary nutrient levels were measured, which indicated an oligotrophic classification (nutrient deficient).

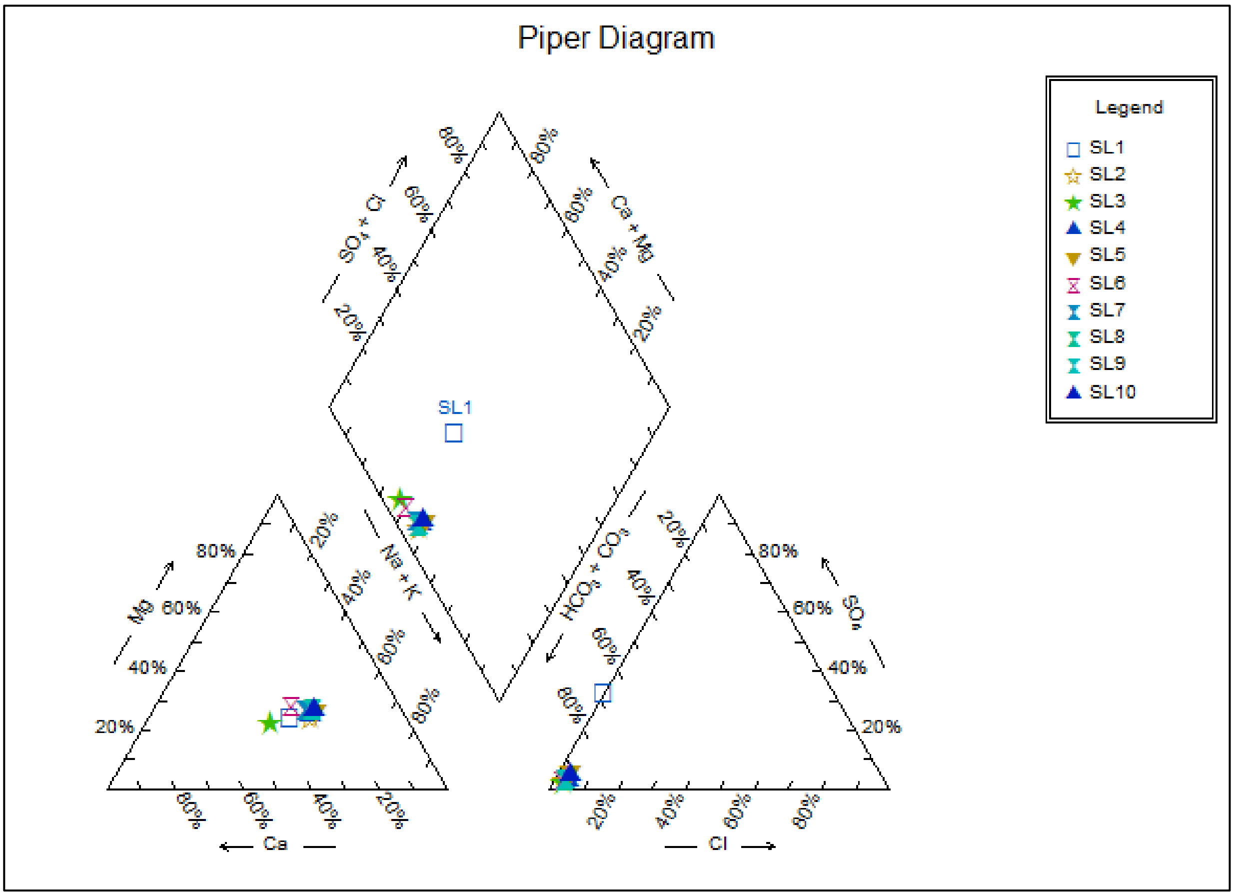

Figure 8-2: Piper diagram illustrating with water signatures of the study sites, April 2018.

Table 8-6: Water quality laboratory analysis for sites located on the Seli / Rokel River, April 2018

Analyte Name	Units	Reporting Limit	Upstream of Bumbuna Dam					Upstream of Bumbuna Dam				
			SL3	SL2	SL1	SL4	SL5	SL6	SL7	SL8	SL9	SL10
Acidity as CO_2	mg/l	10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Bicarbonate Alkalinity as $CaCO_3$	mg/l	12	53	33	28	30	23	23	18	18	15	13
Bicarbonate Alkalinity as HCO_3	mg/l	12	64	40	34	37	27	27	21	21	18	15
Bicarbonate as $CaCO_3$	mg/l	12	53	33	28	30	23	23	18	18	15	13
Carbonate Alkalinity as $CaCO_3$	mg/l	12	<12	<12	<12	<12	<12	<12	<12	<12	<12	<12
Carbonate Alkalinity as CO_3	mg/l	12	<12	<12	<12	<12	<12	<12	<12	<12	<12	<12
M Alkalinity as $CaCO_3$	mg/l	12	53	33	28	30	23	23	18	18	15	13
P Alkalinity as $CaCO_3$	mg/l	12	<12	<12	<12	<12	<12	<12	<12	<12	<12	<12
Total Alkalinity as $CaCO_3$	mg/l	12	53	33	28	30	23	23	18	18	15	13
TDS (0.7µm) @ 105ºC	mg/l	21	65	40	40	45	30	25	25	25	30	25
TSS (0.7µm) @ 105ºC	mg/l	21	<21	<21	<21	<21	<21	<21	<21	<21	<21	<21
Calcium	mg/l	0.5	7.8	3.1	4.0	2.6	1.3	1.9	1.5	1.4	1.4	1.3
Ca hardness as $CaCO_3$	mg/l	1.4	19	7.8	10	6.5	3.4	4.8	3.7	3.6	3.6	3.2
Iron	mg/l	0.05	0.13	0.93	0.84	0.96	0.46	0.34	0.21	0.18	0.14	0.07
Potassium	mg/l	0.2	4.3	3.2	2.4	2.6	0.8	0.8	0.8	0.9	0.8	0.9
Magnesium	mg/l	0.01	2.5	1.6	1.7	1.4	0.82	1.0	0.86	0.89	0.85	0.83
Mg hardness as $CaCO_3$	mg/l	0.05	10	6.5	7.1	5.6	3.4	4.2	3.6	3.7	3.5	3.4
Sodium	mg/l	0.5	5.6	4.2	4.2	3.6	2.4	2.3	2.3	2.4	2.4	2.3
Sulphur	mg/l	0.07	0.19	0.13	0.95	0.13	<0.07	0.07	<0.07	0.07	0.08	0.10
Total hardness as $CaCO_3$	mg/l	1.5	30	14	17	12	6.7	9.0	7.2	7.3	7.1	6.6
Chloride	mg/l	0.05	0.78	0.63	<0.05	0.63	0.21	0.35	0.29	0.32	0.26	0.31

Analyte Name	Units	Reporting Limit	Upstream of Bumbuna Dam					Upstream of Bumbuna Dam				
			SL3	SL2	SL1	SL4	SL5	SL6	SL7	SL8	SL9	SL10
Nitrite	mg/l	0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Nitrite as N	mg/l	0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Nitrate	mg/l	0.1	<0.1	<0.1	<0.1	<0.1	0.2	0.2	0.2	0.2	<0.1	<0.1
Nitrate as N	mg/l	0.03	<0.03	<0.03	<0.03	<0.03	0.04	0.05	0.05	0.04	<0.03	<0.03
Sulphate	mg/l	0.05	0.50	0.52	6.6	0.50	0.37	0.40	0.35	0.33	0.32	0.39
Orthophosphate	mg/l	0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25
Orthophosphate as P	mg/l	0.08	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080
Mercury	µg/l	0.001	0.012	0.027	0.065	0.027	0.014	0.006	0.003	<0.001	<0.001	<0.001
Ammonia	mg/l	0.012	0.52	0.083	0.097	0.095	0.030	0.024	0.019	0.028	0.015	0.018
Ammonia as N	mg/l	0.01	0.43	0.07	0.08	0.08	0.03	0.02	0.02	0.02	0.01	0.02

9. APPENDIX B – DIATOMS

Diatoms are the unicellular algal group most widely used as indicators of river and wetland health as they provide a rapid response to specific physico-chemical conditions in water and are often the first indication of change. The presence or absence of indicator taxa can be used to detect specific changes in environmental conditions such as eutrophication, organic enrichment, salinization and changes in pH. They are therefore useful for providing an overall picture of trends within an aquatic system as they show an ecological memory of water quality over a period of time.

9.1. MATERIALS AND METHODS

9.1.1. LABORATORY ANALYSIS

Diatom laboratory procedures were carried out according to the methodology described by Taylor *et al.* (2005). Diatom samples were prepared for microscopy by using the hot hydrochloric acid and potassium permanganate method. Approximately 300 to 400 diatom valves were identified and counted to produce semi-quantitative data for analysis. Prygiel *et al*. (2002) found that diatom counts of 300 valves and above were necessary to make correct environmental inferences. The taxonomic guide by Taylor *et al.* (2007b) and Cantonati *et al*. (2017) was consulted for identification purposes. Where necessary, Krammer & Lange-Bertalot (1986, 1988, 1991 a, b) were used for identification and confirmation of species identification. Environmental preferences were inferred from Taylor *et al.* (2007b) and Cantonati *et al*. (2017) and various other literature sources as indicated in the discussion section to describe the environmental water quality at each site.

9.1.2. DIATOM-BASED WATER QUALITY INDICES

There are different diatom-based water quality indices that are used globally and are based on the specific water quality tolerances of diatoms. Most of the indices are based on a weighted average equation by Zelinka and Marvan (1961). Two values are assigned to each diatom species used in the calculations of the indices that reflects the tolerance or affinity of the diatom species to a certain water quality (good or bad); and indicates how strong (or weak) the relationship is (Taylor 2004). These values are then weighted by the abundance of the diatom species in the sample (Lavoie *et al*. 2006; Taylor 2004; Besse 2007). The main difference between indices is in the indicator sets (number of indicators and list of taxa) used in calculations (Eloranta & Soininen 2002). These indices underpin the computer software packages used to estimate biological water quality. One such software package commonly used and that has been approved by the European Union has been used for this study is OMNIDIA (Lecointe *et al*. 1993). The program is a taxonomic and ecological database of 7500 diatom species, and it contains indicator values and degrees of sensitivity for given species. It allows rapid calculations of indices of general pollution, saprobity and trophic state, indices of species diversity, as well as of ecological systems (Szczepocka, 2007).

The Specific Pollution Sensitivity Index (SPI; CEMAGREF, 1982) was used in this diatom assessment (**Table 9-1**). The SPI is an inclusive index and takes factors such as salinity, eutrophication and organic pollution into account. This index comprises 2035 taxa (Taylor, 2004) and is recognised as the broadest species base of any index currently in use and has been adapted to include taxa endemic to and commonly found in South Africa, thus increasing the accuracy of diatom-based water quality assessments and is known as the South African Diatom Index (SADI) (Harding & Taylor, 2011). The limit values and associated ecological water quality classes adapted from Eloranta & Soininen (2002), in conjunction with the new adjusted class limits that are provided in (**Table 9-1**; Taylor & Koekemoer, in press), were used for interpretation of the SPI scores. The SPI index is based on a score between 0 – 20, where a score of 20 indicates no pollution and a score of zero indicates an increasing level of pollution or eutrophication.

Table 9-1: Adjusted class limit boundaries for the Specific Pollution Index in the evaluation of water quality applied in this study (adapted from Eloranta & Soininen, 2002; Taylor & Koekemoer, in press)

Interpretation of Index Scores		
Ecological Category (EC)	**Class**	**Index Score (SPI Score)**
A	High quality	18 - 20
A/B		17 - 18
B	Good quality	15 - 17
B/C		14 - 15
C	Moderate quality	12 - 14
C/D		10 - 12
D	Poor quality	8 - 10
D/E		6 - 8
E	Bad quality	5 - 6
E/F		4 - 5
F		< 4

The Percentage Pollution Tolerant Valves (%PTV) is part of the UK Trophic Diatom Index (TDI) (Kelly & Whitton, 1995) and was developed for monitoring organic pollution (sewage outfall- orthophosphate-phosphorus concentrations), and not general stream quality (**Table 9-2**). The %PTV has a maximum score of 100, where a score above 0 indicates no organic pollution and a score of 100 indicates definite and severe organic pollution. The presence of more than 20% PTVs shows significant organic impact. All calculations were computed using OMNIDIA ver. 4.2 program (Lecointe *et al*., 1993).

Table 9-2: Interpretation of the percentage Pollution Tolerant Valves scores (adapted from Kelly, 1998)

%PTV	Interpretation
<20	Site free from organic pollution.
20 to <40	There is some evidence of organic pollution.
40 to 60	Organic pollution likely to contribute significantly to eutrophication.
>60	Site is heavily contaminated with organic pollution.

9.2. Results and Discussion

The diatom assessment is divided into two sub-sections: (i) Discusses the ecological classification of water quality for each site according to the diatom assemblage during this assessment. (ii) Provides analyses and discussion of the dominant species and their ecological preference at each site. Thus, allowing spatial variation analyses of ecological water quality between sites.

9.2.1. Ecological Classification

The ecological classification for water quality according to Van Dam *et al*. (1994) and Taylor *et al*. (2007), includes the preferences of 948 freshwater and brackish water diatom species in terms of pH, nitrogen, oxygen, salinity, humidity, saprobity and trophic state as provided by OMNIDIA (Le Cointe *et al*., 1993) (**Table 9-3**). The overall diatom assemblages comprised of species with a preference for:

- Fresh brackish (<500 µS/cm), circumneutral (pH 7) to alkaline (pH >7) waters and eutrophic conditions.
- The nitrogen requirements for all the sites ranged from N-Autotrophic sensitive indicating a sensitivity for elevated concentrations of organically bound nitrogen, to N-Autotrophic tolerant indicating a tolerance of continuously elevated concentrations of organically bound nitrogen.
- The dissolved oxygen saturation requirements ranged from moderate (>50%) to very high (~100%) saturation for all the sites.
- The pollution levels indicated that there was some form of pollution evident at all the sites (ranging from Oligosaprobic- slightly polluted waters to α-meso-polysaprobic- heavily polluted waters).

Table 9-3: Ecological descriptors for the Yiben sites based on the diatom community assemblage (Van Dam *et al.*, 1994 and Taylor *et al.*, 2007)

Site	pH	Salinity	Organic Nitrogen uptake	Oxygen Levels	Pollution Levels	Trophic State
SL3	Alkaline	Fresh-brackish	N-Autotrophic tolerant	High	α-meso-polysaprobic	Eutrophic
SL2	Alkaline	Fresh-brackish	N-Autotrophic tolerant	Moderate	α-meso-polysaprobic	Eutrophic
SL1	Alkaline	Fresh-brackish	N-Autotrophic tolerant	Moderate	β-mesosaprobic	Eutrophic
SL5	Circumneutral	Fresh-brackish	N-Autotrophic tolerant	Very high	β-mesosaprobic	Eutrophic
SL6	Circumneutral	Fresh-brackish	N-Autotrophic sensitive	Very high	Oligosaprobic	oligo-mesotrophic
SL7	Circumneutral	Fresh-brackish	N-Autotrophic sensitive	Very high	Oligosaprobic	Oligotrophic
SL8	Circumneutral	Fresh-brackish	N-Autotrophic sensitive	Very high	Oligosaprobic	Oligotrophic
SL9	Circumneutral	Fresh-brackish	N-Autotrophic tolerant	Very high	Oligosaprobic	Eutrophic
SL10	Circumneutral	Fresh-brackish	N-Autotrophic sensitive	Very high	Oligosaprobic	Oligotrophic

9.2.2. DIATOM SPATIAL ANALYSIS

A total of 61 diatom species were recorded at the nine Yiben sites and the dominant diatom species recorded at all sites included, *Nitzschia sp*., *Achnanthidium sp.* and *Gomphonema sp*. (**Figure 9-1**; **Table 9-4**). It is important to note that some species like the abovementioned dominant species are cosmopolitan and have very wide ecological amplitudes. Thus, caution must be taken when analysing the predominance of these species at specific sites and it is important to consider the diatom assemblage as a whole in conjunction with focusing on the dominant species. *Achnanthidium sp.* are abundant in rivers, streams, and springs and often inhabit clean and polluted waters, including those affected by acid mine drainage (Ponader & Potapova 2007). This taxon has been recorded in high proportions over a wide range of trophic levels and is usually absent from moderately- to strongly acidic or very electrolyte-poor environments (Cantonati *et al*., 2017). Nitzschia sp. points to α-mesosaprobic to polysaprobic freshwater and is commonly found in untreated wastewater and in habitats that are strongly impacted by industrial sewerage. Gomphonema sp. indicates oligosaprobic and mesosaprobic, oligo- to eutrophic freshwater and suggests impacts associated with agricultural run-off.

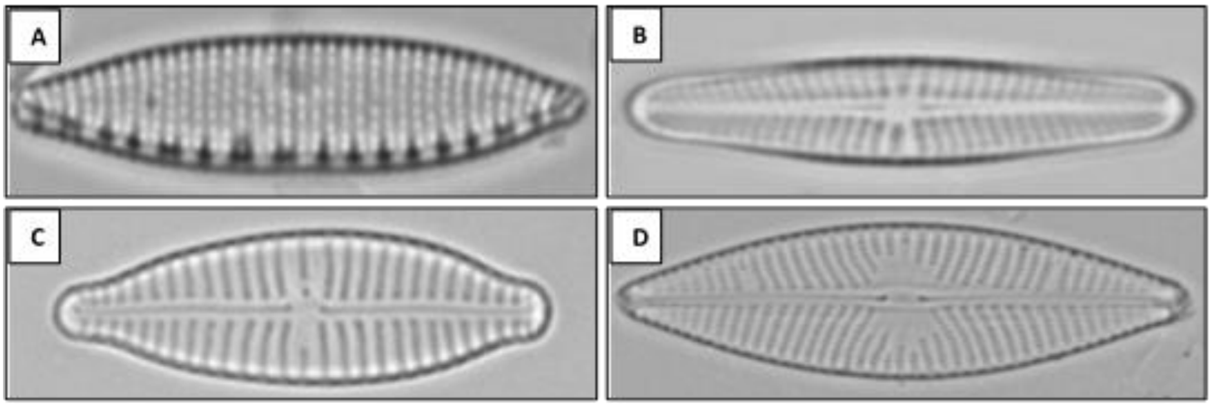

Figure 9-1: Dominant diatom species recorded at all sites included, *Nitzschia sp., Achnanthidium sp., Gomphonema sp.* and *Navicula sp.* (Kelly *et al.,* 2005).

Additional information is provided for the sub-dominant species in order to make ecological inferences for the nine sites assessed (**Table 9-4**; **Table 9-5**, Taylor *et al*., 2007, Cantonati *et al*., 2017):

- **Site SL3**: This site is located furthest upstream and was dominated by *Navicula sp*. which indicates alkaline, low temperature, eutrophic running water with medium-high conductivity, species from this genus are commonly found in organically polluted water. The subdominance of *Planothidium dubium* indicated alkaline, eu- to polytrophic waters, this taxon is tolerant of strongly polluted conditions. The subdominance of *Achnanthidium sp*. which as aforementioned has a wide ecological amplitude and has been recorded in rivers, streams, and springs often inhabits clean and polluted waters. The presence of *Craticula buderi* pointed to freshwater habitats with a moderate electrolyte content and calcium-bicarbonate-rich systems. The diatom community at this site reveals eutrophic conditions with a moderate electrolyte content. This site is characterized as a swamp habitat with a closed forest canopy, resulting in large quantities of organic matter dropping into the water from the above canopy (allochthonous production of organic matter). The closed canopy system is what is contributing to the high organic content of this system and thus there are no serious impacts associated with organic pollution, therefore the overall water quality was Moderate (**Table 9-4**).
- **Site SL2**: This is the translocation site and it was dominated by *Navicula sp*. and *P. dubium* which point towards alkaline, eu- to polytrophic, low temperature, running water with medium-high conductivity. Both species are tolerant of organically polluted water. The subdominance of *Achnanthidium sp*. and *Cyclotella meneghiniana* pointed to eutrophic, electrolyte-rich freshwaters. The presence of *Gomphonema sp*. and *G. parvulum* indicated oligosaprobic and mesosaprobic, oligo- to eutrophic freshwater and points to impacts associated with agricultural run-off. The diatom community at this site therefore suggests alkaline, eutrophic conditions with moderate electrolyte content and owing to the low %PTV score there appears to be no serious impact associated with organic pollution, thus the overall water quality was considered *Moderate* (**Table 9-4**).

- **Site SL1**: This site is the actual location of the known extant plants. It was dominated by *Aulacoseira granulata* which indicates calcium-rich and moderately eutrophic waters. The subdominance of *Achnanthidium sp*. indicates eutrophic, electrolyte-rich freshwaters. The subdominance of *Fragilaria rumpens* indicated oligo-to mesotrophic, electrolyte-poor waters as this taxon is usually absent from acidified and strongly eutrophic environments. The presence of *Planothidium dubium* indicated alkaline, eu- to polytrophic waters and is tolerant of strongly polluted conditions. The presence of *Ulnaria ulna* indicated alkaline, medium conductivity, oligosaprobic, moderately eutrophic habitat. The diatom assemblage at this site reveals calcium carbonate rich, mesotrophic waters with medium to high electrolyte freshwater conditions. The %PTV score was relatively low indicating that this site had a low impact associated with organic pollution and the overall water quality was considered *Moderate* (**Table 9-4**).
- **Site SL5**: This site was located downstream of Bumbuna dam below the waterfall. It was dominated by species that pointed to alkaline, low temperature, eutrophic running water with medium-high conductivity that are commonly found in organically polluted water. The presence of *Navicula radiosa* pointed to moderate electrolyte content, alkaline and mesotrophic conditions and this species is sensitive toward high levels of organic pollution. The presence of *F. rumpens* indicated oligo-to mesotrophic, electrolyte-poor waters and is absent from acidified and strongly eutrophic environments. The presence of *Gomphonema sp.* and *G. parvulum* indicated oligosaprobic and mesosaprobic, oligo- to eutrophic freshwater and points to impacts associated with agricultural run-off. The diatom assemblage at this site points towards oligo-to mesotrophic conditions with moderate electrolyte content. Owing to the dominant diatom species and the %PTV score this site appeared to have a low impact associated with organic pollution and the overall water quality was considered *Good* (**Table 9-4**).
- **Site SL6**: This downstream site was dominated by *F. rumpens,* indicating oligo-to mesotrophic, electrolyte-poor waters, this taxon is absent from acidified and strongly eutrophic environments. The subdominance of *Nitzschia sp., Navicula radiosa* and *Navicula sp*. are commonly found in electrolyte-rich, eutrophic freshwaters that are in polluted conditions. The subdominance of *Encyonema minutum* indicated slight anthropogenic disturbed habitats and oligo-to mesotrophic freshwaters with medium electrolyte content. The presence of *Brachysira serians* indicated oligosaprobic, dystrophic, well-buffered (production of organic acids) freshwaters. The presence of *Ulnaria sp*. indicates alkaline, medium conductivity, oligosaprobic, eutrophic conditions. The diatom assemblage at this site indicated oligo-to mesotrophic freshwaters with moderate electrolyte content. The %PTV score indicated that there was no evidence of organic matter present at this site which is likely due to the upstream impacts of the dam. There appeared to be a very low impact associated with pollution and the overall water quality was considered *Good* (**Table 9-4**).
- **Site SL7**: This site is located downstream of the dam and had an overwhelming dominance of *Achnanthidium sp*. which suggests eutrophic, electrolyte-rich freshwaters. The subdominance of *E. minutum* indicated slight anthropogenically disturbed habitats and oligo- to- mesotrophic freshwaters

with medium electrolyte content. The presence of *Brachysira serians* indicated oligosaprobic, dystrophic freshwaters. The presence of *F. rumpens* indicated oligo-to mesotrophic, electrolyte-poor waters, with this taxon being absent from acidified and strongly eutrophic environments. The diatom community at this site pointed towards alkaline, oligo-to mesotrophic conditions with moderate electrolyte content and owing to the low %PTV score there appeared to be no serious impact associated with organic pollution. The overall water quality was considered *Good* (**Table 9-4**).

- **Site SL8**: This site was dominated by *Brachysira serians* which indicated oligosaprobic, dystrophic freshwaters. The subdominance of *F. rumpens* and *E. minutum* indicated slight anthropogenic disturbed habitats, oligo-to mesotrophic, electrolyte-poor waters as these taxa are absent from acidified and strongly eutrophic environments. The presence of Ulnaria sp. indicated alkaline, medium conductivity, oligosaprobic, eutrophic conditions. The presence of *Achnanthidium sp*. indicated eutrophic, electrolyte-rich freshwaters. The diatom assemblage revealed oligo-to mesotrophic waters with medium to high electrolyte freshwater conditions. The %PTV score was relatively low indicating that this site had a low impact associated with organic pollution and the overall water quality was considered *Good* (**Table 9-4**).
- **Site SL9**: This downstream site had an overwhelming dominance of *Achnanthidium sp*. which pointed to eutrophic, electrolyte-rich freshwaters. The subdominance of *F. rumpens* indicated slight anthropogenically disturbed habitats, oligo-to mesotrophic, electrolyte-poor waters and absent from acidified and strongly eutrophic environments. The subdominance of *Navicula radiosa* and *Navicula sp*. are commonly found in electrolyte-rich, eutrophic freshwaters that are impacted by polluted conditions. The presence of B*. serians* which indicated oligosaprobic, dystrophic freshwaters. The presence of *Gomphonema sp.* and *G. parvulum* indicated oligosaprobic and mesosaprobic, oligo- to eutrophic freshwater and pointed to impacts associated with agricultural run-off. The diatom assemblage at this site pointed towards meso-to eutrophic conditions with moderate electrolyte content. Owing to the dominant diatom species and the low %PTV score this site appeared to have a low impact associated with organic pollution and the overall water quality was considered *Good* (**Table 9-4**).
- **Site SL10**: This downstream site was dominated by *Achnanthidium sp*. which pointed to eutrophic, electrolyte-rich freshwaters. The subdominance of *F. rumpens* and *E. minutum* indicated habitats that were slightly disturbed by anthropogenic activities, oligo-to mesotrophic, electrolyte-poor waters as these taxa are absent from acidified and strongly eutrophic environments. The presence of *Gomphonema sp.* and *G. parvulum* indicated oligosaprobic and mesosaprobic, oligo- to eutrophic freshwater and points to impacts associated with agricultural run-off. The presence of *E. perpusillum* pointed to oligotrophic, usually acidic freshwater habitats with low electrolyte content and is a good indicator of good ecological conditions. The presence of *B. serians* indicated oligosaprobic, dystrophic, well-buffered (production of organic acids) freshwaters. The diatom assemblage at this site indicated oligo-to eutrophic freshwaters with moderate electrolyte content and owing to the dominance of *Achnanthidium sp*. and the low %PTV score this site appeared to have a low impact associated with organic pollution and the overall water quality was considered *Good* (**Table 9-4**).

Table 9-4: Species and their abundances for the Sierra Leone sites

Taxa	SL3	S2	S1	SL5	SL6	SL7	SL8	SL9	SL10
Achnanthidium exiguum (Grunow) Czarnecki	13								
Achnanthidium sp.	30	65	75	131		120	22	147	90
Adlafia bryophila (Petersen) Moser Lange-Bertalot & Metzeltin	14	8	7		6				
Amphora veneta Kützing	12								
Aulacoseira granulata (Ehr.) Simonsen		4	155						
Brachysira neoexilis Lange-Bertalot				4	16	10	28	15	
Brachysira serians (Breb.) Round et Mann var. *serians*					28	58	95	33	48
Caloneis alpestris (Grunow)Cleve					24				
Cavinula variostriata (Krasske) Mann & Stickle		3		2					3
Cocconeis placentula Ehrenberg var. *placentula*								12	5
Craticula accomoda (Hustedt) Mann							9		
Craticula buderi (Hustedt) Lange-Bertalot	25	5		15					
Craticula halophila (Grunow ex Van Heurck) Mann				4				2	
Craticula molestiformis (Hustedt) Lange-Bertalot			4			8		15	10
Cyclotella meneghiniana Kützing		39							
Cymbella turgidula Grunow 1875 in A. Schmidt & al. var. *turgidula*				3					
Cymbopleura cuspidata (Kützing) Krammer						4	19	18	5
Diploneis sp.	12		4						
Encyonema mesianum (Cholnoky) D.G. Mann			3						
Encyonema minutum (Hilse in Rabh.) D.G. Mann	13	10		20	30	88	52	36	35
Encyonema perpusillum (A. Cleve) D.G. Mann					16	4	23	6	29
Eunotia formica Ehrenberg				4					
Eunotia minor (Kützing) Grunow in Van Heurck	20		3	4		4			
Fragilaria capucina Desmazieres var. *capucina*			16						
Fragilaria gracilis Østrup					6				
Fragilaria rumpens (Kütz.) G.W.F. Carlson			73	26	98	48	66	6	45
Frustulia crassinervia (Breb.) Lange-Bertalot et Krammer	14	4		3		13			
Frustulia marginata Amosse					8				
Gomphonema minutum (Ag.) Agardh f. *minutum*								2	3
Gomphonema parvulum (Kützing)	13	18	10	6		3	9	5	3
Gomphonema species	22	15	3	22		18	15	12	45
Gomphosphenia lingulatiformis (Lange-Bertalot & Reichardt) Lange-Bertalot									12
Luticola goeppertiana (Bleisch in Rabenhorst) D.G. Mann	16								
Luticola mutica (Kützing) D.G. Mann	17								
Navicula cryptocephala Kützing								10	6
Navicula erifuga Lange-Bertalot								4	
Navicula radiosa Kützing		4	11	46	32	10	13	30	3
Navicula rostellata Kützing						4			
Navicula sp.	73	95	4	85	52	2	7	33	25
Navicula symmetrica Patrick			6	14		5			

Taxa	**SL3**	**S2**	**S1**	**SL5**	**SL6**	**SL7**	**SL8**	**SL9**	**SL10**
Navicula viridula (Kützing) Ehrenberg		5	4	36		10	8	10	
Nitzschia amphibia Grunow f. *amphibia*			6			3	9		5
Nitzschia sp.1	18	24	12	7	40	8	11	8	8
Pinnularia saprophila Lange-Bertalot. Kobayasi & Krammer	16			2					
Placoneis clementis (Grun.) Cox		4							
Placoneis placentula (Ehr.) Heinzerling					8				
Planothidium dubium (Grun.) Round & Bukhtiyarova	48	80	30	3				10	22
Planothidium frequentissimum (Lange-Bertalot) Lange-Bertalot	14	32			8	5			6
Planothidium rostratum (Oestrup) Lange-Bertalot			8						
Prestauroneis integra (W. Smith) Bruder					8				
Psammothidium ventrale (Krasske) Bukhtiyarova et Round		4							
Sellaphora pupula (Kützing) Mereschkowksy		5		3				20	
Sellaphora species								10	8
Stauroneis anceps Ehrenberg		4							
Stauroneis producta Grunow	18								
Stauroneis separanda Lange-Bertalot & Werum	14								
Surirella terricola Lange-Bertalot & Alles			4						
Tabularia fasciculata (Agardh)Williams et Round						3			
Tryblionella hungarica (Grunow) D.G. Mann	12								
Ulnaria acus (Kützing) Aboal					38	10	32	6	20
Ulnaria ulna (Nitzsch.) Compère	16	22	12	10	32	12	32		14
Total	450	450	450	450	450	450	450	450	450
Nutrients									
Salinity									
Organics									
Other Dominant									

Table 9-5: Diatom index scores for the study sites indicating the ecological water quality

Site	**%PTV**	**SPI**	**Ecological Category (EC)**	**Class**
SL3	2.2	13.9	C	**Moderate**
SL2	4	13.1	C	**Moderate**
SL1	5.6	11.8	C/D	**Moderate**
SL5	1.3	14.6	B/C	**Good**
SL6	0	14.7	B/C	**Good**
SL7	0.7	16.4	B	**Good**
SL8	2	15.8	B	**Good**
SL9	1.1	16.2	B	**Good**
SL10	0.7	15.7	B	**Good**

9.2.3. Diatom Community Structure

The study area was divided into two sub-sections and a description of each sub-section is provided below. The sub-sections include upstream and downstream of Bumbuna I. The cluster analyses groups sites together based on their similarity in the diatom species present. The dominant diatom species at each site indicate the specific environmental conditions promoting their dominance.

Upper catchment sites upstream of Bumbuna I

According to the cluster analyses sites SL3 and SL2 were grouped together and showed a 57% similarity in the diatom community (**Figure 9-2**). The dominant diatom species contributing to these two sites being grouped together was *Navicula sp*. which pointed to alkaline, eutrophic running water with medium-high conductivity and species from these genera are commonly found in organically polluted water. The subdominant species *Planothidium dubium* pointed to alkaline, eu- to polytrophic rivers and are tolerant of polluted conditions. The presence of *Achnanthidium sp*. indicated clean and polluted waters and is absent from moderately- to strongly-acid or very electrolyte poor environments. The ecological water quality at sites SL3 and SL2 upstream of the dam are characterized as alkaline, eutrophic waters that are lightly organically enriched. These sites may have allochthonous material entering the river from the riparian zone. Site SL3 has a closed canopy structure which probably leads to an increase in organic material entering the river.

Proximal and distal lower catchment sites downstream of Bumbuna I

The two sites immediately downstream of the dam and the waterfall (SL5 and SL6) had a 38.44% similarity in the diatom community (**Figure 9-2**). The dominant diatom species contributing to these two sites being grouped together was *Fragilaria rumpens* pointed to oligo- to mesotrophic, electrolyte-poor rivers. The subdominance of *Navicula radiosa* indicated electrolyte-poor, weakly-acidic, meso- to oligotrophic conditions and sensitive to high levels of organic pollution. Site SL1 which is located upstream of the dam shows a slight similarity to the two abovementioned sites. The slight similarity is possibly related to *Navicula sp*. which pointed to alkaline, eutrophic running water with medium-high conductivity and species from these genera are commonly found in organically polluted water.

The sites further downstream (SL7, SL8, SL9 and SL10) are grouped together with a 65% similarity (**Figure 9-2**). The main contributing diatom taxon resulting in the similarity is *Achnanthidium sp*. which pointed to clean and polluted waters and is absent from moderately- to strongly-acid or very electrolyte poor environments. The subdominance of *Brachysira serians* pointed to oligosaprobic, dystrophic, well buffered production of organic acids) freshwater habitats. The subdominance of *Encyonema minitum* which is commonly found in habitats that are not anthropogenically disturbed and in oligo- to mesotrophic freshwater with medium electrolyte content.

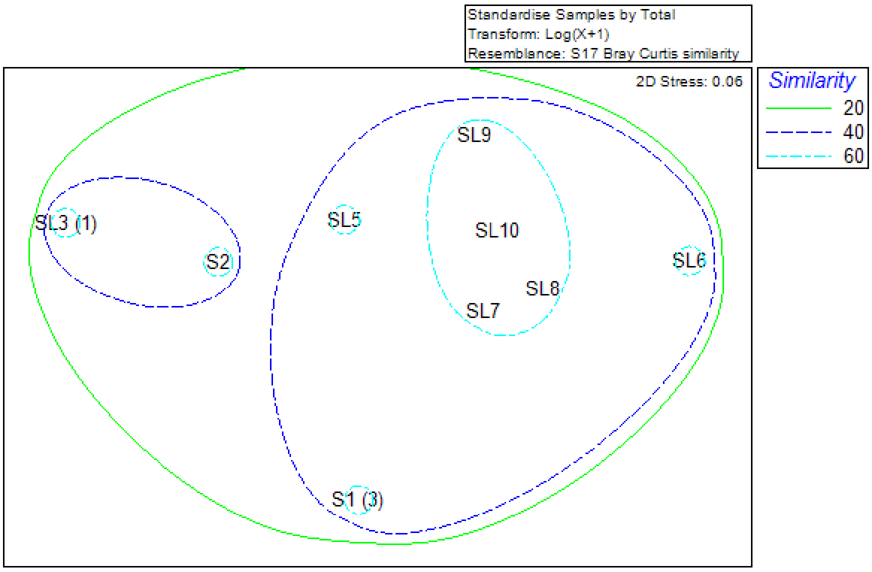

Figure 9-2: MDS analysis of the Yiben sites based on the diatom communities for the April 2018 survey. The clusters are based on a 20%, 40% and 60% similarity.

9.2.4. Diatom Temporal Variation

It is important to monitor temporal trends in the diatom community to determine any changes in the ecological conditions of the aquatic environment and the associated impacts if any. During the previous August 2016 survey, only a small stretch downstream of the dam was surveyed, including sites R1, R2 and R3. These three sites correlate with sites SL5 and SL6 from the current April 2018 survey and thus a comparison among these sites will be discussed (**Table 9-6** and **Table 9-7**). According to trends in the temporal diatom analysis, the ecological water quality showed an overall improvement and the level of organic pollution appeared to decrease. Overall the water quality improved from *Moderate* to *Good* compared to the previous survey.

Table 9-6: Temporal trends of diatom indices for the study sites indicating the variation in ecological water quality for August 2016

Site	%PTV	SPI	Ecological Category	Ecological Water Quality
R 1 (SL5)	16.9	10.6	C/D	**Moderate**
R 2 (SL6)	14	11.2	C/D	**Moderate**
R 3 (SL7)	9.1	10.6	C/D	**Moderate**

Table 9-7: Temporal trends of diatom indices for the study sites indicating the variation in ecological water quality for April 2018

Site	%PTV	SPI	Ecological Category	Ecological Water Quality
SL6	0	14.7	B/C	**Good**
SL7	0.7	16.4	B	**Good**

10. APPENDIX C - INTERMEDIATE INDEX OF HABITAT INTEGRITY

10.1. MATERIAL AND METHODS

The severity of the impact of the modifications is based on six (6) categories. These categories comprise rating scores ranging from 0 to 25: where 0 (no impact), 1 to 5 (small impact), 6 to 10 (moderate impact), 11 to 15 (large impact), 16 to 20 (serious impact) and 21 to 25 (critical impact – **Table 10-1** and **Table 10-2**).

Table 10-1: Descriptive classes for the assessment of modifications to habitat integrity (adapted from Kleynhans, 1996)

Impact Category	Description	Score
None	No discernible impact, or the modification is in such a way that it has no impact on habitat quality, diversity, size and variability.	**0**
Small	The modification is limited to very few localities and the impact on habitat quality, diversity, size and variability is also very small.	**1 - 5**
Moderate	The modifications are present at a small number of localities and the impact on habitat quality, diversity, size and variability is also limited.	**6 - 10**
Large	The modification is generally present with a clearly detrimental impact on habitat quality, diversity, size and variability. Large areas are, however, not influenced.	**11 - 15**
Serious	The modification is frequently present and the habitat quality, diversity, size and variability in almost the whole of the defined area are affected. Only small areas are not influenced.	**16 - 20**
Critical	The modification is present overall with a high intensity. The habitat quality, diversity, size and variability in almost the whole of the defined section are influenced detrimentally.	**21 - 25**

The habitat integrity assessment is based on two different components of a river: (1) the instream channel, and (2) the riparian zone. Separate assessments are done for both aspects, however, the data for the riparian zone is interpreted primarily in terms of the potential impact on the instream component (Kemper, 1999). The rating system is based on different weights for each criterion (**Table 10-2**).

Table 10-2: Criteria and weights used for the assessment of habitat integrity (adapted from Kleynhans, 1996)

Instream Criteria	Weight	Riparian Zone Criteria	Weight
Water abstraction	14	Bank erosion	14
Water quality	14	Indigenous vegetation removal	13
Bed modification	13	Water abstraction	13
Channel modification	13	Water quality	13
Flow modification	13	Channel modification	12
Inundation	10	Exotic vegetation encroachment	12
Exotic macrophytes	9	Flow modification	12
Exotic fauna	8	Inundation	11
Solid waste disposal	6		
TOTAL	**100**	**TOTAL**	**100**

The methodology classifies habitat integrity into one of six classes, ranging from Natural (Category A) to Critically Modified (Category F), for both instream and riparian habitat (**Table 10-3**).

Table 10-3: Ecological categories, key colours and category descriptions presented within the habitat assessment (adapted from Kleynhans, 1996)

Category		Description	Score (%)
A	**Natural**	Unmodified, Natural.	90-100
B	**Largely Natural**	Few modifications. Small change in natural habitats and biota may have taken place but the ecosystem functions are essentially unchanged.	80-89
C	**Moderately Modified**	A loss and change of natural habitat and biota occurred but the basic ecosystem functions are still predominantly unchanged.	60-79
D	**Largely Modified**	Large loss of natural habitat. Biota and basic ecosystem functions occurred.	40-59
E	**Seriously Modified**	The losses of natural habitat, biota and basic ecosystem functions are extensive.	20-39
F	**Critically Modified**	Modifications have reached a critical level and the lotic system has been modified completely with an almost complete loss of natural habitat and biota. In the worst instances, the basic ecosystem functions have been destroyed and the changes are irreversible.	<20

10.2. Results and Discussion

The intermediate Index of Habitat Integrity (IHI) was applied on a site level basis to ascertain the change of instream and riparian habitat from natural conditions (Kemper, 1999). The habitat integrity assessment provides a tool for assessing instream and riparian habitat by incorporating factors and potential impacts (Kleynhans, 1996).

10.2.1. Baseline EcoClassification

The IHI scores and categories per site with justifications for the various metrics calculated during the April 2018 baseline assessment are shown in **Table 10-4** to **Table 10-6.** The main aspects are briefly discussed below:

- Site SL3, located furthest upstream of Bumbuna Reservoir I was classed in a B category (**Table 10-4**). This infers to a *Largely Natural* state, where only small changes / alterations to the natural habitats and biota may have taken place, but the overall ecosystem functions remain relatively unchanged.
- The main driving variables responsible for the decline in habitat integrity at site SL3 included reduced water quality, bed modification and vegetation removal (**Table 10-4**).
- Further downstream, sites SL1 and SL2 classed in A category, which infers a relatively *Unmodified* / *Natural* state (**Table 10-4**).
- Downstream of Bumbuna Dam, all the sites with the exception of site SL9 classed in a B category, inferring a *Largely Natural* state (**Table 10-5**; **Table 10-6**). The habitat integrity at site SL9 was more impacted and the site classed in a C category, inferring a *Moderately* modified state, where alteration to the natural habitat has occurred but the basic ecosystem functions are still predominantly unchanged (**Table 10-6**).
- The main driving variables responsible for the further decline in habitat integrity at site SL9 included increased flow modification within the riparian zone, water abstraction, vegetation removal and bank erosion (**Table 10-6**).
- Spatially, the sites situated downstream of the dam, showed lower overall IHI % scores, mainly because of the impacts associated with flow alteration.

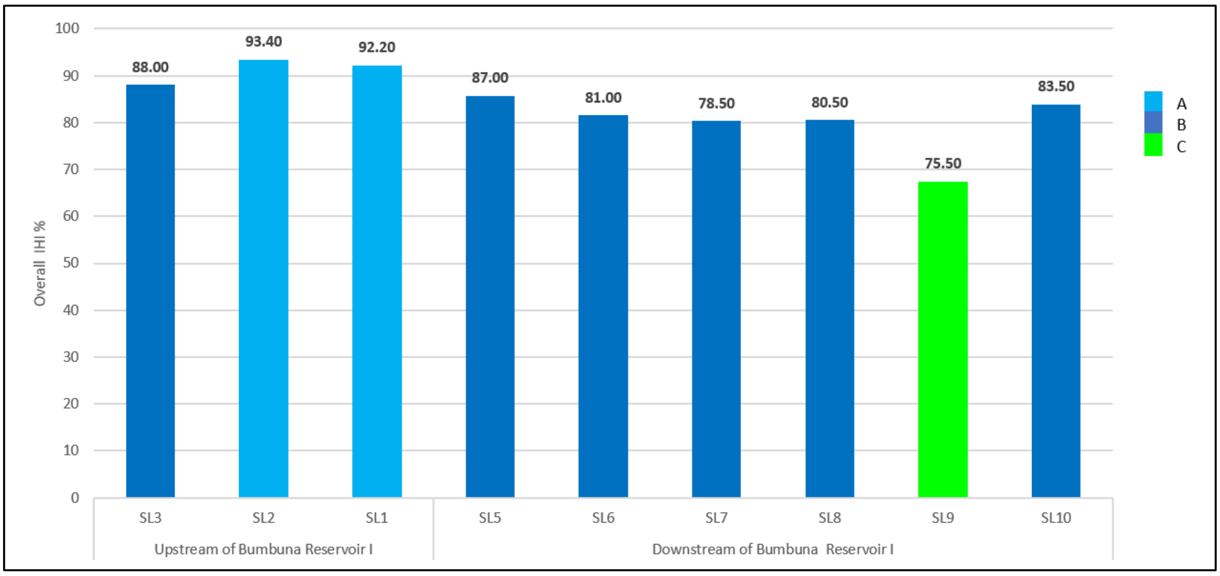

Figure 10-1: Column graph indicating the overall IHI % scores for all the study sites, April 2018.

10.2.2. Bumbuna Reservoir II EcoClassification Modelling

This section will focus on the anticipated change in the instream and riparian integrity based on the construction of Bumbuna Reservoir II and the new proposed hydrological regime. The IHI scores and categories per site with justifications for the various metrics calculated during the April 2018 baseline assessment are shown in **Table 10-4** to **Table 10-6.** The main aspects are briefly discussed below:

- The ecological categories obtained for sites SL3, SL2 should remain unchanged (**Figure 10-2**) as the extent of inundation for the proposed Bumbuna Reservoir II location will not infringe on these reaches. However, a decrease in habitat integrity is anticipated at site SL1, as it falls within the inundation zone:
  - The habitat template within this reach will change considerably, as it will experience deep flooding once the Bumbuna Reservoir II is completed. The overall IHI % score is anticipated to drop substantially into a D category, which will infer a *Largely* modified state (**Table 10-4**; **Figure 10-2**).
  - The driving variables responsible to this drop in ecological category will be flow modification, changes in the extent of inundation, bed modification and the subsequent removal of riparian vegetation (**Table 10-4**).
- The downstream sites are anticipated to experience a smaller drop in habitat integrity following the completion of Bumbuna Reservoir II:

- All the sites are expected to fall in a C category following the completion of the reservoir (**Figure 10-2**). This will infer a *Moderately* modified state where alteration to the natural habitat is anticipated to occur, but the basic ecosystem functions will remain predominantly unchanged.
- The driving variables responsible to the slight drop in ecological integrity will be flow modification, changes in the extent of inundation, channel modification within the riparian zone, erosion and the removal of riparian vegetation (**Table 10-5; Table 10-6**).

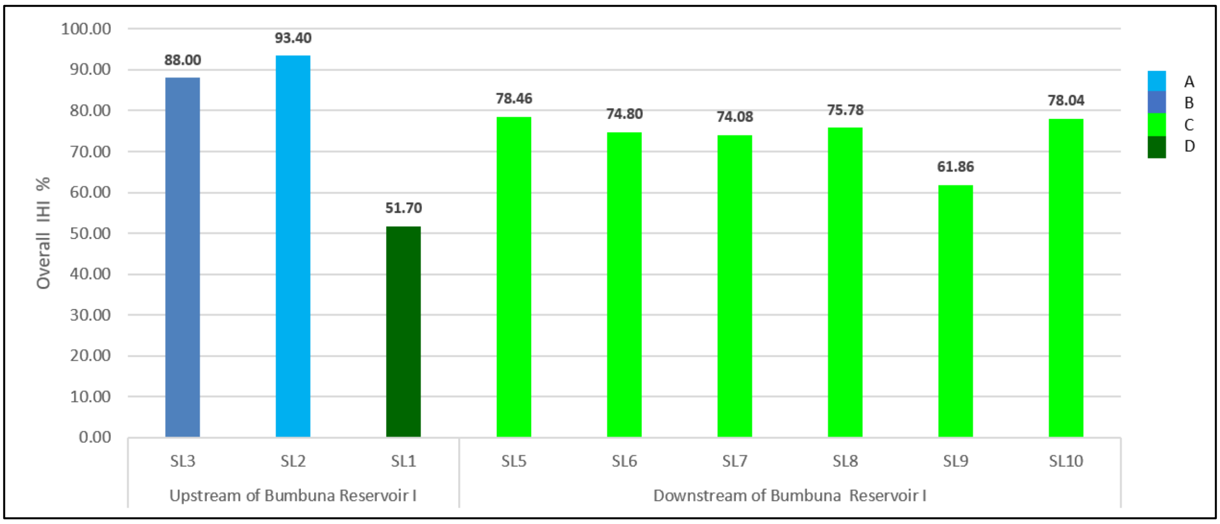

Figure 10-2: Anticipated overall IHI % scores following the construction of Bumbuna Reservoir II.

Table 10-4: Results for the IHI for sites located upstream of Bumbuna Reservoir I Reservoir, April 2018

Criterion	Relevance	SL3				SL2				SL1				Description
		Baseline (April 2018)		Bumbuna Reservoir II		Baseline (April 2018)		Bumbuna Reservoir II		Baseline (April 2018)		Bumbuna Reservoir II		
Instream Habitat Integrity		**Score**	**Cat.**	**Score**	**Cat.**	**Score**	**Cat.**	**Score**	**Cat.**	**Score**	**Cat.**	**Score**	**Cat.**	
Water abstraction	Direct impact on habitat type, abundance and size. Also implicated in flow, bed, channel and water quality characteristics. Riparian vegetation may be influenced by a decrease in the supply of water.	5	Small	5	Small	5	Small	5	Small	0	None	10	Mod.	Water abstraction by rural settlements within the catchment at reaches associated with site SL1 and SL2. The impacts are anticipated to remain the same at sites SL2 and SL3 following the construction of Bumbuna Reservoir II. Water abstraction is anticipated to increase at site SL1, within the inundation zone.
Flow modification	Consequence of abstraction or regulation by impoundments. Changes in temporal and spatial characteristics of flow can have an impact on habitat attributes such as an increase in duration of low flow season, resulting in low availability of certain habitat types or water at the start of the breeding, flowering or growing season.	0	None	0	None	0	None	0	None	0	None	25	Critical	None observed during the April 2018 assessment. The impacts on flow is anticipated to remain the same at sites SL2 and SL3 following the construction of Bumbuna Reservoir II. However, site SL1 will fall within the inundation zone and the natural flow regime will be severely altered.
Channel modification	May be the result of a change in flow, which may alter channel characteristics causing a change in marginal instream and riparian habitat. Purposeful channel modification to improve drainage is also included.	5	Small	5	Small	0	None	0	None	10	Mod.	20	Serious	Artisanal diamond mining at site SL1 has resulted in the sight modification of the channel in parts of the reach. Channel widening was noted at site SL3.The impact is anticipated to remain the same at sites SL2 and SL3 following the construction of Bumbuna Reservoir II. However, site SL1 will fall within the inundation zone and the channel characteristic of the reach will be severely altered.
Water quality	Originates from point and diffuse point sources. Measured directly or agricultural activities, human settlements and industrial activities may indicate the likelihood of modification. Aggravated by a decrease in the volume of water during low or no flow conditions.	10	Mod.	10	Mod.	0	None	0	None	0	None	5	Small	The water is stagnant at site SL3, resulting in decreased dissolved oxygen concentrations. Water quality is expected to increase slightly at site SL1 once the dam is inundated. A slight increase in salt loads and a decrease in the DO concentrations are anticipated.

Criterion	Relevance	SL3				SL2				SL1				Description
		Baseline (April 2018)		Bumbuna Reservoir II		Baseline (April 2018)		Bumbuna Reservoir II		Baseline (April 2018)		Bumbuna Reservoir II		
Inundation	Destruction of riffle, rapid and riparian zone habitat. Obstruction to the movement of aquatic fauna and influences water quality and the movement of sediments (Gordon et al., 1992).	0	None	0	None	0	None	0	None	0	None	20	Serious	None observed during the April 2018 assessment. The impacts are anticipated to remain the same at sites SL2 and SL3 following the construction of Bumbuna Reservoir II. The reach associated with site SL1, will experience deep flooding once the Bumbuna II is inundated.
Bed modification	Regarded as the result of increased input of sediment from the catchment or a decrease in the ability of the river to transport sediment (Gordon et al., 1993). Indirect indications of sedimentation are stream bank and catchment erosion. Purposeful alteration of the stream bed, e.g. the removal of rapids for navigation (Hilden & Rapport, 1993) is also included.	5	Small	5	Small	0	None	0	None	5	Small	15	Large	Artisanal diamond mining at site SL1 has resulted in the physical alteration of the substrate. Increased sedimentation was noted at site SL3. Bed modification is anticipated at site SL1, most likely associated with sediment deposition. Sites SL2 and SL3 will not be affected.
Exotic macrophytes	Alteration of habitat by obstruction of flow and may influence water quality. Dependent upon the species involved and scale of infestation.	0	None	0	None	0	None	0	None	0	None	0	None	None observed during the April 2018 assessment. No addition impacts are anticipated following the construction of Bumbuna II.
Exotic fauna	The disturbance of the stream bottom during feeding may influence the water quality and increase turbidity. Dependent upon the species involved and their abundance.	0	None	0	None	0	None	0	None	0	None	0	None	None observed during the April 2018 assessment. No addition impacts are anticipated following the construction of Bumbuna II.
Solid waste	A direct anthropogenic impact which may alter habitat structurally. Also, a general indication of the misuse and mismanagement of the river.	0	None	0	None	0	None	0	None	0	None	0	None	None observed during the April 2018 assessment. No addition impacts are anticipated following the construction of Bumbuna II.
Instream Habitat Integrity Score		**86**		**86**		**97**		**97**		**92**		**52**		
Integrity Class		**B**		**B**		**A**		**A**		**A**		**D**		

Criterion	Relevance	SL3				SL2				SL1				Description
		Baseline (April 2018)		Bumbuna Reservoir II		Baseline (April 2018)		Bumbuna Reservoir II		Baseline (April 2018)		Bumbuna Reservoir II		
Riparian Habitat Integrity		**Score**	**Cat.**	**Score**	**Cat.**	**Score**	**Cat.**	**Score**	**Cat.**	**Score**	**Cat.**	**Score**	**Cat.**	
Water Abstraction	Direct impact on habitat type, abundance and size. Also implicated in flow, bed, channel and water quality characteristics. Riparian vegetation may be influenced by a decrease in the supply of water.	0	None	0	None	0	None	0	None	0	None	10	Mod.	None observed during April 2018. The impacts are anticipated to remain the same at sites SL2 and SL3 following the construction of Bumbuna Reservoir II. Water abstraction is anticipated to increase at site SL1, within the inundation zone.
Flow Modification	Consequence of abstraction or regulation by impoundments. Changes in temporal and spatial characteristics of flow can have an impact on habitat attributes such as an increase in duration of low flow season, resulting in low availability of certain habitat types or water at the start of the breeding, flowering or growing season.	0	None	0	None	0	None	0	None	0	None	20	Serious	The formation of lateral head cuts was observed at all the upstream sites. The natural flow regime at SL1 will be severely modified because of deep flooding once Bumbuna II is inundated.
Channel Modification	May be the result of a change in flow which may alter channel characteristics causing a change in marginal instream and riparian habitat. Purposeful channel modification to improve drainage is also included.	5	Small	5	Small	5	Small	5	Small	5	Small	20	Serious	The formation of lateral head cuts was observed at all the upstream sites. The channel at site SL1 will be modified because of deep flooding once Bumbuna II is inundated.
Water Quality	Originates from point and diffuse point sources. Measured directly or agricultural activities, human settlements and industrial activities may indicate the likelihood of modification. Aggravated by a decrease in the volume of water during low or no flow conditions.	5	Small	5	Small	5	Small	5	Small	0	None	5	Small	Increased signs of sedimentation within the riparian zone at sites SL1 and SL2, because of sedimentation. A slight alteration in water quality is anticipated at site SL1 following the inundation of Bumbuna II.

Criterion	Relevance	SL3				SL2				SL1				Description
		Baseline (April 2018)		Bumbuna Reservoir II		Baseline (April 2018)		Bumbuna Reservoir II		Baseline (April 2018)		Bumbuna Reservoir II		
Inundation	Destruction of riffle, rapid and riparian zone habitat. Obstruction to the movement of aquatic fauna and influences water quality and the movement of sediments (Gordon et al., 1992).	0	None	0	None	0	None	0	None	0	None	20	Serious	None observed during the April 2018 assessment. The impacts are anticipated to remain the same at sites SL2 and SL3 following the construction of Bumbuna Reservoir II. The reach associated with site SL1, will experience deep flooding once the Bumbuna II is inundated.
Vegetation Removal	Impairment of the buffer the vegetation forms to the movement of sediment and other catchment runoff products into the river (Gordon et al., 1992). Refers to physical removal for farming, firewood and overgrazing. Includes both exotic and indigenous vegetation.	5	Small	5	Small	5	Small	5	Small	5	Small	20	Serious	Small scale farming practices has resulted in the clearing of indigenous vegetation within the riparian zone at all the upstream sites. Vegetation within the riparian zone at site SL1 will be severely impacted because of deep flooding impacts are anticipated at the reaches associated with site SL2 and SL3.
Exotic Vegetation	Excludes natural vegetation due to vigorous growth, causing bank instability and decreasing the buffering function of the riparian zone. Allochthonous organic matter input will also be changed. Riparian zone habitat diversity is also reduced.	0	None	0	None	0	None	0	None	0	None	0	None	None observed during the April 2018 assessment. No addition impacts are anticipated following the construction of Bumbuna II.
Bank Erosion	Decrease in bank stability will cause sedimentation and possible collapse of the river bank resulting in a loss or modification of both instream and riparian habitats. Increased erosion can be the result of natural vegetation removal, overgrazing or exotic vegetation encroachment.	5	Small	5	Small	5	Small	5	Small	5	Small	5	Small	Bank slopes < 30°at all the upstream sites. Lateral headcuts were observed. Bank erosion is not expected to increase upstream of Bumbuna II.
Riparian habitat integrity %		**90**		**90**		**90**		**90**		**92**		**51**		
Riparian habitat integrity Class		**A**		**A**		**A**		**A**		**A**		**D**		
Overall IHI %		**88,00**		**88,00**		**93,40**		**93,40**		**92,20**		**51,70**		
Overall IHI category		**B**		**B**		**A**		**A**		**A**		**D**		

Table 10-5: Results for the IHI for sites SL5 to SL7, located downstream of Bumbuna Dam, April 2018

Criterion	Relevance	SL5				SL6				SL7				Description
		April 2018		Bumbuna Reservoir II		April 2018		Bumbuna Reservoir II		April 2018		Bumbuna Reservoir II		
Instream Habitat Integrity		**Score**	**Cat.**	**Score**	**Cat.**	**Score**	**Cat.**	**Score**	**Cat.**	**Score**	**Cat.**	**Score**	**Cat.**	
Water abstraction	Direct impact on habitat type, abundance and size. Also implicated in flow, bed, channel and water quality characteristics. Riparian vegetation may be influenced by a decrease in the supply of water.	5	Small	5	Small	5	Small	5	Small	5	Small	5	Small	Water abstraction by rural settlements and impoundments, within the catchment at reaches associated with all the reaches. Water abstraction is not expected to change downstream of Bumbuna I, following the construction of Bumbuna II.
Flow modification	Consequence of abstraction or regulation by impoundments. Changes in temporal and spatial characteristics of flow can have an impact on habitat attributes such as an increase in duration of low flow season, resulting in low availability of certain habitat types or water at the start of the breeding, flowering or growing season.	20	Serious	25	Critical	20	Serious	23	Critical	20	Serious	23	Critical	The natural flow regime of the system in the reach downstream of Bambina Dam is seriously impacting on because of: (I) increased duration of high flows, and (ii) the change in the onset of low flows. This impact will be intensified following the new hydrological regime.
Channel modification	May be the result of a change in flow, which may alter channel characteristics causing a change in marginal instream and riparian habitat. Purposeful channel modification to improve drainage is also included.	0	None	0	None	0	None	0	None	0	None	0	None	None observed during the April 2018 assessment. No addition impacts are anticipated following the construction of Bumbuna II.
Water quality	Originates from point and diffuse point sources. Measured directly or agricultural activities, human settlements and industrial activities may indicate the likelihood of modification. Aggravated by a decrease in the volume of water during low or no flow conditions.	0	None	0	None	0	None	0	None	0	None	0	None	None observed during the April 2018 assessment. No addition impacts are anticipated following the construction of Bumbuna II.

Criterion	Relevance	SL5				SL6				SL7				Description
		April 2018		Bumbuna Reservoir II		April 2018		Bumbuna Reservoir II		April 2018		Bumbuna Reservoir II		
Inundation	Destruction of riffle, rapid and riparian zone habitat. Obstruction to the movement of aquatic fauna and influences water quality and the movement of sediments (Gordon et al., 1992).	0	None	5	Small	0	None	5	Small	0	None	5	Small	None observed during the April 2018 assessment. A slight impact is anticipated following construction of Bumbuna II.
Bed modification	Regarded as the result of increased input of sediment from the catchment or a decrease in the ability of the river to transport sediment (Gordon et al., 1993). Indirect indications of sedimentation are stream bank and catchment erosion. Purposeful alteration of the stream bed, e.g. the removal of rapids for navigation (Hilden & Rapport, 1993) is also included.	0	None	0	None	0	None	0	None	0	None	0	None	None observed during the April 2018 assessment. No addition impacts are anticipated following the construction of Bumbuna II.
Exotic macrophytes	Alteration of habitat by obstruction of flow and may influence water quality. Dependent upon the species involved and scale of infestation.	0	None	0	None	0	None	0	None	0	None	0	None	None observed during the April 2018 assessment. No addition impacts are anticipated following the construction of Bumbuna II.
Exotic fauna	The disturbance of the stream bottom during feeding may influence the water quality and increase turbidity. Dependent upon the species involved and their abundance.	0	None	0	None	0	None	0	None	0	None	0	None	None observed during the April 2018 assessment. No addition impacts are anticipated following the construction of Bumbuna II.
Solid waste	A direct anthropogenic impact which may alter habitat structurally. Also, a general indication of the misuse and mismanagement of the river.	10	Mod.	10	Mod.	0	None	0	None	0	None	0	None	None observed during the April 2018 assessment. No addition impacts are anticipated following the construction of Bumbuna II.
Instream Habitat Integrity Score		**84**		**80**		**87**		**83**		**87**		**83**		
Integrity Class		**B**		**B**		**B**		**B**		**B**		**B**		

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Criterion	Relevance	SL5				SL6				SL7				Description
		April 2018		Bumbuna Reservoir II		April 2018		Bumbuna Reservoir II		April 2018		Bumbuna Reservoir II		
Riparian Habitat Integrity		**Score**	**Cat.**	**Score**	**Cat.**	**Score**	**Cat.**	**Score**	**Cat.**	**Score**	**Cat.**	**Score**	**Cat.**	
Water Abstraction	Direct impact on habitat type, abundance and size. Also implicated in flow, bed, channel and water quality characteristics. Riparian vegetation may be influenced by a decrease in the supply of water.	0	None	0	None	5	Small	5	Small	5	Small	5	Small	Water abstraction by rural settlements within the catchment at the reaches associated with all the sites, except SL5. No addition impacts are anticipated following the construction of Bumbuna II.
Flow Modification	Consequence of abstraction or regulation by impoundments. Changes in temporal and spatial characteristics of flow can have an impact on habitat attributes such as an increase in duration of low flow season, resulting in low availability of certain habitat types or water at the start of the breeding, flowering or growing season.	5	Small	10	Mod	5	Small	10	Mod	10	Mod	13	Large	Clearing because of rural settlements has resulted in a small alteration to surface flows within the associated catchments. A larger extent of the riparian zone will be inundated for a larger duration under the new hydrological regime.
Channel Modification	May be the result of a change in flow which may alter channel characteristics causing a change in marginal instream and riparian habitat. Purposeful channel modification to improve drainage is also included.	0	None	3	Small	5	Small	8	Mod	5	Small	8	Mod	The formation of lateral head cuts was observed at site SL6. A larger extent of the riparian zone will be inundated for a larger duration under the new hydrological regime which may result in the formation of erosional features. As the channel morphology at theses reaches are bedrock dominated, channel incision is not anticipated.
Water Quality	Originates from point and diffuse point sources. Measured directly or agricultural activities, human settlements and industrial activities may indicate the likelihood of modification. Aggravated by a decrease in the volume of water during low or no flow conditions.	10	Mod	10	Mod	3	Small	3	Small	3	Small	3	Small	An increase in suspended solids was observed, particularly at site SL5 (refer to Table 8.8) located directly downstream of Bambina dam. No addition impacts on water quality are anticipated following the construction of Bumbuna II.

Criterion	Relevance	SL5				SL6				SL7				Description
		April 2018		Bumbuna Reservoir II		April 2018		Bumbuna Reservoir II		April 2018		Bumbuna Reservoir II		
Inundation	Destruction of riffle, rapid and riparian zone habitat. Obstruction to the movement of aquatic fauna and influences water quality and the movement of sediments (Gordon et al., 1992).	0	None	5	Small	10	Mod	15	Large	10	Mod	15	Large	Erosional features have impacted on the extent of inundation within the riparian zone. This impact is anticipated to intensify slightly following the new hydrological regime.
Vegetation Removal	Impairment of the buffer the vegetation forms to the movement of sediment and other catchment runoff products into the river (Gordon et al., 1992). Refers to physical removal for farming, firewood and overgrazing. Includes both exotic and indigenous vegetation.	5	Small	7	Mod	10	Mod	12	Large	10	Mod	12	Large	Small scale farming practices has resulted in the clearing of indigenous vegetation within the riparian zone at sites SL5. A larger extent of vegetation clearing was noted within the reaches associated with sites SL6 and SL7. As a larger extent of the riparian zone will be inundated for a larger duration under the new hydrological regime, a decrease in vegetation cover may occur.
Exotic Vegetation	Excludes natural vegetation due to vigorous growth, causing bank instability and decreasing the buffering function of the riparian zone. Allochthonous organic matter input will also be changed. Riparian zone habitat diversity is also reduced.	0	None	0	None	5	Small	5	Small	5	Small	5	Small	The presence of exotic vegetation was observed within the riparian zones at sites SL6 and SL7. No addition impacts are anticipated following the construction of Bumbuna II.
Bank Erosion	Decrease in bank stability will cause sedimentation and possible collapse of the river bank resulting in a loss or modification of both instream and riparian habitats. Increased erosion can be the result of natural vegetation removal, overgrazing or exotic vegetation encroachment.	5	Small	10	Mod	5	Small	10	Mod	5	Small	10	Mod	Bank slope >60˚ and lateral headcuts present at site SL5. Bank slopes < 30 at sites SL6 and SL7. The new hydrological regime may result in the formation of erosional features.
Riparian habitat integrity %		**87**		**77**		**76**		**66**		**74**		**65**		
Riparian habitat integrity Class		**B**		**C**		**C**		**C**		**C**		**C**		
Overall IHI %		**85,70**		**78,46**		**81,52**		**74,80**		**80,32**		**74,08**		
Overall IHI category		**B**		**C**		**B**		**C**		**B**		**C**		

Table 10-6: Results for the IHI for sites SL8 to SL10, located downstream of Bumbuna Dam, April 2018

Criterion	Relevance	SL8				SL9				SL10				Description
		April 2018		Bumbuna Reservoir II		April 2018		Bumbuna Reservoir II		April 2018		Bumbuna Reservoir II		
Instream Habitat Integrity		**Score**	**Cat.**	**Score**	**Cat.**	**Score**	**Cat.**	**Score**	**Cat.**	**Score**	**Cat.**	**Score**	**Cat.**	
Water abstraction	Direct impact on habitat type, abundance and size. Also implicated in flow, bed, channel and water quality characteristics. Riparian vegetation may be influenced by a decrease in the supply of water.	5	Small	5	Small	15	Large	15	Large	5	Small	5	Small	Water abstraction by rural settlements and impoundments, within the catchment at reaches associated with all the reaches. Furthermore, an irrigation system was observed at site SL9.
Flow modification	Consequence of abstraction or regulation by impoundments. Changes in temporal and spatial characteristics of flow can have an impact on habitat attributes such as an increase in duration of low flow season, resulting in low availability of certain habitat types or water at the start of the breeding, flowering or growing season.	20	Serious	22	Critical	20	Serious	22	Critical	10	Moderate	13	Large	The natural flow regime of the system in the reach downstream of Bambina Dam is seriously impacting on because of: (I) increased duration of high flows, and (ii) the change in the onset of low flows. This impact appears less extensive at site SL10. This impact is expected to be intensified at site SL8 and SL9 following the new hydrological regime.
Channel modification	May be the result of a change in flow, which may alter channel characteristics causing a change in marginal instream and riparian habitat. Purposeful channel modification to improve drainage is also included.	0	None	0	None	15	Large	18	Serious	0	None	0	None	None observed at site SL8 and SL10 during the April 2018 assessment. Channel incision has taken place to a large extent at site SL9. This impact may be intensified at site SL9, following the new hydrological regime.
Water quality	Originates from point and diffuse point sources. Measured directly or agricultural activities, human settlements and industrial activities may indicate the likelihood of modification. Aggravated by a decrease in the volume of water during low or no flow conditions.	5	Small	5	Small	0	None	0	None	5	Small	5	Small	An increase in algal blooms were observed at site SL8. Agricultural and rural activities taking place in the immediate catchment at site SL10. No addition impacts on water quality are anticipated following the construction of Bumbuna II.

Criterion	Relevance	SL8				SL9				SL10				Description
		April 2018		Bumbuna Reservoir II		April 2018		Bumbuna Reservoir II		April 2018		Bumbuna Reservoir II		
Inundation	Destruction of riffle, rapid and riparian zone habitat. Obstruction to the movement of aquatic fauna and influences water quality and the movement of sediments (Gordon et al., 1992).	0	None	5	Small	15	Large	15	Large	0	None	3	Small	None observed at site SL8 and SL10 during the April 2018 assessment. Extensive channel incision observed at the reach associated with site SL9, prohibits to some extended the seasonal lateral inundation of the riparian zones
Bed modification	Regarded as the result of increased input of sediment from the catchment or a decrease in the ability of the river to transport sediment (Gordon et al., 1993). Indirect indications of sedimentation are stream bank and catchment erosion. Purposeful alteration of the stream bed, e.g. the removal of rapids for navigation (Hilden & Rapport, 1993) is also included.	5	Small	5	Small	0	None	0	None	0	None	0	None	None observed at sites SL9 and SL10 during the April 2018 assessment. Algal growth at site SL8, has resulted in the smothering of some of the substrate. No additional impact is anticipated following construction of Bumbuna II.
Exotic macrophyte	Alteration of habitat by obstruction of flow and may influence water quality. Dependent upon the species involved and scale of infestation.	0	None	0	None	0	None	0	None	0	None	0	None	None observed during the April 2018 assessment. No additional impact is anticipated following construction of Bumbuna II.
Exotic fauna	The disturbance of the stream bottom during feeding may influence the water quality and increase turbidity. Dependent upon the species involved and their abundance.	0	None	0	None	0	None	0	None	0	None	0	None	None observed during the April 2018 assessment. No additional impact is anticipated following construction of Bumbuna II.
Solid waste	A direct anthropogenic impact which may alter habitat structurally. Also, a general indication of the misuse and mismanagement of the river.	0	None	0	None	0	None	0	None	5	Small	5	Small	The presence of litter was at site SL10. No additional impact is anticipated following construction of Bumbuna II.
Instream Habitat Integrity Score		**81**		**78**		**67**		**65**		**88**		**85**		
Integrity Class		**B**		**C**		**C**		**C**		**B**		**B**		

Criterion	Relevance	SL8				SL9				SL10				Description
		April 2018		Bumbuna Reservoir II		April 2018		Bumbuna Reservoir II		April 2018		Bumbuna Reservoir II		
Riparian Habitat Integrity		**Score**	**Cat.**	**Score**	**Cat.**	**Score**	**Cat.**	**Score**	**Cat.**	**Score**	**Cat.**	**Score**	**Cat.**	
Water Abstraction	Direct impact on habitat type, abundance and size. Also implicated in flow, bed, channel and water quality characteristics. Riparian vegetation may be influenced by a decrease in the supply of water.	5	Small	5	Small	5	Small	5	Small	5	Small	5	Small	Water abstraction by rural settlements within the catchment at the reaches associated with all the sites. Water abstraction is not expected to change downstream of Bumbuna I, following the construction of Bumbuna II. No additional impact is anticipated following construction of Bumbuna II.
Flow Modification	Consequence of abstraction or regulation by impoundments. Changes in temporal and spatial characteristics of flow can have an impact on habitat attributes such as an increase in duration of low flow season, resulting in low availability of certain habitat types or water at the start of the breeding, flowering or growing season.	10	Moderate	12	Large	15	Large	17	Serious	5	Small	8	Moderate	Clearing because of rural settlements has resulted in a small alteration to surface flows within the associated catchments. Channel incision taking place within the reach at site SL9 has contributed to the decrease in flood events. This impact is expected to intensify following the new hydrological regime.
Channel Modification	May be the result of a change in flow which may alter channel characteristics causing a change in marginal instream and riparian habitat. Purposeful channel modification to improve drainage is also included.	5	Small	5	Small	10	Moderate	12	Large	0	None	5	Small	Lateral head cut formation was observed at both sites SL8 and SL9, with channel incision also occurring within the reach at site SL9. This impact is anticipated to intensify slightly following the new hydrological regime.
Water Quality	Originates from point and diffuse point sources. Measured directly or agricultural activities, human settlements and industrial activities may indicate the likelihood of modification. Aggravated by a decrease in the volume of water during low or no flow conditions.	5	Small	5	Small	5	Small	5	Small	5	Small	5	Small	A slight increase in suspended solids was observed at all three sites. No addition impacts on water quality are anticipated following the construction of Bumbuna II.

Criterion	Relevance	SL8				SL9				SL10				Description
		April 2018		Bumbuna Reservoir II		April 2018		Bumbuna Reservoir II		April 2018		Bumbuna Reservoir II		
Inundation	Destruction of riffle, rapid and riparian zone habitat. Obstruction to the movement of aquatic fauna and influences water quality and the movement of sediments (Gordon et al., 1992).	0	None	5	Small	5	Small	10	Moderate	0	None	5	Small	Channel incision taking place at site SL9 prohibits seasonal lateral inundation for riparian zones to some extent. Lateral headcuts were also observed. This impact is anticipated to intensify slightly following the new hydrological regime.
Vegetation Removal	Impairment of the buffer the vegetation forms to the movement of sediment and other catchment runoff products into the river (Gordon et al., 1992). Refers to physical removal for farming, firewood and overgrazing. Includes both exotic and indigenous vegetation.	10	Moderate	13	Large	10	Moderate	13	Large	10	Moderate	12	Large	Small scale farming practices has resulted in the clearing of indigenous vegetation within the riparian zone at sites all three of the sites. Clearing has occurred in the lower reaches of the system. This impact is anticipated to intensify slightly as a larger extent of the riparian zone will be inundated and for a longer duration following the new hydrological regime.
Exotic Vegetation	Excludes natural vegetation due to vigorous growth, causing bank instability and decreasing the buffering function of the riparian zone. Allochthonous organic matter input will also be changed. Riparian zone habitat diversity is also reduced.	0	None	0	None	5	Small	5	Small	10	Moderate	10	Moderate	The presence of exotic vegetation was observed within the riparian zones at site SL9. Present at site SL10. This impact is not anticipated to intensify following the new hydrological regime.
Bank Erosion	Decrease in bank stability will cause sedimentation and possible collapse of the river bank resulting in a loss or modification of both instream and riparian habitats. Increased erosion can be the result of natural vegetation removal, overgrazing or exotic vegetation encroachment.	5	Small	8	Moderate	10	Moderate	15	Large	5	Small	8	Moderate	Bank slope >60˚ and lateral headcuts present at site SL8, SL9 and SL10 with a higher erosion potential at site SL10. The new hydrological regime may result in the formation of erosional features, especially at reach SL9.
Riparian habitat integrity %		**80**		**73**		**67**		**59**		**80**		**71**		
Riparian habitat integrity Class		**B**		**C**		**C**		**D**		**B**		**C**		
Overall IHI %		**80,50**		**75,78**		**67,40**		**61,86**		**83,80**		**78,04**		
Overall IHI category		**B**		**C**		**C**		**C**		**B**		**C**		

11. Appendix D - Aquatic Macroinvertebrates

11.1. Materials and Methods

11.1.1. Invertebrate Habitat Assessment System

Macroinvertebrate habitat availability was assessed using the IHAS version 2 methodology (McMillan, 1998). The IHAS is a quantitative and comparable description of habitat availability for aquatic macroinvertebrates. The IHAS reflects the quantity, quality and diversity of biotopes available for habitation by aquatic macroinvertebrates. The quantity and quality of various sampling biotopes were assessed in terms of potential habitat for invertebrates and were expressed as a percentage score. The scores for each biotope were then summed up to give a total habitat score and class (**Table 11-1**). The IHAS, in this context, purely provides a relative measure of habitat availability between sites and does not reflect the ecological state of the system in any way.

Table 11-1: Invertebrate Habitat Assessment Score ratings and categories (McMillan, 1998)

IHAS score %	Description	Category
>80%	Habitat is more than adequate and able to support a diverse invertebrate fauna.	Good
<80 >70%	Habitat is adequate and able to support invertebrate fauna.	Adequate
<70%	Habitat is limited and unable to support diverse invertebrate fauna.	Poor

11.1.2. South African Scoring System (Version 5)

Aquatic macroinvertebrates were collected using the SASS5 sampling protocol (Dickens & Graham, 2002). The protocol is divided amongst three biotopes: (i) Vegetation (VEG), (ii) Stones in Current (SIC) and (iii) Gravel, Silt, Mud (GSM). Samples are collected in an invertebrate net with a pore size of 1000micron on a 30cm x 30cm frame by kick sampling of SIC and GSM, and sweeping of VEG for a standardised time or area. Macroinvertebrates were identified to family level in the field according to the SASS5 protocol and using relative reference guides (Dickens & Graham, 2002; Gerber & Gabriel, 2002). The SASS5 score, Number of Taxa and the Average Score per Taxa (ASPT) were the indices calculated using the sensitivity scores and presence of taxa in each sample.

11.1.3. MODIFIED % EPHEMEROPTERA, PLECOPTERA AND TRICHOPTERA INDEX

Community data collected in the field was used to populate the M%EPT based on the EPT method (MACS, 1996) to assess macroinvertebrate integrity. This metric measures the abundance of the generally pollution-sensitive insect orders of Ephemeroptera, Plecoptera and Trichoptera. Taxa from these orders are sensitive to environmental alterations and occur in clean and well oxygenated waters (Keci *et al.,* 2012). The EPT assemblages are commonly considered good indicators of water quality (Rosenberg & Resh, 1993). Changes in these assemblages indicate possible pollution and disturbance.

11.1.4. FUNCTIONAL FEEDING GROUPS

There are two main approaches to using macroinvertebrates as indicators of ecosystem health, namely the taxonomic approach, with the focus on diversity or taxa richness and the functional approach which focuses on the ecological functions (traits) of the taxa that makeup a given community and is more useful in determining the ecological condition of a system (Cummins *et al.* 2005). Although it has been suggested that identification of invertebrates to species level has many benefits the functional approach is more rapid. The latter approach is based on Functional Feeding Groups (FFGs) that provide information on the balance of feeding strategies (food acquisition and morphology) in the benthic assemblage. The FFGs are divided into five groups, namely scrapers, shredders, gatherers, filterers, and predators. The FFGs for taxa sampled are provided in **Table 11-2**.

Table 11-2: Specific Functional Feeding Groups for macroinvertebrates sampled at the study sites

Taxon	FFG	References
Turbellaria	Predator	Cummins *et al.* (2005) / Purcell (2007)
Oligochaeta	Collector (gatherer)	Cummins *et al.* (2005)
Potamonautidae*	Omnivore	
Atyidae	Collector (gatherer)	Merritt *et al*. (2008)
Hydracarina	Predators	Nhiwatiwa et al., (2009)
Perlidae	Predator	Merritt *et al*. (2008)
Baetidae	Collector (gatherer)	Cummins *et al*. (2005) / Merritt *et al*. (2008)
Caenidae	Collector (gatherer)	Cummins *et al*. (2005) / Merritt *et al*. (2008)
Heptageniidae	Collector (gatherer)	Merritt *et al*. (2008)
Leptophlebiidae	Collector (gatherer)	Cummins *et al.* (2005) / Merritt & Cummins (1996)
Teloganodidae	Collector (gatherer)	Hamid & Rawi (2014)
Tricorythidae	Collector (gatherer)	Bouchard (2004)
Coenagrionidae	Predator	Merritt *et al.* (2008)

Taxon	FFG	References
Gomphidae	Predator	Merritt *et al*. (2008)
Libellulidae	Predator	Merritt *et al*. (2008)
Pyralidae	Shredder	Cummins *et al.* (2005)
Corixidae*	Scraper	Cummins *et al.* (2005)
Gerridae*	Scraper	Cummins *et al.* (2005)
Naucoridae*	Predator	Cummins *et al.* (2005)
Notonectidae*	Predator	Domínguez & Fernández (2009)
Pleidae*	Predator	Cummins *et al.* (2005)
Veliidae*	Predator	Domínguez & Fernández (2009)
Hydropsychidae	Collector (filterer)	Merritt *et al*. (2008)
Hydroptilidae	Collector (gatherer)	Merritt *et al*. (2008)
Leptoceridae	Shredder	Cummins *et al*. (2005)
Dytiscidae*	Predator	Cummins *et al.* (2005)
Elmidae	Scraper	Cummins *et al.* (2005)
Gyrinidae*	Predator	Cummins *et al.* (2005)
Haliplidae*	Shredder	Merritt *et al*. (2008)
Hydrophilidae*	Collector (gatherer)	Cummins *et al*. (2005) / Merritt *et al*. (2008)
Psephenidae	Scraper	Cummins *et al*. (2005) / Merritt *et al*. (2008)
Athericidae	Predator	Cummins *et al.* (2005) / Merritt *et al*. (2008)
Ceratopogonidae	Predator	Cummins *et al.* (2005)
Chironomidae	Collector (gatherer)	Cummins *et al.* (2005)
Culicidae*	Collector (filterer)	Cummins *et al.* (2005)
Simuliidae	Collector (filterer)	Cummins *et al.* (2005)
Tabanidae	Predator	Cummins *et al.* (2005)
Tipulidae	Predator	Cummins *et al.* (2005)
Ancylidae	Scraper	Nhiwatiwa *et al.* (2009)
Sphaeriidae	Collector (filterer)	Purcell (2007)

11.1.5. MACROINVERTEBRATE RESPONSE ASSESSMENT INDEX

Abundance data collected from the implementation of the SASS5 protocol at each site was used to populate the updated MIRAI v2 (Thirion, 2016). The MIRAI is a rule-based index that makes use of a rating approach comprised of four different metric groups that measure the change in present macroinvertebrate assemblages from the reference assemblage. The MIRAI is the change in assemblage in terms of four different metric groups:

- flow modification;

- habitat modification;
- water quality modification, and
- system connectivity and seasonality.

Abundances obtained during the survey were compared to the reference condition to establish the present state of the sites. The MIRAI approach is based on rating the degree of change from natural on a scale of 0 (no change from reference condition) to 5 (maximum change from reference condition) for a variety of different metrics (Thirion, 2016). An increase or decrease in abundance is considered as a change compared to natural conditions.

The outcome of the model is to derive an Ecological Category by combining the four metric groups and expressing it as a percentage of similarity to reference conditions (**Table 11-3**).

Table 11-3: Ecological Integrity Categories (Thirion, 2016 - modified from Kleynhans, 1996 and Kleynhans, 1999)

Ecological Category	Generic Description of Ecological Conditions	Arbitrary Guideline Score (% of Maximum Theoretical Total)
A	Unmodified/natural, close to natural or close too predevelopment conditions within the natural variability of the system drivers: hydrology, physico-chemical and geomorphology. The habitat template and biological components can be considered close to natural or to pre-development conditions. The resilience of the system has not been compromised.	**>92 - 100**
A/B	The system and its components are in a close to natural condition most of the time. Conditions may rarely and temporarily decrease below the upper boundary of a B category.	**>88 - ≤92**
B	Largely natural with few modifications. A small change in the attributes of natural habitats and biota may have taken place in terms of frequencies of occurrence and abundance. Ecosystem functions and resilience are essentially unchanged.	**>82 - ≤88**
B/C	Close to largely natural most of the time. Conditions may rarely and temporarily decrease below the upper boundary of a C category.	**>78 - ≤82**
C	Moderately modified. Loss and change of natural habitat and biota have occurred in terms of frequencies of occurrence and abundance. Basic ecosystem functions are still predominantly unchanged. The resilience of the system to recover from human impacts has not been lost and it is ability to recover to a moderately modified condition following disturbance has been maintained.	**>62 - ≤78**
C/D	The system is in a close to moderately modified condition most of the time. Conditions may rarely and temporarily decrease below the upper boundary of a D category.	**>58 - ≤62**
D	Largely modified. A large change or loss of natural habitat, biota and basic ecosystem functions have occurred. The resilience of the system to sustain this category has not been compromised and the ability to deliver ecological goods and services has been maintained.	**>42 - ≤58**
D/E	The system is in a close to largely modified condition most of the time. Conditions may rarely and temporarily decrease below the upper boundary of an E category. The resilience of the system is often under severe stress and may be lost permanently if adverse impacts continue.	**>38 - ≤42**
E	Seriously modified. The change in the natural habitat template, biota and basic ecosystem functions are extensive. Only resilient biota may survive, and it is highly likely that invasive and problem (pest) species may dominate. The resilience of the system is severely compromised as is the capacity to provide ecological goods and services. However, geomorphological conditions are largely intact but	**>20 - ≤38**

Ecological Category	Generic Description of Ecological Conditions	Arbitrary Guideline Score (% of Maximum Theoretical Total)
	extensive restoration may be required to improve the system's hydrology and physico-chemical conditions.	
E/F	The system is in a close to seriously modified condition most of the time. Conditions may rarely and temporarily decrease below the upper boundary of an F category. The resilience of the system is frequently under severe stress and may be lost permanently if adverse impacts continue.	**>18 - ≤20**
F	Critically/Extremely modified. Modifications have reached a critical level and the system has been modified completely with an almost complete change of the natural habitat template, biota and basic ecosystem functions. Ecological goods and services have largely been lost This is likely to include severe catchment changes as well as hydrological, physico-chemical and geomorphological changes. In the worst instances the basic ecosystem functions have been destroyed and the changes are irreversible. Restoration of the system to a synthetic but sustainable condition acceptable for human purposes and to limit downstream impacts is the only option.	**≤18**

11.2. RESULTS AND DISCUSSION

There are several factors that influence the presence and distribution of aquatic macroinvertebrates, with the most important of these being: *current velocity* (Bunn & Arthington, 2002; Donohue *et al*., 2006; Hussain, 2011), *temperatur*e (Lessard & Hayes, 2003; Sullivan *et al*., 2004; Worthington *et al.,* 2015), *the substratum* (Courtney & Clements, 2002; LeCraw & Mackreth, 2010, Hussain & Pandit, 2012), *vegetation* (Subramanian & Sivaramakrishnan, 2005; Kleynhans *et al.,* 2007), and *dissolved substances* (Sorensen *et al.,* 1977; LeCraw & Mackreth, 2010; Xu *et al*., 2014).

This section deals with spatial variation within the aquatic macroinvertebrate community structures linked to the sites assessed during April 2018, as well as temporal variation associated with the 3 sites assessed in the stretch of river downstream of the dam, surveyed during August 2016. The sensitivity of each community is represented based on the known preferences and tolerances (Thirion, 2016) of invertebrates sampled and the ecological category inferred from the present invertebrate assemblages. **Table 11-6** provides details on the habitat preferences and tolerances of the invertebrate communities sampled at each site, while the macroinvertebrate abundances sampled is summarised in **Table 11-7**. The results of the macroinvertebrate assessment informed the habitat stress curves applied in the EWR.

11.2.1. HABITAT AVAILABILITY

Habitat availability (quality and quantity) is an important part of an ecosystem as it forms a template for the biotic communities. If the habitat quality is low, it will influence the biotic assemblages noted. When the habitat diversity is high and un-impacted, the biotic community structures tend to be in a relatively good condition. Habitat availability and diversity are major determinants in the overall community structure of aquatic macroinvertebrates. For this reason, it is important to evaluate habitat quality and quantity when applying biomonitoring methodologies and assessing ecosystem health. The main points are briefly discussed below:

- Overall, the habitat template for the Seli / Rokel system is characterised mainly by bedrock and boulders, interspersed with areas consisting of cobbles, pebbles, gravel and sand banks (**Table 11-4**). Apart from sites SL3 and SL9, all the sites contained SIC habitat (**Table 11-1 A**).
- All the upstream sites on the Seli, indicated *Poor* habitat availability for the colonization of aquatic macroinvertebrates (**Table 11-5**). Site SL3 lacked SIC habitat while site SL1 lacked inundated marginal vegetation (**Table 11-1 A**). Concurrently, site SL2 indicated higher habitat diversity, but was still considered *Poor*/Adequate overall, mainly due to the lack of enough marginal and aquatic vegetation.

- With regards to the downstream Rokel system, Site SL5, SL8 and SL9 indicated *Poor* habitat availability for the colonization of aquatic macroinvertebrates (**Table 11-5**):
  - Site SL9 obtained the lowest IHAS score of all the sites assessed (**Table 11-1 B**) as only GSM habitat was available for sampling within the reach. This site was dominated by sand habitat (**Table 11-4**).
  - Sites SL5 and SL8 obtained higher scores, but were still considered *Poor* overall, mainly due to the lack of enough marginal and aquatic vegetation.
- Site SL10, obtained the highest score of all the sites assessed and was classed as *Adequate,* while sites SL6 and SL7 obtained slightly lower scores and therefore the habitat was considered *Poor*/Adequate overall (**Table 11-5**):
  - Abundant SIC habitat was present within the reach at site SL10, in addition to the highest vegetation score recorded (**Table 11-1 A**).
  - The lower overall IHAS scores at sites SL6 and SL7 is mainly attributed to lower SIC and vegetation scores recorded (**Table 11-1 A**).

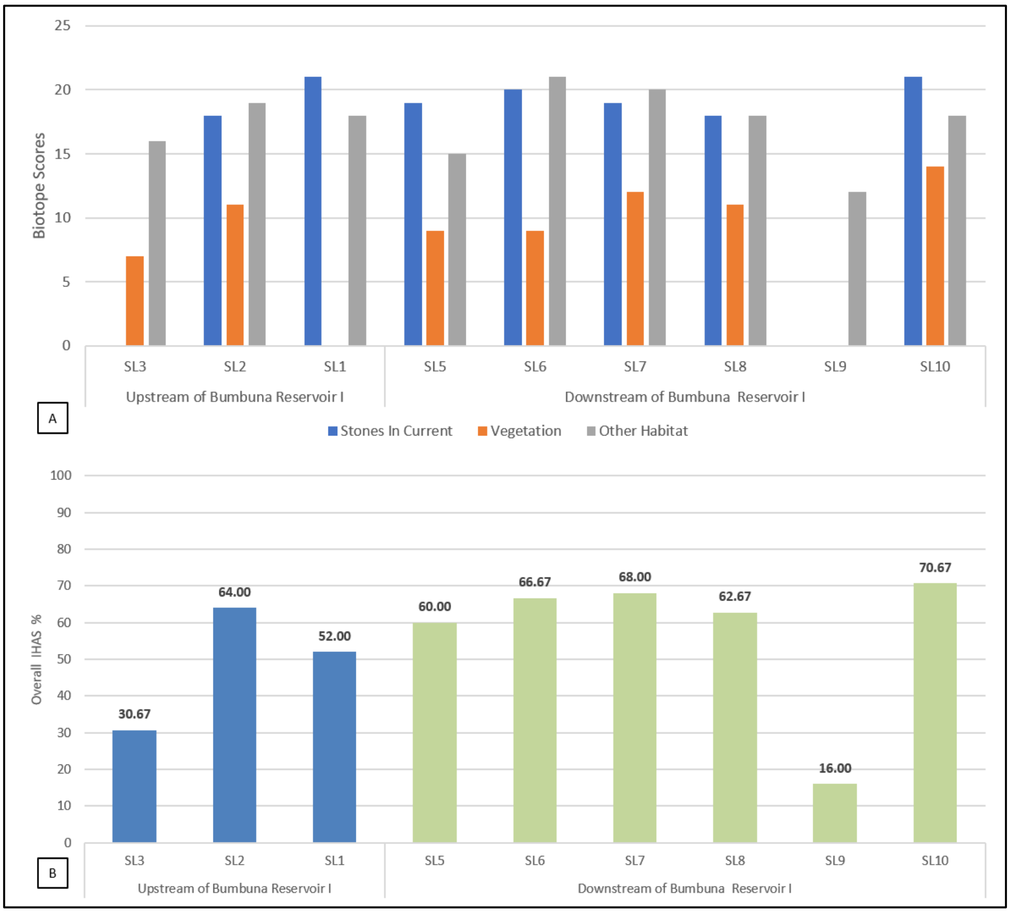


Figure 11-1: Bar graph indicating the (A) biotopes available for habitation by aquatic macroinvertebrates and (B) the overall IHAS %scores at all the study sites during the April 2018 Assessment.

Table 11-4: Substrate composition at all the sites assessed during the April 2018 assessment

Substrate Composition	Upstream of Bumbuna Dam				Downstream of Bumbuna Dam				
	SL3	SL2	SL1	SL5	SL6	SL7	SL8	SL9	SL10
Bedrock	Common	Sparse	Abundant	Abundant	Abundant	Abundant	Abundant	Absent	Absent
Boulder (>256 mm)	Absent	Abundant	Abundant	Abundant	Abundant	Common	Abundant	Absent	Abundant
Cobble (100-256 mm)	Absent	Abundant	Common	Common	Abundant	Common	Common	Absent	Abundant
Pebble (16-100 mm)	Absent	Common	Common	Common	Abundant	Sparse	Sparse	Absent	Abundant
Gravel (2-16 mm)	Sparse	Common	Sparse	Common	Abundant	Common	Sparse	Sparse	Abundant
Sand (0.06-2 mm)	Abundant	Abundant	Abundant	Common	Abundant	Abundant	Common	Abundant	Abundant
Silt/mud/clay (<0.06 mm)	Rare	Sparse	Rare	Rare	Sparse	Sparse	Sparse	Sparse	Absent
Degree of Embeddedness (%)	26-50	0-25	0-25	26-50	26-50	0-25	26-50	0-25	0-25

Table 11-5: IHAS of sites assessed during the April 2018 assessment

System	Upstream of Bumbuna Reservoir I				Downstream of Bumbuna Dam				
	SL3	SL2	SL1	SL5	SL6	SL7	SL8	SL9	SL10
Total IHAS (%)	**30.67**	**64.00**	**52.00**	**60.00**	**66.67**	**68.00**	**62.67**	**16.00**	**70.67**
Class	**POOR**	**POOR / ADEQUATE**	**POOR**	**POOR**	**POOR / ADEQUATE**	**POOR / ADEQUATE**	**POOR**	**POOR**	**ADEQUATE**

11.2.2. Community Assemblage

11.2.2.1. Functional Feeding Groups

Aquatic macroinvertebrates can be useful surrogates for ecosystem attributes, and the relative abundance of functional groups can indicate anthropogenic impact (Merritt *et al.,* 2002, Cummins *et al.,* 2005, Merritt & Cummins, 2006). Specialized feeders, such as scrapers and shredders, are the more sensitive organisms and usually represent healthy streams. Generalists, such as collectors (gatherers and filterers) have a broader diet range compared to specialists (Cummins & Klug, 1979), and thus are more tolerant to pollution that might alter availability of certain food. These functional feeding measures for benthic macroinvertebrates have the potential to be reliable metrics however, they have not been well demonstrated and there have been difficulties associated with the proper assignment of these feeding groups (Karr & Chu, 1997). The FFG's were assessed at each of the study sites with the main aspects briefly discussed below:

- Predator and collector (gatherers) populations were the predominant feeding groups, making up more than 70% of the total FFGs, at all the study sites assessed during the April 2018 assessment (**Figure 11-2**).
- The make-up of the FFGs is expected as the substrate composition of the study sites were dominated by stones / boulder and GSM, which can support diverse predator and collector (gatherer) populations.
- The scraper and collector (filterer) populations made up the next largest groups, with shredders making up the least abundant group, and where absent in the at sites SL1, SL6 and SL9 (**Figure 11-2**).
- Spatially, the FFGs showed no notable variation between the sites up- and downstream of Bumbuna Reservoir I.

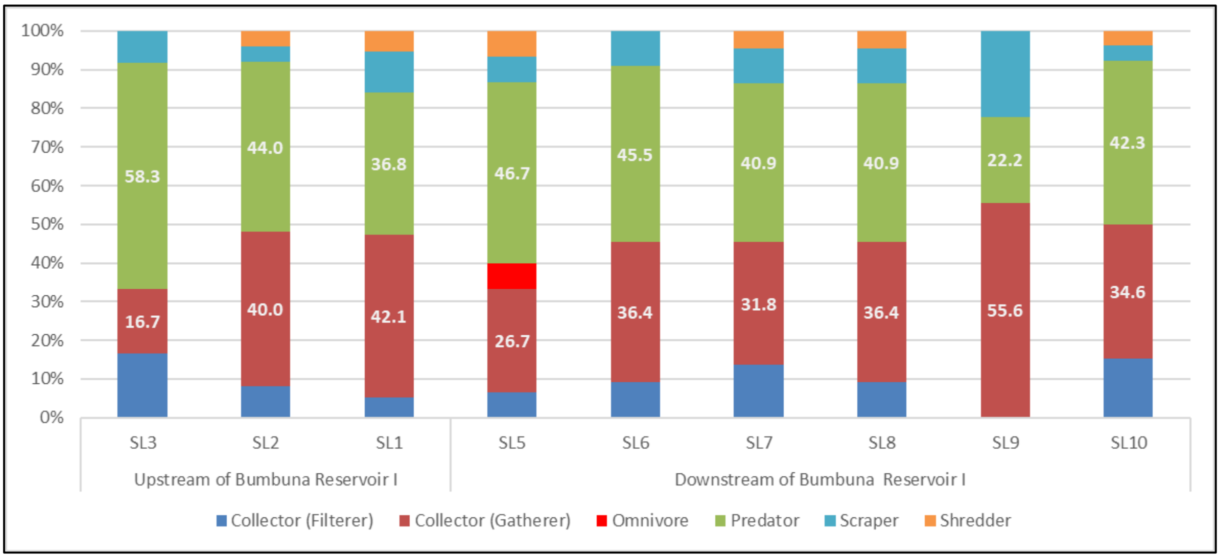


Figure 11-2: Stacked column graph illustrating the percentage distribution of the FFGs at each study site.

11.2.2.2. Invertebrate Sensitivity

The sensitivity assessment used preferences and tolerances of sampled aquatic macroinvertebrates to infer likely sensitivity to alterations in hydrology, substrate composition and water quality. The macroinvertebrate sensitivity took the following three aspects into account:

i. *Presence of sensitive taxa* - This provides a measure of relative sensitivity between the different sites assessed. The assessment is based on the macroinvertebrates sampled and not macroinvertebrates expected to occur.
ii. ASPT - this index is based on the principle that different aquatic macroinvertebrates have different tolerances to pollutants. The sensitivity scores are derived from the tolerances of macroinvertebrates to pollution as used in the SASS5 scoring system, ranging from a high tolerance to a very low tolerance to pollution (Dickens & Graham, 2001).
iii. *Ephemeroptera, Plecoptera* and *Trichoptera* – since EPT taxa are pollution sensitive taxa, using the %EPT will therefore be a good indication of impacts related to land use activities on the diversity and abundance of macroinvertebrates and changes in community structure.

Table 11-6 shows the sensitivity of sampled aquatic macroinvertebrates to alteration in flow, substrate and water quality, based on their respective preferences. Cells marked with an “X” indicate the presence of a specific preference. The following main aspects were identified with regards to the expected and sampled macroinvertebrate community assemblage:

- Several taxa with a high preference for very fast flow water (>0.6 m/s) were sampled at the study sites during the April 2018 assessment. These included taxa from the following families: Oligoneuridae, Philopotamidae, Tricorythidae, Hydropsychidae, Hydraenidae, Elmidae and Simuliidae (**Table 11-6**).
- Regarding taxa with a preference for good water quality, several taxa were sampled both up- and downstream of Bumbuna Dam. This included taxa from the following families: Oligoneuridae, Heptageniidae, Perlidae, and Hydropsychidae (>2 spp). However, Oligoneuridae were only sampled further downstream of Bumbuna Reservoir I (**Table 11-6**).
- The above-mentioned points highlight the fact that the associated reaches located both up- and downstream of Bumbuna Reservoir I indicated good water quality overall, with the presence of taxa sensitive to alteration in flows.
- However, this is not true for site SL5, which is situated directly downstream of Bumbuna Dam. None of the above-mentioned taxa were sampled at site SL5 during the April 2018 assessment (**Table 11-6**).

Table 11-6: Table showing the environmental preferences and tolerances of the sampled aquatic macroinvertebrates (Thirion, 2016)

Taxon	Sens.	SL3	SL2	SL1	SL5	SL6	SL7	SL8	SL9	SL10	Velocity metrics				Habitat metrics				Water Quality
											<0.1	0.1-0.3	0.3-0.6	>0.6	COBBLES	VEG	GSM	WATER	
Oligochaeta	1	X	X	X	X	X	X	X	X	X	4.5	4	3.5	3.5	4	3	4.5	0	VERY LOW
Hirudinea	3	X		X	X			X			3	4.5	4	2.5	4	2.5	4	0	VERY LOW
Potamonautidae	3				X						4	4.5	4.5	4.5	4.5	0.5	4	0	VERY LOW
Atyidae	8	X								X	4	3.5	0.5	0	1	4.5	0.5	0	MODERATE
Hydracarina	8		X			X	X		X	X	3	3	3	3	3	2.5	2.5	0.5	MODERATE
Perlidae	12		X	X	X	X	X	X		X	0.5	3	4	3.5	4	0.5	1.5	0	HIGH
Baetidae 1sp	4							X	X		3	3.5	4	4	4	4	4	0	LOW
Baetidae 2spp	6		X	X	X	X	X			X	3	3.5	4	4	4	4	4	0	LOW
Caenidae	6		X	X		X		X	X	X	4.5	3.5	3	3	3	3	4.5	0	LOW
Heptageniidae	13		X	X			X	X		X	1	4	4.5	3	4.5	0.5	1.5	0	HIGH
Leptophlebiidae	9		X								2	3.5	4.5	3.5	4	1	3.5	0	MODERATE
Oligoneuridae	15					X		X		X	0	0	3	5	4.5	3.5	1	0	HIGH
Polymitarcyidae	10					X		X	X	X	4.5	1	0	0	0.5	0.5	5	0	MODERATE
Trichorythidae	9		X	X		X	X	X		X	0.5	2	3.5	4.5	4.5	1	0.5	0	MODERATE
Chlorocyphidae	10		X								3	4	3	1	4.5	3	1.5	0	MODERATE
Coenagrionidae	4		X		X	X				X	4.5	3.5	2	2	0.5	4.5	0.5	0	LOW
Aeshnidae	8		X								2.5	3.5	4	2.5	4	3	3	0	MODERATE
Gomphidae	6		X	X	X	X	X	X		X	4.5	4	3	2.5	2.5	1	4.5	0	LOW
Libellulidae	4	X			X	X	X	X			3	3.5	4	3.5	4.5	3.5	2.5	0	LOW
Belostomatidae	3	X								X	4	1	0	0	0	4.5	0.5	0	VERY LOW
Corixidae	3			X	X	X	X	X	X		4.5	3	1.5	1	3	2.5	3.5	2	VERY LOW
Gerridae	5	X						X			4	3.5	2.5	0	1	3	0	4	LOW
Naucoridae	7			X					X	X	3	4	3	1.5	3.5	3.5	3.5	3	LOW

Nepidae	3		X					X			4.5	0.5	0	0	0	5	0	0	VERY LOW
Notonectidae	3	X		X				X			4	3	0.5	0	0	4	0	3.5	VERY LOW
Veliidae	5		X	X	X	X	X	X		X	4	2.5	2	2	2.5	3.5	1.5	4.5	LOW
Ecnomidae	8		X		X						2	3.5	3.5	1.5	4	1	1.5	0	MODERATE
Hydropsychidae 2spp	6					X					1	2.5	4	4.5	4.5	1	1.5	0	LOW
Hydropsychidae >2spp	12		X	X			X			X	1	2.5	4	4.5	4.5	1	1.5	0	HIGH
Philopotamidae	10									X	0.5	1.5	3.5	4.5	4.5	1	0.5	0	MODERATE
Hydroptilidae	6		X	X	X	X	X	X		X	3.5	4	4.5	3	3.8	4	1.5	0	LOW
Leptoceridae	6		X	X	X		X	X		X	4	4	4	3.5	3.5	4	4	0	LOW
Dytiscidae	5	X	X			X		X		X	4.5	1.5	0.5	0	2	4	3.5	0	LOW
Elmidae	8		X	X		X	X		X	X	1.5	3	4	4.5	4	1	3.5	0	MODERATE
Gyrinidae	5	X					X			X	3.5	3.5	3.5	3.5	3	3.5	2	4	LOW
Hydraenidae	8		X	X			X				1	1.5	3	4	4	3	1.5	3	MODERATE
Hydrophilidae	5		X			X					3.5	3.5	3.5	3.5	2.5	4.5	1.5	1	LOW
Athericidae	10		X			X	X				3.5	4.5	4	3.5	4	3	3	0	MODERATE
Ceratopogonidae	5	X				X	X	X		X	4.5	3	2.5	4.5	3.5	2	4	0	LOW
Chironomidae	2	X	X	X	X	X	X	X	X	X	4.5	4.5	4.5	4.5	3.5	3	3.5	0	VERY LOW
Culicidae	1	C					X	X		X	4.5	2	0	0	0	4	0	3.5	VERY LOW
Dixidae	10	X									4	3	2	0	0	2.5	0	4.5	MODERATE
Simuliidae	5						X				1.5	2	3.5	4.5	4.5	1.5	0.5	0	LOW
Tabanidae	5		X								1	4.5	4	2.5	4	1	3	0	LOW
Tipulidae	5			X	X	X	X			X	2.5	4	4	4	3.5	0.5	4	0	LOW

	Dominant preference

A total of 37 taxa were sampled upstream of the Bumbuna Dam across the three study sites while a total of 40 taxa where sampled downstream, at the six study sites. The main points are briefly discussed below:

- Overall, all the study area showed a relatively high species diversity with the presence of several taxa with a very low tolerance to pollution and alteration to flow (**Table 11-6**). The highest diversity recorded upstream of Bumbuna Dam was at site SL2, with a total of 25 taxa sampled. Site SL10 obtained the highest species diversity downstream of Bumbuna Dam, with a total of 26 taxa sampled (**Table 11-7**).
- Large variation in SASS5 score and ASPT was observed at the upstream sites (**Table 11-7**). This is most likely associated with the changes in the habitat templates at these sites. Site SL3 lacked SIC habitat and was dominated by sand and bedrock (Refer to **Table 11-4**).
- Site S1, located furthest upstream obtained an ASPT of 6.68, compared to 7.28 recorded at site S3. This increase in ASPT is most likely related to increased habitat availability recorded along the longitudinal profile (**refer to Table 11-5**).
- Spatially, the ASPT and SASS5 scores increased along the longitudinal profile of the Rokel River, between sites SL5 and S10, downstream of Bumbuna Reservoir I (**Figure 11-3**). Site SL5, located directly downstream obtained an ASPT of 4.93 and a SASS5 score of 74, compared to 6.85 and 178 respectively recorded at site SL10 (**Table 11-7**). This decrease in sensitivity at site SL5 is most likely associated with the flow alteration experienced within this reach.
- With reference to the EPT % scores, no EPT taxa were samples at site SL3, with only taxa for the Order Ephemeroptera sampled at site SL9 (**Figure 11-4 A**). This is to be expected, as the habitat at these sites are not conducive to a diverse macroinvertebrate assemblage (Refer to **Figure 11-1**). Taxa from all three orders were present at all the remaining sites (**Figure 11-4 B**), with all the sites obtaining overall percentage score above 30% (**Figure 11-4 A**).
- Spatially, both the upstream sites, SL1 and SL2, obtained %EPT scores between 40 – 42 %, while site SL5, located directly downstream of Bumbuna Reservoir I obtained a score of 33% (**Figure 11-4 A**). However, the % EPT scores did increase along the longitudinal profile of the Rokel River, with a score of 42.3 % recorded at site SL10 (**Figure 11-4 A**).
- The EPT index is based on the premise that rivers/streams with good water quality will typically have a greater species richness and evaluates water quality by the relative abundance of these three orders which have a low tolerance to water pollution. Therefore, based on the aquatic macroinvertebrate assemblages sampled overall, the associated river reaches represent a high ecological integrity based on the sampled macroinvertebrate assemblages. Nevertheless, a decline in ecological integrity was observed at site SL5.

Table 11-7: Invertebrate abundances for sites assessed during November 2017 (A = 2-10 individuals, B = 10-100 individuals, C = 100-1000 individuals, ASPT = Average Score per Taxa, and * = air breathers)

Taxon	Sensitivity Score	Upstream of Bumbuna Reservoir I			Downstream of Bumbuna Reservoir I					
		SL3	SL2	SL1	SL5	SL6	SL7	SL8	SL9	SL10
Oligochaeta	1	1	A	A	A	A	A	A	A	A
Hirudinea	3	1		A	A			1		
Potamonautidae	3				A					
Atyidae	8	A								B
Hydracarina	8		A			A	A		A	A
Perlidae	12		A	B	B	B	B	A		A
Baetidae 1sp	4							A	A	
Baetidae 2spp	6		B	A	A	B	B			B
Caenidae	6		B	A		A		A	A	A
Heptageniidae	13		A	B			B	A		B
Leptophlebiidae	9		A							
Oligoneuridae	15					A		A		A
Polymitarcyidae	10					A		A	A	B
Trichorythidae	9		A	B		A	A	A		A
Chlorocyphidae	10		1							
Coenagrionidae	4		B		A	1				A
Aeshnidae	8		A							
Gomphidae	6		A	A	A	A	A	1		A
Libellulidae	4	A			A	A	A	A		
Belostomatidae	3	1								1
Corixidae	3			A	A	A	A	A	A	
Gerridae	5	A						A		
Naucoridae	7			A					1	A
Nepidae	3		A					1		
Notonectidae	3	A		A				A		
Veliidae	5		A	A	B	B	A	B		B
Ecnomidae	8		1		1					
Hydropsychidae 2spp	6					B				
Hydropsychidae >2spp	12		B	B			B			B
Philopotamidae	10									1
Hydroptilidae	6		A	B	1	A	A	B		A
Leptoceridae	6		A	A	A		A	A		A

Taxon	Sensitivity Score	Upstream of Bumbuna Reservoir I			Downstream of Bumbuna Reservoir I					
		SL3	SL2	SL1	SL5	SL6	SL7	SL8	SL9	SL10
Dytiscidae	5	1	A			B		A		1
Elmidae	8		A	A		B	B		1	A
Gyrinidae	5	A					1			A
Hydraenidae	8		A	A			1			
Hydrophilidae	5		1			1				
Athericidae	10		1			A	A			
Ceratopogonidae	5	A				A	A	A		A
Chironomidae	2	A	B	B	A	A	B	A	A	B
Culicidae	1	C					1	A		A
Dixidae	10	1								
Simuliidae	5						A			
Tabanidae	5		A							
Tipulidae	5			A	1	A	A			A
SASS5 Score		54	175	121	74	141	140	127	49	178
No. of Taxa		**13**	**25**	**19**	**15**	**22**	**22**	**22**	**9**	**26**
ASPT		**4.50**	**7.00**	**6.37**	**4.93**	**6.41**	**6.36**	**5.77**	**5.44**	**6.85**

(pink)	Highly tolerant to pollution
(green)	Moderately tolerant to pollution
(blue)	Very Low tolerance to pollution

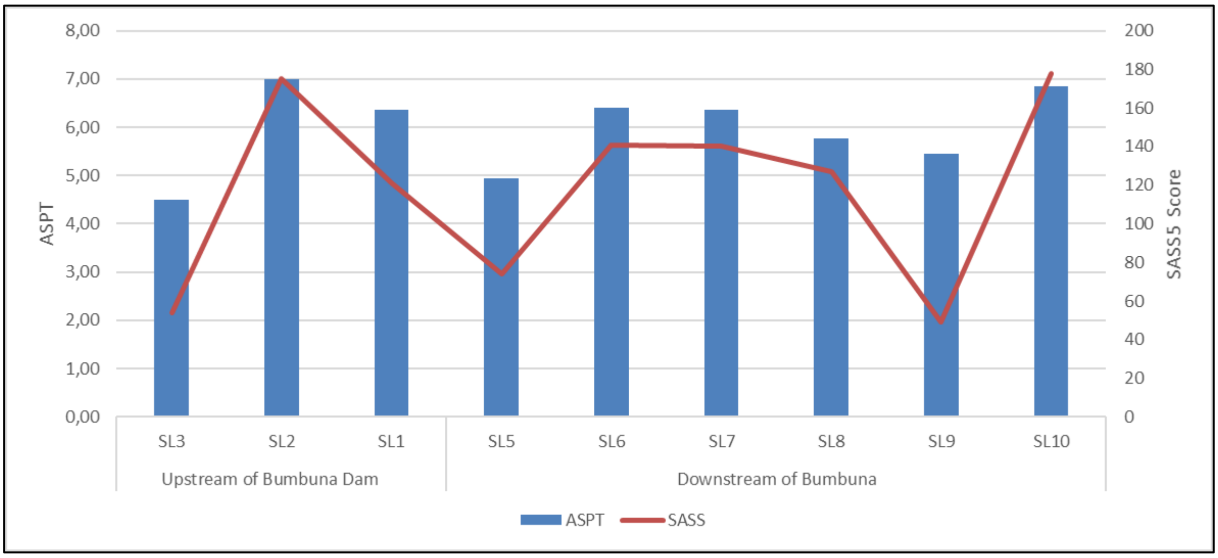


Figure 11-3: ASPT and SASS scores for sites assessed on the Suma River during the November 2017 assessment.

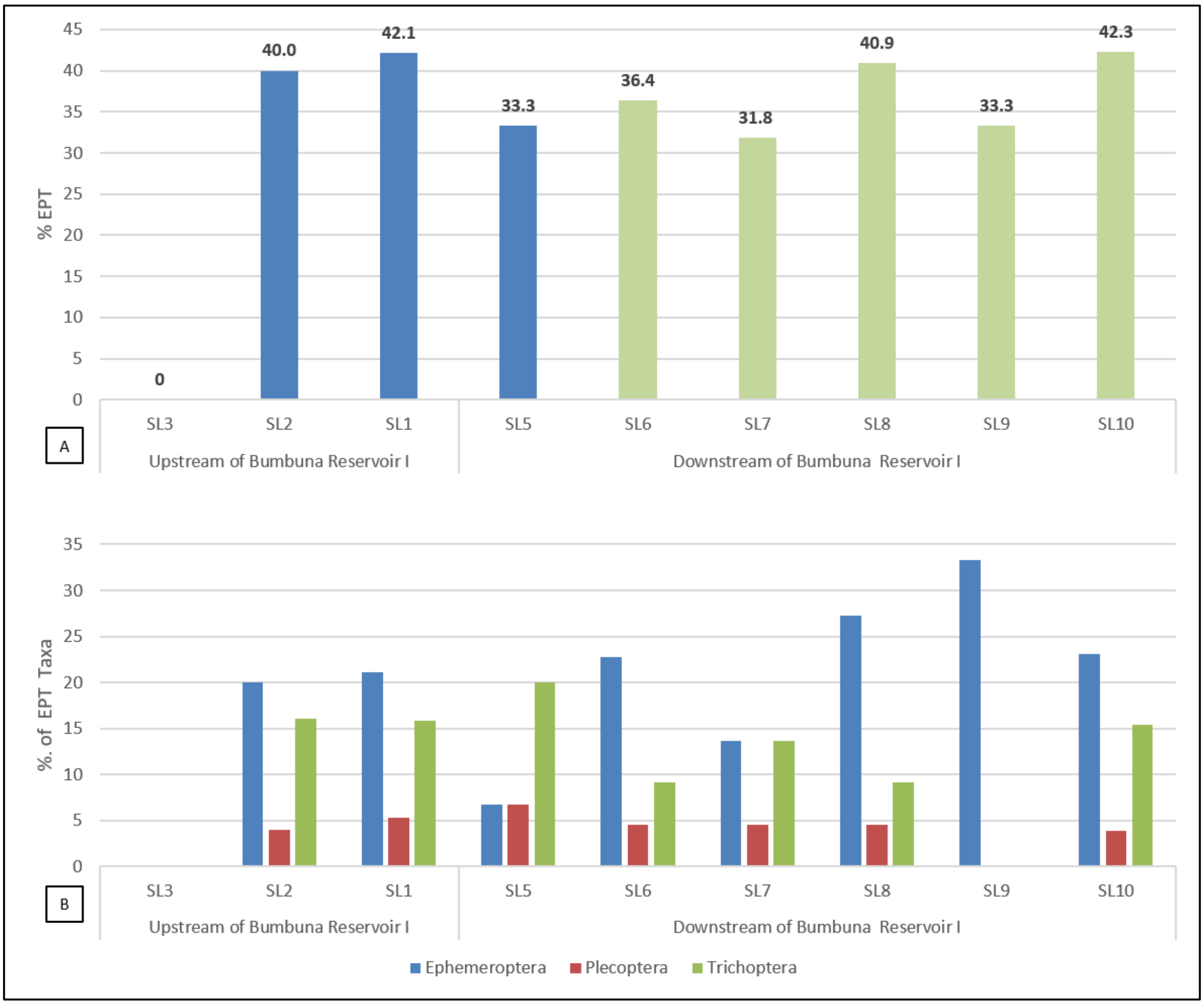


Figure 11-4: Column graph showing %EPT as expressed from the total number of taxa sampled for each site during the April 2018 assessment of the Seli/Rokel River.

11.2.2.3. AQUATIC MACROINVERTEBRATE- INDICATOR SPECIES

Following from the sensitivity description provided in **Sections 11.2.2** and for the purposes of the generating flow requirements suitable to sustain aquatic macroinvertebrate communities, five (5) flow and water quality sensitive invertebrates have been selected:

- These included: Oligoneuridae, Heptageniidae, Perlidae, Tricorythidae and Elmidae. Four of the taxa fall within the order Ephemeroptera while Elmidae are form the order Coleoptera. The habitat and water quality requirements for these species are briefly discussed below:
  - **Oligoneuriidae**: commonly known as brush-legged mayflies, are known from all continents, except for Australia. Nymphs form this family are mainly found in fast-flowing (>0.6m/s) water at high

elevations (Barber-James and Lugo-Ortiz 2003; de Moor *et al.,* 2003). This family is regarded as being a summer taxon with a strong preference for cobbles habitat with a *High* preference for good water quality (Thirion, 2016).

- **Heptageniidae**: nymphs form the family Heptageniidae, or Flat-headed Mayflies occur at a wide range of different altitudes and under stones in riffle/rapid areas where they feed on periphyton (organisms that live attached to underwater surfaces) (de Moor *et al.,* 2003). This family prefer a depth range between 10-30cm over cobbles but prefer fast flowing (0.3 - 0.6 m/s) water, with the greatest response at 0.6 m/s (Thirion, 2016). Heptageniidae have a *High* preference for good water quality (Thirion, 2016).
- **Perlidae**: nymphs may occur throughout the year, however, are more commonly found in spring and summer (de Moor *et al.,* 2003). Nymphs form the family Perlidae prefer moderately fast flowing water (>0.3-0.6m/s) associated with cobble / pebble substrate and have a *High* preference for good water quality (Thirion, 2016).
- **Tricorythidae**: nymphs from the family Tricorythidae, commonly referred to as Stout Crawlers are generally found under rocks with moderate to fast-flowing currents and tend to be found among vegetation in slower currents (de Moor *et al.,* 2003). An assessment carried out by Thirion (2016) indicated that Tricorythidae prefer very fast flowing (>0.6 m/s) water with the greatest response at 1 (m/s) at depths between 10-30cm, associated with cobble/pebble substrate.
- **Elmidae**: commonly known as riffle beetles are found on all continent, except for on Antarctica and are true water beetles, aquatic in all life stages (Stals and Moor, 2007). Nymphs from the family Elmidae are commonly found in shallow depths, less than 20 cm, mostly in very fast flowing (>0.6 m/s) water (Thirion, 2016).

- Oligoneuriidae were sampled at low abundances (<10 individuals) at sites SL6, SL8 and SL10, situated downstream of Bumbuna Reservoir I. No individuals were sampled upstream of the dam during the April 2018 assessment (Refer to **Table 11-7**).
- Taxa from the families Heptageniidae, Perlidae and Tricorythidae were present in varying abundances at the majority of the reaches assessed, both up- and downstream of Bumbuna Reservoir I (Refer to **Table 11-7**).
- None of the above-mentioned taxa were sampled at sites SL3 and SL9 (Refer to **Table 11-7**), as the habitat template at these sites were not suitable to accommodate these families. Only Perlidae were sampled at site SL5, which is located directly downstream of Bumbuna Reservoir I. This is most likely associated with the altered flow regime experienced within this reach, as the remaining taxa are sensitive to alterations in flows.
- It is anticipated that these taxa will provide a robust and meaningful indication of the ecological consequences that may arises due to the Project implementation. The indicator taxa can be applied in

two contexts; (i) setting habitat stress curves for the EWR and (ii) monitoring the significance of potential flow alteration induced by the implementation of the proposed Project.

- Note that any monitoring efforts should remain holistic and all-inclusive and should not be reduced to only focus in spatial and temporal variation within indicator species. Rather, as part of a holistic monitoring regime, variation outside of a meaningful statistical variation of these taxa will be best applied as an early warning for potential loss in ecological integrity.

11.2.3. PRESENT ECOLOGICAL STATE

This section describes the baseline macroinvertebrate assemblages for the different reaches assessed, both upstream (SL3, SL2, SL1 and SL4) and downstream (SL6 to SL10) of Bumbuna Reservoir I, on a continuum between *Natural* and *Seriously* transformed (refer to **Table 11-3**). A total of five sites were assessed downstream of Bumbuna Reservoir I in order longitudinal extent and degree of modification. This section will also ascertain the likely causes for the existing degree of transformation and the direction of change (trend) under the proposed hydrological releases.

11.2.3.1. BASELINE ECOCLASSIFICATION

The MIRAI provides a measure of the residual ecological integrity of a system based on the deviation of the present community in relation to an expected (reference) community. The variation in the preferences and tolerances between the expected and the sampled community also indicates the likely contribution of different drivers (changes in flow, substrate and water quality) to the decrease in ecological integrity. The main aspects with regards to the aquatic macroinvertebrate assemblages under the existing hydrological regime are briefly discussed below:

- The upstream resource unit fell in B category, based on instream macroinvertebrate assemblages sampled at the three (SL3, SL2 and SL1) reaches (**Table 11-8; Table 11-9; Table 11-10**).
- The reach infers a *Largely Natural* state, where only small changes in the attributes of natural habitats and biota may have occurred, with the ecosystem functions and resilience remaining relatively unchanged.
- Directly downstream of Bumbuna Dam, Site SL5 classed in a D ecological category, inferring a *Largely* modified state where a large alterations or loss of natural habitat, biota and basic ecosystem functions has taken place. The MIRAI model highlighted flow modification as the main contributor to the loss of ecological integrity within this reach (**Table 11-11**).
- Spatially, the ecological integrity downstream of Bumbuna Reservoir increased along the longitudinal profile of the Rokel River (**Figure 11-5**):

- Sites SL6, SL7 and SL8 indicated an increased in ecological integrity and classed in a C category, inferring a *Moderately* modified state where loss and alteration of natural habitat and biota have taken place, but the basic ecosystem functions are still relatively unchanged (**Figure 11-5**).
- Once again, flow modification was the main contributor to the loss of ecological integrity at the reaches associated with sites SL6 and SL7 (**Table 11-12**; **Table 11-13**). Concurrently, no clear contributor was highlighted at site SL8 (**Table 11-14**).
- Sites SL9 and SL10 obtained similar scores to that of the upstream sites, and classed in B categories, inferring a *Largely Natural* state (**Table 11-15**; **Table 11-16**; **Figure 11-5**).

* The macroinvertebrate assessment showed that the current flow alterations associated with Bumbuna Reservoir I has resulted in a large alteration to the macroinvertebrate assemblage at site SL5, with residual impacts shown at sites SL6, SL7 and SL8. The system has however, recovered within the reaches associated with sites SL9 and SL10 (**Figure 11-5**).

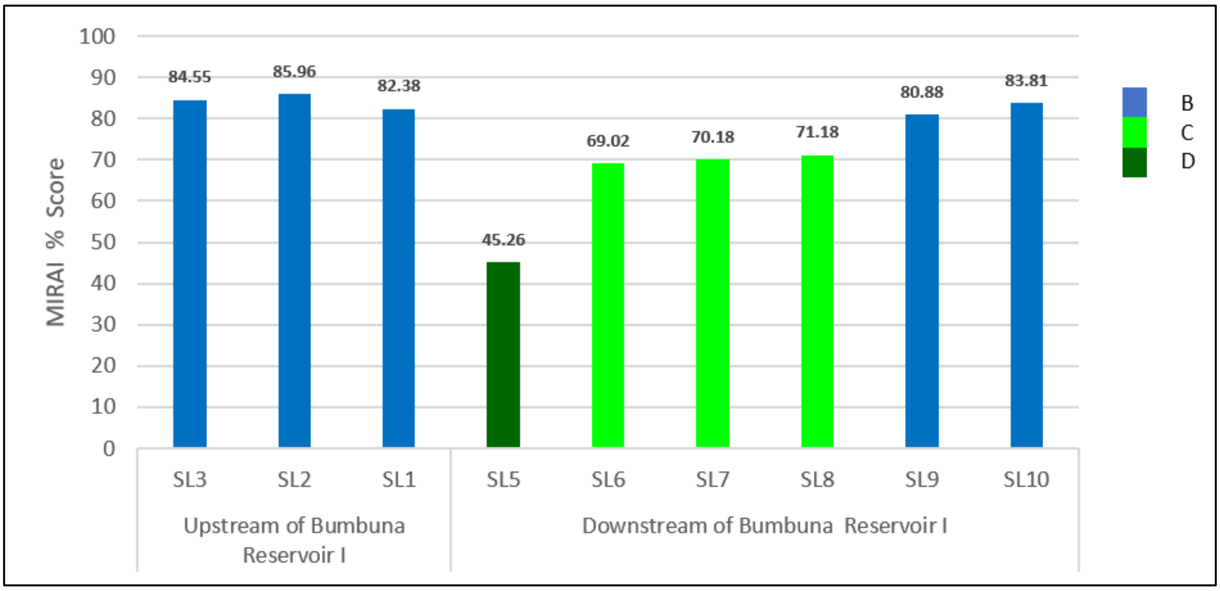


Figure 11-5: Overall MIRAI % scores obtained following the April 2018 assessment.

It is important to monitor temporal trends in the macroinvertebrate assemblages in order to determine any changes in the ecological conditions of the aquatic environment. The initial assessment was carried out in August 2016, where only a small stretch downstream of the Bumbuna Reservoir I was surveyed, including sites R1, R2 and R3. These three sites correlate with sites SL5 and SL6 from the current survey and thus a comparison among these sites will be briefly discussed:

- Site R1, located closest to Bumbuna Reservoir I, classed in an E category during the August 2016 Assessment (**Table 11-17**; **Figure 11-6**). This class infers a *Seriously* modified state, where the alteration of the natural habitat template, biota and basic ecosystem functions are extensive. Site R1, is in close proximity to site SL5 (April 2018), both of which have showed a decline in ecological integrity, most likely associated with flow alteration (**Table 11-11**; **Table 11-17**). With regards to temporal variation, the reach was in a higher category during the April 2018 assessment, with the overall MIRAI % scores increasing form 38.82 to 49.93% (**Table 11-11**; **Table 11-17**).
- Located further downstream, sites R2 and R3, classed in C categories, inferring a *Moderately* modified state (**Table 11-8**; **Table 11-9**; **Figure 11-6**). A similar temporal trend was noted, with the reach associated with site SL6 obtaining a higher overall MIRAI % score during the April 2018 assessment (**Figure 11-2**).
- Overall, the temporal macroinvertebrate analysis trends appeared to show a slight improvement in the macroinvertebrate community assemblages downstream of Bumbuna Reservoir I, following the April 2018 assessment.

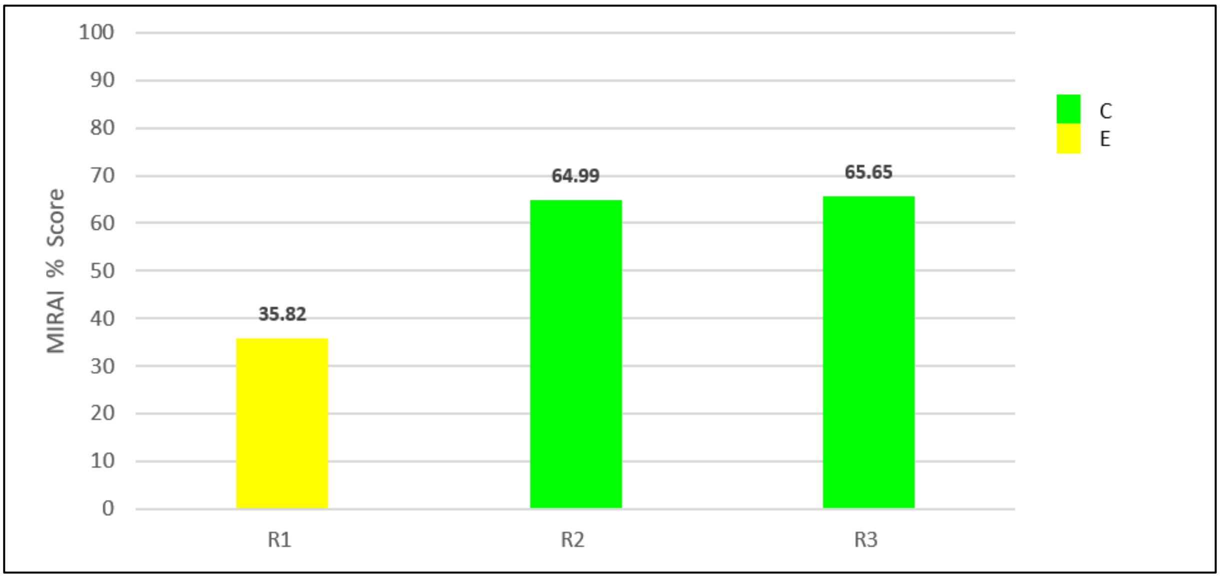


Figure 11-6: Overall MIRAI % scores obtained following the August 2016 assessment.

Table 11-8: Ecological Categories: based on weights of metric groups for site SL3, April 2018

Invertebrate EC Metric Group	Metric Group Calculated Score	Calculated Weight	Weighted Score of Group	Rank	%Weight
Flow Modification	88.9	0.345	30.6513	1	100
Habitat	84.8	0.310	26.3172	2	90
Water Quality	80.0	0.345	27.5862	1	100
Connectivity & Seasonality	100	0.000	0.0000	0	0
					290
Invertebrate EC			**84.55**		
Invertebrate EC Category			B		

Table 11-9: Ecological Categories: based on weights of metric groups for site SL2, April 2018

Invertebrate EC Metric Group	Metric Group Calculated Score	Calculated Weight	Weighted Score of Group	Rank	%Weight
Flow Modification	88.3	0.345	30.460	1	100
Habitat	84.6	0.310	26.269	2	90
Water Quality	84.8	0.345	29.240	1	100
Connectivity & Seasonality	100	0.000	0.0000	0	0
					290
Invertebrate EC			**85.97**		
Invertebrate EC Category			B		

Table 11-10: Ecological Categories: based on weights of metric groups for site SL1, April 2018

Invertebrate EC Metric Group	Metric Group Calculated Score	Calculated Weight	Weighted Score of Group	Rank	%Weight
Flow Modification	89.8	0.345	30.970	1	100
Habitat	73.8	0.310	22.906	2	90
Water Quality	82.7	0.345	28.501	1	100
Connectivity & Seasonality	100	0.000	0.0000	0	0
					290
Invertebrate EC			**82.38**		
Invertebrate EC Category			B		

Table 11-11: Ecological Categories: based on weights of metric groups for site SL5, April 2018

Invertebrate EC Metric Group	Metric Group Calculated Score	Calculated Weight	Weighted Score of Group	Rank	%Weight
Flow Modification	33.0	0.323	10.633	1	100
Habitat	54.4	0.290	15.807	2	90
Water Quality	52.3	0.323	16.886	1	100
Connectivity & Seasonality	30.0	0.065	1.935	3	20
					310
Invertebrate EC			**45.26**		
Invertebrate EC Category			D		

Table 11-12: Ecological Categories: based on weights of metric groups for site SL6, April 2018

Invertebrate EC Metric Group	Metric Group Calculated Score	Calculated Weight	Weighted Score of Group	Rank	%Weight
Flow Modification	67.8	0.323	21.863	1	100
Habitat	74.8	0.290	21.720	2	90
Water Quality	71.8	0.323	23.173	1	100
Connectivity & Seasonality	35.0	0.065	2.2581	3	20
					310
Invertebrate EC			**69.02**		
Invertebrate EC Category			**C**		

Table 11-14: Ecological Categories: based on weights of metric groups for site SL8, April 2018

Invertebrate EC Metric Group	Metric Group Calculated Score	Calculated Weight	Weighted Score of Group	Rank	%Weight
Flow Modification	72.8	0.323	23.478	1	100
Habitat	73.3	0.290	21.290	2	90
Water Quality	73.9	0.323	23.832	1	100
Connectivity & Seasonality	40.0	0.065	2.581	3	20
					310
Invertebrate EC			**71.18**		
Invertebrate EC Category			**C**		

Table 11-13: Ecological Categories: based on weights of metric groups for site SL7, April 2018

Invertebrate EC Metric Group	Metric Group Calculated Score	Calculated Weight	Weighted Score of Group	Rank	%Weight
Flow Modification	70.7	0.323	22.820	1	100
Habitat	72.1	0.290	20.945	2	90
Water Quality	74.9	0.323	24.160	1	100
Connectivity & Seasonality	35.0	0.065	2.258	3	20
					310
Invertebrate EC			**70.18**		
Invertebrate EC Category			**C**		

Table 11-15: Ecological Categories: based on weights of metric groups for site SL9, April 2018

Invertebrate EC Metric Group	Metric Group Calculated Score	Calculated Weight	Weighted Score of Group	Rank	%Weight
Flow Modification	89.3	0.323	29.570	1	100
Habitat	74.4	0.290	24.516	2	90
Water Quality	87.5	0.323	29.167	1	100
Connectivity & Seasonality	50.0	0.065	3.226	3	20
					310
Invertebrate EC			**81.88**		
Invertebrate EC Category			**C/B**		

Table 11-16: Ecological Categories: based on weights of metric groups for site SL10, April 2018

Invertebrate EC Metric Group	Metric Group Calculated Score	Calculated Weight	Weighted Score of Group	Rank	%Weight
Flow Modification	80.4	0.323	25.926	1	100
Habitat	87.0	0.290	25.269	2	90
Water Quality	85.1	0.323	27.452	1	100
Connectivity & Seasonality	80.0	0.065	5.161	3	20
					310
Invertebrate EC			**83.81**		
Invertebrate EC Category			B		

Table 11-17: Ecological Categories: based on weights of metric groups for site R1, August 2016

Invertebrate EC Metric Group	Metric Group Calculated Score	Calculated Weight	Weighted Score of Group	Rank	%Weight
Flow Modification	32.0	0.323	10.335	1	100
Habitat	30.7	0.290	8.925	2	90
Water Quality	47.3	0.323	15.273	1	100
Connectivity & Seasonality	20.0	0.065	1.2900	3	20
					310
Invertebrate EC			**35.82**		
Invertebrate EC Category			E		

Table 11-18: Ecological Categories: based on weights of metric groups for site R2, August 2016

Invertebrate EC Metric Group	Metric Group Calculated Score	Calculated Weight	Weighted Score of Group	Rank	%Weight
Flow Modification	70.0	0.323	22.580	1	100
Habitat	59.1	0.290	17.155	2	90
Water Quality	74.3	0.323	23.963	1	100
Connectivity & Seasonality	20.0	0.065	1.290	3	20
					310
Invertebrate EC			**64.99**		
Invertebrate EC Category			C		

Table 11-19: Ecological Categories: based on weights of metric groups for site R3, August 2016

Invertebrate EC Metric Group	Metric Group Calculated Score	Calculated Weight	Weighted Score of Group	Rank	%Weight
Flow Modification	75.7	0.323	24.432	1	100
Habitat	51.8	0.290	15.044	2	90
Water Quality	77.1	0.323	24.885	1	100
Connectivity & Seasonality	20.0	0.065	1.290	3	20
					310
Invertebrate EC			**65.65**		
Invertebrate EC Category			C		

11.2.3.2. BUMBUNA RESERVOIR II - ECOCLASSIFICATION MODELLING

This section will focus on the anticipated change in the macroinvertebrate assemblage based on the construction of Bumbuna Reservoir II and the new proposed hydrological regime. The section assumes that no daily pulses will occur downstream of Bumbuna Reservoir I during operation and that additional FI habitat will be created based on the habitat distribution model. Also considered was that the majority of the macroinvertebrates sampled and expected to occur in the study area are expected to occur in the FI (>0.3 m.s-1 ; > 0.2 m and ≤ 0.3 m) and the lower end of the FD (>0.3 m.s-1 ; >0.3 m) hydraulic units (Collier, 1959; Hagen, 2008; Thirion, 2016). The distribution of the different hydraulic types is provided in **Figure 11-7**.

Three different flow related scenarios were considered when determining the anticipated change in the macroinvertebrate assemblage's post-construction of Bumbuna Reservoir II:

1) At a discharge of $32m^3/s$, as measured during the April 2018 baseline field survey, approximately 5% of the habitat template comprised of FI habitat (**Figure 11-7**) and the subsequent habitat availability resulted in the ecological categories shown in **Figure 11-5**. This data will be used as a base of comparison.
2) At an environmental flow release of 6 m^3/s, the FI habitat increases to approximately 16 % (**Figure 11-7**). The environmental flow release is associated with the reach directly downstream of the weir and upstream of the release from the tailrace canal.
3) At the proposed mean discharge of 82 m^3/s (year 1) the distribution of FI drops slightly to 3%, with a considerable increase in FD habitat (**Figure 11-7**).

Based on the above assumptions and the three different scenarios the following predictions were made for the following the construction of Bumbuna Reservoir II:

- The ecological categories obtained for sites SL3, SL2 should remain unchanged as the extent of inundation for the proposed Bumbuna Reservoir II location will not infringe on these reaches. However, a considerable decrease in ecological integrity is anticipated at site SL1, as it falls within the inundation zone:

  - The main change to the habitat template at site SL1 will be the loss of SIC habitat, which will result in the absence of taxa with this presence. The subsequent result is that site SL1 will potentially drop to an E category, inferring infers a *Seriously* modified state (**Figure 11-8**).

- With regards to variations downstream of Bumbuna Reservoir I, the largest variation is anticipated for site SL5 which is anticipated to show an increase in ecological integrity:

  - With the removal of daily pulses, macroinvertebrate sensitive to alterations in flow are expected to return within this reach. Furthermore, the proposed flows release within this reach (6 m^3/s) will provide adequate FI habitat.
  - The site is anticipated to jump up to a C ecological category, but will still infer a *Moderately* modified state (**Table 11-20**; **Figure 11-8**). Despite the increase in habitat availability the reach will lose seasonal variation, which may alter the community assemblage and potentially result in the dominance of certain families at the expense of others.

- As FI is expected to occur within the activated fringes at sites SL6 to SL10 at a mean discharge of 82 m^3/s (year 1) (**Figure 11-7**) and with the daily pulses no longer anticipated, the downstream reach is expected to show an overall increase in ecological integrity:

  - Sites SL6, SL7 and SL8, are anticipated to show a slight increase in ecological integrity but should remain in the same ecological categories (**Table 11-21**; **Table 11-22**; **Table 11-23**; **Figure 11-8**).
  - Sites SL9 and SL10, located furthest downstream were not adjusted and are anticipated to remain in the same ecological categories following the construction of Bumbuna Reservoir II (**Figure 11-8**).

- Overall, with the exception of site SL1, the upstream sites will remain in the same ecological categories, with the reaches downstream of Bumbuna Reservoir I expected to show an improvement while the sites furthest downstream to remain relative stable.

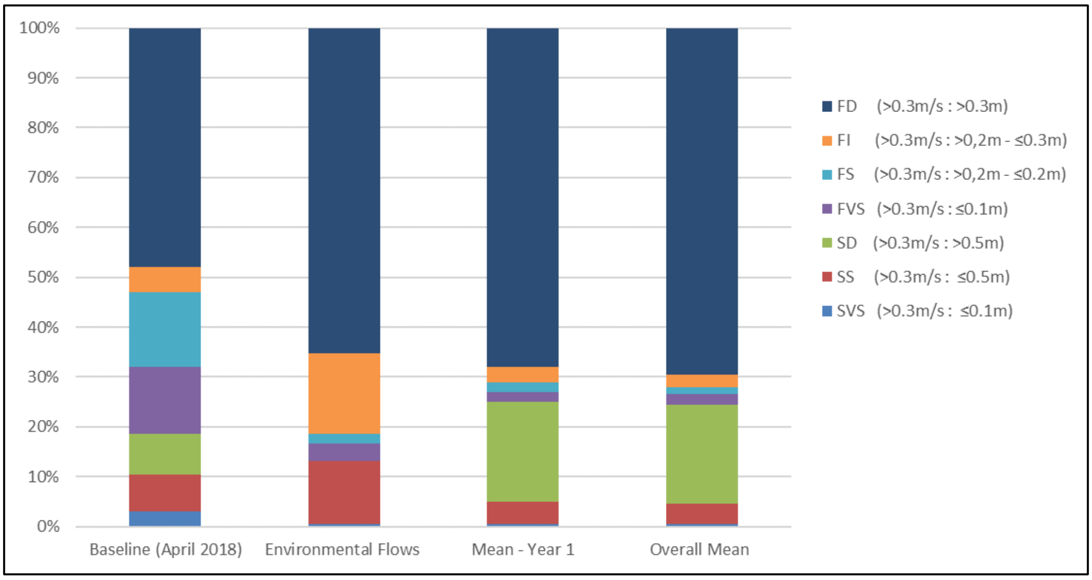


Figure 11-7: Distribution of the different hydraulic habitat types for four scenarios. (1) April 2018 – 32 m^3/s, (2) environmental flows – 6 m^3/s (3) mean discharge during year 1 – 82 m^3/s and (4) overall mean discharge – 88 m^3/s.

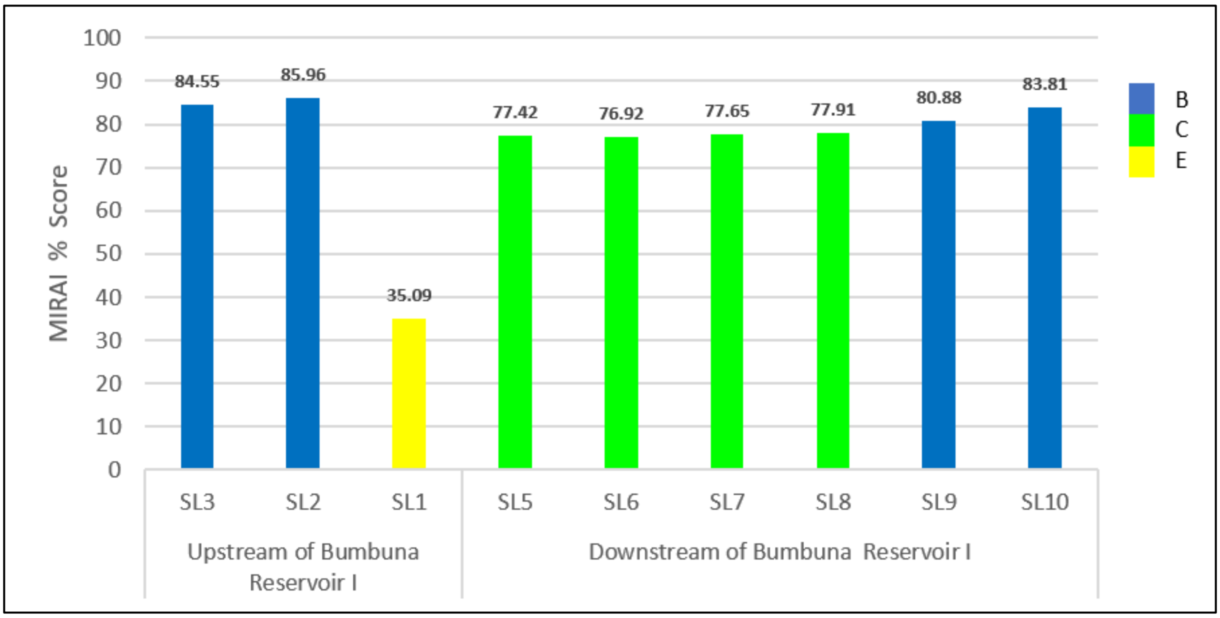


Figure 11-8: Anticipated MIRAI % scores following the construction of Bumbuna Reservoir II.

Table 11-20: Ecological Categories: based on weights of metric groups for site SL1, post Bumbuna Reservoir II

Invertebrate EC Metric Group	Metric Group Calculated Score	Calculated Weight	Weighted Score of Group	Rank	%Weight
Flow Modification	23.3	0.323	7.070	1	100
Habitat	50.0	0.290	13.636	2	90
Water Quality	43.5	0.232	13.173	1	100
Connectivity & Seasonality	10.00	0.065	1.212	3	40
					330
Invertebrate EC			**35.09**		
Invertebrate EC Category			**E**		

Table 11-21: Ecological Categories: based on weights of metric groups for site SL5, post Bumbuna Reservoir II

Invertebrate EC Metric Group	Metric Group Calculated Score	Calculated Weight	Weighted Score of Group	Rank	%Weight
Flow Modification	77.8	0.323	25.090	1	100
Habitat	82.6	0.290	23.979	2	90
Water Quality	83.9	0.232	27.057	1	100
Connectivity & Seasonality	20.0	0.065	1.290	3	20
					310
Invertebrate EC			**77.42**		
Invertebrate EC Category			**C**		

Table 11-22: Ecological Categories: based on weights of metric groups for site SL6, post Bumbuna Reservoir II

Invertebrate EC Metric Group	Metric Group Calculated Score	Calculated Weight	Weighted Score of Group	Rank	%Weight
Flow Modification	80.4	0.323	25.926	1	100
Habitat	77.4	0.290	22.473	2	90
Water Quality	84.1	0.323	26.267	1	100
Connectivity & Seasonality	35.0	0.065	2.2258	3	20
					310
Invertebrate EC			**76.92**		
Invertebrate EC Category			**C**		

Table 11-23: Ecological Categories: based on weights of metric groups for site SL7, post Bumbuna Reservoir II

Invertebrate EC Metric Group	Metric Group Calculated Score	Calculated Weight	Weighted Score of Group	Rank	%Weight
Flow Modification	76.7	0.323	24.731	1	100
Habitat	78.6	0.290	22.811	2	90
Water Quality	86.3	0.323	27.847	1	100
Connectivity & Seasonality	35.0	0.065	2.260	3	20
					310
Invertebrate EC			**77.65**		
Invertebrate EC Category			**C**		

Table 11-24: Ecological Categories: based on weights of metric groups for site SL8, post Bumbuna Reservoir II

Invertebrate EC Metric Group	Metric Group Calculated Score	Calculated Weight	Weighted Score of Group	Rank	%Weight
Flow Modification	81.1	0.323	26.165	1	100
Habitat	77.0	0.290	22.366	2	90
Water Quality	83.1	0.323	26.734	1	100
Connectivity & Seasonality	40.0	0.065	2.580	3	20
					310
Invertebrate EC			**77.91**		
Invertebrate EC Category			**C**		

12. APPENDIX E - FISH

12.1. MATERIALS AND METHODS

12.1.1. FISH HABITAT ASSESSMENT

The fish habitat assessment was adopted from Kleynhans (2007). The frequency of different habitat units was expressed based on the number of occurrences measured for the cross-section assessed. The different habitat units and their descriptions are provided in (**Table 12-1**; **Table 12-2**). The frequency distribution of the substrate and flows were also applied within the EWR to create the stress curves for aquatic macroinvertebrate and fish communities.

Table 12-1: Habitat types and their descriptions included in the April 2018 aquatic ecology assessment

Habitat Type	Description
Overhanging Vegetation	Marginal riparian zone, canopy forming just above the surface of the water
Aquatic Vegetation	Aquatic macrophytes
Undercut banks and root wads	Marginal zone cover provided by cavities within the bank and inter-root wad spaces
Bedrock	>1.5 m
Boulders	>256 mm
Cobbles	>64-256 mm
Pebbles	>4-64 mm
Gravel	>2-4 mm
Sand	>0.05-2 mm
Mud	>0.002-0.05 mm

Table 12-2: Hydraulic units used in modelling variation in fish habitat units

Habitat Type	Depth (m)	Velocity (m s^{-1})
Fast Deep (FD)	>0.3	>0.3
Fast Intermediate (FI)	>0.2; ≤0.3	>0.3
Fast Shallow (FS)	>0.1; ≤0.2	>0.3
Fast Very Shallow (FVS)	≤0.1	>0.3
Slow Deep (SD)	>0.5	≤0.3
Slow Shallow (SS)	≤0.5	≤0.3
Slow Very Shallow (SVS)	≤0.1	≤0.3

12.1.2. Field Sampling

Fish survey methodology was undertaken according to Kleynhans (2007). Fish sampling effort was site specific and based on habitat type and accessibility. Several sampling techniques were used and included: (i) electro-fishing, (iii) fyke nets, and (iv) cast nets. Electro-fishing was undertaken at sites where conductivity was suitable and gill nets were used at sites where adequate depth was available. Where depth and habitat allowed, fyke nets were placed at sites overnight. A description of the equipment used and the fish sampling effort per unit are listed in **Table 12-3**.

Table 12-3: Fish sampling equipment used, and the sampling effort followed during the April 2018 survey

Sampling type	Unit	Unit Sampling Effort	Mesh Size	Depth	Length/Size
Electro-shocking	1	45 min	N/A	<0.5m	NA
Cast net	1	10 casts	20mm	>0.5m	Diameter = 3m
Fyke net	1	Over night	20mm	<0.5m	Mouth size = 50cm

12.1.3. Fish Present Ecological State Assessment

The FRAI model calculates the residual ecological integrity based on the difference between the expected and the sampled fish assemblages (Kleynhans, 2007). The model also indicates likely reasons for the digression from references conditions based on the difference in habitat preferences and tolerances between the expected and sampled fish communities. Main components included within the model are:

- Velocity-depth preferences;
- Cover preferences;
- Tolerance to conditions of no flow;
- Tolerance to alteration in water quality;
- Migration requirements; and
- Alien and invasive species.

Additional components included within the assessment are:

- Dietary requirements;
- Reproductive strategy; and
- Breeding time.

Abundances and frequency of occurrence obtained during the survey were compared to the reference condition to establish the present state of the sites. An increase or decrease in abundance/frequency of occurrence is considered as a change compared to natural conditions. The outcome of the model is the Ecological Category expressed as a percentage of similarity to reference conditions (**Table 12-4**).

Table 12-4: Ecological categories, key colours and category descriptions presented within the biotic assessment (Kleynhans & Louw, 2007)

Category		Description
A	Unmodified	No impacts, conditions natural.
B	Largely natural	Small changes in community characteristics, most aspects natural.
C	Moderately modified	Clear community modifications, some impairment of health evident.
D	Largely modified	Impairment of health clear. Unacceptably impacted state.
E	Seriously modified	Most community characteristics seriously modified, unacceptable state.
F	Critically modified	Extremely low species diversity. Unacceptable state.

12.2. Results and Discussion

12.2.1. Review of Threatened Status and Endemism

The Seli/Rokel River provides habitat for about 20 genera representing approximately 80 known species (**Table 12-5**). Of the expected and sampled species, three are listed by the IUCN Red List as EN, nine are NT and two are DD. A summary of the IUCN Red List data is provided in **Table 12-6**. Details on the IUCN classification justification, habitat requirement and threats are outlined in **Table 12-7**, while the photos in **Figure 12-1** represent some of these species sampled during the August 2018 assessment.

In general, the Seli/Rokel fish are characteristic of the Northern Upper Guinea ecoregion. The area has a moderate to high regional level of endemism (Payne (2018) estimates it at 42%). Most rivers in Sierra Leone have narrow parallel basins which drain the Guinea highlands into the Atlantic Ocean. The tropical and subtropical rivers also drain the savannah and sahael basins of the Sudanien region. The most notable regional endemics relate to the Cichlids, with seven endemic species. In addition, four freshwater genera (*Prolabeo*, *Anomolochromis*, *Heterotilapia* and *Coelotilapia*) are endemic to region. Although the endemic species are represented in the Seli/Rokel River they also occur in the neighbouring rivers (i.e. the Seli/Rokel River reflects a high degree of similarity with other rivers within the ecoregion). Overall taxonomic resolution is moderate to good for the main stem Seli/Rokel, and it is unlikely that new species will be described from the main stem. However, tributaries are likely to yield new species.

Table 12-5: List of sampled and expected fish species for the Rokel/Seli River, with IUCN Red List conservation status

Family	Genus & Species	IUCN Red List	Ecotone Jun 15	Ecotone Apr 18	Payne et al., 2006, 2018
Amphiliidae	*Amphilius rheophilus*	LC		X	
	Amphilius atesuensis	LC			X
	Amphilius platychir	LC		X	
Anabantidae	*Ctenopoma kingsleyae*	LC		X	X
Aplocheilidae	*Epiplatys fasciolatus*	LC		X	X
	Epiplatys njalensis	EN			X
Bagridae	*Auchenoglanis occidentalis*	LC		X	X
	Chrysichthys johnelsi	LC		X	X
	Chrysichthys maurus	LC			X
	Chrysichthys nigrodigitatus	LC		X	X
Centropomidae	*Lates niloticus*	LC		X	X
Characidae	*Brycinus longipinnis*	LC		X	X
	Brycinus macrolepidotus	LC		X	X
	Hydrocynus forskahlii	LC		X	X
Cichlidae	*Anomalochromis thomasi*	LC			X
	Coelotilapia joka	NE			X
	Coptodon guineensis	LC			X
	Coptodon louka	LC	X	X	X
	Hemichromis bimaculatus	LC		X	X
	Hemichromis fasciatus	LC		X	X
	Heterotilapia buttikoferi	LC	X	X	
	Pelvicachromis humilis	LC		X	X
	Sarotherodon caudomarginatus	LC	X	X	X
	Sarotherodon melanotheron	NE	X		
	Sarotherodon occidentalis	NT		X	X
	Tilapia brevimanus	LC	X	X	X
	Tylochromis jentinki	LC			
	Tylochromis leonensis	LC		X	X
Claridae	*Clarias anguillaris*	LC			X
	Clarias buettikoferi	LC	X	X	X
	Clarias laeviceps	NE			X
	Heterobranchus isopterus	LC		X	X
Cyprinidae	*Enteromius ablabes*	LC		X	X
	Enteromius bigornei	NT		X	
	Enteromius cf. macrops	LC			
	Enteromius leonensis	LC			X
	Enteromius liberiensis	EN		X	X
	Enteromius tieckeroi	NE			

Family	Genus & Species	IUCN Red List	Ecotone Jun 15	Ecotone Apr 18	Payne et al., 2006, 2018
	Enteromius trispilos	LC		X	X
	Labeo coubie	LC			X
	Labeo parvus	LC		X	X
	Labeobarbus sacratus	NE		X	X
	Labeobarbus wurtzi	NE			X
	Leptocypris guineensis	NT	X		X
	Prolabeo batesi	DD	X	X	
	Raiamas nigeriensis	NT	X		X
	Raiamas scarciensis	DD			X
	Raiamas steindachneri	LC		X	X
Distichodontidae	*Ichthyborus quadrilineatus*	NT		X	X
	Nannocharax fasciatus	LC	X	X	
	Nannocharax seyboldi	NE	X	X	
	Neolebias unifasciatus	LC	X		X
Eleotridae	*Kribia kribensis*	LC			
Gobidae	*Awaous lateristriga*	NE		X	X
Hepsetidae	*Hepsetus odoe*	LC			
Malapteruridae	*Malapterurus leonensis*	NE		X	X
Mastacembelidae	*Mastacembelus liberiensis*	LC		X	X
Mochokidae	*Chiloglanis occidentalis*	LC	X	X	
	Synodontis annectens	LC		X	X
	Synodontis ansorgii	LC	X		
	Synodontis cf. filamentosus	LC			X
	Synodontis levequei	NT			X
	Synodontis thysi	LC	X	X	X
	Synodontis cf. tourei	NT	X		X
	Synodontis waterloti	LC			X
Mormyridae	*Brienomyrus brachyistius*	NE		X	
	Brienomyrus longianalis	LC			X
	Hippopotamyrus paugyi	LC			X
	Marcusenius mento	LC		X	
	Marcusenius meronai	EN	X	X	X
	Marcusenius thomasi	LC	X	X	X
	Mormyrops anguilloides	LC			
	Mormyrops breviceps	LC	X		X
	Mormyrus cf. rume	NE			X
	Mormyrus tapirus	LC			X
	Petrocephalus cf. levequei	NT		X	
	Petrocephalus pellegrini	LC		X	X
	Petrocephalus tenuicaudata	NE		X	
Nothobranchiidae	*Callopanchax occidentallis*	NE			
Notopteridae	*Papyrocranus afer*	NE		X	X
Schilbeidae	*Schilbe micropogon*	LC	X	X	X
	Schilbe mystus	LC		X	X

Table 12-6: Summary Count of IUCN Red Listed Fish Species Known to be Present in the Rokel/Seli River

Row Labels	Count of IUCN Red List Status
Data Deficient (DD)	2
Endangered (EN)	3
Least Concern (LC)	55
Near Threatened (NT)	9
Not Evaluated (NE)	12
Vulnerable (VU)	0
Grand Total	82

Table 12-7: Species of conservation significance in terms of the IUCN Red List status, their respective range, habitat, threats

Genus & Species	IUCN Red List	Justification	Range	Habitat	Threats
Prolabeo batesi[2]	DD	This species is endemic to Sierra Leone and known from the rivers Sewa, Rokel and Pampana. There is no information on threats in these localities and no data on the species population. Therefore, it is categorised as Data Deficient.	This species is known from Sierra Leone in Sewa, Rokel, Pampana, Little Scarcies and Jong rivers.	This is a demersal fish.	No information available.
Raiamas scarciensis[3]	DD	This species is endemic to Sierra Leone and known from reaches of the Rokel, Little Scarcies River and Waanje River in Sierra Leone. The species is found in only three locations. No information on threats in these localities and no data on the species. Therefore, pending further information, it is categorised as Data Deficient.	This species is known from reaches of the Rokel, Little Scarcies River and Waanje River in Sierra Leone.	This is a benthopelagic species.	No information available.
Epiplatys njalaensis[4]	EN	This species is restricted to fewer than five locations, in small rivers and creeks in the tropical rainforest of south eastern Sierra Leone, with an EOO of less than 5,000 km^2 and an AOO of less than 500 km^2. Mining and deforestation are the major threats to this species. Therefore, the species is qualified as Endangered.	This species is only known from a few localities in in the tropical rainforest of south eastern Sierra Leone; Mano Geleben, Serabu and Baham.	It can be found in small rivers and creeks. The species is a benthopelagic non-migratory fish of maximum size of 6.0 cm TL. The fish is difficult to maintain in aquarium.	Mining and deforestation are the major threats to this species.
Enteromius liberiensis[5]	EN	The species is known in Sierra Leone and Liberia, but exact limits are yet to be confirmed. Based on current distribution data the estimated AOO is less than 500 km^2. It is only known from possibly three locations. The extent and quality of habitat is undergoing and	The species is known in Sierra Leone and Liberia, but exact limits are yet to be confirmed.	This is a benthopelagic species, potamodromous. It grazes on aquatic	Threats to this species include mining and deforestation.

[2] Bousso, T. & Lalèyè, P. 2010. Prolabeo batesi. The IUCN Red List of Threatened Species 2010: e.T182012A7787900. http://dx.doi.org/10.2305/IUCN.UK.2010-3.RLTS.T182012A7787900.en. Downloaded on 15 August 2018.

[3] Bousso, T. & Lalèyè, P. 2010. Raiamas scarciensis. The IUCN Red List of Threatened Species 2010: e.T182685A7942447. http://dx.doi.org/10.2305/IUCN.UK.2010-3.RLTS.T182685A7942447.en. Downloaded on 15 August 2018.

[4] Lalèyè, P. 2010. Epiplatys njalaensis. The IUCN Red List of Threatened Species 2010: e.T181916A7763434. http://dx.doi.org/10.2305/IUCN.UK.2010-3.RLTS.T181916A7763434.en. Downloaded on 15 August 2018.

[5] Entsua-Mensah, M. 2018. Enteromius liberiensis (amended version of 2010 assessment). The IUCN Red List of Threatened Species 2018: e.T182865A126401186. Downloaded on 15 August 2018.

Genus & Species	IUCN Red List	Justification	Range	Habitat	Threats
		continuous decline due to mining and deforestation in Liberia. The species is therefore assessed as Endangered.		plants in streams and lakes.	
Marcusenius meronai[6]	EN	*Marcusenius meronai* is known only from the Bagbé and Rokel Rivers in Sierra Leone (2 locations) which are under threats from habitat degradation (deforestation, agriculture development). The species can be qualified as Endangered as the EOO and AOO are less than 5,000 km^2 and 500 km^2 respectively.	This species is only known from the Bagbé and Rokel Rivers in Sierra Leone.	This is a demersal fish.	Deforestation, agricultural development and drought threaten this species.
Sarotherodon occidentalis[7]	NT	*Sarotherodon occidentalis* occurs in coastal areas, from the River Casamance in Senegal to the St John in Liberia. The species has a wide distribution (EOO). But is found in a limited number of locations (but more than 10) and has widespread threats, particularly from drought, deforestation, overfishing and dams. The species is Near Threatened as it is close to meeting Vulnerable under Criteria B.	This species is known from Casamance River, Senegal to the Saint John River, Liberia.	This is a demersal species. Detritivore and oviparous.	Drought, deforestation, overfishing and dams threaten this species.
Enteromius bigornei[8]	NT	This species is found in fewer than 10 locations. Whilst the EOO is greater than 20,000 km^2, the AOO is close to 2,000 km^2. The species habitat is under threat due to deforestation and sedimentation. The species is assessed as Near threatened (NT) as it is close to meeting Vulnerable under Criteria B.	This species is known from Little Scarcies basin in Sierra Leone, west of Côte d'Ivoire, and east of Liberia.	This is a benthopelagic fish.	This species is threatened by pollution in Cote d' Ivoire, and deforestation in Liberia.
Leptocypris guineensis[9]	NT	This species is found in four rivers. It is limited to mountain slopes of the Guinean mountain ranges: Konkouré, Moa and Waenje Rivers and also the Kogon. No known threats in these localities. It is qualified as Near Threatened due to its restricted range and therefore any threat in this area would cause the species to be assessed as threatened.	Limited to mountain slope of the Guinean mountain ranges: Konkouré, Moa, Waenje Rivers and from the Kogon.	Maximum TL was recorded at 7.6 cm. It would replace L. niloticus in the Guinean zone.	No current threats known.

6 Bousso, T. & Lalèyè, P. 2010. Marcusenius meronai. The IUCN Red List of Threatened Species 2010: e.T182980A8015432. http://dx.doi.org/10.2305/IUCN.UK.2010-3.RLTS.T182980A8015432.en. Downloaded on 15 August 2018.
7 Bousso, T. & Lalèyè, P. 2010. Sarotherodon occidentalis. The IUCN Red List of Threatened Species 2010: e.T181791A7735117. http://dx.doi.org/10.2305/IUCN.UK.2010-3.RLTS.T181791A7735117.en. Downloaded on 15 August 2018.
8 Entsua-Mensah, M. 2018. Enteromius bigornei (amended version of 2010 assessment). The IUCN Red List of Threatened Species 2018: e.T182041A126341088. Downloaded on 15 August 2018.
9 Bousso, T. & Lalèyè, P. 2010. Leptocypris guineensis. The IUCN Red List of Threatened Species 2010: e.T182337A7862800. http://dx.doi.org/10.2305/IUCN.UK.2010-3.RLTS.T182337A7862800.en. Downloaded on 15 August 2018.

Genus & Species	IUCN Red List	Justification	Range	Habitat	Threats
Raiamas nigeriensis[10]	NT	his species seems to be widely distributed with an EOO and AOO of more than 20,000 km² and 2,000 km² respectively. There is an ongoing decline in habitat in the River Cross due to oil exploration. In the Pra the main threats posed to this fish species include effluents from mining activities. These effluents may contain heavy metals like arsenic, mercury and compounds like cyanide. Also, the removal of vegetation pertaining to mining activities, and commercial timber felling, may cause increasing sediment loads, and its attendant problems to the life of the fish. Due to these threats the species is qualified as Near Threatened as it is close to meeting Vulnerable B2.	Raiamas nigeriensis has been collected in the Niger and Benue basins, but also in the Moa, Cavally, Sassandra, Bandama, Comoé, Pra and Cross. This species may thus be sympatric with R. senegalensis or R. steindachneri, even if the latter two have separate distribution areas.	Raiamas nigeriensis is a demersal potamodromous species. The maximum TL was recorded at 12.5 cm.	There is an ongoing decline in habitat in the River Cross due to oil exploration. In the Pra the main threats posed to this fish species include effluents from mining activities. These effluents may contain heavy metals like arsenic, mercury and compounds like cyanide. Also, the removal of vegetation pertaining to mining activities, and commercial timber felling, may cause increasing sediment loads, and its attendant problems to the life of the fish.
Ichthyborus quadrilineatus[11]	NT	This species is currently known in certain costal basins of western Africa: Casamance Corrubal, Kolenté (Geat Scarcies), Waanje and Taja (Pampana of Jong). The species has been recorded in 10 locations and has a wide distribution (EOO slightly exceeding 50,000 km², AOO close to meeting 2,000 km2) but has widespread threats, particularly from drought, deforestation, overfishing, and dams. It is therefore assessed as Near Threatened, as it is close to meeting Criteria B2.	This species is currently known in certain Western African coastal basins: Casamance Corrubal, Kolenté (Geat Scarcies), Waanje and Taja (Pampana of Jong).	This is a pelagic, freshwater species.	Drought, deforestation, overfishing and dams threaten this species

[10] Awaïss, A., Lalèyè, P. & Moelants, T. 2010. Raiamas nigeriensis. The IUCN Red List of Threatened Species 2010: e.T182265A7845780. http://dx.doi.org/10.2305/IUCN.UK.2010-3.RLTS.T182265A7845780.en. Downloaded on 15 August 2018.

[11] Bousso, T. & Lalèyè, P. 2010. Ichthyborus quadrilineatus. The IUCN Red List of Threatened Species 2010: e.T181951A7772219. http://dx.doi.org/10.2305/IUCN.UK.2010-3.RLTS.T181951A7772219.en. Downloaded on 15 August 2018.

Genus & Species	IUCN Red List	Justification	Range	Habitat	Threats
Synodontis levequei[12]	NT	This species is at present known only from the Konkouré basin (Guinea). There is no information on any major threats to the species. Due to its restricted range, the species is assessed as Near Threatened as it is close to meeting the Vulnerable category under criterion B. If any threats to this species are found, it would qualify as threatened.	This species is at present known only from the Konkouré basin (Guinea).	This is a benthopelagic species of 17.6 cm SL maximum size.	No current threats known.
Synodontis tourei[13]	NT	It is suspected that the extent of occurrence (EOO) and area of occupancy (AOO) thresholds for the Critically Endangered category are met (extent of occurrence less than 100 km² and area of occupancy less than 10 km²). The species is also restricted to only one location (Upper Bafing (Senegal basin) in the Fouta Djalon, Guinea). There are however no known current major threats to the species. But due to its restricted range, and the potential threats from deforestation the species can be assessed as Vulnerable.	Synodontis tourei is found in upper Bafing (Senegal basin) in the Fouta Djalon, Guinea.	This is a demersal freshwater fish.	This species is harvested for human consumption.
Petrocephalus levequei[14]	NT	Deforestation and mining, especially in the Upper Guinean zone threaten the habitat of the species. Its extent of occurrence and area of occupancy are close to meeting the thresholds for Vulnerable (at less than 20,000 km² and 2,000 km² respectively) and is found in fewer than 10 locations. The species is assessed as Near Threatened.	This species is known from the Guinean Atlantic area and Sierra Leone. Possibly also in coastal basins of Liberia, but its presence there has not yet been confirmed.	This is a demersal species. 13 cm SL maximum size	This species is threatened by deforestation, mining and human settlement.
Callopanchax occidentalis[15]	NT	This species is known from coastal rivers systems in Sierra Leone, from the Little Scarcies River system to the Lofa River system in western Liberia (just over 10 locations). Its extent of occurrence is	Callopanchax occidentalis is found in coastal river	C. occidentalis is found in pools, temporary swamps and swampy	There is no information on any major threats to the species in Sierra Leone;

[12] Lalèyè, P. 2010. Synodontis levequei. The IUCN Red List of Threatened Species 2010: e.T181726A7715000. http://dx.doi.org/10.2305/IUCN.UK.2010-3.RLTS.T181726A7715000.en. Downloaded on 15 August 2018.

[13] Entsua-Mensah, M. 2010. Synodontis tourei. The IUCN Red List of Threatened Species 2010: e.T182632A7931115. http://dx.doi.org/10.2305/IUCN.UK.2010-3.RLTS.T182632A7931115.en. Downloaded on 15 August 2018.

[14] Entsua-Mensah, M. 2010. Petrocephalus levequei. The IUCN Red List of Threatened Species 2010: e.T182703A7948098. http://dx.doi.org/10.2305/IUCN.UK.2010-3.RLTS.T182703A7948098.en. Downloaded on 15 August 2018.

[15] Lalèyè, P. 2010. Callopanchax occidentalis. The IUCN Red List of Threatened Species 2010: e.T182988A8017250. http://dx.doi.org/10.2305/IUCN.UK.2010-3.RLTS.T182988A8017250.en. Downloaded on 15 August 2018.

Genus & Species	IUCN Red List	Justification	Range	Habitat	Threats
		close to meeting 20,000 km² and area of occupancy may be less than 2,000 km². There is no information on any major threats to the species in Sierra Leone; but in Liberia the species has some threats including mining and deforestation. The species is assessed as Near Threatened as it is close to meeting VU under Criteria B.	systems in Sierra Leone from the Little Scarcies River system, to the Lofa River system in western Liberia. Also present in the adjacent part of southern Guinea.	parts of brooks in the rainforest and the humid forested savannah. It is a benthopelagic and non-migratory fish of 8.0 cm TL. It feeds on worms, crustaceans and insects. It is a bottom spawner, 3 months incubation. It is very difficult to maintain in aquarium.	but in Liberia the species has some threats, including mining and deforestation.

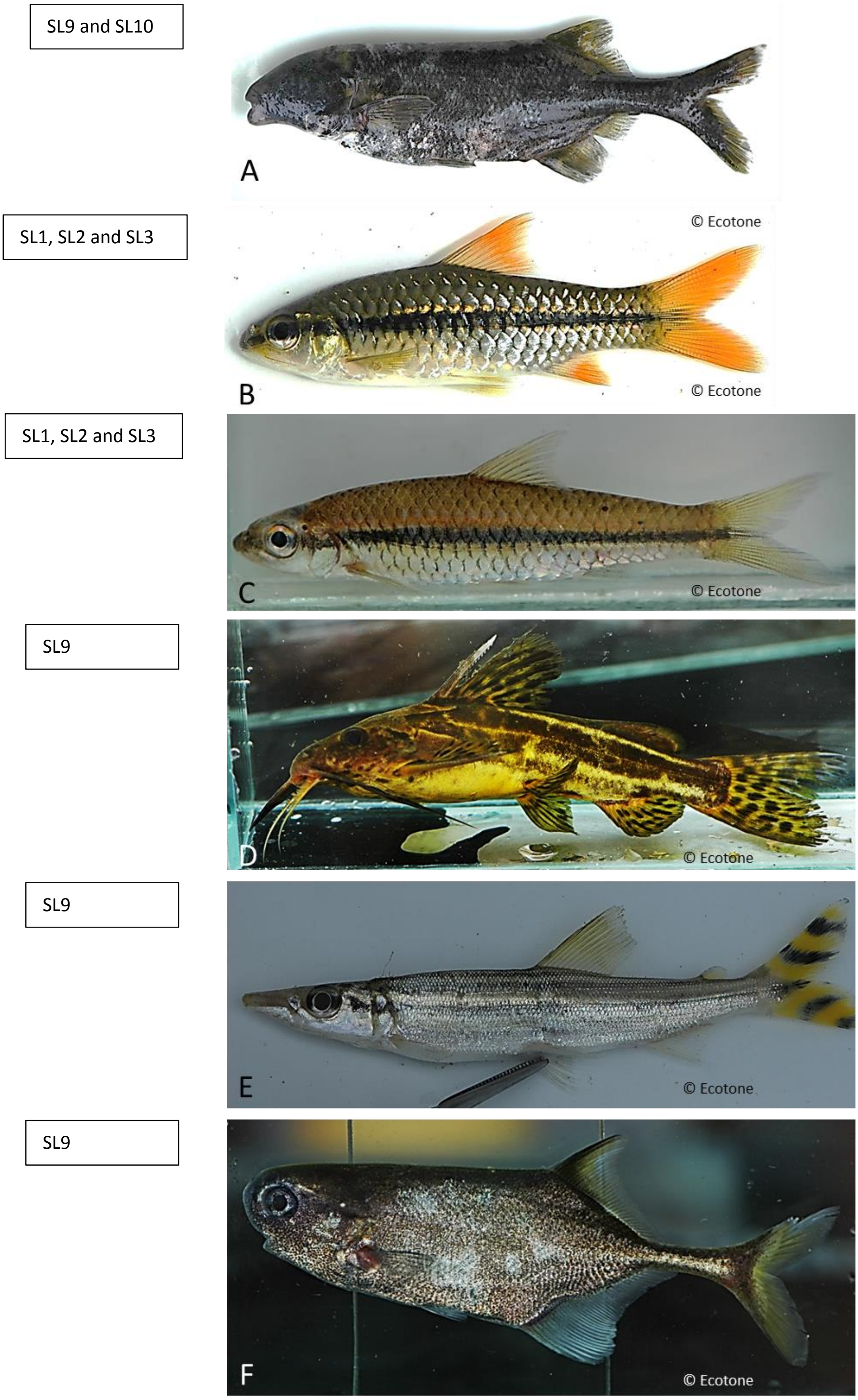


Figure 12-1: Some examples of species sampled during the April 2018 assessment of conservation significance. (A) *Marcusenius meronai* (EN), (B) *Enteromius bigornei* (NT), (C) *Prolabeo cf. batesi* (DD), (D) *Synodontis cf. tourei* (NT), (E) *Ichthyborus quadrilineatus* (NT), (F) *Petrocephalus levequei* NT).

12.2.2. Review of Ecological Guilds for Fish Species

River utilisation, like the construction of dams and changes in flow regime associated with proposed operations typically result in modification of instream habitat. The likely impacts of these possible changes require some form of quantification to inform the management of the natural resource. An assessment of fish ecological guilds provides a cost-effective indicator of fish assemblage response to potential alteration of instream conditions (Welcomme *et al*., 2006). A fish guild application was applied to identify baseline conditions and to predict likely alteration in fish assemblages due to the proposed operations. The following section summarises the analysis of the ecological fish guilds for the fish recorder within the Seli/Rokel River.

The ecological guild classification was based on known requirements of species. Where species data was unavailable, inferences were made from closely related species, or from species that reflect similar habitat preferences. The ecological guilds identify subsets within species assemblages having high potential for competition and provide a means to identify species with similar responses to environmental variation. In essence, fish are grouped together based on their habitat preferences during different life stages.

The use of guilds to group fish species with similar patterns of habitat use is intended to provide indicators and predictors of response to changes in river hydrographs and to modification of geomorphology, habitat structure and ecological function of river ecosystems. Thirteen guilds are described in **Table 12-8**. The reader is also referred to the glossary in the front of the report for an explanation of technical terms.

Table 12-8: Ecological fish guilds applied and their definitions

Term	Explanation
Eupotamonic benthic guild	Benthic species that occupy the centre of the main channel. They are generally intolerant of lowered dissolved oxygen concentrations, although they may have to resist periodic lowering of oxygen tensions during the hot, dry season. They can adapt behaviourally to altered hydrographs, existing in a quasi-lacustrine condition and generally increase in number as other species decline. They are impacted negatively by modifications that change deposition–siltation processes and alter the nature of the substratum and may also be sensitive to deoxygenated conditions in the deeper, refuge areas of the channel during the dry season. They are predominantly psammophils and lithophils.
Eupotamonic lithophilic guild	Species in this guild are often longitudinal migrants, including many anadromous species. They differ from the eupotamonic pelagophilic species in that they are predominantly lithophils and psammophils with a single breeding season. They may be semelparous, having one breeding season only. Fry may be resident at upstream sites for a certain period and may occupy upstream floodplains. These species are also vulnerable to damming and to lowered water quality that prevents migration, although they may respond favourably to appropriately designed fish passes. They are also adversely affected by changes in the timing of high flow events that are inappropriate to their breeding seasonality, as well as to changes in the quality of upstream breeding habitats, which may become choked with silt or have insufficient flow to aerate the developing eggs. The species may be recovered by ensuring longitudinal connectivity by fish passage facilities or removal of cross channel dams, or by ensuring the timing and quantity of flows are adequate to promote migration and ensure the development of eggs and larvae by providing aerating flows in the spawning gravels.
Eupotamonic phytophilic guild	Species in this guild are long distance or short distance longitudinal migrants that also undertake lateral migrations onto and off the floodplain, which they use for breeding, nursery grounds and

Term	Explanation
	feeding by juvenile and adult fish. Adult and juvenile populations may be found in floodplain lagoons as dry season residents. They are predominantly phytophils or phytolithophils, spawning at floodplain margins, in inflowing channels or on the floodplain itself. Eggs and larvae of some species are semi-pelagic and are carried onto the floodplain by passive drift with the rising flood. Species in this guild tend to disappear or become greatly diminished in abundance when the river is dammed and prevents migration, or when access to the floodplain is denied to developing fry and juveniles because flow levels are inadequate to flood riparian lands, or these are cut off by levees.
Eupotamonic riparian	This guild occupies the riparian zone and particularly the vegetation of the main channel and floodplain waterbodies; and may move onto the floodplain to occupy similar habitats during flooding. Populations may have lateral migratory or semi-migratory components, with resident elements that become dominant in controlled conditions. These species usually tolerate low dissolved oxygen. They show a wide range of breeding behaviour but are predominantly phytophils although they also include species showing various degrees of nest building and parental care. They can adapt behaviourally to altered hydrographs, are extremely flexible and may adopt other habitats as river conditions change and increase in number as other species decline. This guild is especially well represented in most rivers. Species in this guild are colonizers of regulated systems and often increase to pest levels following control of flooding and stabilization of river hydrographs or declines in water quality through eutrophication.
Paleopotamonic guild	This guild consists of species tolerant of complete anoxia that are found in isolated floodplain pools and wetlands. They are usually sedentary and sometimes show extremes of parental care with nest building and viviparity. In slightly modified systems they persist in residual floodplain water bodies isolated from the main river and may resist complete desiccation (xerophils). They may also survive in low numbers in deoxygenated backwaters and marginal and floating vegetation and form important components in rice field and ditch faunas. Some of these species have been used for intensive aquaculture because of the readiness with which they adapt to pond conditions and extremely dense populations. The guild is impacted negatively by floodplain reclamation schemes that drain or fill the marginal waterbodies and wetlands in which component species live.
Parapotamonic guild	Species in this guild may be termed semi-lotic in that their behaviour is intermediate between the long-distance migrants of the other three lotic guilds and the lentic groupings. They are sometimes sedentary but also show semi-migratory behaviour. They include lithophils, phytophils, phytolithophils and psammophils. They prefer slow-flowing anabranches of the main river or backwaters with low or seasonal flows. They can also use tributary creeks, blind backwaters or slacks downstream of point bars as breeding grounds and nurseries. The parapotamon is also used as a refuge for many rheophilic species during times of excessive main channel flow. Species in this guild are usually resistant to change and as such could be considered eurytopic (generalist). However, they are sensitive to river straightening and bank revetments that suppress main channel diversity and bank structure. Species can be recovered by rehabilitating main channel diversity, particularly by reconnection of abandoned side arms and active backwaters.
Plesiopotamonic guild	This guild consists of species that are tolerant to reduced dissolved oxygen concentrations but cannot resist complete anoxia. They usually inhabit relatively well-oxygenated water bodies that are regularly connected to the main river by flooding, where they may be found in open waters as well as in the riparian vegetation. Some species may also occupy riparian vegetation of still-water channels and canals. They are often sedentary but may show a limited amount of lateral migration that permits them to escape the worst of deoxygenated conditions. They include guarding and non-guarding phytophilic and nest building species. Species in this guild tend to disappear when the floodplain is disconnected from the main channel and desiccated through levee construction. Limited populations may continue in riparian vegetation in the main channel or in backwaters whose upper end is silted. They may also increase in number in shallow, isolated wetlands, and drainage ditches.
Rhithron-pool guild	Species in this guild are slightly more limnophilic in habit and generally seek to inhabit the slack regions of back eddies where emergent and floating vegetation may occur. Other species inhabit the deeper waters. They tend to be insectivorous, feeding on the drift dislodged from the riffles or on insects falling into the river from riparian vegetation. They may be either limnophilic, breeding in the riffles, or phytophilic, attaching their eggs to vegetation. The various species inhabiting rhithronic pools usually have well-defined home ranges, and appear to have defined habitats delimited by depth, current strength and the distribution of vegetation. As with the riffle guild, variations may occur resulting from the lessening gradient and widening of the channel. These species are also disturbed by changes to the flow regime that desiccate the pools or leave

Term	Explanation
	them for long periods without flow, so they become anoxic. They also generally rely on the delicate balance between pool and riffle of the rhithron and respond negatively to any influence that changes this balance. Again, this guild can be affected by the loss of longitudinal connectivity.
Rhithron-riffle guild	Species in this guild are rheophilic, main channel residents that inhabit rapids and riffle areas. They are generally sedentary, of small size and are equipped with suckers or spines to enable them to grip rocks and other submersed objects. They may also have elongated or laterally flattened forms that allow them to live in the interstitial spaces of the rock and cobble substrate. Riffle species are generally non-guarding and guarding lithophils with extended breeding seasons depositing their eggs among the rocky riffles where they live. They are generally insectivorous or specialists such as algal scrapers or filter feeders. Species inhabiting riffles usually require very well oxygenated water.
Semi-anadromous estuarine guild	This group of species enters fresh or brackish water to breed or to use the lower reaches of the river as a nursery

Of the guilds described in **Table 12-8**, four (rhithron-riffle, rhithron pool, eupotamonic lithophilic and eupotamonic phytophilic) are generally more sensitive to changes in flow, as may occur because of the proposed Bumbuna Extensions (**Figure 12-2**). Jointly these four guilds represent 18 species (~20% of the fish diversity). Typical reactions of these sensitive guilds to change in flow are summarised below from Welcomme *et al*. (2006). In each case a short description of the guild is provided, followed by the proportion of the recorder fish falling within the specific guild and then the anticipated response to a change in flow.

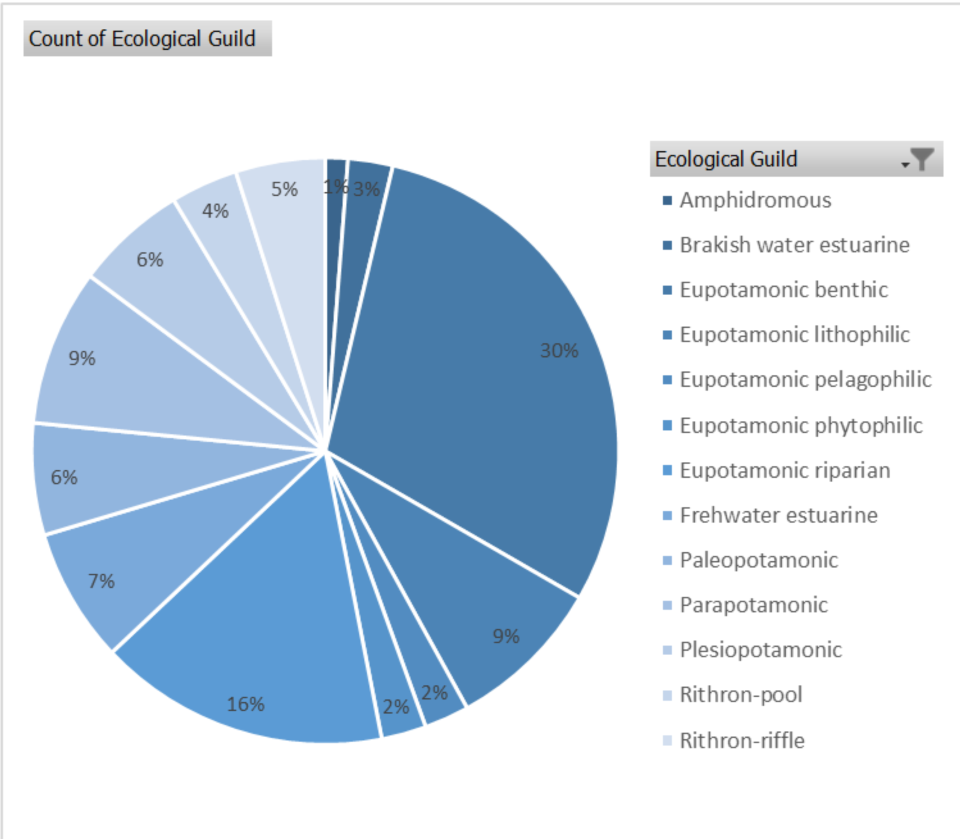


Figure 12-2: Proportional representation of different ecological fish guilds for the observed fish within the Rokel/Seli River.

12.2.2.1. RHITHRON RIFFLE GUILD

Species in this guild are rheophilic, main channel residents that inhabit rapids and riffle areas. They are generally sedentary, of small size and are equipped with suckers or spines to enable them to grip rocks and other submersed objects. They also have elongated or laterally flattened forms that allow them to live in the interstitial spaces of the rock and cobble substrate. Riffle species are generally non-guarding and guarding lithophils with extended breeding seasons depositing their eggs among the rocky riffles where they live. They are generally insectivorous or specialists such as algal scrapers or filter feeders. Species inhabiting riffles usually require very well oxygenated water. Of the recorded species four fall within this guild and represent families such as Mochokidae and Amphiliidae (**Figure 12-3**). Fish in this guild are sensitive to a change in flow in the following ways:

- Sensitive to catastrophic and habitat flows, as could occur from dam development.
- Damage by disturbance to pool-riffle structure, such as seasonal desiccation, or increase in sediment load that choke the interstitial spaces.
- Damage by wash-out or deep inundation of gravel and cobble reaches.

Figure 12-3: Photo examples of rhithron riffle species sampled during the April 2018 assessment. (A) *Amphilius platychir* (LC), (B) *Amphilius rheophilus* (LC) and (C) *Chiloglanis occidentalis* (LC).

12.2.2.2. RHITHRON POOL

Species in this guild are slightly more limnophilic (lake loving) in habit and generally seek to inhabit the slack regions of back eddies where emergent and floating vegetation may occur. Other species inhabit the deeper waters for example *Raiamas* and *Leptocypris* species. They tend to be insectivorous, feeding on the drift dislodged from the riffles or on insects falling into the river from riparian vegetation. They may be either limnophilic, breeding in the riffles, or phytophilic, attaching their eggs to vegetation. The various species inhabiting rhithronic pools usually have well defined home ranges, and appear to have defined habitats delimited by depth, current strength and the distribution of vegetation. As with the riffle guild, variations may occur resulting from the lessening gradient and widening of the channel. These species are also disturbed by changes to the flow regime that desiccate the pools or leave them for long periods without flow, so they become anoxic. They also generally rely on the delicate balance between pool and riffle of the rhithron and respond negatively to any influence that changes this balance. Of the expected species three (*Raiamas nigeriensis*- NT, *R. scarciensis*- LC and *R. steindachneri*- LC) fall within this guild and represent the family Cyprinidae. Only one (*R. steindachneri*- LC) have been sampled during the April 2018 assessment (**Figure 12-4**). Again, this guild can be affected by loss of longitudinal connectivity and are generally affected by the following:

- Changes to flow regime that desiccate the pools or leave them for long periods without flow, as may occur downstream of dams with inappropriate management of environmental flow.
- Changes in water level can disturb habitat structure.
- Generally, rely on delicate balance of pool-riffle structure of the rhithron and response negatively to any influence that changes this balance.

Figure 12-4: Photo examples of rhithron pool species (*Raiamas steindachneri*- LC) sampled during the April 2018 assessment

12.2.2.3. EUPOTAMONIC LITHOPHILIC

Species in this guild are potamodromous and have very specific spawning requirements associated with substrate and flow. They typically spawn during a single breeding season following an upstream migration (*Labeobarbus* and *Labeo* species) (**Figure 12-5**). Species within the guild are also vulnerable to damming and to lowered water quality that prevents migration. They are also adversely affected by changes in the timing of wet season flows that are inappropriate to their breeding seasonality, as well as to changes in the quality of upstream breeding habitats, which may become obstructed with silt or have inadequate flow to air the eggs. The occurrence of these species may be improved by reinstating longitudinal connectivity and mimicking the natural hydrological regime. About 9% of the recorder species within the Seli/Rokel River falls within this guild (**Figure 12-2**). The points below summarise likely risks to this guild due to alteration in flow and instream habitat:

- Tend to disappear when rivers are fragmented through dam construction to prevent migration or due to timing of flow release that is inappropriate to their breeding seasonality.
- Sensitive to habitat flows if upstream breeding substrate destroyed or degraded.
- Sensitive to structure of upstream habitat particularly presence of pebbles cobbles and gravel beds.

Figure 12-5: Photo examples of eupotamonic lithophilic species sampled during the April 2018 assessment. (A) *Labeobarbus sacratus* (NE) and (B) *Labeo parvus* (LC).

12.2.2.4. EUPOTAMONIC PHYTOPHILIC

Species in this guild undertake longitudinal and often lateral migrations onto and off the floodplain, which they use for breeding, nursery grounds and feeding by juvenile and adult fish. Adult and juvenile populations may be found in floodplain lagoons as dry season residents. Fish in this guild have very specific flow, depth and vegetation requirements for breeding. Species such as *Hydrocynus forskahlii* (LC) and *Hepsetus odoe* (LC) falls in this guild and spawns at floodplain margins, in inflowing channels or on the floodplain itself (**Figure 12-6**). Species in this guild tend to disappear or become greatly diminished in abundance when the river is dammed and prevents migration, or when access to the floodplain is denied to developing fry and juveniles because flow levels are inadequate to flood riparian zones, or these are cut off by levees. Two of the recorder species falls into this relatively sensitive guild (**Figure 12-6**). The protection and or rehabilitation for this guild is similar to that of the Eupotamonic lithophilic guild and main responses to changes in flow and instream habitat include:

- Sensitive to habitat fragmentation and tend to disappear when rivers are dammed to prevent migration.
- Damaged when access to floodplain denied to developing fry and juveniles.
- Influenced by amplitude and duration of flooding.

Figure 12-6: Photo examples of eupotamonic phytophilic species sampled during the April 2018 assessment. (A) *Hepsetus* sp. and (B) *Hydrocynus forskahlii* (LC).

12.2.3. Breeding and Migration

In addition to the general ecological sensitivities linked to the different ecological fish guilds, a more specific review of flow related breeding and migration requirements of the expected and sampled fish assemblages were completed and are discussed in the sections below.

12.2.3.1. BREEDING

Details on breeding times for most of the recorded species were obtained from Payne (2018) or inferred from surrogate species or niche sharing species.

A simple analyses of breeding time with the natural hydrological variation identified five main breeding times:

1. The first group spawns during the dry season months (Jan-Apr) and include *Brycinus longipinnis* (LC)*, B. macrolepidotus* (LC)*, Coptodon louka* (LC)*, Heterotilapia buttikoferi* (LC)*, Sarotherodon caudomarginatus* (LC)*, S. melanotheron* (NE) and *S. occidentalis* (NT). Dry season spawners represents approximately 10% of the Rokel/Seli fish (**Figure 12-7**). The large increase in baseflows may impact on the reproductive success of these species as there will be a general decrease in dry season habitat and less pronounced variation between wet and dry season flows.
2. The second group consists of the serial spawners and include *Epiplatys fasciolatus* (LC) and *E. njalensis* (EN). They represent 3% of the Rokel/Seli fish (**Figure 12-7**). These fish spawn throughout the year in low velocity water associated with aquatic macrophytes. *Epiplatys njalensis* has not been sampled within the Rokel River but may occur in lower lying streams flowing into the Rokel River. It is unlikely that serial spawners will be affected by the operational flow changes associated with the Bumbuna Extensions.
3. The third group are late wet season breeders. They typically breed between October and December when wet season flows are receding. Four species are included in this group which comprise of three stargazers (*Amphilius atesuensis*- LC, *A. platychir*- LC, *A. rheophilus*- LC and one mouthbrooder (*Anomalochromis thomasi*- LC). The Amhpilids are rheophilic and very sensitive to flow and substrate variation. Of the three Amphilids two are expected to occur in transitional (steep rapids, riffles sections with FI and FD habitat) zone associated with the upper foothills and the lowland habitats. The marked absence of Amphilids, in areas with suitable habitat, indicate an alteration in the habitat most likely attributed to existing changes in the natural flow regime.
4. The bulk of the expected and sampled species breeds throughout the wet season (40% - **Figure 12-7**). This group consists of migrating and resident fish some of which are sensitive to the attenuation of wet season flows such as the semi-rheophilic *Labeobarbus sacratus* (NE), *Labeobarbus wurtzi* (NE), *Labeo coubie* (LC), *Labeo parvus* (LC) or sudden pulses in discharge such as the rheophilic *Chiloglanis occidentalis* (LC). Under baseline conditions a moderate to large decrease in the occurrence of these species have been observed (see **Section 13.2.4**). In the absence of peaking operations, the operational flows are not

expected to further impact on the wet season breeders, provided enough variation in flow to cue migration and breeding and spawning habitat.

5. The last group consists of early wet season breeders (41% - **Figure 12-7**). These species spawn when the water levels are rising, and all species migrate to some extent. In the context of the Rokel/Seli River, this group is dominated by demersal species such as Mormyrops (of which *Marcusenius meronai* is EN), Synodonts (of which *Synodontis levequei* and *S. tourei* are NT), Clarids and Bagrids. They are not generally considered as sensitive species and often dominate the fish assemblages in modified systems. However, a delay in the onset of the wet season cues and a shorted period with rising water levels, may influence the breeding success of this group. The breeding requirements of each group have been considered in relation to the baseline observation and anticipated operational flows to inform likely changes within the fish component of the overall EcoStatus. This is discussed in more detail in **Section 12.2.4**.

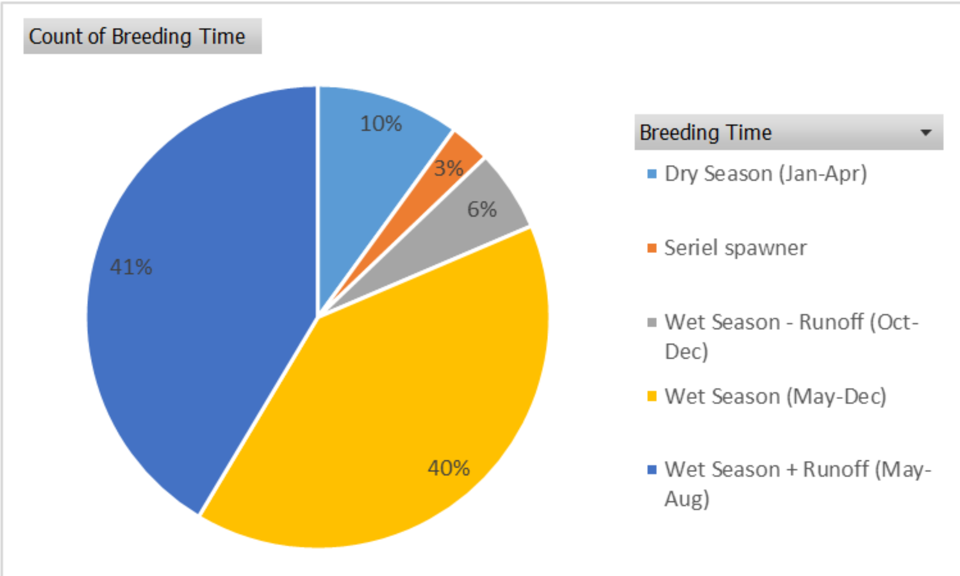


Figure 12-7: Proportions of fish with specific breeding times.

12.2.3.2. MIGRATION

Migration and movement requirements were grouped into four main classes: longitudinal migration, lateral migration and movement within a habitat unit. Longitudinal migrants can be potamodromous (take place entirely within the river channel), diadromous (between salt and freshwater) or amphidromous (between salt and fresh water for reasons other than reproduction). Approximately 80% of the recorded species are potamodromous (**Figure 12-8**). The operational flows may have implication for migration cues as the wet season onset will be delayed. Or result in insufficient spawning grounds, as migrating fish are likely to forcefully spawn below Bumbuna Falls (a natural migration barrier). The potential implications of this were discussed in point 5 in **Section 12.2.3.1**. The second consideration will be the activation of lateral (floodplain) connectivity. The operational flows will attenuate wet season flows, with less intense floods lasting for a shorter time and occurring less frequently. It follows that floodplain activation will be reduces and this will impact on floodplain dependent species. Many of the expected and sampled species will opportunistically (facultatively) recruit and utilise floodplain habitat if available. However, their reproductive success is not expected to decrease in the absence of floodplain activation. However, one species *Malapterurus leonensis* (NE) reflects a greater preference for floodplain activation and may experience a decrease in reproductive success.

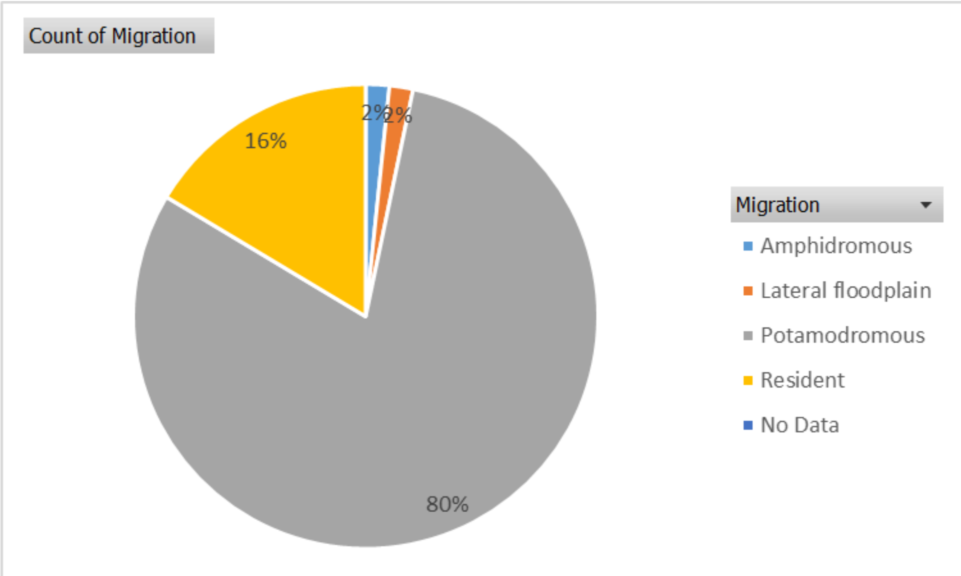


Figure 12-8: Proportion of fish with specific migration requirements

12.2.4. Present Ecological State

The PES assessment was completed to determine baseline modification in fish assemblages by measuring the digression in the representation of expected ecological fish guilds and the sampled representation during the April 2018 assessment. The environmental requirements, as defined by the guild classifications, were applied with a more in-depth analyses of breeding and migration requirements to predict the potential change in fish assemblages that may occur during the operation of the Bumbuna Extensions.

The main operational flow changes include the following:

1. Flooding of the upper foothills reach associated with the inundation zone of the proposed Yiben Reservoir. This section is represented by sampling location SL1. Site SL2 also represents upper foothills habitat but represents a reach that will not be affected by the inundation zone.

2. The 'dry reach' between the existing Bumbuna Dam and the tailrace of the Bumbuna Extension HEP will experience a decrease in flow for most of the time, with a constant 6 m^3s^{-1} 'environmental compensation' flow. This reach is represented by Site SL5 and includes the Bumbuna Falls.
3. Downstream from the Bumbuna Extension HEP some part of the river will experience a near static 78 m^3s^{-1} discharge during operations. Sites SL6, SL7 and SL8 represent lowland aquatic habitat that is most likely to be affected by the operational flow changes, while site SL9 (lowland habitat but with more pronounced floodplain features) and SL10 (a rejuvenated zone also with well-defined floodplain features) will be less affected by operational flows.

The flow-habitat analyses outlined in **Section 4.3.1**, **Figure 4-2** and **Figure 4-3** informed the interpretation of operational flow related habitat changes on fish assemblages. While, **Figure 4-5** conceptualised the degree and extent of flow related changed to the river downstream of the Bumbuna Extensions.

The following sections discuss the baseline fish assemblage integrity and the predicted changes within the fish assemblages during operations.

12.2.4.1. THE REACH WITHIN THE INUNDATION ZONE

The fish guild assemblage for site SL1, representing the upper foothills reach that will be affected by the inundation zone of the Yiben Reservoir, yielded a 'B' category integrity score which translates into a *Largely* natural state (**Table 12-9**). Some digression from the reference fish assemblages were observed for the Paleopotamonic (*Clarias anguillaris*, *C. buettikoferi* and *Ctenopoma kingsleyae*) and Plesiopotamonic guilds (*Epiplatys fasciolatus* and *Heterobranchus isopterus*) (**Figure 12-9 -SL1**). The digression may be attributed to sampling effort.

Fish representing the eupotamonic lithophilic (*Labeobarbus sacratus*, and *Labeo parvus*), parapotamonic (*Enteromius* species of which *Enteromius liberiensis* is EN) and rhithronic (Amphilius species and Chiloglanis occidentalis) guild are expected to decrease during operations, due to the inundation. Eupotamonic riparian, eupotamonic benthic and paleopotamonic species are likely to dominate the fish assemblages under inundated conditions. These most notably represent Cichlids such as *Coptodon louka* and Alestids such as *Brycinus longipinnis*. The subsequent predicted change in fish assemblage integrity is a drop from a 'B' category to an 'E' (Seriously modified) category (**Table 12-9** and **Figure 12-9 -SL1**).

Table 12-9: Fish assemblage integrity score and EcoStatus for the resource unit associated with the upstream reach (sites SL1-SL3) and the downstream reach (sites SL5-SL10)

Resource Unit	Relative Fish Assemblage (%) Baseline	Fish Assemblage Integrity Category Baseline	Relative Fish Assemblage (%) Bumbuna Extensions	Fish Assemblage Integrity Category Bumbuna Extensions
SL3	80.4	B	80.4	B
SL2	82.6	B	82.6	B
SL1	84.0	B	36.0	E
SL5	51.6	D	41.9	D
SL6	54.8	D	41.9	D
SL7	60.6	C	45.5	D
SL8	57.5	D	40.0	D
SL9	68.2	C	54.2	D
SL10	68.2	C	54.5	D

12.2.4.2. 'Dry Reach'

During operation the 'dry reach' (represented by SL5) will receive a constant flow of 6 m^3s^{-1}. At this discharge the active channel will be approximately 18 m wide of which more than 50% will be occupied by FD, FI and FS habitat units (**Figure 4-2**). The representation of fast habitat units is typically more important for sustaining sensitive rheophilic invertebrate and fish species. These conditions will be enough to maintain some feeding and breeding habitat for rhithronic species. But may not be enough to provide spawning habitat for more sensitive migrating fish belonging to the eupotamonic lithophilic guild. The baseline fish assemblage integrity for this reach is a 'D' category which translates into a *Largely* modified state (**Table 12-9**).

A review of the environmental preferences of the sampled and expected species indicate hydrology as the main reason for the decrease in fish assemblage integrity. Most of the flow sensitive fish were absent (**Figure 12-9 -SL5**), despite ample structural habitat (cover) available. The proposed operational flows will provide more constant habitat for rhithronic species but will not provide enough spawning habitat for lithophils or feeding habitat for some of the expected demersal species. If the predicted fish assemblages are corrected for the anticipated change in flow the ecological integrity remains in a 'D' category during operations (**Figure 12-9 -SL5** and **Table 12-9**).

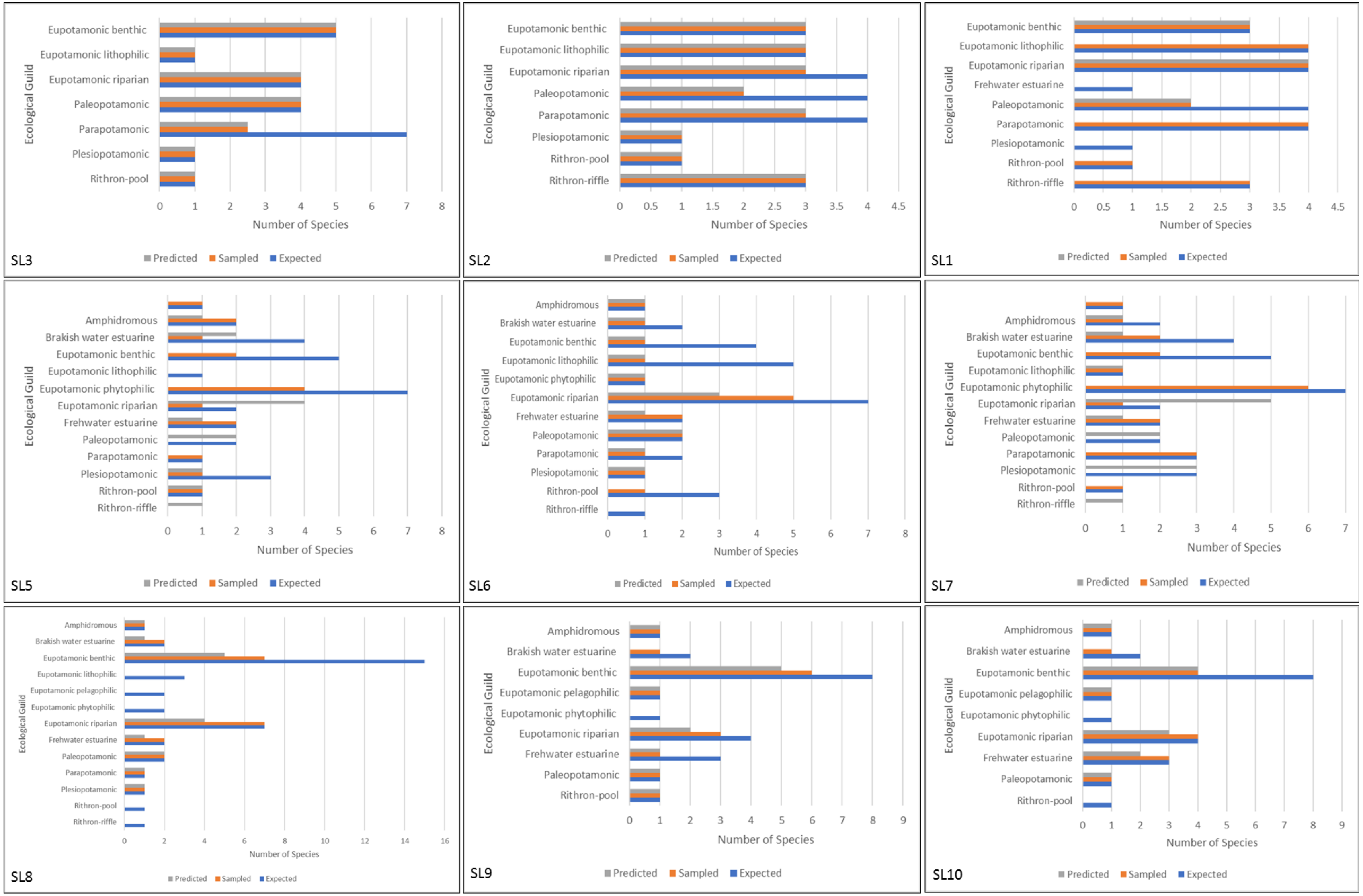

SL3
Eupotamonic benthic
Eupotamonic lithophilic
Eupotamonic riparian
Paleopotamonic
Parapotamonic
Plesiopotamonic
Rithron-pool
Ecological Guild
Number of Species
Predicted Sampled Expected
SL2
Eupotamonic benthic
Eupotamonic lithophilic
Eupotamonic riparian
Paleopotamonic
Parapotamonic
Plesiopotamonic
Rithron-pool
Rithron-riffle
Ecological Guild
Number of Species
Predicted Sampled Expected
SL1
Eupotamonic benthic
Eupotamonic lithophilic
Eupotamonic riparian
Frehwater estuarine
Paleopotamonic
Parapotamonic
Plesiopotamonic
Rithron-pool
Rithron-riffle
Ecological Guild
Number of Species
Predicted Sampled Expected
SL5
Amphidromous
Brakish water estuarine
Eupotamonic benthic
Eupotamonic lithophilic
Eupotamonic phytophilic
Eupotamonic riparian
Frehwater estuarine
Paleopotamonic
Parapotamonic
Plesiopotamonic
Rithron-pool
Rithron-riffle
Ecological Guild
Number of Species
Predicted Sampled Expected
SL6
Amphidromous
Brakish water estuarine
Eupotamonic benthic
Eupotamonic lithophilic
Eupotamonic phytophilic
Eupotamonic riparian
Frehwater estuarine
Paleopotamonic
Parapotamonic
Plesiopotamonic
Rithron-pool
Rithron-riffle
Ecological Guild
Number of Species
Predicted Sampled Expected
SL7
Amphidromous
Brakish water estuarine
Eupotamonic benthic
Eupotamonic lithophilic
Eupotamonic phytophilic
Eupotamonic riparian
Frehwater estuarine
Paleopotamonic
Parapotamonic
Plesiopotamonic
Rithron-pool
Rithron-riffle
Ecological Guild
Number of Species
Predicted Sampled Expected
SL8
Number of Species
Predicted Sampled Expected
SL9
Amphidromous
Brakish water estuarine
Eupotamonic benthic
Eupotamonic pelagophilic
Eupotamonic phytophilic
Eupotamonic riparian
Frehwater estuarine
Paleopotamonic
Rithron-pool
Ecological Guild
Number of Species
Predicted Sampled Expected
SL10
Amphidromous
Brakish water estuarine
Eupotamonic benthic
Eupotamonic pelagophilic
Eupotamonic phytophilic
Eupotamonic riparian
Frehwater estuarine
Paleopotamonic
Rithron-pool
Ecological Guild
Number of Species
Predicted Sampled Expected

Figure 12-9: Bar graphs showing the variation within fish assemblages between expected, sampled and predicted fish assemblages.

12.2.4.3. DOWNSTREAM OF BUMBUNA EXTENSION HEP TAILRACE

The change within instream habitat associated with the reach downstream of the Bumbuna Extension HEP can roughly be approximated for the upper foothills and transitional sections from **Figure 4-2**. Similarly, the flow-habitat relationship for the lowland sections can be estimated form **Figure 4-3.** The operational flow of 78 m^3s^{-1} will results in a channel width of about 110 m wide over the upper foothills habitat, of which 65% will be FD and 15% will SD. At this discharge availability of FI and FS (required for smaller rhithronic species) are constraint to about 10% of the channel. Although expected, most of the more sensitive rhithronic and eupotamonic lithophilic species were absence during the April 2018 baseline assessment within the river reach downstream of the existing Bumbuna operations. Sites SL5 and SL6 reflected the largest digression from refence assemblages and fell in a 'D' category (**Table 12-9**). Site SL7 improved to a 'C' category indicating a recovery in hydrological impacts associated with the existing Bumbuna operations. Site SL8 decreased again to a 'D' category, but this may be related to sampling constraints or possible impacts associated with the large Magburaka settlement. Sites SL9 and SL10 recovered to a 'C' category (**Table 12-9**).

As a broad trend, the baseline fish assemblages were consistent with the invertebrate results and reflected a greater hydrological impact within the upper foothills and lowland aquatic habitats represented by SL5, SL6, SL7 and SL8 and improved assemblages at SL9 and SL10. The fish assemblages during operations of the Bumbuna Extensions are expected to reflect a similar recovery based on the correction in functional flow requirements approximated in **Section 4.3.2**, **Figure 4-5 C** and **D** and discussed in **Table 4-17**. The predicted changes within fish guild assemblages were informed by the degree to which functional flows and habitat requirements will be met during future operational flows. Functional flows related to dispersal and reproductive triggers will be affected for the lowland habitat represented by SL6, SL7 and SL8, while dry season baseflows will increase with the entire length of river downstream of the Extensions. The implications of these alteration are expressed for the specific fish guilds in relation to baseline observations at each site assessed and are provided in **Figure 12-9.** The disparity between observed and predicted fish integrity scores are greater for sites SL6, SL7 and SL8 compared to that of SL9 and 10, as more of the functional flow requirements will be altered during future operations. However, it is likely that residual fish assemblage integrity categories for the entire downstream reach will fall into a 'D' category (**Table 12-9**).

13. APPENDIX G – ENVIRONMENTAL WATER REQUIREMENTS ASSESSMENT

13.1. MATERIALS AND METHODS

The RDRM is based on integrating hydrology, hydraulics, and ecology and makes use of the frequencies of different hydraulic habitat types (based on depth and velocity: **Table 13-1**), and how these change with discharge, to define levels of ecological stress.

The first step in the model is to use the natural hydrological time series (and present day if available) to separate out volumes of slowly changing baseflows and high flows from the total streamflow volume. The baseflow time series are used to define the critical wet and dry season months and to quantify the maximum baseflow discharge within these two months.

The second step is to define the channel cross-section using a field surveyed channel cross-section. Part of this process also establishes a representative depth-discharge rating curve. The hydraulic sub-model also establishes the table of habitat frequencies for the full range of discharges that are used within the ecological sub-model for low flows.

Table 13-1: Hydraulic habitat types and their definitions

Habitat Type	Velocity (m s^{-1})	Depth (m)
Fast Deep (FD)	> 0.3	>0.3
Fast Intermediate (FI)	> 0.3	> 0.2; ≤ 0.3
Fast Shallow (FS)	> 0.3	> 0.1; ≤ 0.2
Fast Very Shallow (FVS)	> 0.3	≤ 0.1
Slow Deep (SD)	≤ 0.3	>0.5
Slow Shallow (SS)	≤ 0.3	≤ 0.5
Slow Very Shallow (SVS)	≤ 0.3	≤ 0.1

The first part of the ecological sub-model uses the habitat frequency data to quantify the relationship between discharge (or flow) and stress for the critical wet and dry season months based on a set of weighting parameters that allow the FS, FI and FD habitats to assume different levels of importance. These relationships extend from the calculated maximum baseflow (for each month), where the stress is assumed to be zero, down to zero flow, where the stress is assumed to be 10. The shape of the relationship is determined by the patterns of habitat loss as the discharge reduces. The natural time series data of baseflows are then processed through these flow-stress relationships to determine the exceedance frequency distribution of stress under natural conditions.

The default positions of the maximum and minimum stress for each category were manually edited based on the observed flow requirements.

The final part of the process is to transform the category stress frequency curves into flow duration curves using the flow-stress relationships. The flow duration curves for the other months of the year are created using interpolation from the critical wet and dry season months and the variations in the natural flow time series. The final time series of the EWR low flows are based on the variability characteristics of the natural flow time series but using the flow duration curves of the EFR categories (see Hughes *et al.*, 2014 for further details).

13.1.1. Channel Cross-section Selection

The cross-section information used within the New RDRM is illustrated in Figure 13-1 and **Table 13-2**. The channel dimensions are represented by figures labelled Figure 13-1 **A**, while the stage discharge curves, are represented by the Figure 13-1 **B** and show the relationship between discharge and depth for each cross-section included in the New RDRM.

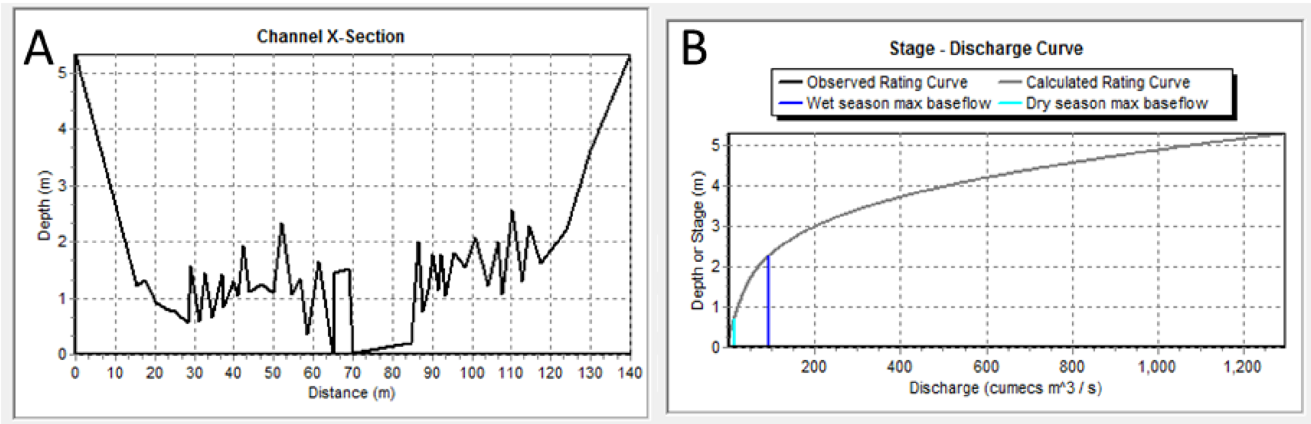


Figure 13-1: (A) Channel Cross-section SL5 and (B) stage discharge curve at channel cross section SL5

Table 13-2: Input data for the new RDRM hydrological sub-model

Hydraulic Parameter	Value
Geomorphological zone	5
Width Depth Scaling	0.50
Hydrological variability	2.31
Valley slope fraction	0.002
Catchment area (km²)	3990
Maximum depth (m)	5.6
Maximum width (m)	90
Bed width (fraction)	0.7
Macro roughness (m)	0.74
Micro roughness (m)	0.009
Maximum gradient	0.0052
Minimum gradient	0.002

Hydraulic Parameter	Value
Gradient shape factor	11
Maximum Manning n	0.112
Minimum Manning	0.042
n Shape factor	50

13.1.2. Hydrological data

The available hydrological data consist of simulated flows for a period of some 50 years for both the assumed natural flow regime as well as for the total hydro-power release regime (referred to here as the HP scenario).

13.2. Results and Discussion

It is recognized that under future conditions the hydro-power releases will be returned to the channel of the Seli River some 4 km below the dam wall and that within this channel reach there are some ecologically important areas (rapids and waterfalls). The key environmental flow requirement issue in this channel reach is therefore to ensure that some flow is maintained in the channel through releases directly from the Bumbuna Dam into the channel. This is referred to in this report as the ‘Lower Flows EWR’. However, in the channel below the point at which the hydro-power releases are returned to the channel the key issue is the loss of habitat diversity due to elevated low flows. Establishing the EWR for these channel areas involves quantifying the seasonal pattern of reductions in hydro-power releases that are required to ensure some habitat diversity and this is referred to in the report as the ‘Higher Flows EWR’. The Revised Desktop Model is designed to be applicable for the ‘Lower Flows EWR’ but cannot be used for the ‘Higher Flows EWR’ and therefore a different approach was required for the latter.

13.2.1. ‘Dry Reach’

The basic principles of the approach used for the lower flows EWR is to establish appropriate relationships between ecological habitat stress (between 0 and 10) and discharge for the main wet and dry season months and then to identify the frequency with which key stress levels should be equaled or exceeded within an acceptable flow regime. The natural flow regime variations are then used to determine a future flow regime that will satisfy these stress requirements. Figure 4 shows the flow-stress relationships for both the key wet (September) and dry

(April) season months (the 'smoothed' curves are those used in the final analysis). It is clear that the habitat variations in this channel cross-section generate quite complex flow-stress curves with a considerable break of slope at about 6 $m^3 s^{-1}$ where the fast habitats start to decrease (Figure 2).

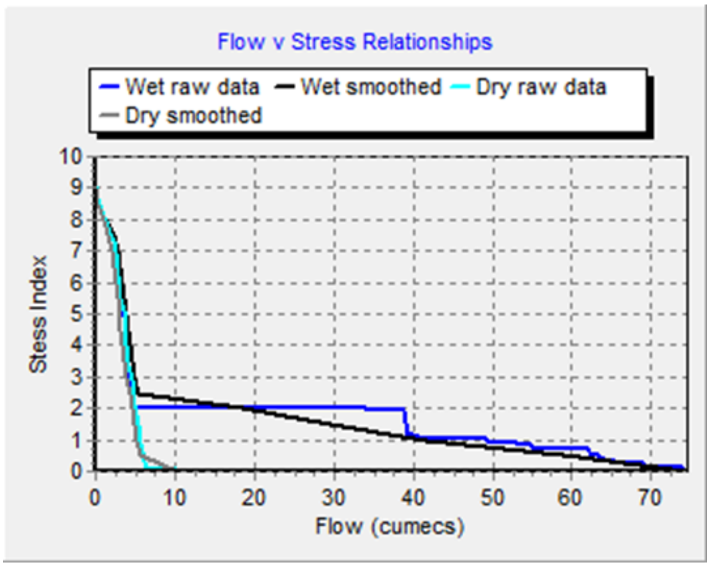
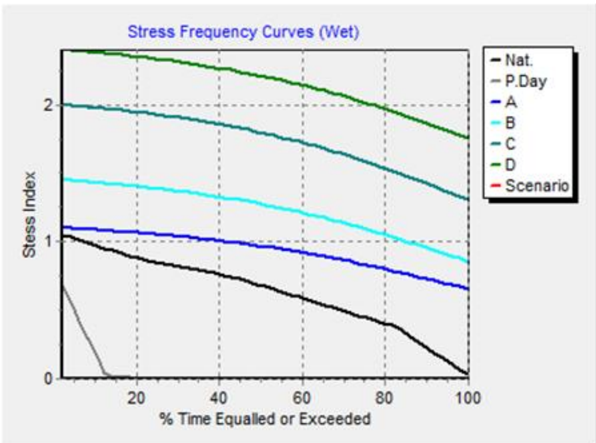


Figure 13-2: Flow-habitat stress relationships for the wet and dry seasons.

Figure 5 illustrates the stress frequency curves, for the different levels of ecological protection, that have been calibrated by the ecological specialists on the basis of an interpretation of the habitat data for the cross-section (Figure 2). The 'present day' (assumed to be represented by the planned operation of the hydro-power plant) stress curve only appears on the wet season graph, as the stress values for present day in the dry season are always zero.



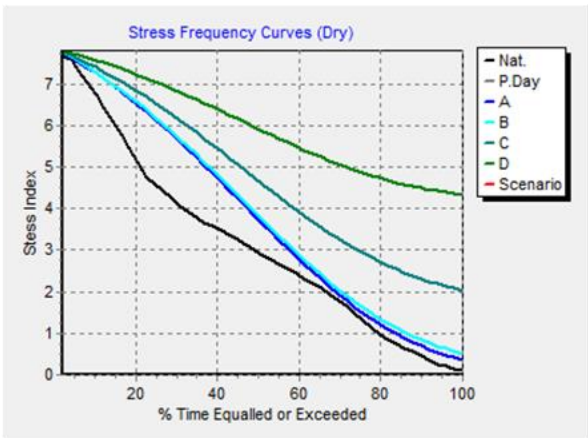


Figure 13-3: Habitat stress frequency curves for the wet and dry seasons.

The potential uncertainty issue with the natural flow time series data used in the model is highlighted by the results for the dry season. The high natural stress (of about 7.65) represents a flow of approximately 1.45 m3 s-1 and at this flow there is no fast-deep habitat and only 16% fast intermediate. The stress requirements for the different ecological protection categories can therefore only be increased slightly higher than natural on the assumption that at least some fast-intermediate habitats are to be preserved. The D category maximum stress has therefore been set at 7.8, equivalent to a discharge of 1.2 m3 s-1 and a little less than 10% fast intermediate habitat in a wetted channel section of some 15 m. The fast-deep habitat occurs at discharges of approximately 2.1 m3 s-1 and higher. This result indicates that the overall assessment of habitat and flow requirements is be very sensitive to the way in which the natural low flows have been scaled and it has already been noted that this is highly uncertain.

The stress frequency relationships shown in Figure 5 are processed through the flow-stress relationships to generate the flow duration curves (or discharge frequency curves) shown in Figure 6 for the wet and dry season and for all the different levels of ecological protection. It is clear that while there are quite large differences in calibrated stress and discharge between all the levels of ecological protection for the wet season, the dry season requirements are very similar for the higher (A and B) levels of protection. This is largely a result of the very steep decrease in fast habitat availability at lower flows. Figure 6 shows the final result of the low flow component of the model, while Table 1 summaries the low flow mean annual requirements in terms of both volume and percentage natural mean annual runoff (MAR).

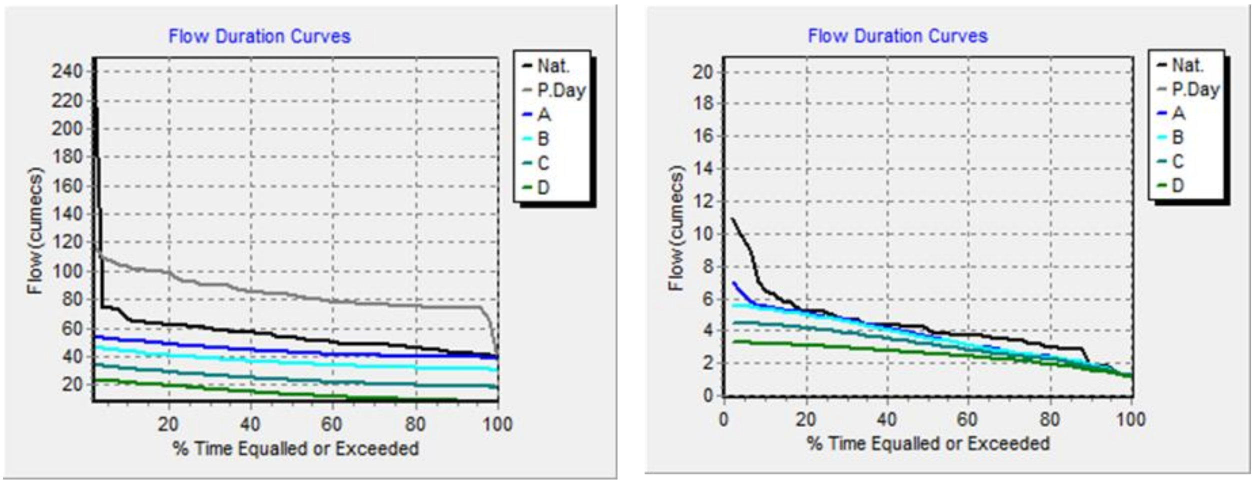


Figure 13-4: Discharge frequency curves for the wet and dry seasons

Table 13-3: Summary of mean annual low flow requirements (natural MAR is 3 485.4 m^3 * 106)

Ecological protection category	Mean annual low flow requirements $m^3 * 10^6$	% Natural MAR
A	629.2	22.6
A/B	591.7	21.2
B	557.9	20.0
B/C	493.1	17.7

C	432.0	15.5
C/D	371.8	13.3
D	311.6	11.0

The EWR stress frequency curves are used together with the flow-stress relationships and the natural flows to generate time series of EWR flows (with interpolation from the main wet and dry months for the remaining months of the year). In this study no allowance has been made for additional high flow releases as the so-called baseflow requirements are seen as adequate for the desired habitat diversity. Figure 7 illustrates a 20 year period of the 'Lower Flows EWR' for the selected category C and this represents about 15.5% of the natural flows and a mean annual volume of 432 * 106 m3 (Table 1). The full time series of all monthly flow volumes are tabulated in Appendix A, while the total output from the RDRM for all ecological protection categories is provided in Appendix B. Appendix B includes the high flow estimates generated by the RDRM, but these have not been calibrated and can be ignored.

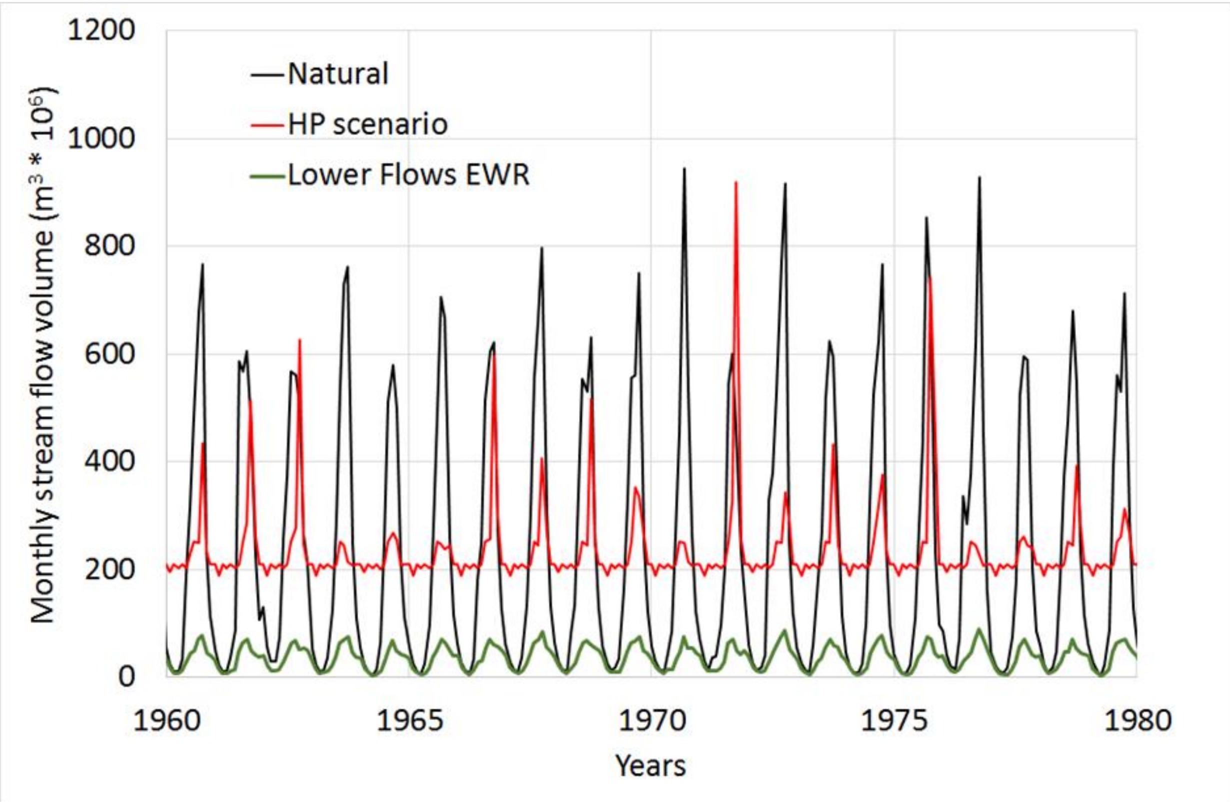


Figure 13-5: Example time series period of 'Lower Flows EWR' compared to natural and present-day downstream hydro-power releases.

13.2.2. DOWNSTREAM OF BUMBUNA EXTENSIONS

The approach for the higher flows EWR started with the ecologists specifying a flow-stress relationship that is the reverse of the type of relationship used in the previous section, i.e. increasing stress with increasing flows to reflect the problem of reduced habitat diversity with increasing flows during the dry season months. This relationship is shown in Figure 8. The next step was to fit a non-linear equation to the curve and the most appropriate equation was found to be:

Discharge = 30.0 * Stress0.36 + 11.5 or Stress = ((Discharge – 11.5) / 30.0)2,78

The non-linear equation was used to convert the monthly time series of present day mean monthly discharge into a time series of habitat stress, after which the stress values for the dry season months of February to May were ranked (separately for each month). The ecology specialists provided relationships between frequencies of exceedance and stress for the two main dry season months (March and April) as well as for the other two months (Figure 9). These frequencies were designed to increase the level of habitat diversity quite substantially during the two main dry season months (hence lower stress and therefore lower flows) and to add some additional diversity during the other two months.

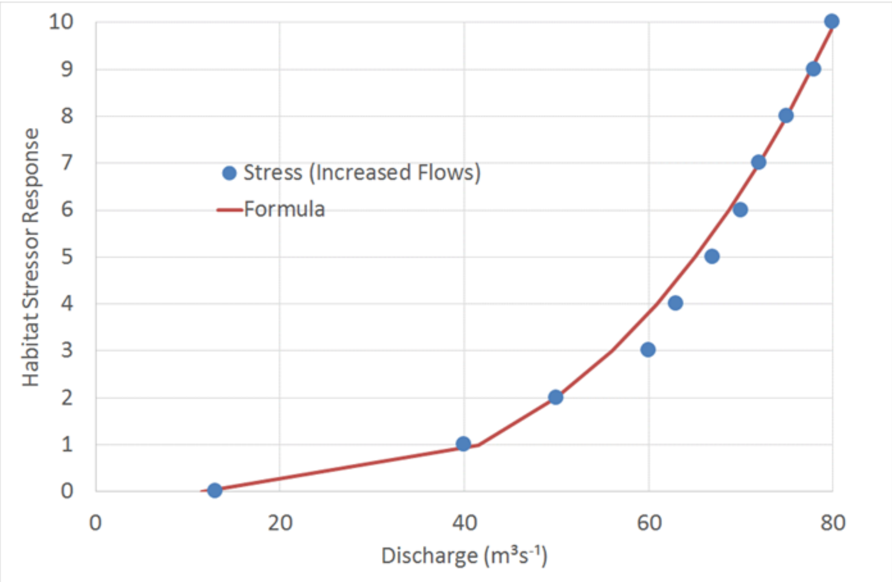
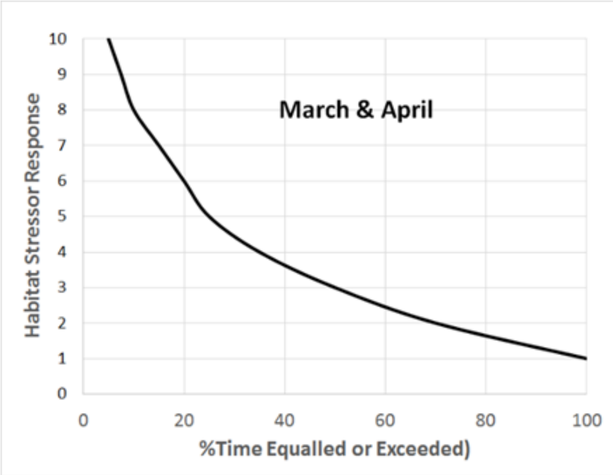


Figure 13-6: Flow-habitat stress relationships for the dry seasons under higher flows than natural conditions associated with hydro-power releases.



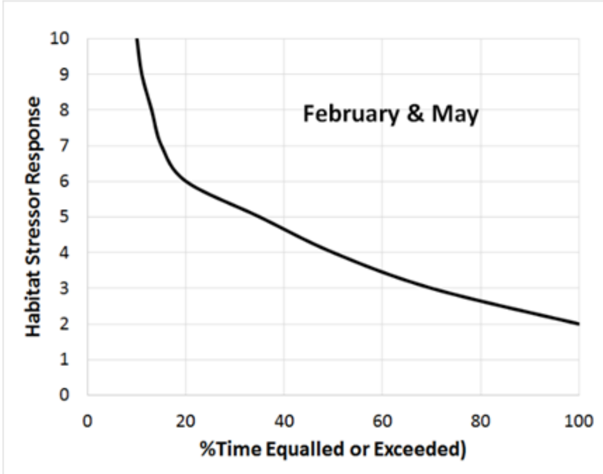


Figure 13-7: Frequencies of exceedance for modified hydro-power releases.

In the context of this report 'Present day' represents the simulated total releases from the dam for hydropower purposes. The present day discharge and stress values for these four low flow months are almost all the same and therefore could not be used to guide the allocation of new stress values. The total natural flows for the four months were therefore used to guide the allocation of the new stress frequencies (Figure 9) into the time series. Approximate logarithmic relationships between % frequency and stress were developed for each of the graphs in Figure 9 and these used to estimate the stress values that should be allocated to the four months for each year in the time series on the basis of the exceedance frequency of the total natural flow within the four months.

The stress frequency relationships illustrated in Figure 9 were used to create an alternative ranking of stress values for each of the months and the two rankings (present day stress and EWR stress) were used as lookup tables in excel to modify the present day time series of stress into a time series of required stress values for the EWR. The stress to flow conversion equation was then used to create the time series of 'Higher Flows EWR' as shown in Figure 10. The present day mean annual volume is some 2 806 * 106 m3, while the EWR represents a mean annual volume of 2 609 * 106 m3, a 7% reduction in the volume of water released for hydro-power. However, given that some the 'Higher Flows EWR' during the dry season would be met from the upstream releases ('Lower Flows EWR') the reduction in release volume would be slightly less. Note that no other months of the year apart from February to May have been changed and the green lines in Figure 9 are over the red lines for the non-dry season months. The extra flow derived from the upstream releases during the wet season would have no negative ecological consequences as the present day flows are already well below the natural wet season flows.

Table 13-4: Natural baseflow duration curve, m^3/s

Natural Baseflow duration curve - m^3/s										
Percentile	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**99**
Oct	67.667	62.384	59.647	56.591	53.250	50.359	48.259	46.067	42.718	40.169

Nov	42.403	38.239	35.479	34.353	33.813	32.873	32.478	30.117	28.876	25.917
Dec	33.311	28.242	26.702	26.010	25.346	24.858	24.256	22.807	21.386	18.483
Jan	24.474	22.389	21.671	21.151	20.554	20.048	19.136	17.744	17.104	14.240
Feb	17.321	12.197	11.840	11.390	10.990	10.720	9.952	9.413	8.712	8.318
Mar	7.856	5.616	5.464	5.072	4.840	4.608	4.136	3.648	3.120	2.759
Apr	6.777	5.402	4.904	4.479	4.235	3.864	3.576	3.104	1.992	1.319
May	9.577	7.154	6.474	6.150	5.864	5.532	4.887	4.091	3.101	2.093
Jun	22.328	16.279	14.976	12.070	11.047	10.154	9.642	8.977	7.949	4.043
Jul	29.926	27.144	25.283	24.076	23.276	21.788	20.221	19.064	16.024	10.761
Aug	43.253	41.470	39.890	38.501	38.006	37.245	36.337	34.974	33.512	27.432
Sep	60.650	56.910	55.634	53.493	52.320	50.623	49.728	48.687	45.843	35.495

Table 13-5: Low flow assurance curves, per category, m^3/s

Category Low Flow Assurance Curves - m^3/s										
A Category										
Oct	51.374	48.881	46.583	44.585	42.904	41.540	40.733	40.087	39.562	39.173
Nov	33.423	31.521	29.878	28.944	27.633	26.765	25.886	25.553	25.551	25.041
Dec	25.922	25.357	23.929	23.227	21.848	20.977	19.916	19.380	19.371	18.676
Jan	20.412	20.399	19.764	19.222	17.858	16.954	15.646	15.497	15.472	15.022
Feb	12.430	10.329	10.130	9.687	8.824	8.217	7.637	7.621	7.605	7.553
Mar	6.244	5.315	5.262	4.938	4.353	3.895	3.293	2.919	2.908	2.862
Apr	5.500	5.101	4.680	4.199	3.667	3.191	2.745	2.396	1.928	1.277
May	7.896	7.001	6.298	5.884	5.227	4.691	3.897	3.238	2.766	2.341
Jun	16.536	14.748	13.072	11.108	9.546	8.454	7.502	6.839	6.245	4.887
Jul	23.980	23.922	22.892	21.717	19.931	18.503	16.575	15.433	14.205	12.095
Aug	34.950	34.950	34.115	33.007	31.750	31.108	30.271	29.808	29.805	28.408
Sep	45.117	44.810	43.247	41.893	41.180	40.757	40.378	39.255	38.759	35.861
A/B Category										
Oct	47.565	44.657	41.975	40.211	38.831	37.694	36.766	36.012	35.399	34.946
Nov	31.405	30.002	28.372	27.415	26.088	25.208	24.251	23.871	23.865	23.401
Dec	24.853	24.399	23.011	22.298	20.911	20.038	18.945	18.429	18.423	17.784
Jan	19.795	19.783	19.156	18.611	17.245	16.351	15.052	14.909	14.885	14.460
Feb	11.859	10.163	9.976	9.547	8.680	8.083	7.510	7.493	7.477	7.425
Mar	5.954	5.273	5.220	4.906	4.318	3.868	3.273	2.904	2.895	2.849
Apr	5.436	5.056	4.643	4.167	3.641	3.174	2.732	2.387	1.928	1.277
May	7.555	6.916	6.237	5.837	5.177	4.651	3.866	3.217	2.752	2.334
Jun	15.773	14.421	12.814	10.921	9.378	8.312	7.371	6.722	6.147	4.834

Jul	23.125	23.072	22.060	20.917	19.159	17.780	15.904	14.798	13.660	11.729
Aug	33.042	33.032	32.068	30.930	29.664	28.980	28.047	27.423	27.420	26.256
Sep	41.999	41.432	39.590	38.187	37.484	37.093	36.837	36.723	36.507	33.423
B Category										
Oct	43.756	40.764	38.609	36.735	35.159	33.859	32.798	31.937	31.237	30.719
Nov	29.603	28.591	27.154	26.164	24.696	23.687	22.616	22.181	22.171	21.753
Dec	23.903	23.505	22.256	21.523	20.063	19.119	17.973	17.470	17.466	16.884
Jan	19.210	19.207	18.648	18.090	16.687	15.759	14.455	14.314	14.291	13.892
Feb	8.442	7.373	7.248	6.937	6.297	5.859	5.436	5.424	5.412	5.373
Mar	5.762	5.234	5.175	4.867	4.284	3.840	3.252	2.889	2.879	2.834
Apr	5.372	5.011	4.606	4.135	3.616	3.157	2.719	2.378	1.927	1.277
May	7.340	6.833	6.177	5.784	5.129	4.610	3.835	3.196	2.737	2.324
Jun	15.304	14.110	12.589	10.749	9.221	8.172	7.241	6.605	6.047	4.778
Jul	22.320	22.279	21.372	20.246	18.461	17.073	15.231	14.162	13.109	11.355
Aug	31.278	31.269	30.427	29.249	27.787	26.902	25.824	25.069	25.032	24.098
Sep	39.040	38.329	36.697	35.235	34.568	34.556	34.545	34.534	34.243	30.969
B/C Category										
Oct	37.486	34.953	32.618	30.588	28.934	27.655	26.611	25.764	25.076	24.567
Nov	25.992	25.341	24.100	23.115	21.718	20.798	19.774	19.615	19.610	19.294
Dec	21.263	21.012	19.977	19.288	17.975	17.176	16.139	15.993	15.991	15.511
Jan	17.281	17.281	16.853	16.353	15.123	14.365	13.367	13.353	13.340	13.006
Feb	10.238	9.109	9.008	8.659	7.922	7.457	7.126	7.114	7.102	7.063
Mar	5.158	4.801	4.766	4.508	4.009	3.647	3.121	2.839	2.836	2.796
Apr	4.828	4.581	4.247	3.831	3.386	2.996	2.620	2.318	1.896	1.277
May	6.608	6.227	5.682	5.351	4.791	4.368	3.671	3.098	2.669	2.297
Jun	13.672	12.765	11.486	9.862	8.532	7.658	6.839	6.302	5.805	4.666
Jul	19.960	19.954	19.220	18.208	16.633	15.478	13.872	12.998	12.140	10.755
Aug	27.559	27.559	26.751	25.536	24.072	23.181	22.115	21.449	21.433	20.903
Sep	33.699	33.135	31.421	30.916	30.909	30.902	30.894	30.887	30.581	27.273
C Category										
Oct	31.869	29.173	26.887	24.903	23.233	21.856	20.733	19.820	19.079	18.530
Nov	22.946	22.260	21.157	20.248	18.981	18.062	17.097	17.059	17.053	16.844
Dec	18.888	18.672	17.777	17.179	16.057	15.319	14.510	14.500	14.489	14.121
Jan	15.479	15.479	15.118	14.708	13.687	13.024	12.373	12.363	12.353	12.093
Feb	9.245	8.278	8.205	7.937	7.349	6.969	6.841	6.833	6.826	6.812
Mar	4.667	4.400	4.368	4.164	3.757	3.452	2.993	2.784	2.779	2.748
Apr	4.393	4.184	3.890	3.537	3.200	2.840	2.522	2.244	1.834	1.277
May	6.000	5.674	5.201	4.935	4.482	4.124	3.511	2.995	2.585	2.259
Jun	12.290	11.524	10.415	9.016	7.900	7.152	6.450	5.993	5.533	4.532
Jul	17.777	17.774	17.141	16.280	14.956	13.948	12.571	11.848	11.138	10.127

Aug	24.035	24.021	23.213	22.055	20.658	19.674	18.585	18.025	18.023	17.744
Sep	28.903	28.118	27.290	27.289	27.287	27.286	27.285	27.284	26.892	23.559
C/D Category										
Oct	26.784	24.396	22.194	20.280	18.670	17.138	15.858	14.819	13.975	13.350
Nov	19.519	18.958	18.082	17.422	16.343	15.503	14.720	14.710	14.700	14.597
Dec	16.131	15.972	15.302	14.953	14.060	13.452	13.055	13.039	13.022	12.770
Jan	13.288	13.288	13.067	12.889	12.101	11.591	11.375	11.359	11.341	11.158
Feb	7.922	7.167	7.147	7.044	6.614	6.528	6.526	6.524	6.522	6.520
Mar	4.002	3.827	3.816	3.714	3.405	3.177	2.813	2.683	2.679	2.662
Apr	3.770	3.609	3.391	3.172	2.893	2.623	2.391	2.133	1.739	1.271
May	5.154	4.898	4.541	4.397	4.057	3.788	3.293	2.830	2.447	2.190
Jun	10.522	9.913	9.048	7.986	7.100	6.514	5.980	5.589	5.166	4.341
Jul	15.220	15.220	14.771	14.210	13.160	12.354	11.261	10.650	10.062	9.447
Aug	20.406	20.396	19.716	18.785	17.531	16.543	15.483	15.023	15.016	14.919
Sep	24.356	23.824	23.809	23.800	23.791	23.782	23.774	23.765	23.296	20.101
D Category										
Oct	21.921	19.621	17.325	15.148	13.317	11.807	10.575	9.574	8.762	8.160
Nov	16.393	15.917	15.179	14.492	13.489	12.761	12.346	12.329	12.313	12.297
Dec	13.647	13.540	13.026	12.692	11.949	11.529	11.481	11.471	11.460	11.342
Jan	11.355	11.355	11.213	11.065	10.454	10.239	10.237	10.236	10.235	10.153
Feb	6.757	6.255	6.243	6.202	6.200	6.199	6.198	6.198	6.197	6.196
Mar	3.417	3.355	3.348	3.282	3.062	2.919	2.619	2.566	2.564	2.563
Apr	3.228	3.125	2.976	2.798	2.608	2.427	2.229	1.964	1.640	1.252
May	4.418	4.234	3.973	3.880	3.640	3.472	3.059	2.626	2.288	2.106
Jun	8.960	8.510	7.848	6.981	6.300	5.896	5.473	5.105	4.755	4.120
Jul	12.930	12.930	12.603	12.117	11.278	10.709	9.842	9.296	9.061	8.704
Aug	17.026	17.009	16.347	15.344	14.091	13.129	12.159	12.132	12.127	12.123
Sep	20.037	19.988	19.975	19.961	19.948	19.934	19.921	19.908	19.512	16.550

14. APPENDIX F – EWR ASSURANCE TABLES AND TIME SERIES

Table 14-1: Present day flow data, m^3/s

Present Day flows - m^3/s												
	Oct	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
1943	85.200	87.600	78.700	87.132	81.511	81.323	78.700	81.323	78.700	78.700	97.753	95.800
1944	80.700	80.000	78.700	87.132	78.700	81.323	78.700	81.323	78.700	78.700	97.753	108.800

Present Day flows - m³/s												
	Oct	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
1945	141.600	96.300	78.700	87.132	78.700	81.323	78.700	81.323	78.700	78.700	97.753	100.700
1946	87.600	87.200	78.700	87.132	78.700	81.323	78.700	81.323	78.700	78.700	97.753	94.800
1947	84.500	80.000	78.700	87.132	81.511	81.323	78.700	81.323	78.700	78.700	97.753	105.300
1948	91.900	80.000	78.700	87.132	78.700	81.323	78.700	81.323	78.700	78.700	97.753	120.000
1949	98.600	80.000	78.700	87.132	78.700	81.323	78.700	81.323	78.700	78.700	97.753	96.300
1950	253.700	132.200	78.700	87.132	78.700	81.323	78.700	81.323	78.700	78.700	97.753	98.300
1951	96.000	100.000	78.700	87.132	81.511	81.323	78.700	81.323	78.700	78.700	97.753	94.600
1952	161.700	94.200	78.700	87.132	78.700	81.323	78.700	81.323	78.700	78.700	97.753	98.900
1953	241.500	118.200	79.500	87.132	78.700	81.323	78.700	81.323	78.700	78.700	97.753	96.600
1954	291.200	103.000	78.700	87.132	78.700	81.323	78.700	81.323	78.700	78.700	97.753	98.900
1955	80.000	80.000	78.700	87.132	81.511	81.323	78.700	81.323	78.700	78.700	97.753	95.500
1956	100.200	89.200	78.700	87.132	78.700	81.323	78.700	81.323	78.700	78.700	97.753	104.200
1957	241.700	129.900	83.500	87.132	78.700	81.323	78.700	81.323	78.700	78.700	97.753	105.000
1958	260.300	117.700	80.400	87.132	78.700	81.323	78.700	81.323	78.700	78.700	97.753	100.600
1959	231.400	93.000	78.700	87.132	81.511	81.323	78.700	81.323	78.700	85.400	97.753	96.300
1960	162.200	90.100	78.700	87.132	78.700	81.323	78.700	81.323	78.700	78.700	97.753	110.700
1961	191.800	101.200	78.700	87.132	78.700	81.323	78.700	81.323	78.700	78.700	97.753	107.300
1962	233.600	95.600	78.700	87.132	78.700	81.323	78.700	81.323	78.700	78.700	97.753	94.600
1963	80.000	80.000	78.700	87.132	81.511	81.323	78.700	81.323	77.200	78.700	97.753	104.000
1964	95.000	80.000	78.700	87.132	78.700	81.323	78.700	81.323	78.700	78.700	97.753	95.500
1965	89.000	95.000	78.700	87.132	78.700	81.323	78.700	81.323	78.700	78.700	97.753	99.400
1966	222.900	115.400	78.700	87.132	78.700	81.323	78.700	81.323	78.700	78.700	97.753	94.600
1967	152.100	102.600	78.700	87.132	81.511	81.323	78.700	81.323	78.700	78.700	97.753	94.600
1968	193.300	96.500	78.700	87.132	78.700	81.323	78.700	81.323	78.700	78.700	97.753	136.100
1969	126.000	101.400	78.700	87.132	78.700	81.323	78.700	81.323	78.700	78.700	97.753	96.100
1970	80.000	80.000	78.700	87.132	78.700	81.323	78.700	81.323	78.700	78.700	97.753	127.500
1971	343.300	98.100	78.700	87.132	81.511	81.323	78.700	81.323	78.700	78.700	97.753	96.500
1972	127.900	113.800	78.700	87.132	78.700	81.323	78.700	81.323	78.700	78.700	97.753	96.400
1973	161.800	94.600	78.700	87.132	78.700	81.323	78.700	81.323	78.700	78.700	97.753	124.000

Present Day flows - m³/s												
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1974	140.600	91.400	78.700	87.132	78.700	81.323	78.700	81.323	78.700	78.700	97.753	96.200
1975	276.800	172.300	78.700	87.132	81.511	81.323	78.700	81.323	78.700	78.700	97.753	94.600
1976	84.700	80.000	78.700	87.132	78.700	81.323	78.700	81.323	78.700	78.700	97.753	100.800
1977	91.500	92.600	78.700	87.132	78.700	81.323	78.700	81.323	78.700	78.700	97.753	94.600
1978	147.000	109.700	78.700	87.132	78.700	81.323	78.700	81.323	78.700	78.700	97.753	100.600
1979	116.900	103.100	78.700	87.132	81.511	81.323	78.700	81.323	78.700	78.700	97.753	94.600
1980	162.900	90.900	78.700	87.132	78.700	81.323	78.700	81.323	78.700	78.700	97.753	94.600
1981	177.400	96.800	78.700	87.132	78.700	81.323	78.700	81.323	78.700	78.700	97.753	96.800
1982	125.900	87.400	78.700	87.132	78.700	81.323	78.700	81.323	78.700	78.700	97.753	137.800
1983	185.300	89.400	78.700	87.132	81.511	81.323	78.700	81.323	78.700	78.700	97.753	114.300
1984	84.100	80.000	78.700	87.132	78.700	81.323	78.700	81.323	78.700	78.700	97.753	99.200
1985	80.000	80.000	78.700	87.132	78.700	81.323	78.700	81.323	78.700	78.700	97.753	111.800
1986	119.800	99.300	78.700	87.132	78.700	81.323	78.700	81.323	78.700	78.700	97.753	103.500
1987	81.800	80.000	78.700	87.132	81.511	81.323	78.700	81.323	78.700	78.700	97.753	110.200
1988	87.500	80.000	78.700	87.132	78.700	81.323	78.700	81.323	78.700	78.700	97.856	107.200
1989	80.700	80.000	78.700	87.132	78.700	81.323	78.700	81.427	64.000	69.800	78.843	94.600
1990	80.300	80.000	78.700	87.132	78.700	70.060	57.000	10.023	32.000	73.700	136.813	108.800
1991	147.500	98.500	78.700	87.132	81.511	81.323	78.700	81.323	78.700	78.700	97.753	112.100

Table 14-2: Lower Flows EFR flow data, m³/s

Lower Flows EWR - m³/s												
Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1943	2.404	1.854	1.748	1.236	0.683	0.278	0.287	0.518	0.798	1.756	2.055	2.729
1944	1.953	1.705	1.449	1.375	0.690	0.368	0.431	0.490	0.585	1.504	2.402	2.728
1945	2.003	1.792	1.584	1.463	0.789	0.421	0.273	0.355	0.555	1.243	2.290	2.837
1946	2.475	1.889	1.730	1.236	0.683	0.278	0.248	0.342	0.722	1.376	1.953	2.729
1947	2.101	1.705	1.449	1.237	0.684	0.283	0.273	0.392	0.705	1.174	1.977	2.691
1948	2.146	1.706	1.450	1.463	0.725	0.387	0.394	0.472	0.522	1.104	1.802	2.729
1949	2.339	1.933	1.748	1.421	0.780	0.396	0.194	0.250	0.601	1.115	1.802	2.890
1950	2.551	2.156	1.614	1.548	0.826	0.440	0.309	0.536	1.207	1.679	2.314	2.729

Lower Flows EWR - m³/s												
Year	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
1951	3.419	2.579	1.889	1.548	0.835	0.433	0.226	0.366	0.688	1.487	2.223	2.729
1952	1.985	2.078	1.787	1.502	0.812	0.431	0.394	0.293	1.056	1.778	2.403	2.728
1953	2.222	1.816	1.774	1.548	0.925	0.467	0.442	0.600	1.035	1.643	2.394	2.729
1954	2.765	2.361	1.889	1.516	0.819	0.438	0.448	0.600	1.229	1.728	2.103	2.729
1955	3.069	2.179	1.842	1.339	0.739	0.362	0.266	0.451	0.767	1.225	1.802	2.729
1956	1.883	1.706	1.584	1.536	0.819	0.433	0.435	0.263	0.569	1.562	1.883	2.729
1957	2.591	2.236	1.761	1.548	0.925	0.467	0.439	0.600	1.224	1.139	1.802	2.729
1958	3.125	2.455	1.889	1.548	0.925	0.467	0.380	0.597	1.229	1.344	1.802	2.729
1959	2.720	2.287	1.889	1.290	0.710	0.340	0.317	0.433	1.176	1.665	1.864	2.729
1960	2.907	1.769	1.540	1.237	0.684	0.288	0.294	0.461	0.620	1.778	2.403	2.729
1961	1.896	1.706	1.451	1.548	0.925	0.467	0.445	0.600	1.229	1.778	2.403	2.670
1962	1.923	2.089	1.889	1.237	0.684	0.294	0.387	0.445	0.866	1.470	2.360	2.769
1963	2.859	1.871	1.451	1.311	0.718	0.349	0.165	0.243	0.510	1.214	1.977	2.700
1964	1.909	1.706	1.498	1.311	0.685	0.349	0.205	0.323	0.648	1.407	1.904	2.729
1965	2.371	2.040	1.555	1.516	0.809	0.428	0.238	0.433	1.096	1.201	2.037	2.728
1966	2.278	2.223	1.842	1.548	0.825	0.439	0.317	0.481	0.922	1.593	2.403	2.729
1967	3.181	2.239	1.889	1.548	0.879	0.440	0.343	0.600	1.006	1.777	2.403	2.643
1968	2.308	2.133	1.880	1.397	0.725	0.378	0.417	0.425	1.074	1.772	2.403	2.670
1969	2.811	1.907	1.663	1.351	0.826	0.453	0.343	0.525	0.593	1.286	1.802	2.890
1970	2.021	2.108	1.710	1.548	0.904	0.439	0.451	0.505	0.638	1.115	2.376	2.728
1971	1.859	1.706	1.889	1.495	0.800	0.439	0.412	0.513	1.229	1.778	2.271	2.890
1972	3.293	2.015	1.637	1.267	0.690	0.368	0.243	0.587	1.122	1.313	2.076	2.729
1973	2.196	2.238	1.520	1.236	0.682	0.278	0.219	0.311	0.671	1.689	2.250	2.729
1974	2.958	1.835	1.450	1.235	0.680	0.272	0.254	0.273	0.752	1.431	1.802	2.890
1975	2.633	1.728	1.449	1.548	0.925	0.467	0.406	0.600	1.229	1.452	1.802	2.729
1976	3.349	2.696	1.889	1.236	0.683	0.310	0.254	0.250	0.555	1.089	2.166	2.728
1977	2.170	1.665	1.448	1.500	0.684	0.278	0.422	0.532	1.146	1.778	1.817	2.729
1978	2.039	1.747	1.570	1.510	0.766	0.396	0.124	0.301	0.610	1.778	2.403	2.644
1979	2.676	2.237	1.787	1.536	0.835	0.438	0.330	0.406	0.888	1.743	1.803	2.729
1980	2.079	2.205	1.818	1.237	0.684	0.302	0.373	0.577	0.954	1.778	2.403	2.530
1981	2.439	1.706	1.451	1.238	0.684	0.310	0.358	0.499	0.736	1.708	2.338	2.728
1982	3.237	1.962	1.476	1.235	0.682	0.278	0.422	0.509	1.229	1.778	2.134	2.729
1983	1.847	1.705	1.449	1.236	0.683	0.278	0.336	0.552	0.954	1.532	1.802	2.890
1984	2.513	1.706	1.450	1.235	0.682	0.278	0.151	0.219	0.492	1.161	1.846	2.890
1985	2.123	1.705	1.449	1.237	0.683	0.278	0.294	0.565	0.820	1.187	2.194	2.729
1986	1.871	1.706	1.450	1.421	0.751	0.396	0.358	0.406	0.782	1.618	1.805	2.864
1987	3.013	2.063	1.689	1.235	0.682	0.278	0.205	0.273	0.844	1.070	2.018	2.729
1988	2.059	1.705	1.448	1.238	0.684	0.310	0.226	0.379	0.627	1.263	1.828	2.860

Lower Flows EWR - m^3/s												
Year	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
1989	2.250	1.991	1.458	1.235	0.812	0.278	0.184	0.239	0.539	0.957	1.929	2.729
1990	1.969	1.706	1.450	1.185	0.683	0.278	0.132	0.234	0.416	1.081	1.748	2.189
1991	1.938	1.705	1.378	1.351	0.825	0.440	0.175	0.323	0.660	1.778	2.403	2.806

Table 14-3: Higher Flows EWR data, m^3/s

						Higher Flows EWR - m^3/s					
Year	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
1943	85.200	87.616	78.704	78.704	59.689	54.884	54.900	59.700	78.704	78.704	94.609	95.795
1944	80.682	80.015	78.704	78.704	65.311	61.380	61.381	65.300	78.704	78.704	94.609	108.796
1945	141.614	96.296	78.704	78.704	55.432	49.694	49.691	55.444	78.704	78.704	94.609	100.694
1946	87.590	87.191	78.704	78.704	51.959	45.176	45.139	51.971	78.704	78.704	94.609	94.792
1947	84.491	80.015	78.704	78.704	54.936	49.059	49.074	54.921	78.704	78.704	94.609	105.285
1948	91.883	80.015	78.704	78.704	63.285	59.102	59.066	63.284	78.704	78.704	94.609	119.985
1949	98.604	80.015	78.704	78.704	52.455	45.811	45.833	52.457	78.704	78.704	94.609	96.296
1950	253.696	132.215	78.704	78.704	72.173	68.959	68.943	72.170	78.704	78.704	94.609	98.302
1951	95.990	100.000	78.704	78.704	56.961	51.635	51.620	56.974	78.704	78.704	94.609	94.599
1952	161.701	94.213	78.704	78.704	55.928	50.329	50.347	55.929	78.704	78.704	94.609	98.881
1953	241.487	118.210	79.488	78.704	80.233	78.928	78.935	80.234	78.704	78.704	94.609	96.605
1954	291.219	103.009	78.704	78.704	75.893	72.954	72.955	75.904	78.704	78.704	94.609	98.881
1955	80.010	80.015	78.704	78.704	58.573	53.577	53.588	58.580	78.704	78.704	94.609	95.486
1956	100.209	89.198	78.704	78.704	59.110	54.249	54.244	59.140	78.704	78.704	94.609	104.205
1957	241.711	129.900	83.483	78.704	80.233	80.234	80.208	80.234	78.704	78.704	94.609	105.015
1958	260.305	117.708	80.384	78.704	79.282	76.576	76.582	79.301	78.704	78.704	94.609	100.617
1959	231.407	93.017	78.704	78.704	58.036	52.905	52.932	58.020	78.704	85.387	94.609	96.296
1960	162.186	90.085	78.704	78.704	56.465	51.001	51.003	56.452	78.704	78.704	94.609	110.687
1961	191.794	101.196	78.704	78.704	80.233	80.234	80.208	80.234	78.704	78.704	94.609	107.292
1962	233.610	95.602	78.704	78.704	57.498	52.270	52.276	57.497	78.704	78.704	94.609	94.599
1963	80.010	80.015	78.704	78.704	50.513	43.123	43.133	50.515	77.199	78.704	94.609	104.012
1964	94.982	80.015	78.704	78.704	53.447	47.118	47.145	53.427	78.704	78.704	94.609	95.486
1965	89.008	94.985	78.704	78.704	60.268	55.556	55.556	60.260	78.704	78.704	94.609	99.383
1966	222.894	115.394	78.704	78.704	64.608	60.596	60.610	64.628	78.704	78.704	94.609	94.599
1967	152.106	102.585	78.704	78.704	74.529	71.498	71.489	74.522	78.704	78.704	94.609	94.599
1968	193.287	96.489	78.704	78.704	63.947	59.849	59.838	63.956	78.704	78.704	94.609	136.111
1969	126.008	101.389	78.704	78.704	69.238	65.748	65.741	69.258	78.704	78.704	94.609	96.103
1970	80.010	80.015	78.704	78.704	73.289	70.154	70.177	73.290	78.704	78.704	94.609	127.508

Higher Flows EWR - m^3/s

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1971	343.302	98.110	78.704	78.704	68.370	64.815	64.815	68.399	78.704	78.704	94.609	96.489
1972	127.912	113.812	78.704	78.704	71.139	67.802	67.824	71.125	78.704	78.704	94.609	96.412
1973	161.813	94.599	78.704	78.704	51.463	44.504	44.483	51.486	78.704	78.704	94.609	123.997
1974	140.606	91.397	78.704	78.704	49.521	41.704	41.705	49.545	78.704	78.704	94.609	96.219
1975	276.807	172.299	78.704	78.704	77.464	74.634	74.614	77.472	78.704	78.704	94.609	94.599
1976	84.715	80.015	78.704	78.704	50.967	43.795	43.827	51.001	78.704	78.704	94.609	100.810
1977	91.510	92.593	78.704	78.704	67.584	63.881	63.889	67.578	78.704	78.704	94.609	94.599
1978	146.991	109.684	78.704	78.704	52.951	46.483	46.489	52.942	78.704	78.704	94.609	100.617
1979	116.898	103.086	78.704	78.704	62.665	58.356	58.372	62.649	78.704	78.704	94.609	94.599
1980	162.896	90.895	78.704	78.704	70.147	66.756	66.744	70.154	78.704	78.704	94.609	94.599
1981	177.382	96.798	78.704	78.704	61.425	56.937	56.944	61.417	78.704	78.704	94.609	96.798
1982	125.896	87.384	78.704	78.704	62.045	57.646	57.639	62.015	78.704	78.704	94.609	137.809
1983	185.297	89.390	78.704	78.704	66.014	62.201	62.191	66.047	78.704	78.704	94.609	114.313
1984	84.117	80.015	78.704	78.704	48.074	39.464	39.468	48.088	78.704	78.704	94.609	99.190
1985	80.010	80.015	78.704	78.704	66.799	63.023	63.040	66.794	78.704	78.704	94.609	111.806
1986	119.810	99.306	78.704	78.704	60.847	56.265	56.250	60.820	78.704	78.704	94.609	103.511
1987	81.803	80.015	78.704	78.704	49.066	40.995	40.972	49.059	78.704	78.704	94.609	110.185
1988	87.515	80.015	78.704	78.704	54.439	48.424	48.418	54.435	78.704	78.704	94.683	107.215
1989	80.682	80.015	78.704	78.704	50.017	42.413	42.438	50.030	64.005	69.818	76.314	94.599
1990	80.309	80.015	78.704	78.704	48.570	40.248	40.239	48.574	31.983	73.701	132.392	108.796
1991	147.513	98.495	78.704	78.704	53.943	47.790	47.762	53.913	78.704	78.704	94.609	112.114