Consulting Services for Environmental Flows Assessment and Water Quality Modelling within the Lesotho Lowlands Water Development Project Phase II (LLWDP II)

Final EFlows Scenario Assessment Report

Ministry of Water, Lesotho

March 18th, 2022

Prepared by

Multiconsult

Deltares
Enabling Delta Life

southern waters

Multi - Nodal Development Consultants

REPORT

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Executive Summary

The Lesotho Lowlands Water Development Project Phase II (LLWDP II) is aimed at increasing access to water and improving the reliability of supply to Leribe and neighbouring towns. The transfer from Katse Dam into the Hlotse River, via the Hlotse Adit, and abstraction of this water from the Hlotse Abstraction Point, forms part of a broader program of donor support to the Government of Lesotho's strategic investments in the water and sanitation sector.

The overall objective of the Environmental Flows (EFlows) assessment is to guide the development of future operating rules for the Hlotse Adit and Hlotse Abstraction Point. The intent is to ensure that downstream water quality and aquatic ecosystem conditions after the scheme is in place are as good, or better, than pre-project conditions.

This document is the Hlotse EFlows Scenario Assessment Report, which summarises the results of the EFlows scenarios assessment.

Study area

The study area is the Hlotse River, situated in western Lesotho, Southern Africa.

EFlows sites

Six EFlows sites were selected to represent six reaches of the Hlotse River. EFlows0 is a control site. EFlows1-5 are sites that would be affected by the Inter Basin Transfer (IBT) via the Hlotse Adit. EFlows1-3 are downstream of the Hlotse Adit and upstream of the Hlotse Abstraction Point, while EFlows4 and 5 are downstream of the Hlotse Abstraction Point.

The EFlows sites were first assessed by the EFlows Assessment team on a field trip in September 2021, during which the first set of data were collected. The collection, analysis and use of these data in the EFlows Assessment are written into the Baseline Report, which contains sub-Sections for each discipline assessed.

Scenarios analysed

Five sets of scenarios covering different aspects of the planned operation of the Hlotse Adit and the Hlotse Abstraction Point were assessed. These were:
Set 1: Releases from the Hlotse Adit (from the Katse dam via the transfer tunnel)
Set 2: Abstractions of water from the Hlotse Abstraction Point
Set 3: Additional dry season flows in Lower Hlotse River
Set 4: Climate change
Set 5: Overall reduction in flows in Hlotse River.

Guidelines

The guidelines with respect to the future operating rules for the Hlotse Adit and Hlotse Abstraction Point arising from the scenario assessment are:

- Releases from Hlotse Adit should not exceed 1.7 m3/s (see Chapter 11.1)

- Releases should be implemented gradually in a manner that limits water level changes in the downstream river (EFlows1) to no more than 0.05 m/hour (MRC 2020)
- Abstractions from Hlotse Abstraction Point should not exceed releases from Hlotse Adit in the dry season, plus losses in the channel, and should allow ~0.4 m3/s of the released water to remain in the river, in addition to the water supplied by the Hlotse catchment.

Furthermore:

- Releases should be implemented in a manner that limits water level changes (up or down) at EFlows1 to ⩽ 0.05 m/hour
- Abstractions at the Hlotse Abstraction Point should not commence before the discharge at Gauge CG25 indicates that the water from the Adit has arrived
- Abstractions at the Hlotse Abstraction Point should stop once the discharge readings at Gauge TS3 indicate that the flows have dropped back down to pre-release levels
- The recommendation will require complete re-evaluation should additional medium or large-scale[1] abstractions or water-resource development be planned or implemented in the Hlotse River.

The predicted responses of the ecosystem to the modelled climate change scenarios are by and large positive.

[1] Relative to the MAR of the Hlotse River

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LIST OF ACRONYMS

AEC	Alternative Ecological Category
CSIR	Council for Scientific and Industrial Research
DRIFT	Downstream Response to Instream Flow Transformation
EFA	Environmental Flows Assessment
EFlows	Environmental Flows
ESIA	Environmental and Social Impact Assessment
IWRM	Integrated Water Resource Management
GoL	Government of Lesotho
LHDA	Lesotho Highlands Development Authority
LHWP	Lesotho Highlands Water Project
LLBWSS	Lesotho Lowland Bulk Water Supply Scheme
LLWDP II	Lesotho Lowlands Water Development Project Phase 2
MAR	Mean Annual Runoff
masl	Meters Above Sea Level
m^3/s	Cubic metres per second
M^3/m	Cubic metres per month
MCM	Million Cubic Meters
ML/d	Megalitres per day
RSA	Republic of South Africa
TIN	Total Inorganic Nitrogen
WTW	Water Treatment Works

PREFACE

This is the Final EFlows Scenario Assessment Report of the ***Consulting Services for Environmental Flow Assessment (EFA) and Water Quality Modelling within the Lesotho Lowlands Water Development Project Phase II (LLWDP II)***.

This assignment is led by the Ministry of Water Lesotho, through the Lesotho Lowlands Water Development Phase II (LLWDP II) as Client. The study is funded by the World Bank. The LWDP II component will support the implementation of critical bulk water infrastructure in Zones 2 and 3 (Hlotse and Maputsoe) accompanied by improvements to the distribution systems and implementation of low-scale sanitation and hygiene measures. LLWDP II has hired Multiconsult (Norway), Southern Waters (Republic of South Africa), Deltares (the Netherlands) and Multi-Nodal Development Consultants (Lesotho) to carry out the assessment.

The following LLWDP II personnel are supervising the assignment:

- Nthame Monare (Environmental Safeguards Specialist)
- Matumelo Daemane (Procurement Officer)
- Leshoboro 'Nena (Water Resources Scientist)
- Mamothokoane Tlali (IT Specialist)
- Tsibela Mochaba (Mechanical Engineer)
- Thabang Ts'ehlo (Hydrologist)
- Billy Makakole (DWA Hydrologist seconded to the project).

The following consultancy team members are contributing to the assignment:

Key Experts

- Leif Lillehammer (Lead Consultant/Project Manager) – Multiconsult
- Cate Brown (EFR Lead/Expert) - Southern Waters
- Ron Passchier (Hydrologist) – Deltares
- Andrew Birkhead (Water Resources Engineer) – Southern Waters
- Nico Rossouw (Water Quality Specialist) – Southern Waters
- Jørn Stave (Biologist) – Multiconsult.

Non-Key Experts

- Kate Rowntree (Geomorphologist/Sediment Expert) – Southern Waters
- Marie-Pierre Gosselin (Ecohydrologist) – Multiconsult
- Karl Reinecke (Riparian Vegetation and Invertebrate Expert) – Southern Waters
- Bruce Paxton (Fish Biologist) – Southern Waters
- Mantoa Moiloa[2]/James Tsilane (Avifauna and Mammal Expert) – Multi-Nodal
- Dylan Marrs (Social Scientist) – Multi-Nodal
- Vuyani Monyake (National Coordinator and Water Quality Support Expert) – Multi-Nodal
- Alison Jourbet (DRIFT DSS Manager) – Southern Waters
- Mijke van Oorschot (Freshwater Ecologist) – Deltares

[2] Our dearest team member Mantoa Moiloa sadly passed away of Covid 19 during the pandemic in 2021. She will be greatly missed by the team.

- Frederiek Sperna Weiland (Climate Change Expert) – Deltares
- Helene Boisgontier (Hydrological Modeller) – Deltares
- Filip Patocka (Project Controller – Co-Management support) – Multiconsult
- Sigurd Sørås (GIS Expert) – Multiconsult.

Supporting Experts

- Nick Huckzermeyer (Geomorphology Support) – Southern Waters
- Matankiso Phooko (Research Assistant – Sustainability) – Multi-Nodal
- Makalo Nthathakane (Research Assistant – Environment) – Multi-Nodal
- Lerato Lekhera (Research assistant – Water Quality) – Multi-Nodal
- Manapo Namane (Research Assistant – Socio-Economics) – Multi-Nodal
- Maqetha Tlaba (Research Assistant – Avifauna) – Multi-Nodal.

1 INTRODUCTION

1.1 General description of the Hlotse Catchment

Lesotho is divided into four topographical regions: the Highlands > 2 200 m above sea level (masl); the Foothills (1 800-2 200 masl); the Lowlands (1 400-1 800 masl), and; the Senqu River Valley (Table 1.1). The Hlotse Adit and Abstraction Point will be in the Lowlands region along the western border of Lesotho. The Hlotse Basin drains parts of the highlands, foothills and the lowlands, and then merges with Mohokare Sub-Basin at the border with the Republic of South Africa (RSA). The catchment falls within the Drakensberg-Maloti Highlands Ecoregion (Abell *et al.* 2008), which includes the headwaters of the Orange-Senqu River Basin.

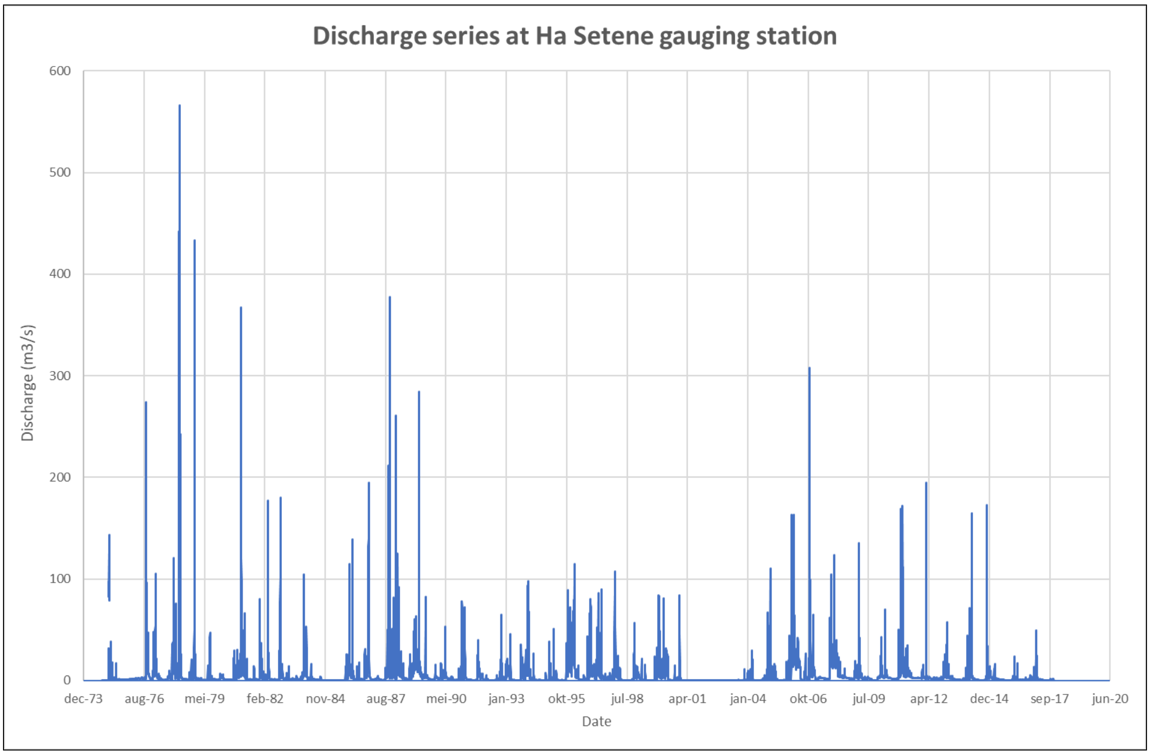
Table 1.1 The four topographic regions of Lesotho (from Lillehammer et al. 2007; Lesotho IWRM Strategy)

Regions	Area (km2)	% of land area	Altitude (masl)
Lowlands	5 760	19	1500-1800
Foothills	2 430	8	1800-2200
Mountains	19 730	65	2200-3400
Senqu River valley	2 430	8	1400-1800

The average Mean Annual Runoff (MAR) of the Hlotse River at its confluence with the Mohokare River is 148.55 MCM. The hydrology of the Hlotse River is characterized by a clear wet and dry season (Figure 1.1a). Figure 1.1a shows the discharge time-series of the Ha Setene gauging station (Code CG25), which is close to the confluence with the Mohokare River and thus captures most of the flow in the basin. In this time-series, 1975 – 2020, there is a clear seasonal pattern and large variability between the years. However, there is no clear increasing or decreasing trend in discharge.

The frequency analysis of the discharge series for the 10%, 20%, 50%, 80% and 90% percentile values is shown in Figure 1.1b. Here the seasonality is also evident; in the dry season discharge is stable, and; in the wet season (~February to August) the flows are highly variable. Major floods occur relatively frequently and have a large impact on sediment transport, erosion and deposition, and thus on channel morphology.

Geology is an important determinant of river channel morphology because it is the source of bed sediment. The lithology of the upper catchment is basalt, which weathers to spherical cobble and boulder plus smaller material down to the clay fraction. The basalt topography consists of V-shaped valleys with steep slopes, separated by narrow ridges. Massive sandstones of the Clarens Formation dominate the middle of the catchment. These rocks form steep cliffs that often rise adjacent to or close to the valley floor in some sections of the valley. In the lower part of the catchment the Elliot Formation and the Molteno Formation predominate. The two formations are similar and are comprised of alternating strata of sandstones, mudstones and siltstones (Final Inception and Scoping Report, Multiconsult 2022a).



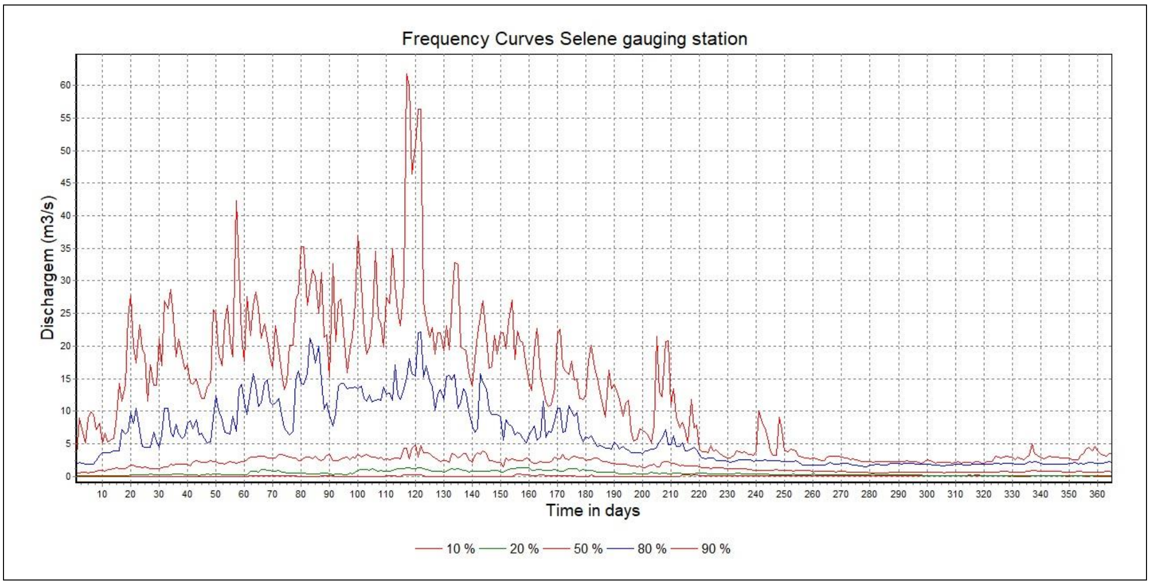


Figure 1.1 a) Hydrograph of the Hlotse River at Ha Setene gauging station (top), b) Frequency curve at Setene station (bottom)

The biodiversity of the Lesotho Highlands is relatively well documented, but that of the Lowlands have been significantly less studied. The main reports with information on the biology of the rivers and riparian ecosystems in the Lesotho Lowlands, including the Hlotse River, are the Baseline Study for the Lesotho Highlands Development Authority (LHDA) by the CSIR (LHDA 1993), the original Environmental Flow Assessment (EFA) by Jeffares and Green (LHDA 2008) and the updated Environmental and Social Impact Assessment (ESIA) study by Aurecon Lesotho (Aurecon *et al.* 2018).

The rivers of the Lesotho lowlands are generally in a moderate to poor condition because of high sediment loads from incremental catchments with little vegetation, having been cleared for cultivation and grazing. The high sediment loads move down the rivers and embed gravels and cobbles in the channel thereby reducing the diversity of instream habitats for invertebrates. High sediment loads also increase water turbidity that reduces incident light into the channel, which reduces the growth of aquatic plants and algae that support invertebrate communities as food and habitat. Some sections of the Hlotse River are fringed by a narrow strip of riparian trees (including exotic poplars, willows and the Silver wattle), but for most of its length the riverbank vegetation consists of reeds, sedges and grassland (used for summer grazing in the upland areas). Riparian plants are harvested for domestic and commercial use and are cleared to make way for cultivated crops; both activities reduce the diversity of wet bank plants that provide habitat for invertebrates. Cattle and goats also graze along and drink from rivers, while doing so pats are dropped in the river that dissolve and increase the concentration of nutrients in the water, which reduces water quality and favours hardy invertebrates over those sensitive to poor water quality. This in turn affects the fish and other animals in and alongside the river.

The catchment supports a fairly dense rural human population that is largely dependent on subsistence agriculture and livestock farming to support their livelihoods, which takes place predominantly in the lowland section (Figure 1.2). The foothills are a mixture of cultivated areas and grassland and highlands mainly grassland and shrubland. Small isolated patches of evergreen and deciduous forest occur in the foothills and the highlands. The grasslands in the upland parts of the catchment are used for summer grazing (Baseline Report, Multiconsult 2022b) and areas cultivation and settlements are sparse.

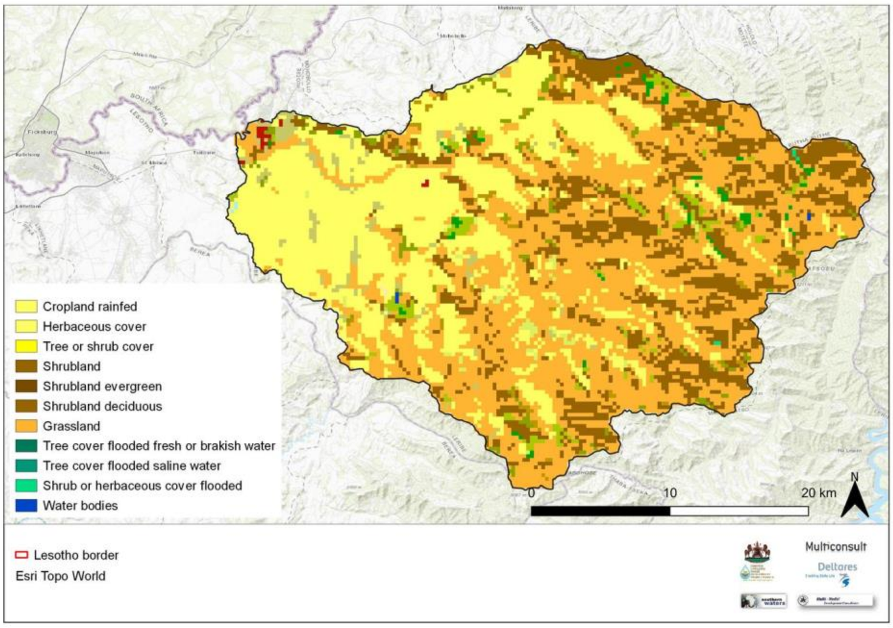


Figure 1.2 Landcover of the Hlotse River basin (ESA 2015): https://www.esa-landcover-cci.org/)

1.2 Project context

The Lesotho Lowlands Water Development Project Phase II (LLWDP II) is a key program of the Government of Lesotho (GoL) to improve potable water supply. One aspect of LLWDP II is the Lesotho Lowlands Bulk Water Supply Scheme (LLBWSS), which aims to address the water demands in the Lowlands by supplying water to the settlements with populations greater than 2 500. Figure 1.3 is a schematic of the LLWDP area and its various zones (Zones 1 to 8 in Figure 1.3). This study focuses on Zones 2 and 3.

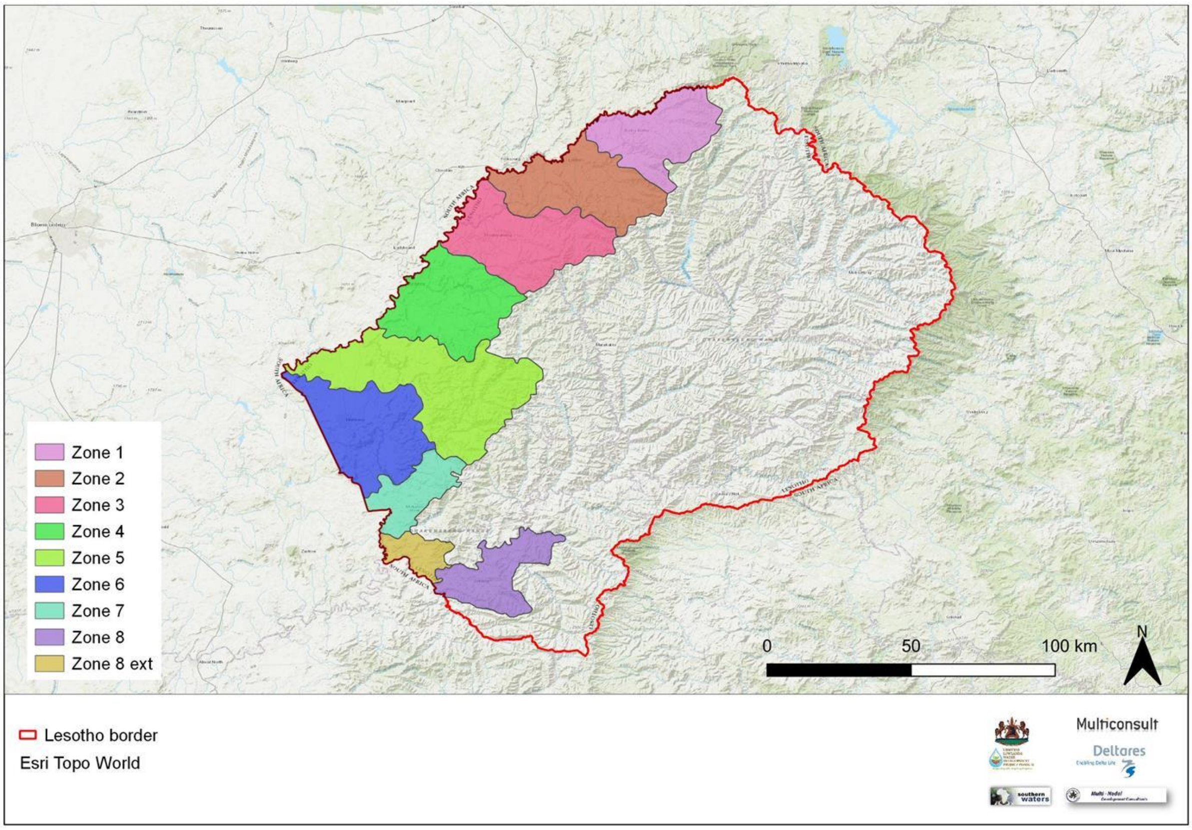


Figure 1.3 Bulk water supply zones of the Lesotho Lowlands (Source: adapted from Aurecon et al. 2018)

The LLBWSS was established in 2002 through a Cabinet Memorandum, with the mandate to oversee the implementation of the LLWDP in accordance with the provisions of the Lesotho Water and Sanitation Policy of 2007 (LWSP) – Policy Statement 2: Water Supply and Sanitation Services.

1.2.1 Water Transfer from Katse Dam to the Hlotse Adit

Water-resource analyses and water-demand estimates indicate that there is insufficient water in the Hlotse River during low flow periods to supply the current and future demand forecasts, and to maintain ecological functioning downstream of the proposed water abstraction intake point. This means that flows will need to be augmented during the dry season and time of drought by means of water transfers from Katse Dam (part of the Lesotho Highlands Water Project - LHWP). These can be supplied through an existing tunnel, into the upper reaches of the Hlotse River, via the Hlotse Adit.

The LHWP Treaty of 1986 (Article 4) (GoL and RSA 1986) and protocols allows for storage and draw down of water from the LHWP system through the Hlotse Adit into Hlotse River. Annually the Government of Lesotho can draw down up to 5 MCM (Million Cubic Metres) from the storage of which 25% is allocated to the environment flows of the Muela River. Thus, the net quantity of water that can be utilized by Lesotho and released into Hlotse River is 3.75 MCM per annum. The treaty also allows accumulation or banking of unused annual allocation up to a maximum storage of 15 MCM that can be drawn down when required. The draw down from Katse Dam takes place through releases via a tunnel connecting to Muela dam – the Hlotse Adit. Operational rules and planning for the releases from the LHWP will be refined in the future including possible expansion of the water release and conveyance system that has been installed at the Hlotse Adit especially for the Hlotse River.

1.2.2 Water abstraction treatment works

The location of the water abstraction intake and the treatment works is approximately around 7 kilometres upstream of the confluence of the Caledon and Hlotse Rivers (Figure 1.4). The proposed water treatment plant will be 10 km east of Hlotse Town.

The LLBWSS implementation plan for Zones 2 and 3 is packaged in two phases, with Phase 1 from 2018 to 2030, and Phase 2 from 2031 to 2045. Thus, the designs were undertaken to meet potable water demands over a design horizon up to 2045. Construction for Phase 1 was originally from January 2019 for completion by December 2020, but was delayed pending the conclusion of this EFlows study. Phase 2 is planned from 2029 to meet water demands from 2031-2045 (Aurecon *et al.* 2018; SMEC 2017).

The infrastructure components in the Zones 2 and 3 bulk water supply schemes are discussed in the following sub-section.

1.2.3 Water intake

Direct surface water abstraction will take place at Ha Setene from the Hlotse River, augmented by the LHWP transfer in the short to medium-term,[3] for potable water supply. The pumps in the Hlotse intake station will be designed to meet the demand for Zones 2 and 3 at the peak duties for 2030 initially and ultimately for 2045. The average flow to be extracted from the river will be 41 846 m^3/day by 2030 and will be increased to 53 023 m^3/day by 2045. Peak demands will be higher than the average flow (LLWDP 2021).

1.2.4 Water treatment works

The proposed Water Treatment Works (WTWs) will be constructed near Ha Makotoane in two phases. The treatment works will have a design capacity of 40 ML/d during Phase 1 and additional 20 ML/d to be added in Phase 2. The WTWs will process raw water extracted directly from the Hlotse River by pumps located in a wet-well intake sump. It will be required to treat the peak amount of water required to meet the demand requirement (Aurecon *et al.* 2018; SMEC 2017).

[3] Phase 1 from 2018 to 2030, and Phase 2 from 2031 to 2045

1.2.5 *Pump stations and pipeline*

Fourteen pumping stations will be constructed to the service reservoirs in Zone 2 and 3. Two pumping stations (Z2/3PS1 and Z2/3PS2) will be located downstream of the WTW. These are proposed to be installed inside a single pump house. The remaining pumping stations will be located in appropriate locations throughout Zone 2 and 3 (SMEC 2017).

The proposed pipeline will be 144.2 km long, with a diameter ranging from 100 to 800 mm. Most pipes used in the designs will be ductile iron. The pipeline will convey the water to storage tanks throughout the Zones (Aurecon *et al.* 2018; SMEC 2017).

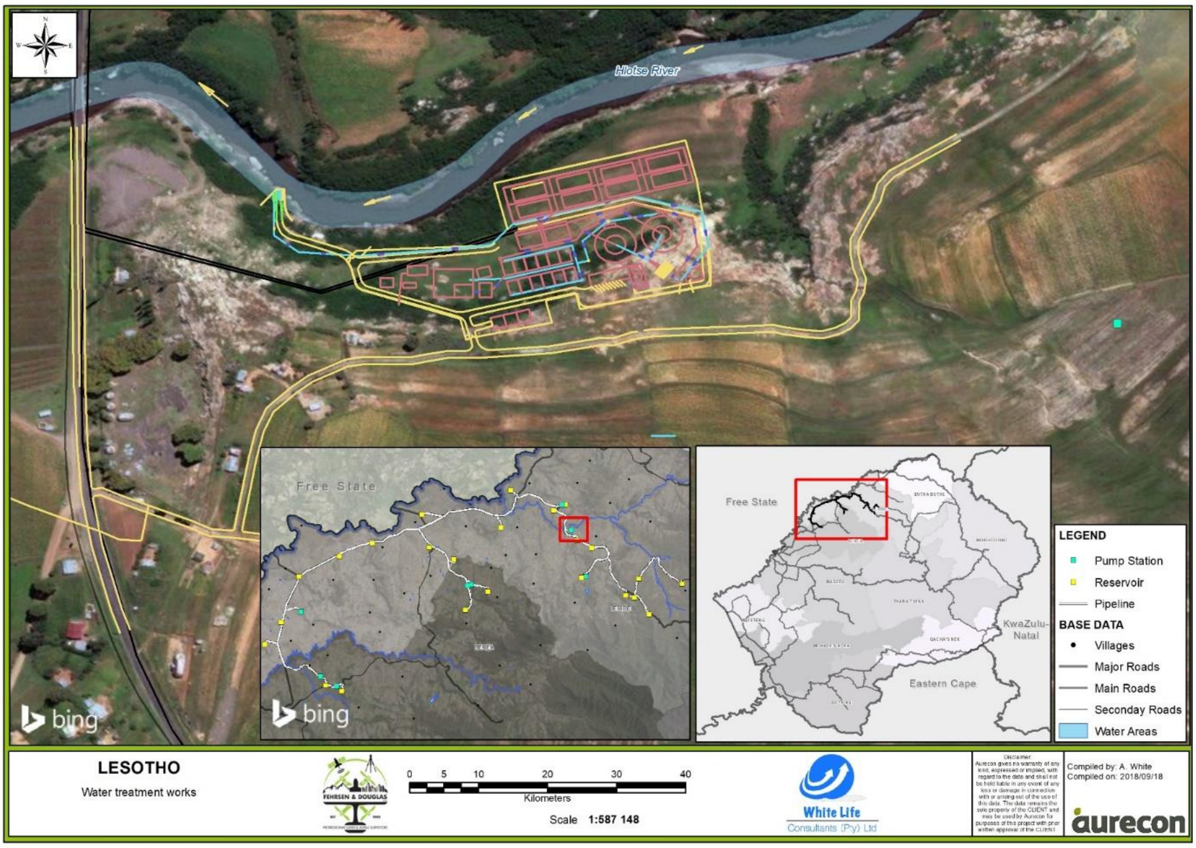


Figure 1.4 Water treatment works site layout (Aurecon et al. 2018)

1.3 The EFlows assessment

This assignment is the EFlows (Figure 1.5) assessment for the Hlotse River to support implementation of LLBWSS in Zones 2 and 3 (Hlotse and Maputsoe; Figure 1.3). The overall objective of the Environmental Flows (EFlows) assessment is to guide the development of future operating rules for the Hlotse Adit and Hlotse Abstraction Point.

The results will be used to better define the magnitude and extent of potential impacts (geomorphological, ecological and social) of the proposed operation (and mitigation of these) with an emphasis on key ecosystem drivers, fish, macroinvertebrates and downstream users. The intent is to ensure that downstream water quality and aquatic ecosystem conditions after the scheme is in place are as good, or better, than pre-project conditions.

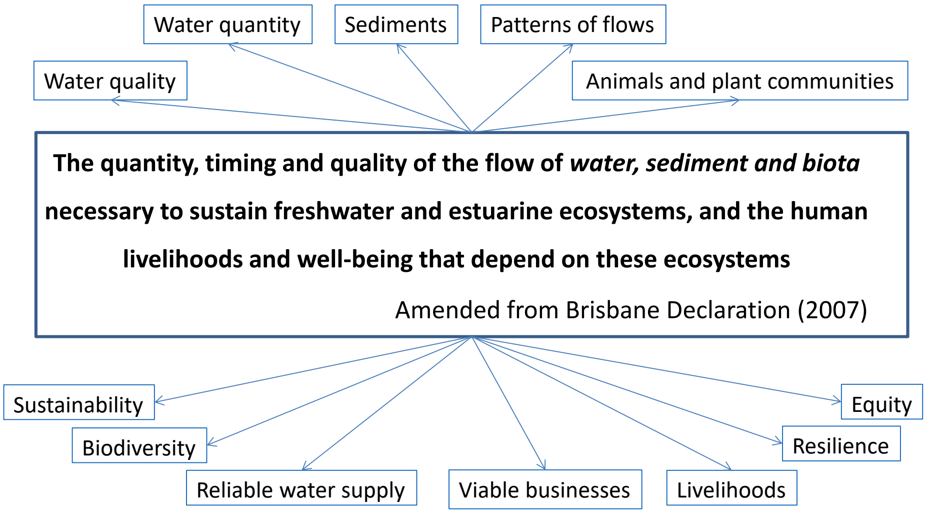


Figure 1.5 Definition of EFlows, the types of data considered and the implications for societies of well-managed healthy river systems

The assignment collated and synthesised existing information and collected some new data on the Hlotse River and used it to:

- Delineate the river into five EFlows sites and their representative reaches
- Model the hydrology and hydrodynamics of the Hlotse River downstream of the proposed Hlotse Adit
- Identify a set of indicators to describe the Hlotse River ecosystems
- Define the baseline condition of the Hlotse River indicators
- Describe the historical trajectory of changes in the selected indicators
- Identify the factors that drive change in each of the indicators
- Set up an EFlows model (DRIFT-Hlotse) that describes the relationship between each driver and each indicator (using response curves)
- Construct a set of scenarios that varied in terms of the planned operation of the Hlotse Adit in the dry season (Table 4.1), in terms of different release volumes and abstractions from the Hlotse River, and also more widely in terms of extreme wet and dry years and seasons
- Predict the response of each indicator to changes in drivers linked with the set of scenarios
- Predict overall ecosystem condition linked with the set of scenarios
- Use the information generated to highlight the options of sustainable use of the Hlotse River ecosystem.

1.3.1 Approach

The DRIFT framework (www.DRIFT-eflows.com) was used to develop a conceptual model of the EFlows-related interactions in the Hlotse River. DRIFT[4] is a process and computer program for managing and interrogating knowledge on the links between river flows, ecosystem functioning and social uses. It was developed to aid management and future planning of water-resource

[4] An acronym for: Downstream Response to Imposed Flow Transformations

developments, rehabilitation of rivers or any other management activity that could affect the flow of water and sediment through inland water ecosystems.

It allows for:

- Time-series based evaluation of development plans based on changes to hydrology, hydraulic or sediment characteristics of the ecosystem
- Incorporation and evaluation of measured or modelled time-series data at any time-step for water flows, sediment supply, and water quality
- Use of a combination of models, data, knowledge and experience to predict how the river ecosystem will change
- Calibration or evaluation of time-series predictions against monitoring data, where available
- Inclusion of social criteria.

An important aspect of a DRIFT assessment is that is does not result in a recommended EFlows regime. Rather, it uses scenarios to illustrate the potential impacts associated with different levels of flow regime changes, from which a decision (by the Client/Government) is needed to arrive at the acceptability of the level(s) of impact predicted for different scenarios.

The approach adopted for this assignment comprised the following steps:

- Identification of the kinds of scenarios that required assessment
- Delineation of the study area and select assessment sites
- Modelling of external inputs to DRIFT, viz.: hydrology, hydraulics and water quality, for baseline and each scenario, and summarise these as a series of ecologically-meaningful indicators
- Selection of ecological and social indicators to represent the river ecosystem and its users
- Evaluation of the baseline status and past trends for each of the indicators selected
- Description of the links between the indicators that drive ecological condition in the system
- Assessment of the scenarios in terms of qualitative changes in the ecosystem and social indicators.

The Hlotse EFlows assessment followed the World Bank Group Good Practice Handbook on Environmental Flows for Hydropower Projects Guidance for the Private Sector in Emerging Markets (World Bank 2018)[5]. In terms of the level of EFlows assessment as indicated in the Handbook, this assessment is a Comprehensive Assessment.

1.3.2 EFlows Assessment team

The EFlows Assessment team are listed in Table 1.2.

[5] Available at: http://documents.worldbank.org/curated/en/372731520945251027/pdf/124234-WP-Eflows-for-Hydropower-Projects-PUBLIC.pdf

Table 1.2 Hlotse River EFlows Assessment team

Role	Name	Organisation
Project Manager	Leif Lillehammer	Multiconsult
EFlows Assessment Project Leader	Dr Cate Brown	Southern Waters
EFlows Assessment Co-ordinator	Dr Karl Reinecke	Southern Waters
Hydrology	Hélène Boisgontier, Ron Passchier	Deltares
Hydraulics and hydrodynamic modelling	Dr Andrew Birkhead/Marie-Pierre Gosselin (the latter-ecohydraulics)	Southern Waters/Multiconsult
Water quality	Nico Rossouw/ Vuyani Tshabalala-Monyake	Southern Waters/ Multinodal
Geomorphology	Prof Kate Rowntree Nick Huckzermeyer	Southern Waters
Vegetation/Macroinvertebrates	Dr Karl Reinecke	Southern Waters
Fish	Dr Bruce Paxton	Southern Waters
Socioeconomics and livelihoods	Dylan Marrs/ Dr Jørn Stave	Multinodal/ Multiconsult
Birds and mammals	James Tsilane / Dr Jørn Stave	
EFlows Assessment Database Manager	Dr Alison Joubert	Southern Waters

1.4 This report

This report is the EFlows Assessment report. The reporting for the Hlotse EFlows Assessment comprises ten final milestone reports:

- Inception Report
- Baseline Report
- Monitoring and Modelling report
- Training Manual
- Water Resources and Water Quality Assessment Report
- Hydraulics and Hydrodynamics Report
- EFlows Assessment Report (this report)
- Hlotse DRIFT Manual
- EFlows Policy and EFlows Management Plan
- Completion Report.

Two supplementary (non-milestone reports) have also been elaborated. These are:

- Baseline Water Quality Monitoring Programme Design
- Baseline Water Quality Sampling Manual.

2 EFLOWS SITES

For the purposes of the EFlows assessment, six EFlows sites were selected on the Hlotse River, five assessment sites (EFlows1-5) and one control site (EFlows0), and their representative reaches. These are listed in Table 2.1 and shown in Figure 2.1.

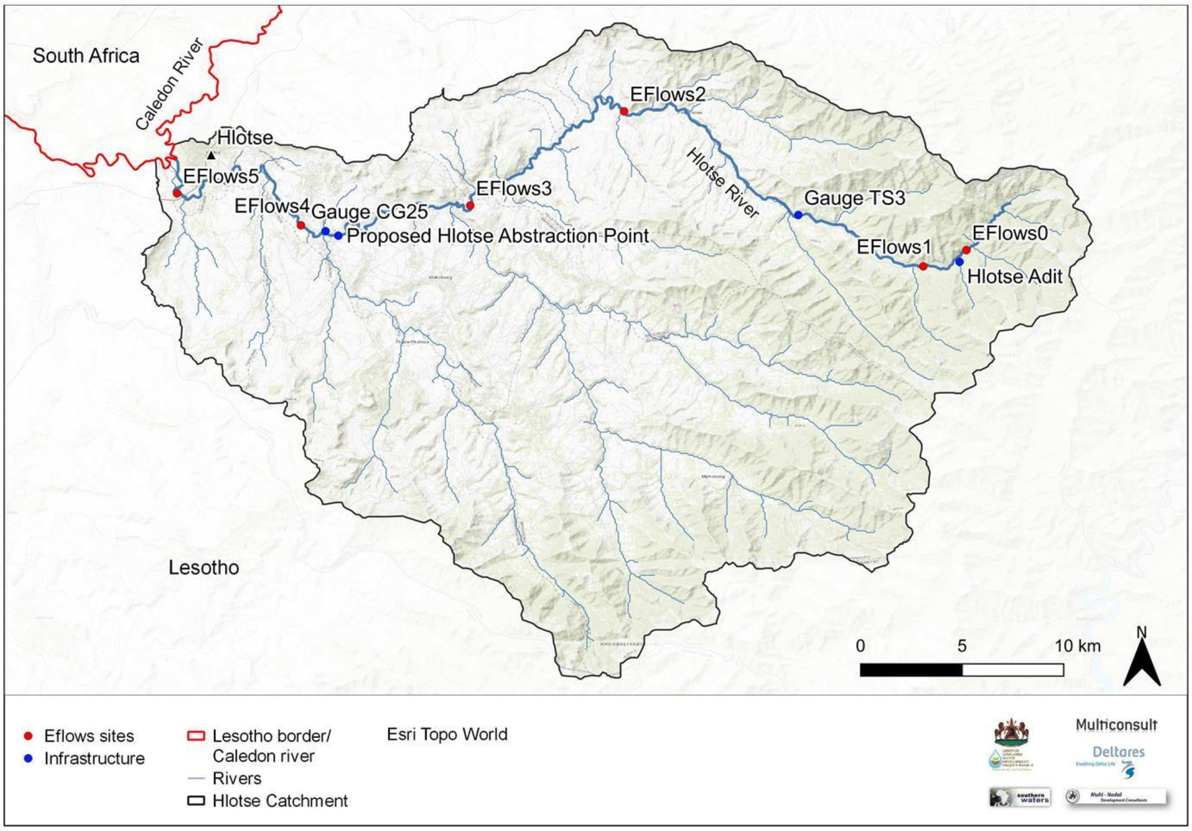


Figure 2.1 Hlotse River Basin, showing the location EFlows sites, hydrological gauges, the Hlotse Adit and Hlotse Abstraction Point, and Hlotse Town[6]

Additional detail on each site is provided in the relevant discipline chapters in the Hlotse River Baseline Report (Multiconsult 2022b).

Table 2.1 Locations and co-ordinates for the six EFlows sites, and length of each representative reach

Site	Location	Co-ordinates	Reach length
EFlows0	Tsehlanyane National Park	-28° 55’ 13.38’’ 28° 26’ 01.08’’	1.5 km
EFlows1	1 km downstream of the Hlotse Adit	-28° 55’ 42.91’’ 28° 24’ 42.52’’	6.0 km

6 Gauge TS3 is not the code for the gauging weir but rather the code TS3 represents the Department of Water Affairs monitoring site. Not gauge code has been assigned to the new gauge that will be built at monitoring site TS3 yet.

Site	Location	Co-ordinates	Reach length
EFlows2	Hlotse road bridge at Khabos Village	-28° 51' 00.4'' 28° 15' 37.6''	3.0 km
EFlows3	Upstream of Seetsas Village	-28° 53' 52.1'' 28° 10' 57.2''	3.0 km
EFlows4	Downstream of the Proposed Hlotse Abstraction Point at Moliboeas Village	-28° 54' 28.2'' 28° 05' 48.8''	4.0 km
EFlows5	Downstream of road bridge at entrance to Hlotse Town	-28˚ 53' 29.90'' 28˚ 02' 03.13''	3.0 km

2.1 Baseline (2021) condition

Estimated baseline (2021) conditions expressed as ecological condition categories (Table 2.2) at the EFlows sites for individual disciplines and ecosystem integrity as a whole are provided in Table 2.3.

The reasoning behind the estimates is provided in the Baseline Report (Multiconsult 2022b).

Table 2.2 Definitions of the ecological condition categories (Kleynhans 1999)

Ecological Category	Description of habitat
A	Still in a natural condition
A/B	
B	Slightly modified. A small change in natural habitats and biota has taken place but the ecosystem functions are essentially unchanged for natural
B/C	
C	Moderately modified from natural. Loss and change of natural habitat and biota has occurred, but the basic ecosystem functions are still predominantly unchanged
C/D	
D	Largely modified. A large loss of natural habitat, biota and basic ecosystem functions has occurred
D/E	
E	Seriously modified. The loss of natural habitat, biota and basic ecosystem functions is extensive
E/F	
F	Critically/Extremely modified. The system has been critically modified with an almost complete loss of natural habitat and biota. In the worst instances, basic ecosystem functions have been destroyed and the changes are irreversible

Table 2.3 Estimated baseline integrity (condition) of the reaches represented by the EFlows sites on the Hlotse River for individual disciplines and the ecosystem as a whole

Discipline	EFlows1	EFlows2	EFlows3	EFlows4	EFlows5
Geomorphology	C	C	C	C	D
Water quality	B	B	B	B	B
Vegetation	C	E	E	E/F	F
Invertebrates	A/B	C/D	B	E/F	C
Fish	E	D	E	E	E
Birds	C	C	c	C	C
Mammals	C	C		C	C
River	C	C/D	CD	D/E	D

3 APPROACH

3.1 Percentage change from baseline

Into the foreseeable future, predictions of river change will be based on limited knowledge. Most river scientists, particularly when using sparse data, are thus reluctant or unable to quantify predictions: it is relatively easy to predict the nature and direction of ecosystem change, but more difficult to predict its timing, intensity or absolute end value. DRIFT describes increase/decreases for an indicator in response to changes in the flow indicators as a (range of) percentage change relative to the baseline condition.

3.2 DRIFT-Hlotse EFlows model

DRIFT-Hlotse comprises three modules (Figure 3.1):

- Set-up
- Knowledge Capture
- Analysis.

These three modules, with all their components, are presented within the cream block at the bottom of Figure 3.1. The elements that provide input to and outputs from these are indicated in the area above the cream block.

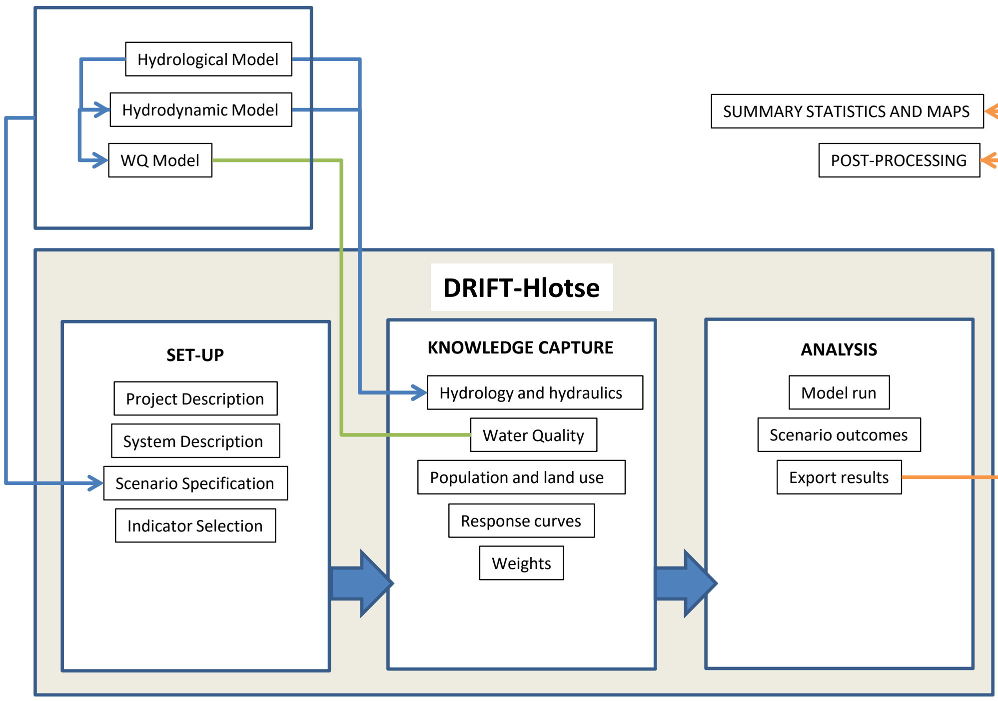


Figure 3.1 Arrangement of modules in DRIFT-Hlotse (light-brown shading) and inputs/outputs from/to external models

The first two modules deal with the set-up, population and calibration of the flow-eco-social relationships that will be used to predict the ecosystem response to potential development/ management actions. The third module is used to generate results once the first two modules have been configured, and to export the output data detailing the predictions for the configurations under consideration to MS Excel for post-processing and reporting.

3.2.1 Representative reaches and sites

DRIFT-Hlotse focuses on five representative EFlows sites (Figure 2.1). The EFlows sites are the focus of all data collection/collation, hydrological/hydraulic modelling, indicator selection, and reporting.

3.2.2 Disciplines

The ecological and social aspects of the Hlotse River ecosystem are represented by eight disciplines in DRIFT-Hlotse, *viz*.:

- Hydrology
- Hydraulics
- Water Quality
- Geomorphology
- Vegetation
- Fish
- Birds, mammals and amphibians
- Social use.

3.2.3 Indicators and links

Discipline-specific indicators and the links between driving and responding indicators were derived by the EFlows team (Baseline Report, Multiconsult 2022b). Some of the driving indicators are generated outside of the DRIFT-Hlotse (Section 3.2.3.1). Others are ecosystem indicators whose predicted changes are provided through response curves in DRIFT-Hlotse.

3.2.3.1 External 'driver' indicators

DRIFT-Hlotse used input data from several external sources, which were used to generate the relevant time-series information for the baseline and other scenarios (Figure 3.1).

Table 3.1 External 'driver' indicators in DRIFT-Hlotse

Discipline	Indicator	Discipline	Indicator
Hydrology	Mean annual runoff	Hydraulic Habitat	Dry: ave XS1 Slow shallow
	Dry onset		T1: ave XS1 Slow shallow
	Dry duration		Wet: ave XS1 Slow shallow
	Dry Min 5d Q		T2: ave XS1 Slow shallow
	Dry Q AVE		Dry: ave XS1 Slow deep
	Dry Q MAX		T1: ave XS1 Slow deep
	Wet onset		Wet: ave XS1 Slow deep
	Wet duration		T2: ave XS1 Slow deep
	Wet Max 5d Q		Dry: ave XS1 Fast shallow
	Wet season volume		T1: ave XS1 Fast shallow
	Dry ave daily vol		Wet: ave XS1 Fast shallow
	T1 ave daily vol		T2: ave XS1 Fast shallow
	Wet ave daily vol		Dry: ave XS1 Fast deep
	T2 ave daily vol		T1: ave XS1 Fast deep

Discipline	Indicator
	T1 duration
	T2 duration
Hydrology (floods; number per year)	Dry Class1
	Dry Class2
	Dry Class3
	Dry Class4
	T1 Class1
	T1 Class2
	T1 Class3
	T1 Class4
	Wet Class1
	Wet Class2
	Wet Class3
	Wet Class4
	T2 Class1
	T2 Class2
	T2 Class3
	T2 Class4
	1:2 Class5
	1:5 Class6
	1:10 Class7
	1:20 Class8
Water quality	Dry: min temperature
	Wet: min temperature
	Dry: max temperature
	T1 max temperature
	Wet: max temperature
	T2: max temperature
	Dry: ave temperature
	T1: ave temperature
	Wet: ave temperature
	T2: ave temperature

Discipline	Indicator
	Wet: ave XS1 Fast deep
	T2: ave XS1 Fast deep
Hydraulics	xs1 Dry min of Ave 5d Velocity
	xs1 Wet min of Ave 5d Velocity
	xs1 Wet max of Ave 5d Velocity
	xs1 Dry min of Ave 5d WetPerim
	xs1 Wet min of Ave 5d WetPerim
	xs1 Wet max of Ave 5d WetPerim
	xs1 Dry min of Ave 5d Depth
	xs1 Wet min of Ave 5d Depth
	xs1 Wet max of Ave 5d Depth
	D: MAX XS1 Depth
	T1: MAX XS1 Depth
	W: MAX XS1 Depth
	T2: MAX XS1 Depth
	D: MAX XS2 Depth
	T1: MAX XS2 Depth
	W: MAX XS2 Depth
	T2: MAX XS2 Depth
	Dry: ave XS2 Depth
	T1: ave XS2 Depth
	Wet: ave XS2 Depth
	T2: ave XS2 Depth
	Dry: ave XS2 Velocity
	T1: ave XS2 Velocity
	Wet: ave XS2 Velocity
	T2: ave XS2 Velocity
	Dry: ave XS2 Width
	T1: ave XS2 Width
	Wet: ave XS2 Width
	T2: ave XS2 Width
	Dry: ave XS2 Wet perimeter
	T1: ave XS2 Wet perimeter
	Wet: ave XS2 Wet perimeter
	T2: ave XS2 Wet perimeter
	D: MAX XS3 Depth
	T1: MAX XS3 Depth
	W: MAX XS3 Depth
	T2: MAX XS3 Depth
	Dry: ave XS3 Depth
	T1: ave XS3 Depth
	Wet: ave XS3 Depth
	T2: ave XS3 Depth
	Dry: ave XS3 Velocity
	T1: ave XS3 Velocity
	Wet: ave XS3 Velocity
	T2: ave XS3 Velocity
	Dry: ave XS3 Width
	T1: ave XS3 Width
	Wet: ave XS3 Width
	T2: ave XS3 Width
	Dry: ave XS3 Wet perimeter
	T1: ave XS3 Wet perimeter
	Wet: ave XS3 Wet perimeter
	T2: ave XS3 Wet perimeter

Past changes in sediment supply as a result of catchment erosion are covered in the Baseline Report (Multiconsult 2022b). Sediment supply (from the catchment) was kept constant throughout the scenarios. Changes in in-channel sediment transport (and erosion and deposition) are included in the predictions in this report.

3.2.3.2 Ecosystem and social indicators

The ecosystem and social indicators in DRIFT-Hlotse are listed in (Table 3.2). The links with the external indicators and with each other are presented and discussed in the Baseline Report (Multiconsult 2022b).

Table 3.2 Ecosystem and social indicators in DRIFT-Hlotse

Discipline	Indicator	Discipline	Indicator
Water Quality	Turbidity	Farming	Dryland crop farming
	Orthophosphate		Livestock farming
	Total Inorganic Nitrogen (TIN)	Natural resource use	Cultural; Spiritual activities
Geomorphology	Percent fines in low flow channel		River crossings
	Percent fines in cobble lateral bars		Laundry; washing
	Pool depth		Drinking water
	Extent backwaters and pools		Sand mining; brick making
	Extent wet zone benches		Stone mining
	Extent dry zone benches		Wood harvesting
	Proportion of cobble and boulder	Community health; Social well-being	Farming
Vegetation	Green algae		Natural resource use
	Wet bank sedges		
	Dry bank grasses		
	Dry bank exotic Trees		
Macro-invertebrates	Caenids		
	Simulids		
	Baetids		
	Comp: Invertebrate abundance		
Fish	Orange-Vaal smallmouth yellowfish		
	Rock catfish		
	Chubbyhead barb		
	Comp: Fish abundance		
Birds	Piscivirous Birds - Giant kingfisher		
	Riparian Tree Dwellers - Hamerkop		
	Insectivirous Birds - Wagtail		
Mammals and Amphibians	Cape clawless otter		
	Frogs		

3.2.4 Response curves and scoring system

3.2.4.1 Response curves

Response curves depict the relationship between a biophysical indicator and a driving variable (e.g., discharge). The ecosystem indicators also link to other indicators deemed to be driving change. The aim is not try to capture every conceivable link, but rather to restrict the linkages to those that are most meaningful and can be used to predict the bulk of the likely responses to a change in the flow, water quality or sediment regimes of the river.

A response curve for the relationship between relative fish (e.g., Orange-Vaal smallmouth yellowfish) abundance (given as a severity rating – see Section 3.2.4.2) and a modelled indicator, in this case, availability of fast shallow habitat in the wet season, is shown in Figure 3.2. In Figure 3.2, less habitat leads to a decreased abundance and more habitat leads to an increased abundance.

☑ Wet: ave XS1 Fast shallow [F season]

Desc	%Area	Y1	Y2
Min	0.000	-1.447	
Min Base	10.790	-0.600	
	23.122	-0.250	
Median	35.454	0.000	
	36.492	0.125	
Max Base	37.530	0.200	
Max	43.159	0.600	

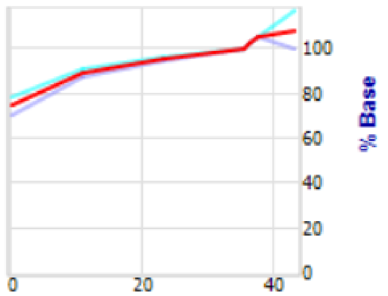


Figure 3.2 Example of a response curve – in this case of the area (m^2) with fast shallow flows suitable for Orange-Vaal smallmouth yellowfish

The units on the x-axis depend on the driving indicator under consideration. For instance, for the area with fast shallow flows (Figure 3.2), these are in m^2.

The y-axis may refer to abundance as in Figure 3.2, but also to other measures such as concentration or area, depending on the indicator. Response curves were constructed using severity ratings (Section 3.2.4.2).

Each response curve is accompanied by an explanation of its importance and the relationship it depicts. For the example in Figure 3.2, the explanation reads as follows:
"*Smallmouth yellowfish lay their eggs in gravel beds in fast flowing well-oxygenated riffles and runs (Fast shallow habitat class - >0.3 m/s and <0.3 m) (O'Brien and De Villiers 2011; Tómasson et al. 1984). An increased availability and quality of this habitat class will therefore positively influence recruitment in the following year. Spawning takes place at the onset of the wet season as temperatures rise and flows increase (Oct), but will continue through the wet season until January (Nthimo 2000; Tómasson et al. 1984) – the wet season was therefore selected as the season of interest for this linked indicator.*"

The response curves are used to evaluate scenarios by taking the value of the flow indicator for any one scenario and reading off the resultant values for the biophysical indicators from their respective response curves. Once this is done, DRIFT-Hlotse combines these values to predict the overall change in each biophysical indicator and in the overall ecosystem under each scenario.

3.2.4.2 Scoring system

It is relatively easy to predict the nature and direction of ecosystem change, but more difficult to predict its timing and intensity. To calculate the implications of loss of resources to subsistence and other users in order to facilitate discussion and trade-offs, it is nevertheless necessary to quantify these predictions as accurately as possible.

To aid this, two types of information were generated for each biophysical indicator, *viz*.:

- Severity ratings, which described increases/decreases for an indicator in response to changes in the modelled indicators
- Integrity ratings, which indicated whether the predicted change was a move towards or away from the natural ecosystem condition, i.e., how the change influences overall ecosystem condition.

The severity ratings were used to construct the response curves. The integrity ratings were used to predict changes in overall ecosystem condition/health.

3.2.4.2.1 Severity ratings

The severity ratings represented a continuous scale from -5 (large reduction) to +5 (very large change; Table 3.3), where the + or – denoted an increase or decrease in abundance or extent. These ratings are converted to percentages using the relationships provided in Table 3.3. The scale accommodated uncertainty, as each rating encompasses a range of percentages; however, greater uncertainty can also be expressed through providing a range of severity ratings (i.e., a range of ranges) for any one predicted change (Brown *et al.* 2013).

Note that the percentages applied to severity ratings associated with gains in abundance are strongly non-linear[7] and that negative and positive percentage changes are not symmetrical (Figure 3.3; King *et al.* 2003).

Table 3.3 DRIFT severity ratings and their associated abundances and losses – a negative score means a loss in abundance relative to baseline, a positive means a gain

Severity rating	Severity	% abundance change
5	Critically severe	501 % gain to ∞ up to pest proportions
4	Severe	251-500 % gain
3	Moderate	68-250 % gain
2	Low	26-67 % gain
1	Negligible	1-25 % gain
0	None	no change
-1	Negligible	80-100 % retained
-2	Low	60-79 % retained
-3	Moderate	40-59 % retained
-4	Severe	20-39 % retained
-5	Critically severe	0-19 % retained includes local extinction

7 The non-linearity was necessary because the scores had to be able to show that a critically-severe loss equated to local extinction whilst a critically severe gain equated to proliferation to pest proportions.

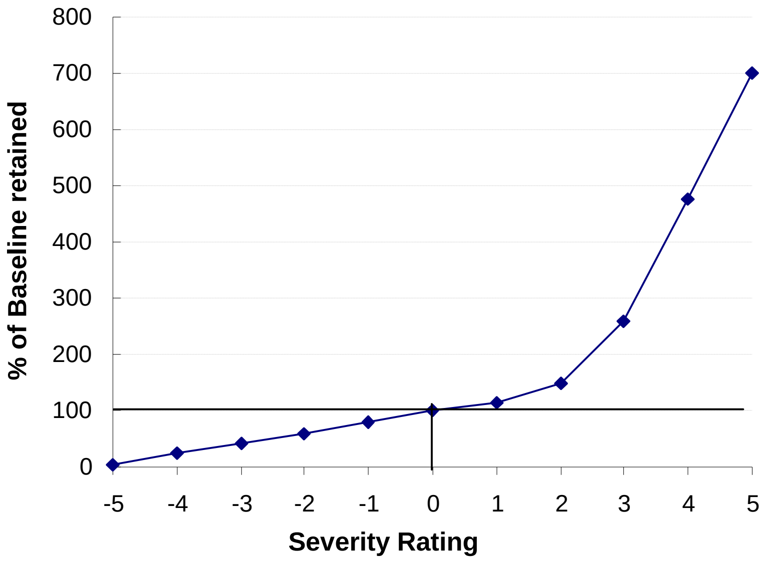


Figure 3.3 The relationship between severity ratings and percentage abundance lost or retained as used in DRIFT and adopted for the DSS. (Baseline is always = 100%)

For each year of the hydrological record, and for each ecosystem indicator, the severity rating corresponding to the value of a driving indicator is read off its Response Curve and converted to a percentage change. The severity ratings for each driving indicator are then combined to produce an overall change in abundance for each season, which provide an indication of how abundance, area or concentration of an indicator is expected to change under the given flow conditions over time, relative to the changes that would have been expected under baseline conditions.

3.2.4.2.2 Integrity ratings

Integrity ratings are on a scale from 0 to -5.

The integrity ratings are calculated by assigning a positive or negative sign to changes in abundance depending on whether an increase in abundance was a move towards natural or away. The integrity ratings for each indicator are then combined to provide a discipline level integrity score. Discipline level integrity scores are in turn combined to provide an overall site level integrity score, which are used to place a flow scenario within a classification of overall river condition, using the South African Eco-classification categories A to F (Table 2.2).

The ecological condition of a river is defined as its ability to support and maintain a balanced, integrated composition of physico-chemical and habitat characteristics, as well as biotic components on a temporal and spatial scale that are comparable to the natural characteristics of ecosystems of the region. As an example, if the baseline ecological status of a river was a B-category, and there is a predicted decrease in an indigenous fish species, this would cause the integrity score to be more negative, representing movement in the direction of categories C to F.

Overall integrity scores are calculated for the ecosystem as a whole, i.e., the combined effect of changes in the indicators at each site. The categories represent points along a continuum, thus the 'divisions' between the categories are only guides as to the general position at which the ecological condition might be expected to shift from one category to the next. Furthermore, the integrity categories provide an indication of the relative categories associated with each scenario and should not be misconstrued as an absolute prediction of future condition.

4 RELEASES INTO, AND ABSTRACTIONS FROM, THE HLOTSE RIVER

The LLWDP II provided the release and abstraction volumes proposed for the Hlotse Adit and Hlotse Abstraction Point (Table 4.1) from 2024 to 2045 (Gebreselassie 2021).

The releases and abstractions are steady and the volume of water released via the Hlotse Adit, less in-channel losses and EFlows, will be abstracted at the Hlotse Abstraction Point. The releases and abstractions will be limited to four dry months of the year, *viz.*: June, July, August and September, and are planned to take place as a continuous release/abstraction for the entire four-month period each year.

Table 4.1 Proposed volumes of water release from the Hlotse Adit and abstraction from the Hlotse Abstraction Point (Gebreselassie 2021)

Year	Month	Days in Month	Water Supply Demand m3/day	Water Supply Demand m3/s	Environmental Flow Requirements m3/s	Water losses in the river channel (QL) m3/s	Required Water Release m3/s	Required Water Release m3/day	Required Water Release Mm3/month	Required Water Release (QRR) Annual Mm3
2024	Jun-24	30	44431	0.514	0.395	0.160	1.070	92,426	2.773	11.276
	Jul-24	31		0.514	0.395	0.160	1.070	92,426	2.865	
	Aug-24	31		0.514	0.395	0.160	1.070	92,426	2.865	
	Sep-24	30		0.514	0.395	0.160	1.070	92,426	2.773	
2025	Jun-25	30	44998	0.521	0.396	0.162	1.079	93,228	2.797	11.374
	Jul-25	31		0.521	0.396	0.162	1.079	93,228	2.890	
	Aug-25	31		0.521	0.396	0.162	1.079	93,228	2.890	
	Sep-25	30		0.521	0.396	0.162	1.079	93,228	2.797	
2026	Jun-26	30	45591	0.528	0.408	0.165	1.101	95,094	2.853	11.601
	Jul-26	31		0.528	0.408	0.165	1.101	95,094	2.948	
	Aug-26	31		0.528	0.408	0.165	1.101	95,094	2.948	
	Sep-26	30		0.528	0.408	0.165	1.101	95,094	2.853	
2027	Jun-27	30	46191	0.535	0.420	0.168	1.123	97,002	2.910	11.834
	Jul-27	31		0.535	0.420	0.168	1.123	97,002	3.007	
	Aug-27	31		0.535	0.420	0.168	1.123	97,002	3.007	
	Sep-27	30		0.535	0.420	0.168	1.123	97,002	2.910	
2028	Jun-28	30	46799	0.542	0.432	0.172	1.145	98,955	2.969	12.072
	Jul-28	31		0.542	0.432	0.172	1.145	98,955	3.068	
	Aug-28	31		0.542	0.432	0.172	1.145	98,955	3.068	
	Sep-28	30		0.542	0.432	0.172	1.145	98,955	2.969	
2029	Jun-29	30	47416	0.549	0.444	0.175	1.168	100,953	3.029	12.316
	Jul-29	31		0.549	0.444	0.175	1.168	100,953	3.130	
	Aug-29	31		0.549	0.444	0.175	1.168	100,953	3.130	
	Sep-29	30		0.549	0.444	0.175	1.168	100,953	3.029	
2030	Jun-30	30	48039	0.556	0.457	0.179	1.192	102,995	3.090	12.565
	Jul-30	31		0.556	0.457	0.179	1.192	102,995	3.193	
	Aug-30	31		0.556	0.457	0.179	1.192	102,995	3.193	
	Sep-30	30		0.556	0.457	0.179	1.192	102,995	3.090	
2031	Jun-31	30	48733	0.564	0.470	0.182	1.217	105,115	3.153	12.824
	Jul-31	31		0.564	0.470	0.182	1.217	105,115	3.259	
	Aug-31	31		0.564	0.470	0.182	1.217	105,115	3.259	
	Sep-31	30		0.564	0.470	0.182	1.217	105,115	3.153	
2032	Jun-32	30	49436	0.572	0.483	0.186	1.242	107,284	3.219	13.089
	Jul-32	31		0.572	0.483	0.186	1.242	107,284	3.326	
	Aug-32	31		0.572	0.483	0.186	1.242	107,284	3.326	
	Sep-32	30		0.572	0.483	0.186	1.242	107,284	3.219	
2033	Jun-33	30	50150	0.580	0.497	0.190	1.267	109,503	3.285	13.359
	Jul-33	31		0.580	0.497	0.190	1.267	109,503	3.395	
	Aug-33	31		0.580	0.497	0.190	1.267	109,503	3.395	
	Sep-33	30		0.580	0.497	0.190	1.267	109,503	3.285	
2034	Jun-34	30	50875	0.589	0.511	0.194	1.294	111,773	3.353	13.636
	Jul-34	31		0.589	0.511	0.194	1.294	111,773	3.465	
	Aug-34	31		0.589	0.511	0.194	1.294	111,773	3.465	
	Sep-34	30		0.589	0.511	0.194	1.294	111,773	3.353	
2035	Jun-35	30	51610	0.597	0.525	0.198	1.321	114,094	3.423	13.919
	Jul-35	31		0.597	0.525	0.198	1.321	114,094	3.537	
	Aug-35	31		0.597	0.525	0.198	1.321	114,094	3.537	
	Sep-35	30		0.597	0.525	0.198	1.321	114,094	3.423	
2036	Jun-36	30	52430	0.607	0.525	0.200	1.331	115,020	3.451	14.032
	Jul-36	31		0.607	0.525	0.200	1.331	115,020	3.566	
	Aug-36	31		0.607	0.525	0.200	1.331	115,020	3.566	
	Sep-36	30		0.607	0.525	0.200	1.331	115,020	3.451	
2037	Jun-37	30	53264	0.616	0.524	0.201	1.342	115,962	3.479	14.147
	Jul-37	31		0.616	0.524	0.201	1.342	115,962	3.595	
	Aug-37	31		0.616	0.524	0.201	1.342	115,962	3.595	
	Sep-37	30		0.616	0.524	0.201	1.342	115,962	3.479	

2038	Jun-38	30	54110	0.626	0.524	0.203	1.353	116,919	3.508	14.264
	Jul-38	31		0.626	0.524	0.203	1.353	116,919	3.624	
	Aug-38	31		0.626	0.524	0.203	1.353	116,919	3.624	
	Sep-38	30		0.626	0.524	0.203	1.353	116,919	3.508	
2039	Jun-39	30	54970	0.636	0.524	0.205	1.364	117,891	3.537	14.383
	Jul-39	31		0.636	0.524	0.205	1.364	117,891	3.655	
	Aug-39	31		0.636	0.524	0.205	1.364	117,891	3.655	
	Sep-39	30		0.636	0.524	0.205	1.364	117,891	3.537	
2040	Jun-40	30	55843	0.646	0.523	0.206	1.376	118,880	3.566	14.503
	Jul-40	31		0.646	0.523	0.206	1.376	118,880	3.685	
	Aug-40	31		0.646	0.523	0.206	1.376	118,880	3.685	
	Sep-40	30		0.646	0.523	0.206	1.376	118,880	3.566	
2041	Jun-41	30	56815	0.658	0.537	0.211	1.405	121,418	3.643	14.813
	Jul-41	31		0.658	0.537	0.211	1.405	121,418	3.764	
	Aug-41	31		0.658	0.537	0.211	1.405	121,418	3.764	
	Sep-41	30		0.658	0.537	0.211	1.405	121,418	3.643	
2042	Jun-42	30	57803	0.669	0.551	0.215	1.435	124,013	3.720	15.130
	Jul-42	31		0.669	0.551	0.215	1.435	124,013	3.844	
	Aug-42	31		0.669	0.551	0.215	1.435	124,013	3.844	
	Sep-42	30		0.669	0.551	0.215	1.435	124,013	3.720	
2043	Jun-43	30	58809	0.681	0.565	0.220	1.466	126,664	3.800	15.453
	Jul-43	31		0.681	0.565	0.220	1.466	126,664	3.927	
	Aug-43	31		0.681	0.565	0.220	1.466	126,664	3.927	
	Sep-43	30		0.681	0.565	0.220	1.466	126,664	3.800	
2044	Jun-44	30	59831	0.692	0.580	0.225	1.497	129,375	3.881	15.784
	Jul-44	31		0.692	0.580	0.225	1.497	129,375	4.011	
	Aug-44	31		0.692	0.580	0.225	1.497	129,375	4.011	
	Sep-44	30		0.692	0.580	0.225	1.497	129,375	3.881	
2045	Jun-45	30	60871	0.705	0.596	0.229	1.529	132,145	3.964	16.122
	Jul-45	31		0.705	0.596	0.229	1.529	132,145	4.096	
	Aug-45	31		0.705	0.596	0.229	1.529	132,145	4.096	
	Sep-45	30		0.705	0.596	0.229	1.529	132,145	3.964	

The current release pipe at the Adit is 150 mm in diameter and capable of releasing a discharge of 0.364 m^3/s. There are plans to increase the diameter of the pipe to 800 mm and therefore the release discharge to a maximum of 3.284 m^3/s (Giji Tsegaye Gebreselassie, Pers. Comm. November 2021).

The projected discharge required at the Hlotse Abstraction Point by 2045 was calculated as 0.705 m^3/s and is to be met by a total release of 1.529 m^3/s; the sum of the water supply demand, an environmental flow release of 0.596 m^3/s and losses estimated as 15 % of the release (Table 4.1).

Thus, the range of discharges released via the Hlotse Adit considered in the scenarios evaluated in the EFlows assessment was 0.4, 1.5 (or 1.2) and 2.1 m^3/s[8], i.e.; from the current maximum discharge up to a value that exceeds the maximum release discharge required by 2045.

Recommendations to guide the development of future operating rules for the Hlotse Adit and Abstraction Point are provided in Section 11 from the results of the scenario assessment (Sections 6-10). These must be fine-tuned and developed further once the construction plans are finalized and the discussions between stakeholders about the proposed use of the system for domestic water supply finalized.

[8] In consultation with LLWDP II

5 SCENARIOS SELECTED FOR ASSESSMENT

The scenarios selected for assessment are a combination of different releases and abstractions from the Hlotse Adit and Hlotse Abstraction Point, plus a series of scenarios designed to understand the river's general responses to flow reduction. To model these, the past daily hydrology (1982-2020; 39 years) was used as a starting point, and then adjusted for the Hlotse Adit and Hlotse Abstraction Point releases and abstractions. The scenarios, apart from those for climate change, assume the climatic conditions from 1982-2020.

Each section presents the results for one of five sets of scenarios (Table 5.1), each designed to test a different aspect:

Set 0: Baseline

Set 1: Releases from the Hlotse Adit

i. Sc 0.4-0.4[9]
ii. Sc 1.5-1.5
iii. Sc 2.1-2.1

Set 2: Abstractions from the Hlotse Abstraction Point

i. Sc 0.0-0.4
ii. Sc 0.0-1.2
iii. Sc 0.0-2.1

Set 3: Additional dry season flows in Lower Hlotse River

i. Sc 0.4-0.0
ii. Sc 1.2-0.0
iii. Sc 2.1-0.0

Set 4: Climate change[10]

i. Base CC D 2050
ii. Sc 1.5 CC M 2035
iii. Sc 1.5 CC M 2050
iv. Sc 1.5 CC D 2035
v. Sc 1.5 CC D 2050

Set 5: Overall reduction in flows in Hlotse River

- See Section 5.2.

Some of the scenarios analysed are not realistic. For instance, it is unlikely that the exact amount of water released at the Hlotse Adit will be abstracted at the Hlotse Abstraction Point or lost in the system between the Adit and Abstraction Point (Table 5.1); there is bound to be a slight excess or deficit that results from operations. Nonetheless, analysis of such scenarios are

[9] For Scenario Sets 1-3: S0.4-0.4 means; Scenario release discharge 0.4 m^3/s, abstraction 0.4 m^3/s

[10] For Scenario Set 4: Sc 1.5 CC M 2035; Scenario release discharge 1.5 m3/s, climate change median by year 2035; D = dry; Base = baseline with no release

valuable in understanding the impact of different kinds of flow changes on the aquatic ecosystems, and are useful in setting EFlows for the system.

The number of scenarios to be analysed was limited to 10 in the Inception Report, including baseline. In the end, however, 14 scenarios of various Hlotse Adit/Hloste Abstraction Point permutations were run. These all focused on the implication of the planned releases and abstractions. In addition, to complete the EFlows assessment, which should also consider other aspects of the flow regime, an additional five scenarios were analysed (Set 5).

Set 1 focuses on EFlows1, 2 and 3, as in these scenarios the water released via the Hlotse Adit is either abstracted at the Hlotse Abstraction Point or lost to evapo(transpi)ration and or seepage enroute, i.e., hydrological flows at EFlows4 and 5 are ~baseline.

Table 5.1 Scenarios assessed

Set #	Scenario #	Release from Adit (m^3/s)	Abstraction from abstraction point (m^3/s)	Climate change
		EFlows1, 2, 3 (Jun-Sep)	EFlows4 and 5 (Jun-Sep)	
Set 0	1	0.0	0.0	Baseline
Set 1	1.i	0.4	0.4	Baseline
	1.ii	1.5	1.5	Baseline
	1.iii	2.1	2.1	Baseline
Set 2	2.i	0.0	0.4	Baseline
	2.ii	0.0	1.2	Baseline
	2.iii	0.0	2.1	Baseline
Set 3	3.i	0.4	0.0	Baseline
	3.ii	1.2	0.0	Baseline
	3.iii	2.1	0.0	Baseline
Set 4	4.i	0.0	0.0	Baseline
	4.ii	1.5	1.5	M 2035
	4.iii	1.5	1.5	M 2050
	4.iiii	1.5	1.5	D 2035
	4.iiii	1.5	1.5	D 2050
Set 5	See Section 5.2.			Baseline

Set 2 focuses on abstractions from EFlows4 and 5, as the water released via the Hlotse Adit is kept constant for all of the scenarios in the set.

Set 3 also focuses on the EFlows4 and 5 as the volumes released via the Hlotse Adit are the same as some of the scenarios in Set 1. However, Set 3 explores what would happen to the river as represented by EFlows4 and 5 if that water was not abstracted at the Hlotse Abstraction Point.

Set 4 considers five climate change scenarios. The first is the dry (D) future climate for 2050 superimposed on baseline (Base CC D 2050). The remaining four are (2 and 3) median (M) future climates for each of 2035 and 2050 superimposed on Scenario 1.ii[11], and (4 and 5) dry (D) climate futures for each of 2035 and 2050 superimposed on Scenario 1.ii.

Set 5 considers a range of reductions in flows in the Hlotse River that may be unrelated to the Hlotse Adit and/or the Hlotse Abstraction Point. These scenarios are used to set EFlows to facilitate maintenance of the river reaches represented by the EFlows sites in one of three future ecological conditions, *viz*.: baseline condition and then usually two Alternative Ecological Categories (AECs); half a category higher than baseline condition and half a category lower than baseline condition. The rules used to generate the scenarios for Set 5 are explained in 5.2.

For each of the sets, the overall ecosystem conditions are presented using maps (Section 5.4.1.1), ecological (Section 5.4.1.2) and social icons (Section 5.4.1.2), and, where relevant, results for individual indicators to illustrate more detailed discussion points.

5.1 Assumptions underpinning the scenarios

All scenarios assume that the following guidelines for starting (Section 5.1.1) and stopping the releases (Section 5.1.2) from the Hlotse Adit are strictly adhered to.

5.1.1 Guidelines for releases

Rapid changes in discharge (increases or decreases) are dangerous for the downstream river, and can lead to erosion and to either washing away or stranding of people and animals. The generally accepted wisdom is that releases should be implemented gradually in a manner that limits water level changes in the downstream river (EFlows1) to no more than 0.05 m/hour (MRC 2020). These levels are unlikely to strand fish or promote large scale bank failure.

5.1.2 Guidelines for abstraction

From the time that water is first released into the Hlotse River at the Hloste Adit, it takes several days to reach the Hlotse Abstraction Point. Higher discharges will arrive more quickly than lower discharges. For this reason, abstractions at the Hlotse Abstraction Point should not commence until the discharge readings at the nearest gauge (at this stage this is Gauge CG25) indicate that the water from the Adit has arrived. The same applies when the releases stop, i.e., abstractions at the Hlotse Abstraction Point should stop once the discharge readings at Gauge TS3 indicate the flows have dropped back down to pre-release levels.

Once there is a coordinated test release against which the hydrodynamic model (Multiconsult 2022c) can be calibrated, it will be possible to produce a table of water travel times down the Hlotse River between the Hlotse Adit and Hlotse Abstraction Point at different release discharges. These data can then be incorporated into future operating rules for the Hlotse Adit

[11] Scenario 1.ii (Table 5.1) approximates the expected release of 1.529 m^3/s proposed by LLWP for 2045 (Section 4).

and Abstraction Point, along with the use of the fully operational gauges (CG25 and TS3) to monitor discharge. However, given that no test release was possible during the EFlows study, the hydrodynamic model is currently calibrated against a 2018 test release, which was not ideal as the 2018 test release coincided with a natural flood in the system.

5.2 Generation of hydrological scenarios for Set 5

The Set 5 scenarios represent a range of hypothetical flow regimes with reduced baseflow in the wet and dry seasons and fewer within year (intra-annual) flood events. These scenarios are designed to assist in assessing EFlows regimes that could maintain the river ecosystem in a range of possible future conditions. The names used for these scenarios are headed with SS to denote ‘Synthetic Scenario’. Baseline temperatures were used for all of the Set 5 scenarios.

The synthetic scenarios were constructed in two steps:

1. Flows less than the 1:2 year floods were restricted to be less than five different percentiles:
    a. 50th (SS4)
    b. 70th (SS3)
    c. 90th (SS2)
    d. 95th (SS1)
    e. 99th (SS1a)

    Class 5 to 8 floods (floods with a return period of 1:2, 1:5, 1:10 and 1:20 years, respectively) were retained for all scenarios.

2. Within year floods were added back to the flows obtained from step 1. The number of floods in each flood class was obtained from the Baseline (Table 5.2) and reduced from Baseline levels to zero, providing four increments. The two scenarios with the lowest flows from step 1 (SS1 with 95th percentile, and SS1a with 99th percentile) had the fewest floods added – four increments fewer than Baseline. The highest flows from step 1 (SS4 with 50th percentile) had the most floods added (one increment fewer than Baseline). Figure 5.2 shows the Baseline flows and those for SS2 before and after adding the floods back.

    In any one year, floods were only added if floods of a suitable magnitude, or larger, occurred in the baseline hydrological record for that year. If the flood that occurred in the baseline was larger than the magnitude of the flood required, the magnitude was capped.

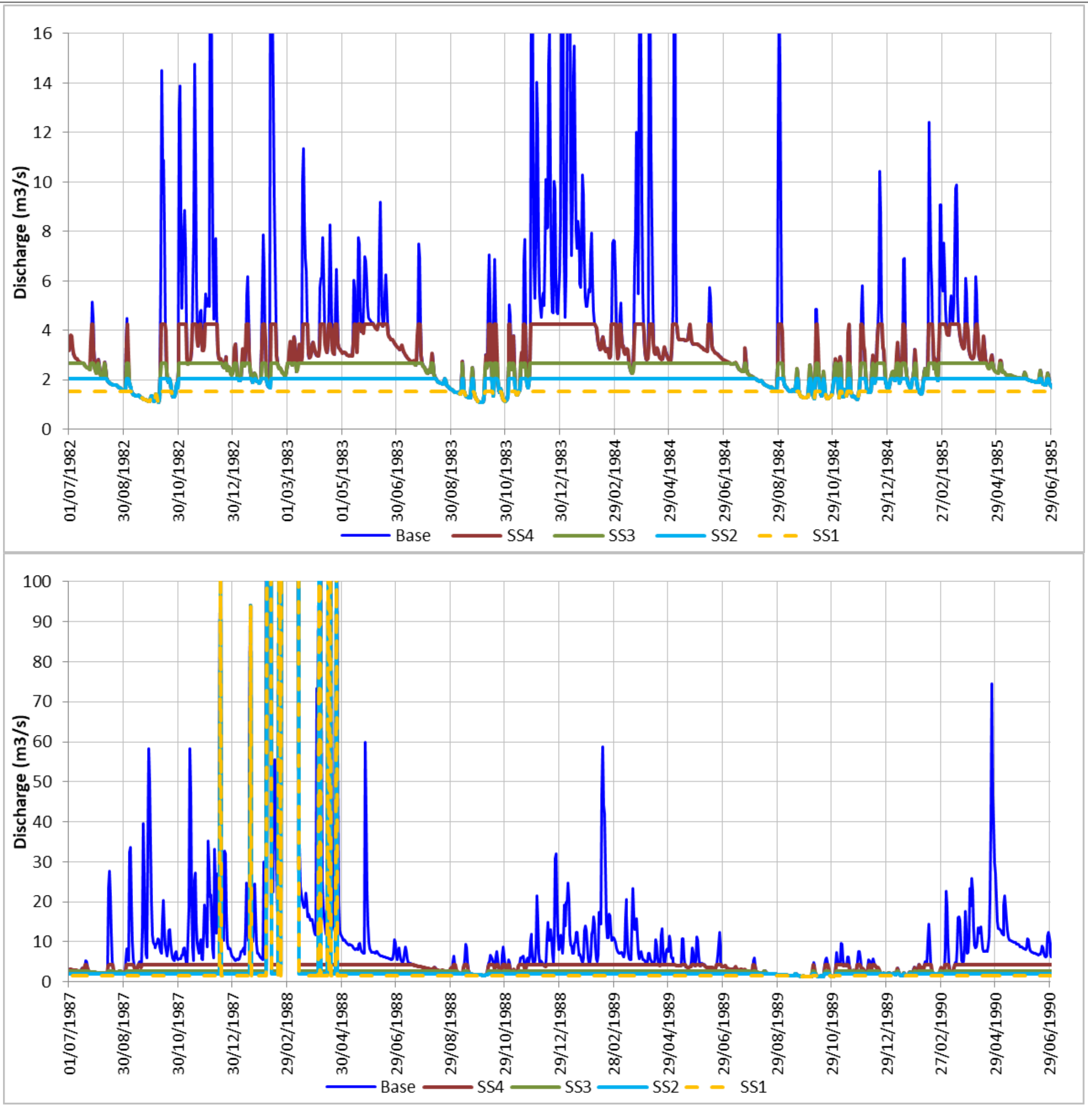


Figure 5.1 Baseline whole flow and the baseflows for four synthetic scenarios showing three years where (top) flow was always less than the 1:2 year flood and (bottom) one year has events with flow greater than the 1:2 year flood

Table 5.2 Flood allocations for Class 1 to 8 floods for the Set 5 scenarios

Class	Base	SS4	SS3	SS2	SS1	SS1a	SSMin
1	589	472	355	238	121	121	0
2	301	241	181	121	61	61	0
3	155	124	93	62	31	31	0
4	80	64	48	32	16	16	0
5	28	23	18	13	8	8	0
6	5	4	3	2	1	1	0
7	6	5	4	3	2	2	0
8	1	1	1	1	1	1	0
	1165	934	703	472	241	241	0

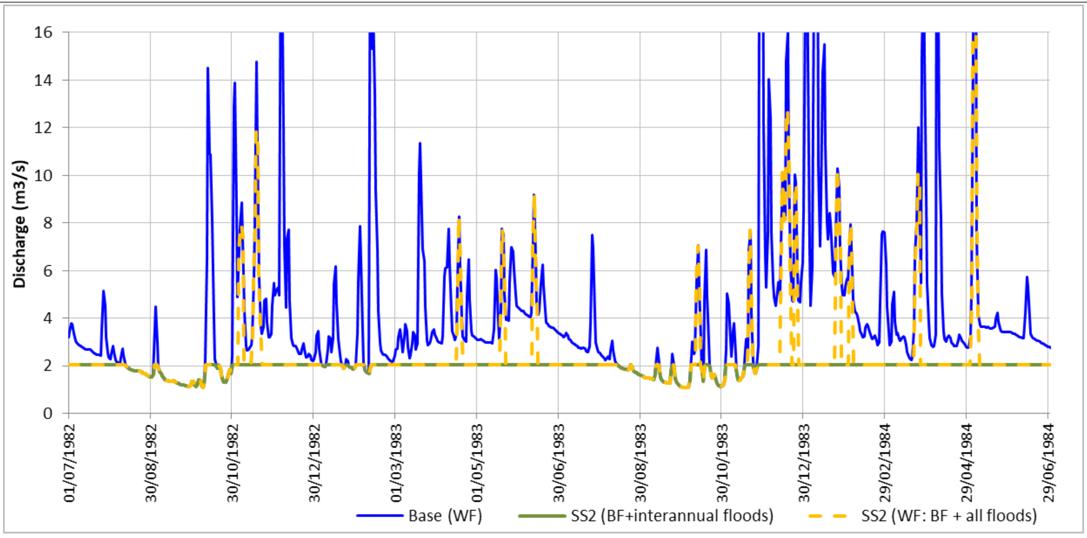


Figure 5.2 Baseline whole flow and the "wholeflow" for SS2 comprising flows less than the 1:2 year flood restricted to the 90th percentile and floods of all classes added back at the third increment fewer in number than Baseline

In other words, the synthetic scenarios comprised:

SS4: Baseflows which are <1:2 year flood restricted to be <= 50th percentile of Base2021; Floods = one increment fewer than Base2021

SS3: Baseflows which are <1:2 year flood restricted to be <= 70th percentile of Base2021; Floods = two increments fewer than Base2021

SS2: Baseflows which are <1:2 year flood restricted to be <= 90th percentile of Base2021; Floods = three increments fewer than Base2021

SS1: Baseflows which are <1:2 year flood restricted to be <=95th percentile of Base2021; Floods = four increments fewer than Base2021

SS1a: Baseflows which are <1:2 year flood restricted to be <=99th percentile of Base2021; Floods = SS1.

The total frequency of all within year floods (i.e., the sum) in the Set 5 flow regimes may be slightly more or slightly less than the "target" frequency. The effect of applying the criterion (sufficient magnitude occurring in baseline flow regime) and of capping floods tended to reduce the number of the larger floods and increase the frequency of the smaller floods. Differences may also arise due to differences in "clicking" off the floods in the DRIFT DSS.

The results for the Set 5 scenarios are provided in Section 10.

5.3 DRIFT hydrology indicators for Set 1, 2, 3 and 4 scenarios

5.3.1 Set 1

The median values for the ecologically-relevant flow indicators for the flow regime of Set 1 scenarios at EFlows1, 2 and 3 are provided in Table 5.3. These show the changes in different indicators when 0.4, 1.5 or 2.1 m^3/s are added during the dry season months of June, July, August and September. This means the river flow regime is the same as baseline in the other three seasons; there are also no changes to the onset and duration of the seasons.

The flow indicators that best describe the differences between baseline and the Set 1 scenarios are: Mean Annual Runoff (MAR); minimum 5-day discharge; average dry season discharge and maximum dry season discharge (Table 5.3). In addition, the higher dry season flows mean that, relative to baseline, there are more Class 1 floods with the 0.4 m^3/s release, and more Class 2 floods when 1.5 m^3/s and 2.1 m^3/s are released (Table 5.3).

Table 5.3 Median annual values over the 39-year record for ecologically-relevant flow indicators for the flow regime of Set 1 scenarios at EFlows1, 2 and 3. Flood frequencies are annual averages rather than medians

Flow indicator	Baseline	Sc 0.4 - 0.4	Sc 1.5 - 1.5	Sc 2.1 - 2.1
EFlows1				
Mean annual runoff	0.7	0.8	1.2	1.4
Dry onset	22.0	22.0	22.0	22.0
Dry duration	122.0	122.0	122.0	122.0
Dry Min 5d Q	0.1	0.5	0.8	0.9
Dry Q AVE	0.2	0.6	1.7	2.3
Dry Q MAX	0.8	1.2	2.3	2.9
Wet onset	48.0	48.0	48.0	48.0
Wet duration	151.0	151.0	151.0	151.0
Wet Max 5d Q	5.2	5.2	5.2	5.2
Wet season volume	15.3	15.3	15.3	15.3
Dry ave daily vol	0.0	0.1	0.1	0.2
T1 ave daily vol	0.0	0.0	0.0	0.0
Wet ave daily vol	0.1	0.1	0.1	0.1
T2 ave daily vol	0.0	0.0	0.0	0.0
T1 duration	61.0	61.0	61.0	61.0
T2 duration	31.0	31.0	31.0	31.0
Dry Class1	6.0	8.0	0.0	0.0
Dry Class2	0.0	0.0	8.0	8.0
Dry Class3	0.0	0.0	0.0	0.0
Dry Class4	0.0	0.0	0.0	0.0
T1 Class1	3.5	3.5	3.5	3.5
T1 Class2	0.5	0.5	0.5	0.5
T1 Class3	0.0	0.0	0.0	0.0
T1 Class4	0.0	0.0	0.0	0.0
Wet Class1	8.5	8.5	8.5	8.5
Wet Class2	6.0	6.0	6.0	6.0
Wet Class3	3.0	3.0	3.0	3.0
Wet Class4	1.0	1.0	1.0	1.0
T2 Class1	2.0	2.0	2.0	2.0
T2 Class2	0.0	0.0	0.0	0.0
T2 Class3	0.0	0.0	0.0	0.0
T2 Class4	0.0	0.0	0.0	0.0
EFlows2				
Mean annual runoff	2.3	2.4	2.8	3.0
Dry onset	22.0	22.0	22.0	22.0
Dry duration	122.0	122.0	122.0	122.0
Dry Min 5d Q	0.4	0.8	1.7	1.8

Flow indicator	Baseline	Sc 0.4 - 0.4	Sc 1.5 - 1.5	Sc 2.1 - 2.1
Dry Q AVE	0.9	1.3	2.4	3.0
Dry Q MAX	2.9	3.3	4.4	5.0
Wet onset	48.0	48.0	48.0	48.0
Wet duration	151.0	151.0	151.0	151.0
Wet Max 5d Q	14.1	14.1	14.1	14.1
Wet season volume	46.1	46.1	46.1	46.1
Dry ave daily vol	0.1	0.1	0.2	0.3
T1 ave daily vol	0.1	0.1	0.1	0.1
Wet ave daily vol	0.3	0.3	0.3	0.3
T2 ave daily vol	0.2	0.2	0.2	0.2
T1 duration	61.0	61.0	61.0	61.0
T2 duration	31.0	31.0	31.0	31.0
Dry Class1	5.0	8.0	7.0	6.5
Dry Class2	0.0	0.0	1.0	3.0
Dry Class3	0.0	0.0	0.0	0.0
Dry Class4	0.0	0.0	0.0	0.0
T1 Class1	2.0	2.5	2.5	2.5
T1 Class2	1.0	1.0	1.0	1.0
T1 Class3	0.0	0.0	0.0	0.0
T1 Class4	0.0	0.0	0.0	0.0
Wet Class1	7.0	7.0	7.0	7.0
Wet Class2	7.0	7.0	7.0	7.0
Wet Class3	2.5	2.5	2.5	2.5
Wet Class4	1.0	1.0	1.0	1.0
T2 Class1	2.0	2.0	2.0	2.0
T2 Class2	0.0	0.0	0.0	0.0
T2 Class3	0.0	0.0	0.0	0.0
T2 Class4	0.0	0.0	0.0	0.0
EFlows3				
Mean annual runoff	3.0	3.1	3.5	3.7
Dry onset	22.0	22.0	22.0	22.0
Dry duration	122.0	122.0	122.0	122.0
Dry Min 5d Q	0.5	0.9	2.0	2.3
Dry Q AVE	1.2	1.6	2.7	3.3
Dry Q MAX	3.6	4.0	5.1	5.7
Wet onset	48.0	48.0	48.0	48.0
Wet duration	151.0	151.0	151.0	151.0
Wet Max 5d Q	21.6	21.6	21.6	21.6
Wet season volume	61.9	61.9	61.9	61.9
Dry ave daily vol	0.1	0.1	0.2	0.3
T1 ave daily vol	0.2	0.2	0.2	0.2
Wet ave daily vol	0.4	0.4	0.4	0.4
T2 ave daily vol	0.2	0.2	0.2	0.2
T1 duration	61.0	61.0	61.0	61.0
T2 duration	31.0	31.0	31.0	31.0
Dry Class1	3.0	6.5	6.0	7.0
Dry Class2	0.0	0.0	0.0	1.0
Dry Class3	0.0	0.0	0.0	0.0
Dry Class4	0.0	0.0	0.0	0.0
T1 Class1	2.5	2.5	3.0	3.0
T1 Class2	1.0	1.0	1.0	1.0
T1 Class3	0.0	0.0	0.0	0.0
T1 Class4	0.0	0.0	0.0	0.0
Wet Class1	7.0	8.0	7.5	7.5
Wet Class2	5.5	5.5	5.5	5.5

Flow indicator	Baseline	Sc 0.4 - 0.4	Sc 1.5 - 1.5	Sc 2.1 - 2.1
Wet Class3	2.5	2.5	2.5	2.5
Wet Class4	1.0	1.0	1.0	1.0
T2 Class1	1.0	1.5	1.5	1.5
T2 Class2	0.0	0.0	0.0	0.0
T2 Class3	0.0	0.0	0.0	0.0
T2 Class4	0.0	0.0	0.0	0.0

5.3.2 Set 2 and 3

The median values for the ecologically-relevant flow indicators for the Set 2 and 3 scenarios at EFlows4 and 5 are provided in Table 5.4. These show the changes in the indicators when 0.4, 1.2 or 2.1 m^3/s are abstracted without any released from the Hloste Adit and when 0.4, 1.2 or 2.1 m^3/s is added to EFlows 4 and 5 in June, July, August and September, i.e., if not all of the water released from the Hlotse Adit is abstracted at the Hlotse Abstraction Point. The river flow regime is the same as baseline in the other three seasons; there are also no changes to the onset and duration of the seasons.

The flow indicators that best describe the differences between baseline and the Set 2 scenarios are (Table 5.4): Mean Annual Runoff (MAR); minimum 5-day discharge; average dry season discharge and maximum dry season discharge. There are also fewer Class 1 floods in the dry season relative to baseline.

The flow indicators that best describe the differences between baseline and the Set 3 scenarios are (Table 5.4): Mean Annual Runoff (MAR); minimum 5-day discharge; average dry season discharge, maximum dry season discharge and number of Class 1 floods in the dry season.

Table 5.4 Median values over the 39-year record for ecologically-relevant flow indicators for the flow regime of Set 2 and 3 scenarios at EFlows4 and 5

		Set 2			Set 3		
	Baseline	Sc 0.0 - 0.4	Sc 0.0 - 1.2	Sc 0.0 - 2.1	Sc 0.4 - 0.0	Sc 1.2 - 1.2	Sc 2.1 - 0.0
EFlows4							
Mean annual runoff	7.1	7.0	6.7	6.4	7.3	7.5	7.8
Dry onset	22	22	22	22	22	22	22
Dry duration	122	122	122	122	122	122	122
Dry Min 5d Q	1.4	1.0	0.2	0.0	1.8	2.6	3.5
Dry Q AVE	3.2	2.8	2.0	1.2	3.6	4.4	5.3
Dry Q MAX	9.2	8.8	8.0	7.1	9.6	10.4	11.3
Wet onset	48	48	48	48	48	48	48
Wet duration	151	151	151	151	151	151	151
Wet Max 5d Q	53.9	53.9	53.9	53.9	53.9	53.9	53.9
Wet season volume	139.8	139.8	139.8	139.8	139.8	139.8	139.8
Dry ave daily vol	0.3	0.2	0.2	0.1	0.3	0.4	0.5
T1 ave daily vol	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Wet ave daily vol	0.9	0.9	0.9	0.9	0.9	0.9	0.9
T2 ave daily vol	0.5	0.5	0.5	0.5	0.5	0.5	0.5
T1 duration	61	61	61	61	61	61	61
T2 duration	31	31	31	31	31	31	31

		Set 2			Set 3		
	Baseline	Sc 0.0 - 0.4	Sc 0.0 - 1.2	Sc 0.0 - 2.1	Sc 0.4 - 0.0	Sc 1.2 - 1.2	Sc 2.1 - 0.0
Dry Class1	4	3	3	2	5	6	8
Dry Class2	0	0	0	0	0	0	0
Dry Class3	0	0	0	0	0	0	0
Dry Class4	0	0	0	0	0	0	0
T1 Class1	2	2	2	2	2	2	2
T1 Class2	0.5	0.5	0.5	0.5	0.5	0.5	0.5
T1 Class3	0	0	0	0	0	0	0
T1 Class4	0	0	0	0	0	0	0
Wet Class1	7	7	7	7	7	7	7
Wet Class2	5.5	5.5	5.5	5.5	5.5	5.5	5.5
Wet Class3	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Wet Class4	1.5	1.5	1.5	1.5	1.5	1.5	1.5
T2 Class1	1.5	1.5	1.5	1.5	1.5	1.5	1.5
T2 Class2	0	0	0	0	0	0	0
T2 Class3	0	0	0	0	0	0	0
T2 Class4	0	0	0	0	0	0	0
EFlows5							
Mean annual runoff	7.5	7.3	7.1	6.8	7.6	7.9	8.2
Dry onset	22	22	22	22	22	22	22
Dry duration	122	122	122	122	122	122	122
Dry Min 5d Q	1.5	1.1	0.3	0.0	1.9	2.7	3.6
Dry Q AVE	3.3	2.9	2.1	1.3	3.7	4.5	5.4
Dry Q MAX	10.0	9.6	8.8	7.9	10.4	11.2	12.1
Wet onset	48	48	48	48	48	48	48
Wet duration	151	151	151	151	151	151	151
Wet Max 5d Q	55.5	55.5	55.5	55.5	55.5	55.5	55.5
Wet season volume	147.3	147.3	147.3	147.3	147.3	147.3	147.3
Dry ave daily vol	0.3	0.3	0.2	0.1	0.3	0.4	0.5
T1 ave daily vol	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Wet ave daily vol	1.0	1.0	1.0	1.0	1.0	1.0	1.0
T2 ave daily vol	0.5	0.5	0.5	0.5	0.5	0.5	0.5
T1 duration	61	61	61	61	61	61	61
T2 duration	31	31	31	31	31	31	31
Dry Class1	4	4	3	2	4.5	6	7.5
Dry Class2	0	0	0	0	0	0	1
Dry Class3	0	0	0	0	0	0	0
Dry Class4	0	0	0	0	0	0	0
T1 Class1	3	3	3	3	3	3	3
T1 Class2	1	1	1	1	1	1	1
T1 Class3	0	0	0	0	0	0	0
T1 Class4	0	0	0	0	0	0	0
Wet Class1	6.5	6.5	6.5	6.5	6.5	6.5	6.5
Wet Class2	5	5	5	5	5	5	5
Wet Class3	3	3	3	3	3	3	3
Wet Class4	1	1	1	1	1	1	1
T2 Class1	1.5	1.5	1.5	1.5	1	1	1
T2 Class2	0	0	0	0	0	0	0
T2 Class3	0	0	0	0	0	0	0
T2 Class4	0	0	0	0	0	0	0

5.3.3 Set 4

The median values for the ecologically-relevant flow indicators for the Set 4 climate change scenarios each of the EFlows Sites are provided in Table 5.5. These provide the hydrological indicators for the baseline with Base CC D 2050 (the dry climate change scenario at year 2050) and for the other median and dry future climates projected to 2035 and 2050 with a 1.5 m^3/s release from the Hlotse Adit and 1.5 m^3/s abstracted at the Hlotse Abstraction Point in June, July, August and September.

All the flow indicators show differences between baseline and the climate change scenarios (Table 5.5). In general, for Base CC D 2050, the discharges are lower and floods are fewer than baseline at all the EFlows Sites. Of the four scenarios with climate change and 1.5 releases/abstractions, three, Sc 1.5 CC M 2050, Sc 1.5 CC D 2035 and Sc 1.5 CC D 2050 are similar, although Sc 1.5 CC D 2050 is drier. For these three, Dry Min 5d Q is roughly half that of Sc 1.5-1.5 and the inter-annual floods are fewer. Sc 1.5 CC M 2035 is wetter than the other climate change scenarios and is roughly comparable to Sc 1.5-1.5; it has a slightly higher wet season discharge, and a similar magnitude and frequency of intra- and inter-annual flood events.

Table 5.5 Median values over the 39-year record for ecologically-relevant flow indicators for the flow regime of Set 4 scenarios at EFlows4 and 5

	Baseline	Base CC D 2050	Sc 1.5 CC M 2035	Sc 1.5 CC M 2050	Sc 1.5 CC D 2035	Sc 1.5 CC D 2050
EFSite1						
Mean annual runoff	0.70	0.57	1.17	1.11	1.11	1.07
Dry onset	22.00	22.00	22.00	22.00	22.00	22.00
Dry duration	122.00	122.00	122.00	122.00	122.00	122.00
Dry Min 5d Q	0.10	0.07	0.37	0.32	0.34	0.31
Dry Q AVE	0.20	0.18	1.71	1.69	1.68	1.66
Dry Q MAX	0.80	0.45	2.27	2.12	2.04	1.95
Wet onset	48.00	48.00	48.00	48.00	48.00	48.00
Wet duration	151.00	151.00	151.00	151.00	151.00	151.00
Wet Max 5d Q	5.20	4.16	5.03	4.51	4.58	4.16
Wet season volume	15.30	11.60	14.49	12.98	12.93	11.60
Dry ave daily vol	0.00	0.02	0.15	0.14	0.14	0.14
T1 ave daily vol	0.00	0.02	0.04	0.04	0.03	0.02
Wet ave daily vol	0.10	0.08	0.10	0.09	0.09	0.08
T2 ave daily vol	0.00	0.04	0.04	0.04	0.04	0.04
T1 duration	61.00	61.00	61.00	61.00	61.00	61.00
T2 duration	31.00	31.00	31.00	31.00	31.00	31.00
Dry Class1	6.00	4.11	0.05	0.11	0.11	0.42
Dry Class2	0.00	0.05	7.87	7.92	7.89	7.66
Dry Class3	0.00	0.00	0.16	0.11	0.11	0.05
Dry Class4	0.00	0.00	0.03	0.00	0.00	0.00
T1 Class1	3.50	3.61	3.58	4.21	3.34	3.97
T1 Class2	0.50	0.74	1.08	0.92	0.89	0.74
T1 Class3	0.00	0.34	0.55	0.50	0.39	0.34
T1 Class4	0.00	0.11	0.11	0.08	0.08	0.11
Wet Class1	8.50	11.53	9.89	11.18	10.42	11.84
Wet Class2	6.00	4.87	5.71	5.32	5.39	4.87
Wet Class3	3.00	2.08	3.00	2.53	2.50	2.08
Wet Class4	1.00	1.08	1.16	1.11	1.05	1.08
T2 Class1	2.00	2.11	2.08	2.18	2.05	2.16
T2 Class2	0.00	0.13	0.18	0.16	0.16	0.13
T2 Class3	0.00	0.03	0.03	0.03	0.03	0.03
T2 Class4	0.00	0.00	0.00	0.00	0.00	0.00

	Baseline	Base CC D 2050	Sc 1.5 CC M 2035	Sc 1.5 CC M 2050	Sc 1.5 CC D 2035	Sc 1.5 CC D 2050
1:2 Class5	0.53	0.39	0.45	0.47	0.47	0.39
1:5 Class6	0.13	0.08	0.13	0.08	0.11	0.08
1:10 Class7	0.05	0.03	0.08	0.05	0.03	0.03
1:20 Class8	0.05	0.03	0.05	0.03	0.03	0.03
EFSite2						
Mean annual runoff	2.30	1.69	2.68	2.46	2.34	2.19
Dry onset	22.00	22.00	22.00	22.00	22.00	22.00
Dry duration	122.00	122.00	122.00	122.00	122.00	122.00
Dry Min 5d Q	0.40	0.35	1.30	1.17	1.19	1.11
Dry Q AVE	0.90	0.69	2.36	2.28	2.25	2.18
Dry Q MAX	2.90	1.59	4.23	3.80	3.64	3.11
Wet onset	48.00	48.00	48.00	48.00	48.00	48.00
Wet duration	151.00	151.00	151.00	151.00	151.00	151.00
Wet Max 5d Q	14.10	9.76	13.46	11.65	11.18	9.76
Wet season volume	46.10	33.23	43.78	39.28	37.68	33.23
Dry ave daily vol	0.10	0.06	0.20	0.20	0.19	0.19
T1 ave daily vol	0.10	0.07	0.11	0.10	0.09	0.08
Wet ave daily vol	0.30	0.22	0.29	0.26	0.25	0.22
T2 ave daily vol	0.20	0.12	0.15	0.13	0.13	0.12
T1 duration	61.00	61.00	61.00	61.00	61.00	61.00
T2 duration	31.00	31.00	31.00	31.00	31.00	31.00
Dry Class1	5.00	3.53	7.34	7.71	7.74	8.03
Dry Class2	0.00	0.08	0.95	0.79	0.71	0.37
Dry Class3	0.00	0.05	0.18	0.05	0.03	0.05
Dry Class4	0.00	0.00	0.03	0.03	0.03	0.00
T1 Class1	2.00	3.05	3.34	3.61	3.05	3.16
T1 Class2	1.00	1.00	1.21	1.08	1.05	1.00
T1 Class3	0.00	0.45	0.66	0.55	0.53	0.45
T1 Class4	0.00	0.11	0.11	0.16	0.11	0.11
Wet Class1	7.00	9.55	8.05	9.03	8.87	9.63
Wet Class2	7.00	5.32	6.26	5.97	5.97	5.34
Wet Class3	2.50	2.66	3.34	2.95	2.71	2.66
Wet Class4	1.00	1.21	1.74	1.39	1.45	1.21
T2 Class1	2.00	1.97	1.84	1.84	1.87	1.97
T2 Class2	0.00	0.16	0.50	0.34	0.34	0.16
T2 Class3	0.00	0.08	0.11	0.11	0.11	0.08
T2 Class4	0.00	0.00	0.00	0.00	0.00	0.00
1:2 Class5	0.71	0.34	0.58	0.45	0.45	0.34
1:5 Class6	0.16	0.16	0.21	0.18	0.18	0.16
1:10 Class7	0.11	0.05	0.11	0.08	0.05	0.05
1:20 Class8	0.03	0.03	0.03	0.03	0.03	0.03
EFSite3						
Mean annual runoff	3.0	2.2	3.4	3.1	2.9	2.7
Dry onset	22.0	22.0	22.0	22.0	22.0	22.0
Dry duration	122.0	122.0	122.0	122.0	122.0	122.0
Dry Min 5d Q	0.5	0.5	1.8	1.6	1.7	1.6
Dry Q AVE	1.2	1.0	2.7	2.6	2.5	2.5
Dry Q MAX	3.6	2.0	5.0	4.6	4.1	3.5
Wet onset	48.0	48.0	48.0	48.0	48.0	48.0
Wet duration	151.0	151.0	151.0	151.0	151.0	151.0
Wet Max 5d Q	21.6	15.1	20.4	18.0	15.9	15.1
Wet season volume	61.9	45.1	61.0	55.7	52.0	45.1
Dry ave daily vol	0.1	0.1	0.2	0.2	0.2	0.2
T1 ave daily vol	0.2	0.1	0.1	0.1	0.1	0.1
Wet ave daily vol	0.4	0.3	0.4	0.4	0.3	0.3
T2 ave daily vol	0.2	0.2	0.2	0.2	0.2	0.2

	Baseline	Base CC D 2050	Sc 1.5 CC M 2035	Sc 1.5 CC M 2050	Sc 1.5 CC D 2035	Sc 1.5 CC D 2050
T1 duration	61.0	61.0	61.0	61.0	61.0	61.0
T2 duration	31.0	31.0	31.0	31.0	31.0	31.0
Dry Class1	3.0	2.4	6.5	6.8	6.8	7.1
Dry Class2	0.0	0.2	0.7	0.6	0.4	0.2
Dry Class3	0.0	0.1	0.3	0.3	0.2	0.1
Dry Class4	0.0	0.0	0.0	0.0	0.0	0.0
T1 Class1	2.5	3.0	3.1	3.1	3.1	3.1
T1 Class2	1.0	0.9	1.2	1.2	1.0	0.9
T1 Class3	0.0	0.4	0.4	0.4	0.4	0.4
T1 Class4	0.0	0.1	0.3	0.2	0.2	0.1
Wet Class1	7.0	9.3	7.7	8.6	8.9	9.7
Wet Class2	5.5	4.6	5.7	5.1	5.0	4.6
Wet Class3	2.5	2.5	3.4	3.0	2.8	2.5
Wet Class4	1.0	0.8	1.3	1.0	1.0	0.8
T2 Class1	1.0	1.9	1.7	1.8	1.9	2.0
T2 Class2	0.0	0.2	0.5	0.3	0.3	0.2
T2 Class3	0.0	0.1	0.1	0.1	0.1	0.1
T2 Class4	0.0	0.0	0.0	0.0	0.0	0.0
1:2 Class5	0.7	0.6	0.7	0.6	0.6	0.6
1:5 Class6	0.2	0.1	0.2	0.2	0.1	0.1
1:10 Class7	0.1	0.1	0.2	0.2	0.1	0.1
1:20 Class8	0.0	0.0	0.1	0.0	0.0	0.0
EFSite4						
Mean annual runoff	7.13	5.35	6.83	6.26	5.86	5.35
Dry onset	22.00	22.00	22.00	22.00	22.00	22.00
Dry duration	122.00	122.00	122.00	122.00	122.00	122.00
Dry Min 5d Q	1.44	1.28	1.41	1.36	1.34	1.29
Dry Q AVE	3.22	2.47	3.08	2.80	2.70	2.46
Dry Q MAX	9.19	5.55	8.78	7.56	6.62	5.57
Wet onset	48.00	48.00	48.00	48.00	48.00	48.00
Wet duration	151.00	151.00	151.00	151.00	151.00	151.00
Wet Max 5d Q	53.89	37.90	50.13	44.79	41.30	37.90
Wet season volume	139.75	104.43	137.62	124.77	117.09	104.43
Dry ave daily vol	0.28	0.22	0.27	0.25	0.24	0.22
T1 ave daily vol	0.38	0.25	0.35	0.31	0.28	0.25
Wet ave daily vol	0.93	0.69	0.91	0.83	0.78	0.69
T2 ave daily vol	0.50	0.38	0.47	0.41	0.41	0.38
T1 duration	61.00	61.00	61.00	61.00	61.00	61.00
T2 duration	31.00	31.00	31.00	31.00	31.00	31.00
Dry Class1	4.00	2.74	3.97	3.29	3.21	2.76
Dry Class2	0.00	0.13	0.37	0.34	0.26	0.13
Dry Class3	0.00	0.05	0.21	0.21	0.08	0.05
Dry Class4	0.00	0.00	0.03	0.00	0.00	0.00
T1 Class1	2.00	2.87	2.97	2.89	2.89	2.95
T1 Class2	0.50	0.82	1.21	1.08	0.97	0.82
T1 Class3	0.00	0.42	0.47	0.42	0.39	0.42
T1 Class4	0.00	0.16	0.21	0.21	0.18	0.16
Wet Class1	7.00	9.03	7.63	8.21	8.58	9.13
Wet Class2	5.50	4.87	5.71	5.39	5.37	4.87
Wet Class3	2.50	2.50	2.87	2.76	2.50	2.50
Wet Class4	1.50	0.92	1.63	1.29	1.26	0.92
T2 Class1	1.50	1.82	1.63	1.68	1.71	1.84
T2 Class2	0.00	0.29	0.50	0.39	0.39	0.29
T2 Class3	0.00	0.11	0.11	0.11	0.11	0.11
T2 Class4	0.00	0.00	0.03	0.03	0.03	0.00
1:2 Class5	0.74	0.50	0.74	0.63	0.58	0.50
1:5 Class6	0.13	0.05	0.16	0.11	0.05	0.05

	Baseline	Base CC D 2050	Sc 1.5 CC M 2035	Sc 1.5 CC M 2050	Sc 1.5 CC D 2035	Sc 1.5 CC D 2050
1:10 Class7	0.16	0.13	0.13	0.16	0.16	0.13
1:20 Class8	0.03	0.00	0.05	0.00	0.00	0.00
EFSite5						
Mean annual runoff	7.48	5.60	7.18	6.54	6.13	5.60
Dry onset	22.00	22.00	22.00	22.00	22.00	22.00
Dry duration	122.00	122.00	122.00	122.00	122.00	122.00
Dry Min 5d Q	1.51	1.34	1.48	1.42	1.39	1.34
Dry Q AVE	3.34	2.59	3.25	2.94	2.82	2.58
Dry Q MAX	10.05	5.86	9.63	8.54	7.13	5.87
Wet onset	48.00	48.00	48.00	48.00	48.00	48.00
Wet duration	151.00	151.00	151.00	151.00	151.00	151.00
Wet Max 5d Q	55.49	39.89	53.43	48.80	44.59	39.89
Wet season volume	147.26	109.68	145.40	132.46	123.13	109.68
Dry ave daily vol	0.29	0.23	0.28	0.26	0.25	0.23
T1 ave daily vol	0.39	0.27	0.36	0.33	0.29	0.27
Wet ave daily vol	0.98	0.73	0.96	0.88	0.82	0.73
T2 ave daily vol	0.52	0.39	0.49	0.43	0.43	0.39
T1 duration	61.00	61.00	61.00	61.00	61.00	61.00
T2 duration	31.00	31.00	31.00	31.00	31.00	31.00
Dry Class1	4.00	2.97	3.92	3.82	3.32	3.18
Dry Class2	0.00	0.11	0.42	0.42	0.34	0.11
Dry Class3	0.00	0.08	0.24	0.18	0.13	0.08
Dry Class4	0.00	0.00	0.03	0.03	0.00	0.00
T1 Class1	3.00	2.97	3.00	3.13	2.97	3.11
T1 Class2	1.00	0.89	1.32	1.13	1.00	0.89
T1 Class3	0.00	0.37	0.50	0.37	0.39	0.37
T1 Class4	0.00	0.18	0.24	0.21	0.18	0.18
Wet Class1	6.50	8.24	7.03	7.79	7.95	8.39
Wet Class2	5.00	5.24	5.74	5.37	5.45	5.24
Wet Class3	3.00	2.55	3.08	3.03	2.71	2.55
Wet Class4	1.00	1.05	1.71	1.37	1.29	1.05
T2 Class1	1.50	1.76	1.58	1.66	1.66	1.76
T2 Class2	0.00	0.39	0.55	0.50	0.50	0.39
T2 Class3	0.00	0.11	0.16	0.13	0.13	0.11
T2 Class4	0.00	0.00	0.03	0.00	0.00	0.00
1:2 Class5	0.84	0.55	0.89	0.76	0.63	0.55
1:5 Class6	0.18	0.11	0.13	0.11	0.13	0.11
1:10 Class7	0.11	0.08	0.13	0.16	0.08	0.08
1:20 Class8	0.03	0.03	0.05	0.03	0.03	0.03

5.4 Presentation of DRIFT-Hlotse results

For every scenario assessed, DRIFT-Hlotse generates time-series outputs for every indicator at every EFlows site. This represents a great deal of information that can be summarised in numerous ways. In the interests of space-saving, the results for individual indicators are not included in the report because they comprise over 50 pages of detail, which will be made available to the Client in MS Excel spreadsheets. Sections 6 to 10 use this information, appropriately integrated and summarised, to discuss the influence on ecosystem condition and social use for combinations of scenarios.

All the scenarios are adjudged relative to the Baseline 2021 condition, not only in terms of the overall ecological integrity, but also in terms of the discipline integrities and predicted percentage change in individual indicators.

All scenarios predict change on a 39-year horizon, i.e., the same period used for the baseline flow regime.

5.4.1 Scenario Sets 1-4

5.4.1.1 Maps

Overall ecosystem integrity (Section 3.2.4.2.2) for some of the scenarios is reported using coloured maps of the reaches represented by the five EFlows sites downstream of the Hlotse Adit (Figure 5.3). The definition of colours used is the same as that for the icons in Table 5.6.

Figure 5.3 Hlotse: Map showing the baseline integrity for the river reaches represented by the EFlows sites

5.4.1.2 Ecological icons

The icons used in the reporting of scenario results are provided Table 5.6.

Table 5.6 Icons and key to color-coding

Category	Description	Health/Condition						
		Ecosystem	Geomorphology	Vegetation	Inverte-brates	Fish	Birds	Mammals
A	Unmodified, natural							
A/B								
B	Largely natural							
B/C								
C	Moderately modified							
C/D								
D	Largely modified							
D/E								
E	Completely modified							
E/F								
F								

5.4.1.3 Social icons

River-related social well-being is affected by various factors. Those included in the scenario assesment for the Hlotse EFlows are (Table 5.7):

- intangible contributions that affect the psychological quality of life, either individually or collectively, such as cultural and spiritual links to a healthy river, with trees, fish birds and wildlife
- tangible contributions such as riverbank farming and harvesting of river-linked natural resources.

Table 5.7 River-related social concerns included in the assessment

Social well-being	The combination of the Farming and Natural Resource use: Material and non-material benefits that accrue to individual households. It is an overall summary of the knock-on effects of each scenario, relative to the baseline, on the people who rely on the river for their livelihoods.	
Subsistence Farming	The weighted sum of the percentage change in household yield from subsistence recession/riverbank farming and livestock.	
Natural resource use	The weighted sum of the relative change in per household harvest of grass, reeds, wood, sand, fish and wildlife.	

The icons are reported as increasing or decreasing in value relative to the 2021 Baseline (Table 5.8). The results represented by the farming and natural resource use icons are average measures and are not comparable between EFlows Sites since the population size and household densities differ.

Table 5.8 Definitions of colours used to report change in social icons

	Marked improvement (>+40%)
	Improvement (+20 to +40%)
	Slight improvement (+5 to +20%)
	Little or no change (-5 to +5%)
	Slight deterioration (-5 to -20%)
	Deterioration (-20 to -40%)
	Marked deterioration (<-40%)

5.4.2 Scenario Set 5

The Set 5 scenarios are presented for EFlows4 only. This is because EFlows 4 is the EFlows site where EFlows are most likely to be monitored. It is positioned downstream of the Hlotse Abstraction Point, but upstream of the influence of Hlotse Town, and is close to Gauge CG25, (Figure 2.1).

For Set 5, the overall ecosystem integrity scores for each of the scenarios, which position them in an ecological category, are plotted against MAR at EFlows4. Thereafter, the scenarios that would facilitate maintenance of a D category are identified[12].

[12] EFlows were provided for a D category river, half an ecological category higher than baseline (D/E) because a D category is normally the lowest acceptable condition from a river management perspective. No flows were provided for a category lower, as usually done, because an E category is worse than acceptable.

6 RESULTS: SCENARIO SET 1 - RELEASES FROM THE HLOTSE ADIT

6.1 Ecological condition

Scenario Set 1 focusses entirely on the releases from the Hlotse Adit, with the amount released at the Adit being entirely abstracted before EFlows4, i.e., all released water abstracted either at the Hlotse Abstraction Point or further upstream or lost to groundwater or the atmosphere. Thus the scenarios only affect EFlows1, 2 and 3. The flows at EFlows4 and 5 are unaffected. The DRIFT-Hlotse outputs for overall ecosystem integrity for baseline, and releases of 0.4, 1.5 and 2.1 m^3/s at the Hlotse Adit; and no change in flow at EFlows4 and 5 are shown in Figure 6.1.

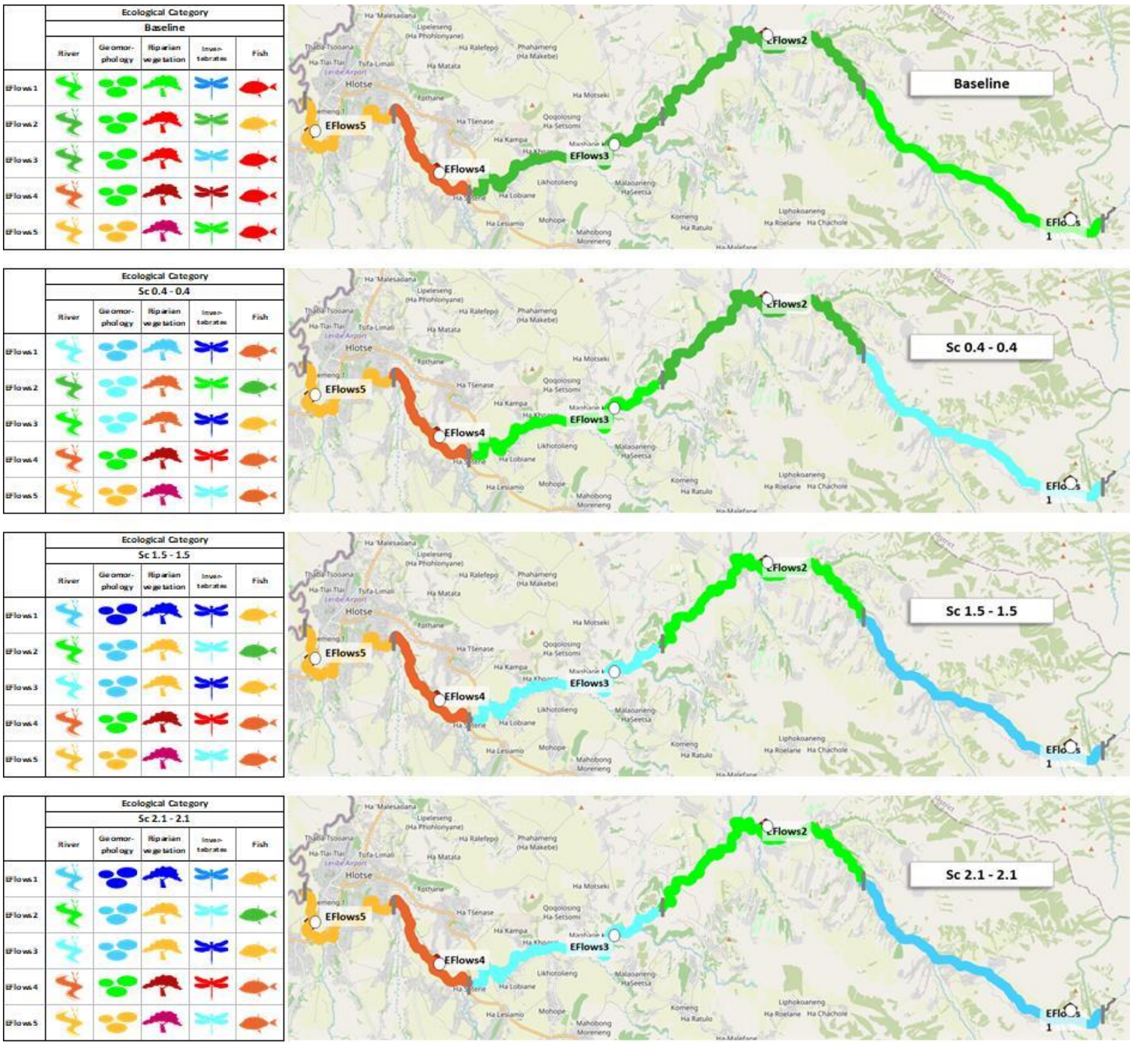


Figure 6.1 DRIFT-Hlotse: Predicted overall ecosystem integrity for baseline, and releases of 0.4, 1.5 and 2.1 m^3/s at the Hlotse Adit; and no change in flow at EFlows4 and 5[13]

13 In the interests of space saving, mammals, birds and amphibians are not included in the icons but are included in the calculation of overall ecosystem integrity.

It is clear from Figure 6.1, that DRIFT predicts that the river condition at EFlows1, 2 and 3 will improve with additional water released from the Adit. The main predictions relating to the individual disciplines are:

Geomorphology: In general, it is expected that the water released from Katse Dam via the Adit will be sediment hungry and will scour. This is expected to reduce the fines on the river bed (Figure 6.2) and deepen some of the pools. Given the sedimentation that has occurred in these reaches as a result of catchment degradation, the slight scouring is expected to increase habitat diversity, moving it back towards a more natural state. These effects are expected to be greatest at EFlows1, which has a lower natural discharge and a narrower channel, and then decrease with distances downstream (EFlows2 and 3).

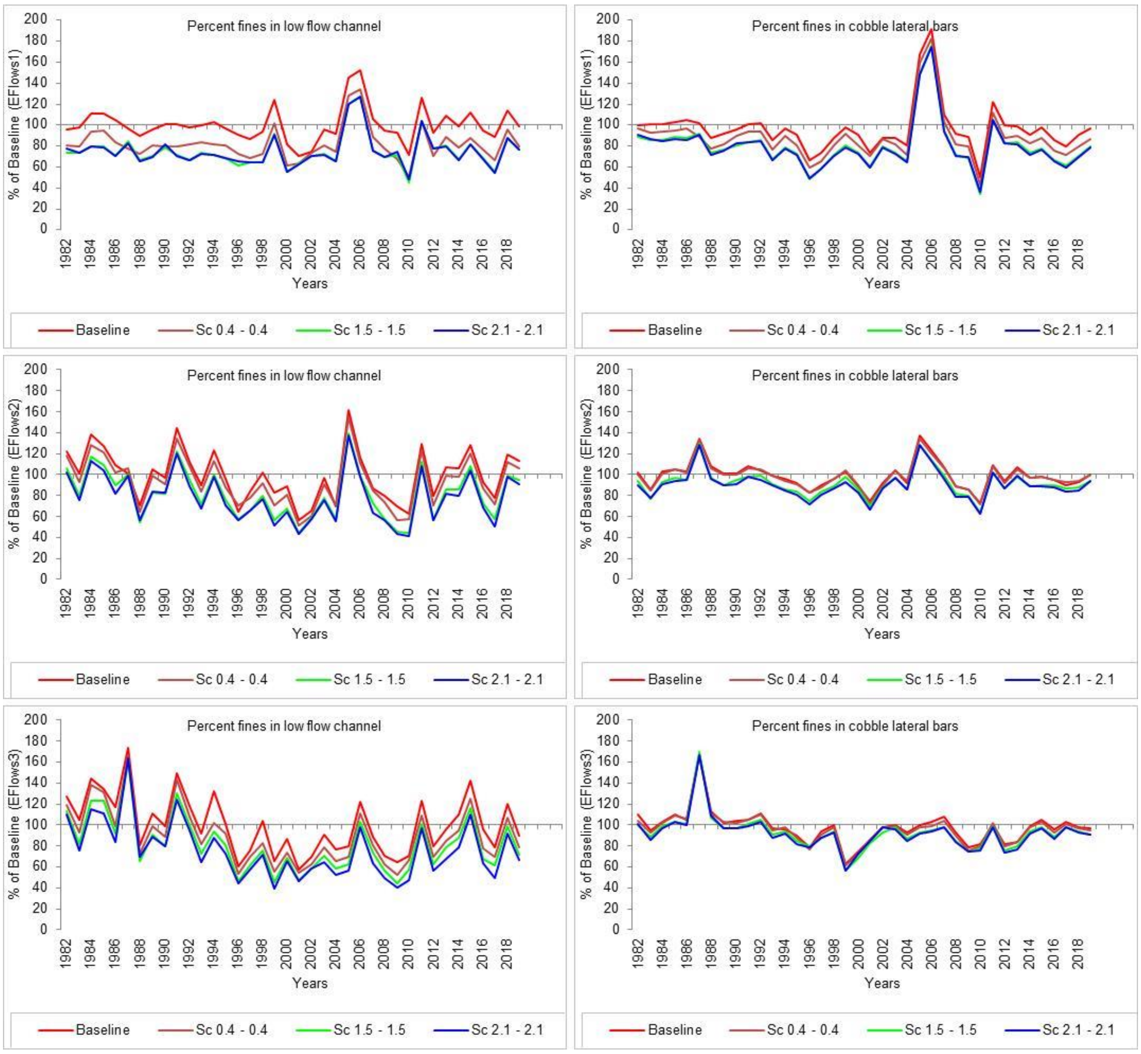


Figure 6.2 DRIFT-Hlotse: Predicted relative changes in fines at EFlows1, 2 and 3 for baseline, and releases of 0.4, 1.5 and 2.1 m^3/s at the Hlotse Adit

Vegetation: In general, the water released from Katse Dam via the Adit will increase the velocity of water in the channel that is expected to scour green algae from the rocks in the channel (Figure 6.3). The elevated flows will also provide additional water to the vegetation growing on the river banks. This is expected to increase the amount of wet bank sedges and dry bank grasses. Given that the presence of green algae at EFlows1 and 2 is considered to be unnatural and that there were very few sedges and grasses on the river banks in the baseline 2021 condition, both are expected to improve the condition of the vegetation moving it back towards a more natural state. These effects are expected to be greatest at EFlows1, which has a lower natural discharge and a narrower channel, and then decrease with distances downstream (EFlows2 and 3).

Figure 6.3 DRIFT-Hlotse: Predicted relative changes in wet bank sedges and dry bank grasses at EFlows1, 2 and 3 for baseline, and releases of 0.4, 1.5 and 2.1 m^3/s at the Hlotse Adit

Invertebrates: In general, the expected reduction in fines (Figure 6.2) will result in a decline in caenid numbers as they prefer slow flowing water over fine substrata. At the same time, simulids and baetids (Figure 6.4), which prefer faster flowing water and a rocky substrate, are expected to increase. These changes would move the invertebrate community structure back towards a more natural state. These effects are expected to be greatest at EFlows1, which has the lowest baseline discharge of the three EFlows sites and so the releases, and their influence, are proportionally larger there.

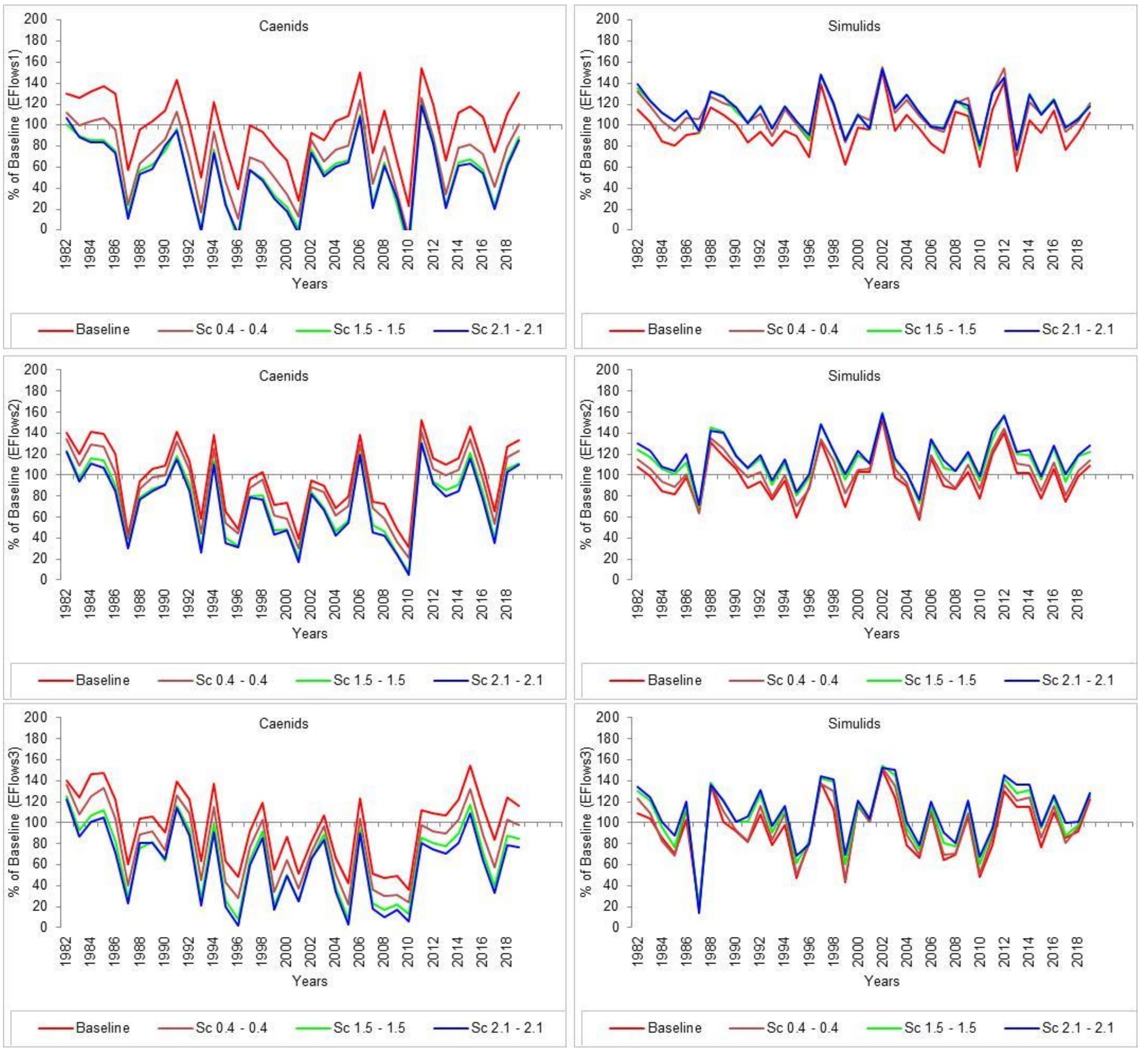


Figure 6.4 DRIFT-Hlotse: Predicted relative changes in caenid and simulid invertebrates at EFlows1, 2 and 3 for baseline, and releases of 0.4, 1.5 and 2.1 m^3/s at the Hlotse Adit

Fish: In general, the expected reduction in fines (Figure 6.2) and the increases in the abundance of baetids and simulids (Figure 6.4) are expected to support an increase in the number of fish in the river (Figure 6.5). The reduction in fines should improve spawning gravels in riffles for the Orange-Vaal smallmouth yellowfish and cobble habitat for the rock catfish, which have become embedded as a result of increase sediments from a degraded catchment (Baseline Report, Multiconsult 2022b). An increase in baetids and simulids will mean more food for the yellowfish and catfish, respectively. These effects are expected to be greatest at EFlows3, which has a higher natural discharge and a wider channel than EFlows 1 and 2, and so offers better fish habitat.

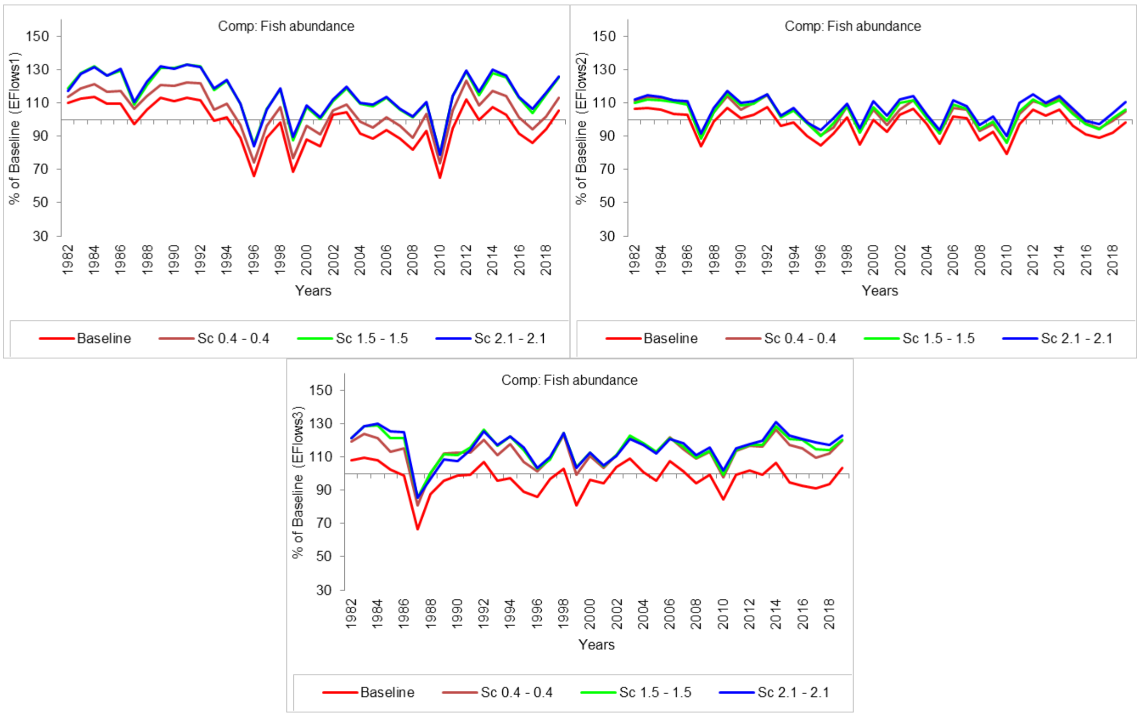


Figure 6.5 DRIFT-Hlotse: Predicted relative changes in fish abundance at EFlows1, 2 and 3 for baseline, and releases of 0.4, 1.5 and 2.1 m^3/s at the Hlotse Adit

Mammals and amphibians: It is expected that the improvements in habitat (Figure 6.2 and Figure 6.3) and increases in the abundance of invertebrates (Figure 6.4) and fish (Figure 6.5) will result in better conditions for mammals and amphibians (Figure 6.6). The reductions in fines and algae and increases in sedges and grasses are expected to improve habitat conditions for otters and frogs, while the increases in the abundance of fish and invertebrates provide more food for them.

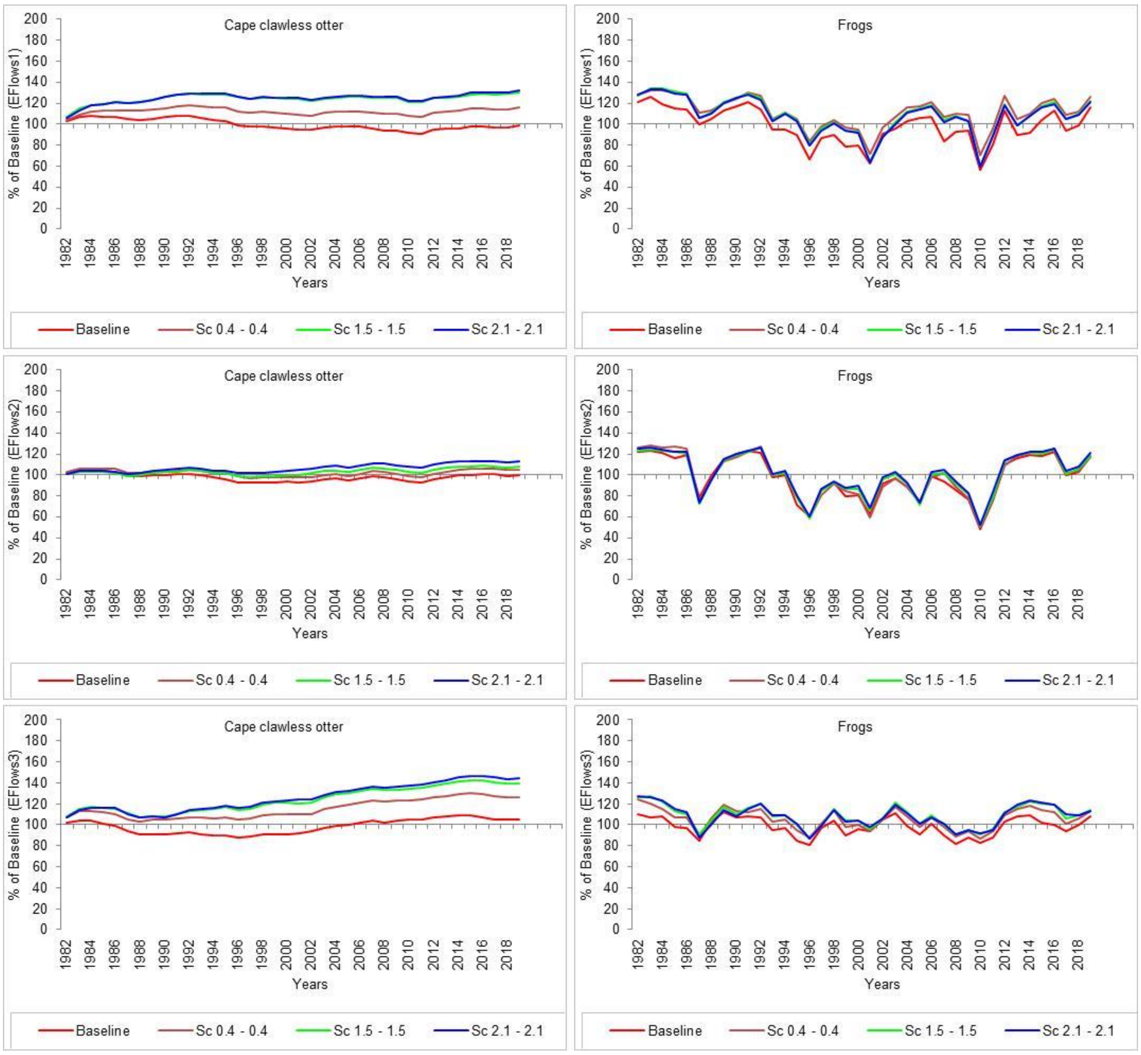


Figure 6.6 DRIFT-Hlotse: Predicted relative changes in otters and frogs at EFlows1, 2 and 3 for baseline, and releases of 0.4, 1.5 and 2.1 m^3/s at the Hlotse Adit

Birds: It is expected that the improvements in habitat (Figure 6.2 and Figure 6.3) and increases in the abundance of invertebrates (Figure 6.4) and fish (Figure 6.5) will altogether provide better conditions for birds (Figure 6.7).

6.2 River-related social wellbeing

The DRIFT-Hlotse outputs for river-related social wellbeing for changes from baseline, and releases of 0.4, 1.5 and 2.1 m^3/s at the Hlotse Adit; and no change in flow at EFlows4 and 5, are shown in Table 6.1. Natural resource use is expected to be slightly negatively affected by the releases. This is because the increased flows are likely to result in river conditions that are slightly less favourable than baseline for river crossings (Figure 6.8), laundry and mining of sand and stones. This is related to the discharge being released but also to the shape of the channel at the EFlows sites, i.e., where the channel is narrower the water gets deeper and is more dangerous. Farming is expected to be slightly negatively affected by the releases because there are fewer slower flowing sections of the river channel where the animals can drink safely and access to grazing grounds on the other side of the river is reduced because of changes to river crossings. The benefits of household access to piped water from the water treatment works are not included in this analysis – these benefits are likely to be realised particularly in the lower catchment along the EFlows4 and 5 reaches.

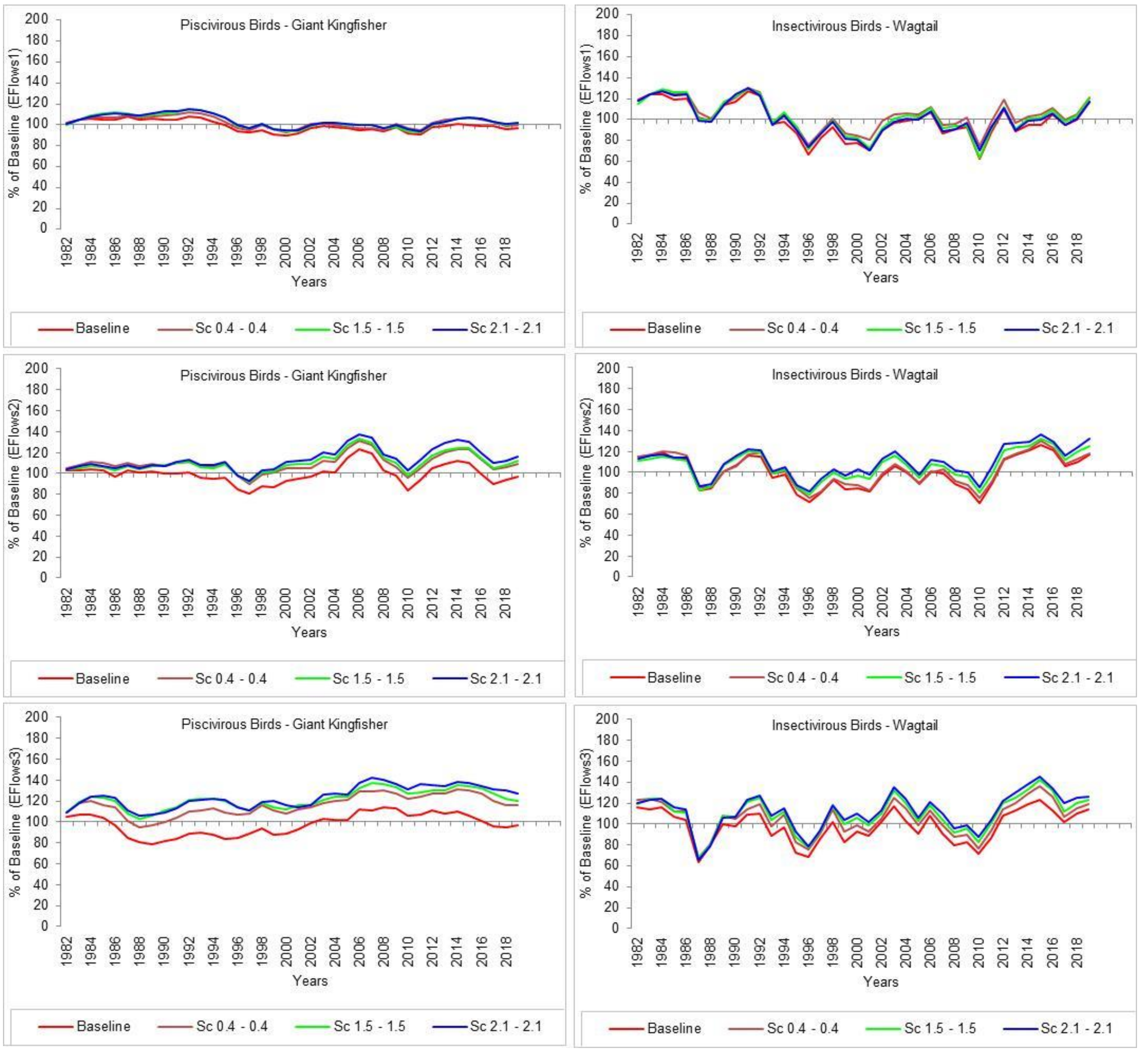
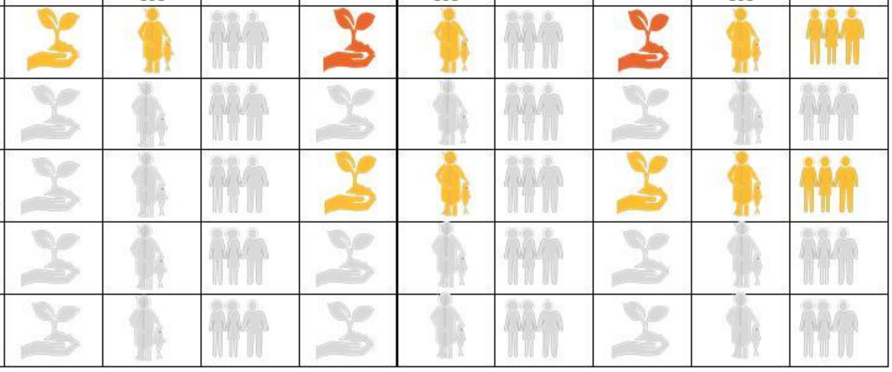


Figure 6.7 DRIFT-Hlotse: Predicted relative changes in birds at EFlows1, 2 and 3 for baseline, and releases of 0.4, 1.5 and 2.1 m^3/s at the Hlotse Adit

Overall river-related social well-being should not affected by the scenarios in Set 1 (Table 6.1). This is because some aspects are expected to be affected positively, e.g., quality and availability of drinking water (Figure 6.9) and others negatively, e.g., danger during river crossings by the releases (Figure 6.8).

Table 6.1 The DRIFT-Hlotse outputs for river-related social wellbeing for baseline, and releases of 0.4, 1.5 and 2.1 m^3/s at the Hlotse Adit; and no change in flow at EFlows4 and 5

	% Change from Base								
	Sc 0.4 - 0.4			Sc 1.5 - 1.5			Sc 2.1 - 2.1		
	Farming	Natural Resource Use	Social well-being	Farming	Natural Resource Use	Social well-being	Farming	Natural Resource Use	Social well-being
EF Zone 1									
EF Zone 2									
EF Zone 3									
EF Zone 4									
EF Zone 5									



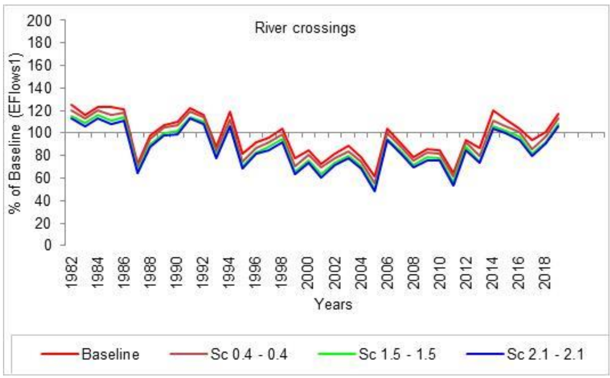


Figure 6.8 DRIFT-Hlotse: Predicted relative changes in danger associated with river crossings at EFlows1 for baseline, and releases of 0.4, 1.5 and 2.1 m^3/s at the Hlotse Adit

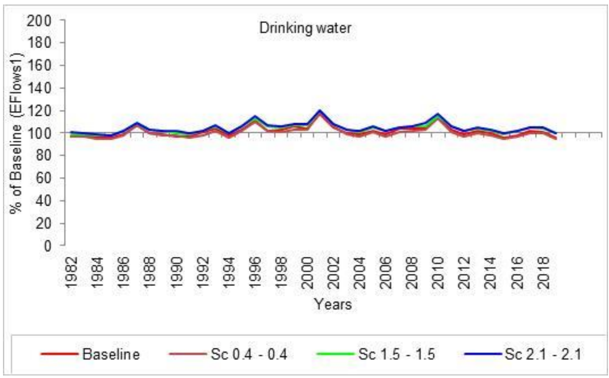


Figure 6.9 DRIFT-Hlotse: Predicted relative changes in quality and availability of drinking water at EFlows1 for baseline, and releases of 0.4, 1.5 and 2.1 m^3/s at the Hlotse Adit

6.3 Comment on maximum release volumes

The predictions for the three release volumes were all for a slight improvement in river condition, and limitations on the number of scenarios that could be analysed in this assessment meant that higher releases were not assessed. However, some negative implications are expected to accompany the release of 2.1 m³/s; particularly related to disrupted seasonal flow patterns (Table 5.3), natural resource use, farming and social wellbeing (Table 6.1). These are especially evident at EFlows1 (Figure 6.10). At EFlows1, the releases result in a change in the seasonality of the river, with two wet seasons evident. The seasonal influence of the Hlotse Adit releases are less pronounced with distance downstream.

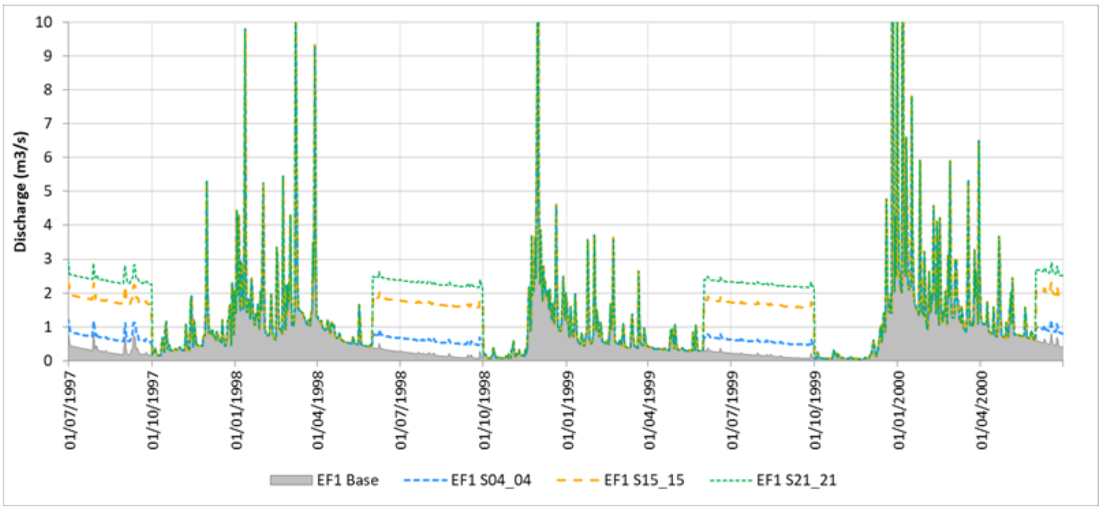


Figure 6.10 Hydrographs for EFlows1 showing baseline and the Hlotse Adit releases in the Set 1 scenarios

This suggests that the maximum release volume should be limited to somewhere between 1.5 and 2.1 m³/s; probably closer to 1.5 than 2.1, e.g., 1.6 or 1.7.

With respect to this it would be better, from the perspective of the river and the people reliant on it, if and when the releases from the Hlotse Adit are increased to 1.5 m³/s (Section 4), for them to rather be extended to an additional month of releases (i.e., May), possibly with some variation to mimic the natural hydrograph, than for higher volumes being released in June, July, August and September. This possibility was not included in the scenarios, but judging from the other results, would provide a more favorable outcome than higher releases limited to four months.

7 RESULTS: SCENARIO SET 2 - ABSTRACTIONS FROM THE HLOTSE ABSTRACTION POINT

7.1 Ecological condition

Scenario Set 2 focusses on the abstractions for the Hlotse Abstraction Point, with no releases from the Adit. Thus, the scenarios only affect EFlows4 and 5. EFlows1, 2 and 3 are unaffected.

The DRIFT-Hlotse outputs for overall ecosystem integrity for baseline, and abstractions of 0.4, 1.2 and 2.1 m^3/s at the Hlotse Abstraction Point; and no change in the baseline flow regimes at EFlows1, 2 and 3 are shown in Figure 7.1.

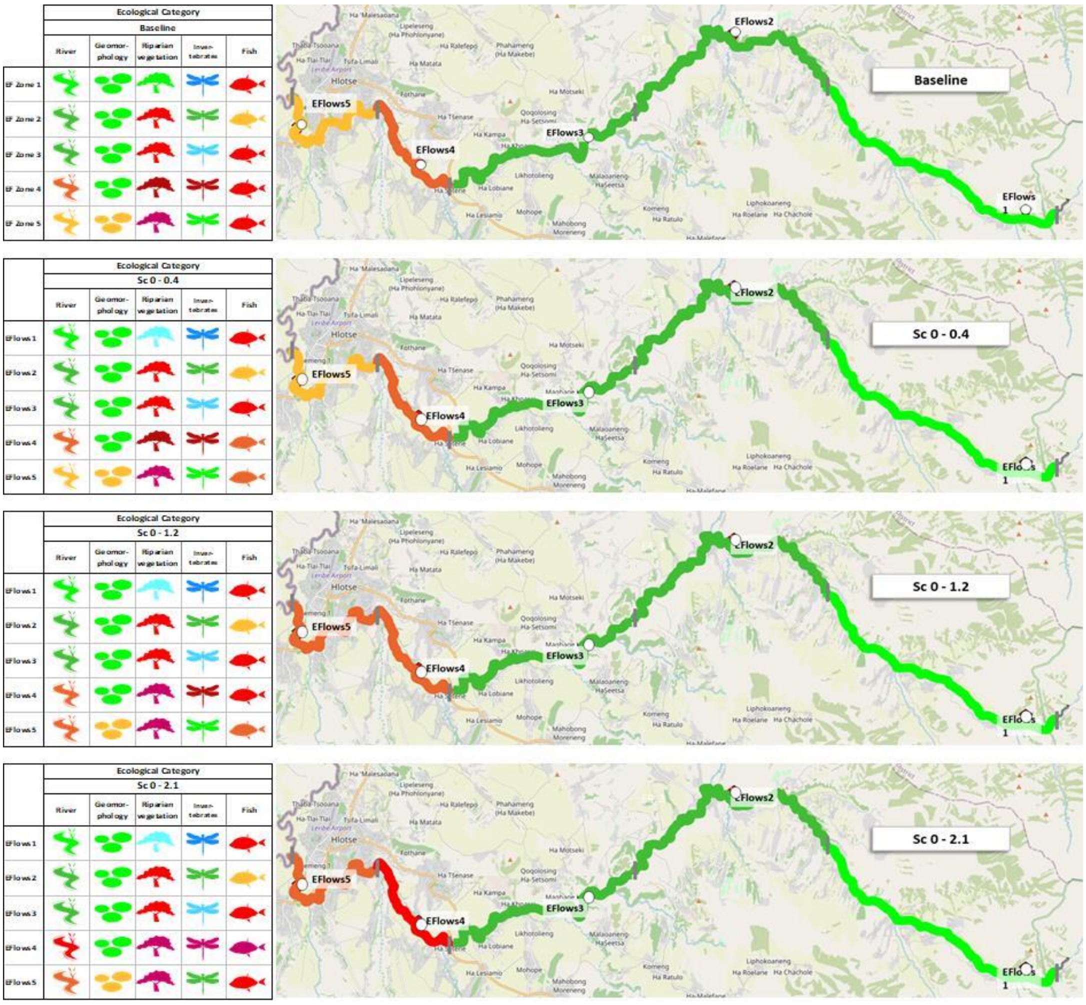


Figure 7.1 DRIFT-Hlotse: Predicted overall ecosystem integrity for baseline, and abstractions of 0.4, 1.2 and 2.1 m^3/s at the Hlotse Abstraction Point; and no change in flow at EFlows1, 2 and 3.[14]

14 In the interests of space saving, mammals, birds and amphibians are not included in the icons but are included in the calculation of overall ecosystem integrity.

DRIFT predicts that the river condition at EFlows4 and 5 will decline if abstractions from the Hlotse Abstraction Point are not supported by releases from the Hlotse Adit (Figure 7.1). The changes are not expected to result in a drop in ecological category with abstractions of 0.4 m^3/s but small changes are expected among the disciplines. An abstraction of and 1.2, however, is predicted to lead to a decline in river condition from a D to a D/E at EFlows4 and an abstraction 2.1 m^3/s from a D/E to a E at EFlows5. This is because macroinvertebrates and fish would be negatively affected, partly because abstractions of 2.1 m^3/s result in zero flows for part of the year (Figure 7.2).

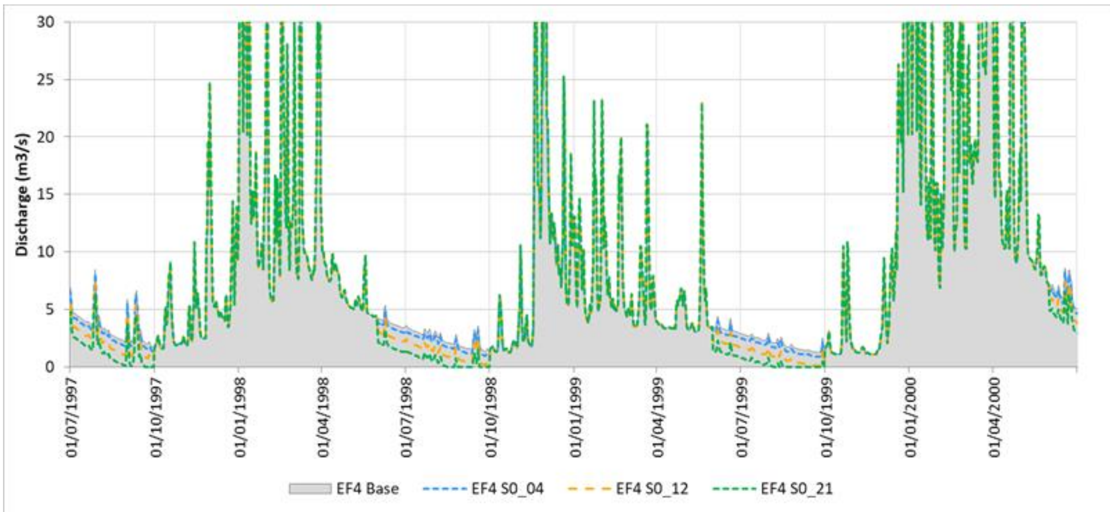


Figure 7.2 Hydrographs for EFlows4 showing baseline and the unsupported abstractions from The Hlotse Abstraction Point in the Set 2 scenarios

The main predictions relating to the individual disciplines are:

Geomorphology: In general, it is expected that the reductions in flow from the abstractions at the Hlotse Abstraction Point will increase fines on the riverbed slightly (Figure 7.3) because they reduce the ability of the river to transport suspended sediments. This slight deposition is expected to negatively impact habitat conditions, but not so much as to result in a change in category.

Vegetation: In general, it is expected that the reductions in flow from the abstractions at the Hlotse Abstraction Point will decrease the abundance of wet sedges and dry grasses on the riverbanks (Figure 7.4); albeit that there are very few riparian plants at EFlows4 and 5 under baseline. The sedges should be more responsive to changes in flow than the grasses because they are less drought tolerant and the effects are expected to be the same at EFlows4 and 5 because discharge, channel shape and bank and bed conditions at the two sites are similar.

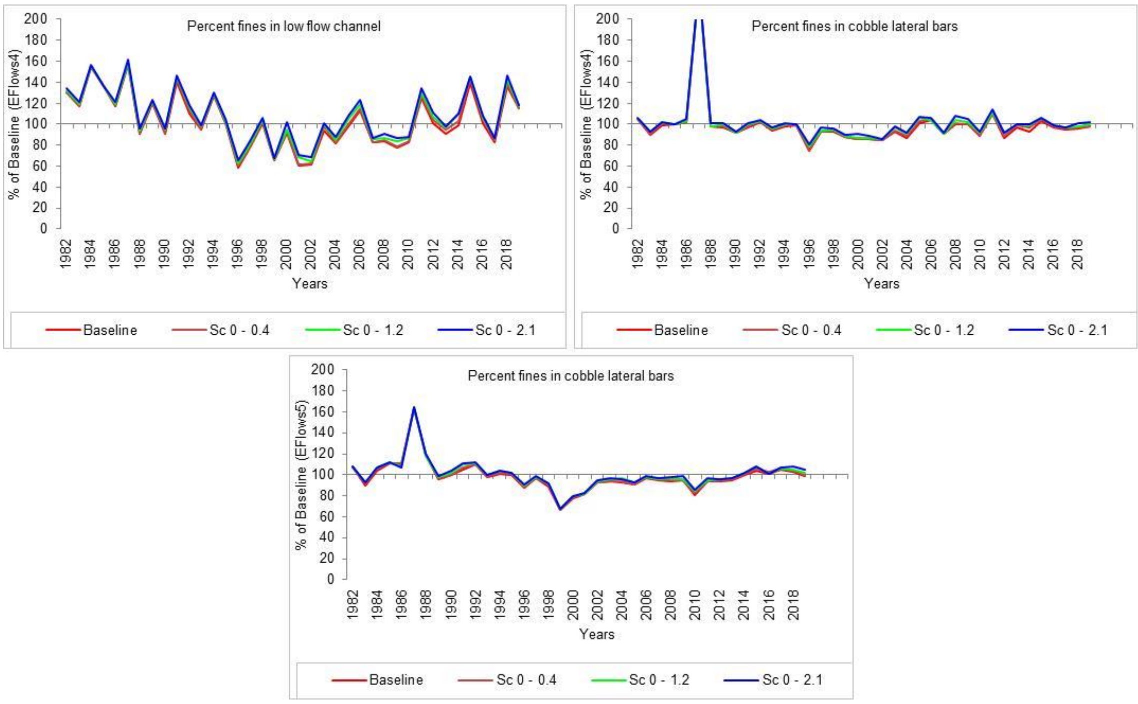


Figure 7.3 DRIFT-Hlotse: Predicted relative changes in fines at EFlows4 and 5 for baseline, and abstractions of 0.4, 1.2 and 2.1 m^3/s at the Hlotse Abstraction Point

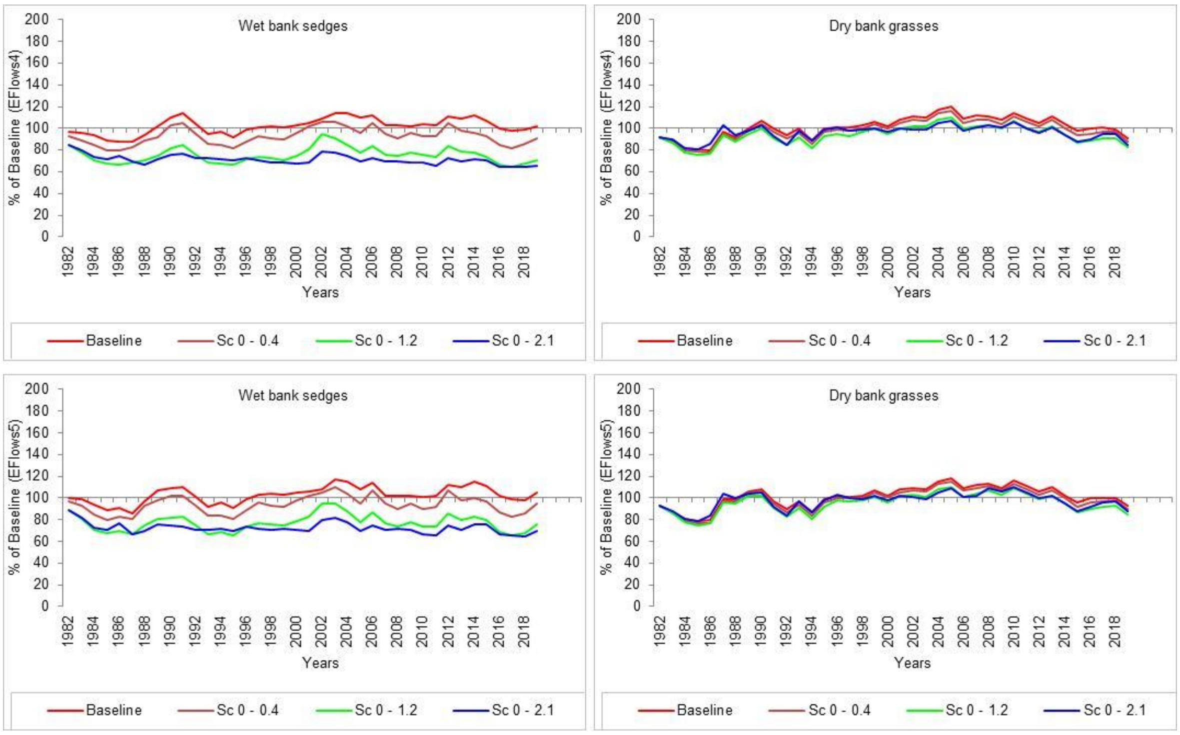


Figure 7.4 DRIFT-Hlotse: Predicted relative changes in wet bank sedges and dry bank grasses at EFlows4 and 5 for baseline, and abstractions of 0.4, 1.2 and 2.1 m^3/s at the Hlotse Abstraction Point

Invertebrates: The reductions in discharge and the slight increase in the abundance of fines (Figure 7.3) should mean fewer baetids and simulids at EFlows4 and 5 (Figure 7.5) as they prefer faster flowing water and a rocky substrate. These effects are expected to be the similar at EFlows4 and 5 because discharge, channel shape and bank and bed conditions at the two sites are similar.

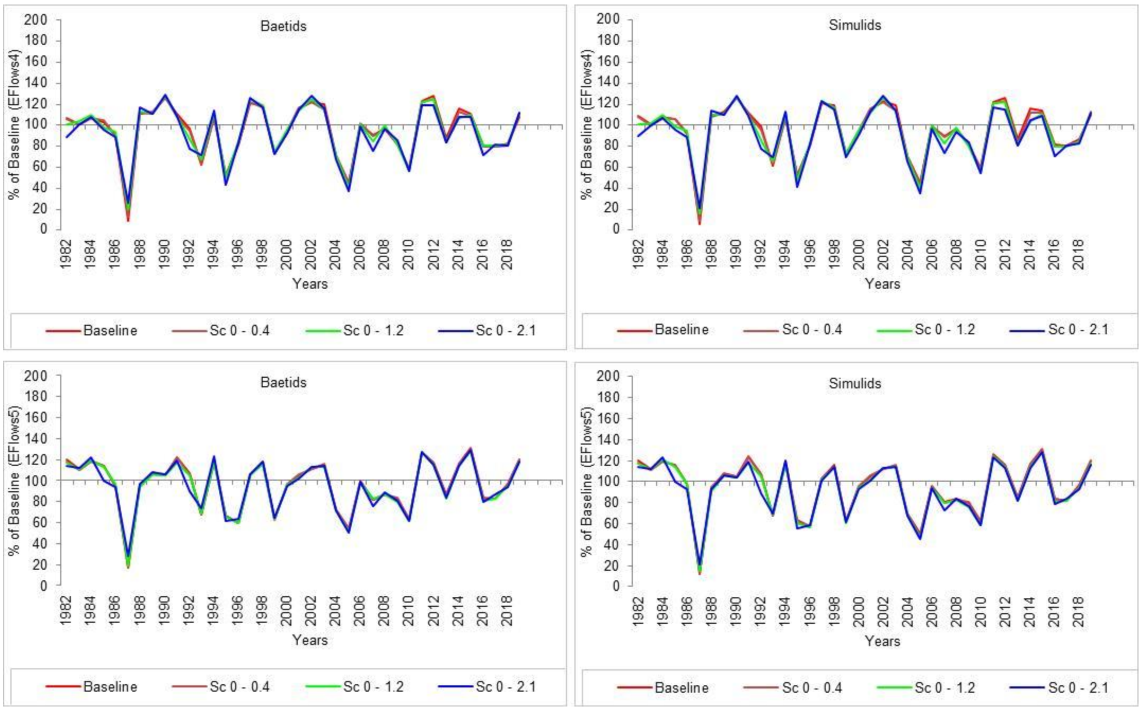


Figure 7.5 DRIFT-Hlotse: Predicted relative changes in baetid and simulid invertebrates at EFlows4 and 5 for baseline, and abstractions of 0.4, 1.2 and 2.1 m^3/s at the Hlotse Abstraction Point

Fish: In general, it is expected that the reductions in flow over the dry months, the slight increase in the abundance of fines (Figure 7.3) and decrease in the abundances of baetids and simulids (Figure 7.5) are expected to lead to a decrease in the number of fish that the river can support (Figure 7.6). The Orange-Vaal smallmouth yellowfish and rock catfish make use of rocky habitat and eat baetids and simulids. The effects are expected to be similar at EFlows4 and 5 because discharge, channel shape and bank and bed conditions at the two sites are similar.

Birds, mammals and amphibians: The knock on effects of reduced sedges, invertebrates and fish in the river would mean poorer conditions for birds (Figure 7.7) mammals and amphibians (Figure 7.8), and so they would be expected to decline in numbers.

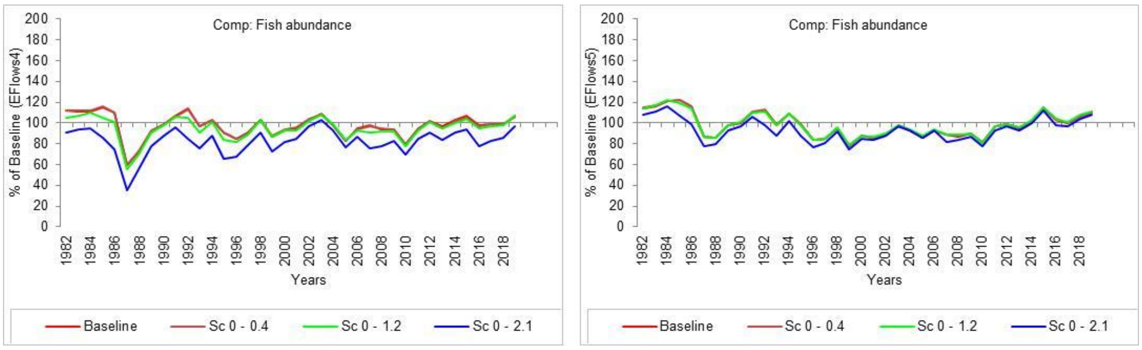


Figure 7.6 DRIFT-Hlotse: Predicted relative changes in fish abundance at EFlows4 and 5 for baseline, and abstractions of 0.4, 1.2 and 2.1 m³/s at the Hlotse Abstraction Point

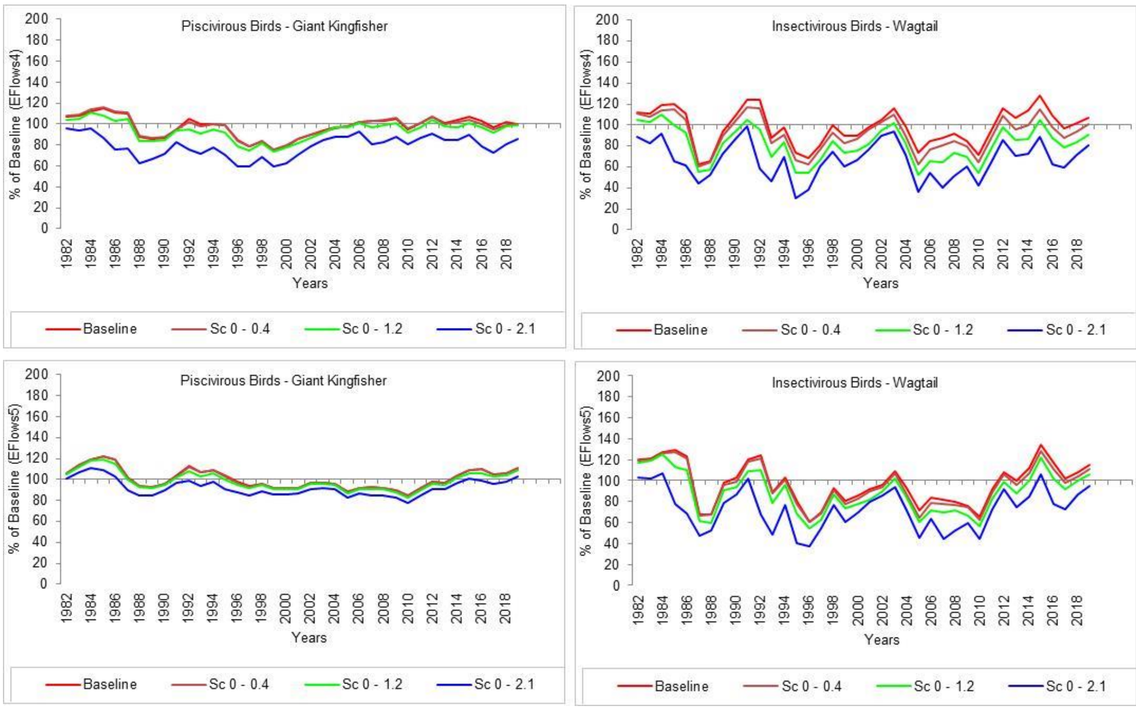


Figure 7.7 DRIFT-Hlotse: Predicted relative changes in birds at EFlows4 and 5 for baseline, and abstractions of 0.4, 1.2 and 2.1 m³/s at the Hlotse Abstraction Point

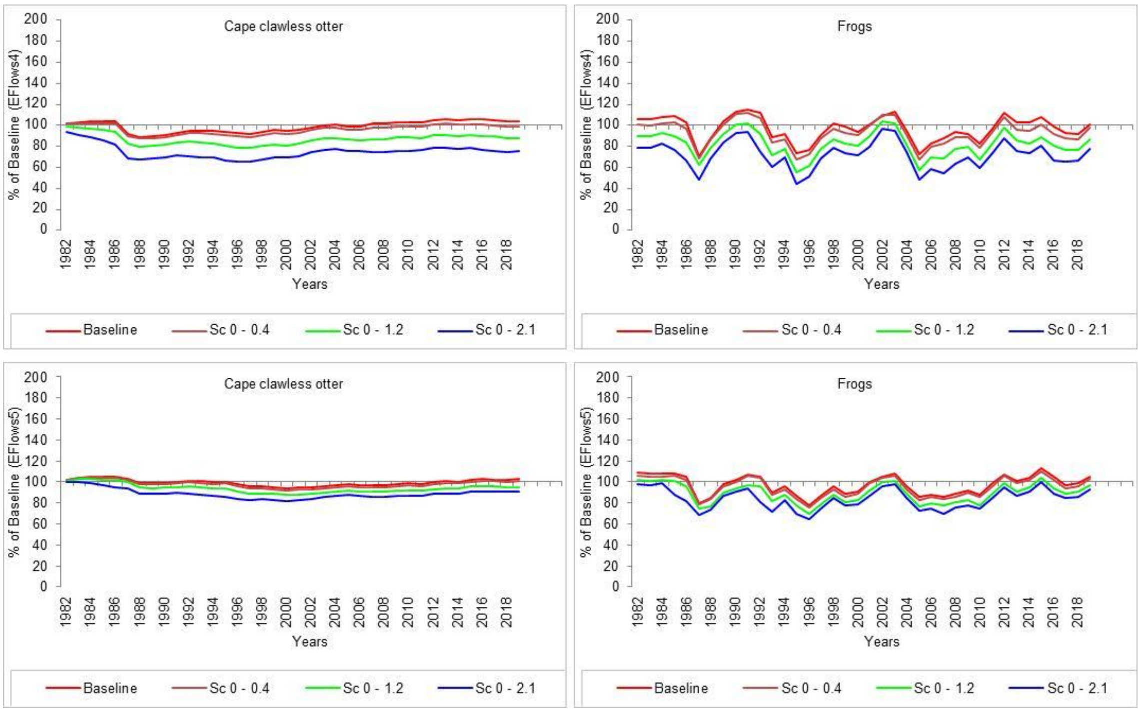


Figure 7.8 DRIFT-Hlotse: Predicted relative changes in otters and frogs at EFlows4 and 5 for baseline, and abstractions of 0.4, 1.5 and 2.1 m^3/s at the Hlotse Abstraction Point

7.2 River-related social wellbeing

The DRIFT-Hlotse outputs for river-related social wellbeing for changes from baseline, and abstractions of 0.4, 1.2 and 2.1 m^3/s at the Hlotse Abstraction Point, with no changes in flow at EFlows1, 2 and 3, are shown in Table 7.1. Farming is expected to be slightly positively affected by the 1.2 m^3/s abstractions as there are more slower-flowing sections in the river channel at EFlows4 and so animals can drink safely and cross the river easily. Farming is expected to be slightly negatively affected by the 2.1 m^3/s abstraction because less water would be available to water dryland crops and livestock (Figure 7.9) and poor water quality starts to become an issue. Natural resource use and social welfare are expected to be largely unaffected. The benefits of household access to piped water from the water treatment works are not included in this analysis – these benefits are likely to be realised particularly in the lower catchment along the EFlows4 and 5 reaches.

Table 7.1 The DRIFT-Hlotse outputs for river-related social wellbeing for baseline, and abstractions of 0.4, 1.2 and 2.1 m³/s at the Hlotse Abstraction Point and no change in flow at EFlows1, 2 and 3

	% Change from Base								
	Sc 0.0 - 0.4			Sc 0.0 - 1.2			Sc 0.0 - 2.1		
	Farming	Natural Resource Use	Social well-being	Farming	Natural Resource Use	Social well-being	Farming	Natural Resource Use	Social well-being
EF Zone 1									
EF Zone 2									
EF Zone 3									
EF Zone 4									
EF Zone 5									

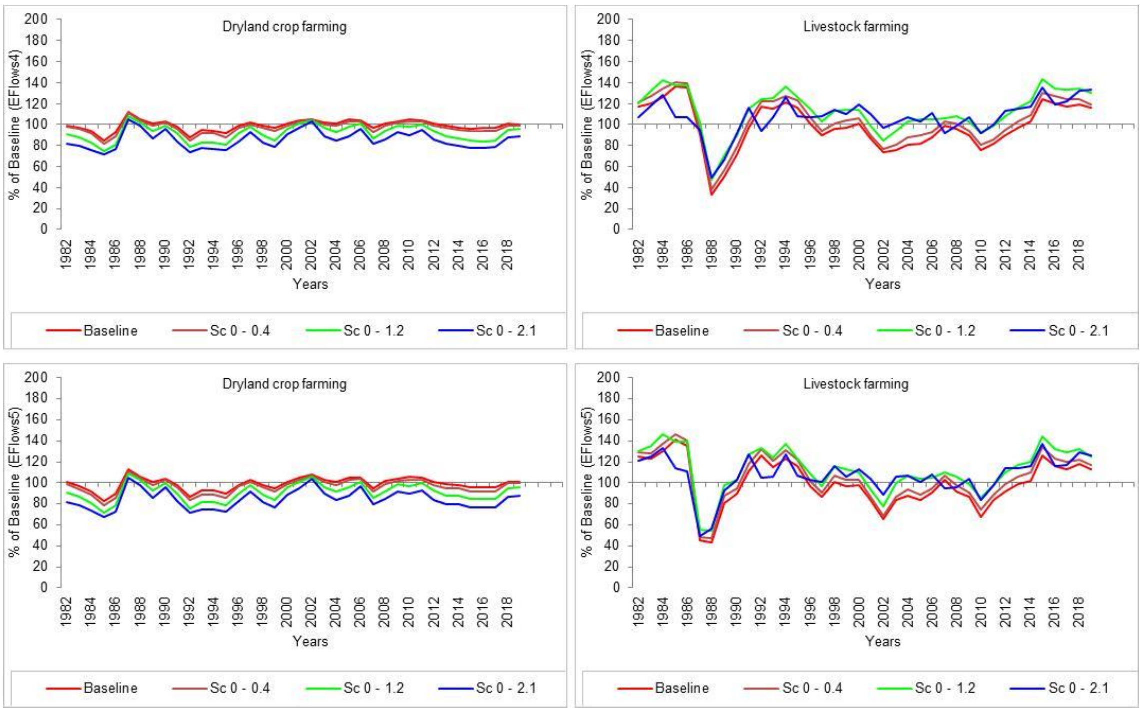


Figure 7.9 DRIFT-Hlotse: Predicted relative changes in farming at EFlows4 and 5 for baseline, and abstractions of 0.4, 1.2 and 2.1 m³/s at the Hlotse Abstraction Point

8 RESULTS: SCENARIO SET 3 - ADDITIONAL DRY SEASON FLOWS IN LOWER HLOTSE RIVER

8.1 Ecological condition

Scenario Set 3 focusses on the releases from the Hlotse Adit at all EFlows sites where no abstractions are made at the Hlotse Abstraction Point. The effects at EFlows1, 2 and 3 are the same as Scenario Set 1 so Set 3 focusses on EFlows4 and 5 downstream of the Hlotse Abstraction Point that would experience additional dry season flows.

The results pertaining to EFlows1, 2 and 3 are summarised in Section 6 and not repeated here. The DRIFT-Hlotse outputs for overall ecosystem integrity for baseline, and releases of 0.4, 1.2 and 2.1 m^3/s at the Hlotse Adit and how these influence EFlows4 and 5 are shown in Figure 8.1.

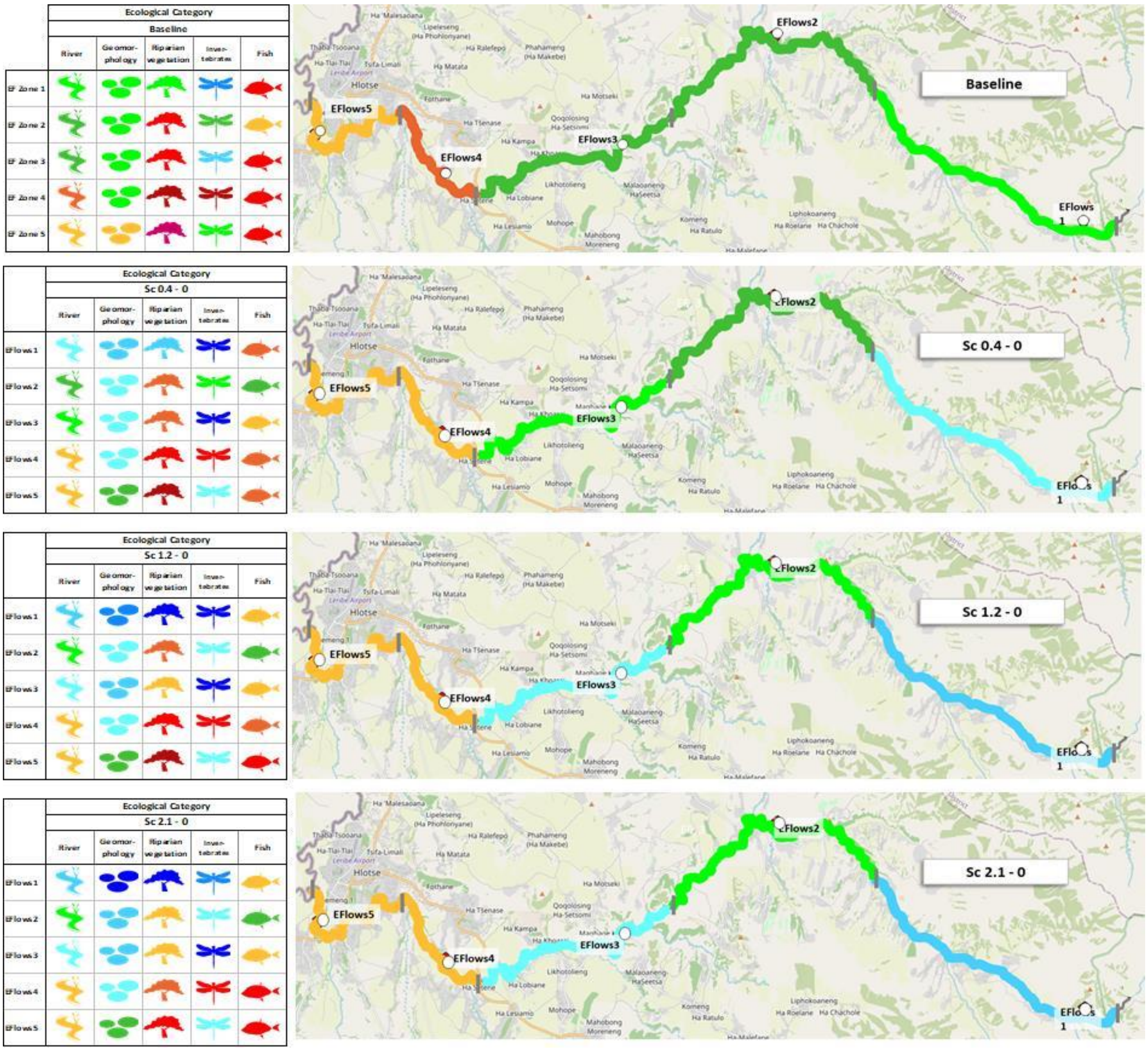


Figure 8.1 DRIFT-Hlotse: Predicted overall ecosystem integrity for baseline, and releases of 0.4, 1.2 and 2.1 m^3/s at the Hlotse Adit; and no abstractions at EFlows4 and 5.

It is clear from Figure 8.1, that DRIFT predicts that the river condition at EFlows4 will improve while the condition at EFlows5 remains the same with additional water released from the Adit. The main predictions relating to the individual disciplines are:

Geomorphology: If the water released from Katse Dam via the Adit continued to flow past EFlows4 and 5 there would be more water in the dry season that is expected to result in a very slight reduction in fines, which would improve the available habitats relative to baseline (Figure 8.2).

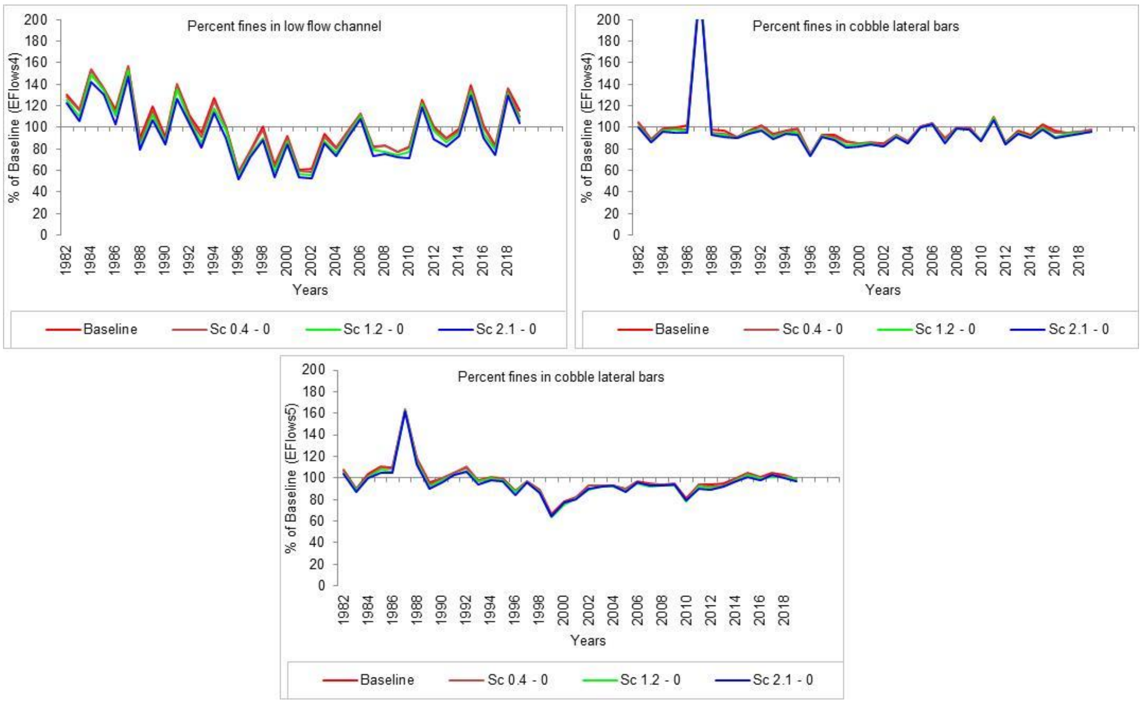


Figure 8.2 DRIFT-Hlotse: Predicted relative changes in fines at EFlows4 and 5 for baseline, and releases of 0.4, 1.2 and 2.1 m^3/s at the Hlotse Adit

Vegetation: Set 3 scenarios would mean additional water to the vegetation growing on the river banks (Figure 8.3), and so an increase in the amount of wet bank sedges and dry bank grasses is expected.

Invertebrates: As was the case for Set 1 at EFSites1, 2 and 3, the expected reduction in fines (Figure 8.2) would mean a decrease in the abundance of caenids, which prefer slow flowing water and a finer substrate, and an increase in simulids and baetids (Figure 8.4), which prefer faster flowing water and a rocky substrate.

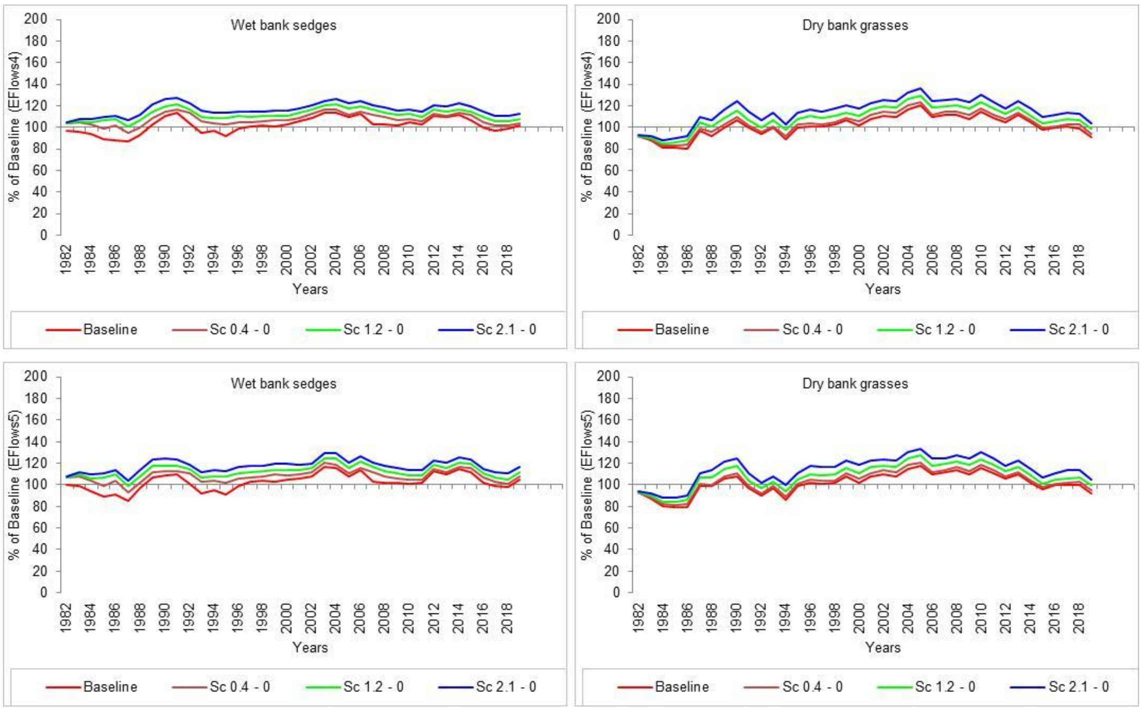


Figure 8.3 DRIFT-Hlotse: Predicted relative changes in wet bank sedges and dry bank grasses at EFlows4 and 5 for baseline, and releases of 0.4, 1.2 and 2.1 m³/s at the Hlotse Adit

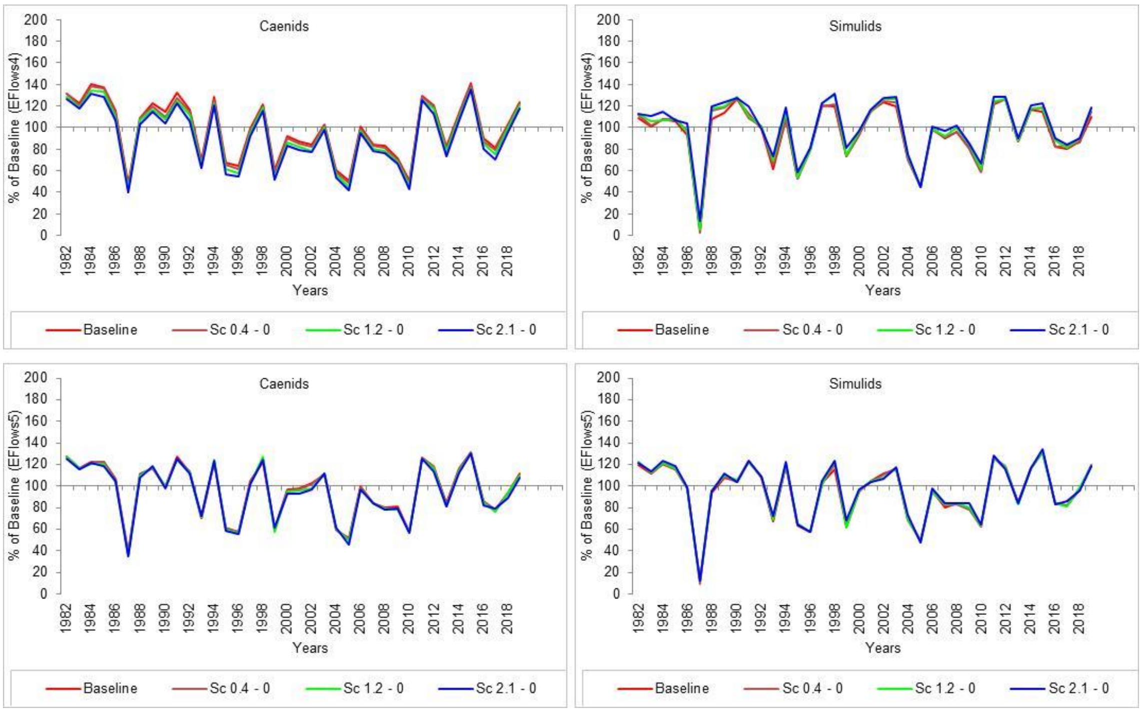


Figure 8.4 DRIFT-Hlotse: Predicted relative changes in caenid and simulid invertebrates at EFlows4 and 5 for baseline, and releases of 0.4, 1.2 and 2.1 m³/s at the Hlotse Adit

Fish: In general, the water released from Katse Dam via the Adit is expected to reduce fines in the channel (Figure 8.2) and increase the abundance of simulids and baetids (Figure 8.4) that are favoured prey items of rock catfish and Orange-Vaal smallmouth yellowfish respectively. The reduction in fines improves cobble habitat for the rock catfish, while an increase in the abundance of baetids and simulids should provide more food for the yellowfish and catfish respectively. There is expected to be a slight increase in the abundance of rock catfish as they are adapted to fast flow and a corresponding decrease in yellowfish that prefer slower flow in the dry season (Figure 8.5).

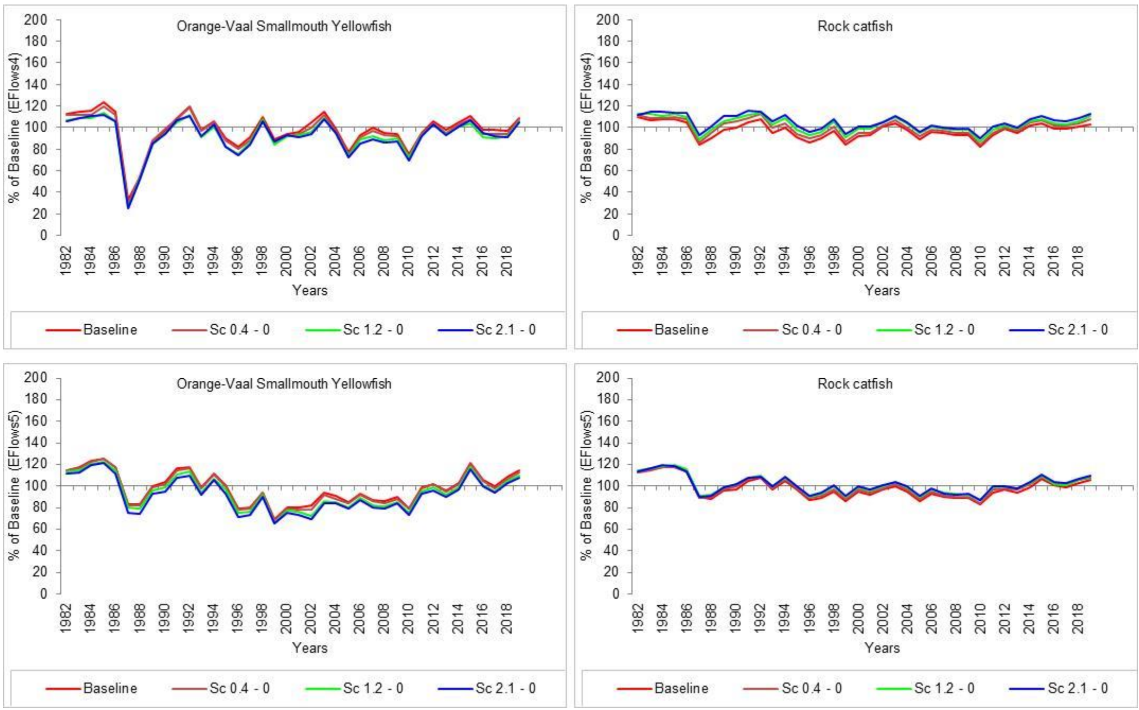


Figure 8.5 DRIFT-Hlotse: Predicted relative changes in fish abundance at EFlows4 and 5 for baseline, and releases of 0.4, 1.2 and 2.1 m^3/s at the Hlotse Adit

Birds, mammals and amphibians: The knock on effects of increased sedges, invertebrates and fish in the river would mean better conditions for birds (Figure 8.6) mammals and amphibians (Figure 8.7), and so they would be expected to increase in numbers.

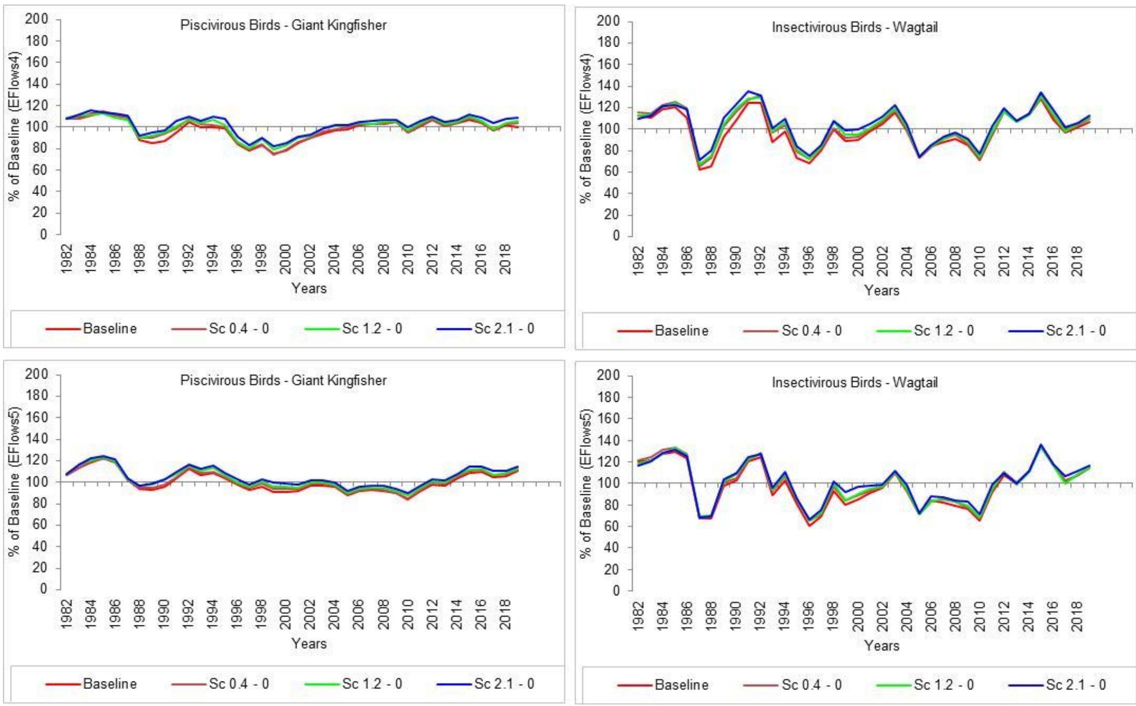


Figure 8.6 DRIFT-Hlotse: Predicted relative changes in birds at EFlows1, 2 and 3 for baseline, and releases of 0.4, 1.2 and 2.1 m³/s at the Hlotse Adit

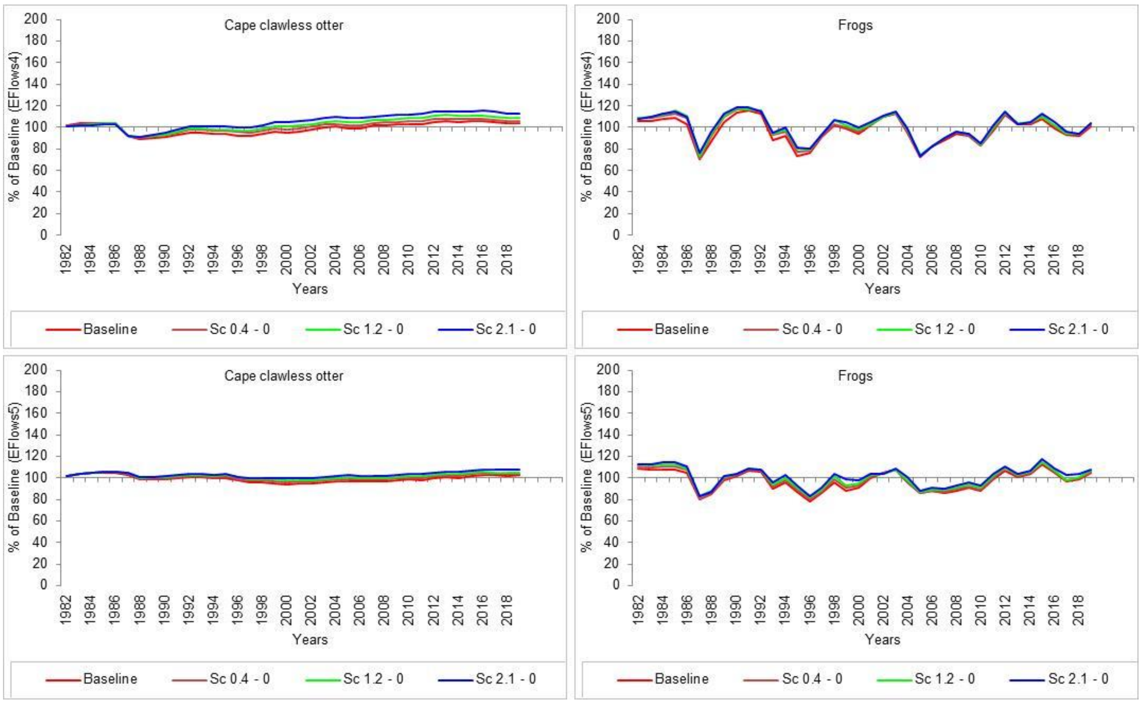


Figure 8.7 DRIFT-Hlotse: Predicted relative changes in otters and frogs at EFlows4 and 5 for baseline, and releases of 0.4, 1.2 and 2.1 m³/s at the Hlotse Adit

8.2 River-related social wellbeing

The DRIFT-Hlotse outputs for river-related social wellbeing for changes from baseline, and dry releases of 0.4, 1.2 and 2.1 m^3/s at the Hlotse Adit without any abstraction at the Hlotse Abstraction Point, are shown in Table 8.1.

Table 8.1 The DRIFT-Hlotse outputs for river-related social wellbeing for baseline, and releases of 0.4, 1.5 and 2.1 m^3/s at the Hlotse Adit; and no change in flow at EFlows4 and 5

	% Change from Base								
	Sc 0.4 - 0.0			Sc 1.2 - 0.0			Sc 2.1 - 0.0		
	Farming	Natural Resource Use	Social well-being	Farming	Natural Resource Use	Social well-being	Farming	Natural Resource Use	Social well-being
EF Zone 1									
EF Zone 2									
EF Zone 3									
EF Zone 4									
EF Zone 5									

There are no expected changes overall to the scores for natural resource use despite the increased flows being likely to result in river conditions that are less favourable than baseline for river crossings and sand mining (Figure 8.8). This is because there are little to no changes expected in cultural or spiritual activities, laundry washing, drinking water and wood harvesting. The former are usually restricted to specific locations while the latter take place at a variety of locations. Farming is expected to be slightly negatively affected by the releases (Figure 8.9) because there are fewer slower flowing sections of the river channel where the animals can safely drink or cross the river.

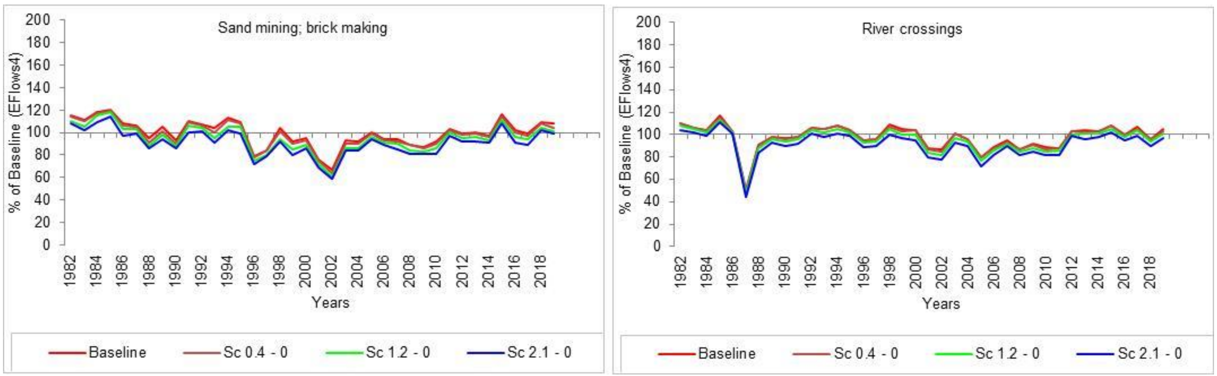


Figure 8.8 DRIFT-Hlotse: Predicted relative changes in danger associated with access to the river for sand mining and river crossings at EFlows4 for baseline, and releases of 0.4, 1.2 and 2.1 m^3/s at the Hlotse Adit

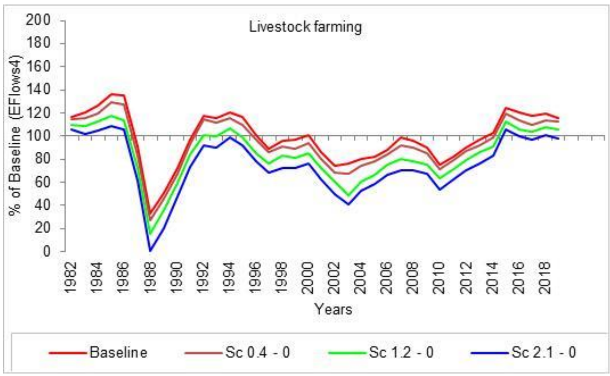


Figure 8.9 DRIFT-Hlotse: Predicted relative changes in livestock as a result of access to the river for water and ability to cross to reach grazing fields at EFlows4 for baseline, and releases of 0.4, 1.2 and 2.1 m^3/s at the Hlotse Adit

River-related social well-being at EFlows4 and 5 is expected to be unaffected by the scenarios in Set 3 (Table 8.1). The benefits of household access to piped water from the water treatment works are not included in this analysis – these benefits are likely to be realised particularly in the lower catchment along the EFlows4 and 5 reaches.

9 RESULTS: SCENARIO SET 4 – CLIMATE CHANGE

9.1 Ecological condition

Scenario Set 4 (Section 5.3.3) focusses on the possible effects of climate change in combination with releases and/or abstractions of 1.5 m^3/s from the Hlotse Adit and Hlotse Abstraction Point, respectively.

The DRIFT-Hlotse outputs for overall ecosystem integrity for baseline, and the dry climate future, Base CC D 2050 are shown in Figure 9.1. DRIFT predicts the conditions will deteriorate slightly at EFlows 2 under Base CC D 2050 through deterioration of vegetation, and improve slightly at EFlows4, mostly through improvements in the outcome for invertebrates and fish.

Figure 9.1 DRIFT-Hlotse: Predicted overall ecosystem integrity for baseline and Base CC D 2050

The DRIFT-Hlotse outputs for overall ecosystem integrity for baseline, and the four climate futures with 1.5 releases and abstractions are shown in Figure 9.2. All the scenarios show an improvement for EFlows1, 2 and 3, and all except 1.5 CC M 2035 show an improvement at EFlows4. As expected given the similarities in their hydrology (Section 5.3.3), 1.5 CC M 2035 returns similar results to Sc 1.5 - 1.5. There are no changes at EFlows5.

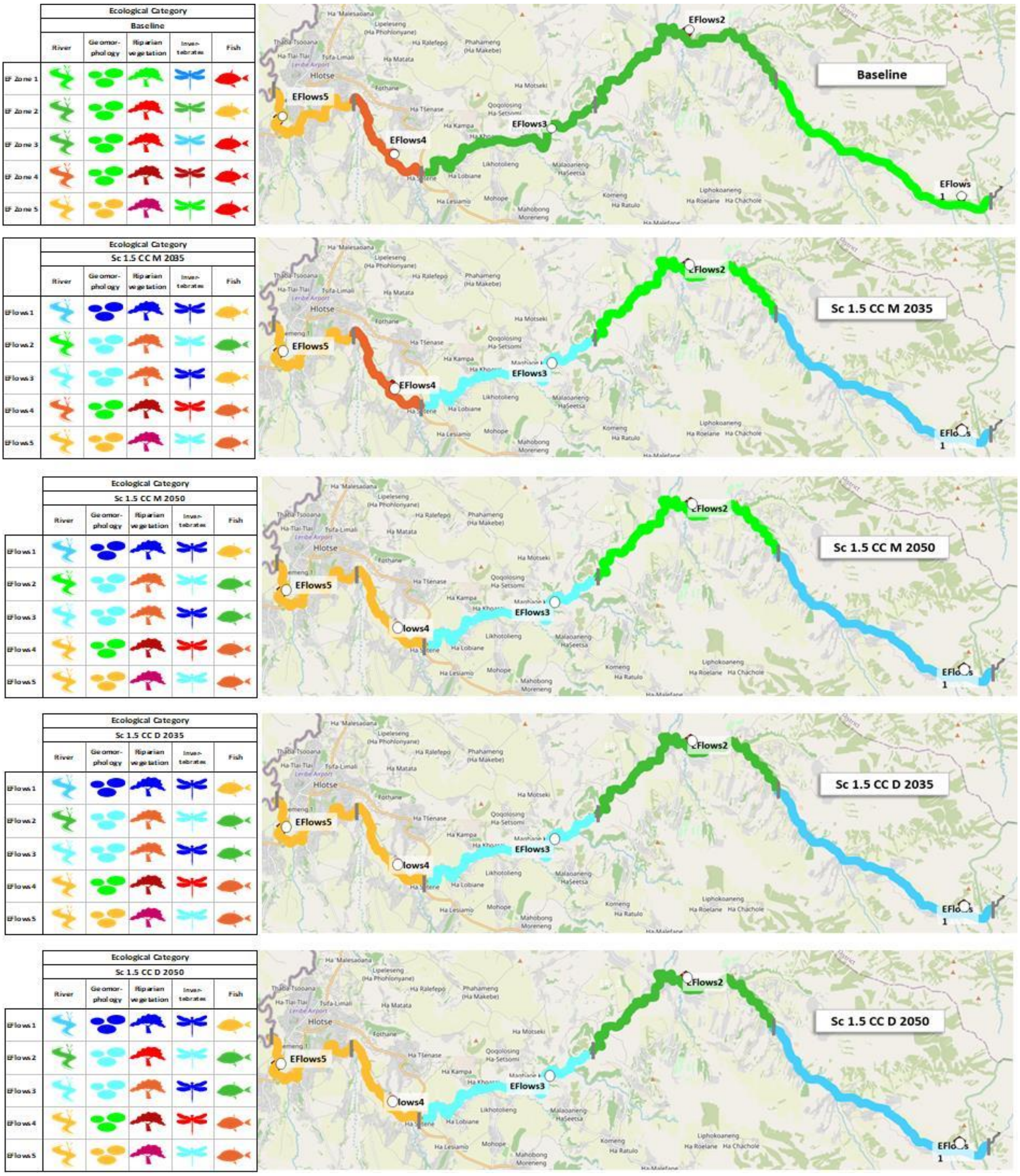


Figure 9.2 DRIFT-Hlotse: Predicted overall ecosystem integrity for baseline, and median and dry climate change at 2035 and 2050, with release and abstraction of 1.5 m^3/s

The main predictions relating to the individual disciplines are:

Geomorphology: There is expected to be little change in the fines between the baselines with and without climate change, and a reduction in fines with water released from Katse Dam via the Adit at EFlows1, 2 and 3, and little change in fines at EFlows4 and 5 (Figure 9.3).

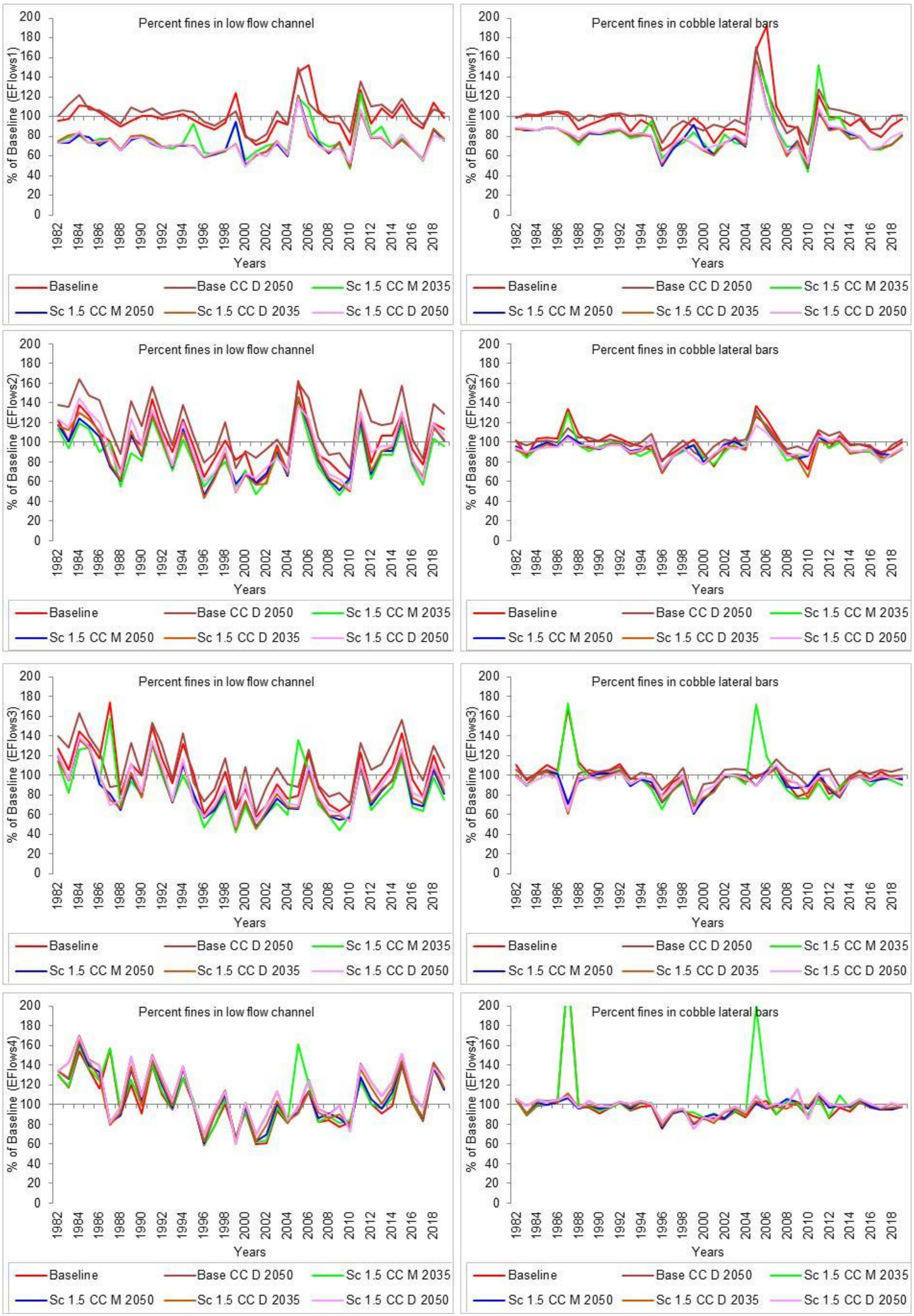


Figure 9.3 DRIFT-Hlotse: Predicted relative changes in fines at EFlows1 to 4 (changes at 5 were minor) for baseline and the median and dry climate change scenarios with release/abstraction of 1.5 m^3/s

Vegetation: There is expected to be an increase in algae and a reduction in riparian vegetation with climate change alone. When releases are made, the situation is expected to be reversed at EFlows1, 2 and 3 where the additional water in the dry season leads to a reduction in algae and an increase in riparian vegetation (Figure 9.4). There is expected to be is little change in vegetation at EFlows 4 and 5.

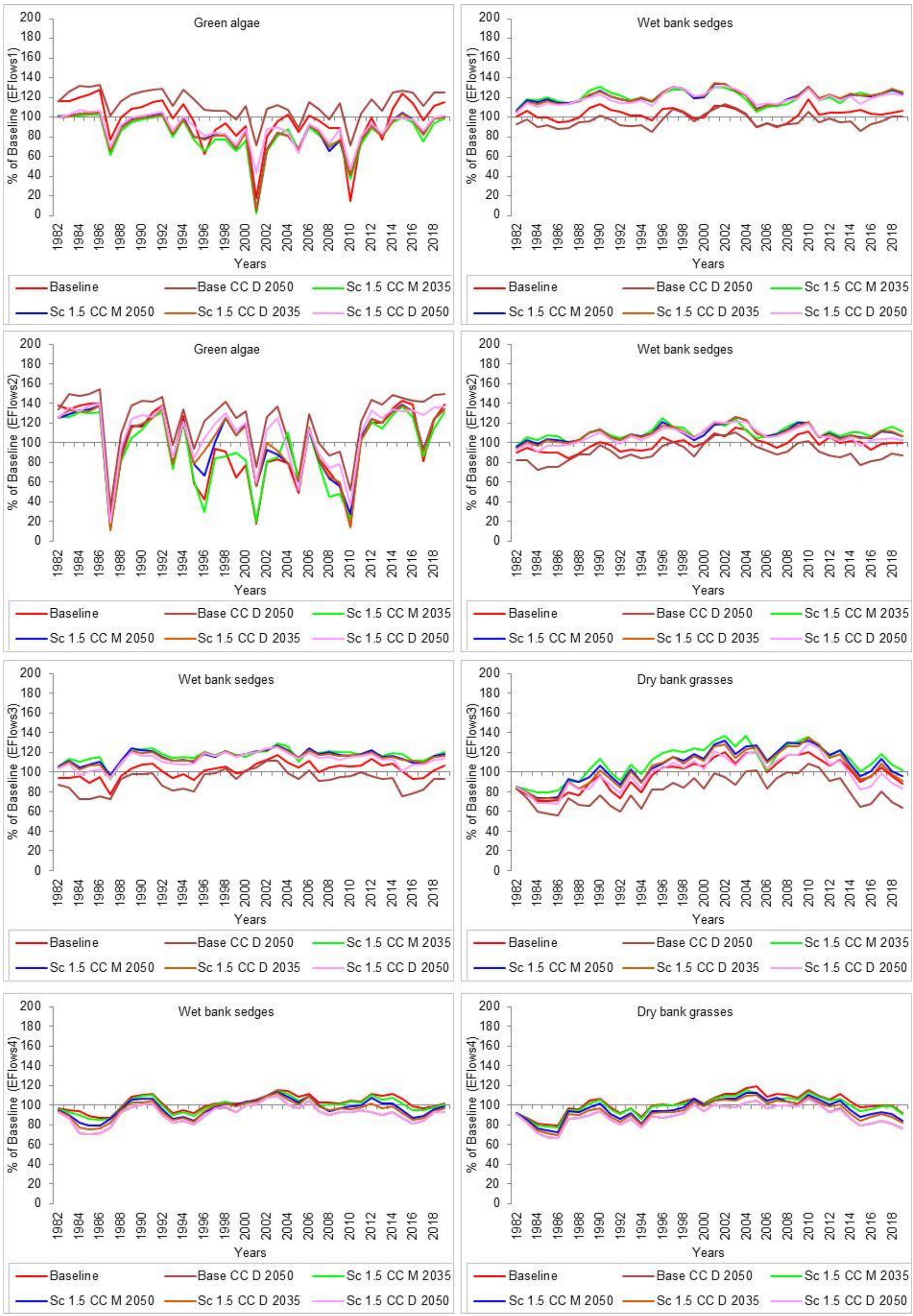


Figure 9.4 DRIFT-Hlotse: Predicted relative changes in vegetation at EFlows1 to 4 (changes at 5 were minor) for baseline and the median and dry climate change scenarios with release/abstraction of 1.5 m^3/s

Invertebrates: There is a predicted increase in caenids under climate change and a decrease with the Adit releases, as caenids prefer slower flowing water. There are fewer simulids (and baetids) with climate change and an increase in simulids (and baetids) with the releases, as they prefer faster flowing water (Figure 9.5).

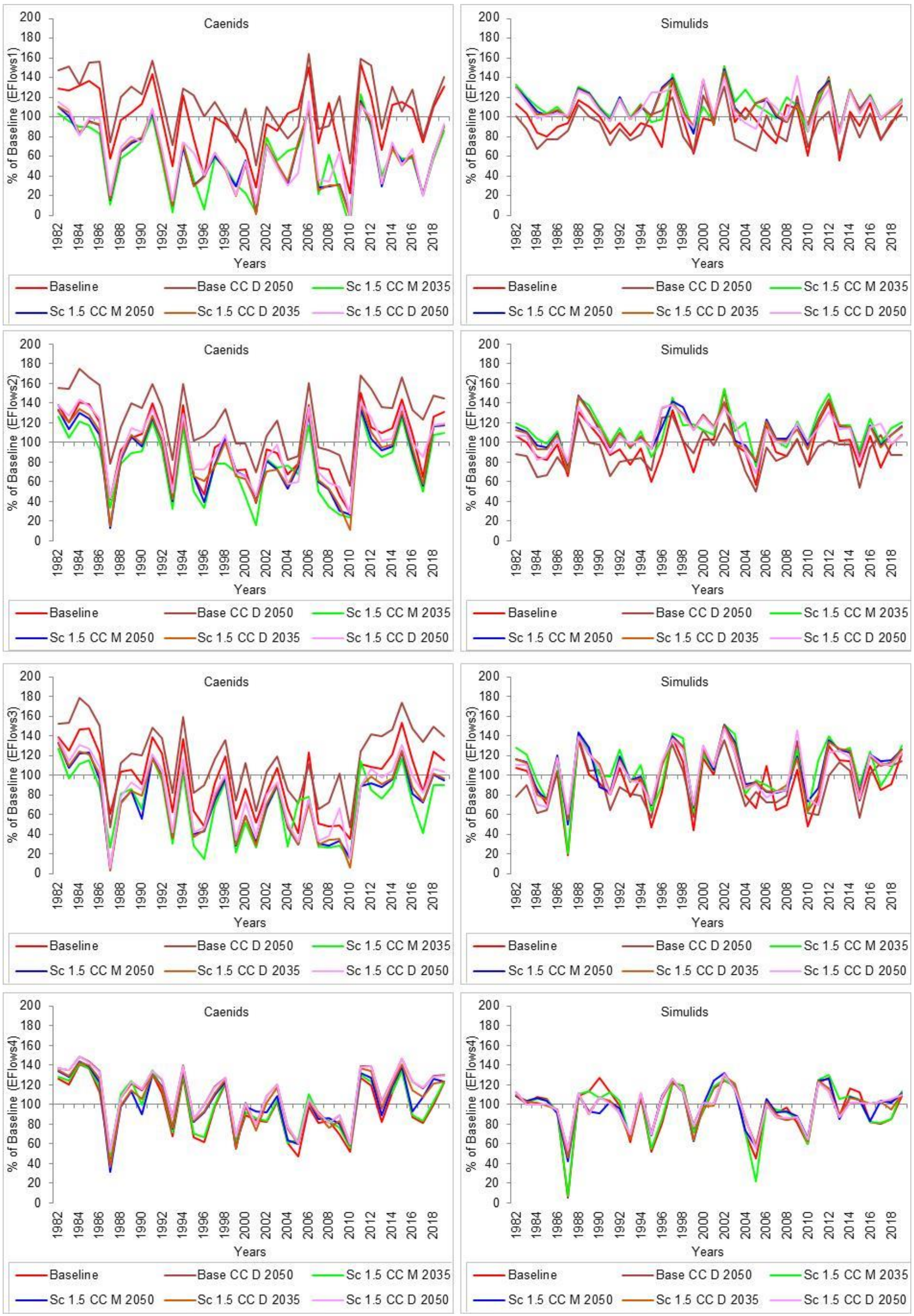


Figure 9.5 DRIFT-Hlotse: Predicted relative changes in invertebrates at EFlows1, 2, 3 and 4 (changes at 5 were minor) for baseline and the median and dry climate change scenarios with release/abstraction of 1.5 m^3/s

Fish: There is expected to be an increase in the abundance of fish at EFlows1, 2 and 3 with climate change as a result of a reduction in wet season flow, and further increases with the releases due to increased dry season flows (Figure 9.6). There is expected to be little change in fish at EFlows 4 and 5, apart from in the median 2035 scenario due to the additional 1:20 year flood.

Figure 9.6 DRIFT-Hlotse: Predicted relative changes in fish at EFlows1, 2, 3 and 4 (changes at 5 were minor) for baseline and the median and dry climate change scenarios with release/abstraction of 1.5 m^3/s

Birds: There is a decrease predicted for kingfishers under climate change due to reduced flows and an increase with the releases due to increased flow in the dry season. Wagtails are expected to increase under climate change, due to an increase in slow-shallow flow where they hunt, and with releases because of increases in riparian vegetation, where they hunt, and invertebrates upon which they feed (Figure 9.7).

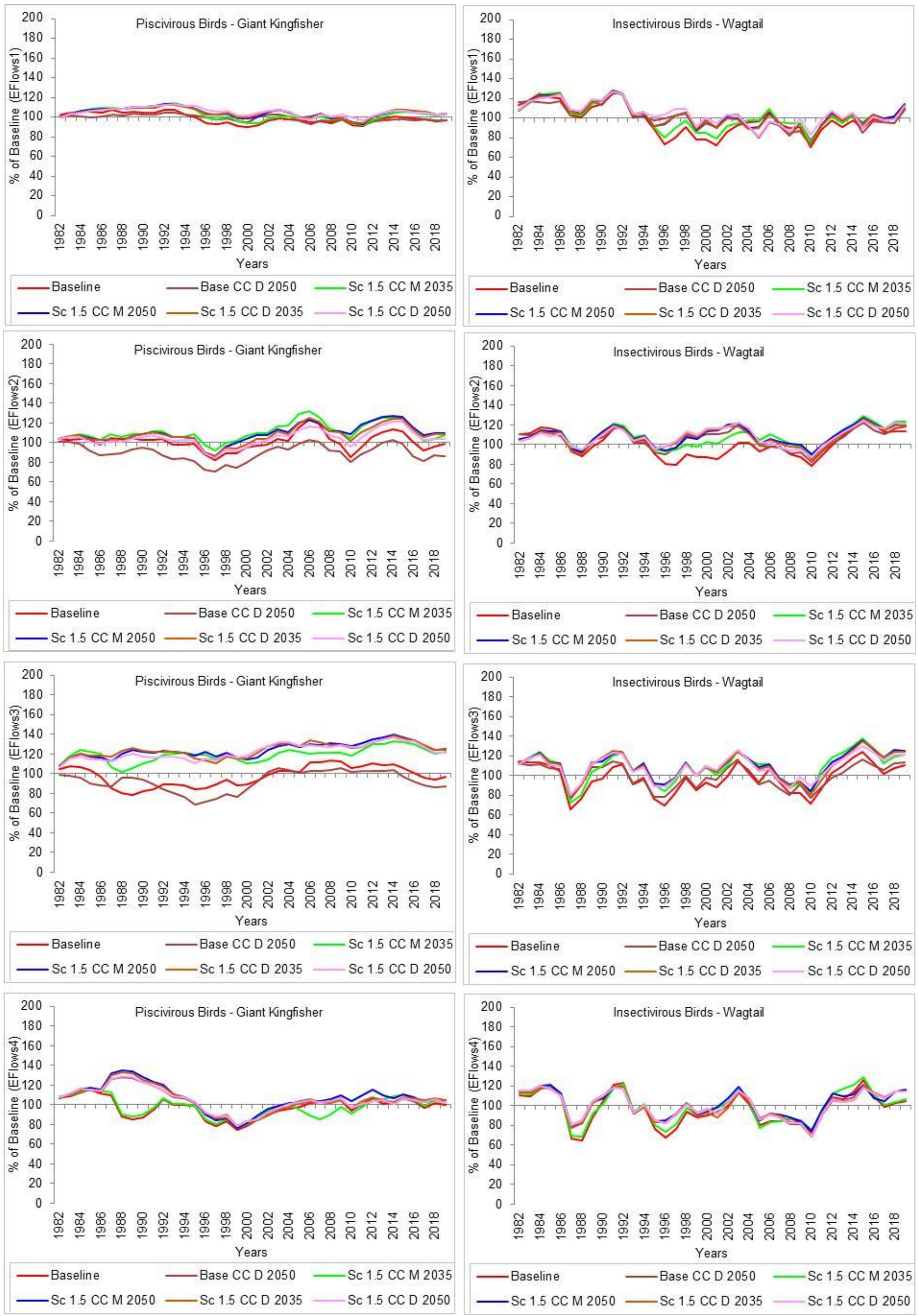


Figure 9.7 DRIFT-Hlotse: Predicted relative changes in birds at EFlows1, 2, 3 and 4 (changes at 5 were minor) for baseline and the median and dry climate change scenarios with release/abstraction of 1.5 m^3/s

Mammals and amphibians: There is little different predicted for the abundance of mammals and amphibians with climate change but there is an increase in their abundance with the releases, which provide additional water in the dry season (Figure 9.8).

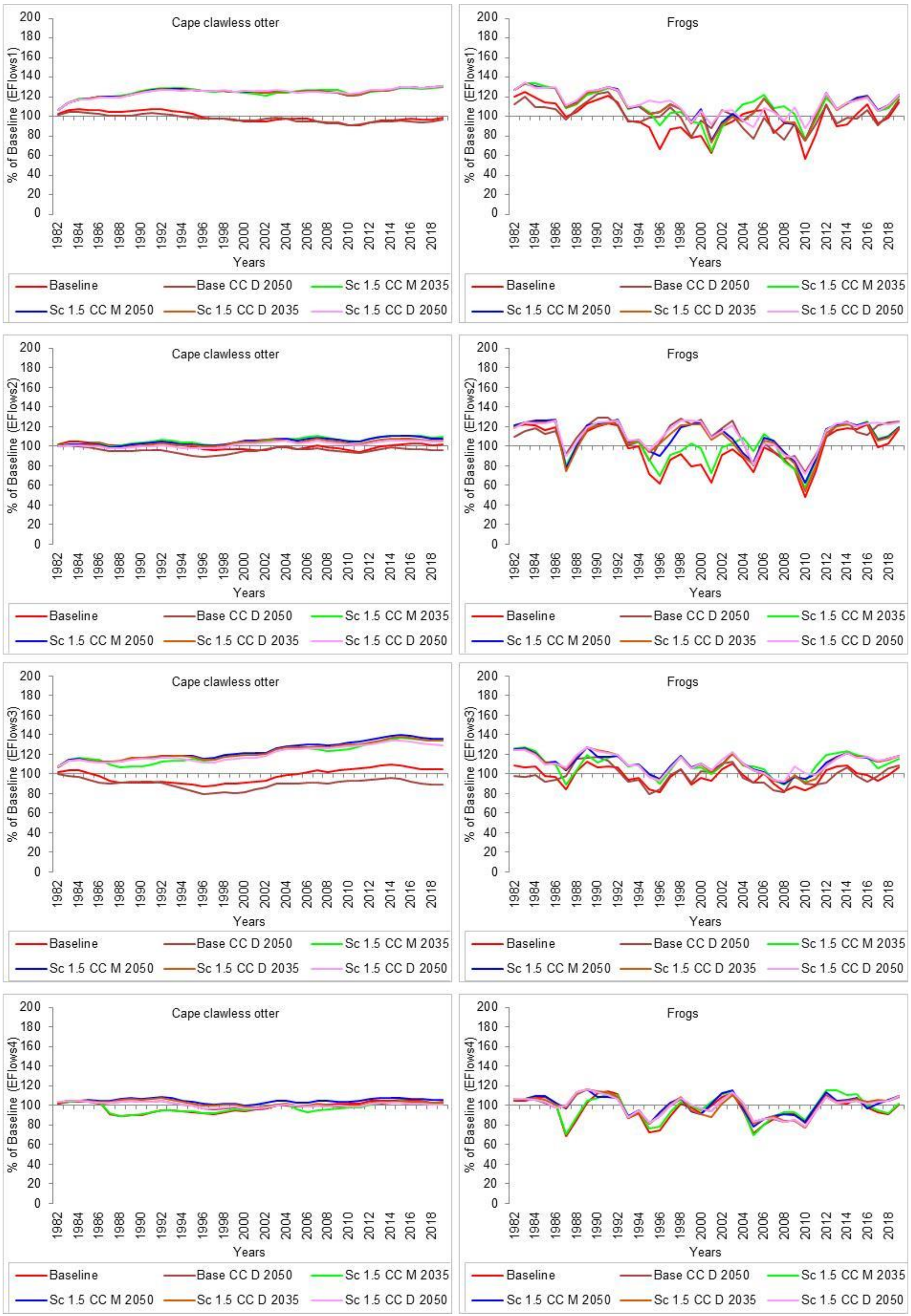


Figure 9.8 DRIFT-Hlotse: Predicted relative changes in mammals and amphibians at EFlows1, 2, 3 and 4 (changes at 5 were minor) for baseline and the median and dry climate change scenarios with release/abstraction of 1.5 m^3/s

9.2 River-related social wellbeing

The DRIFT-Hlotse outputs for river-related social wellbeing for changes from baseline, climate change and dry releases of 1.5 m^3/s at the Hlotse Adit and abstraction at the Hlotse Abstraction Point, are shown in Table 9.1.

There is expected to be a slight reduction in farming due to a reduction in water for livestock (Figure 9.9) in the climate change scenarios and access being made more difficult with the releases at EFlows1, 2 and 3, which cause a slight reduction in natural resource use due to a decrease in sand/stone mining. At EFlows4 and 5, there is a slight improvement in farming predicted due to an increase in slow-shallow habitat for watering animals.

Table 9.1 The DRIFT-Hlotse outputs for river-related social wellbeing for climate change superimposed on baseline and 1.5 release and abstractions

	% Change from Base								
	Base CC D 2050			Sc 1.5 CC M 2035			Sc 1.5 CC M 2050		
	Farming	Natural Resource Use	Social well-being	Farming	Natural Resource Use	Social well-being	Farming	Natural Resource Use	Social well-being
EF Zone 1									
EF Zone 2									
EF Zone 3									
EF Zone 4									
EF Zone 5									

				Sc 1.5 CC D 2035			Sc 1.5 CC D 2050		
				Farming	Natural Resource Use	Social well-being	Farming	Natural Resource Use	Social well-being

Overall there are no changes expected in social well-being despite the slight declines in farming and sand mining. The benefits of household access to piped water from the water treatment works are not included in this analysis – these benefits are likely to be realised particularly in the lower catchment along the EFlows4 and 5 reaches.

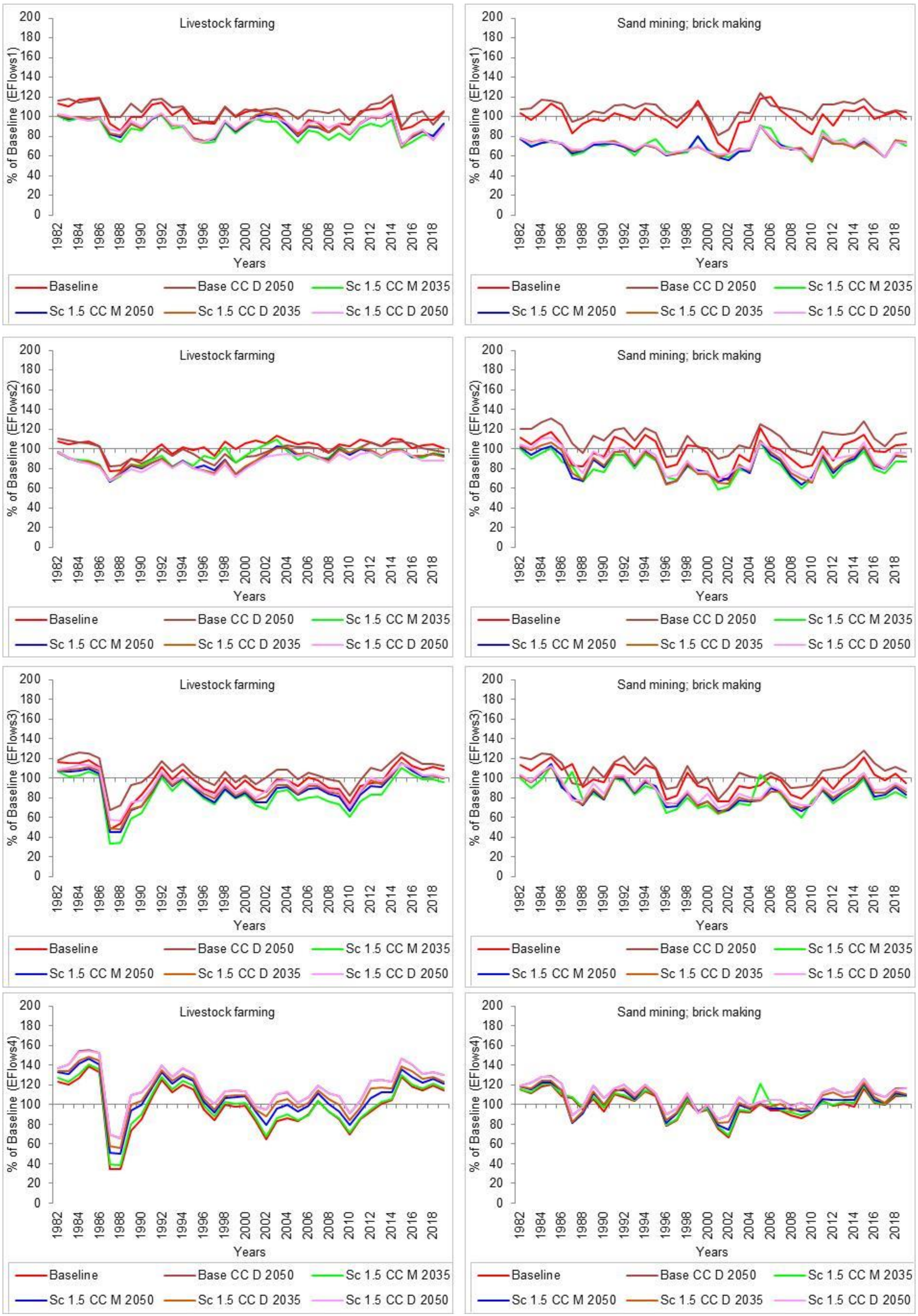


Figure 9.9 DRIFT-Hlotse: Predicted relative changes in livestock farming and sand mining at EFlows1, 2, 3 and 4 (change at 5 were minor) for baseline and the median and dry climate change scenarios with release/abstraction of 1.5 m^3*/s*

10 RESULTS: SCENARIO SET 5 - REDUCTION IN FLOWS IN HLOTSE RIVER (WITH A FOCUS ON EFLOWS4)

The Set 5 scenarios have reduced baseflows and a decreased number of (small) intra-annual floods, and were only run at EFlows4. The results of Set 5 are compared to the Set 2 to 4 scenarios with a view to identifying those that maintain or improve the ecological condition of the river.

10.1 Ecological condition

The overall ecosystem integrity scores for each of the scenarios in Set 5 are plotted in Figure 10.1 and against MAR at EFlows4 in Figure 10.2. Figure 10.2 can be used to identify scenarios that would facilitate maintenance of Baseline condition (category D/E) and half a category higher (category D) and the flow regime associated with each.

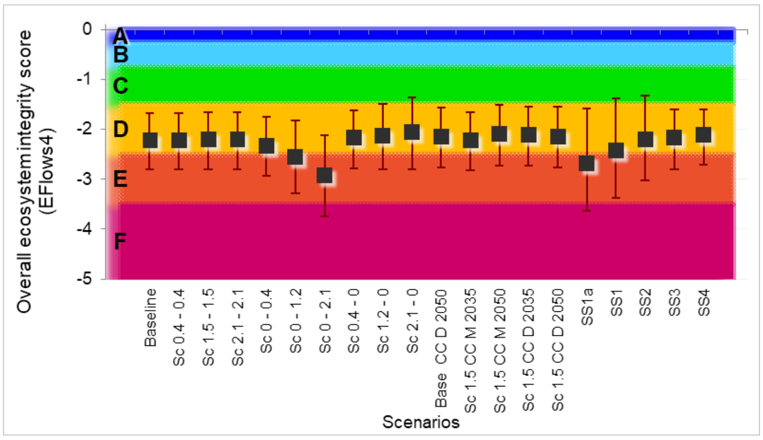


Figure 10.1 Overall ecosystem integrity scores vs MAR for the scenarios at EFlows4

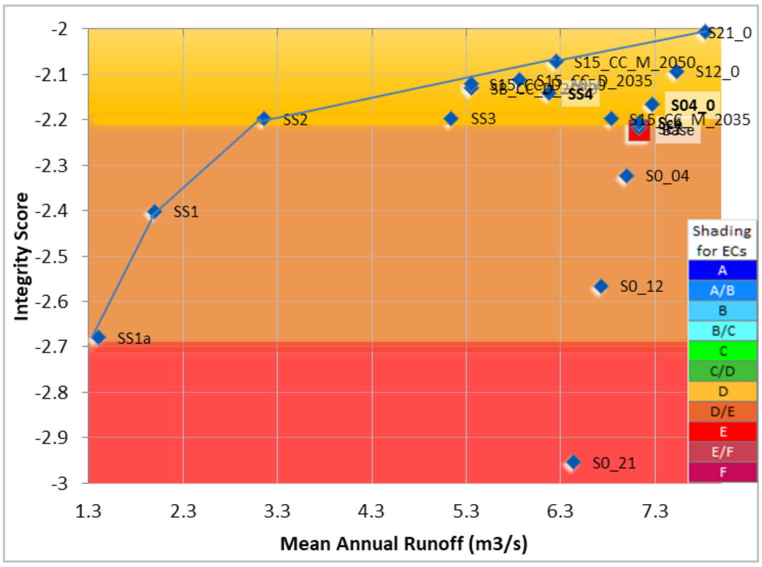


Figure 10.2 Overall ecosystem integrity scores vs MAR for the scenarios at EFlows4

A D-category is widely considered to be the minimum category for sustainability. The results shown in Figure 10.1 and Figure 10.2 suggest that:

- Without the Hlotse Adit:

- SS1a would mean a decline to an E category, even if the non-flow related impacts were addressed.
- SS1 and SS2 should maintain the river in a D/E category (i.e. the same as the Baseline), provided all of the non-flow related impacts on condition, such as sediment supply and removal of vegetation are addressed.
- SS3 and SS4 would support a D condition, a slight improvement (half a category) from Baseline.

- With the Hlotse Adit:
  - and corresponding abstractions: Sc 0.4-0.4, Sc 1.5-1.5, or Sc 2.1-2.1 would maintain a D/E.
  - and no abstractions: scenarios Sc 0.4-0, Sc 1.2-0, or Sc 2.1-0 would (just) support a D ecological condition, a slight improvement from Baseline.
- With climate change:
  - Base CC D 2050, Sc 1.5 CC M 2050, Sc 1.5 CC D 2035, and Sc 1.5 CC D 2050 would support a D condition at EFlows4, a slight improvement (half a category) from Baseline, but that Sc 1.5 CC M 2035 would maintain a D/E.

The more detailed results in Figure 10.3 suggest that Sc 04-0 slightly outperforms the others in terms of impacts on individual disciplines.

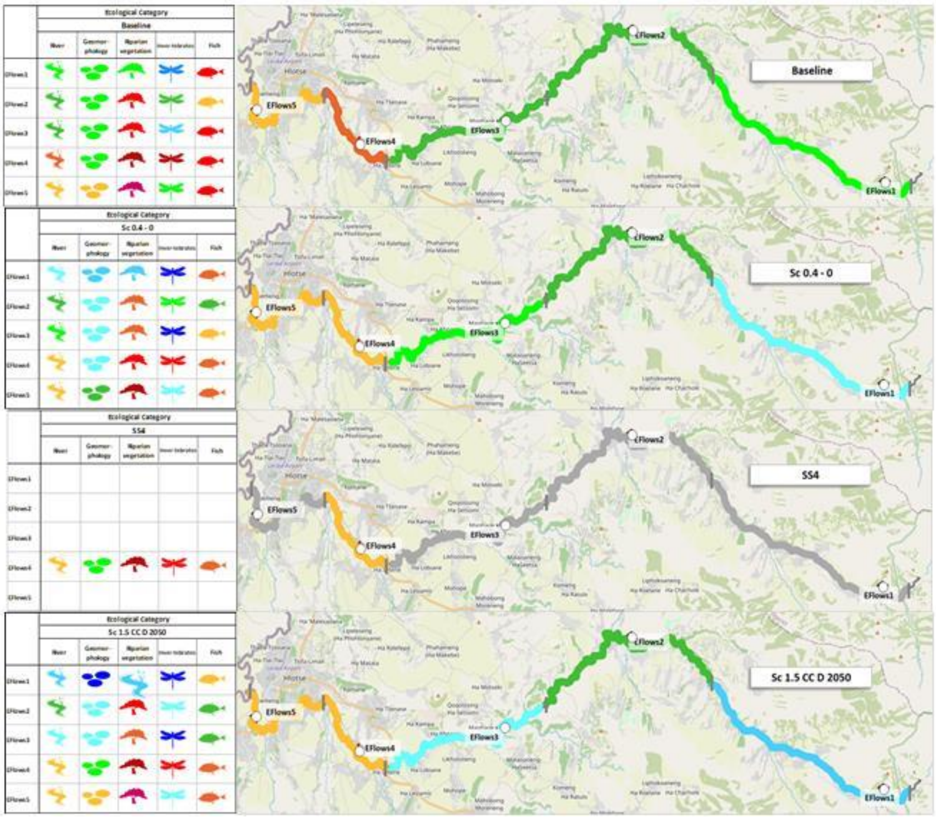


Figure 10.3 Overall ecosystem integrity for the Baseline and four scenarios that result in a D ecological condition at EFlows4 (SS4 was only run at EFlows4)

10.2 River-relative social well-being

The Set 5 scenarios were predicted to have no, or slightly positive impacts on social well-being at EFlows4 as did the climate change scenarios. The Set 3 scenarios, apart from Sc 04-0, were expected to have slightly negative impacts on farming, and in the case of Sc 21-0 a slightly negative impact on overall river-related social well-being. Figure 10.4 shows the river-related social results for the same scenarios as in Figure 10.3.

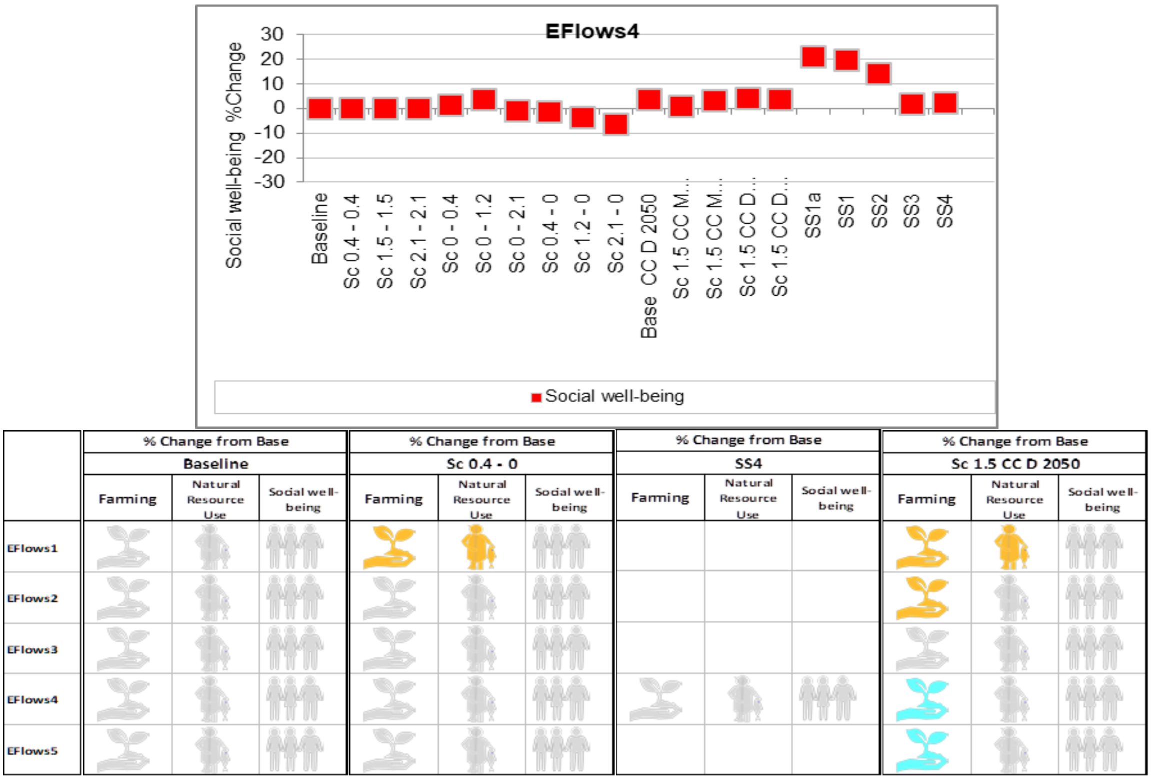


Figure 10.4 River-related farming, natural resource use and overall social well-being at EFlows4 for all scenarios (top) and the same scenarios as displayed in Figure 10.3 (bottom)

10.3 Summary of flow regimes for SS4 and Sc 04-0

On the basis of the results in Figure 10.2, SS4 and Sc 04-0 are predicted to maintain a D category at EFlows4:

- SS4 would apply in the absence of the Hlotse Adit
- Sc 0.4-0 would apply once the Hlotse Adit is in place. Note that Sc 0.4-0 could represent other scenarios, for example, a scenario with a 1.2 m^3/s release and a 0.8 m^3/s abstraction.

Table 10.1 EFlows regimes predicted to maintain a D category at EFlows4

EFSite4	D category without Adit	D category D with Adit
	SS4	Sc 04-0

The flow regimes linked with SS4 and Sc 04.0 are provided in Table 10.2 and Table 10.3, respectively. These flows should be met at Gauge CG25, which is just downstream of the Hlotse Abstraction Point and just upstream of EFlows4.

Table 10.2 EFlows4: Summary of SS4 flow regime. The information is in the format traditionally used for "Reserves" in South Africa. "Lowflows" are the recommended baseflows and Highflows are the recommended intra-annual floods. Appendix B contains the tables and rule curves in MCM and m^3/s

<table>
<tr><th colspan="7">EFlows summary for SS4</th></tr>
<tr><td rowspan="4"></td><td>Low flows</td><td>High flows (excl. >1:2 yr)</td><td>Class1</td><td>Class2</td><td>Class3</td><td>Class4</td></tr>
<tr><td rowspan="3">Ecological Category: D</td><td>Discharge (m3/s)</td><td>7.30</td><td>17.50</td><td>34.10</td><td>61.70</td></tr>
<tr><td>Duration (days)</td><td>3</td><td>5</td><td>5</td><td>6</td></tr>
<tr><td>Number</td><td>15</td><td>7</td><td>3</td><td>1</td></tr>
<tr><td>Month</td><td>Discharge (m^3/s)</td><td>Monthly volume (10^6m^3)</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Oct</td><td>2.22</td><td>5.95</td><td>1</td><td rowspan="3">3</td><td></td><td></td></tr>
<tr><td>Nov</td><td>3.00</td><td>7.79</td><td>1</td><td rowspan="2">1</td><td></td></tr>
<tr><td>Dec</td><td>3.66</td><td>9.79</td><td>1</td><td rowspan="6">1</td></tr>
<tr><td>Jan</td><td>4.18</td><td>11.19</td><td>1</td><td rowspan="4">4</td><td rowspan="3">2</td></tr>
<tr><td>Feb</td><td>4.90</td><td>11.85</td><td>1</td></tr>
<tr><td>Mar</td><td>5.89</td><td>15.79</td><td>2</td></tr>
<tr><td>Apr</td><td>4.53</td><td>11.74</td><td>1</td><td></td></tr>
<tr><td>May</td><td>3.86</td><td>10.33</td><td>2</td><td></td><td></td></tr>
<tr><td>Jun</td><td>3.67</td><td>9.52</td><td>2</td><td></td><td></td><td></td></tr>
<tr><td>Jul</td><td>3.15</td><td>8.43</td><td>1</td><td></td><td></td><td></td></tr>
<tr><td>Aug</td><td>2.44</td><td>6.54</td><td>1</td><td></td><td></td><td></td></tr>
<tr><td>Sep</td><td>1.95</td><td>5.06</td><td>1</td><td></td><td></td><td></td></tr>
<tr><td>Vol (10^6m^3)</td><td></td><td>113.98</td><td>20.3</td><td>25.2</td><td>22.1</td><td>11.0</td></tr>
<tr><td>% Base MAR</td><td></td><td>44.02</td><td>7.82</td><td>9.73</td><td>8.52</td><td>4.26</td></tr>
</table>

```
AEC1                    SS4
MAR                     258.951 MCM
S.Dev.                  16.663
CV                      0.064
Q75                     8.1928325
Ecological Category     D
                        MCM        % MAR
Total IFR               193.173    74.598 (excl. >=1:2)     (Incl. >=1:2 = 83.209)
Maint. Lowflow          113.978    44.015
Drought Lowflow         54.065     20.879
Maint. Highflow         79.195     30.583
```

```
Monthly Distributions (m³/s)
Month   Baseline Flows    Modified Flows (IFR)
                          Low flows             High Flows   Total Flows
        Mean              Maint.     Drought    Maint.       Maint.
Oct      3.989            2.222      1.443      1.474         3.696
Nov      7.773            3.004      1.460      3.285         6.289
Dec     10.564            3.656      1.478      3.820         7.477
Jan     13.415            4.179      1.544      4.529         8.708
Feb     16.768            4.897      2.157      4.761         9.657
Mar     15.023            5.895      3.421      4.934        10.829
Apr     11.163            4.530      1.565      3.905         8.435
May      6.539            3.857      1.521      1.521         5.378
Jun      4.752            3.675      1.521      0.668         4.342
Jul      3.416            3.147      1.519      0.212         3.359
Aug      3.064            2.442      1.503      0.596         3.037
Sep      2.689            1.951      1.455      0.596         2.547
```

Table 10.3 EFlows4: Summary of Sc 04-0 flow regime. The information is in the format traditionally used for "Reserves" in South Africa. "Lowflows" are the recommended baseflows and Highflows are the recommended intra-annual floods. Appendix B contains the tables and rule curves in MCM and m^3/s

<table>
<tr><td colspan="7">EFlows summary for Sc 04-0</td></tr>
<tr><td rowspan="4"></td><td>Low flows</td><td>High flows (excl. >1:2 yr)</td><td>Class1</td><td>Class2</td><td>Class3</td><td>Class4</td></tr>
<tr><td rowspan="3">Ecological Category: D</td><td>Discharge (m3/s)</td><td>7.30</td><td>17.50</td><td>34.10</td><td>61.70</td></tr>
<tr><td>Duration (days)</td><td>3</td><td>5</td><td>5</td><td>6</td></tr>
<tr><td>Number</td><td>16</td><td>7</td><td>4</td><td>2</td></tr>
<tr><td>Month</td><td>Discharge (m³/s)</td><td>Monthly volume (10⁶m³)</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Oct</td><td>2.49</td><td>6.68</td><td>1</td><td rowspan="3">2</td><td></td><td></td></tr>
<tr><td>Nov</td><td>3.90</td><td>10.12</td><td>1</td><td rowspan="2">2</td><td></td></tr>
<tr><td>Dec</td><td>5.61</td><td>15.02</td><td>1</td><td rowspan="3">1</td></tr>
<tr><td>Jan</td><td>6.85</td><td>18.34</td><td>1</td><td rowspan="4">4</td><td rowspan="3">2</td></tr>
<tr><td>Feb</td><td>8.19</td><td>19.81</td><td>1</td></tr>
<tr><td>Mar</td><td>9.18</td><td>24.60</td><td>2</td><td rowspan="3">1</td></tr>
<tr><td>Apr</td><td>6.88</td><td>17.82</td><td>1</td><td></td></tr>
<tr><td>May</td><td>5.43</td><td>14.54</td><td>2</td><td rowspan="5">1</td><td></td></tr>
<tr><td>Jun</td><td>4.62</td><td>11.98</td><td>2</td><td></td><td></td></tr>
<tr><td>Jul</td><td>3.61</td><td>9.68</td><td>1</td><td></td><td></td></tr>
<tr><td>Aug</td><td>2.85</td><td>7.63</td><td>1</td><td></td><td></td></tr>
<tr><td>Sep</td><td>2.42</td><td>6.27</td><td>2</td><td></td><td></td></tr>
<tr><td>Vol (10⁶m³)</td><td></td><td>162.5</td><td>21.6</td><td>25.2</td><td>28.2</td><td>24.3</td></tr>
<tr><td>% nMAR</td><td></td><td>62.8</td><td>8.3</td><td>9.7</td><td>10.9</td><td>9.4</td></tr>
</table>

```
AEC2                    Sc 04-0
MAR                     258.951 MCM
S.Dev.                  16.663
CV                      0.064
Q75                     8.1928
Ecological Category     D
                        MCM        % MAR
Total IFR               242.865    93.788 (excl. >=1:2)     (Incl.     >=1:2     =
101.628)
Maint. Lowflow          162.500    62.753
Drought Lowflow         54.065     20.879
Maint. Highflow         80.365     31.035

Monthly Distributions (m3/s)
Month   Baseline Flows     Modified Flows (IFR)
                           Low flows            High Flows    Total Flows
        Mean               Maint.     Drought   Maint.        Maint.
Oct      3.989             2.495      1.443     1.494          3.989
Nov      7.773             3.904      1.460     3.543          7.447
Dec     10.564             5.609      1.478     4.093          9.702
Jan     13.415             6.847      1.544     5.074         11.921
Feb     16.768             8.189      2.157     5.288         13.477
Mar     15.023             9.185      3.421     4.454         13.639
Apr     11.163             6.877      1.565     3.715         10.591
May      6.539             5.429      1.521     1.110          6.539
Jun      4.752             4.622      1.521     0.529          5.152
Jul      3.416             3.613      1.519     0.203          3.816
Aug      3.064             2.848      1.503     0.616          3.464
Sep      2.689             2.419      1.455     0.670          3.089
```

A D category, i.e., higher than Base2021, is not expected to be maintained through application of EFlows alone; the 'one-up' D category will not be achieved without addressing the many non-flow related impacts (Baseline Report, Multiconsult 2022b).

11 RECOMMENDATIONS

11.1 Guidelines for release and abstraction volumes

With respect to the volumes released from the Hlotse Adit and abstracted at the Hlotse Abstraction Point, the guidelines are:

1. Releases from the Hlotse Adit should not exceed 1.7 m^3/s (but see Note 2 below)
2. Releases should be implemented gradually in a manner that limits water level changes in the downstream river (EFlows1) of no more than 0.05 m/hour (MRC 2020)
3. Abstractions from the Hlotse Abstraction Point should not exceed releases from the Hlotse Adit, plus losses in the channel, and should allow ~0.4 m^3/s of the released water to remain in the river, in addition to the water supplied by the Hlotse catchment.

The guidelines arose from an assessment of the planned release and abstraction volumes, however, from the perspective of the river and the people reliant on it, if and when the releases from the Hlotse Adit are increased to 1.53 m^3/s (Section 4), for them to rather be extended to an additional month of releases (i.e., May), possibly with some variation to mimic the natural hydrograph, than for higher volumes being released in June, July, August and September. This possibility was not included in the scenarios, but judging from the other results, would provide a more favorable outcome than higher releases limited to four months.

With respect the river downstream of the Hlotse Abstraction Point, it is far better from an ecological and social perspective to err on the site of caution and abstract slightly less at the Abstraction point than is released at the Adit (after in-channel losses have been accounted for). Indeed, the ~0.4 m^3/s has already been catered for in the planned release schedules (see Environmental Flows Requirements in Table 4.1). Given the downstream benefits of leaving some additional water in the system over the dry months, and the dis-benefits of abstracting too much water from the system, the higher allowance of losses is the precautionary approach.

These recommendations assume that the guidelines for releases and abstractions (Section 5.1) are adhered to. They will also require re-evaluation should additional medium or large-scale[15] abstractions or water-resource development be planned or implemented in the Hlotse River, or if abstractions and releases are planned outside of the dry season window assessed, *viz.* June, July, August and September.

11.1.1 *Guidelines for releases*

Releases should be implemented in a manner that limits water level changes (up or down) at EFlows1 to ⩽ 0.05 m/hour (see Chapter 5.1.1 and MRC 2020). Small increases in discharge will increase water depth in the channel by 0.05 m increments when discharge is low (Table 11.1)[16]. As

[15] Relative to the MAR of the Hlotse River

[16] Values provided are for the cross-section across the rapid, cross-section 1.6 (Hydraulics and Hydrodynamics Report, Multiconsult 2022c).

discharge in the channel increases, larger increases are required to increase water depth. These values for increases in discharge can be used to guide the slow and steady increases in discharge at 0.05 m increments at EFlows1. The time taken for the different discharges to move down river from the Hlotse Adit to EFlows1 must be determined by measuring discharge at EFlows1 during calibration when the operating rules are finalised in the future.

Table 11.1 The relationship between discharge and water depth in the channel at EFlows1

Discharge (Q) (m^3/s)	Water depth (m)	Increase in Q (m^3/s)
0.01	0.10	
0.04	0.15	0.03
0.08	0.20	0.04
0.16	0.25	0.08
0.28	0.30	0.12
0.45	0.35	0.17
0.73	0.40	0.28
0.97	0.44	0.24
1.42	0.50	0.45
1.89	0.55	0.47

11.1.2 Guidelines for abstraction

From the time that water is first released into the Hlotse River at the Holste Adit, it takes several days to reach the Hlotse Abstraction Point. Higher discharges released will arrive more quickly than lower discharges. For this reason:

- abstractions at the Hlotse Abstraction Point should not commence before the discharge readings at the nearest downstream gauge (CG25) indicate that the water from the Hlotse Adit has arrived.

At this stage this is Gauge CG25, which is just downstream of the Hlotse Abstraction Point and just upstream of EFlows4 (Figure 2.1).

The same applies when the releases stop, i.e.:

- abstractions at the Hlotse Abstraction Point should stop once the discharge readings at the upstream nearest gauge indicates that the flows have dropped back down to pre-release levels.

At this stage this is Gauge TS3, which is between EFlows1 and 2 (Figure 2.1)

Once there is a coordinated test release against which the hydrodynamic model can be calibrated, it will be possible to produce a table of water travel times down the Hlotse River between the Hlotse Adit and Abstraction Point at different discharges released. However, given that no test release was possible during the EFlows study, the hydrodynamic model is currently calibrated again a 2018 test release, which was not ideal as the 2018 test release coincided with a natural flood in the system.

11.2 EFlows for possible future reductions in flow in Hlotse River

The recommendation with respect to the upper limits and timing of releases from Hlotse Adit are provided in Section 11.1. This section provides the recommendations with respect to limits on other abstractions from the Hlotse River to facilitate maintenance of a D-category ecological status.

The values provided are for the river at Gauge CG25 for:

- Option 1 (Table 11.2): Without the Hlotse Adit in place.
- Option 2 (Table 11.3): With the Hlotse Adit in place.

The overall ecosystem condition predicted to result from the proposed operation of the Hlotse Adit and Abstraction Point is shown in Figure 11.1: a release of ~1.5 m^3/s in the dry season, losses along the river through EFlows1-3 of ~0.4 m^3/s, abstraction of ~0.7 m^3/s, and an environmental flow of 0.4 m^3/s moving past the Abstraction Point through EFlows4 and 5. The increased flows in the dry season are expected to result in an improvement in condition at EFlows1-4 and no change in condition at EFlows5.

Figure 11.1 Overall ecosystem integrity for the proposed operation of the Hlotse Adit and Abstraction point by 2045 (Table 4.1)

11.3 Summary of results for all scenarios

A summary of the Ecosystem Integrity and river-related Social Well-being results for all the scenarios analysed are provided in Appendix Figure 1. A summary of the pre- and post- Adit recommended flow regimes at EFlows4 is provided below and more details are provided in Appendix B.

Table 11.2 EFlows provisions at Gauge CG25 to maintain a D-category (Option 1: SS4 – no Adit)

Month	Low flows (excludes all floods (m^3/s) Monthly average	Floods (Average daily peak) Class 1: 7.30 m^3/s ~ 3days duration	Class 2: 17.50 m^3/s ~ 5days duration	Class 3: 34.10 m^3/s ~ 5days duration	Class 4: 61.70 m^3/s ~ 6days duration	Inter-annual floods	TOTAL volumes $M.m^3$
Oct	2.22	1	3			Not included in EFlows volume	Excluding inter-annual floods 193
Nov	3.00	1		1			
Dec	3.66	1			1		
Jan	4.18	1	4	2			
Feb	4.90	1					
Mar	5.89	2					
Apr	4.53	1					Including inter-annual floods 213
May	3.86	2					
Jun	3.67	2					
Jul	3.15	1					
Aug	2.44	1					
Sep	1.95	1					
$M.m^3$		20.3	25.2	22.1	11.0	20	
%MAR		**7.82**	**9.73**	**8.52**	**4.26**		

Table 11.3 EFlows provisions at Gauge CG25 to maintain a D-category (Option 2: Sc 04-0 - Adit)

Month	Low flows (excludes all floods (m^3/s) Monthly average	Floods (Average daily peak) Class 1: 7.30 m^3/s ~ 3days duration	Class 2: 17.50 m^3/s ~ 5days duration	Class 3: 34.10 m^3/s ~ 5days duration	Class 4: 61.70 m^3/s ~ 6days duration	Inter-annual floods	TOTAL volumes $M.m^3$
Oct	2.49	1	2			Not included in EFlows volume	Excluding inter-annual floods 243
Nov	3.90	1		2			
Dec	5.61	1			1		
Jan	6.85	1	4	2			
Feb	8.19	1					
Mar	9.18	2			1		
Apr	6.88	1					Including inter-annual floods 263
May	5.43	2	1				
Jun	4.62	2					
Jul	3.61	1					
Aug	2.85	1					
Sep	2.42	2					
$M.m^3$		21.6	25.2	28.2	24.3	20	
%MAR		**8.3**	**9.7**	**10.9**	**9.4**		

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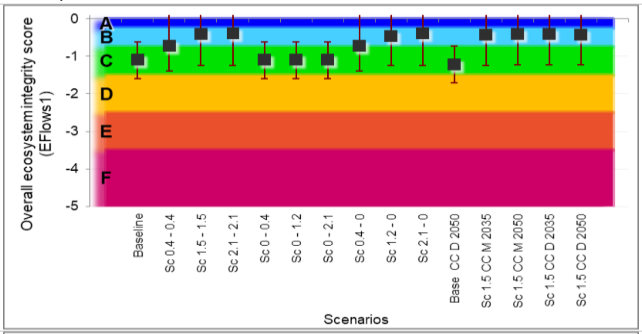
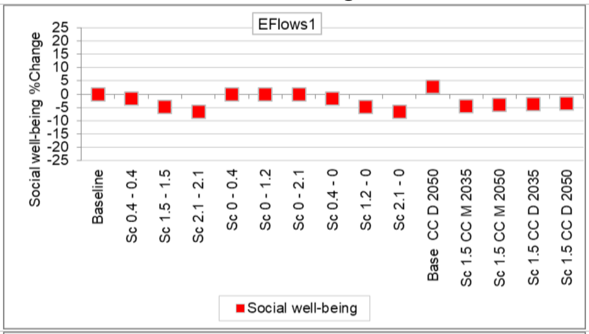
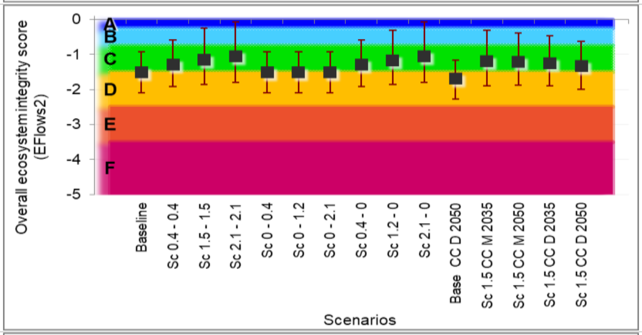
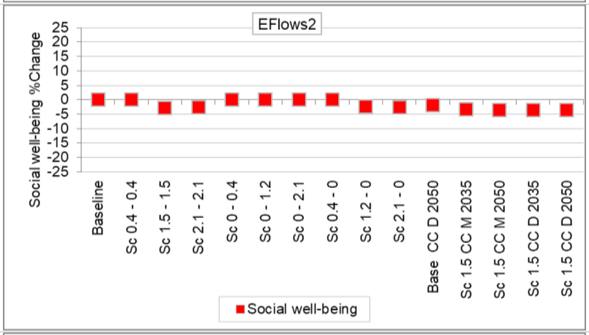
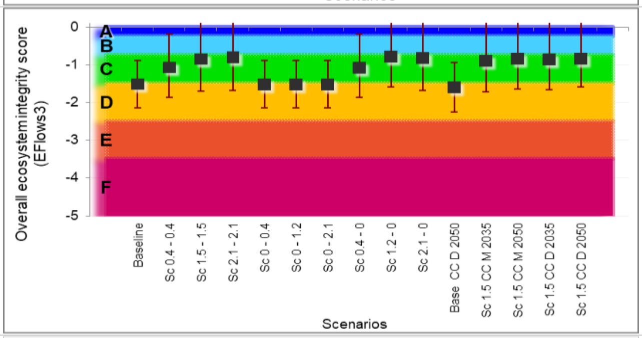
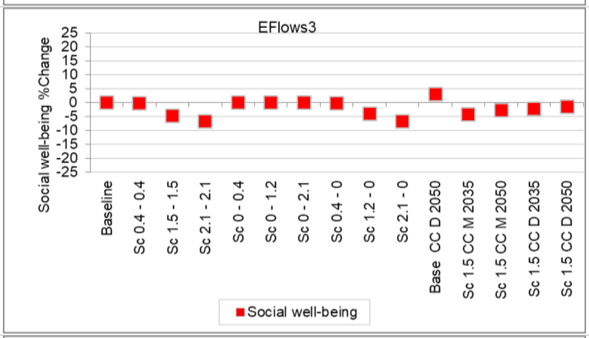
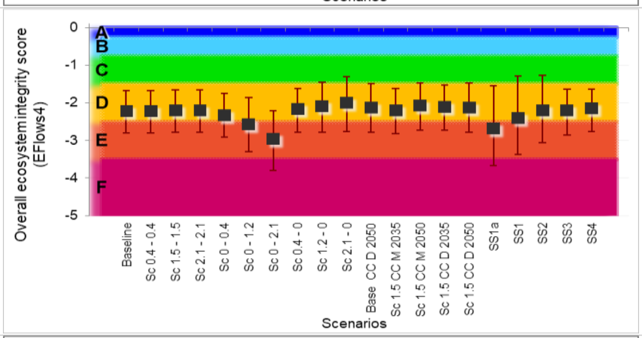
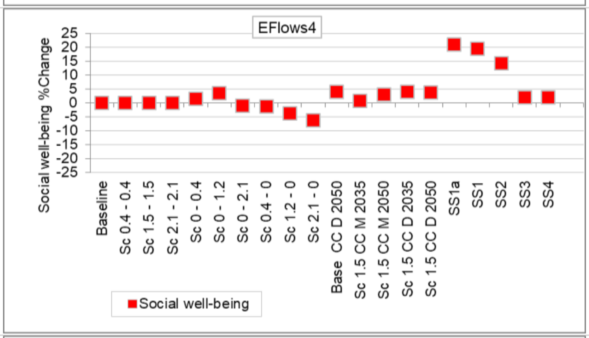
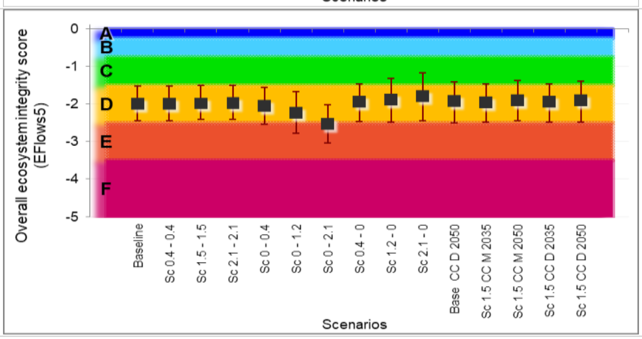
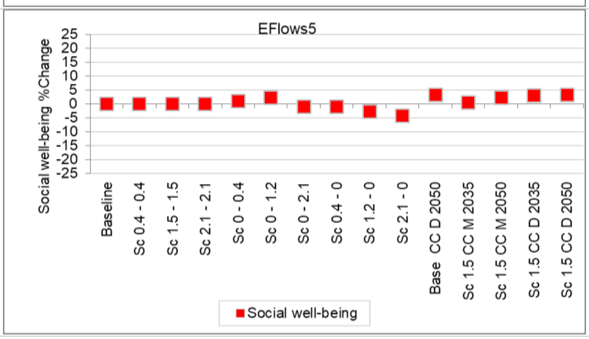
Appendix A. *Summary of results for all scenarios*

Appendix Figure 1 Summary of results for all scenarios

Ecosystem health	River related social well-being
	
	
	
	
	

Appendix B. *Summary flow results and rule curves for S04-0 and SS4*

Appendix Table 1 EFlows4: Summary of SS4 low- and high-flow regimes and rule curves in MCM

```
AEC1                    SS4
MAR                     258.951  MCM
S.Dev.                  16.663
CV                      0.064
Q75                     8.19283
Ecological Category     D
                        MCM      % MAR
Total IFR               193.173  74.598 (excl. >=1:2)        (Incl. >=1:2 = 83.209)
Maint. Lowflow          113.978  44.015
Drought Lowflow         54.065   20.879
Maint. Highflow         79.195   30.583
```

Monthly Distributions (MCM)

Month	Baseline Flows Mean	Modified Flows (IFR) Low flows Maint.	Low flows Drought	High Flows Maint.	Total Flows Maint.
Oct	10.684	5.950	3.866	3.949	9.900
Nov	20.147	7.785	3.783	8.515	16.301
Dec	28.295	9.793	3.958	10.232	20.026
Jan	35.931	11.192	4.136	12.131	23.323
Feb	40.564	11.846	5.219	11.517	23.363
Mar	40.237	15.788	9.162	13.216	29.004
Apr	28.934	11.741	4.055	10.122	21.863
May	17.514	10.331	4.074	4.073	14.404
Jun	12.316	9.524	3.942	1.731	11.255
Jul	9.151	8.429	4.070	0.568	8.997
Aug	8.207	6.540	4.027	1.596	8.135
Sep	6.971	5.057	3.772	1.546	6.603

AEC1 SS4
Summary of IFR rule curves (without >=1:2 year floods)
Ecological Category D
Data are given in MCM (mean monthly)

Month (% Points)	10	20	30	40	50	60	70	80	90	99
Oct	0.629	0.396	0.388	0.276	0.255	0.209	0.175	0.154	0.128	0.115
Nov	1.120	0.915	0.734	0.619	0.436	0.365	0.186	0.161	0.121	0.096
Dec	0.989	0.953	0.866	0.752	0.629	0.525	0.493	0.383	0.217	0.086
Jan	1.148	1.094	0.927	0.813	0.702	0.655	0.539	0.318	0.229	0.132
Feb	1.419	1.199	1.038	0.868	0.736	0.627	0.510	0.380	0.325	0.157
Mar	1.341	1.123	0.928	0.862	0.801	0.672	0.522	0.409	0.332	0.267
Apr	1.324	1.228	0.858	0.726	0.602	0.562	0.452	0.376	0.328	0.211
May	0.705	0.578	0.532	0.486	0.452	0.432	0.383	0.366	0.210	0.166
Jun	0.532	0.447	0.413	0.388	0.349	0.341	0.333	0.295	0.259	0.160
Jul	0.378	0.352	0.343	0.306	0.293	0.268	0.263	0.236	0.184	0.135
Aug	0.383	0.331	0.263	0.254	0.228	0.210	0.203	0.188	0.176	0.112
Sep	0.283	0.252	0.198	0.179	0.167	0.149	0.142	0.137	0.130	0.088

Reserve Flows without High Flows

	10	20	30	40	50	60	70	80	90	99
Oct	0.302	0.240	0.205	0.190	0.162	0.155	0.146	0.138	0.128	0.107
Nov	0.400	0.367	0.347	0.285	0.259	0.197	0.165	0.137	0.117	0.096
Dec	0.412	0.376	0.367	0.366	0.348	0.340	0.304	0.242	0.156	0.086
Jan	0.513	0.393	0.367	0.367	0.367	0.366	0.338	0.236	0.196	0.132
Feb	0.619	0.447	0.373	0.367	0.367	0.347	0.326	0.291	0.208	0.128
Mar	0.472	0.396	0.367	0.367	0.367	0.356	0.319	0.281	0.254	0.137
Apr	0.548	0.503	0.367	0.367	0.367	0.367	0.365	0.321	0.261	0.197
May	0.367	0.367	0.367	0.367	0.367	0.366	0.344	0.305	0.210	0.166
Jun	0.367	0.367	0.367	0.348	0.339	0.331	0.313	0.275	0.210	0.160
Jul	0.353	0.339	0.317	0.280	0.273	0.263	0.250	0.224	0.180	0.135
Aug	0.288	0.257	0.244	0.227	0.203	0.200	0.186	0.175	0.136	0.110
Sep	0.217	0.199	0.181	0.166	0.157	0.143	0.141	0.136	0.125	0.088

Natural Duration curves

	10	20	30	40	50	60	70	80	90	99
Oct	0.720	0.411	0.389	0.293	0.255	0.213	0.175	0.154	0.128	0.116
Nov	1.564	1.118	0.909	0.674	0.485	0.367	0.186	0.161	0.121	0.096
Dec	1.914	1.322	1.110	0.879	0.690	0.627	0.522	0.391	0.220	0.086
Jan	2.135	1.736	1.389	1.097	0.954	0.833	0.592	0.358	0.229	0.132
Feb	3.014	2.138	1.385	1.239	0.903	0.780	0.555	0.400	0.326	0.157
Mar	2.129	1.472	1.365	1.111	0.962	0.796	0.569	0.436	0.344	0.272
Apr	1.602	1.547	1.210	0.866	0.770	0.656	0.619	0.420	0.342	0.213
May	0.966	0.880	0.689	0.532	0.503	0.462	0.413	0.370	0.210	0.166
Jun	0.613	0.548	0.487	0.426	0.357	0.345	0.333	0.295	0.259	0.160
Jul	0.394	0.358	0.344	0.312	0.293	0.268	0.263	0.236	0.184	0.135
Aug	0.398	0.336	0.263	0.254	0.233	0.210	0.203	0.188	0.176	0.112
Sep	0.292	0.252	0.201	0.183	0.168	0.149	0.142	0.138	0.131	0.088

Appendix Table 2 EFlows4: Summary of Sc 04-0 low- and high-flow regimes and rule curves in MCM

AEC2	S04_0		
MAR	258.951	MCM	
S.Dev.	16.663		
CV	0.064		
Q75	8.1928325		
Ecological Category	D		
	MCM	% MAR	
Total IFR	242.865	93.788	(excl. >=1:2) (Incl. >=1:2 = 101.628)
Maint. Lowflow	162.500	62.753	
Drought Lowflow	54.065	20.879	
Maint. Highflow	80.365	31.035	

Monthly Distributions (MCM)

Month	Baseline Flows	Modified Flows (IFR)			
		Low flows		High Flows	Total Flows
	Mean	Maint.	Drought	Maint.	Maint.
Oct	10.684	6.682	3.866	4.002	10.684
Nov	20.147	10.119	3.783	9.185	19.304
Dec	28.295	15.024	3.958	10.962	25.986
Jan	35.931	18.339	4.136	13.591	31.930
Feb	40.564	19.810	5.219	12.794	32.604
Mar	40.237	24.600	9.162	11.929	36.530
Apr	28.934	17.824	4.055	9.628	27.452
May	17.514	14.542	4.074	2.972	17.514
Jun	12.316	11.981	3.942	1.372	13.353
Jul	9.151	9.678	4.070	0.544	10.222
Aug	8.207	7.629	4.027	1.650	9.279
Sep	6.971	6.270	3.772	1.737	8.008

AEC2 S04_0
Summary of IFR rule curves (without >=1:2 year floods)
Ecological Category D
Data are given in MCM (mean monthly)

Month	% Points									
	10	20	30	40	50	60	70	80	90	99
Oct	0.720	0.411	0.389	0.293	0.255	0.213	0.175	0.154	0.128	0.116
Nov	1.470	1.118	0.909	0.674	0.485	0.367	0.186	0.161	0.121	0.096
Dec	1.546	1.322	1.110	0.879	0.690	0.627	0.522	0.391	0.220	0.086
Jan	1.931	1.485	1.339	1.097	0.954	0.833	0.592	0.358	0.229	0.132
Feb	2.403	1.905	1.384	1.212	0.873	0.780	0.555	0.400	0.326	0.157
Mar	2.029	1.472	1.365	1.111	0.962	0.796	0.569	0.436	0.344	0.272
Apr	1.597	1.540	1.172	0.866	0.770	0.656	0.619	0.420	0.342	0.213
May	0.966	0.880	0.689	0.532	0.503	0.462	0.413	0.370	0.210	0.166
Jun	0.648	0.582	0.521	0.461	0.392	0.379	0.368	0.330	0.294	0.195
Jul	0.429	0.392	0.379	0.346	0.327	0.302	0.297	0.271	0.219	0.170
Aug	0.432	0.371	0.298	0.288	0.267	0.245	0.238	0.223	0.210	0.146
Sep	0.327	0.287	0.235	0.218	0.203	0.183	0.177	0.173	0.165	0.122

Reserve Flows without High Flows

	10	20	30	40	50	60	70	80	90	99
Oct	0.378	0.248	0.205	0.195	0.162	0.155	0.147	0.138	0.128	0.113
Nov	0.666	0.535	0.416	0.363	0.274	0.198	0.169	0.138	0.121	0.096
Dec	0.862	0.767	0.594	0.471	0.434	0.397	0.346	0.244	0.156	0.086
Jan	1.143	0.790	0.658	0.562	0.523	0.489	0.396	0.236	0.197	0.132
Feb	1.266	1.142	0.836	0.695	0.500	0.441	0.357	0.305	0.208	0.128
Mar	1.053	0.907	0.777	0.696	0.630	0.453	0.332	0.304	0.254	0.140
Apr	1.029	0.854	0.744	0.548	0.523	0.502	0.416	0.344	0.265	0.197
May	0.788	0.628	0.548	0.443	0.421	0.391	0.351	0.305	0.210	0.166
Jun	0.562	0.521	0.462	0.384	0.377	0.365	0.345	0.310	0.244	0.195
Jul	0.407	0.381	0.353	0.314	0.308	0.297	0.286	0.257	0.215	0.170
Aug	0.325	0.289	0.273	0.261	0.242	0.236	0.220	0.209	0.171	0.146
Sep	0.252	0.233	0.215	0.199	0.192	0.178	0.175	0.171	0.161	0.122

Natural Duration curves

	10	20	30	40	50	60	70	80	90	99
Oct	0.720	0.411	0.389	0.293	0.255	0.213	0.175	0.154	0.128	0.116
Nov	1.564	1.118	0.909	0.674	0.485	0.367	0.186	0.161	0.121	0.096
Dec	1.914	1.322	1.110	0.879	0.690	0.627	0.522	0.391	0.220	0.086
Jan	2.135	1.736	1.389	1.097	0.954	0.833	0.592	0.358	0.229	0.132
Feb	3.014	2.138	1.385	1.239	0.903	0.780	0.555	0.400	0.326	0.157
Mar	2.129	1.472	1.365	1.111	0.962	0.796	0.569	0.436	0.344	0.272
Apr	1.602	1.547	1.210	0.866	0.770	0.656	0.619	0.420	0.342	0.213
May	0.966	0.880	0.689	0.532	0.503	0.462	0.413	0.370	0.210	0.166
Jun	0.613	0.548	0.487	0.426	0.357	0.345	0.333	0.295	0.259	0.160
Jul	0.394	0.358	0.344	0.312	0.293	0.268	0.263	0.236	0.184	0.135
Aug	0.398	0.336	0.263	0.254	0.233	0.210	0.203	0.188	0.176	0.112
Sep	0.292	0.252	0.201	0.183	0.168	0.149	0.142	0.138	0.131	0.088

Appendix Table 3 EFlows4: Summary of SS4 low- and high-flow regimes and rule curves in m3/s where possible

AEC1	SS4			
MAR	258.951	MCM		
S.Dev.	16.663			
CV	0.064			
Q75	8.19283			
Ecological Category	D			
	MCM	% MAR		
Total IFR	193.173	74.598	(excl. >=1:2)	(Incl. >=1:2 = 83.209)
Maint. Lowflow	113.978	44.015		
Drought Lowflow	54.065	20.879		
Maint. Highflow	79.195	30.583		

Monthly Distributions (m^3/s)

Month	Baseline Flows	Modified Flows (IFR)			
		Low flows		High Flows	Total Flows
	Mean	Maint.	Drought	Maint.	Maint.
Oct	3.989	2.222	1.443	1.474	3.696
Nov	7.773	3.004	1.460	3.285	6.289
Dec	10.564	3.656	1.478	3.820	7.477
Jan	13.415	4.179	1.544	4.529	8.708
Feb	16.768	4.897	2.157	4.761	9.657
Mar	15.023	5.895	3.421	4.934	10.829
Apr	11.163	4.530	1.565	3.905	8.435
May	6.539	3.857	1.521	1.521	5.378
Jun	4.752	3.675	1.521	0.668	4.342
Jul	3.416	3.147	1.519	0.212	3.359
Aug	3.064	2.442	1.503	0.596	3.037
Sep	2.689	1.951	1.455	0.596	2.547

AEC1 SS4
Summary of IFR rule curves (without >=1:2 year floods)
Ecological Category D
Data are given in m^3/s mean monthly flow

Month	% Points									
	10	20	30	40	50	60	70	80	90	99
Oct	7.280	4.586	4.491	3.198	2.956	2.419	2.030	1.778	1.484	1.329
Nov	12.965	10.596	8.497	7.170	5.042	4.227	2.155	1.864	1.403	1.107
Dec	11.449	11.030	10.021	8.707	7.275	6.071	5.712	4.432	2.515	0.995
Jan	13.289	12.660	10.729	9.405	8.122	7.584	6.243	3.677	2.651	1.524
Feb	16.429	13.874	12.012	10.041	8.524	7.255	5.902	4.393	3.762	1.823
Mar	15.517	13.003	10.741	9.974	9.269	7.775	6.045	4.733	3.842	3.088
Apr	15.321	14.216	9.927	8.404	6.967	6.499	5.236	4.357	3.800	2.445
May	8.161	6.687	6.158	5.629	5.230	5.003	4.438	4.231	2.436	1.925
Jun	6.163	5.174	4.776	4.492	4.035	3.943	3.860	3.416	3.001	1.855
Jul	4.379	4.075	3.976	3.537	3.388	3.097	3.043	2.734	2.131	1.567
Aug	4.431	3.836	3.048	2.938	2.642	2.436	2.352	2.177	2.035	1.295
Sep	3.281	2.917	2.290	2.076	1.927	1.720	1.646	1.590	1.508	1.013

Reserve Flows without High Flows

	10	20	30	40	50	60	70	80	90	99
Oct	3.492	2.777	2.376	2.202	1.870	1.789	1.686	1.596	1.484	1.236
Nov	4.633	4.243	4.013	3.295	2.993	2.283	1.913	1.583	1.356	1.107
Dec	4.767	4.347	4.245	4.240	4.027	3.930	3.519	2.803	1.802	0.995
Jan	5.932	4.544	4.247	4.245	4.245	4.234	3.908	2.730	2.268	1.524
Feb	7.162	5.172	4.312	4.245	4.245	4.021	3.770	3.373	2.404	1.482
Mar	5.461	4.582	4.245	4.245	4.245	4.120	3.690	3.258	2.935	1.586
Apr	6.345	5.818	4.245	4.245	4.245	4.245	4.223	3.716	3.018	2.281
May	4.245	4.245	4.245	4.245	4.245	4.232	3.979	3.525	2.436	1.925
Jun	4.245	4.245	4.245	4.032	3.922	3.826	3.628	3.184	2.426	1.855
Jul	4.083	3.927	3.675	3.240	3.160	3.045	2.898	2.587	2.084	1.567
Aug	3.336	2.969	2.819	2.623	2.355	2.312	2.150	2.021	1.570	1.269
Sep	2.514	2.308	2.096	1.921	1.820	1.660	1.629	1.579	1.442	1.013

Natural Duration curves

	10	20	30	40	50	60	70	80	90	99
Oct	8.336	4.761	4.503	3.390	2.956	2.466	2.030	1.778	1.484	1.343
Nov	18.099	12.944	10.518	7.804	5.619	4.251	2.155	1.864	1.403	1.107
Dec	22.148	15.302	12.849	10.171	7.990	7.252	6.038	4.521	2.548	0.995
Jan	24.708	20.088	16.080	12.701	11.037	9.638	6.856	4.144	2.651	1.523
Feb	34.882	24.741	16.030	14.336	10.457	9.032	6.421	4.631	3.768	1.823
Mar	24.636	17.033	15.795	12.859	11.138	9.209	6.582	5.049	3.980	3.144
Apr	18.544	17.905	14.008	10.022	8.911	7.593	7.161	4.856	3.960	2.465
May	11.179	10.181	7.977	6.158	5.827	5.352	4.781	4.284	2.436	1.925
Jun	7.098	6.339	5.632	4.935	4.135	3.990	3.860	3.416	3.001	1.855
Jul	4.560	4.139	3.986	3.609	3.388	3.097	3.043	2.734	2.131	1.567
Aug	4.605	3.892	3.048	2.938	2.693	2.436	2.352	2.177	2.034	1.295
Sep	3.382	2.917	2.323	2.122	1.946	1.720	1.646	1.597	1.512	1.013

Appendix Table 4 EFlows4: Summary of Sc 04-0 low- and high-flow regimes and rule curves in m3/s where possible

AEC2	S04_0		
MAR	258.951	MCM	
S.Dev.	16.663		
CV	0.064		
Q75	8.1928325		
Ecological Category	D		
	MCM	% MAR	
Total IFR	242.865	93.788 (excl. >=1:2)	(Incl. >=1:2 = 101.628)
Maint. Lowflow	162.500	62.753	
Drought Lowflow	54.065	20.879	
Maint. Highflow	80.365	31.035	

Monthly Distributions (m^3/s)

Month	Baseline Flows	Modified Flows (IFR)			
		Low flows		High Flows	Total Flows
	Mean	Maint.	Drought	Maint.	Maint.
Oct	3.989	2.495	1.443	1.494	3.989
Nov	7.773	3.904	1.460	3.543	7.447
Dec	10.564	5.609	1.478	4.093	9.702
Jan	13.415	6.847	1.544	5.074	11.921
Feb	16.768	8.189	2.157	5.288	13.477
Mar	15.023	9.185	3.421	4.454	13.639
Apr	11.163	6.877	1.565	3.715	10.591
May	6.539	5.429	1.521	1.110	6.539
Jun	4.752	4.622	1.521	0.529	5.152
Jul	3.416	3.613	1.519	0.203	3.816
Aug	3.064	2.848	1.503	0.616	3.464
Sep	2.689	2.419	1.455	0.670	3.089

AEC2 S04_0
Summary of IFR rule curves (without >=1:2 year floods)
Ecological Category D
Data are given in m^3/s mean monthly flow

Month	% Points									
	10	20	30	40	50	60	70	80	90	99
Oct	8.336	4.761	4.503	3.390	2.956	2.466	2.030	1.778	1.484	1.343
Nov	17.018	12.944	10.518	7.805	5.619	4.251	2.155	1.864	1.403	1.107
Dec	17.888	15.302	12.849	10.171	7.990	7.252	6.038	4.521	2.548	0.995
Jan	22.354	17.192	15.492	12.701	11.037	9.638	6.856	4.144	2.651	1.523
Feb	27.810	22.048	16.018	14.022	10.101	9.032	6.421	4.631	3.768	1.823
Mar	23.478	17.033	15.795	12.859	11.138	9.209	6.582	5.049	3.980	3.144
Apr	18.486	17.823	13.568	10.022	8.911	7.593	7.161	4.856	3.960	2.465
May	11.179	10.181	7.977	6.158	5.826	5.352	4.781	4.284	2.436	1.925
Jun	7.497	6.739	6.032	5.334	4.535	4.390	4.260	3.816	3.401	2.255
Jul	4.960	4.539	4.386	4.009	3.788	3.497	3.443	3.134	2.531	1.967
Aug	5.005	4.292	3.448	3.338	3.092	2.836	2.752	2.577	2.435	1.695
Sep	3.782	3.317	2.723	2.522	2.346	2.120	2.046	1.997	1.912	1.413

Reserve Flows without High Flows

	10	20	30	40	50	60	70	80	90	99
Oct	4.380	2.866	2.376	2.253	1.870	1.789	1.707	1.595	1.484	1.307
Nov	7.713	6.192	4.812	4.200	3.166	2.288	1.961	1.595	1.403	1.107
Dec	9.979	8.883	6.879	5.453	5.020	4.591	4.009	2.824	1.802	0.995
Jan	13.225	9.147	7.615	6.500	6.056	5.665	4.587	2.728	2.277	1.523
Feb	14.654	13.219	9.680	8.045	5.782	5.102	4.133	3.534	2.404	1.482
Mar	12.188	10.500	8.996	8.055	7.291	5.238	3.838	3.523	2.935	1.621
Apr	11.909	9.883	8.611	6.343	6.049	5.814	4.812	3.981	3.065	2.281
May	9.119	7.265	6.341	5.126	4.877	4.524	4.060	3.531	2.436	1.925
Jun	6.499	6.026	5.343	4.450	4.359	4.227	3.995	3.583	2.823	2.255
Jul	4.708	4.411	4.082	3.631	3.560	3.439	3.314	2.972	2.484	1.967
Aug	3.756	3.346	3.159	3.015	2.806	2.728	2.550	2.421	1.973	1.684
Sep	2.914	2.701	2.487	2.298	2.220	2.060	2.028	1.979	1.868	1.413

Natural Duration curves

	10	20	30	40	50	60	70	80	90	99
Oct	8.336	4.761	4.503	3.390	2.956	2.466	2.030	1.778	1.484	1.343
Nov	18.099	12.944	10.518	7.804	5.619	4.251	2.155	1.864	1.403	1.107
Dec	22.148	15.302	12.849	10.171	7.990	7.252	6.038	4.521	2.548	0.995
Jan	24.708	20.088	16.080	12.701	11.037	9.638	6.856	4.144	2.651	1.523
Feb	34.882	24.741	16.030	14.336	10.457	9.032	6.421	4.631	3.768	1.823
Mar	24.636	17.033	15.795	12.859	11.138	9.209	6.582	5.049	3.980	3.144
Apr	18.544	17.905	14.008	10.022	8.911	7.593	7.161	4.856	3.960	2.465
May	11.179	10.181	7.977	6.158	5.827	5.352	4.781	4.284	2.436	1.925
Jun	7.098	6.339	5.632	4.935	4.135	3.990	3.860	3.416	3.001	1.855
Jul	4.560	4.139	3.986	3.609	3.388	3.097	3.043	2.734	2.131	1.567
Aug	4.605	3.892	3.048	2.938	2.693	2.436	2.352	2.177	2.034	1.295
Sep	3.382	2.917	2.323	2.122	1.946	1.720	1.646	1.597	1.512	1.013