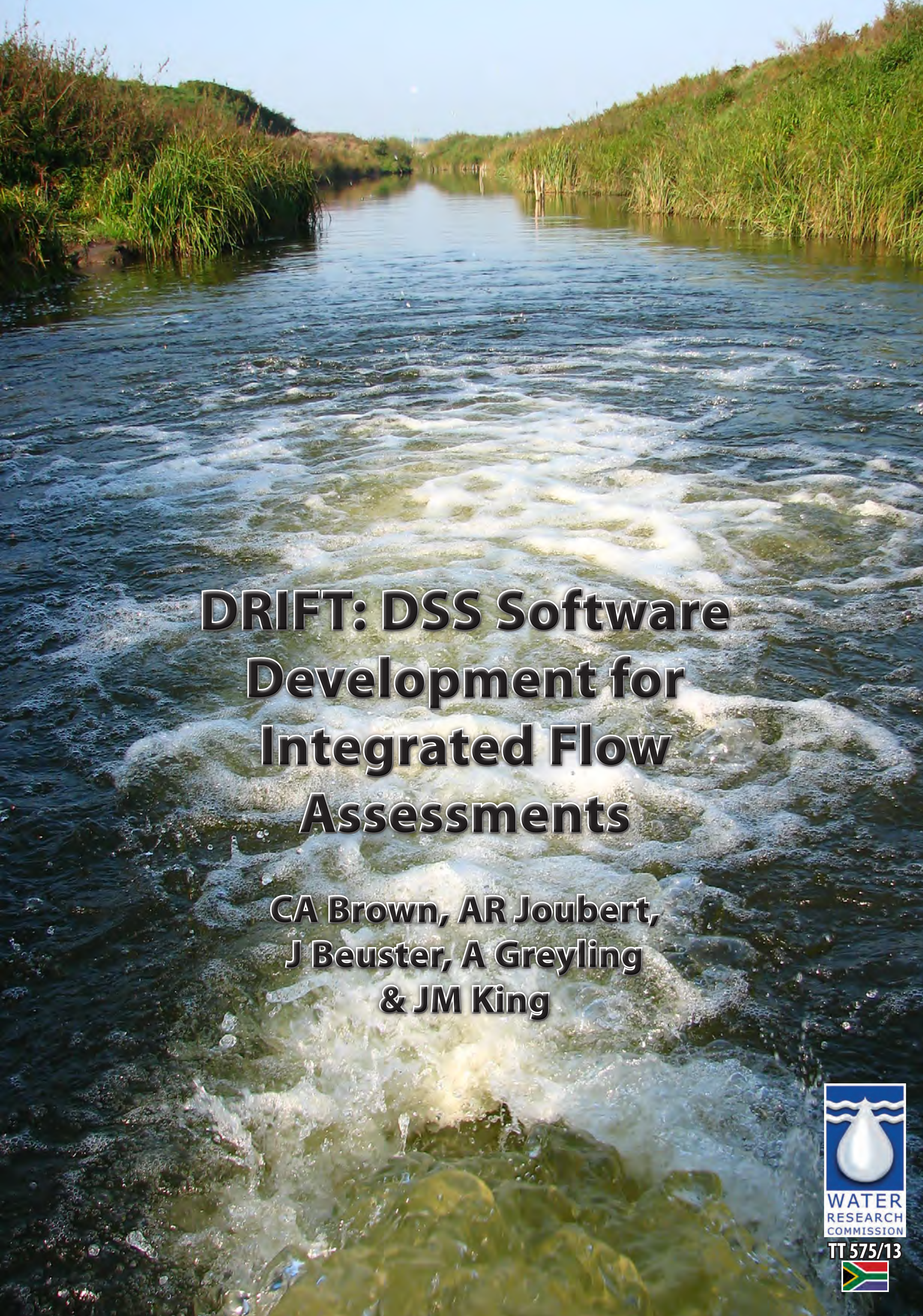

DRIFT: DSS Software Development for Integrated Flow Assessments

CA Brown, AR Joubert, J Beuster, A Greyling & JM King

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Report to the
Water Research Commission

by

CA Brown, AR Joubert, J Beuster, A Greyling & JM King

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Dr Heather Malan	University of Cape Town
Dr Steve Mitchell	Eon Consulting
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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF BOXES

ACRONYMS and ABBREVIATIONS

DRIFT	Downstream Response to Imposed Flow Transformations
DSS	Decision Support System
DWA	Department of Water Affairs
EF	Environmental Flow
EFA	Environmental Flow Assessment
HEP	Hydropower
IUCN	International Union for Conservation of Nature
IWRM	Integrated Water-resource Management
PBWO	Pangani Basin Water Office
PD	Present Day
PES	Present Ecological Status
WRC	Water Research Commission

1. Introduction

"*Decision support systems are interactive computer-based systems that bring together data from different sources and/or models to assist with the decision making process. They enable the user to ask 'what if' type questions to test theoretical management situations*" (Young *et al.* 2003).

1.1 Background

Water-resource developments in the past have been mainly judged by the benefits they bring to society. Only as the global degradation of the donating aquatic ecosystems has become apparent over the last few decades have the ecological and social costs of the developments begun to be understood. The aim now is for Integrated Water-resource Management (IWRM), whereby the three pillars of sustainable development – ecological integrity, social justice and economic development – are given equal weight in water-management decisions.

A new science, maturing from a naïve concept of minimum flows in the 1960s to the most recent concept of Integrated Flow Management, addresses the need to inform decision-makers of the costs as well as the benefits of any considered water management activity. Methods are now being applied that provide a number of scenarios of possible management pathways, with each scenario spelling out the resulting state of the donor aquatic system, the impacts this will have on peoples' lives and livelihoods, and the economic implications from household to regional levels.

Such methods are presently applied semi-manually on a project-by-project basis, which has proven that inputted flow simulations per scenario can produce a wide range of predictions of change from present, in factors as varied as loss of pool refugia for fish, household incomes and GDP (King and Brown 2010).

In 2006, Brown (2007) undertook a global review of available DSSs for the automated incorporation of ecological and social issues into water-resource options assessment and concluded that no such DSSs were in use at that time. The review also yielded a number of pleas from water-resource professionals for the development of a DSS that incorporated the ecological, social and socio-economic aspects of management options to a similar level of detail and sensitivity as the economic and engineering aspects.

Following the review, a proposal was submitted to the Water Research Commission (WRC) for a project to investigate the feasibility of developing a decision support system (DSS) for integrated flow assessments based on DRIFT (Box 1.1; Section 2; King *et al*. 2003; Brown and Joubert 2003). The project (K8/797: Feasibility Study: DSS software development for Integrated Basin Flow Management), was funded by WRC and was undertaken between March 2007 and December 2008. The Final Report for K8/797 detailed the conceptual design of the DSS, the development of a Pilot DSS, and the outcome of the feasibility assessment based on a number of criteria considered to be impediments to development of the DSS, such as alternatives to single, end-point based ecosystem response modelling and automated hydrograph separation and classification to produce ecologically relevant flow categories. The study found that it was feasible to develop a DSS based on DRIFT (King *et al*. 2008), but that two main innovations should be added (a) the use of indicators dependent on other indicators (i.e. so-called linked-indicators), rather than only on flow (see King *et al*. 2003), and; (b) the use of a time-series approach rather than an integrated response over the full flow record.

Box 1.1 DRIFT

DRIFT (an acronym for Downstream Response to Imposed Flow Transformations) is an environmental flow assessment process that was developed by Southern Waters Ecological Research and Consulting cc (South Africa). It is an interactive, holistic approach for advising on environmental flows for rivers. The DRIFT methodology can be used to provide flow scenarios and descriptive summaries of their consequences in terms of the condition of the river ecosystem and the impacts on human users of it, allowing integration at a basin level, for examination and comparison by decision makers and other interested parties.

More detail on DRIFT and its past applications can be found in, *inter alia*, King *et al.* (2003); Brown and Joubert (2003); Brown *et al.* (2008); King and Brown (2009); King and Brown (2010).

On the basis of the outcome of K8/797, a proposal for a second project to develop the DSS (K5/1873) was approved with a budget of R 2 000 000.00 (c. US$ 250 000) over two years. There were, however, delays in the funding for K5/1873, and so the WRC provided interim funding of R 200 000.00 for a start-up phase (K8/848)[1], which was used to address the incorporation of time-series assessments into the DSS and the development of appropriate numerical and graphical summary outputs. The time-series approach was used (and tested) in the GEF-FAO-UNDP-funded Transboundary Diagnostic Analysis (TDA) for the Okavango Basin, which was completed in 2010 (King and Brown 2009).

Funds for K5/1873 became available in May 2009.

1.2 Project K5/1873 – DRIFT: DSS software development for Integrated Basin Flow Management

1.2.1 Dates and budget

Start date: 01/05/2009
Original end date: 28/02/2012
Extended end date: 28/02/2013.

The project duration was extended by one year to allow for testing of the DSS in a real international project.

The budget was R1 800 000.00.

[1] This reduced the budget for K5/1873 to R 1 800 000.00.

1.2.2 Aims of K5/1873

The aims of project K5/1873 were:

- to further develop a DSS for supporting sustainable use of water-resources, through equal consideration of the ecological, social and economic implications of management options
- to code the DSS for use in any size catchment, from local to international.

1.2.3 Project team

The study was undertaken by a five-person team with expertise in water-resource planning, development of environmental and social information of water-resource decision making, programming, and software development:

- Professor Cate Brown (Southern Waters ER&C) – Project Leader
- Professor Jackie King (Water Matters)
- Dr Alison Joubert (Southern Waters ER&C)
- Mr Andre Greyling (Beuster and Associates)
- Mr Hans Beuster (Beuster and Associates).

1.2.4 Deliverables

The project deliverables were revised several times during the project as the direction and needs of the project became more apparent. The final list of project deliverables and their submission dates are listed in Table 1.1. These initial deliverables have been incorporated into the Final Report and its appendices, as appropriate.

Table 1.1 Project deliverables

No.	Title	Target Date	Submitted	Comment
1	Draft: Literature review of 'Key Questions'	31/03/2010	31/03/2010	Appendix A
2	Draft 'Indicators' Chapter	31/03/2010	31/03/2010	Subsumed into Section Appendix B
3-5	Reworked DSS process, including descriptions of all modules	31/07/2010	27/07/2010	Subsumed into Sections 3 and Appendix B.
6	Draft 'Demands Generation Chapter'	01/04/2011	23/12/2010	
7	Draft 'Socio-economics response' Chapter	01/04/2011	13/07/2011	
8	Design of flow regimes	01/04/2011	16/03/2011	
9	Beta version of the DSS	31/08/2011	01/12/2011	-
10	DRAFT Final Report	31/12/2012	30/11/2012	-
11	Print-ready Final Report and User Manual	15/12/2012	-	-
12	Decision Support System	31/01/2013	-	-
13	Print-ready Final Report and User Manual	31/01/2013	-	-

1.3 Structure of this report

Section 2 provides the conceptual background to the DRIFT process, and tools. Section 3 provides an introduction to the DRIFT-DSS and Section 4 suggests the way forward in terms of improvements to knowledge, process and the DRIFT-DSS.

Appendix A is a review of key questions relating to various DSSs for flow assessments.

Appendix B provides some technical details for aspects of the DRIFT process and DSS.

The DRIFT-DSS User Manual is in Appendix B and is to be used in conjunction with the information provided in Sections 2 and 3, and Appendix B.

2. The DRIFT process and tools

DRIFT is a process that was developed in South Africa to aid management and future planning of water-resource developments, rehabilitation of rivers or any other management activity that could affect the flow or inundation patterns of an inland water ecosystem. Development has taken place through extensive application of the process within South Africa, in southern and eastern Africa, and in other continents – mostly Asia and South America.

The overall process contains three main steps:

1. Set up
2. Knowledge capture, comprising:
    a. hydrological modelling of present day, naturalised and possible future daily flow regimes (scenarios);
    b. predictions of the response of relevant physical, chemical, biological and socio-economic variables to described changes in the future scenario flow regimes;
    c. predictions of the economic implications of the scenarios.
3. Analysis.

The DRIFT Decision Support System (DSS) holds the input data for Steps 1 and 2b, makes the predictions in Step 2c and receives data from outside on Step 2a (the hydrological modelling). It provides the information upon which the outside[2] economic analysis is based (Step 2c) and brings all the information together for the summary reports (Step 3).

2.1 Step 1: Set up

The main activities involved in setting up the study are: appointment of the team; basin delineation; choosing study sites; and selecting scenarios. Summary guidelines are provided below.

2.1.1 Specialist team

A multidisciplinary team is appointed, if possible consisting of senior specialists with hands-on working knowledge of the basin. The full team could consist of some or all of the following:

- DRIFT process management team
- Basin hydrologist
- Hydraulic modeller
- Fluvial geomorphologist
- Aquatic chemist
- Botanist(s) (riparian, marginal and aquatic)
- Sociologist
- Resource economist
- Basin/national economist
- GIS specialist.
- Zoologist(s) (plankton, aquatic invertebrates, fish, water birds, river-dependent mammals)

‘

[2] ‘Outside’ refers to the relevant task being done outside of the DSS, with the results either being fed into the DSS (hydrological) or being derived from data provided by the DSS (economic).

Their roles are clearly defined in DRIFT as they work together to achieve consensus on the project details and the predictions of change.

2.1.2 Basin delineation and selection of study Integrated Units of Analysis

Basin delineation sets the scene for all that follows, defining the boundaries of the work, and the nature of the basin, its river system and its people.

The activities and considerations involved are:

1. describe the basin location, relevant political boundaries, roads and towns;
2. note hazardous areas, such as areas of conflict or a high level of criminal activities, areas where there may be landmines and/or dangerous animals such as crocodiles, hippos or sharks;
3. describe topography, vegetation, land use, and geomorphological zones;
4. describe the boundary of the project study area in terms of its main rivers and tributaries, wetlands, floodplains, estuaries, swamps, etc.;
5. describe and locate the main water-resource infrastructures that affect flow, aquatic and social systems; also identify the flow or water level gauges;
6. identify conservation priority areas and ecosystems likely to be especially vulnerable to flow changes;
7. identify socially, culturally and economically important activities and/or areas;
8. delineate homogeneous surface and sub-surface hydrological zones along the river system;
9. delineate homogeneous geomorphological zones along the river system;
10. delineate homogeneous chemical and thermal zones along the river system;
11. delineate homogeneous biological zones along the river system;
12. combine the zonation from activities 8 to 11 into relatively homogeneous longitudinal river zones;
13. delineate relatively homogeneous socio-economic areas that have links with the river system, and adjust the socio-economic areas so that they correspond with hydrological boundaries, so that each socio-economic area is linked to a specific river zone;
14. identify and name Integrated Units of Analysis (IUAs), which are combined and harmonised social areas and biological zones;
15. develop simple base maps and Excel spreadsheets for use as required, and for reporting.

2.1.3 Selection of study sites

Representative biophysical sites and social sampling site / areas are chosen in each of the final set of IUAs and characterised in terms of the zones represented, ecological condition and socio-economic activities.

At the end of this step there should be a good understanding of the nature of the river system of interest within the context of its drainage basin, and a set of sites will have been established that will form the focus of all field data collection and hydrological/hydraulic modelling exercises.

Important considerations when choosing sites are as follows (only some will apply at each site):

1. Availability of reasonably accurate hydrological data.
2. Areas with good data already available in any or, preferably, all relevant ecological and social disciplines.
3. Accessibility.
4. Safety.
5. Areas where there is good understanding of the sediment dynamics, and soil chemistry.
6. Areas of high conservation importance.
7. Areas expected to be particularly vulnerable to changes in flow or sediment regimes, such as:
   - shallow rocky rapids;
   - steep cobble beds;
   - channels with intermittently flooded floodplains;
   - channels vulnerable to silting up or eroding deep into their bed.
8. Areas in good ecological condition, so that the relationships between flow, ecosystem components and social use are not masked by a degraded environment.
9. Areas where there is a reasonable chance of doing hydraulic or hydrodynamic modelling of water depths, velocities, widths and inundations areas.
10. Areas where potential water conflicts are high.
11. Areas of high social use or dependence on the goods and services provided by the river system, such as:
    - fish
    - wild vegetables
    - construction materials
    - reeds for roofs and mats
    - drinking water
    - tourism
    - nutritional herbs
    - firewood
    - livestock grazing and shade
    - plants for crafts markets
    - navigation
12. Areas with strong links between the river system and human and animal health (e.g. any areas prone to malaria, bilharzias, etc.).

2.1.4 Selection of scenarios

Scenarios are a means of exploring possible pathways into the future. In DRIFT, they may describe a range of potential management options, such as further development of the river's water-resources (through infrastructure, abstraction or return flows), revision of operating rules for existing water-resource infrastructure or rehabilitation of a degraded system. Scenario outcomes are expressed in terms of their ecological, social and economic effects, giving equal consideration to the three pillars of sustainability – social justice, ecological integrity and economic wealth – in a way that stakeholders can understand and use in discussions and negotiation.

Integrated Water Resource Management (IWRM) promotes a basin or regional approach, as opposed to a narrow project focus, which takes into account the overall distribution and scarcity of water-resources and the needs of other potential water users (King and Brown, in press).

Even where a study is project focussed, consideration needs to be given to the broader context within which the project exists. Scenarios should cover as wide a range as possible of planned or possible options, whether they be of development or rehabilitation. The scenarios should reflect the issues of concern to stakeholders, and so identification of a suitable range of scenarios, through consultation with stakeholders, is a crucial step in Environmental Flow Assessments (EFAs). Depending on the objectives of the project, major stakeholders could include national, regional and local scale water-resource, environmental and agricultural departments, hydropower operators, community organisations, national parks and conservation agencies, researchers, and more.

Consultations, perhaps through one or more workshops, should explore the major water-related issues, trends and known development options (e.g. Table 2.1).

Table 2.1 Examples of issues, trends and potential developments identified for a river basing or project.

Issues and trends	Potential developments
Shortages of supply and availability of water	Hydro-electric power facilities
River and catchment degradation and loss of biodiversity	Irrigation schemes
Increasing levels of water-borne pollutants	River reach rehabilitation
Climate change	Sewage plants
Water over-allocation and conflicts between stakeholders	Expansion of irrigated farming areas
Uncoordinated basin planning	Expansion of commercial forestry
Rivers drying up	
Lack of conservation awareness	
Lack of enforcement of relevant legislation	
Increases in population numbers, leading to pressure on urban supplies and increasingly severe water shortages	
Increasing reliance on groundwater and rainwater harvesting	
Changes in the water quality of donating rivers	

Issues and trends identified with the client/government and stakeholders form the basis for selection of the scenarios. The number of scenarios chosen will depend partly on time and cost limitations, but also on data limitations. Where data are few, and understanding of the social and ecological structures linked to the river is poor, then fewer rather than more scenarios should be chosen. These should be as dissimilar as possible, so that broad basin-level trends can be described. In general, four to six scenarios is a good starting point. When the DSS is set up and functioning, it allows additional scenarios to be explored relatively quickly and easily. Considerations when selecting scenarios include:

- the available hydrological modelling capacity, which will dictate the variables that can be changed per scenario;
- the possible spatial resolution (i.e. number of sites), which will be partially driven by the hydrological delineation of the basin;
- the base year and time of interpretation for the scenarios – often taken as 20-30 years into the future from the base year.

Projects may choose to define a series of scenarios that reflect increasing levels of water-resource development within the basin of interest. Each, once analysed, will describe the resulting condition of the ecosystem and society (e.g. Table 2.2). Sometimes, however a scenario is required that specifies a target ecosystem condition. Such scenarios require a flow regime to that will facilitate attainment of the target ecosystem condition. This is discussed further in Sections 3.3.1 and B.14.

Table 2.2 Hypothetical example of the matrix of information that could be developed for each part of a river basin. The indicators would be more numerous than shown and would differ from river to river. The crosses represent the level of beneficial use under each scenario as gleaned from directed supporting research and are used here merely to illustrate possible trends in the status of each indicator. PD = present day. HEP = hydropower (King and Brown 2010).

Indicators	Scenarios of increasing levels of basin development					
	PD	**A**	**B**	**C**	**D**	**E**
Development benefits						
HEP generation	x	x	x	xx	xxx	xxx
Crop production	x	x	xx	xxx	xxxx	xxxx
Water security	x	xx	xxx	xxx	xxxx	xxxx
National economy	x	x	xxx	xxxx	xxxx	xxxx
Aquaculture	x	xx	xxx	xxx	xxx	xxx
Development costs						
Wild fisheries	xxxx	xxx	xxx	xx	xx	x
Water quality	xxx	xxx	xx	xx	x	x
Floodplain functions	xxxx	xxxx	xxx	xx	x	x
Cultural, religious values	xxxx	xxx	xxx	xxx	xx	xx
Natural-resource buffer against need for compensation for subsistence users	xxxx	xxx	xx	xx	x	x

2.2 Step 2: Knowledge capture

2.2.1 Hydrological modelling

A deliberate decision was taken not to include hydrological modelling as part of DRIFT, but rather to specify what hydrological data would be needed. This allows the hydrologists to work with hydrological models already set up for the basin of interest, or ones that they feel are best suited to the work at hand.

For an EFA, hydrology data for each EF site are required. The present day, naturalised and expected future flow regimes associated with scenarios need to be modelled / generated by whatever hydrological / water-resource systems model is appropriate for the study basin, the available data and the scenarios that are envisaged. Typically, the outputs required from the model are daily flow data (monthly data do not provide the resolution required), except where EF sites are influenced by hydroelectric power (HEP) schemes that generate power at peak times each day, in which case the data are required at a sub-daily level. In the case of proposed HEP schemes where sub-daily hydrological data are not available, the sub-daily summary statistics required for the DSS will need to be developed from descriptions of the intended operation of the HEP.

The basic requirement for DRIFT is to obtain daily (or, on occasion, sub-daily) hydrological flow sequences for a consecutive run of years – preferably 30 or more. The first time-series produced is a continuous record of present day flows for each site over a stated period. Thereafter, simulated time series are produced for the naturalised condition and for all chosen scenarios, over the same period. For each time series, the water-resource conditions chosen are imposed over the full period.

The flow sequences are not, as they stand, easy to interpret ecologically. They are therefore transformed into a set of flow indicators and summary statistics chosen by the ecologists and resource economists.

The nature and use of indicators in DRIFT are explained in Section B.6. The flow indicators are attributes of the flow regime that are believed to be of ecological importance. They are usually identified first by season and then by a series of features of each flow season. An example of a set of flow indicators, for flow seasons Dry, Transition 1, Wet/Flood, Transition 2, is as follows:

- Mean annual runoff (Mm^3)
- Dry season onset (calendar week)
- Dry season minimum 5-day flow (m^3/s)
- Dry season duration (days)
- Ascension slope for Transition 1
- Recession slope for Transition 2.
- Wet season onset (calendar week)
- Wet season 5-day peak (m^3/s)
- Wet season volume (Mm^3)
- Wet season duration (days)
- Wet season type (types 1 to 6)

In DRIFT, the hydrologist creates rules that help to define when a season begins and ends, thus allowing for year-by-year information for each flow indicator: a 40-year hydrological record, for instance, will have 40 values for “dry season onset”. The flow indicators thus reflect the natural variations of the intra-annual and inter-annual hydrological cycle. They are summarised by mean, median, standard deviation and range.

In summary, daily (or sub-daily) time series form the hydrological input to the DRIFT-DSS, while the DSS calculates the values for the flow indicators and summary statistics.

2.2.2 Predictions of flow-driven ecosystem change

The inputted hydrological information links with biophysical information already within the DSS, in order to produce predictions of the changes that would occur in the ecosystem as a result of flow changes. This section describes the steps involved.

2.2.2.1 Using a time-series approach

Earlier applications of DRIFT required specialists to describe the predicted final response of the indicators at the end of the time period (typically about 25-30 years) used in the hydrological modelling. In a new endeavour, DRIFT now evaluates the response of each biophysical indicator for each season, at the end of each year, and summarises this for the total period. This is explained further in Section B.9.

2.2.2.2 *Biophysical indicators*

The various specialists involved in the study each choose a set of indicators that represents ecosystem attributes that are likely to be flow sensitive. The indicators must be objects (e.g. sand bars) rather than processes (e.g. nutrient cycling) and will be described through changes in their abundance, concentrations (for e.g. water quality) or extent/area (for e.g. riffles). Some examples of indicators are provided in Table 2.3. In total 50-70 or even more biophysical indicators could be used within one project.

Table 2.3 Examples of indicators used in the Okavango study project to predict the biophysical and social impacts of development-driven flow changes (King and Brown 2009)

Discipline	**Indicator**
Geomorphology	Sand bars
Water quality	Conductivity
Vegetation – river	Upper Wet Bank (trees and shrubs)
Vegetation – delta	Lower Floodplain
Macroinvertebrates	Channel – submerged vegetation habitat
Fish	Large fish that migrate onto floodplains
Birds	Specialists – water lilies
Wildlife	Outer floodplain grazers
Social – economic	Household income – reeds
Social – lifestyle	Wellbeing from intangible river attributes

2.2.2.3 *Response curves and ratings of change*

Response curves form the heart of the DSS. Biophysical response curves are compiled by the relevant specialists, based on any available relevant knowledge: their own data, national and international literature, global understanding and local wisdom. Each response curve depicts the relationship between a driving indicator (either a flow indicator or a biophysical indicator) and a responding indicator. An example of the former would be 'how the <u>onset of the dry season</u> affects fish guild A'. An example of the latter would be 'how a change in the <u>area of riffles</u> affects fish guild A'. A responding biophysical indicator in one response curve can be a driving indicator in another (e.g. a change in the area of riffles affects the abundance of macroinvertebrates, which in turn affects the abundance of fish guild A).

For the foreseeable future, these predictions of river change will be based on limited knowledge. Many river scientists, particularly when using sparse data, are thus reluctant to quantify predictions: it is relatively easy to predict the nature and direction of ecosystem change, but more difficult to predict when it will change or by how much. To provide the option of expressing predicted change coarsely or more precisely, the response curves capture knowledge as ratings of change that can be converted to percent change, as explained further below.

Each response curve describes the expected impact of a single driving indicator on the abundance of a single responding indicator, in terms of Severity ratings on a scale of 0 (no response) to 5 (critically high), where a negative sign indicates a decrease in abundance and a positive sign indicates an increase. In the case illustrated in Figure 2.1, if the onset of the dry season in a certain year is in week 30, this is not expected to influence abundance of fish guild A, but if it were to start earlier (e.g. week 20) it could contribute to a reduced abundance (e.g. Severity -1) and if it started later it could contribute to an increased abundance.

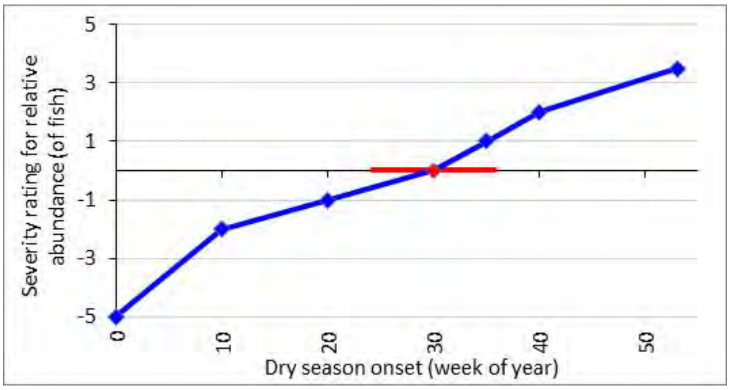

Figure 2.1 An example of a response curve for the Okavango project – in this case of the relationship between fish abundance of fish guild A and onset of the dry season in weeks. The red marker and line indicate the median and range of the present day onset of the dry season and the present abundance of fish guild A – always given as 0 or 100%.

The conversion of -5 to +5 Severity ratings to percentage changes in abundance (Figure 2.2) shows that each Severity point *decline* has an associated equal percentage decline in abundance (Rating -1 is a 0-20% loss of abundance; rating 4 is a 60-80% loss), while increases in Severity ratings are translated non-linearly to increases in percentages (in order to capture possible increases of organisms to pest proportions (King *et al*. 2003)).

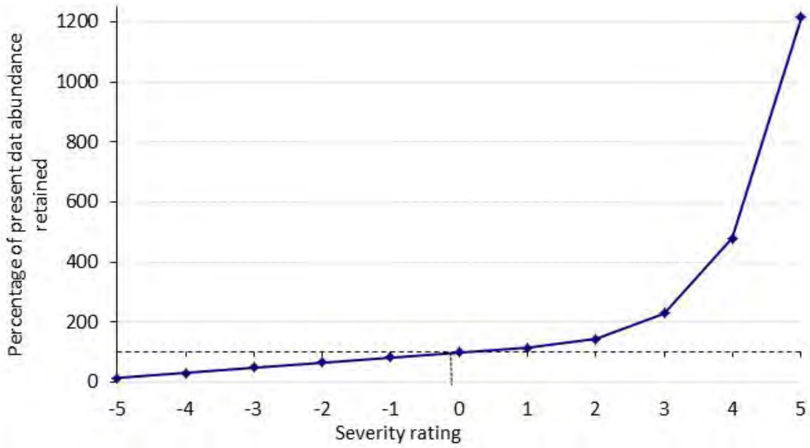

Figure 2.2 The relationship between severity ratings and percentage abundance lost or retained, used in the interpretation of response curves (King *et al*. 2003).

The specialists first choose their indicators and draw a links diagram that shows which are linked to which (e.g. Figure 2.3). In effect they are outlining a simplistic ecosystem model, which when joined with all other links diagrams, forms a more complex web (Figure 2.4). They then draw a response curve for each of the link lines, using the DRIFT software.

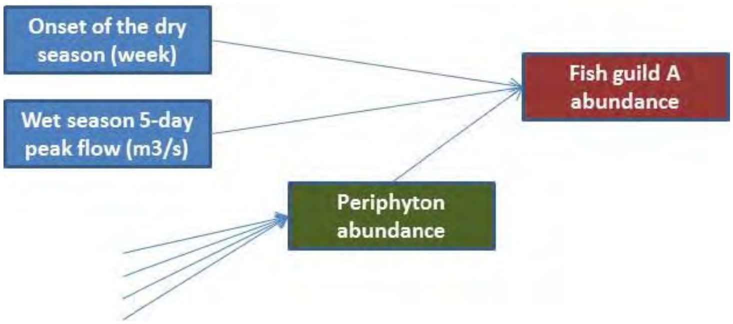

Figure 2.3 Factors influencing Fish guild A.

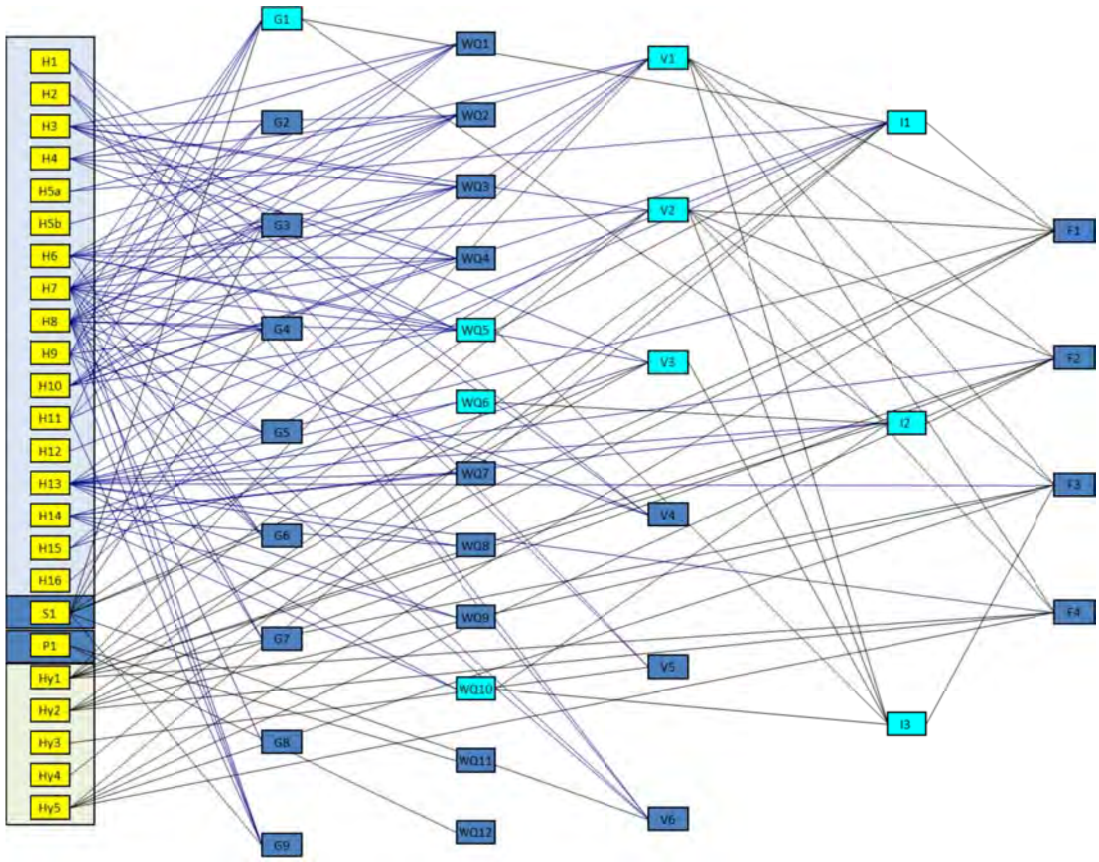

Figure 2.4 The links between indicators as identified in a DRIFT application for non-perennial rivers

The response curves provide each year's response to each year's flow indicator value. By example, for a 40-year hydrological record, there will 40 values for the onset of the dry season. These successively link to the response curve shown in Figure 2.1, providing a sequence of 40 values for the abundance of fish guild A. These outcomes are shown in various permutations in the DSS, including as a time series, and a summary end-of-series final abundance value.

The outcomes can be further synthesised to produce a summary value at the end of the time series, per scenario and site, not only of the status of a single indicator but also of the status of each discipline and of the ecosystem as a whole. To achieve the latter, the response curves are again used to provide information on changes in integrity of the indicator and, in summary, of the whole ecosystem. To do this, the Severity ratings retain their size but are converted to Integrity scores by indicating, in the DRIFT software, whether increases and decreases in Severity ratings represent a shift toward or away from naturalness (Brown and Joubert 2003), where:

- *toward natural* is represented by a positive integrity rating; and
- *away from natural* is represented by a negative integrity rating.

The Integrity scores are used to allocate a scenario to a class of overall river condition, based on three guidelines:

- the known present ecological condition of each site/zone (Section 2.1.3);
- the South African ecoclassification categories A to F (Kleynhans 1996; Kleynhans 1999; Table 2.4);
- the rules used to assign each scenario to an ecoclassification category (Brown and Joubert 2003).

Table 2.4 Generic ecological categories (PES), descriptions and percentage ratings (Kleynhans 1996; Kleynhans 1999).

PES	Description	PES % Score
A	Unmodified, natural	90-100%
B	Largely natural with few modifications. A small change in natural habitats and biota may have taken place but the ecosystem functions are essentially unchanged	80-89%
C	Moderately modified. Loss and change of natural habitat and biota have occurred, but the basic ecosystem functions are still predominantly unchanged.	60-79%
D	Largely modified. A large loss of natural habitat, biota and basic ecosystem functions has occurred.	40-59%
E	Seriously modified. The loss of natural habitat, biota and basic ecosystem functions is extensive.	20-39%
F	Critically / Extremely modified. Modifications have reached a critical level and the system has been modified completely with an almost complete loss of natural habitat and biota. In the worst instances the basic ecosystem functions have been destroyed and the changes are irreversible.	0-19%

The resulting Integrity plots consist of Integrity scores (y-axis) vs. disciplines (x-axis) or sites (Figure 2.5). The ecoclassification categories represent points along a continuum, and so are denoted as blurred lines in the Integrity plots. The plots should be used to identify each scenario's ecological condition in relation to the others and present day, rather than seen as an absolute prediction of future condition.

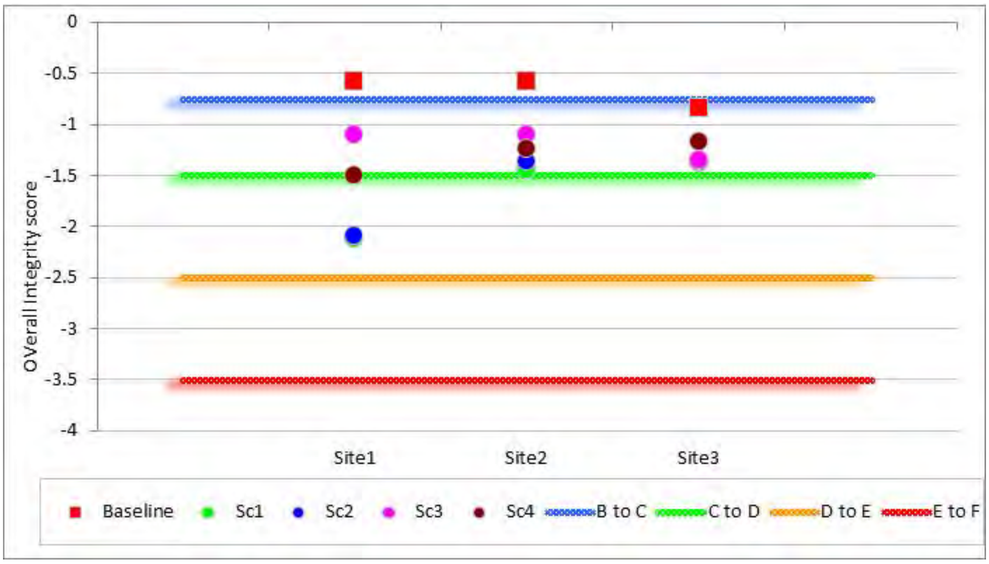

Figure 2.5 DRIFT integrity plot of overall ecosystem integrity under five scenarios at each of three study sites on a river system (Sc 1 mostly hidden behind Sc 2). Red blocks indicate Present Day ecosystem condition at each site. Sc = scenario. B to C, etc. lines indicate the approximate position of ecosystem transition to a different condition.

2.2.3 Predictions of flow or ecosystem-driven social change

The social specialists choose their indicators in the same way as the biophysical specialists, and identify which flow and biophysical indicators each of their indicators links to. This is an interactive process whereby the biophysical specialists may have to adjust indicators or add extra ones in order to supply information needed by the social team. Ultimately, the full set of biophysical predictions of change should be able to supply the social team with all the ecosystem-related information that they feel is important. They may wish to know, for instance, how water quality could change as this could impact health and wellbeing, or how fish abundance could change as this could affect household incomes.

Once their indicators and all required links have been finalised, the social team draws its response curves, using the DRIFT software. During a run of the DSS, the outputs for the biophysical indicators will form inputs to the social indicators where required, so that the final DSS output describes the predicted impact of a scenario/ flow change on both the ecosystem and its users. The social outputs include summary graphs or tables at site or basin level and per scenario of, for instance, household incomes related to the ecosystem; overall recreational and spiritual wellbeing; and river-related health issues.

2.3 Step 3: Analysis

The DRIFT process and DSS are designed to assist with consistent and coherent handling of information and data, and to allow for the meaningful comparison of the effects of scenarios across disciplines, across sites, and over time.

The DSS provides a range of options for reporting on the products of a DRIFT analysis. Graphs, histograms and tables summarise present day and scenario outcomes by indicator, site, basin and discipline in a variety of permutations. The DSS also provides the reasoning given by each specialist on the shape of their response curves, but the onus remains with the report writers to understand the DSS outputs and explain them in accessible language for the benefit of a wide array of stakeholders.

At this stage, the parallel macro-economic assessment of the scenarios should also be incorporated so that the macro-economic (from external sources), social and ecological (both from DRIFT) implications of each scenario can be presented together.

Supporting reports would usually include specialist reports that include their fieldwork findings and data and a final hydrological report.

3. Overview of the DRIFT-DSS

This section presents an overview of the DRIFT-DSS. The more technical considerations and explanations are dealt with in Appendix B.

The DRIFT-DSS was developed using Delphi XE and uses a NexusDB v3 database. The software is designed for use on all computers running Windows XP and upwards, and supports both single- and multi-user modes:

- Single-user mode (Standalone): The application and database are installed on the same computer. No configuration is required but only one concurrent user is permitted.
- Multi-user mode (Client-server): The database is installed on a computer which needs to run a NexusDB database server as a Windows service. This is a simple installation. The application can then be installed on the same computer or any other computer connected to the database server via a network. Any number of concurrent users is allowed.

The DSS also makes use of Google Earth (standard version) and Google Earth .kml files. No licence is required but any images used in reports need to acknowledge Google Earth as the source.

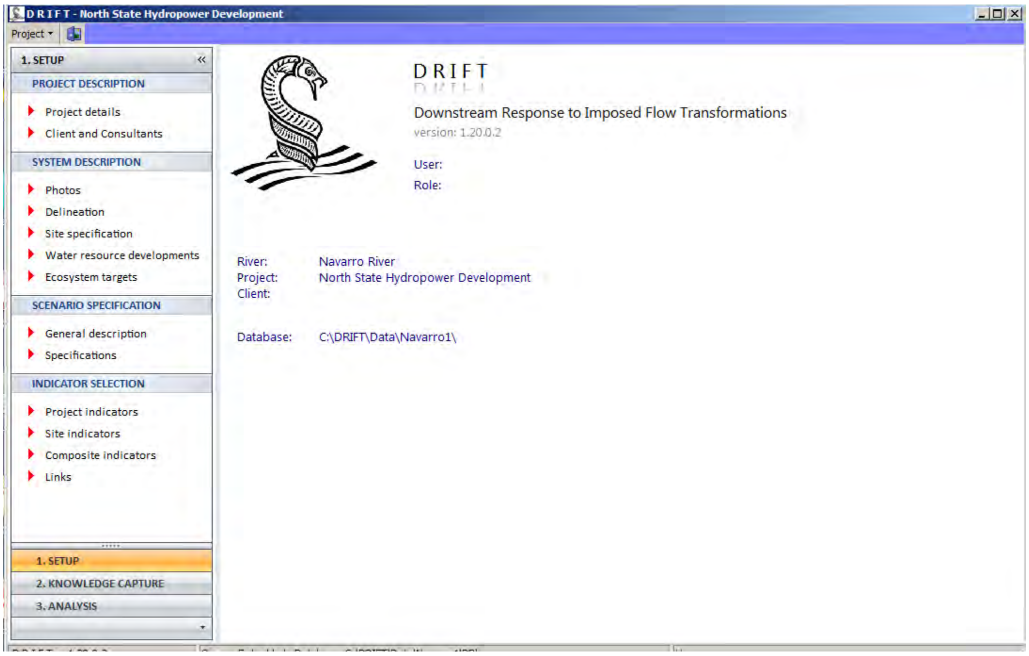

Figure 3.1 The DRIFT-DSS window showing the navigation (left) panel and main panel

The DRIFT-DSS is divided into three sections, each dealing with a different stage in an EFA. These are (Figure 3.1 and Figure 3.2):

1. Set-up
2. Knowledge Capture
3. Analysis.

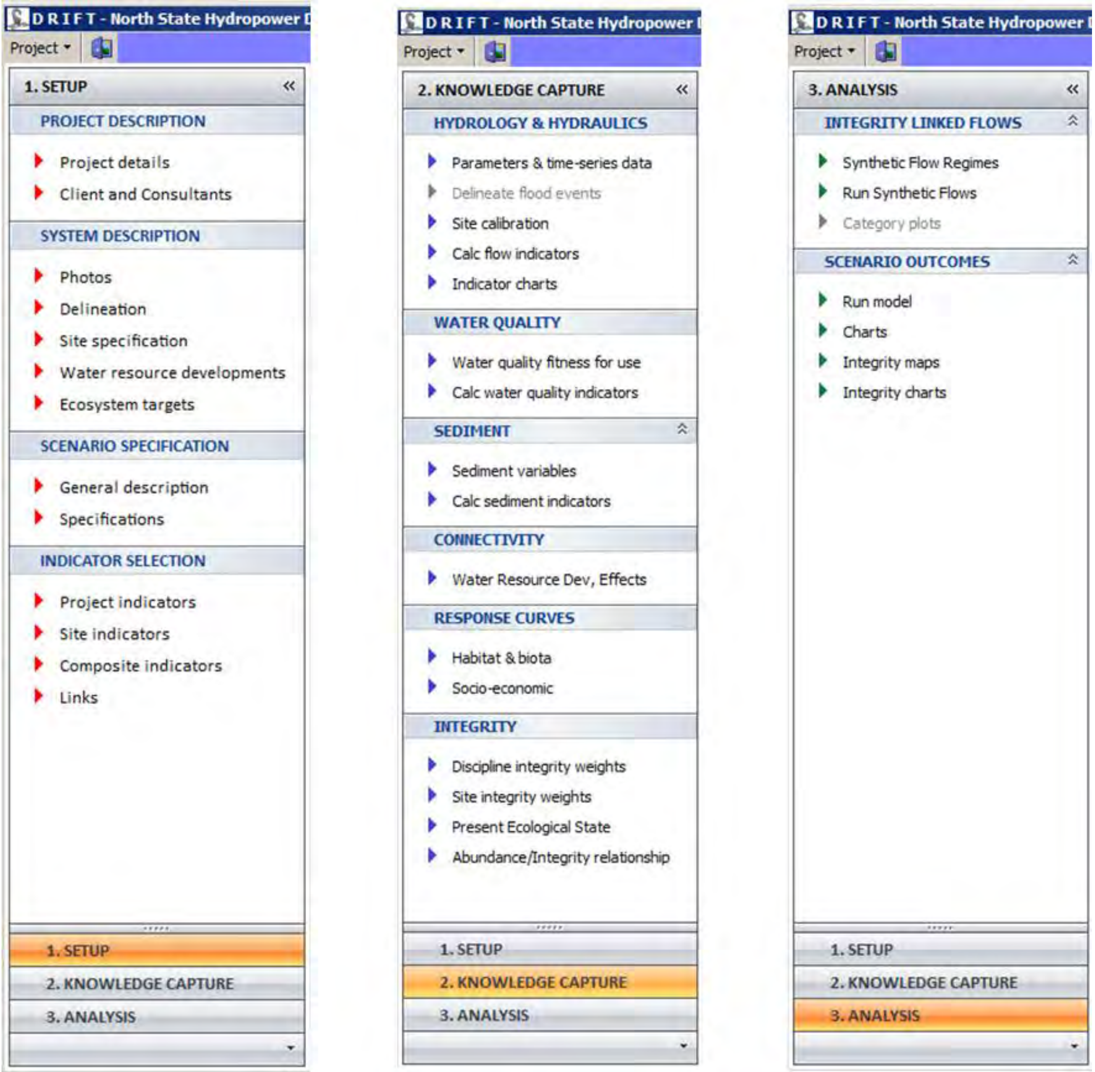

Figure 3.2 DRIFT-DSS navigation panels, showing the groups of modules contained in each of the three sections.

The first two sections deal with the population of the DSS and the calibration of the relationships that will be used to predict the ecosystem response to changes in flows. The third section is used to generate results once the first two sections have been populated, and to produce the reports and graphics detailing the predictions for the scenarios under consideration.

All hydrological modelling, is done outside of the DSS, and so depends on:

- a hydrological model to provide naturalised and present day basin hydrology; and
- a water-resource model to predict the changes in the flow regime associated with the existing and proposed water-resource developments under the various scenarios.

In addition:

- the Water Quality and Sediment Modules allow for optional import of external data (or model results if these are available and calibrated for the EF sites), and

- predictions about the effects of the scenarios on macro-economics require use of an external Macro-economic Model, calibrated for the study basin.

The module groups in the DRIFT-DSS and external models are shown in Figure 3.3. Data pathways between the modules and external models are discussed in Appendix C: User Manual.

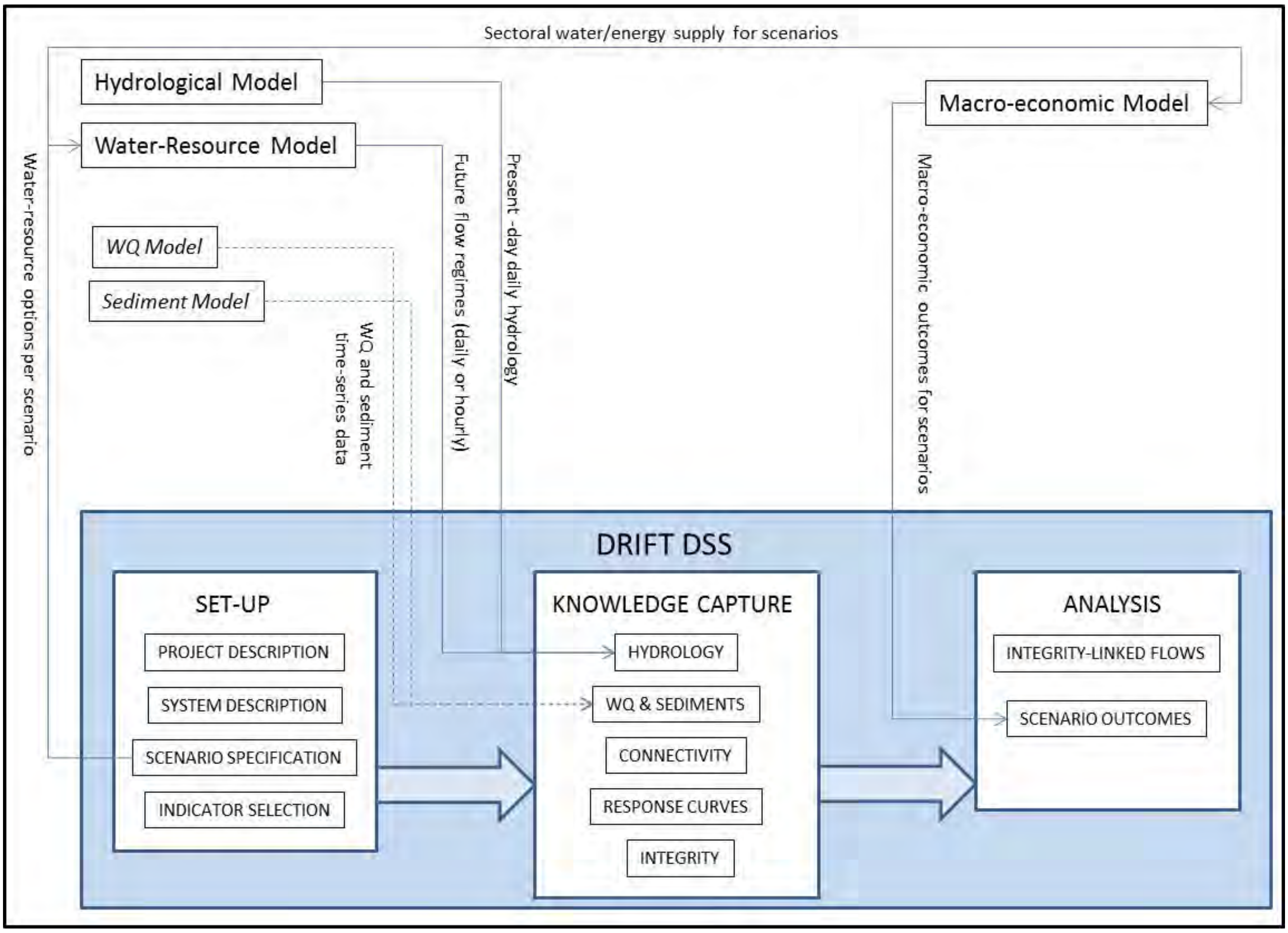

Figure 3.3 Arrangement of modules in the DSS and inputs required from external models.

3.1 Set-up

Set-up contains the modules that are used to define the basic elements of the EFA, such as the project description, description of the study area and the location and nature of the EF sites; the type, location and operation of existing and proposed water-resource developments that will comprise the scenarios of future water use; the components of the aquatic ecosystems for which indicators will be chosen to describe the consequences of flow change; and the types of social uses for which consequences of flow change will be described.

Set-up comprises the following groups of modules:

1. Project Description modules
2. System Description modules

3. Scenario Specification modules
4. Indicator Selection modules.

Each module is populated in roughly the sequence shown above, although there are some feedback loops within the DSS.

3.1.1 Project description modules

The Project Description modules are used to enter general contractual information about the project. Once entered, some of this information will appear on the DSS main panel (Figure 3.1).

The modules within Project Description are:

- Project details, such as project name, location of the study area, names of study rivers, contact details and contract dates, as well as any other relevant description of the context and purpose of the study.
- Client's and consultants' details.

3.1.2 System description modules

The System Description modules are a repository for spatial information. Manipulations of spatial data such as those required for delineation must be done outside of the DSS, as a separate exercise and the results imported into the System Description modules, as appropriate. The purpose of the System Description modules is thus to:

- import and store relevant data for the project, including:
    - homogeneous longitudinal river zones in terms of biophysical characteristics (reach analysis) and land-use;
    - homogeneous sampling areas for socio-economic surveys;
    - the biophysical zones and social areas so that the social and ecological data focus on compatible zones – called Integrated Units of Analysis (IUAs);
    - EF sites;
- provide simple base maps for use as required, and for reporting.

The modules within System Description are:

- Photos: where photos can be uploaded and geo-referenced.
- Delineation: where zones are defined and uploaded,
- Site specification: where sites are defined and geo-referenced.
- Water-resource developments: where the location and type of water-resource developments in present day and planned scenarios are listed and geo-referenced.
- Ecosystem targets: where possible ecosystem targets for particular zones can be specified.

3.1.3 Scenario specification modules

The Scenario Specification modules are used to define the infrastructure, water-resource development and/ or ecosystem targets to be included in each scenario.

The modules within Scenario Specification are:

- General description: which gives the identification code and a description for each scenario. The description should include, as relevant:
    - sectoral water demands and the location of those demands;
    - assurance of supply to different sectors;
    - operating rules for existing and proposed infrastructure; and,
    - climate change scenarios.
- Specifications: which allows the user to define the water-resource developments present in each scenario. Ecosystem targets proposed for each scenario may also be included (but at this stage are only placeholders as they are not yet linked to the ecosystem targets in the "Integrity-linked flows" module in the Analysis section.

The scenarios all follow the same route through the rest of the modules in the DSS.

3.1.4 Indicator selection modules

The purpose of the Indicator Selection modules is to generate the final list of indicators and to show the links between them for use in the Knowledge Capture and Analysis sections.

The modules within Indicator Selection are:

- Project indicators: the disciplines to be included in the study are listed here as well as the indicators within each discipline. Indicators can be entered anew, chosen from a pool of indicators from previous studies, or imported from Excel.
- Site indicators: the user allocates indicators to particular EF sites;
- Composite indicators: the user can define indicators which are an aggregation of two or more other indicators (e.g. household income may be a composite indicator, composed of a number of sources of household income);
- Links: the user selects the one or many driving indicators for each of the indicators.

3.2 Knowledge Capture

Knowledge Capture comprises the modules that contain the information used to make predictions. This includes the modules that are used to calculate and produce times-series of flow indicators, facilities to import water quality and sediment data and calculate their indicators, and the response curves modules for habitat, biota and socio-economics.

Knowledge Capture comprises the following groups of modules:

1. Hydrology & Hydraulics modules: where hydrological data are uploaded and flow (and hydraulic if needed) indicators calculated.

2. Water Quality modules: where water quality data can be uploaded and certain water quality indicators calculated.
3. Sediment modules: where sediment data can be uploaded and sediment indicators calculated.
4. Connectivity modules: where the effects of the infrastructure (listed in 3.1.2 and 3.1.3) on inter-site links along the river system (specified in 3.1.4) can be estimated.
5. Response Curves modules: where the shape and size of the relationship between driver and responder indicators is defined.
6. Integrity modules: where the relationship between abundance and the overall integrity of an ecosystem or well-being of society is defined.

3.2.1 Hydrology & Hydraulics modules

The Hydrology & Hydraulics modules are used to import hydrological time-series for scenario flow regimes produced by external models (see explanation in Section 2.2) and to convert these to time-series of flow indicators for use in the DSS.

The modules within Hydrology & Hydraulics are:

- Parameters & time-series: lists the daily/sub daily hydrological files that have been generated and imported into, and are available for use in, the DSS. The user must specify the start year and number of years of these data sets (which must be common for all scenarios).
- Delineate flood events: In DRIFT, the flow regimes of temperate rivers are separated into floods and lowflows. This module is used to manually separate highflows events (floods) from the lowflow as represented in the hydrological time series. Low flows are visually distinguished from high flows using guidelines such as the rate of change of the slope of the daily hydrograph, or the discharge at which selected features of the channel become inundated.
- Site calibration: A series of site-specific parameters must be set so that the flow (and hydraulic, if relevant) indicators can be calculated, and the seasonal time-series produced.
- Calc flow indicators: calculates the flow (and hydraulic) indicator time-series, and makes them available to other modules in the DSS.
- Indicator charts: allows the user to view graphs of the time-series of indicators for all sites and scenarios.

3.2.2 Water Quality modules

The Water Quality modules are used to import water quality time-series for scenarios, if available, and to convert these to time-series of water quality indicators for use in the DSS.

The modules within Water Quality are:

- Water quality fitness for use: used for importing time-series of water quality parameters and specifying fitness for use criteria.
- Calc water quality indicators: calculates the water quality indicators for use in the DSS.

3.2.3 Sediment modules

The Sediment modules are used to import sediment time series for scenarios, if available, and to convert these to time-series of sediment indicators for use in the DSS.

The modules within Sediment are:

- Sediment variables: is used for importing time-series of sediment variables.
- Calc sediment indicators: calculates the sediment indicators for use in the DSS.

3.2.4 Connectivity modules

The Connectivity module allows the user to assess the effects of in-channel obstructions, e.g. a dam wall and impoundment, or an area where abstraction is extreme, on longitudinal biotic connectivity and thus, the degree of connectivity between the EF sites. This is particularly important for animals that migrate up and downstream to feed or breed.

There is just one module:

- Water-resource development effects: The user estimates the percentage reduction in connectivity associated with any of the water-resource developments in any of the scenarios to be entered. Connectivity adjustments will only affect the outputs of linked indicators at sites upstream and downstream of the relevant development. For instance, if fish numbers at Site A (upstream) are dependent on adults arriving from Site B (downstream), and a dam is planned for between the two, then the connectivity adjustment will be applied to the output for Fish at Site B, i.e. fish leaving Site B will not reach site A because of the dam wall obstructing their passage. Or, if there is a fish ladder, then some but not all fish leaving Site B may reach Site A. Thus, even if the flow at Site B is sufficient to support the fish, the population at Site A will not benefit from this because of in-channel obstructions.

3.2.5 Response Curves modules

The Response Curve modules (see explanation in Section 2.2.2.3) convert predictions of changes in the quantity and timing of flows to changes in:

- individual habitat and biotic indicators;
- the ecological condition of river reaches, wetlands and the estuary as relevant;
- the change in ecosystem services identified by the social and economic studies.

The modules within Response Curves are:

- Habitat and Biota: the data for the habitat and biota response curves, and their appropriate modifiers (see Section B.8) are entered; and,

- Socio-economic: the data for the socio-economic response curves and their appropriate weightings (see Section B.8) are entered.

3.2.6 Integrity modules

The information needed to calculate Ecological Integrity at various levels of aggregation is entered into the Integrity modules (see explanation in Section B.10). This includes information on the contributors to Integrity and the present condition of components of the ecosystem.

The modules within Integrity are:

- Discipline integrity weights: where weights are given to indicators in order to be able to calculate Discipline Integrity.
- Site integrity weights: where weights are given to disciplines in order to be able to calculate Site Integrity.
- Present Ecological Status: where the present condition (see Section 2.2.2.3) of each discipline is entered, both for general information, and for use in adjusting Integrity to be relative to natural rather than present day.
- Abundance / integrity relationship: where the user specifies whether an increase in abundance of each indicator translates to move towards or away from natural (see Section 2.2.2.3), which is needed in calculation of Discipline Integrity.

3.3 Analysis

Analysis is used to run the DSS and view the results. It comprises the following groups of modules:

1. Integrity-linked Flows, and
2. Scenario Outcomes.

3.3.1 Integrity-linked Flows modules

Instead of reacting to a flow regime developed by the hydrologist, it is also possible to initiate flow regimes from the ecological 'end point' of ecosystem integrity. This can be done in order to describe flows needed for a target ecosystem condition or to explore ecosystem functioning and possible thresholds in this. See Section B.14.

The modules within Integrity-linked Flows are:

- Synthetic flow regimes: constructs a suite of synthetic flow regimes between the harshest water-resource development scenario and the present day or naturalised flow regime, and calculates the flow and hydraulic indicators for each.
- Run synthetic flows: runs the flow and hydraulic indicators through the DSS, calculating abundance, integrity and social well-being for each synthetic flow regime.
- Category plots: creates plots of integrity scores (y-axis) vs. percentage or volume of MAR (x-axis). Category plots can be used to examine the relationship between volume of water and ecosystem integrity, and identify features, such as inflection points, where

integrity changes considerably for a small change in flow. Scenarios can also be generated and plotted to evaluate the implications of non-optimal distribution of flows, such as may happen where large floods cannot be released through an upstream dam.

3.3.2 Scenario Outcomes modules

Runs of the populated, calibrated DSS are done in Scenario Outcomes. This module also contains the resulting scenario graphics and maps.

The modules within Scenario Outcomes are:

- Run model: runs the DSS.
- Charts: comprises various charts and graphs used to display the results. These will be explained in detail in Appendix C: User Manual.
- Integrity maps: comprises various maps that are used to display the results. This module links with the System Description module (Section 3.1.2). The details of ‘Maps’ will be explained in detail in Appendix C: User Manual.
- Integrity charts: for viewing Integrity plots (Section 2.2.2.3).

The technical considerations and explanation for the application of DRIFT are given in Appendix B.

4. The way forward

4.1 Conclusions

DRIFT consists of procedures and software developed in South Africa to predict the expected ecological and social implications of proposed water-resource management activities. Its outputs complement the engineering and economic information usually available on such activities and so DRIFT helps provide a more balanced picture of the full suite of costs and benefits linked to water-resource proposals.

The DRIFT-DSS is a first-generation, simplified ecosystem model in which relevant data are organised to provide predictions of ecosystem and social change. The process of providing the data requires specialists from many disciplines to work together and may push them to the limits of their understanding of the ecological and social systems involved. This often triggers new focused research, teaching and post-graduate studies, as described in the 99-page list provided by King and Pienaar (2011) for South African EF work over the last two decades. This is beneficial for the country in terms of skills development and for water management in that it has at hand up-to-date research understanding for use in its projects.

The DRIFT-DSS remains under development and some aspects could not be addressed in this project. The recommended next steps for development appear in Section 5.2, but it is worth noting here that the DRIFT process has provided valued input in a range of management situations around the world and is now recognised as best practice by the World Bank, IUCN, UNEP, OKACOM and many international consulting firms. By doing so it has played a strong role in highlighting South Africa as one of the global 'super powers' in the science of environmental flows, a space that the country should aim to continue to claim, and indeed to extend, in terms of the global knowledge economy.

DRIFT, as it stands, illustrates what is possible and its many successful applications internationally reveal the need for such a tool. Further development requires investors, as the funds needed are beyond those available for the average South African research project. These funds would be used, *inter alia*, to:

- enhance the model's capabilities and its outputs
- include better mapping facilities
- incorporate better ecosystem modelling
- market the software globally
- develop and present training courses.

The intellectual property encompassed in DRIFT should be registered, and it is the intention of Southern Waters to do this in 2013.

4.2 Capacity building

Two factors have adversely affected the ability to increase the number of people applying DRIFT. First, both internationally and nationally, capacity building posts are usually not accepted as part of most projects. Where are they asked for, people are usually allocated intermittently by the client to these posts, whether or not they are suitable, and may be too committed elsewhere to be able to benefit from hands-on training.

Second, the developmental nature of the DRIFT-DSS has made it difficult to train others because much of it still changes from time to time. Having a programmed version will mean that interested river specialists could start training in that version, while further development proceeds.

A first step in such training is an international course on DRIFT and environmental flows that will be offered in 2013 by the authors of this report under the auspices of the University of the Western Cape. Further national training courses could follow or precede this using the same material, for DWA and potential practitioners.

The help of the WRC will be sought to devise a cohesive plan for national training.

4.2.1 Capacity-building activities in the project

The following DRIFT-related capacity-building activities were undertaken during the course of the project:

- Okavango Technical Diagnostic Analysis (2009-2010: Funded by the FAO):
    - o Specialist teams from Angola, Namibia and Botswana were trained in DRIFT concepts, population of the DRIFT (Excel) database and interpretation of the outputs. Training was done in a real-project situation, with the input from about 30 specialists from the basin forming the basis of the EFA underpinning the TDA.
- Checras HPP, Peru (2012):
    - o Dr Geordie Ractliffe (water quality, periphyton and macroinvertebrates) and Dr Bruce Paxton (fish) were trained in population of the DRIFT (Excel) database and interpretation of the outputs. Training was done in a real-project situation, with the specialists' input forming the basis of the EFA underpinning the Cheves EF Management Plan.
- Kishenganga/Neelum Jhelum, Pakistan (2010-2012):
    - o A Pakistani team of specialists was trained in DRIFT concepts, population of the DRIFT Excel database and the DSS and interpretation of the outputs. Training was done in two real-project situations.
- University of the Free State non-perennial rivers, RSA (2010-2012):
    - o DRIFT was used as the platform for developments specific to non-perennial rivers. Hence the UFS project team received instruction in DRIFT.
- International Court of Arbitration (The Hague; 2012):

- DRIFT was a focal point in the environmental component of the dispute between India and Pakistan over Kishenganga Dam. The proceedings of the court case, which were heard at the International Court of Arbitration, Peace Palace, The Hague, Netherlands, is possibly the first time environmental flows have received such import in an international dispute.

- Reserve determination studies for selected surface water, groundwater, estuaries and wetlands in the Usuthu to Mhlatuze catchment, RSA (2013-2014):
    - Southern Waters is contracted to assist Adhishri Singh and Coleen Todd in running DRIFT for the DWA-funded study to determine the Reserve for rivers in the Usuthu to Mhlatuze catchment. Part of the duties will include training the specialists in DRIFT concepts, population of the DRIFT (Excel) database and interpretation of the outputs.
- EFA International Training Course (2013-??):
    - In April 2012 Drs King and Brown were appointed as Extraordinary Professors at the University of the Western Cape. As part of their duties they will run an international EFA Training Course. The course outline was submitted to and accepted by the UWC accreditation committee and, as such, successful participants will earn a UWC certificate.
- MSc student (2012-2013):
    - Dr Brown is supervising the MSc of Ms Rozwi Magoba, which focuses on environmental flow requirements of riparian vegetation. Although she is not using DRIFT directly, many of the concepts that underlie the project were developed using DRIFT, and her studies will contribute towards expanding the capital used to construct response curves (see Section 4.3.4).

4.3 Recommended research

4.3.1 Streamlining the decision-making process

DRIFT applications rely on an external macro-economic assessment of the scenarios to complement their ecological and socio-economic assessments. This is usually not done because funds are not made available outside those for the EFA or because any economic assessment that is done does not focus on the DRIFT scenarios (even though they are chosen in consultation with the client/government) and so it cannot provide comparable data.

Once scenarios are identified in the DRIFT process and approved by the client/government, the planning process should ensure that these are taken up for economic assessment. This will need some liaison with DWA for projects within South Africa, and liaison to produce the extra funds and organisation needed for international projects.

4.3.2 Valuing ecosystem services

Even with the economic and socio-economic assessments in place, the total economic picture can be distorted because ecosystem services are often not included. Until we can value the cost of losing, for instance, a functioning wetland or estuary in a way which allows for comparison with the benefit value of real estate that could obliterate them we do not have a balanced picture on which to make decisions.

4.3.3 Catchment sediments and pollution

DRIFT takes the hydrological times series as its starting point for all predictions of change. Experience has shown that certain catchment characteristics, specifically sediment inputs from the catchment and envisaged pollution, cannot be incorporated into scenarios through this route. Sediments may become trapped in reservoirs built into some scenarios, and the change of flows caused by the dams would not capture the additional impact caused by downstream losses of these sediments. Similarly, increased levels of pollutants entering the river may be an obvious part of a scenario but not necessarily linked to a flow change and so cannot be captured. Research is needed on the best way to incorporate such aspects into the DRIFT process.

4.3.4 Response curves

This excerpt is taken from Chapter 8 of King and Pienaar (2011):

> **"Increasing the knowledge capital":** The information provided for Reserve determinations to date is based on a mix of data, expert opinion and local wisdom. This is the 'capital' that is being used and it is expanding extremely slowly because it takes years to develop a better understanding of how complex social-ecological systems function. As a result much the same reasoning goes into every Reserve determination, with poor feedback of how accurate this is. It could be, for instance, that the Reserves recommended by scientists and approved by DWA are in fact too low to maintain the health of the aquatic systems and that is one reason why they are still degrading. It is time to shift focus and aim to expand the 'capital'."

To expand our capital, individual focused discipline research is needed on many fronts to improve the information being used to compile response curves. Flow-related studies are excellent topics for post-graduate studies and are already enhancing our understanding of flow-ecosystem relationships. This kind of work needs to be more strongly promoted.

Linked to this we are probably in the position by now to initiate a national library of response curves. This would require some coordination and thought in order to incorporate indicators effectively, but its outcome would be a national pool of information that could be accessed for DRIFT applications and other water management purposes. The response curves so housed would be amenable to adjustment using local knowledge.

4.4 Planned development of the DRIFT-DSS

The DRIFT process and DSS continually evolve, and a number of known improvements or changes have been identified for inclusion in future versions of the DRIFT-DSS. These include:

- copy and paste from one response curve to another.

- rephrasing of some menu items and column headers.
- inclusion of help sections or hints.
- standardisation of input data file formats.
- refinement of the relationship between abundance and integrity: Currently the DSS only allows for ‘towards’ or ‘away’ relationships, whereby ecosystem integrity either improves or declines with a one-way change in abundance of an indicator. In some cases, however, ecosystem integrity could exhibit both a ‘towards’ and an ‘away’ response: it could initially improve as an indicator increases in abundance, but then eventually decline with a continued increase of the same indicator.
- inclusion of non-flow related scenario indicators, such as land-use.

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Appendix A. REVIEW OF KEY QUESTIONS

Note that this review has only been marginally adjusted since delivery in 2010. Minor adjustments were made to link the content better with that described in the main report (but inconsistencies might still exist). A summary section has been added (Section A.12).

A.1. Introduction

The aim of the review of key questions is to evaluate different approaches used in Decision Support Systems (DSSs) to set and evaluate environmental flows (EFs) in order to inform the approach that will be adopted in the 1873-EF-DSS. We identified a set of questions of particular relevance to the design and operation of the 1873-EF-DSS (Appendix Table 1) and we then identified software and theory (e.g. modelling, statistics, mathematical analyses) that we thought would provide a wide range of approaches and the best guidance in answering each question. Thus, we did not necessarily review any one DSS in its entirety nor did we limit ourselves to environmental flow methods or DSSs, to water-resources software, or to any particular discipline. We also did not attempt to review all environmental flow methods, as there are over 200 of these (e.g. Tharme 2003) many of which do not provide the sort of detailed information required to undertake a full integrated flow analysis for a basin (see Brown, 2007).

Appendix Table 1 The key questions addressed in this review

#	Issue	Key questions
1	Scale and representivity	How is the study area represented?
		What scale(s) are the results provided at?
		Do any of the DSSs provide an integrated basin output?
2	Sequence of analysis of data	Which is the first step in the analysis sequence?
3	Use of hydrological data	What flow indicators are used, and how are they calculated?
4	Measuring change	How is change reported?
		What is change relative to?
5	Indicators	What number and type of indicators are used?
6	Constructing response relationships	How are responses of the ecosystem captured?
		What types of relationships are used and how are they aggregated?
		Are the flow indicators the only inputs to the biophysical and social aspects or are there others?
		Is there feedback between indicators, are there upstream / downstream linkages?
		Are the outputs quantitative or qualitative?
7	Dealing with uncertainty	Is uncertainty captured and, if so, how?
8	Time steps – inputs and outputs	Are the inputs single values or time series?
		Are the outputs single values or time series?
		How are scenarios evaluated?
9	Presentation of outputs	How are the results presented?
10	Programming languages / platforms	What programming language/modelling platform is used?
		Is a GIS platform used?
11	User interface	Is a GIS platform used?
12	Linking biophysical and socio-economic outputs	Forms part of Task 5.2

The full list of methods and DSSs referred to are listed in Appendix Table 2, together with their references. To facilitate readability, references are not repeated in the remainder of the text. The specific methods or DSSs reviewed for each question are listed at the start of the section dealing with each question. Where relevant, we conclude each section with a comment on the approach that was adopted for the 1873-EF-DSS.

Appendix Table 2 Methods and DSSs referred to in the text

Name (alphabetical)	Reference / Source	Type of method / DSS
1. BayFish	Baran et al. (2003)	EF DSS for fish only
2. BBM	King et al. (2008)	Non-computer-based EF method
3. BCG-DSS	Auble et al. (2009)	General water-resource / EF DSS
4. Catchment2Coast	Monteira and de Paula (2006)	Estuarine / Bay DSS
5. DEMIOS	Turpie et al. (2008 a and b)	STELLA-based Estuarine EF DSS
6. Desktop Model	Hughes and Hannart (2003)	EF DSS
7. DRIFT-DSS 1[3]	Brown et al. (2008)	EF DSS
8. ELOHA	Poff et al. (2010)	EF DSS
9. Habitat Flow Stressor Response (HFSR)	O'Keeffe et al. (2002)	EF method
10. IFIM[4]	Stalnaker et al. (1995), but see King et al. (2008) for a summary.	EF method and models
11. Latrobe Bayesian Network (BN)	Hart et al. (2009)	Bayesian EF DSS
12. MDSS4	Fondazione Eni Enrico Mattei (2008)	MCA based water-resource / EF DSS
13. MFAT	Young et al. (2003)	EF DSS
14. DRIFT-DSS 2	King et al. (2008)	EF DSS
15. PIMCEFA	Barton and Berge (2008)	MCA based water-resource / EF DSS
16. RAP	Marsh (2004)	General water-resource / EF DSS
17. WFET[5]	Colorado Water Conservation Board (2009)	EF DSS
18. WRCS	Water-resources Classification System, Dollar et al. (2009)	General water-resource / EF DSS
Packages / generic methods		
19. EcoPath with EcoSim	Christensen et al. (2008)	Ecosystem modelling package
20. EcoWin2000	Ferreira et al. (2008)	Ecosystem modelling platform
21. Netica, Hugin Lite	Netica (© Norsys Software Corp (2010), Hugin Lite (© Hugin Expert A/S (2009)	Bayesian belief network creation packages
22. STELLA, Vensim	STELLA (ISEE Systems, 2009), Vensim (Ventana Systems, 2010)	System dynamics modelling packages

[3] For the purposes of this review, the original DRIFT-DSS (King et al. 2003; Brown and Joubert 2003; Brown et al. (2008) is referred to as "DRIFT-DSS 1" as compared to the Excel-based time-series version referred to as "DRIFT-DSS 2"

[4] The name IFIM is used in a generic sense in this chapter referring to the IFIM process as well as the associated physical habitat simulation models (PHABSIM) and similar models developed separately (e.g. RHYHABSIM).

[5] WFET is an application of ELOHA.

A.2. Scale and representivity

Types of information reviewed: EF Methods, DSSs and other modelling paradigms.

Methods and DSSs referred to: BBM, DEMIOS; Desktop Model; DRIFT-DSS 1; ELOHA; IFIM, LaTrobe BN; MDSS4; MFAT; DRIFT-DSS 2; PIMCEFA; RAP; WFET, WRCS.

A.2.1. How is the study area represented?

Most of the approaches, particularly those dealing with rivers, use data collected at demarcated sites to represent larger parts of the ecosystem. The results from these sites are then extrapolated to the reaches or areas that they represent. Exceptions to this include some estuary (e.g. DEMIOS) and wetland (e.g. DRIFT-DSS 2 – Delta Module) approaches, which consider the ecosystem as a whole.

Time and financial constraints usually limit the number of representative sites that can be incorporated into a study, which in turn limits the coverage of the ecosystem, particularly in the case of river systems where the upstream parts of the basin will respond differently to flow change than the downstream parts, and where tributaries will respond differently to the main river.

A.2.2. What scale(s) are the results provided at?

BBM, DRIFT, BCG-DSS, IFIM, MDSS4 and PIMCEFA all produce site- or reach-specific results and do not have an approach for aggregating results or extrapolating up to the basin level. In the RAP DSS, it may be possible to provide combined results for more than one site.

In the case of WFET, the responses for a site are based on data from rivers in various locations, but of the same 'type' (Rocky Mountains, Western Interior and Great Plains). The WFET approach is intended to be fairly coarse watershed-scaled, supplemented by more detailed site-specific studies where required. However, results are presented as effects on nodes and reaches and overall or aggregated impacts on the watershed are not presented.

MFAT and DRIFT-DSS 2 begin with site- or reach-specific responses. Results can be integrated and aggregated to represent multiple scales, including integrated basin outputs. The Latrobe Bayesian Network (BN) is also reach specific, but the BNs from the different reaches can be integrated to obtain an overall assessment.

In the WRCS approach, relationships are extrapolated from sites in the basin with information (e.g. from previous EFAs) to similar reaches within the basin. Extrapolation is based on grouping of similar reaches based on ecoregions, hydrological and geomorphic type, present ecological status, ecological importance, and infrastructure. Results can be integrated and aggregated to represent multiple scales, including integrated basin outputs.

The Desktop Model, produces results as flow requirements for a site (based on quaternary catchment scale parameters), rather than for different disciplines or indicators for any site.

In contrast to the above, Catchment2Coast and DEMIOS aim to model a whole ecosystem (the estuary, and bay and estuary, respectively). Catchment2Coast presents results by zone within the estuary and bay, as well aggregated outcomes for the whole study area. DEMIOS produces results for the estuary as a whole, as well as areas of different habitats and abundances of different indicators. One of the modules of the DRIFT-DSS 2 (Delta Module) also produces results integrated results for one large section of the Okavango Swamp, version intermediate between 1 and 2 also had components developed especially for the estuary and lakes (King and Brown 2009).

In general though, the ability to provide basin-level outputs is mainly driven by the hydrological systems model that is used. However, for a fully integrated approach issues such as upstream/downstream linkages should be taken into account (see Section A.7.3). For instance, migratory fish species present at one site may be dependent on the availability of breeding areas at another and/or on connectivity between the two sites. We were unable to locate any EF DSSs that included linkages of this nature. Similarly, we found no EF DSSs that included consideration of landuse change, although some hydrological models (e.g. ACRU) include consideration of these, in particular aspects such as afforestation and erosion.

A.2.3. Approach adopted in the 1873-EF-DSS

The 1873-EF-DSS is based on site-specific assessments which are integrated / aggregated up to broader zones and for the basin as a whole. The user is, therefore, able to view both site-specific and summarised basin level information.

The DSS also makes provision for the inclusion of upstream/downstream linkages (see Section A.7.3).

A.3. Sequence of analysis of data

Types of information reviewed:	EF methods and DSSs
Methods and DSSs referred to:	BBM; DRIFT-DSS 1; ELOHA; MDSS4; MFAT; DRIFT-DSS 2; PIMCEFA; RAP; WFET.

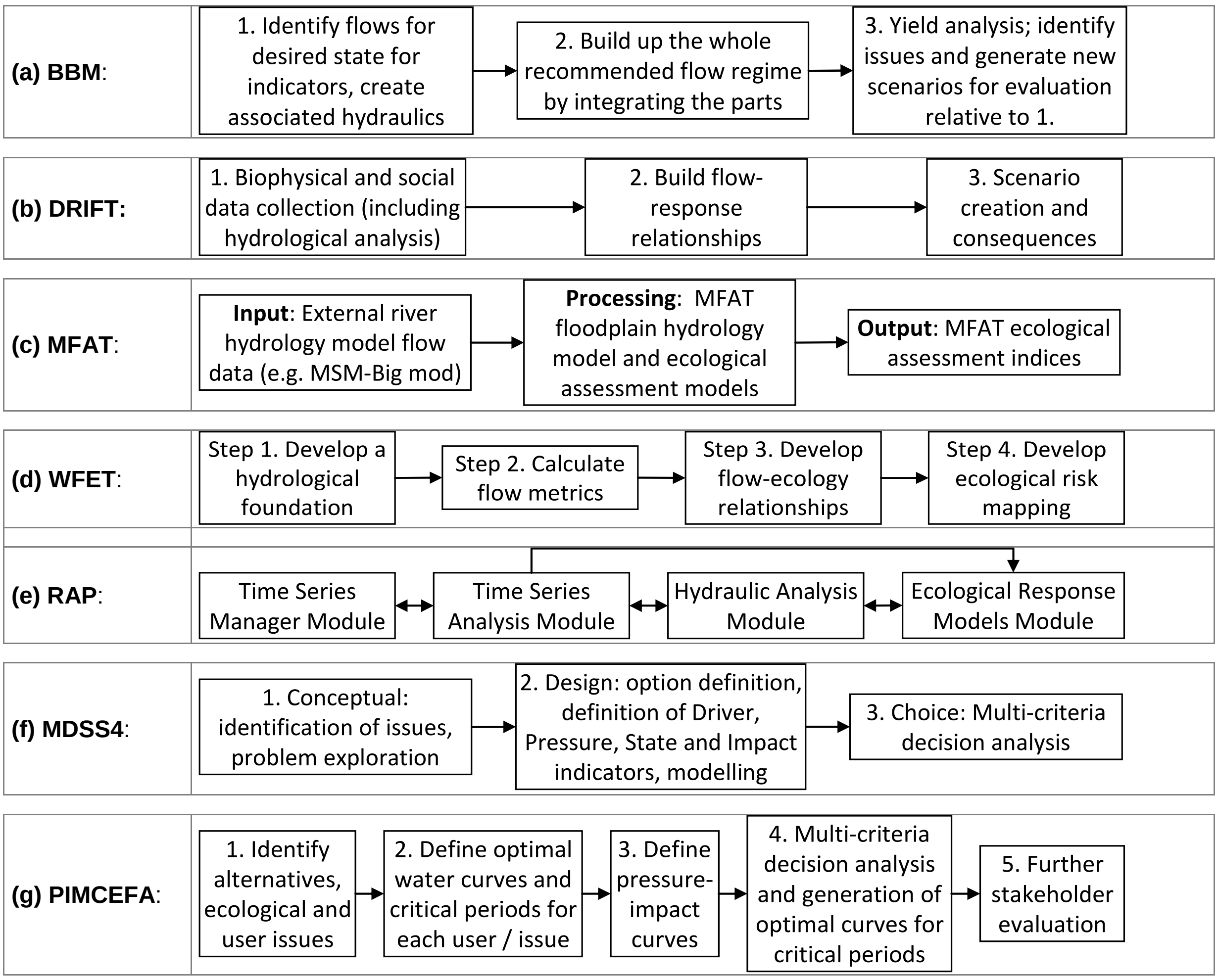
A.3.1. Which is the first step in the analysis sequence?

At first glance, the sequences of activities in EF methods and DSSs appear to differ from one another. The more explicitly MCA-based approaches (MDSS4 and PIMCEFA) start with problem structuring; many EF approaches start with hydrology (DRIFT-DSS 1, MFAT, DRIFT-DSS 2, WFET, ELOHA); while RAP is a more a generalist package with four modules (e.g. Appendix Figure 1) that can be used in sequence or separately.

If, however, one accepts that some form of problem structuring must precede application of any of the methods or DSSs, regardless of whether it occurs within or outside of the DSS, then hydrological analyses are the first step in the analysis sequence for all the methods and DSSs reviewed, except for the BBM.

BBM (Appendix Figure 1) starts with an expression of the 'desired future state' for an ecosystem and then sets the environmental flow requirements for the different components of the river ecosystem (e.g. channel maintenance, fish species x) to meet this state. Only once a full modified-flow regime has been constructed is this compared with the actual flow regime.

Although hydrological analyses and the calculation of flow indicators initiate the process for many DSSs (see e.g. Appendix Figure 1, (b) to (d)), these are not necessarily done within the DSS. For instance, with MFAT, these analyses are done using an external model, MSM-Big Mod, and the resultant flow indicators are the input to MFAT. However, the MFAT DSS includes a model for simulating floodplain hydrology (driven by flow data from the external river hydrology model).



Appendix Figure 1 **Comparison of process flow for BBM, DRIFT, MFAT, WFET, RAP, MDSS4 and PIMCEFA**

Similarly, the flow analyses for DRIFT-DSS 1 are done outside of the EF-Module (in DRIFT-Hydro) and the resultant flow indicators are used as input into the DSS. RAP, on the other hand, includes modules for the calculation of several flow indicators from a hydrological time series, for hydraulic analysis (Appendix Figure 1), a module with tools for 'gap filling' of the input time-series data as well as the ecological response module.

A.3.2. Approach adopted in the 1873-EF-DSS

The 1873-EF-DSS

- does not include a hydrological model, as the preference is to use the most appropriate model for any particular system;
- specifies hydrological analyses as one of the first stages in the process;
- includes a module for the calculation of a wide range of flow indicators for two river types (temperate and flood pulse) and numerous types of water-resource interventions.

A.4. Use of hydrological data

Most of the DSSs or methods do not specify which flow indicators should be calculated but rather use whichever ones seem appropriate for the particular study, or are needed in order to determine ecological responses of a particular indicator (Appendix Table 3 lists some of those used). In contrast, DRIFT-DSS 1 (for temperate rivers) breaks the hydrological regime into several defined components (e.g. wet season low flow, dry season low flow, several classes of intra-annual and inter-annual floods), and these are used as the inputs for the ecological responses. DRIFT-DSS 1 has also been adapted for a number of non-temperate river types (e.g. flood pulse systems) and different types of flow indicators were defined and calculated. For example, for the DRIFT-DSS 2, a flood-pulse system, the relevant flow indicators related to the onset of the dry and flood seasons, their durations and volumes as well as the flood type (categories of flood volume) and slope of the flood recession (Appendix Table 3).

Appendix Table 3 Examples of flow indicators

MFAT	WFET (ELOHA)	BCG-DSS	DRIFT-DSS 1 (temperate)	DRIFT-DSS 2	FLOWS	LaTrobe BN
Not specified by method (example application)	*Not specified by method (example application)*	*Not specified by method (example application)*	*Specified by method and DSS*	*Not specified by method (example application)*	*Specified by method*	*Not specified by method (example application)*
Daily water depth	Mean annual flow	Annual Minimum Daily Discharge	Wet season low flows	Onset of dry season	Cease to flow / no surface flow	Summer low flows
Daily depth variability for the year	Mean January flow	Annual Mean Daily Discharge	Dry season low flows	Minimum dry-season Q	Low flow / minimum flow	Autumn fresh flows
Flow percentile	Mean August flow	Annual Maximum Daily Discharge	Flood: Class 1	Duration of dry season	Freshes / flow greater than median flow	Spring fresh flows
Rate of depth increase	One-day peak flow	Annual 14-Day Maximum Daily Discharge	Flood: Class 2	Onset of flood season	High flows / connect most in-channel habitats	Bankfull flows
Duration of rate of depth increase		Ramp Rate	Flood: Class 3	Flood type (based on flood volume)	Bankfull flows / high flow within channel capacity	(all above, magnitude and frequency)

MFAT	WFET (ELOHA)	BCG-DSS	DRIFT-DSS 1 (temperate)	DRIFT-DSS 2	FLOWS	LaTrobe BN
Rate of depth decrease		Flow Constancy	Flood: Class 4	Duration of flood season	Overbank flows / flow extending to floodplain	
Duration of dry period between inundation		Coefficient of Variation of Monthly Discharge within Years	Floods 1:2	Slope of Transition between flood and dry season		
Percentage of total area inundated			Floods1:5			
Duration of inundation			Floods1:10			
Calendar months for spawning.			Floods1:20			
Flood memory						

Most of the DSSs examined rely on flow indicator inputs derived from existing hydrological models rather than creating their own analyses within the DSS. However, DSS (RAP) has a module dedicated to the calculation of a number of flow indicators as well as a module for analysis of hydrological or other time series (Appendix Table 4) and DRIFT-DSS 1 has a module (DRIFT-Hydro) which is used to calculate certain summary hydrological data and flow indicators.

Appendix Table 4 The hydraulic and time-series analyses available in RAP

Hydraulic Analysis	Time Series Analysis
Surface width	General statistics, Mean, median, Q90, Q10, Skew, coefficient of variation
Wetted Perimeter	High flow spell analysis
Cross-sectional area	Low flow spell analysis
Local depth	Colwell's statistics
Thalweg Depth	Rates of rise and fall
Lateral gradient	Base flow analysis
Volumetric flow per width	Partial series flood frequency
Bulk (Mean) flow velocity	Annual series flood frequency
Hydraulic Radius	**Displays:**
Froude Number	Input data
Aspect ratio	Graphical interpretation of time series metrics (annual, seasonal, monthly basis)
	Flow duration curves (whole period, annual, seasonal, monthly)
	Flood Frequency curves (partial and annual series)
	Baseflow component of flow

A.5. Measuring change

Types of information reviewed: EF Methods and DSSs.

Methods and DSSs referred to: BayFish; BBM; DRIFT-DSS 1; ELOHA; HFSR; IFIM; MDSS4; MFAT; Okavango EF DSS; PIMCEFA; RAP; WFET.

A.5.1. How is change reported?

Typically, estimates of the abundance or area of species or habitats are not available for a study river or basin, and quantification of these is outside the scope of most EF studies. Thus, change as a result of flow change cannot be described in absolute terms, and most EF methods and DSSs return a description of change relative to some common reference point. For instance, if provided at all, instead of a prediction of change with a particular change in flow being that the abundance[6] of Fish sp. A will decline from 10 to 5 individuals, depending on the method used, the predictions could be:

- a 50% probability that the abundance of Fish sp. A will decline (e.g. BayFish);
- there is a 50% decline in the suitability of the habitat for Fish Sp. A (e.g. MFAT);
- there is a 50% decline in the availability of the habitat for Fish Sp. A (e.g. IFIM);
- the ecological condition of Fish Sp A will decline – for instance from an A to a C-category (e.g. HFSR, BBM);
- there will be a 50% (or rather 25-75%; see Section A.8) decline in the abundance of Fish Sp. A (e.g. DRIFT-DSS 1 and 2).

Thus, in many cases, the results are presented on 'unitless' scales, e.g. scales relative to some reference condition (Section A.5.2). If known biomasses, areas, concentrations, etc. are available, these relative figures could potentially be converted back to the original units. For example, known fish catches, or fish abundance estimates might be available for a site.

RAP allows for the entry of response curves in 'natural' units (e.g. numbers, mass, area), but these can be subsequently normalised by converting to a 0 to 1 or 0 to 100 (unitless) scale.

Catchment2Coast, DEMIOS and IFIM produce results in absolute terms such as in numbers, areas, concentrations, biomass or weighted useable area (IFIM). In the case of DEMIOS, results are ultimately presented as relative to natural.

A.5.2. What is change relative to?

Most of the approaches reviewed report change relative to some hypothetical or measured reference state. Some use a reference site, which is deemed to be closer to natural condition than the test site (e.g. HFSR). MFAT uses natural hydrology and a 'reference scenario' (Appendix Table 5) against which results are reported (as ratios of the reference scenario). Indices for ecosystem components, such as vegetation, are given on a scale from intolerable to ideal, where ideal habitat is not necessarily achieved under natural conditions. Thus, a high score for a particular indicator is not necessarily associated with the "most natural" flow regime, but when aggregated with a number of other indicators, higher scores would tend to reflect more natural conditions.

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[6] The term abundance is used, but the measure might also be density, concentration, area, etc. as relevant for the indicator and / or DSS in question.

In contrast to many of the DSSs, DRIFT-DSS 1 describes change at a site relative to present day. However, these descriptions are converted to relative to natural for the overall summary of basin condition (Section A.5.4). This is necessitated by the fact that only the natural condition provides a common reference point across all sites and also because the relative to natural condition can be placed in an integrity category or given a present ecological status.

In some instances, the user can choose whether to use natural, present day or some other reference condition.

Appendix Table 5 Scenarios in MFAT (http://www2.mdbc.gov.au/ livingmurray/mfat/)

Scenario	Definition
Natural	The flow conditions without flow regulation or diversion
Current	The flow conditions under levels of development that existed in 2002-land use, regulation and diversions
Reference	The flow condition as at the 93/94 Cap, which represents the limit placed on the volume of water that can be diverted from the Basin's rivers for consumption (see http://www.mdbc.gov.au/naturalresources/the_cap/the_cap.htm.)
Alternatives	Three overall volumes (350, 750 and 1500 GL), with three variations each (called 'cap', 'b', and 'c')

A.5.3. Approach adopted in the 1873-EF-DSS

The 1873-EF-DSS uses the approach in DRIFT-DSS 1 and the DRIFT-DSS 2, *viz*.:

- present day is the reference point for the construction of site-specific response curves (see Section A.7), and change in individual indicators is reported relative to present day;
- these are converted to relative to natural based on an assessment of Present Ecological Status for the discipline and basin-level summaries.

This because specialists find it easier to assess change relative to a condition that they can see and measure, rather than a hypothetical naturalised condition that in some case may not have existed for many decades.

A.5.4. Conversion of relative change from present day to a naturalised condition

The conversion between present day and naturalised condition adopted for the 1873-EF-DSS has been developed over a number of years and provides an approximation of the change relative to natural. Obviously the closer to natural that the study ecosystem is, the better will be the resultant approximation. The conversion relies on the site or reach having been given a Present Ecological Status (PES) rating. This PES rating is then used to adjust the Integrity ratings, which are relative to present day, to Adjusted Integrity scores that are relative to natural, so that instead of a 0 Integrity score applying to present day, a 0 applies to natural.

The PES is a rating given to a site or reach on a five point scale (Appendix Table 6) from A (near natural) to F (critically modified) (Kleynhans and Louw 2008), where the letters refer to Ecological

Categories. Each category is associated with a percentage score, relative to natural, which is 100%.

Appendix Table 6 Generic ecological categories (PES), descriptions and percentage ratings (from Kleynhans and Louw 2008).

PES	Description	PES % Score
A	Unmodified, natural	90-100%
B	Largely natural with few modifications. A small change in natural habitats and biota may have taken place but the ecosystem functions are essentially unchanged	80-89%
C	Moderately modified. Loss and change of natural habitat and biota have occurred, but the basic ecosystem functions are still predominantly unchanged.	60-79%
D	Largely modified. A large loss of natural habitat, biota and basic ecosystem functions has occurred.	40-59%
E	Seriously modified. The loss of natural habitat, biota and basic ecosystem functions is extensive.	20-39%
F	Critically / Extremely modified. Modifications have reached a critical level and the system has been modified completely with an almost complete loss of natural habitat and biota. In the worst instances the basic ecosystem functions have been destroyed and the changes are irreversible.	0-19%

In order to get the adjusted Integrity score, three steps are undertaken:

<u>1. Unadjusted score:</u>

The DRIFT ecological Integrity scores are on a scale from -5 to +5, with 0 being the score associated with present day. Positive scores resulting from a scenario mean that the reach has moved towards natural and negative scores mean that the reach has moved further away from natural. In DRIFT, the Integrity score is the same value (size) as the Severity rating, but the sign might be different. For example, a Severity rating of -2 might indicate a 30 to 40% loss of abundance. If this is a loss in abundance of an alien species it would indicate an improvement in Integrity, therefore an Integrity score of +2. In DRIFT-DSS 1 a single (Severity or Integrity) value applied to each site, however the DRIFT-DSS 2 produces a time-series of Severity ratings. It was felt not to be appropriate to have a time-series of Integrity scores as ecosystem integrity would not be experienced on an annual basis, but rather is an accumulation of effects over time. Therefore, the average Severity over the time period was used to derive the Integrity score. For example, for a time series of 5 seasons, with Severity scores of -3, +1, -2, -1, +2, the average Severity score would be -0.6. The sign for Integrity, would be given by the specialist, who would indicate whether the predicted change was a move towards (+) or away from (-)natural conditions. If a decrease (e.g. -0.6) in abundance is a move towards natural condition for the indicator then the change in integrity would be positive. In the above example, the Integrity score would be +0.6.

<u>2. Final adjustment to adjust natural Integrity to zero:</u>

Given that the Integrity score was the average of a time series of data, the Integrity for present day would not have been exactly 0. An adjustment is therefore done for each site, by adding or subtracting the amount by which the present day Integrity score differs from 0.

3. Score adjusted to relative to natural:

In order to adjust the score from Step 2 so that a 0 score refers to natural rather than present day, the following rules were then applied (Appendix Table 6):

If the reach is in an A or A/B category, do not adjust the Integrity score.

If the reach is in a B category, subtract 0.5 from the score.

If the reach is in a C category, subtract 1 from the score.

If the reach is in a D category, subtract 2 from the score.

If the reach is in an E category, subtract 3 from the score.

Appendix Table 7 The conversion used in DRIFT-DSS 2 to adjust Integrity scores from relative to present day to relative to natural.

Ecological category (PES)	If present day PES is in category "X", then subtract the following from the present day Integrity ratings found in Step 2:
A	0
B	0.5
C	1
D	2
E	3
F	-

A.6. Indicators

Types of information reviewed: EF Methods, DSSs and other modelling paradigms.

Methods and DSSs referred to: BCG-DSS; Desktop Model, DRIFT-DSS 1; ELOHA; ENFRAIM; IFIM; LaTrobe BN; MDSS4; MFAT; DRIFT-DSS 2; PIMCEFA; RAP; WFET; DEMIOS.

This section describes the types of indicators used in the various applications and DSSs. Note that the terminology used to describe indicators differs between approaches. In the interests of clarity, we have used the following terms throughout:

Discipline: A major area of study, such as water quality or birds.

Indicator: Aspects within a discipline that will receive detailed attention, such as upper wetbank reeds or bank cormorant.

Sub-indicators: Aspects within an indicator that will receive detailed attention, such as availability of bank cormorant nesting; roosting or feeding habitat.

Driving indicators: Outputs from an indicator that form inputs to an indicator or sub-indicator, i.e. indicator change is a function of change in its driving indicators. Also referred to as 'linked indicators'.

There are some parameters that will affect the responses of particular indicators in the DSSs, such as extent of woody debris (MFAT), growth or density-dependence parameters, and thus are required as inputs. These are not driving indicators, but because they form inputs to determining the indicator or sub-indicator responses, they are listed with the driving indicators in the sections below.

Indicators are commonly used to in EF methods to describe an ecosystem. Indeed of those reviewed here, only the Desktop Model, does not use indicators. Instead it defines responses in terms of the overall ecological condition of river reaches (different flow regimes are associated with different Ecological Categories; Appendix Table 6).

A.6.1. What number and type of indicators are used?

DRIFT-DSS 1 and the DRIFT-DSS 2 are the only DSSs that specify a full suite of disciplines as a starting point, but disciplines can be omitted if they are irrelevant to the area. DRIFT-DSS 2 and DEMIOS are the only approaches that explicitly include socio-economics within the DSS. DRIFT, DRIFT-DSS 2 and DEMIOS are the only DSSs that included water quality indicators (salinity and nutrients in the case of DEMIOS and case dependent for DRIFT). BCG-DSS included a management indicator – how often a specific water requirement was met. While the IFIM approach was originally developed to determine the availability of fish habitat, it has since been applied to other indicators (e.g. invertebrates, riparian vegetation). In other approaches, the choice of disciplines and indicators depends entirely on the application. The indicators used in some of the approaches are discussed in more detail below.

A.6.1.1 DRIFT-DSS 1 and the DRIFT-DSS 2

DRIFT-DSS 1 and the DRIFT-DSS 2 specify a full suite of disciplines for consideration in an EFA, namely, geomorphology, water quality, invertebrates, fish and, depending on the application, mammals, birds and herpetofauna (Appendix Table 8). The indicators and sub-indicators used within these disciplines are application specific and are chosen by the specialists, depending on the site, basin being studied and available knowledge.

Appendix Table 8 Examples of DRIFT-DSS 2 indicators (river sites)

Discipline	Indicator	Linked indicator (examples)
Hydrology	See, e.g., Appendix Table 3	Inputs into the DSS (i.e. not functions of DRIFT-DSS 2 response curves or models)
Geomorphology	Extent – exposed Rocky Habitat	Dry: Minimum Q, Flood: Type
	Extent – Coarse Sediments	Flood: Type
	Cross Sectional Area of Channel	Flood: Duration, type
	Extent of Backwaters	Dry: Minimum Q Flood: Type
	Extent of Vegetated Islands	
	Sand Bars at low flow	
	Percentage Clays on Floodplain	
	Extent of inundated floodplain	
	Inundated Pools and Pans	
	Extent of Cut Banks	Dry: Minimum Q, Flood: Duration, Type
Water Quality	pH	Dry: Onset, duration, minimum Q Flood: Onset, duration, type
	Conductivity	
	Temperature	
	Turbidity	
	Dissolved oxygen	
	Total nitrogen	
	Total phosphorus	
	Chlorophyll a	

Discipline	Indicator	Linked indicator (examples)
Vegetation	Channel macrophytes	Dry: Onset, duration, minimum Q Flood: Onset, duration, type
	Lower Wet Bank (hippo grass, papyrus)	
	Upper Wet Bank 1 (reeds)	
	Upper Wet Bank 2 (trees, shrubs)	
	River Dry Bank	
	Floodplain Dry Bank	
	Floodplain residual pools	
	Lower floodplain	
	Middle floodplain (grasses)	Flood: Onset, duration, type
	Upper floodplain (trees)	
Invertebrates	Channel-submerged vegetation	Dry: Onset, duration, minimum Q Flood: Onset, duration, type
	Channel-marginal vegetation	
	Channel-fine sediments	
	Channel-cobbles, boulders	
	Channel rapid, fast flowing	
	Channel-pools	
	Floodplain-marginal vegetation	Flood: Onset, duration, type
	Floodplain-pools, backwaters	
Fish	Fish resident in river	Dry: Onset, duration, minimum Q Flood: Onset, duration, type
	Migrate floodplain small fish	
	Migrate floodplain large fish	
	Fish-sandbank dweller	
	Fish-rock dweller	
	Fish-marginal vegetation	
	Fish in backwaters	
Wildlife	Semi Aquatics (hippos, crocodiles)	Dry: Onset, duration, minimum Q Flood: Onset, duration, type
	Frogs, river snakes	
	Lower floodplain grazers	
	Middle floodplain grazers	Flood: Onset, duration, type
	Outer floodplain grazers	
Birds	Piscivores – open water	Dry: Onset, duration, minimum Q Flood: Onset, duration, type
	Piscivores – shallow water	
	Piscivores and invertebrate feeders	
	Specialists – floodplains	
	Specialists – water lilies	
	Specialists – fruit trees	
	Breeders – reedbeds, floodplains	
	Breeders – overhanging trees	
	Breeders – banks	
	Breeders – rocks, sandbars	
Social	e.g. household income from fishing	Fish resident in river, Large migratory flood plain fish
	e.g. household income from livestock	Upper Wet Bank 1 (reeds), Lower floodplain
	e.g. health / incidence of diarrhea in under 5 year olds,	Turbidity, Total nitrogen, Chlorophyll a
	etc.	

A.6.1.2 MFAT

MFAT has a comprehensive collection of ecological indices, grouped within five disciplines. Each discipline usually comprises several indicators (Appendix Table 9). Each indicator usually had two sub-indicators: one for adult and one for juvenile (or recruitment) habitat conditions (Appendix Table 9).

Appendix Table 9 MFAT indicators.

Discipline	Indicators	Sub-indicator	Driving indicators
Hydrology and hydraulics	See Appendix Table 3	Inputs into the DSS (i.e. not functions of MFAT preference curves or models)	
Water Quality	Salinity	Inputs into the DSS (i.e. not functions of MFAT preference curves or models)	
	Mouth-opening index		
	Turbidity		
Floodplain vegetation	River red gum forest	Adult habitat condition	Flood timing, flood duration, drying period, flood memory
		Recruitment habitat condition	Inundation depth, inundation duration, germination timing
	River red gum woodland	As for River red gum forest	As for River red gum forest
	Black box woodland		
	Lignum shrubland		
	Rats tail couch grassland		
Wetland vegetation	Edge plant: Cumbungi (*Typha*) rushlands	Adult habitat condition	Inundation depth, inundation timing, depth duration, rate of depth change
		Recruitment habitat condition	Recruitment timing, rate of depth decrease, rate of depth increase, duration of the period between water level draw-down and rewetting
	Edge plants: *Phragmites australis* rushlands	As for Cumbungi rushlands	As for Cumbungi rushlands
	Edge plants: Spiny mudgrass (Moira grass) grasslands		
	Edge plants: Giant rush rushlands		
	Open water plants: Ribbonweed (Vallisneria) herblands	Adult habitat condition: as for Cumbungi rushlands	
		Recruitment habitat condition	Recruitment timing, water depth
Waterbirds	Colonial nesting waterbirds (Ibis, Egrets, Herons, Spoonbills)	Breeding habitat condition	Percentage area inundated, flood duration, rate of water level fall, duration of the dry period before flooding, extent of suitable nesting vegetation
	Waterfowl and grebe (Grey teal, pinkeared duck, freckled duck, Australasian shoveler, great-crested grebe, hoary-headed grebes)	Breeding habitat condition	
	Waterbirds (all)	Foraging habitat condition	Percentage area inundated, water depth variability
Native fish	Flood spawners (Golden perch, Silver perch), Macquarie perch)	All: Adult habitat condition	Woody debris, fish passage, water temperature, channel condition, maintenance flow
	Macquarie perch		
	Wetland specialists (Australian smelt, bony herring, carp gudgeons, southern pygmy perch, hardyheads, *Galaxias rostratus*, freshwater catfish)	All: Recruitment habitat condition	Spawning habitat condition: depending on group, spawning habitat condition when no flood, flood magnitude, spawning timing, rate of flow rise, duration of rate of flow rise, substrate condition, rate of flow fall (spawning), flow percentile (spawning)
	Freshwater catfish		
	Main channel generalists (Australian smelt, bony herring, flathead gudgeons)		
	Main channel specialists (Murray Cod, trout cod, river blackfish, two-spined blackfish)		Larval-juvenile habitat condition: depending on group, inundation area, inundation duration, dry period, flow duration, larval-juvenile habitat condition (no flood), rate of flow fall (larval), flow percentile (larval),
	Low-flow specialists (Crimson-spotted rainbow fish, carp gudgeons)		
Algal Growth*	*Any species: algal population parameters changed accordingly. Designed for those which take advantage of stratification. Result is a cell count which is converted into an algal index associated with an alert level.		Simulated daily river discharges, average daily flow depths and flow velocities, mean monthly turbidity levels, minimum and maximum mean monthly air temperatures – minimum and maximum (^{O}C), mean monthly relative humidity (%), mean monthly wind speed (m/s), weir pool location (latitude) and width (m), various algal population parameters*.

A.6.1.3 WFET

The WFET application in Colorado used six indicators for which sufficient published data was available and which were felt to represent important components of ecosystem function (Appendix Table 10). Note that work was done on the development of several other indices, but these were not used in the final application and risk mapping. Ultimately the type and number of indicators was severely constrained by the lack of data.

Appendix Table 10 WFET indicators

Discipline	Indicator	Sub-indicator	Linked indicator
Hydrology	See Appendix Table 3	Inputs into the DSS (i.e. not functions of WFET response curves or models)	
Biophysical – not organised according to discipline	Trout	None	Percentage of mean annual flow that occurs during the low flow summer months
	Warm water fishes Fountain Creek	None	Percentage of mean annual flow that occurs during the low flow summer months
	Warm water fishes Roaring Fork	Flannelmouth sucker	24-hour average low flow for summer-autumn
	Riparian vegetation	None	Annual peak daily flow magnitude
	Erosion potential	None	Standard parameters in sediment transport model
	Recreation	Paddling	Mean annual flow

A.6.1.4 BCG-DSS

The BCG-DSS was specifically developed to evaluate Gunnison River flow regimes with respect to the resources of the Black Canyon of Gunnison National Park. The application used five indicators, two for vegetation, one for trout, one for sediment and one for a water right (Appendix Table 11).

Appendix Table 11 BCG-DSS indicators

Discipline	Indicator	Sub-indicator	Linked indicator
Hydrology and hydraulics	See Appendix Table 3	Flow is input into the DSS (i.e. not functions of BCG-DSS response curves or models). Relationship between flow and weighted useable area, shear stress, inundation area and sediment mobilisation are data entered into the DSS (i.e. can be changed).	
Not organised in disciplines	Vegetation (Box Elder) clearing	None	inundation durations shear stress
	Plant community composition	None	long-term inundation duration
	Trout habitat suitability	Rainbow Trout Brown Trout	average daily flow within critical time intervals for each year
	Sediment mobilization	None	annual mean daily discharge annual maximum daily discharge 14-day maximum daily discharge
	National Park Service Federal reserved water	Minimum flow Peak flow (May to June) Shoulder flow	forecast hydrologic conditions reservoir storage levels

A.6.1.5 DEMIOS

The selection of disciplines and indicators used in DEMIOS (Appendix Table 12) is similar to that for DRIFT, both having been developed within similar contexts (i.e. EF studies in Southern Africa). There are eight biophysical disciplines (called sectors), plus two others: management and socio-economic.

Appendix Table 12 DEMIOS indicators

Discipline	Indicator	Sub-indicators	Driving indicators
Physical	berm height, water volume, water level, breaching events	None	Wave height (data set), sea level (data set) and daily freshwater inflow (modelled).
Salinity	Average salinity	None	Salt water from seawater (modelled), loss of salt during breaching (modelled).
Nutrients	Dissolved inorganic nitrogen (DIN)	None	Freshwater and saltwater inputs, uptake by microalgae, plant uptake, water outflows (modelled).

Discipline	Indicator	Sub-indicators	Driving indicators
Microalgae (Appendix Figure 12)	Phytoplankton Microphytobenthos(sediments) Microphytobenthos (sub-merged aquatic macrophytes)	None	Breaching, consumption (by zooplankton, invertebrates, fish), water residence time, turbidity, salinity, DIN, mud, sand and submerged plant area.
Macro-phytes	Supra- and intertidal saltmarsh, reeds and sedges and submerged macrophytes	None	Freshwater inflow, tidal exchange, salinity, water level fluctuations and sediment dynamics.
Inverte brates	Zooplankton Benthic macrofauna	None	Phytoplankton concentration, water outflow, mouth state, population growth parameters, sand, mud, macrophyte area, areas at different depths, mouth state
Birds	Resident diving piscivores (kingfisher, Fish Eagle) Migratory diving piscivores (terns) Pursuit swimming piscivores (cormorants, grebes) Wading piscivores (storks, herons, egrets) Resident waders (oyster-catcher, plover) Migratory waders (sandpiper, whimbrels) Herbivores (teal, shelduck)	None	Season, water level and mouth status
Fish	Marine-spawning fish	Cape stumpnose *Rhabdosargus holubi,* White steenbras *Lithognathus lithognathus,* mullet species and kob *Argyrosomus japonicas.*	Recruitment / Immigration, mouth breaching, natural and fishing mortality
	Estuary-spawning fish	Estuarine roundherring *Gilchristella aestuaria,* estuarine pipefish *Syngnathus watermeyeri,* and gobies (Gobidae)	Estuary surface area, loss from stranding from exposed macrophyte area and flushing, population growth parameters
Management Indicators model	Mouth condition, Salinity, Water quality (DIN), Intertidal area, Phytoplankton, Benthic microalgae, Macrophytes, Zooplankton, Benthic invertebrates, Fish, Birds	None	Average values over the total run period
Total Economi c Value	Recreational and aesthetic value (property and tourism)	None	Water level, water quality (indicated by cumulative days closed), angling fish stocks (indicated by Kob) and intertidal saltmarsh abundance
	Nursery value	None	Fish exports
	Existence value	None	Abundance of estuarine pipefish

A.6.1.6 ENFRAIM -Procedure for ecotope modelling in setting an EFR

ENFRAIM (Marchand, 2003) proposes an ecotope approach to EFAs. An Ecotope map can be defined using remote sensing and a field survey. Ecotope suitability rules are defined to link ecotopes to species or groups of particular ecological or economic importance. A digital elevation and hydrodynamic model are used to model the hydro-physical characteristics of the ecotopes, thus defining an ecotope model. Ecotopes can also be linked to ecosystem processes and services. Changes in the hydrodynamic situation can then be reflected as changes in the ecotope distribution and consequent biological changes, e.g. fish abundance.

A.6.2. Approach adopted in the 1873-EF-DSS

The 1873-EF-DSS uses the standard list of biophysical disciplines used in DRIFT-DSS 1 and DRIFT-DSS 2 (any can be added or removed), and allows for the selection of site/study-specific indicators and sub-indicators. It also includes socio-economics as discipline areas.

A.7. Constructing response relationships

Types of information reviewed:	EF Methods, DSSs and other modelling paradigms such as system dynamics modelling.
Methods and DSSs referred to:	BBM, BCG-DSS; DEMIOS; Desktop Model, DRIFT-DSS 1; ELOHA; HFSR; IFIM; LaTrobe BN; MDSS4; MFAT; Okavango EF DSS; PIMCEFA; RAP; WFET.

The primary aim of an EF-DSS is to assess how changes to the hydrological regime of an ecosystem will change the biophysical, social and economic aspects of the system. To do this, some type of flow-indicator response needs to be defined either as a direct relationship with flow or indirectly via intermediary indicators. The following sections describe some of the approaches adopted.

A.7.1. How are responses of the ecosystem captured?

A.7.1.1 What types of data are used?

The methods use existing data, models or expert opinion in some combination to develop relationships. Depending on the method, the relationship was included directly or via a scoring system.

WFET and BCG-DSS relied on relationships (equations) developed using empirical data and incorporate the model equations directly into the DSS. In the WFET / ELOHA process, equations are developed outside of the overall process. Information from similar rivers in the region was gathered, to form data points in the relationships. The equation chosen to best describe the data was then extrapolated to the region. Available data constrained the indicators that could be included in the assessment.

MFAT use existing relationships together with expert panel discussions to develop the equations finally used in the models. Each discipline area therefore has a particular and different set of equations developed for response curves and the aggregation of sub-indicators and indicators. DRIFT-DSS 1 and DRIFT-DSS 2, in contrast, rely directly on specialists to provide the Severity ratings as an integral part of the process. The ratings may relate to known data points, information or relationships for the site or river in question, but such information is not directly included in the DSS (except as references). RAP appears to be the most flexible of the DSSs as known models of flow-response relationships may be entered as equations or flow-response curves or they may be created during an expert panel process and entered directly into the DSS.

ENFRAIM was the only approach that specifically used remote sensing (and a field trip) in order to establish baseline conditions of ecotope distribution.

A.7.1.2 What types of relationships are used and how are they aggregated?

A.7.1.2.1 Preference curves

Preference curves capture the range of "preference" of an indicator (e.g. Fish Sp. A) for a particular variable, such as a flow indicator (e.g. minimum dry season discharge) or a driving indicator (e.g. depth). Preferences are expressed on a scale of 0 to 1. For example, an indicator may have evolved to take advantage of floods between August and November. Thus, floods in August and November would be given a preference score of 1 (i.e. ideal). Floods at other times of the year may be less than ideal (scoring less than 1). If a flood at another time of the year would be damaging to the ecosystem (e.g. causing fry to be washed away) this would be given a score of 0. Thus, the x-axis would be months of the year and the y-axis would be the preference levels of the indicator (Appendix Figure 2).

An index value of one (1) is not necessarily related to "natural" flow conditions, because although natural flow conditions may be ecologically optimal for an entire system, they may not be ideal for all biota at all times.

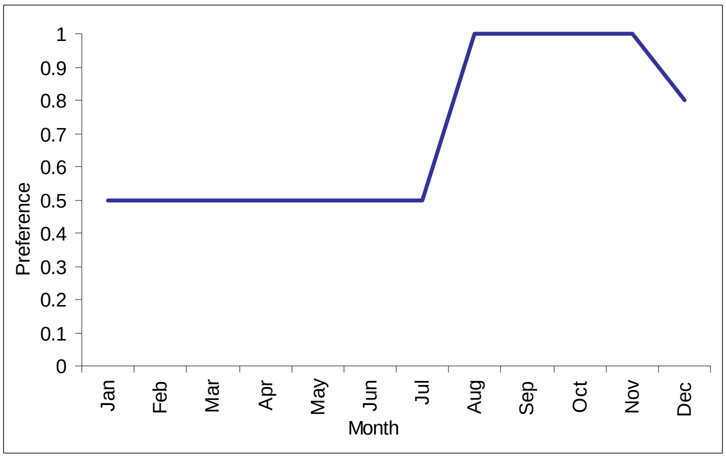
A.7.1.2.2 MFAT – Preference curves

MFAT uses preference curves that describe the preference of a particular sub-indicator (see Section A.6 for terminology) for a particular condition from "ideal" (scoring 1) or "intolerable" (scoring 0). The individual preference curves are combined in various ways to give an indication of overall "habitat condition" for a variety of habitats (Appendix Figure 2, see

Appendix Table 9 for a list of MFAT indicators).

In MFAT, the x-axis is always a hydrological or hydraulic variable.

For example, adult floodplain vegetation habitat condition (AHC) might depend on (amongst other things flood timing (FT), which would be a driving indicator. A preference curve is developed for AHC relative to FT indicating the relative preference for the different calendar months for the timing of inundation of the floodplain (for the maintenance of adult vegetation). In the example shown in Appendix Figure 2, the ideal FT (scoring 1) is from August to November. The rest of the year gets an intermediate score of 0.5, indicating that the flood timing is never be "intolerable" (scoring 0) for adult vegetation.



Appendix Figure 2 **Example of an MFAT preference curve: Adult vegetation preference (Y-axis) for Flood Timing (X-axis).**

Preference curves do not vary between localities.

The overall habitat condition for an indicator under a particular flow regime is obtained by aggregating the outputs from the individual preference curves for the sub-indicators, although some variations that apply, which are not discussed here.

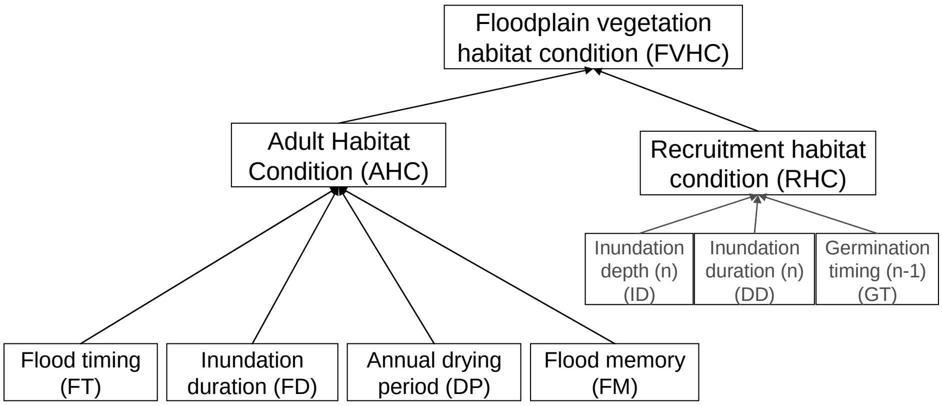
For example, the impact on Indicator: river red gum forest floodplain vegetation habitat condition (FVHC) is determined by aggregating individual preference curves for sub-indicator 1: adult vegetation component (AHC) and sub-indicator 2: recruitment habitat condition (RHC; Appendix Figure 3). The driving indicators for AHC include FT (discussed in (i) above), inundation duration (ID), annual drying period (DP), and flood memory (FM).

In the example given, AHC is a function of FT, FD, DP and FM:

$$AHC = \sqrt[4]{FT \times FD \times DP \times FM} \ .$$

AHC is then combined with RHC using a weighted sum to give the overall floodplain vegetation habitat condition (FVHC):

$FVHC = x_1 AHC + x_2 RHC$, where x_1 and x_2 are normalised weights defined for each indicator (river red gum forest floodplain vegetation habitat condition).



Appendix Figure 3 Aggregation of preference curves to obtain an index of overall habitat condition in MFAT, using FVHC as an example

Weights dictate the contributions of different preference curves to a higher level overall measure. MFAT offers an option for the use of weights at several aggregation stages:

1. To aggregate preference curves for a sub-indicator at a site: (e.g. FT, FD, DP and FM to give AHC using $AHC = \sqrt[4]{FT \times FD \times DP \times FM}$ (equal weights in this example));
2. To aggregate sub-indicator preferences to derive an indicator preference at a site, such as FVHA (e.g. AHC and RHC using $FVHA = x_1 AHC + x_2 RHC$);
3. To aggregate indicator preferences to derive a discipline preference at a site. For example, the importance of River red gum forest, River red gum woodland, Black box woodland, Lignum shrubland, Rats Tail Couch grassland relative to each other within the riparian vegetation at a particular locality;
4. To aggregate disciplines at a site or within a zone (i.e. riparian vegetation, wetland vegetation, waterbirds, fish, algae).
5. To aggregate site outputs into basin level outputs. Weights used allocated to indicate the importance of different zones along the river.

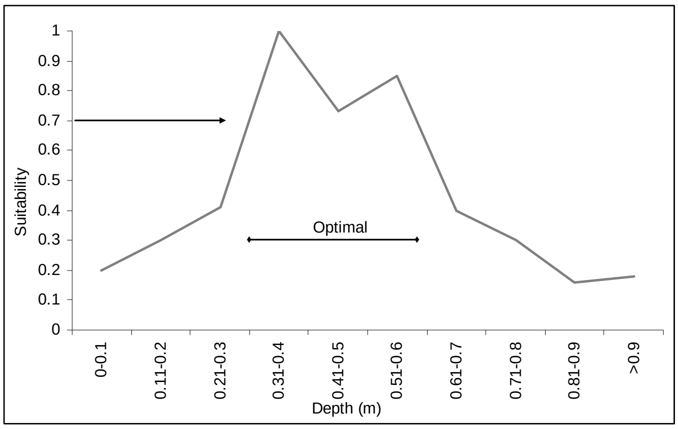
A.7.1.2.3 RAP – Rating Curves

The Ecological Response Module (ERM) of RAP uses "Rating Curves" to describe the ecological responses to flow indicators. ERM is used to capture the knowledge generated during the expert panel process.

"Rating Curve[7]" is a generic term, which can refer to habitat use, availability or preference curves, or functions (users decide on which of these they wish to use) (Appendix Figure 4). In fact, the

[7] Also referred to as 'models' in RAP.

RAP software seems generic enough to be able to incorporate any type of response rating system, including the Severity ratings used for DRIFT response curves (Section A.7.1.2.6).



Appendix Figure 4 An example of a RAP Rating Curve (2004)

Rating curves are constructed for the relationships between sub-indicators[8] (see terminology in Section A.6) and driving indicators that can include flow and other biophysical indicators.

RAP allows for the definition of non-flow driving indicators as well as flow linked indications. RAP also allows a rating curve to be used by more than one sub-indicator or indicator.

The rules for combining the effects of driving indicators, or the effects on sub-indicators, indicators[9] or discipline[10] rating curves, are also defined, although we could not access these definitions from the literature at our disposal.

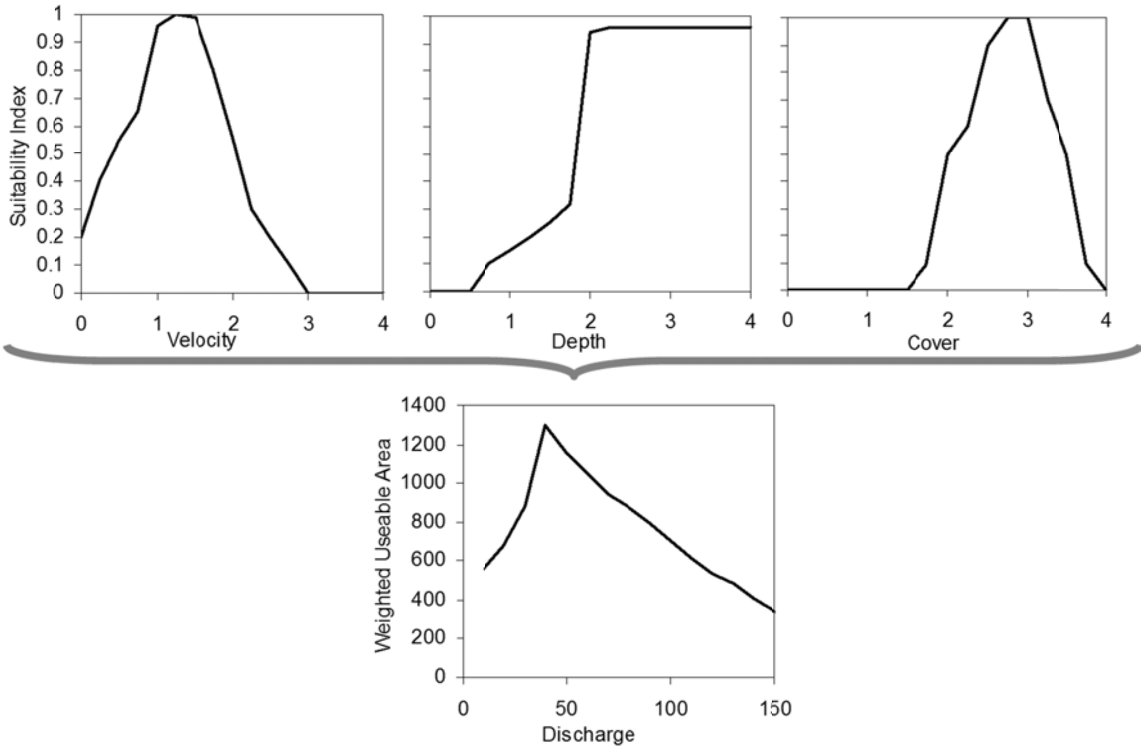
A.7.1.2.4 IFIM – weighted useable area

The PHABSIM component of IFIM calculates the amount of (micro) habitat available to different life-stages of a species or group of species, normally in terms of weighted useable area. Velocity, depth and cover conditions (for example) are measured for a given discharge to develop suitability index values for each cell in a cross-section. These values are used to weight the area of each cell when summing to obtain the weighted useable area for a discharge, to ultimately derive weighted useable area of habitat for a full range of discharges (Appendix Figure 5). Thus, for any discharge scenario, the weighted useable area resulting can be determined. These

[8] Referred to as attributes in RAP, although not exactly comparable.

[9] Referred to as components in RAP, although not exactly comparable.

[10] Referred to as groups in RAP, although not exactly comparable.



Appendix Figure 5 **Construction of weighted useable area curve based on discharge, and suitability indices (SI) applied to each cell in the study site.**

weighted useable area result is not in itself a 'preference curve', although the suitability relationships can be regarded as such.

A.7.1.2.5 Response curves

Response curves estimate the direct impact of change in abundance, biomass, concentration, area or diversity of an indicator. Thus, a change in flood timing might result in a change in abundance of a fish species reliant on flood at a particular time of year. Responses are usually, but not always (e.g. WFET), provided as percentage change from some reference condition (i.e. natural or present day or some other reference) rather than in absolute terms. Response curves are therefore different to the preference curves discussed earlier: preference curves describe preference for a condition, whereas response curves describe changes in abundance.

A.7.1.2.6 DRIFT-DSS 1 and the DRIFT-DSS 2

In DRIFT-DSS 1 and the DRIFT-DSS 2, response curves are constructed to describe the relationship between each biophysical indicator and each flow indicator. The severity of the response of the indicator to the change being dealt with is expressed using a Severity rating. Severity ratings are on a scale from -5 to +5 and are (asymmetrically) associated with a relative percentage change in abundance (or area or concentration) from present day (Appendix Table 13). Change is measured relative to present day, thus the Severity rating for the present day equals 0. Changes in flow indicators are expressed in absolute amounts.

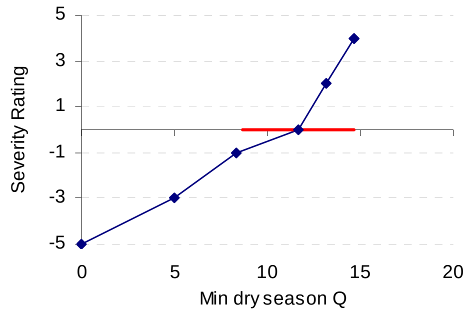
Appendix Table 13 Severity ratings for predictions of change in abundances, and conversion to percentages (King et al. 2003)

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

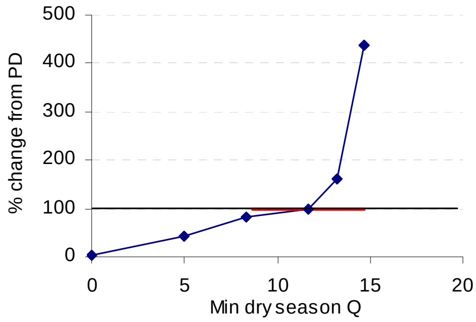
The axes of a response curve are (an example is shown in Appendix Figure 6):
x-axis = Range of possible change in flow indicator, e.g. minimum dry season discharge.
y-axis = Response of indicator in terms of Severity (in terms of impacts on abundance) relative to present day (Appendix Figure 6(a)).

Appendix Figure 6(b) presents the Severity scores shown in Appendix Figure 6(a) as they are when translated to the mid-points of their ranges.

(a)



(b)



Appendix Figure 6 DRIFT (a) Severity scores (0 is present day) and translation to (b) percentage of present day (100% is present day). The red bars show the standard deviation of the flow indicator for present day conditions.

The impact on an indicator under a particular flow regime at a site is obtained by aggregating the outputs from the individual response curves (i.e. responses of the indicator to each flow indicator) using a weighted sum.

Each Severity rating response curve has an associated Integrity rating response curve. These are identical to the Severity response curves, except that the direction of response might change, because instead of expressing changes in abundance, the response expresses changes in “integrity” or condition of the particular indicator. Conversion from Severity to Integrity is achieved by determining whether a change in abundance represents a move towards or away from the natural condition of the ecosystem. If an increase in abundance represents a move away from natural then the Severity rating is changed to Integrity by multiplying by -1 (i.e. by changing the sign). If an increase in abundance represents a move towards natural then the sign of the

Integrity rating stays the same as the Severity rating. Integrity ratings are used to aggregate responses at difference sites to provide an indication of the overall impact on ecosystem condition.

DRIFT offers option to indicate the relative importance of the contributing factors through the use of weights at the following stages:

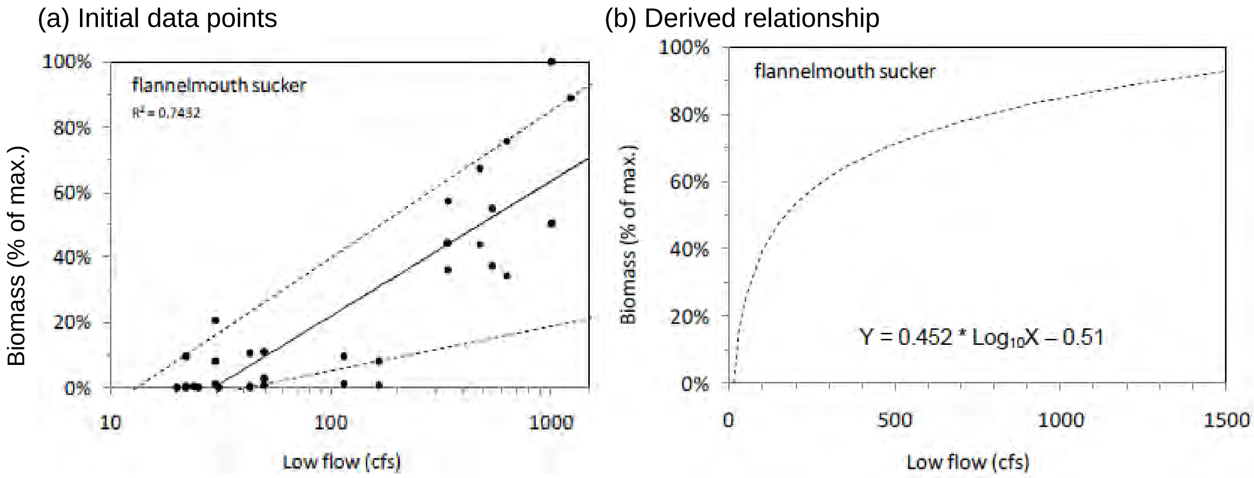
1. To aggregate response curves for an indicator at a site to arrive at change in abundance for that indicator;
2. To aggregate indicator preferences to derive a discipline preference at a site.

As yet, the zonal and basin level assessments do not have an option for weighting.

A.7.1.2.7 WFET

In WFET (Colorado Water Conservation Board 2009) flow-ecology response curves are constructed between sub-indicators/indicators and flow driving indicators (no non-flow driving indicators). These are based on statistical relationships from the literature (e.g. Appendix Figure 7). The Y-axis is usually in the form of a *percentage change* in abundance or diversity relative to the reference (natural in this case) state, but may also be in terms of a *percentage of maximum*. Flow indicators (X-axis) are either absolute values or percentages of natural.

The values on the y-axis are allocated to “ecological risk categories”, which were used to predict the level of ecological risk associated with new flow scenarios.



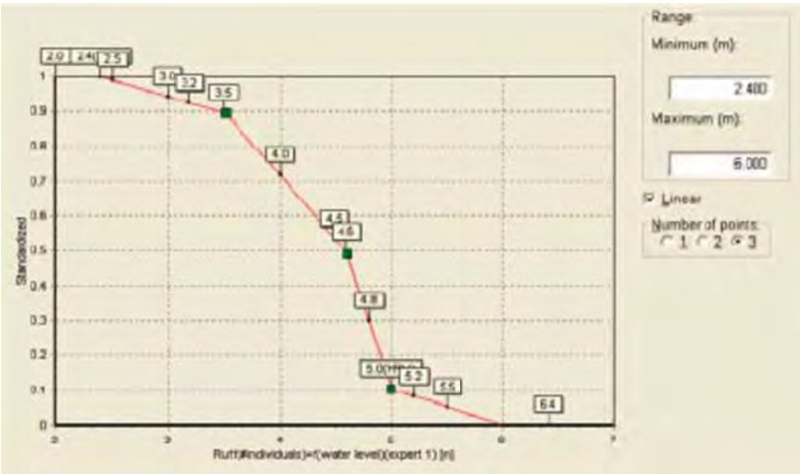
Appendix Figure 7 Example of WFET/ELOHA flow-ecology relationship for indicator: flannelmouth sucker

The example in Appendix Figure 7 (Colorado Water Conservation Board 2009) shows the response curves for indicator: flannelmouth sucker to driving indicator: low flows. The responses were expressed in terms of percentage of maximum biomass. The ecological risk categories associated with the percentage of maximum biomass are <10% low ecological risk, 10-25% minimal ecological risk, 26-50% moderate ecological risk, >=51% high ecological risk.

There is no aggregation of individual response curves and no weighting. For example, although there were several fish species assessed in the Colorado application, the impact on fish abundance was not determined.

A.7.1.2.8 PIMCEFA

The response curves for PIMCEFA are called "pressure impact curves" (PIC) (Appendix Figure 8, Barton and Berge 2008). To construct these, "optimal water level curves" are drawn for the relevant indicators, which denote the maximum or minimum water levels that define the best possible situation across seasons for each indicator. These were used to define "critical periods" (e.g. the lowest flow period) for which PIC's could be constructed. For instance, this may be May to June period for a bird species that breeds in the (USA) summer. The indictor responses are provided on a scale of 1 / 100% (no impact) to 0 / 0% (full loss of the ecological component). In the examples given, the water level (in m) was the only flow indicator considered, but there is no reason why the approach could not be used for any flow indicator.



Appendix Figure 8 **Example of a PIMCEFA pressure-impact curve: Adult ruff (bird species) (Y-axis), water level in metres (X-axis)**

PIMCEFA makes use of the DEFINITE MCA software for the constructing of the PICs and for the allocation of weights. Several different MCA techniques can then be applied using the DEFINITE software for evaluation of the alternatives.

Note that the responses to the pressures are given a rating that is related to abundance (i.e. 100% retained or full loss).

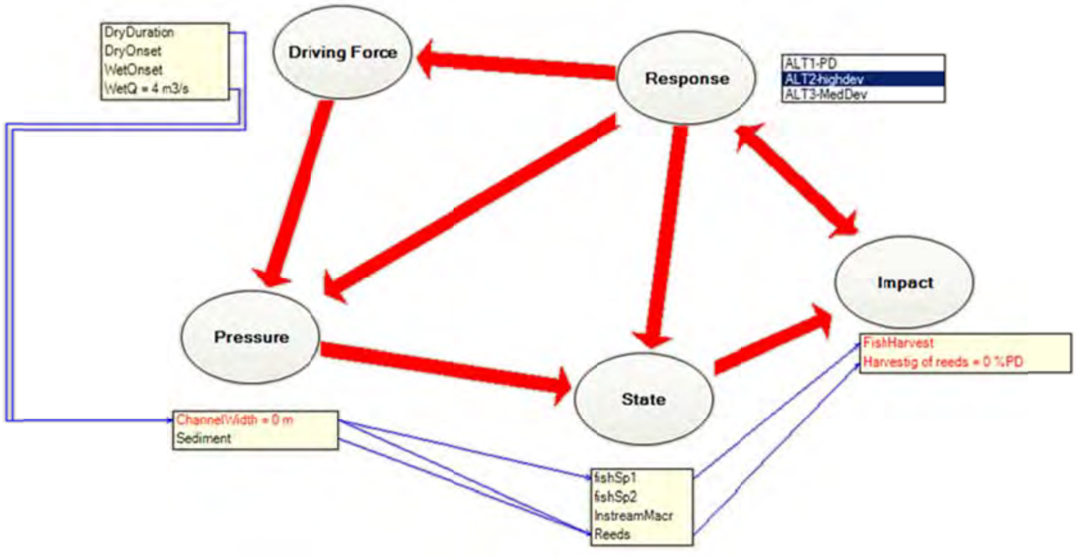
A.7.1.2.9 Driving force/Stressor-response approaches

MDSS4 defines all input and output indicators in terms of whether they are driving forces, pressures or impacts and establishes the causal chain between these. The HFSR method, defines stress levels (y-axis) in response to hydraulic parameters that are translated via the hydrology to create a "stress duration curve".

A.7.1.2.10 Driving force, Pressure, State, Impact, Response – MDSS4

MDSS4 captures all information in the Driving force, Pressure, State, Impact, Response (DPSIR) framework (e.g. see Appendix Figure 9), whereby all variables / indicators are either (adapted from MDSS4 manual – Fondazione Eni Enrico Mattei. 2008):

- Driving forces – the underlying causes and origins of pressure on the environment
- Pressures – the variables which directly cause environmental problems
- States – the current condition of the environment
- Impacts – the ultimate effects of changes of state, the damage cause [or benefit achieved]
- Response – decisional option, effort to solve the problem caused by the specific impact



Appendix Figure 9 The DPSIR window of MDSS4 for linking drivers, pressures, states, impacts and responses

Once the DPSIR links have been made and the values for the alternatives entered, values are passed to an "Analysis Matrix". The indicators passed to the Analysis Matrix can be Driving Forces, Pressures, States or Impacts, although normally indicators representing the endpoint (Impact) are of the most interest. The values in the Analysis Matrix are analysed using a number of different MCA techniques built into the software. This allows for non-linear value functions to be defined and weights to be set. A "Group Decision" module is also included, where weights from different sources can be added and results compared.

A.7.1.2.11 Flow-Stressor-Response method (HFSR)

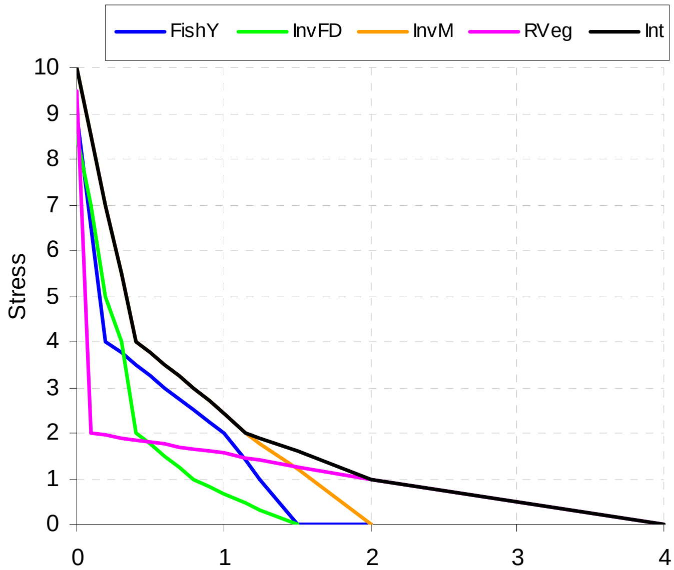
The Habitat-Flow-Stressor-Response (HFSR) method (e.g. O'Keeffe *et al*. 2002) uses an index of flow-related "stress" (Appendix Table 14). Specialist knowledge about relationships between flow and hydraulic parameters and instream biota are captured in the stress index on a scale from 0 (no stress) to 10 (highest stress). The stress index values are translated into a "stress regime" using the hydrological time series, for any scenario, and viewed as a stress-duration curve (similar in concept to a flow-duration curve). The impact on an indicator is judged by assessing changes in the magnitude, frequency and duration of stress relative to the natural stress regime.

The HFSR model currently only defines stress index values for periods of lowflow but used the full flow regime to create the stress duration curves.

To obtain a basis for overall comparison between different scenarios, the stress curves for each indicator are combined and a "critical curve" identified (Appendix Figure 10). This composite flow-stress relationship is made from the most sensitive species (highest stress levels) for any particular flow. There is no weighting.

Appendix Table 14 An example of a Generic Stress Index table used to generate stress scores (WP = wetted perimeter, spp = species)

Stressors		Stress Index	**Biological responses of target organism(s)** (location dependent)		
Flow-related hydraulics (e.g. Depth, velocity and WP)	Physical habitat (quantity and quality)		Abundance	Aquatic Life Stages	Persistence
Very fast Very deep Very wide WP	In excess Very high quality	0	Very abundant	All healthy	Yes
Fast Deep Wide WP	Plentiful High quality	1	Abundant.	All healthy	Yes
Fast Deep Wide WP, slightly reduced	Critical habitat sufficient Quality slightly reduced	2	Slight reduction for sensitive rheophilic spp	All healthy in some areas	Yes
Moderate velocity Fairly deep WP slightly/ moderately reduced	Reduced critical habitat Reduced critical quality	3	Reduction for all rheophilic spp	All healthy in limited areas	Yes
Moderate velocity Some deep areas WP moderately reduced	Critical habitat limited Moderate quality	4	Further reduction for all rheophilic spp	All viable in limited areas, critical life-stages of some sensitive rheophilic spp at risk	Yes
Moderate/slow velocity Few deep areas WP moderately/very reduced	Critical habitat very reduced Moderate/low quality	5	Limited populations of all rheophilic spp	Critical life-stages of sensitive rheophilic spp at risk or non-viable	Yes
Moderate/slow velocity No deep areas Narrow WP	Critical habitat residual Low quality	6	Sensitive rheophilic spp rare	Critical life-stages of sensitive rheophilic spp non-viable, and at risk for some less sensitive spp	In the short-term
Slow Shallow Narrow WP	No critical habitat Other habitats moderate quality	7	Most rheophilic spp rare	All life-stages of sensitive rheophilic spp at risk or non-viable	Most sensitive rheophilic spp disappear
Slow Trickle Very narrow WP	Flowing water habitats residual Low quality	8	Remnant populations of some rheophilic spp	All life-stages of most rheophilic spp at risk or non-viable	Many rheophilic spp disappear
No flow	Standing water habitats only Very low quality	9	Mostly pool dwellers	All life-stages of most rheophilic spp non- viable	Most or all rheophilic spp disappear
No surface water	Only hyporheic refugia	10	Only specialists persist	Virtually no development	Only specialists persist



Appendix Figure 10 Forming the "critical curve" in the HFSR approach.

A.7.1.2.12 Mixed – e.g. BCG-DSS

The BCG-DSS (Auble et al. 2009), developed by the United States Geological Survey, is specifically set up for the Black Canyon, Gunnison River, but could be adapted to other situations. BCG-DSS uses a set of Excel spreadsheets and VBA macros. The basic input data are daily flow data for any scenario (including current, natural, etc.). Any other time series might equally well be used as an input. Calculations are made based on these regarding the impacts on four main indicators as well as a flow requirement. Each indicator is of a different type and each has an associated inbuilt model developed from existing information and relationships (see also Section A.6.1.4):

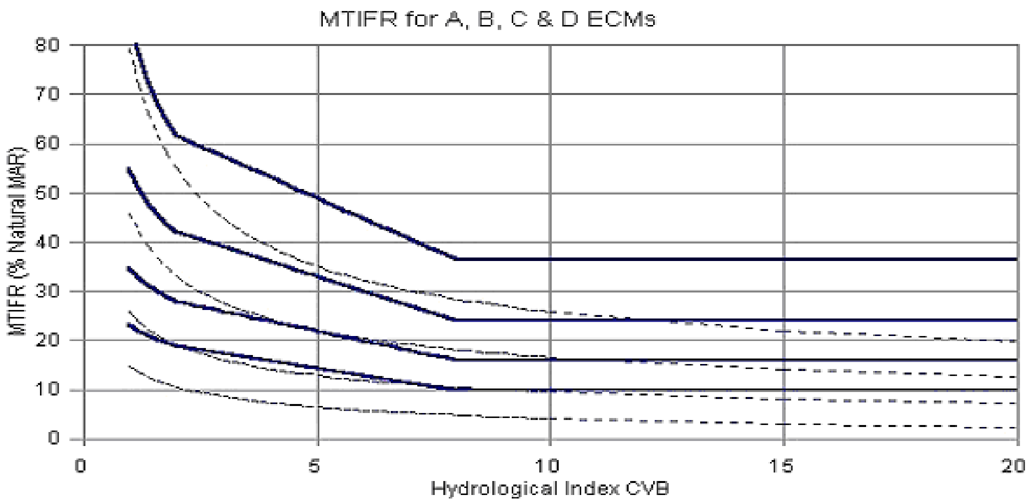
- The Box Elder Clearing model reports on the total percentage of bottomland cleared and the percentage of bottomland cleared by scour. Results are presented as box and whisker plots over the time period and tabular annual values.
- The Community percentage model reports on the percentage of bottomland in four community types (aquatic, hydric, mesic and xeric). Results are presented as pie charts for the time period and tabular annual values.
- The rainbow trout fry habitat and brown trout fry habitat models find the weighted useable habitat area and presents results as weighted useable area box and whisker plots over the time period and tabular annual values.
- The sediment mobilization model reports on the annual percentage of river length mobilised for three different fractions. Results are presented as percent of length mobilised box and whisker plots over the time period and tabular annual values.
- The National Park Service Federal reserved water right was calculated for the May-June peak flow and shoulder flow and results reported as percentage of years in which the three aspects of the water right are met or not.

The BCG-DSS has an advantage compared to some approaches of specifically dealing with the main issues identified, and in a flexible manner, rather than tracking many relatively unimportant index values or forcing them to be dealt with in a particular way (e.g. preference, severity or stress). However, the flexibility at the stage of specifying types of indicators and relationships, means that aggregation of results to obtain an overall assessment might require rescaling and weighting of each indicator.

There is no aggregation of indicator values and no weighting. However, within each sub-model a number of inputs may contribute to the output indicator value using the equations developed.

A.7.1.2.13 Aggregate ecosystem – e.g. Desktop Model

The Desktop Model uses the relationship between recommended environmental flows in South Africa (as a percentage of natural Mean Annual Runoff (MAR)) relative to the condition in which the rivers are expected to be maintained, *viz*. Class A, B, C or D (Appendix Figure 11). The descriptions attached to the Classes are provided in Appendix Table 6. The percentage MAR recommended varies depending on the hydrological nature of the target river. This is captured in the Hydrological Index (CVB- the ratio of the coefficient of variability to a baseflow index), where strongly perennial systems have a low index value and ephemeral rivers a high index value.



Appendix Figure 11 Maintenance total IFR requirements for EMCs A, B, C and D. The heavy lines are the total flow requirements, while the broken lines represent the low flow requirements. The high flow requirements are the differences between the two sets of lines.

The data set for Appendix Figure 11 comprises the results of past comprehensive EF studies and only includes rivers with index values up to 9.0. Most rivers are in the region of 1.8 to 6.0, therefore estimates for rivers with higher index values have a low confidence.

A.7.1.2.14 Other approaches

A.7.1.2.15 Multi-criteria approaches

In MCA approaches to EF index development (i.e. preference, severity, suitability indices), the index scores were made up of a weighted sum of sub-indices. This is the approach followed in DRIFT, MFAT (sub-index values were aggregated with other functional forms in MFAT), and PIMCEFA. MDSS4, on the other hand, does not allow for the aggregation of sub-index scores as it does not have a hierarchical structure, a major shortcoming for this software. Some software / methods did not aggregate index values (e.g. BCG-DSS, WFET). Only a few indices were used in these cases, and they were left as separate values.

However, as is the case in MFAT, the general use of weighted summation, does not preclude the use of other types of aggregation based on known or hypothesised relationships between indices and sub-indices. Within any particular MCA approach one could also make use of ‘vetos’ whereby if a sub-index falls below a certain threshold the value of the index is in turn limited to a certain threshold. However, the two MCA-based approaches discussed here (MDSS4 and PIMCEFA) do not allow for the inclusion of other decision rules.

MCA-based approaches generally rely on specialists to provide weights for aggregation. Scores for sub-indices are provided either directly or via known relationships between the input and output. Specialists would also be required to specify other rules that might apply such as vetos, min-max, etc. This is the case for MFAT, DRIFT, MDSS4 and PIMCEFA.

The benefit of placing the EFA within an MCA framework is that, with due care regarding the shapes of the responses, the scales and the weights, separate indicator responses can be aggregated to gain overall insights into the effects of changes in flow pattern. Some attention to the problem structuring stage, required in MCA, can help to avoid over-elaboration in terms of the numbers of indicators included, and help to ensure that vital issues are not overlooked.

A.7.1.2.16 System dynamics modelling tools (e.g. STELLA, Vensim)

STELLA and Vensim are modelling packages for system dynamics modelling. They provide a (relatively) user friendly way to construct these models through a graphical user interface whereby stocks and flows are added and linked, together with positive and negative feedback loops (“convertors”). There have been numerous examples of the use of STELLA in water-resources management (a particular example is discussed in more detail below).

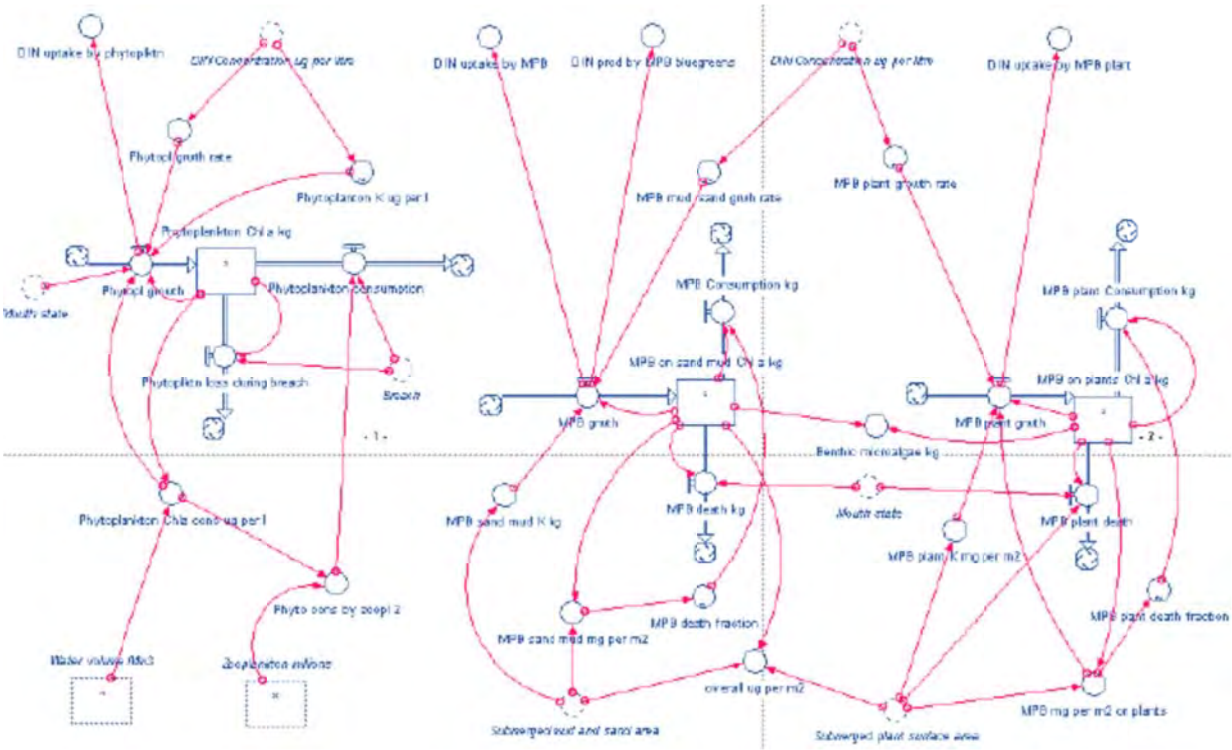
The units used to develop the model (stocks, flows, convertors) allow for much flexibility in the types of interactions and relationships between variables and the types of inputs and outputs. Thus, inputs can be continuous or discrete, relationships can be of the value function type, or if-then rules, etc.

Initial development of a conceptual model and model framework within these packages is relatively easy, and the interface makes it particularly useful in workshop settings. However, setup time for full model development is high, and models quickly become very complex and error checking consequently difficult.

Example: DEMIOS

One directly relevant use of the STELLA modelling package is an ecological-economics estuary model (DEMIOS, Turpie *et al*. 2008a and 2008b) to assess the potential impacts of changing river flows and management on the Kleinemonde estuary and to provide the information necessary for the determination of the estuarine Reserve. Thus the model, DEMIOS, is an example of an EF DSS.

The STELLA model comprised a number of linked sub-models called sectors (corresponding more-or-less to “disciplines” in the earlier terminology). Outputs from each sector become inputs into other sectors (Appendix Table 12). The indicators are therefore fully interlinked and positive and negative feedbacks from one to another can be included. The graphical representation of the microalgae sub-model is shown in Appendix Figure 12. “Convertors” (circles) and stocks (rectangles) with dotted outlines indicate inputs from other sub-models.



Appendix Figure 12 The microalgae sub-model in DEMIOS.

A.7.1.2.17 Bayesian networks

In the last decade, Bayesian networks (BNs) have become increasingly popular in the context of natural resources management including river management. BNs model the probability of a particular outcome given (quantitative and / or subjective) inputs regarding the probabilities of preceding events, given a particular initial state (e.g. scenarios). They could be regarded as a special form of expert system.

BNs have three elements (Cain 2001):

- Nodes representing management system variables with a set of mutually exclusive states. Most software requires that these are discrete (continuous variables need to be discretised).
- Links representing causal relationships between nodes and therefore having direction. Nodes can then be classed as 'parent nodes' and 'child nodes'
- Probabilities: a set of probabilities is given for each node specifying the belief that a node will be in a particular state given the states of connecting nodes (parents). These are called conditional (or marginal) probability tables. Thus, each child node has a CPT that defines the probabilities of each of the discretised states of the child node conditional on the parent node.

Comparison of scenarios takes place by altering the states of some nodes and viewing the effects on the probabilities of interest (endpoints). The parent nodes' probabilities are combined through a joint probability distribution to produce the child probabilities. The child will generally have a certain probability of being in several states.

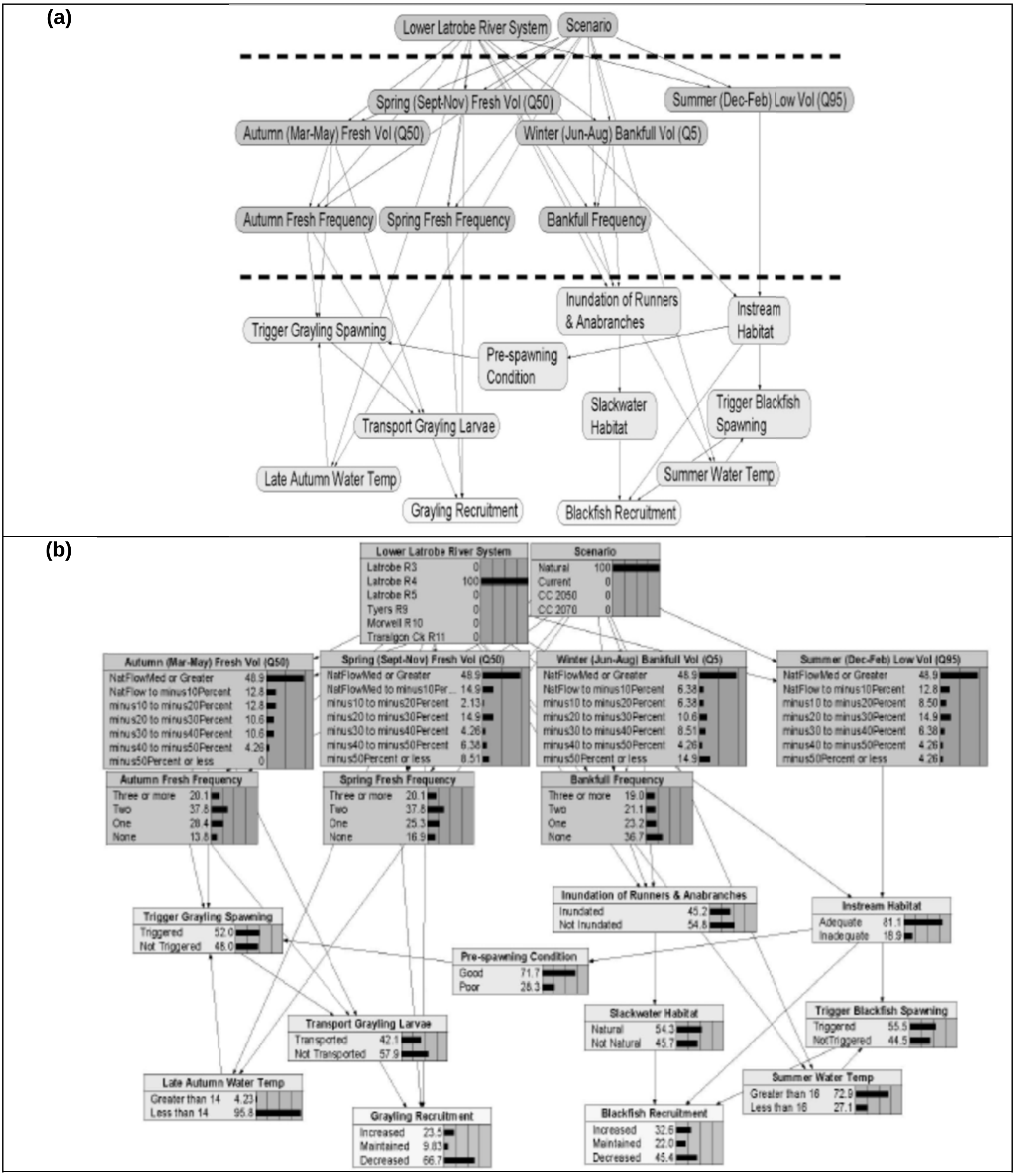
BNs are limited in that (a) they do not allow for feedback functions, (b) they do not deal with time (other than by replicating the whole model for the next time step), (c) most BN software requires that continuous probability distributions be discretised leading to over-simplification and (d) spatial information is not easily included. Perhaps overriding these issues is that BNs (as for system dynamics models), quickly become very complex and, particularly in the case of BNs, require a lot of input from the user and developer. For example, a simple network of four nodes (three parents and a child), with five states each, requires 625 probabilities to be specified. In comparison, DRIFT-DSS 1 or the DRIFT-DSS 2 would require the specification of 125 points on three response curves in the equivalent situation.

Limited versions of two BN creation and analysis packages (Netica © Norsys Software Corp 2010 and Hugin Lite © Hugin Expert A/S 2009) are available online.

Example: Latrobe and Daly BNs

Example BNs have recently been developed and applied in the EF context in Australia (Hart et al. 2009). The intention was to model the impacts of environmental and regulatory factors on ecological "endpoints". Two different BNs were created for two different types of rivers: one was a highly regulated and flow-stressed system (Latrobe River) and the other an unregulated river with low levels of extraction (Daly River).

The model for the Latrobe River was focused on the effects of restoring particular flow components to the levels previously defined using the FLOWS method (Earth Tech 2006). The ecological indicators chosen were the recruitment of two native fish species (Australian Grayling (*Prototroctes maraena*) and River Blackfish (*Gadopsis marmoratus*) which have very different life cycles and flow-ecology responses. The rationale was that, given the degraded state of the river, if conditions for the two fish species could be improved, conditions for other species would also be improved. The BN had two sub-models: the hydrological sub-model and the ecological sub-model. Appendix Figure 13 (top) shows the conceptual model of the Latrobe BN and bottom shows the BN with probability tables and a particular scenario selected.



Appendix Figure 13 **(a) The LaTrobe River BN conceptual model and (b) the LaTrobe River BN showing probability tables for a particular scenario (natural).**

A.7.1.2.18 Ecosystem or ecological modelling and tools

Ecosystem or ecological modelling has regained popularity in the last decade or two after its "golden age" in the 1970s (Wu and Marceau 2002). While future EFAs may be done using ecological modelling, the wide variety of conceptual or modelling bases (spatial, chaos theory, self-organisation, hierarchical patch dynamics, statistical and machine learning approaches to finding pattern, systems thinking) and the inherent complexity still form barriers to its widespread practical use.

There are a number of software packages that help the user to build ecosystem or ecological models. Only two are mentioned here EcoWin2000 and EcoPath with Ecosim (Christensen et al., 2008).

A.7.1.2.19 EcoWin2000

EcoWin2000 (Nobre et al. 2010 and Ferreira et al. 2008) is an ecological model for aquatic systems that deals with hydrodynamics, biogeochemistry, population dynamics for target species as well as various socio-economic attributes. It is based on a "multilayered ecosystem modelling" approach, which allows links between different sub-models and different temporal and spatial scales. It consists of a "shell" and series of self-contained "objects" (models). The software is written in C++, with Excel as the user interface, and for storage of user files. While the software provides a useful and practical framework, considerable effort and collaboration with the developer is required to set it up for any particular context (J. Ferreira pers. comm.).

(Please note that there is also a package called "*EcoWin* Pro" which is a macroeconomic and financial database and software.)

A.7.1.2.20 EcoPath with EcoSim

The EcoPath with EcoSim software is designed to help in the construction of a model of the trophic flows in an ecosystem (Christensen *et al.* 2008). The software and models were built for fisheries and are inappropriate for use to construct of any other type of ecosystem model. For instance, in an EF study, disciplines such as "geomorphology" and "water quality" would have to be placed in trophic level.

A.7.1.2.21 Machine learning approaches

"Machine learning" methods (e.g. neural networks, genetic algorithms, classification and regression trees) are essentially non-parametric approaches to finding relationships between independent variables and a dependent variable. Thus, they are tools for fitting models to existing data. In the context of EFAs, these may well have some value in assisting specialists with developing response relationships (provided sufficient appropriate data are available). A number of such tools are available, including freeware such as the Rule Discovery System™ V2.6.0 (Compumine 2007).

A.7.2. Are the flow indicators the only inputs to the biophysical and social aspects or are there others?

Most of the DSSs and the particular applications in the associated literature used only flow indicator inputs (Appendix Table 15). However, in many cases the input data could also be any

Appendix Table 15 Types of inputs

Only flow indicators	Potential for other biophysical inputs	Potential for other inputs, but does not allow for time series
Desktop Model	RAP: Any time series of biophysical inputs, including derived ones, can be used	MDSS4
DRIFT-DSS 1 and DRIFT-DSS 2	DEMIOS: (only limited by STELLA limits on input data rows and therefore number of years that can be included).	LaTrobe BN
IFIM		
MFAT		
PIMCEFA		
WFET		
BCG-DSS: Could potentially be any time series input, but currently specifically set up for BCG which uses flow indicators		

other biophysical input (e.g. BCG-DSS). RAP explicitly allows for time series of any kinds of data, while DEMIOS included a number of non-hydrological input variables generated by cross-linkages between modules (e.g. phytoplankton abundance and nutrients). While MDSS4 and the LaTrobe BN could potentially accommodate non-hydrological inputs, they do not allow for time series data and therefore are not useful in the context of the development of the 1873-EF-DSS.

A.7.3. Is there feedback between indicators, are there upstream / downstream linkages?

DEMIOS is the only method which allows for feedback between indicators, and if a similar model were set up for a river system with a number of reaches, would also allow for upstream / downstream linkages. However, the DRIFT-DSS 2 did allow for links from one indicator to the next in terms of how the socio-economics indicators were handled, but did not allow for upstream / downstream linkages. The Latrobe BN and MDSS4 also included links between indicators. The remaining methods all consider reaches in relative isolation from those upstream or downstream and did not include linkages between indicators.

A.7.4. Are the outputs quantitative or qualitative?

Only DEMIOS expressed results in terms of absolute abundance. Although RAP allows for the input of absolutes in the ERM, these need to be normalised in order to find the overall effects. Most express the results in terms of relative abundance such as percentage changes in abundance relative to a reference condition (i.e. the resulting scores are at best on interval scales). The reference condition might be present day (DRIFT) or natural (WFET, RAP). In the case of MFAT, the habitat preference scores are expressed in terms of how 'ideal' the habitat is for that particular ecosystem component. Ideal is not necessarily natural for any of the components. So each ecosystem component is a relative measure, relative to a different ideal.

To get an idea of the overall condition at a site for example, a (weighted) average of these scores was taken. This aggregate measure is somewhat more difficult to interpret than the 'relative to present' or 'relative to natural' aggregate measures used by some other DSSs. In several cases (e.g. WFET, MFAT, BCG-DSS), the relationships were derived from some more 'absolute' measures from the literature.

Appendix Table 16 Quantitative or qualitative outputs

Quantitative – Absolute	Quantitative – Percentage change relative to reference	Quantitative – relative to 'ideal'	Other
DEMIOS (abundance)	DRIFT- percentage change from present day i.e. relative abundance.	MFAT-habitat preference scores relative to ideal	BNs-probability of a state or impact occurring. Cannot be related to abundance, intensity or severity of impact
IFIM (weighted useable area)	WFET – percentage change from natural, percentage of maximum or similar. i.e. relative abundance		
BCG-DSS– can be absolute or relative (abundance or weighted useable area as relevant)			
RAP – can be absolute or relative (abundance or weighted useable area as relevant)			

A.7.5. Approach adopted in the 1873-EF-DSS

The 1873-EF-DSS is:

- based on the approach used in the DRIFT-DSS 2, with the exception that it allows for weightings at the aggregation stages;
- follows the RAP approach of flexibility with respect to inclusion of models and expert-derived response curves, to allow for better use of existing data and/or relationships.
- includes non-flow driving indicators
- includes upstream/downstream linkages.

As is the case with DRIFT-DSS 2, the 1873-EF-DSS also includes some elements of a system dynamics model such as density-dependent population or abundance growth. Currently, density dependence is included in the first season of the year and it is based on the logistic equation (for discrete time):

$N_{t+1} = N_t + r \times N_t \times (1-(N_t/K))$,

where K is the carrying capacity, r is the growth parameter, N_t is the population at time t and N_0 is the starting population size.

'K' is the long-term median of present day (i.e. 100% of present day) and 'r' is based on expert opinion. There were two "r" parameters allowing for different degrees of reaction to density, depending on if the indicator's abundance is less than or greater than 100% of present day.

A.8. Dealing with uncertainty

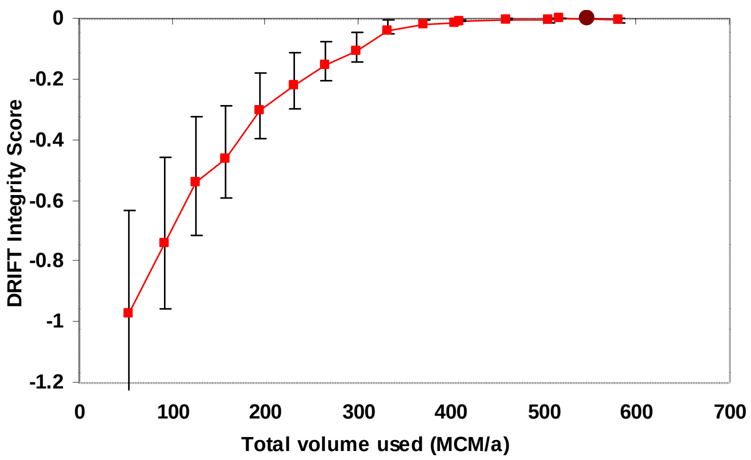
Types of information reviewed: EF Methods, DSSs and other modelling paradigms.

Methods and DSSs referred to: BBM, BCG-DSS; DEMIOS; DRIFT-DSS 1; ELOHA; MDSS4; MFAT; DRIFT-DSS 2; PIMCEFA; RAP; WFET.

A.8.1. Is uncertainty captured and, if so, how?

Of the approaches reviewed, only DRIFT-DSS 1 and PIMCEFA deal with uncertainty quantitatively. The others included, at most, a qualitative statement regarding confidence in the data, sometimes in the form of a confidence rating provided by the specialists involved in parameterising the models (e.g. MFAT).

DRIFT Severity scores are associated with a range of percentages (e.g. a score of 1, if associated with an increase, means an increase in abundance of 1 to 25%). In addition, a range can be entered for Severity (e.g. 1 to 2; Appendix Table 13), implying an even wider uncertainty (e.g., from 1 to 67%). These ranges are included in the calculation of abundance and Integrity score ranges. An example is shown in Appendix Figure 14 where the DRIFT Integrity scores are plotted against volume, showing the range of possible Integrity scores at each volume.



Appendix Figure 14 DRIFT-DSS 1: DRIFT-CATEGORY plot showing the range of possible DRIFT Integrity scores associated with different volumes.

PIMCEFA includes uncertainty at the level of the individual response curve in two ways:

1. If different experts express different views about the shape of the curve, the maximum and minimum boundary around are included as separate curves in the MCA software and given equal weight. Sensitivity analysis then displays the broader range of possible results resulting from this uncertainty.
2. Specialists can also place “confidence intervals” around their response curves, which are then handled in a similar way.

A.8.2. Approach adopted in the 1873-EF-DSS

The 1873-EF-DSS is based on the approach used in the DRIFT-DSS 1.

A.9. Time steps – inputs and outputs

Types of information reviewed:	EF Methods, DSSs and other modelling paradigms.
Methods and DSSs referred to:	BBM, Desktop Model; DRIFT-DSS 1; ELOHA; LaTrobe BN; MDSS4; MFAT; PIMCEFA; RAP; WFET; DEMIOS; DRIFT-DSS 2.

A.9.1. Are the inputs single values or time series?

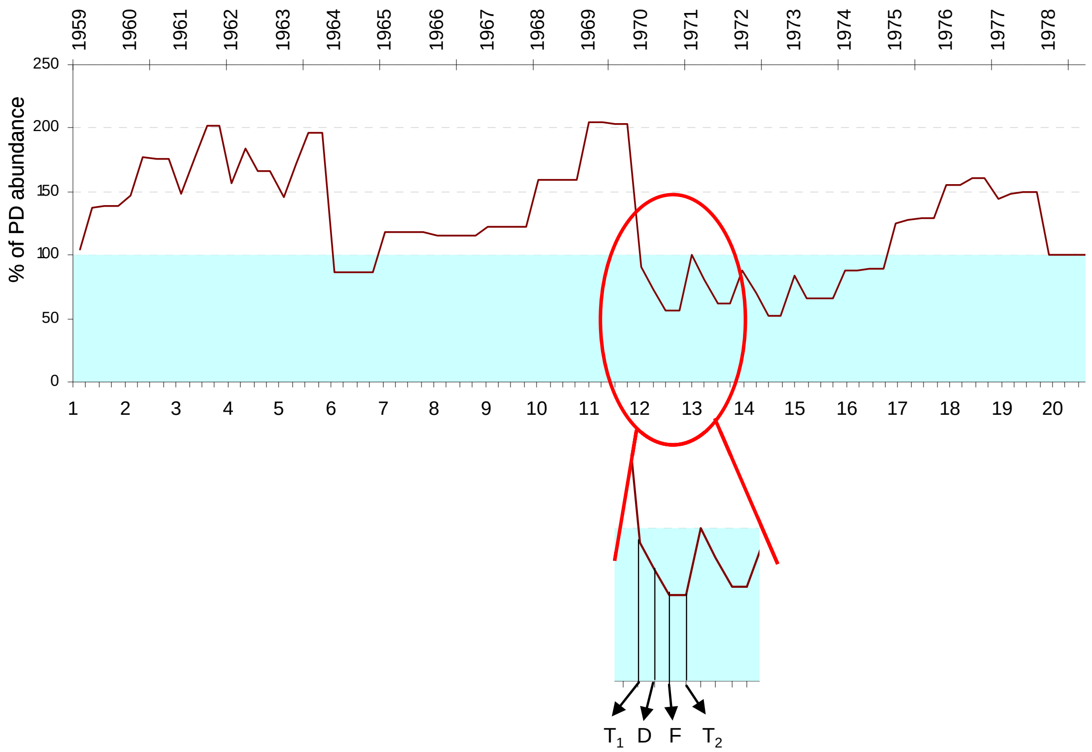
Most of the methods require time series inputs, even when the output is a single value. In some cases (e.g. DEMIOS, MFAT, DRIFT-DSS 2) various constant parameters are also required to model the response (e.g. population growth parameters in DEMIOS and DRIFT-DSS 2). MDSS4 is limited to single value inputs, such as the average or median over a time series.

A.9.2. Are the outputs single values or time series?

MDSS4 and the Latrobe BN produce single point outputs, while PIMCEFA produces results for a 'critical period'. DRIFT-DSS 1 produces results as the average value (Severity or Integrity) over a given period. The HFSR produces "instantaneous" stress-index values for each point on the hydrological time series, thereby producing a stress time series that is translated to a stress-duration curve for each scenario. BCG-DSS, DEMIOS, the Desktop Model, MFAT, DRIFT-DSS 2 and WFET all produce a time-series of results.

In MFAT, the habitat condition scores are initially calculated on a daily or event basis, but are converted to annual values based on discipline dependent rules. For example, the maximum or the average daily score for the year might be used. The time series of annual values consists of values varying between 0 and 1 depending on the suitability of the flow for a particular indicator / discipline. For more summarised overviews, the average of the annual scores was used.

The DRIFT-DSS 2 produced an initial "quasi time-series" of relative abundance values for each flow indicator. These were combined into seasonal values (Appendix Figure 15) where the value of season n+1 depends on the value of season n. The annual value was taken as the abundance at the end of the year. For calculation of ecological Integrity and for overall results presentation, the average over the time period was used. DEMIOS and DRIFT-DSS 2 appear to be the only DSSs that allow for cumulative effects over time.



Appendix Figure 15 **The "quasi time series" of the DRIFT-DSS 2. The magnified portion of the time series shows the four seasonal (T1, D, F, T2) values for that year.**

A.9.3. Approach adopted in the 1873-EF-DSS

The 1873-EF-DSS adopted the approach used in the DRIFT-DSS 2, in initially creating "quasi time-series" based on the aggregation of flow indicators into seasonal and annual values.

A.10. Presentation of outputs

Types of information reviewed:	EF Methods, DSSs and other modelling paradigms.
Methods and DSSs referred to:	BBM, BCG-DSS; BNs; Catchment2Coast; DEMIOS; DRIFT-DSS 1; ELOHA; LaTrobe BN; MDSS4; MFAT; PIMCEFA; RAP; WFET.

A.10.1. How are the results presented?

The DSSs are varied in the sophistication and user friendliness of results presentation. BCG-DSS, for example, is very simple, using box-and-whisker plots, pie graphs and tables. The simplicity makes the results very easy to understand and digest (together with the limited number of indicators). MFAT and DRIFT-DSS 2 also produce clear graphical results comparing scenarios at all scales. Because of the number of indicators and sites, overview summarised results are essential. DEMIOS (being developed in STELLA) can produce whatever graphs the user specifies, and these can be collected on a results 'page' within STELLA. However, presentation and reporting of these graphs is probably best done by exporting the data to Excel and recreating the graphs there. RAP also produces time-series graphs and tables (which would need to be exported for reporting purposes).

WFET presented results as a series of maps of risk level at nodes for each scenario. Comparison of maps (and therefore comparison of results) is very difficult, and a simple overview is missing.

Catchment2Coast produces maps showing, in different colours, abundances, etc. While these are useful, they either need to be further simplified or converted to bar-charts, etc. in order to be able to easily compare scenarios. Catchment2Coast therefore allows for a wide range of charts and tables to be specified and edited by the user.

A.10.2. Approach adopted in K5/1873

The 1873-EF-DSS:

- produces time-series plots for each sub-indicator, indicator and discipline at each site;
- produces bar charts to compare scenarios at the level of indicators/sub-indicators up to the level of the whole basin assessment. These may be adapted to produce box-and-whisker charts in order to include uncertainty;
- produce maps of the results showing the extent and degree of predicted change for each scenario.

A.11. Programming languages / platforms

Types of information reviewed:	EF Methods, DSSs and other modelling paradigms.
Methods and DSSs referred to:	BBM, DRIFT-DSS 1; ELOHA; LaTrobe BN; MDSS4; MFAT; PIMCEFA; RAP; WFET; DEMIOS.

A.11.1. What programming language/modelling platform is used

For many of the DSSs reviewed the programming language was not identified or is not applicable, e.g. BBM. For the others, this information is provided below:

BCG-DSS	MS Excel and VBA macros
DEMIOS	STELLA
Desktop Model	Delphi
DRIFT	MS Excel and VBA macros (PLUS DRIFT-Hydro in what language?)
EcoWin 2000	C++ with MS Excel as the user interface
MDSS4	Visual Basic.NET
MFAT	MS Visual Basic (the underlying RAISON™ software) and C# (in Microsoft .NET environment).
DRIFT-DSS 2	MS Excel and VBA macros.
RAP	.NET Framework.

A.11.2. Is a GIS platform used?

Catchment2Coast is the only DSS that was assessed that used a GIS platform, although a number of hydrological models include GIS capabilities.

A.11.3. Approach adopted in K5/1873

The new version of the DRIFT-DSS links to Google Earth / Google maps (if needed), allowing site locations, etc. to be viewed *in situ*.

A.12. Conclusions

RAP was the only DSS that has similar functionality to the DRIFT-DSS, although the process behind it differed somewhat from that of DRIFT. RAP also includes some valuable functionality, such as a library of response curves, which is currently not available in the DRIFT-DSS.

A.13. References

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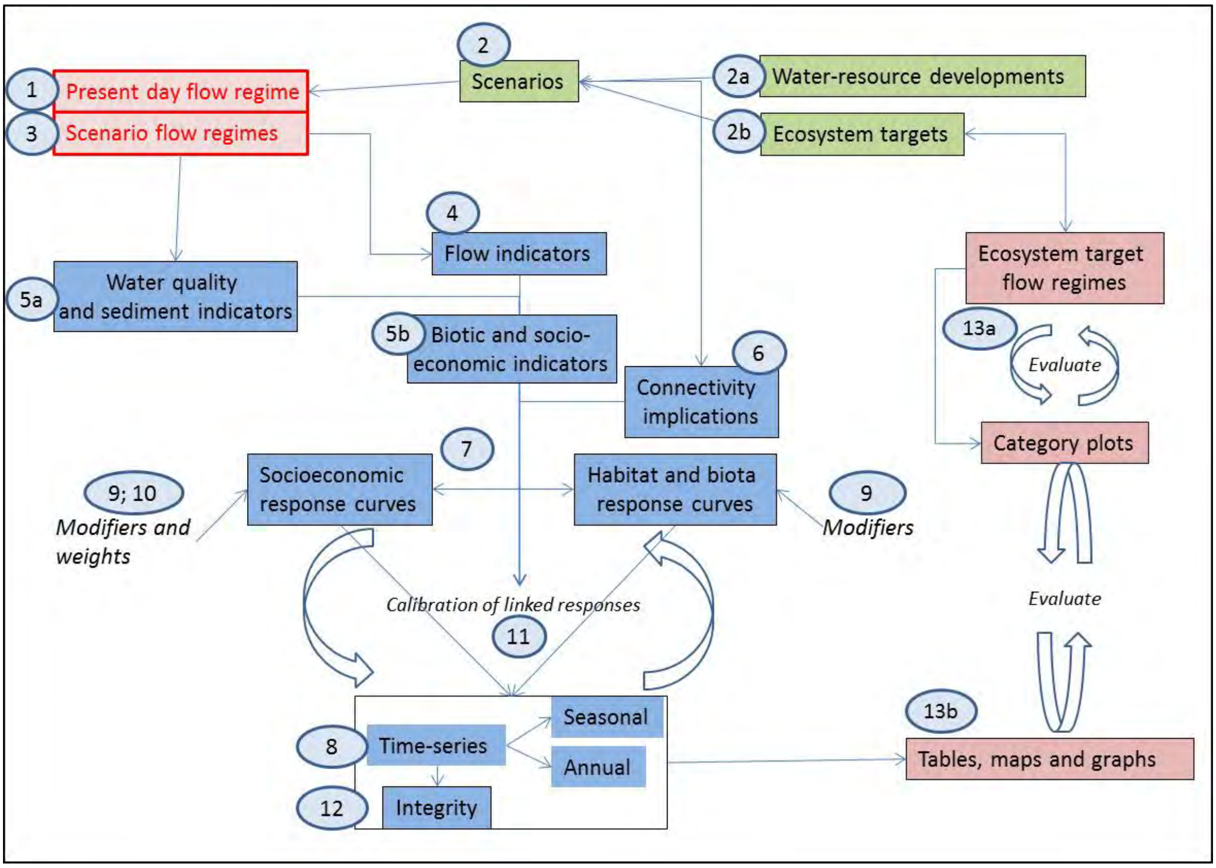
Appendix B. TECHNICAL CONSIDERATIONS AND EXPLANATIONS

B.1. Introduction

The flow of information through the DRIFT-DSS is summarised in Appendix Figure 16. The purpose of this section is to provide the background information, technical information and calculations used to produce each set of information. Calculations are given with relevant mathematical notation, and worked examples are also given where relevant.



Appendix Figure 16 The flow of information through the DRIFT-DSS. Information in red is produced outside of the DRIFT-DSS.

The explanations are provided as numbered in Appendix Figure 16, which loosely follows the flow of information, except that calibration and modifiers are used at the same time as viewing the time-series. However, they are explained in sequence as the explanation for the time-series provides the context needed to explain the modifiers, weights and calibration.

The flow of information, apart from the exception above, is as follows (Appendix Figure 16):

1. The catchment hydrology is produced for present day.
2. Scenarios are decided through discussions with the client and other stakeholders (see Section 2.1.4). Scenarios incorporate possible futures for the basin in terms of:

    a. water-resource developments;
    b. and/or protection or restoration of riverine ecosystems. Flow regimes that will facilitate either maintenance or improvement of the baseline ecological condition of different river zones condition will then be needed. These are referred to as Ecosystem Target Flow Regimes, and require the construction of Category plots (part of number 13 in Appendix Figure 16). This is discussed in Section B.14.
3. The information from (1) and (2) is used to produce the flow regimes associated with each scenario.
4. The flow regimes generated in (4) are imported into the DRIFT-DSS, and used to create seasonal time-series of flow indicators (see Section 2.2).
5. Biophysical and socio-economic indicators are defined:
    a. Time series of water quality or sediment can be imported into the DRIFT-DSS (see Section B.6.2).
    b. see Section B.6 for a discussion on indicators.
6. Water-resource developments that comprise part of the scenarios developed in (2) may affect connectivity along the length of a river system, for instance, by blocking downstream flow of sediments or the bi-directional movement of fish. The mechanisms within the DSS for incorporating the effects of a change in connectivity are explained in Section B.7.
7. The responses of biophysical and socio-economic indicators to changes in flow or other (linked) indicators are captured in the response curves (see Section 2.2.2.3).
8. The indicator responses to each scenario are available as seasonal and annual time-series. An explanation is provided in Section B.9. A time-series approach to the evaluation of the consequence of flow change in a river system was pursued because it:
    a. allows for consideration of changes in the timing of particular flows, such as a delay in the onset of the wet season flows;
    b. is easier for specialists to consider a response to a condition for a particular time-step rather than thinking of an averaged response over several years. Also, specialists may have knowledge of, or data from, a particular year or season, which can be used to calibrate the response curves.
9. The responses of the habitat, biota and socio-economic indicators can be modified in various ways to account for, *inter alia*, residual populations, 'carrying-capacity' and resilience, and recovery of a population. An explanation is provided in Section B.10.
10. In addition, the contributions of indicators towards "composite indicators" and towards calculation of Integrity scores can be adjusted using weights. This is described in Sections B.10.10 to B.13.2.
11. The calibration of response curves that link biotic or socio-economic indicators to indicators other than flow requires careful planning because altering a response curve for one indicator has knock-on effects for the response of its linked indicators.
12. Integrity is calculated at the discipline, site and basin levels, and a set of weights must be defined to achieve this, as well as information on the current health of the system. This is discussed in Section B.13.
13. Scenarios are assessed and compared:

a. Ecosystem target flow regimes can be generated and particular ones chosen to meet the targets specified in 2b, and these are then analysed along with all other scenarios.
b. To facilitate an understanding of the implications of the scenarios and their relative effects, various graphical and mapped results are provided as described in Section B.15.

Note:
1. In the discussions that follow it is assumed that there are four seasons.
2. Depending on the indicator in question, the result may be expressed in terms of abundance, concentration, area, cover, harvest, income, etc. In the discussions that follow, the term abundance is used, but one of the others could apply depending on the indicator.

B.2. Present day and scenario flow regimes

The catchment hydrology is produced for present day conditions using an appropriate hydrological or rainfall run-off model. This is done outside of the DRIFT-DSS (see PBWO 2006; Beuster and Lugomela 2005; King and Brown 2009 for examples).

The information from the scenario discussions, specification and the modelled catchment hydrology is used in a water-resources model to produce the predicted flow regimes associated with each scenario. This is done outside of the DRIFT-DSS (see PBWO 2006; Beuster and Lugomela 2005; King and Brown 2009 for examples).

B.3. Scenario specification

General principles regarding the specification of scenarios are given in Section 2.1.4. Within the DRIFT-DSS, scenario specification is completed in a number of different steps and sections:

- The location and type of all existing and planned (i.e. part of scenarios) water-resource developments are listed and georeferenced in the 'Water-resource developments' module (in the System description group of modules in Setup);
- Scenarios are described in general terms in the 'General description' module (in the Scenario specification group of modules)
- Which water-resource developments are present in which scenarios is listed in the 'Specification' module (in the Scenario specification group of modules);
- Daily time-series of the flow regimes for each scenario are imported into the DSS in the Hydrology & Hydraulics group of modules (in Knowledge capture);
- If relevant, time-series of water quality and sediment data for each scenario are imported into the Water Quality and Sediment groups of modules.

In addition, the water-resource systems modelling of the scenarios requires information on:

- planning horizons;
- temporal resolution;
- sectoral water demands and the location of those demands;

- assurance of supply;
- operating rules for existing infrastructure;
- details of new infrastructure, regarding location and proposed operating rules;
- climate change scenarios, if relevant; and,
- the location of the EF sites (from the delineation and site selection).

B.4. Flow indicators, seasons and years

It has become common practice in EFAs to convert the simulated river-flow data emanating from hydrological models into a form that is useable by river ecologists. Long-term daily-flow time series can be grouped into parts of the flow regime that are thought to play different roles in sculpting and maintaining the river ecosystem, which makes it easier to predict how changes in the hydrology could affect the ecosystem (Appendix Table 17). The first attempts to do this in South Africa recognised ‘base flows’, ‘freshets’ and ‘floods’ (King and Louw 1998). The baseflows defined the basic perenniality or non-perenniality of the river and its location in either a summer or winter rainfall area. The freshets were seen as important triggers for fish spawning and maintenance of water quality, whilst the floods maintained the channel and wetted banks and floodplains. These three flow groupings evolved over time to more detailed summaries, such as the flow categories used in early applications of DRIFT (King *et al.* 2003).

The flow categories successfully summarised ecologically-relevant aspects of South African flashy hydrographs (Appendix Table 17), but were less successful in describing large flood-pulse rivers where a single flood pulse could dominate the whole year’s hydrograph. The concept of flow seasons was thus introduced (Appendix Table 18), which differed from the previous flow categories in that the hydrograph was now divided by time as well as by flow magnitude. This marked the beginning of the use of time series in the DRIFT-DSS.

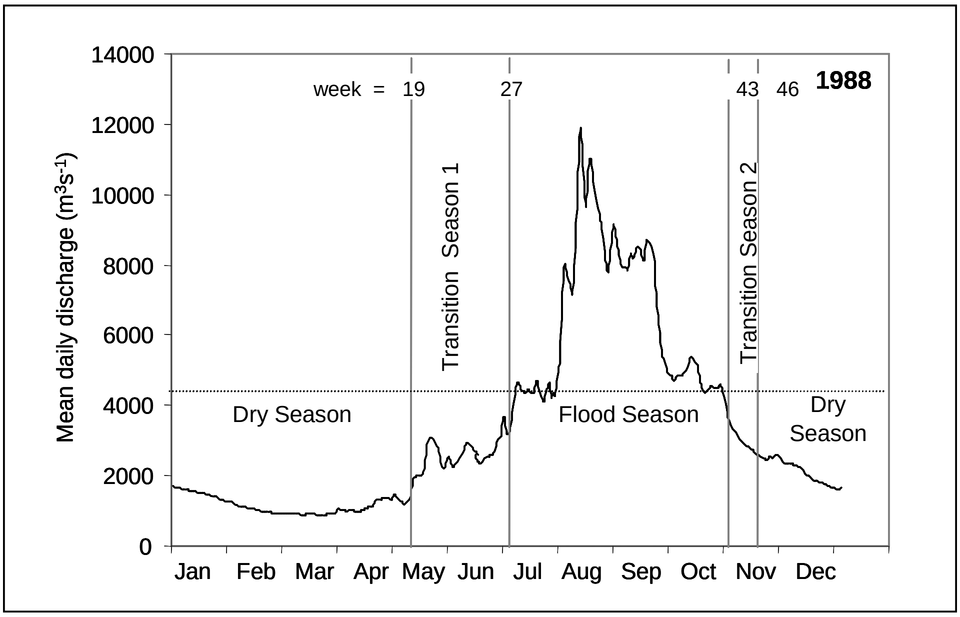
Appendix Table 17 Some possible links between flow categories and ecosystem functioning in Western Cape rivers, South Africa

Flow categories	Ecosystem link
Dry-season low flows	Maintain perenniality and thus wet habitat for survival of aquatic species, trigger emergence of some insect species
Wet-season low flows	Maintain wetbank vegetation and fast-flow habitat
Intra-annual flood 1	Trigger fish spawning in mid-dry season, flush out poor-quality water
Intra-annual flood 2	Trigger fish spawning in early dry season, flush out poor-quality water
Intra-annual flood 3	Sort sediments by size, maintain physical heterogeneity, flush riffles, scour cobbles
Intra-annual flood 4	Sort sediments by size, maintain physical heterogeneity, flush tree seedlings from edge of active channel
1:2 yr flood	Maintain tree line on banks, scour out sedimented areas in active channel
1:5 yr flood	Maintain lower part of tree/shrub vegetation zone on banks, deposit sediments in riparian zone
1:10 yr flood	Maintain channel, reset physical habitat, maintain middle part of tree/shrub zone
1:20 yr flood	Maintain channel, reset physical habitat, maintain top part of tree/shrub zone

Appendix Table 18 **Summary data for each of the DRIFT flow categories for the natural state and for four scenarios of increasing development at Site 2 on the Malibamatso River downstream of Katse Dam, Lesotho (King and Brown 2010)**

Flow categories	Natural	Minimum degradation	Design limitation	Fourth Scenario	Treaty
Wet season low flows (m^3 /s)	0.05-30.85	0.07-25.00	0.07-1.90	0.00-1.90	0.50- 0.50
Dry season low flows (m^3 /s)	0.08-23.01	0.05-9.00	0.05-1.20	0.00-1.20	0.50-0.50
Class 1 floods (# /annum)	8	3	3	2	1
Class 2 floods (# /annum)	2	2	1	0.5	0
Class 3 floods (# /annum)	2	2	2	0.5	0
Class 4 floods (# /annum)	1	1	0	0	0
1:2 floods (present/absent)	Present	Present	Absent	Absent	Absent
1:5 floods (present/absent)	Present	Present	Absent	Absent	Absent
1:10 floods (present/absent)	Present	Present	Absent	Absent	Absent
1:20 floods (present/absent)	Present	Present	Present	Present	Present
Mean annual runoff (Mcm)	554	367	184	97	22
% natural mean annual runoff	100%	66%	33%	18%	4%
Total System Yield (m^3/s)	N/a	18.3	22.8	25.2	26.8

The variability of the flow regime in timing and magnitude, both in its natural state and in any future scenario, is captured in the DSS, through identifying values of flow indicators year-by-year. In (Appendix Figure 17), for instance, the flow indicator 'flood season' starts at week 27 in 1988, but it will start in different weeks in other years. Capturing these long-term data allows the natural variability of the flow regime to be summarised, as well as how this variability will be affected in future scenarios. Specific flow seasons, for instance, could start earlier or later, or to be shorter or longer, in a scenario than under natural conditions (Appendix Table 19).



Appendix Figure 17 **The annual hydrograph for the Lower Mekong River at Luang Prabang in 1988, showing the four ecologically relevant flow seasons recognised for the Lower Mekong River.** Data source: Mekong River Commission; analysis Peter Adamson.

Appendix Table 19 **Median values of dry-season duration (in days) for sites along the Okavango River.** PD = present day. Low, Medium and High represent scenarios of increasing development (King and Brown 2009)

IFA Site	PD	Low	Medium	High	Comment
1	86	212	212	213	All Scenarios similar and approx 18 wk longer than PD
2	96	124	143	152	Progressively longer than PD by 4, 7 and 8 wk
4	135	150	168	176	Progressively longer than PD by 2, 5 and 6 wk
5/6	115	130	145	193	Progressively longer than PD by 2, 4 and11 wk

Further information can be gained by adding other descriptors for each flow season, and the DRIFT-DSS now calculates many flow (and hydraulic) indicators (Appendix Table 20) based on these. Specific indicators can be chosen for a particular study to reflect the areas of concern for that river. If chosen well they can capture the essence of the flow regime in a few key attributes, providing a clear set of relevant information upon which to base predictions of ecosystem and social changes in the face of flow changes.

Appendix Table 20 **Ecologically-relevant summary flow statistics calculated in the DSS (those used in the Okavango study (King and Brown 2009), are highlighted in green).**

Season	Type	Name	Units	Abbr
Whole year	Hydrological	Mean Annual Runoff	m^3/s	MAR
Dry season	Hydrological	Dry season onset	cal week	Do
		Dry season relative onset	weeks	DoR
		Dry season duration	days	Dd
		Min 5d dry season discharge (Q)	m^3/s	Dq
		Dry season ave daily volume	Mm^3/d	Ddv
	Hydrological (subdaily)	Dry season min instantaneous discharge (Q)	m^3/s	DQmni
		Dry season max instantaneous discharge (Q)	m^3/s	DQmxi
		Dry season max rate of change	m^3/s/min	DRmxi
	Hydraulic	Min 5d dry season velocity	m/s	DqV
		Min 5d dry season WetPerim	m	DqW
		Min 5d dry season Stage	m	DQH
Transitional season 1	Hydrological	T1 ave daily volume	Mm^3/d	T1dv
	Hydrological (subdaily)	T1 min instantaneous discharge (Q)	m^3/s	T1Qmni
		T1 max instantaneous discharge (Q)	m^3/s	T1Qmxi
		T1 max rate of change	m^3/s/min	T1Rmxi
Wet season	Hydrological	Wet season onset	cal week	Fo
		Wet season relative onset	weeks	FoR
		Max 5d flood season discharge (Q)	m^3/s	Fq
		Flood volume	Mm^3	Fv
		Flood type		F_Type
		Wet season duration	days	Fd
	Hydrological (subdaily)	Wet season min instantaneous discharge (Q)	m^3/s	FQmni
		Wet season max instantaneous discharge (Q)	m^3/s	FQmxi
		Wet season max rate of change	m^3/s/min	FRmxi
	Hydraulic	Min 5d flood season Stage	m	FminQH
		Max 5d flood season velocity	m/s	FqV
		Max 5d flood season WetPerim	m	FqW
		Max 5d flood season Stage	m	FqH
		Min 5d flood season velocity	m/s	FminQV
		Min 5d flood season WetPerim	m	FminQW
		Wet season ave daily volume	Mm^3/d	Fdv

Season	Type	Name	Units	Abbr
Transitional season 2	Hydrological	T2 recession slope	$m^3/s/d$	T2s
		T2 ave daily volume	Mm^3/d	T2dv
	Hydrological (subdaily)	T2 min instantaneous discharge (Q)	m^3/s	T2Qmni
		T2 max instantaneous discharge (Q)	m^3/s	T2Qmxi
		T2 max rate of change	$m^3/s/min$	T2Rmxi

B.5. Hydraulic indicators

The current version of the DRIFT-DSS calculates the hydraulic indicators shown in Appendix Table 20 (in the Hydrology & Hydraulics module) and they are included as part of the full suite of “flow indicators”. This requires that suitable cross-sectional or time-series data are available. Failing that, hydraulic indicators can be estimated using the Response Curves module.

B.5.1. Notation

A fundamental concept of DRIFT is that the hydrological regime can be summarised in ‘**flow indicators**’ that are biophysically and socio-economically relevant. The relevant flow indicators are likely to differ in type and number for different river systems, and the DSS currently accommodates two types of flow regimes, “flashy” and “flood-pulse” systems.

In mathematical notation, the flow indicators are denoted as $\boldsymbol{FI_i}$, where i = 1, n denotes the individual flow indicators (i.e. i =1 to 7 for the Okavango IBFA).

For example, using the flow indicators from the Okavango study (King and Brown 2009) as an example:

1. Annual dry- season onset (Do) by calendar week (FI_1)
2. Annual dry-season minimum 5-day discharge (Dq) in m^3s^{-1} (FI_2)
3. Annual dry-season duration (Dd) in days (FI_3)
4. Annual flood-season onset (Fo) by calendar week number (FI_4)
5. Annual flood-season 5-day peak discharge in m^3s^{-1} (FI_5)
6. Annual flood-season duration (Fd) in days (FI_6)Annual rate of decline of transition season 2 (T2s) (after the flood season): (FI_7).

Regardless of the river system in question, DRIFT recognises **four flow seasons** within a year (dry season, wet season, and two transitional seasons). However, within a particular study, one or more of the seasons can be left out (by not linking any indicators to them). For example, for the Okavango study (King and Brown 2009), three seasons were used: the dry season; the flood season; and, the transitional season after the flood season. The FI_i’s may ‘belong’ to a particular season. For example, for the Okavango study, FI_1, FI_2, and FI_3 were all dry season characteristics.

The entire list of flow indicators currently calculated in the DRIFT-DSS is given in Appendix Table 20.

B.6. Selection of biophysical and socio-economic indicators

Indicators are the basic building blocks of monitoring and evaluation systems (Global Water Partnership 2010). In IWRM work, indicators are part of a hierarchy of terms used, to assess progress toward some goal (GWP 2010). From the highest to lowest level these terms are:

Goals	broad qualitative statements about what is to be achieved or what problem is to be solved.
Objectives	the means identified to achieve the goals.
Actions	the specific activities identified to accomplish the objectives.
Targets	defined and measurable criteria for achieving the goals, objectives and actions.
Indicators	measures selected to assess progress.

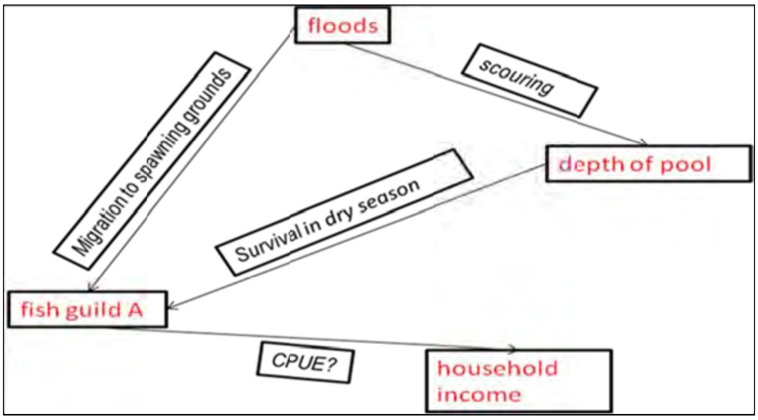
Indicators within this hierarchy can be:

- process indicators – tracking progress;
- outcome indicators – monitoring results;
- impact indicators – monitoring progress.

Although specifically described for IWRM, most of the above essentially refer to monitoring progress and not to evaluation for other purposes. In EFAs, the aim is not to monitor but to describe the present situation and then to predict how this could change with management activities. Thus, the accent is on informing planning and not on measuring progress or compliance. The indicators are chosen for this purpose and could be seen as 'outcome indicators' whilst recognising that they *predict* results rather than *monitoring* them. Nonetheless, once a planning pathway has been agreed on, the same indicators can be used for monitoring compliance.

There do not appear to be general guidelines as to what makes an ideal indicator, except the obvious: that they have to relate to the issue being addressed; be amenable to quantification in some form and, broadly, reflect stakeholder concerns. The DRIFT indicators have always met these criteria. They are seen as attributes that have describable relationships with river flow or the river ecosystem, and that can change as the flow regime and ecosystem changes. Indicators that have no obvious links to flow cannot be used to predict the outcome of water-management plans, and so would be of no use in the DSS. An example of a useful EF indicator is 'the community of trees on the lower floodplain'. An example of an inappropriate indicator could be 'the number of people living along the river who have cell phones'.

In the DRIFT-DSS a network of indicators is used to describe the river ecosystem and its human users. In Appendix Figure 18, arrows that link indicators show the flow of cause-and-effect. In essence, the arrows are the processes and the indicators represent the outcomes of the processes, with the network as a whole representing a simplified ecosystem model. The indicators are used to describe, aspect of the flow regime of the river, ecosystem attributes and river-linked social attributes.



Appendix Figure 18 A small network of indicators (red boxes) and processes (arrows)

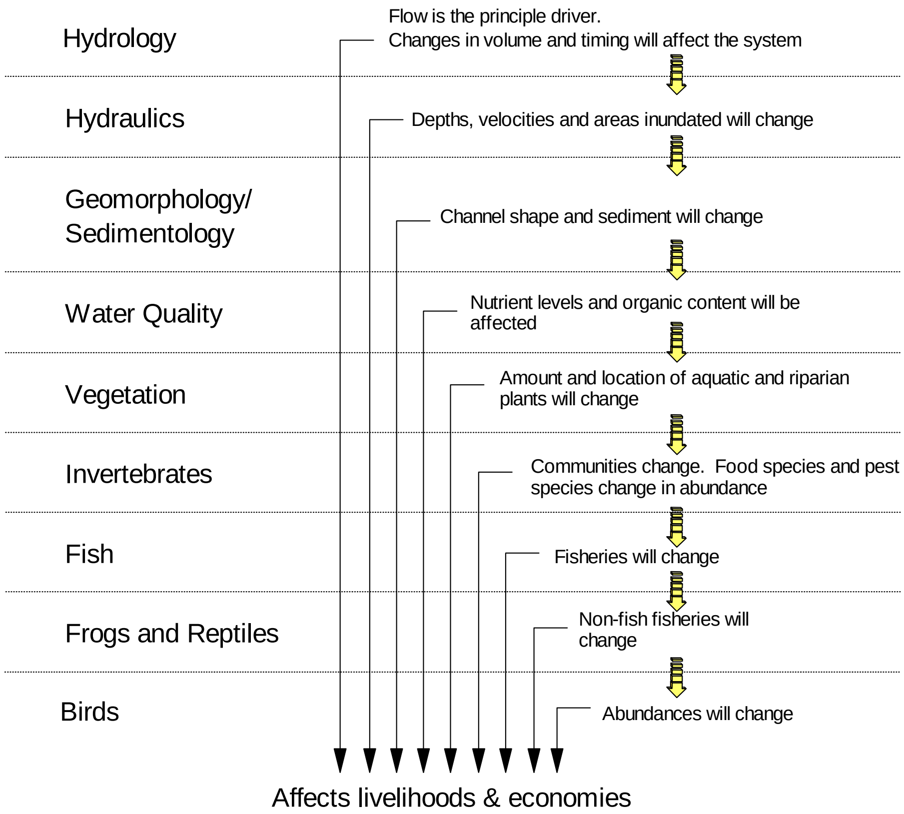
B.6.1. The flow of information

Information flows from indicator to indicator in a way that reflects a simple version of reality. Because DRIFT is an EFA DSS, the sequence always starts with the flow regime as changes in it will affect hydraulic conditions, which sequentially affect geomorphological conditions, which affect chemical and thermal, vegetation, invertebrates, fish, other wildlife, and social activities in turn (Appendix Figure 19).

The present and changing nature of each of the major descriptors of the system, shown on the left in Appendix Figure 19, is described through the indicators chosen by the specialist team undertaking the EFA. Choosing appropriate indicators is arguably one of the most fundamental and important concerns in the EFA. If this exercise is done well, the specialist team should already be some considerable way along the road of achieving a successful EFA.

Three major considerations should be borne in mind. First, the indicators must have some relationship to the flow regime of the river (although this might be indirectly through another indicator), so that the outcomes of water-resource plans can be predicted, via simulated hydrological changes, as ecosystem and social changes. Second, the indicators must exist within a logic matrix that shows which are linked to which, and identifies the processes are that used to form the links. Third, the indicators must be expected to respond to a change in the river's flow regime by changing in one of the following ways:

- abundance/size: e.g. number of large mammals on upper floodplain; size of household income from river resources
- extent (area): e.g. cover of riparian tree community on upper dry bank
- concentration: e.g. conductivity



Appendix Figure 19 **The outcomes of water-resource developments, showing a simplified cause-and-effect sequence through the major descriptors**

In the logic matrix, indicators may be of the following two kinds:

- driving indicators, which force change in another indicator as they change;
- responding indicators, which respond to changes in driving indicators.

In the DRIFT-DSS flow indicators are always driving indicators as they initiate the entire process (as above). Indicators chosen for a discipline are in effect 'responding indicators'. These can in turn become driving indicators as is, for instance, pool depth in Appendix Figure 18.

In the following sections the indicators are considered by the major ecosystem descriptors, hereafter called disciplines, and then important considerations for final indicator selection are described (in Section B.6.3).

B.6.2. Indicators by discipline

Note that in the DRIFT-DSS, flow and hydraulic indicators can only be chosen from among the fixed set calculated in the DSS, while others can be specified by the user.

B.6.2.1 Flow indicators

See Section B.4.

B.6.2.2 Hydraulic indicators

See also Section B.4.

The flow regime, as such, does not affect the ecosystem, but rather its impacts are felt through changes in the hydraulic conditions. Different magnitude discharges create deeper or shallow water, faster or slower flow, inundate more or less of the banks and floodplains, and provide more or less freshwater to the estuary. An EFA captures this range of conditions with indicators such as those used in the Mekong study (MRC 2006), some of which are listed below:

- annual high water level
- high water average depth
- longitudinal connectivity along the system
- area of inundation of floodplain
- channel stability factor
- annual low water level
- low water average depth
- lateral connectivity with the floodplain
- depth of inundation of floodplain
- height of groundwater table in dry season.

Indicators such as these speak directly to the knowledge required by the ecologists in order to predict ecosystem change, although they may not necessarily be ones easily gleaned from standard hydrology-hydraulic models.

The current version of the DRIFT-DSS calculates the hydraulic indicators shown (Appendix Table 20; in the Hydrology & Hydraulics Module) and they are included as part of the full suite of "flow indicators".

B.6.2.3 Geomorphological indicators

Hydraulic conditions directly affect channel morphology and available habitat, through the transport and size-sorting of sediments, scouring of rocky beds and facilitation of siltation by fine sediments. Again, the indicators need to be able to describe how critical habitat conditions can change and how social attributes can be impacted. Indicators chosen for the Mekong, Okavango and Pangani (Tanzania) studies reflect a degree of similarity even though the two former are large, flood-pulse rivers with vast floodplains and the latter is a smaller single-channel river (Appendix Table 21).

Appendix Table 21 Some of the geomorphological indicators for the Mekong, Okavango and Pangani EF studies (MRC 2006; King and Brown 2009; PBWO/IUCN 2008)

Mekong	Okavango	Pangani
Pool depth	Inundated pools and pans	Pools
Extent of sand bars in channel	Sand bars at low flow	
Bank recession rate	Extent of cut banks	Bank erosion
Number of islets at annual low water level	Extent of vegetated islands	
Grain size of bedload	Extent of coarse sediments	Riffles and rapids
Bed elevation end of dry season		
Suspended sediment concentration	Percentage clays on floodplain	Fine sediments

B.6.2.4 Water quality indicators

Water quality is arguably one of the more challenging disciplines to work with. The choice of indicators may be similar between projects (Appendix Table 22), but interpretation must be done with care. Essentially, though, water-quality indicators should reflect variables that are seen as important in the river in question, which could respond to flow changes and thus affect ecosystem functioning, and which could be of concern to people.

Appendix Table 22 Water-quality indicators for the Mekong, Okavango and Pangani EF studies (MRC 2006; King and Brown 2009; PBWO/IUCN 2008)

Mekong	Okavango	Pangani
pH	pH	pH
Salinity	Conductivity	Conductivity
	Temperature	Temperature
Light penetration/TSS	Turbidity	Turbidity
Dissolved oxygen	Dissolved oxygen	Dissolved oxygen
Nutrients	Total nitrogen	Total nitrogen
	Total phosphorus	Total phosphorus
	Chlorophyll a	Chlorophyll a
E. coli		
Schistosomes		

Within the DRIFT-DSS, water quality can either be added as one of the Habitat & Biota disciplines with response curves defined for each link to flow or other indicators, or the Water Quality Module can be used. Water quality indicators within this module are based on a “fitness for use” concept. Water quality constituent (e.g. NO_3, TDS) concentration thresholds can be defined for different uses (e.g. domestic consumption, aquatic ecosystem, agricultural use). Water quality indicators are defined as the percentage of samples that exceed the specified threshold in a particular season (indicators are calculated separately for the dry and wet seasons). The sample data are imported into the DSS. A maximum of three constituents and three uses can be defined, giving a potential maximum of 18 indicators (3x3x2seasons). The sample data imported for water quality can be at a variable time-step.

B.6.2.5 Sediment indicators

Within the DRIFT-DSS, sediment can be included by using the Sediment Module. Sediment indicators are defined as the maximum, minimum, and mean values of sediment variables recorded or simulated at a site. A maximum of three sediment variables are defined by the user, and time series for these variables are imported into the DSS. Indicators are calculated separately for the dry and wet seasons, meaning that a maximum of 18 sediment indicators (3 variables times 3 statistical properties times 2 seasons) can be generated.

The sample data imported for sediment can be at a variable time-step.

B.6.2.6 Biological indicators

Biological indicators represent all living parts of the river ecosystem other than people, namely, vegetation, aquatic invertebrates, plankton, fish, birds and other wildlife. Species should be grouped by their characteristic habitat conditions. For instance, large mammals that graze on the outer edges of floodplains can be grouped separately from those that graze on the middle floodplains, with those typically found closest to water on the lowest part of the floodplain forming a third group. Fish that stay all year in one zone of the channel can be grouped separately from those that migrate along the channel and those that move onto inundated floodplains. A useful way to identify such groups is to create a matrix of species versus hydraulic requirements that will show up groupings such as those for birds in the Okavango study (Appendix Table 23). All the species within one indicator are assumed to be similarly affected by changes in their hydraulic habitat.

Appendix Table 23 Indicators for birds in the Okavango study (adapted from King and Brown 2009)

No.	Indicator	Food items	Feeding habits	Areas used for feeding	Areas used for breeding	Species
1	Piscivores of open water	Medium-sized fish	Diving swimming after fish	Open deep waters devoid of vegetation	Trees, reeds or a ledge	Fish Eagle, Reed Cormorant
2	Piscivores of shallow water	Small fish	Hunt from overhanging trees on shallow backwaters by ambush techniques	Shallow water, seasonal pools and flooded sedgelands	Trees	Pel's Fishing Owl, Greater egret, Grey Heron, kingfishers
3	Invertebrate and fish-fry feeders in receding waters	Invertebrates and fish fry	Feed on fish-fry at receding water level times after spawning in flood-plains, or fish trapped in drying pools	Shallow water	Bushes or reeds	Smaller herons/ egrets, pelicans, storks, snipes, plovers, sandpipers, rallids
4	Floodplain specialists	Molluscs, frogs, fish and seeds	Wade in shallow water	Floodplains	Nesting habitat in reedbeds lining river banks and islands.	African Openbill, ducks, geese, Wattled Crane, Slaty Egret
5	Water lily specialists	Insects, mollusks, seeds, crustacea	Walks or runs on surface vegetation, pecking food and often overturning leaves	Water lilies, on floodplains or in backwaters	On floating vegetation at water level	African and Lesser Jacanas
6	Fruit tree specialists	Fruit	Clampers among branches	Fruit trees	In trees (nests or holes)	Parrots, turacos, bulbuls, starlings, barbets
7	Breeders on banks	Various	Various	Open water	Totally dependent on emerged rocks, sandbars and islands in the main river for nesting purposes	Rock Pratincole, African Skimmer

All biological indicators will be responders, linked to driving hydrological, physical and chemical indicators. They may also be drivers for other biological indicators.

B.6.2.7 Social indicators

People who use river resources directly are catered for in the DRIFT-DSS because these resources can change with flow changes, affecting incomes, health and well-being. Indicators of such links with the river can cover the following areas of interest:

- household incomes from good harvested from the river, tourism and more;
- food security from goods harvested from the river;
- social wellbeing stemming from recreational, cultural, spiritual and religious (e.g. baptism sites) links to the river such;
- conservation values including those derived from the presence of rare or iconic species, and international or national conservation areas;
- the health of people and livestock;
- navigation;
- and more.

Social indicators are each linked to an array of hydrological, physical, chemical and biological indicators earlier in the sequence, which will drive change in them.

B.6.3. Selection of indicators

Users of the DSS will be able to specify their own set of indicators as these will differ depending on, *inter alia*, the nature of the aquatic ecosystems under consideration, the nature of the natural flow regime; the water-resource developments under consideration (for instance, for Peaking-power HEP projects, the flow indicators will need to consider sub-daily fluctuations); and the objectives of the project (see Beilfuss and Brown 2010 for a different set of DRIFT indicators).

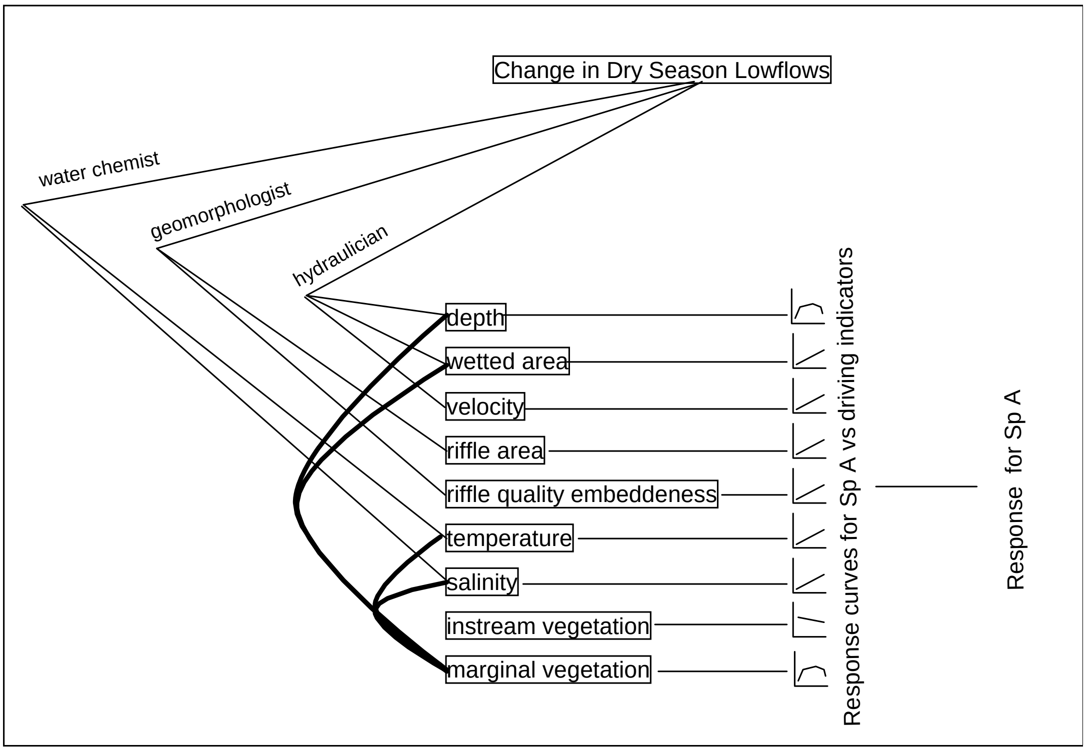
Appendix Table 24 summarises the important considerations in the selection of indicators.

The consequences for some indicators will depend on how a driving indicator earlier in the sequence has performed. For instance, biological indicators will be driven by expected changes of selected physical or chemical driving indicators. As an example, the consequences of a reduction in dry-season low-flows for a riffle-dwelling fish species (Sp A), may be dependent on the effect of the flow change on the following (Appendix Figure 20):

- depth and wetted area (from hydraulics);
- water velocity (from hydraulics);
- temperature (from WQ);
- salinity concentrations (from WQ);
- habitat quality (e.g. riffle embeddedness; from geomorphology), and;
- inundation of marginal vegetation (from vegetation);
- extent of instream vegetation (from vegetation).

Appendix Table 24 **Summary of important considerations in the selection of indicators**

No.	Indicator requirement	Comment
1	The indicator should be linked to flow/water levels, or to another indicator that is so linked	Indicators not so linked cannot be used to predict flow-related changes.
2	The indicator should be expected to change in abundance, area or concentration.	See explanation in text.
3	It should be possible to describe the relationship between a driving and a responding indicator.	These relationships are described using response curves.
4	Items that respond in the same way to flow can be combined as a single indicator.	For instance, fish species with the same or similar relationships to flow can be combined in Flow Guilds. Some water quality variables, such as conductivity and Total Dissolved Solids, may respond in a similar way to flow and can be grouped.
5	The list of indicators may vary from site to site, but indicators at one site that are dependent on what happens at another site should be in both lists.	This is likely to be especially relevant for sediment, water quality and fish indicators.
6	Indicators should include any representing socially-important river resources.	This involves an iterative process whereby social specialists check that the biophysical attributes of interest to them are included as indicators



Appendix Figure 20 **Schematic giving hypothetical example of driving indicators for Fish Sp A. Responses curves are required for each driving indicator. These are combined to derive the response for Fish Sp A for a change in dry-season low-flows A. The thick black line represents linked indicators.**

If the indicator lists compiled by the physical specialists do not include the necessary driving indicators then the information required by the fish specialist will not be available. It is therefore important to identify the information required from other disciplines and to ensure that these are included in their indicator lists.

The number of indicators per discipline is limited to enable more efficient database design and operation and also in order to focus the specialists' minds on what is most important. Each discipline is represented by a maximum of ten (10) indicators.

B.7. Connectivity implications

The Connectivity module allows the user to assess the effects of in-channel obstructions, such as where a dam and impoundment, or an area where extreme abstraction, results in a barrier to longitudinal biotic connectivity and thus, reduces the degree of connectivity between the EF sites. This is particularly important for animals that migrate up and downstream to feed or breed.

The Connectivity module is prepared by the DRIFT-DSS, based on:

1. the location of the infrastructure and other relevant water-resource developments on Arcs as specified in "System description";
2. the specification of that development as present in the relevant scenario as specified in "Scenario specification" (see Sections 3.1.2 and 3.1.3); and
3. the specification of inter-site relationships between a driver and response indicator (in "Links", see Section 3.1.4). Usually inter-site linkages are between the same indicator at different sites. For example, Fish species A at an upstream site might depend on a link with Fish species A at the next site downstream, because of up-migration for breeding. Here the down-stream Fish species A is the driver and the upstream Fish species A is the responder.

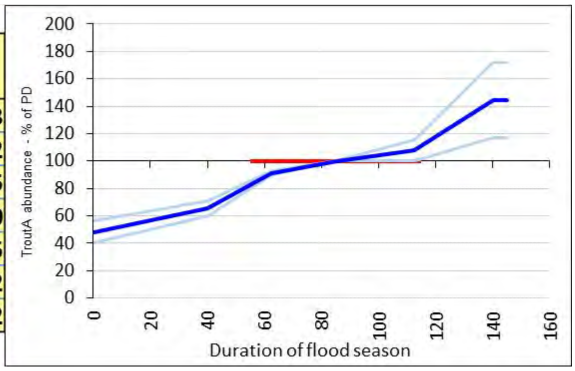
Once these three streams of information are available, the DSS brings them together to produce a table, which lists the links and the relevant infrastructure or development that occur between the sites concerned and the user estimates the associated percentage reduction in connectivity.

B.8. Response curves

Response curves capture how an indicator will react to a change in an input indicator such as may be a flow, habitat or biota indicator. The reaction is expressed in terms of a Severity score, which is related to a percentage change in abundance (see Appendix Figure 21).

The user is provided with the reference (usually present day) range and median values for each driving indicator. They are also given minimum and maximum values that encompass the likely ranges of the scenarios (see columns shaded green in Appendix Figure 21). According to the values in Appendix Figure 21, if the duration of the flood season in a particular year is 40 days, the severity rating will be -2, meaning that 70% of the present-day abundance will be retained (range 60-79%, Appendix Figure 21). For any intermediate values, the response is linearly interpolated (e.g. if the input is 126.25, the severity rating will be 1.25 or a 26.14% increase on Present Day abundance).

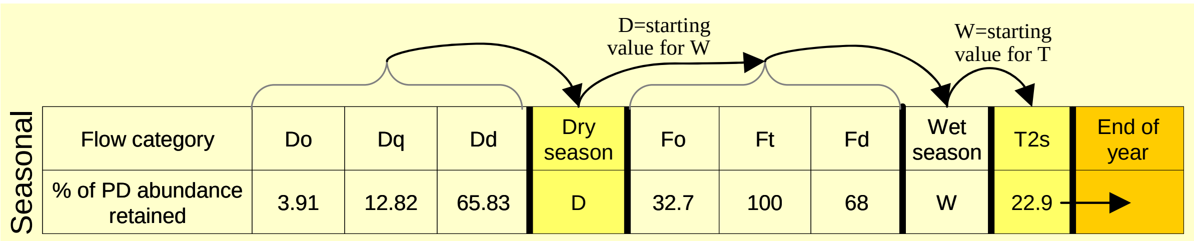
Level	Duration of flood season	TROUTA response
Min	0	**-3**
Min PD	40	**-2**
	62.5	**-0.5**
Median PD	**85**	**0**
	112.5	**0.5**
Max PD	140	**2**
Max	145	**2**



Appendix Figure 21 **The seven points provided in the DSS for completion of the response curve, with the resulting curve shown on the right. The lighter blue lines represent the range implied by the severity score.**

B.9. Time series

An approach was needed to aggregate the responses of an indicator to changes in its various linked indicators, in order to obtain an overall indicator response per season and per year. The approach adopted involves a seasonal, and then an annual, aggregation of responses (Appendix Figure 22).



Appendix Figure 22 **Schematic of the 'seasonal' approach to time-series development used in the DRIFT-DSS. For full version of flow indicators see Appendix Table 20.**

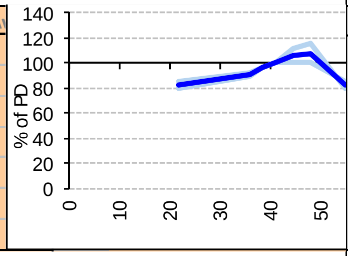
A particular indicator (e.g. FishSpeciesA; see Appendix Box 1) may respond to a number of "linked indicators". For example: FishSpeciesA may respond to the onset (FI_1) and the duration (FI_3) of the dry season and the flood-season 5-day peak discharge (FI_5), but not respond to anything in particular in the transitional seasons. The responses are captured by the response curves described in Sections 2.2.2.3 and B.8.

The indicator's overall response (P) for a particular season is an aggregation of the responses (p) to each linked indicator, i, relevant to that season. In this example, FishSpeciesA only responds to one indicator in the flood season (FI_5), but two in the dry season (FI_1 and FI_3), so the responses in the dry season need to be aggregated. In general terms, the response is calculated

Appendix Box 1 **Worked example: creating a time-series of response for FishSpecies A**

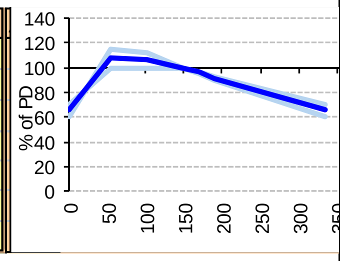
Dry season onset

Description	week	range
Min May	21.8	-1
Min PD Septeml	36	-0.5
	38.5	-0.2
Median PD Octo	41	0
	44.5	0.2
Max PD Novemb	48	0.5
Max (failed sea	55	-1



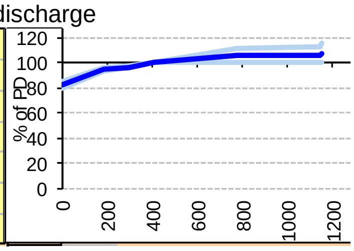
Dry season duration

Description	days	range
Min	0	-2
Min PD	55	0.5
	103	0.25
Median PD	150	0
	170	-0.2
Max PD	190	-0.5
Max	334	-2



Flood-season 5-day peak discharge

Min	0	-1
Min PD	183	-0.3
	297	-0.2
Median PD	411	0
	777	0.2
Max PD	1143	0.3
Max	1154	0.5



If, in year 1:

- the dry season starts in week 36, the severity score is -0.5 = percentage decrease of -8.64.
- the dry season lasts for 103 days, the severity score is 0.25 = percentage increase of 5.97.
- the wet season 5-day peak discharge is 297, the severity score is -0.2 = percentage decrease of -3.44.

Thus, with no modifiers applied, the overall response in the dry season is – 8.64 + 5.97 = -2.67, i.e. a decrease of -2.67. Each season of year 1 (with no modifiers), expressed as a percentage of PD (where PD is 100):

The % abundance at the end of the dry season S_1^1 is:	100-2.67 = 97.33
The % abundance at the end of the first transition season S_2^1 is:	97.33 +0 = 97.33
The % abundance at the end of the wet season S_3^1 is:	97.33-3.44 = 93.89
The % abundance at the end of the second transition season S_4^1 is:	97.33+0 = 93.89
And therefore, the % abundance at the end of the year is:	93.89

as the total increase or total decrease (in percentage points), which applies to that season. The calculation is (equation 1):

$$P_X = \sum_{i=1}^{n} p_i, \text{ where:} \qquad (1)$$

- P_X is the overall percentage increase or decrease (amount to be added or subtracted) for a season X (also represented as $P_X^{\,t}$ where t refers to the particular year),
- p_i is the percentage increase or decrease resulting from input i.
- there are n inputs affecting season X.

This is a sum of the percentage increases or decreases resulting from each input 1 to n that is relevant to season X. For FishSpeciesA in the dry season (season 1) this equates to:

$P_1^t = \ p_1 + p_2$, where p_1 is the response from dry season onset, and p_2 the response from dry season duration.

With no modifiers applied, the remaining calculations are as follows:

The overall percentage of present day abundance at the end of the first season S_1 (generally the dry season), in year t, is:

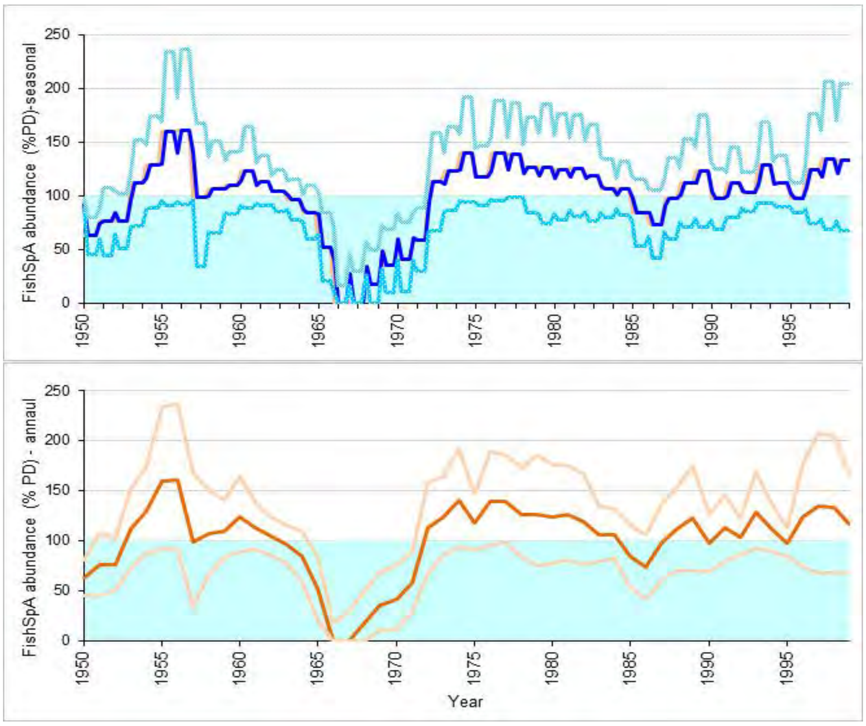
$S_1^t = 100 + P_1^t$, where P_1^t is the % change in the dry season. **2**

And the percentage abundance at the end of each subsequent season (if no modifiers apply) of year t:

$S_X^t = S_1^t + P_X^t$, where P_X^t is the % change in season X. **3**

The end of year value as a % of present day is thus = S_4.

Ultimately, what is created is a 'time-series' of values for each season of each year. One can view the time-series response including all the seasonal variation, or just using the end of year value (Appendix Figure 23).



Appendix Figure 23 **Seasonal (top) and annual (bottom) representations of the overall response of indicator "FishSpeciesA".**

B.10. Modifiers

Various modifications can be made to the overall seasonal result Px of each indicator as described here. These are test applications at this stage, which need more research.

B.10.1. Dependency on previous year

Specialists can specify whether or not an indicator depends on the end of previous year abundance. For example, a fish species may be dependent on breeding stock from a previous year, whereas temperature tends to be independent of the previous year's values. The specialist indicates the degree of dependence using percentages.

If the specialist has indicated that the response is not dependent on the end of the previous year's abundance (and no other modifiers are used), then equations 2 and 3 above apply.

In cases where there ***is*** dependency on the previous year, and the percentage dependency is indicated by Y, the calculations to find the overall seasonal response as a percentage of PD are as follows. For season 1:

$$S_1^t = (S_4^{t-1} \times \frac{Y}{100}) + (\widehat{100} \times (\frac{100-Y}{100})) + P_1^t \quad \textbf{4}$$

, where:

$S_1{}^t$ is the seasonal result as a % of PD of Season 1 for year t,

$\widehat{100}$ is the beginning of year – 100% starting point if there were *no* dependency, and

$P_1{}^t$ is the result of equation 1 for season 1 (year t).

For subsequent seasons of that year, equation 3 above applies.

B.10.2. Tendency back to median levels

In situations where abundance increases above PD or declines below PD, there may be a tendency for it to return to PD values when average conditions prevail again (i.e. input indicator values). For example, in a very dry year, macroinvertebrate populations may decline significantly but, because they are short-lived and recolonise rivers each year, once conditions improve to average, their numbers may also improve to PD levels. Depending on the indicator, there might be a quick return to PD values when abundance is above PD, and a slow return to PD when abundance is below PD.

B.10.2.1 When starting point is above PD

The specialist provides the number of years the indicator would take to return to median under favourable conditions, M^a (the respondent is asked to provide the number of years to return from 200% of PD). The calculations applied for returning to median when abundance is above PD is:

If conditions are unfavourable (one or more inputs less than median) results for the season remain as for equation 2, 3 or 4.

If conditions are favourable, and there are N seasons, then the resulting abundance T_X for season X is:

$$T_X^t = S_X^t + \frac{(100-200)}{(M^a \times N)}\,, \qquad (5)$$

where 100 refers to 100% of PD, 200 is the level at which the abundance started, thus 100-200 gives the difference between the starting and end points. For example if the specialist said that the abundance would take two years to return to PD from 200% of PD, and there were 4 seasons, the equation would be:

$$T_X^t = S_X^t + \frac{(100-200)}{(2\times4)} = S_X^t + \left(\text{-}12.5\right)\,,$$

i.e. 12.5 will be subtracted from the result obtained from equation 2, 3 or 4, thus causing the abundance to more quickly return to median. If the number of years were given as 15, the amount subtracted would be 1.67.

B.10.2.2 When starting point is below PD

The specialist provides the number of years the indicator would take to return to median under favourable conditions, M^b (the respondent is asked to provide the number of years to return from 5% of PD). The calculation applied for returning to median when abundance is above PD is:

If conditions are unfavourable (all inputs less than median) results for each season remain as for equation 2, 3 or 4.

If conditions are favourable, and there were N seasons, then the resulting abundance T_X for season X is:

$$T_X^t = S_X^t + \frac{(100-5)}{(M^b \times N)}\,, \qquad (6)$$

where 100 refers to 100% of PD, 5 is the level at which the abundance starts, thus 100-5 gives the difference between the starting and end points. For example, if there were four seasons, and if the specialist said that the abundance would take two years to return to PD from 5% of PD, the equation would be:

$$T_X^t = S_X^t + \frac{(100-5)}{(2\times4)} = S_X^t + (11.9)\,,$$

i.e. 11.875 will be added to the result obtained from equation 2, 3 or 4, thus causing the abundance to more quickly return to median. If the number of years were given as 15, the amount subtracted would be 1.583.

B.10.3. Minimum percentage of PD

Certain indicators might never fall to zero, and so the specialist can specify a minimum percentage abundance, U% of PD. The calculation checks if the abundance returned from equation 6 is less than this number and if so, the abundance is adjusted to be equal to U.

B.10.4. *Maximum percentage of PD*

Certain indicators will never increase in abundance above a certain point. For example, it is highly unlikely that large mammals such as rhinoceros will increase to 1000% of PD values (unless the time period is very long, and the starting value of PD is very low compared to possible natural levels). The user can specify an upper limit to abundance of Z% of PD. The calculation checks if the abundance returned from equation 6 is greater than this number and if it is, the abundance is adjusted to be equal to Z.

B.10.5. *Persistence – percentage increase from very low if conditions return to average*

When a population drops to very low levels, it might recover to a higher level if conditions (i.e. the input indicators) return to at least median conditions. The user specifies the abundance to which the abundance will return, as V% of PD. The calculation checks if the abundance has dropped below V, and whether input indicator levels are at least at PD levels, and if so abundance is adjusted to be equal to V.

B.10.6. *Density dependence and logistic population growth*

In many populations, the population growth rate may depend on the population size, such that when the population is low, the growth rate is high and when the population is high, growth rate is low or even negative. This concept was included in the calculations through the two modifiers referred to as the “upper limit modifier” and the “lower limit modifier”.

The upper and lower limit modifiers are based on the logistic population growth function. In its continuous form, the logistic growth function is (e.g. Gotelli 2008; Hastings 1997):

$$N^t = \frac{K}{1+(\frac{K-N^0}{N^0})e^{-rt}} ,$$

where r is the growth factor and K is the carrying capacity.

In discrete form, where populations can be calculated at each time step, this equation equates to:

$$N^t = N^{t-1} + r_D \times N^{t-1} \times (1 - {N^{t-1}}/{K}) , \quad 7$$

where r_D is now a discrete growth factor.

B.10.6.1 Carrying capacity parameter K and growth parameter r

In the DSS, in general, we have no means of knowing the true carrying capacity parameter K, and so an adjustment was made to the modelling of density dependence by making it relative to PD. Thus, if a population is less than PD, the population growth rate is higher than if there were no density dependence, and if the population is greater than PD, the growth rate is lower.

In the DSS version of the logistic model there are two (discrete) growth parameters, one functioning as the lower limit modifier and one as the upper limit modifier. These are provided by the specialist, and termed $\widehat{r_L}$ and $\widehat{r_U}$ respectively, and are rates between 0 and 1. Where values are close to zero, there is lower density dependence, and closer to 1 there is a higher density dependence.

B.10.6.2 Density dependent population growth in the DSS

Adjustments for density dependence will be applied to the season chosen by the specialist (as representing the growth season). The calculation applied, with adjustments made to make population growth rate relative to PD rather than K and using the growth factors as supplied by the specialist, using $\hat{r}_L$ when the population is less than PD and $\hat{r}_U$ when the population is greater than PD:

$$N_1^t = T_1^t + \widehat{r}_{L \text{ or } U} \times \ T_1^t \ \ \times (1 - \left({T_1^t}/{100} \right)) \ \ , \tag{8}$$

where 100 refers to 100% of PD, which is used in lieu of carrying capacity K.

For example, where the calculations up to equation 6 have resulted in an abundance of 130% of PD, and the upper limit modifier has been given by the specialist as 0.5, the resulting abundance will be:

$$N_1^t = 130 + 0.5 \times \ 130 \ \ \times (1 - (130/100)) \ ,$$

$$N_1^t = 130 + (-19.5) \ \ ,$$

This results in an abundance of 110.5 rather than the 130 that would have resulted without any density dependence.

Note that the final season's result now becomes the value for the end of the year, i.e. N_4^t is the overall result for the end of year abundance.

B.10.7. Lag effect

The lag effect modifier is intended to allow for the previous years' results to affect the overall result for the year in question. The specialist provides Q, the number of years of lag. When calculated, more recent years have a larger effect on the outcome than years that are further removed. Once Q has been provided, the weights f^t to be applied to each year are calculated as:

$$f^t = t / \sum_{t=1}^{Q} t + 1 \tag{9}$$

For example, if Q=4, then $\sum_{t=1}^{Q} t + 1$ = 1+2+3+4+5 = 15, therefore:

f^1 = 1 / 15 = 0.067

f^2= 2 / 15 = 0.133

f^3= 3/ 15 = 0.200

f^4= 4/ 15 = 0.267

f^5= 5/ 15, = 0.333

where t = 1 is the earliest year included in the lag period, and t=5 is the current year

Applying this within equation 8, the resulting abundance in year 5 is therefore:

$$\widehat{N}_4^t = f^1 N_4^1 + f^2 N_4^2 + f^3 N_4^3 + f^4 N_4^4 + f^5 N_4^5 ,$$

$$\widehat{N}_4^t = 0.067 \times N_4^1 + 0.133 \times N_4^2 + 0.2 \times N_4^3 + 0.267 \times N_4^4 + 0.33 \times N_4^5 ,$$

B.10.8. List of modifier parameters provided by the specialist for each indicator

In summary, the following modifiers may be used for each indicator:

1. Y degree of dependence on previous year, given as % dependence.
2. M^a tendency toward median from greater than PD, given as number of years to return to 100% of PD from 200% if conditions are at least PD.
3. M^b tendency toward median from less than PD, given as number of years to return to 100% of PD from 5% if conditions are at least PD.
4. U minimum percentage that the abundance can fall to, given as % of PD.
5. Z maximum percentage that the abundance can rise to, given as % of PD.
6. V persistence – where the population will recover to from near extinction, if conditions are at least PD, given as % of PD.
7. $\widehat{r_L}$ lower limit modifier – density dependence, given as a factor from 0 to 1.
8. $\widehat{r_U}$ upper limit modifier – density dependence, given as a factor from 0 to 1.

B.10.9. Other parameters

1. T whether increase in abundance is a move away from or towards natural (for calculating Integrity), see Section B.13.1;
2. PES the present ecological status (health or integrity) of the particular specialist area, see Section B.13. PES is used to adjust the Integrity scores to Integrity relative to natural, see Section B.13.1.
3. w_i weights applied to indicators within a discipline when combining to find overall Integrity (e.g. fish indicators combined to find overall fish condition, socio-economic indicators combined to find overall social well-being), see Section B.13.1.
4. c_i weights of indicators contributing to a composite indicator (socio-economics only) (Section B.11).

B.10.10. Weights

There are a number of calculations within the DSS, which use weights, or have the possibility to use weights. These are discussed below.

Note:	The Severity ratings used in response curves are, by definition, a weighted representation of the size of a response. Using the example in Appendix Box 1: Dry season duration will have a larger impact on abundance than Dry season onset as the Severity ratings range from -2 to 0.5 as opposed to -1 to 0.5. It is thus imperative that the specialists adjust their ratings to reflect relative influences. Consequently, responses to individual inputs are not weighted when calculating the overall response.

Weights are used when calculating:

1. the overall abundance, concentration, income, etc. of composite indicators (socio-economics indicators only);
2. the Overall Integrity of a discipline; and
3. the Overall Ecological Integrity of a site.

B.11. Socio-economics: composite indicators

In the case of socio-economics, it is likely that there will be composite indicators (C) that comprise an aggregation of several driving indicators. For example, “household income from fish”, “household income from irrigation farming”, and “household income from livestock” might all contribute to a composite indicator called “household income”. Weights are relevant here because each may contribute differently to overall household income, and so the contributions of the various sources of income need to be weighted. In this case the C_X (composite indicator value for season X), is the <u>weighted</u> sum of each contributing indicator’s seasonal (% of PD) value (from equation 3):

$C_X = \sum_{i=1}^{n} c^i \, S_X^i$, where:

10

- C_X is the overall value (as % of PD) of composite indicator C in season X,
- S_X^i is the contribution (% of PD) of contributor i in season X.
- c_i is the weight applied to contributor i,
- and there are n contributors.

Thereafter, the composite indicator C is treated in the same way as the individual indicators S.

B.12. Calibration of linked responses

Once all response curves have been entered, the responses are calibrated to:

- Present day: the overall average abundance over the time-series should be about 100% of PD (±5%). Specialists can check whether decreases and increases in the abundance time-series relate to years in the hydrological record which are drier or wetter than usual, as appropriate. If there are data available for particular years (e.g. fish surveys, socio-economic surveys), these can also be checked against the values in the time-series.

- Test scenarios: these are often useful to allow specialists to calibrate their response curves for extreme minimum and maximum values (see Section B.8). They usually take the form of a sequence of 40 dry years or one of 40 wet years, and permutations thereof, such as 20 wet years followed by 20 dry years, or 20 dry years followed by 20 wet years.

Note. Responses for any one indicator can only be calibrated once initial response curves have been created for all links as any changes will have a ripple effect through the Response Curve modules. Calibration begins with assessing the time series of PD abundances for any obvious anomalous trends and cross-checking with available data. The aim of calibration is to ensure the PD time series fluctuates around the PD (100%) abundance line. The process of calibration and adjustment should be methodical, iterative and with the manipulations recorded:

1. start with the habitat and biota module at the 'end' of the chain of calculation (e.g. fish) and work back to that at the beginning (e.g. geomorphology);
2. look first for obvious errors in the overall response time-series for each indicator (in fish), such as the overall PD response being too high (average over the time period being >110%), or fish populations decreasing in years where they were expected to increase;
3. where problems are apparent, switch input-indicators on and off to see which one(s) cause the behaviour noted;
4. once the problematic linked indicator is identified, check the response curve to see that it is correct (in direction and magnitude);
5. if the response curve is correct, then track back to the linked indicator in question (e.g. in a discipline earlier in the chain of calculations), and go through the same process as outlined in (2) to (3); and
6. repeat (2) to (4) for all the indicators.

B.13. Integrity

B.13.1. Calculating the Ecological Integrity for a discipline

Ecological Integrity is a measure of 'health' or 'ecological status' of the river ecosystem. The Integrity of the discipline (e.g. Fish), is an aggregation of the Integrity of each of the identified indicators within that discipline (e.g. FishSpeciesA, FishSpeciesB, FishSpeciesC). The various indicators (fish species) might be more or less important in terms of their contribution to the overall Integrity (of Fish). Thus, in calculating discipline Integrity, weights can be used.

Firstly, the Integrity I of the individual indicators within a discipline area must be determined. To do this, the average abundance over all seasons in the time-series is found (e.g. if there are 4 seasons and 20 years, the average is taken of 80 values). The average is then translated back from a % of PD abundance into a Severity score: this is the inverse of the conversion from Severity to abundance (Figure 2.2). The Severity score is then multiplied by +1 or -1 (T) depending on whether an increase in the indicator is an improvement in condition or not, respectively. Then the individual indicator Integrities can be aggregated using a weighted sum to find Overall Integrity, OI:

$$OI_D = \sum_{i=1}^{n} w^i \, I^i \text{ , where:} \qquad (11)$$

I is the Integrity of individual indicator i,
W_i is the importance of indictor i,
OI_D is the overall integrity of discipline D,
and there are n indicators contributing to the integrity of discipline D.

Note: When calculating Overall integrity for socio-economics (overall Social well-being or Societal well-being), the Integrity from the composite indicators, if any, are used in equation 11 instead of the individual contributors.

B.13.2. Calculating the Ecological Integrity of a site or zone

The condition of various habitats and biota contribute to the general ecological condition of a zone or site in an EFA, but different habitats or groups of animals may be more or less important in determining the condition, and therefore may need to be weighted.

B.13.3. Adjusting Integrity for PES and relative to natural

The integrity scores need to be adjusted in order to be able to compare discipline with discipline and site with site on the same scale. In order to get the adjusted Integrity score, three steps are undertaken:

Step 1. <u>Unadjusted score:</u>

The DRIFT ecological Integrity scores are on a scale from -5 to +5, with <u>0 being the score associated with baseline condition (here assumed to be PD)</u>. Positive scores resulting from a scenario mean that the site/ zone has moved towards natural and negative scores mean that the site/ zone has moved further away from natural. In DRIFT, the Integrity score is the same value (size) as the Severity rating, but the sign might be different. For example, a Severity rating of -2 might indicate a 30 to 40% loss of abundance. If this is a loss in abundance of an alien species it would indicate an improvement in Integrity, therefore the Integrity score would be +2. In the original DRIFT method, a single (Severity or Integrity) value applied to each site, however the DRIFT-DSS produces a time-series of Severity ratings, which are averaged over the period (including all seasons, not just the end of year value) to derive the Integrity score. For example, for a time series of 5 seasons, with Severity scores of -3, +1, -2, -1, +2, the average <u>Severity score</u> would be -0.6. The sign for Integrity, given by the specialist, indicates whether the predicted change was a move towards (+) or away from (-) the natural condition. If a decrease (e.g. -0.6) in abundance is a move towards the natural condition for the indicator then the change in integrity would be positive. In the above example, the Integrity score would be +0.6.

Step 2. Adjustment to adjust present day Integrity to zero:

Given that the Integrity score for a scenario is the average of a time-series of data, the Integrity for present day is unlikely to be exactly 0. An adjustment is therefore done for each discipline/site, by adding or subtracting the amount by which the present day Integrity score differs from 0 to each scenario (making present day exactly 0).

Step 3. Score adjusted to relative to natural:

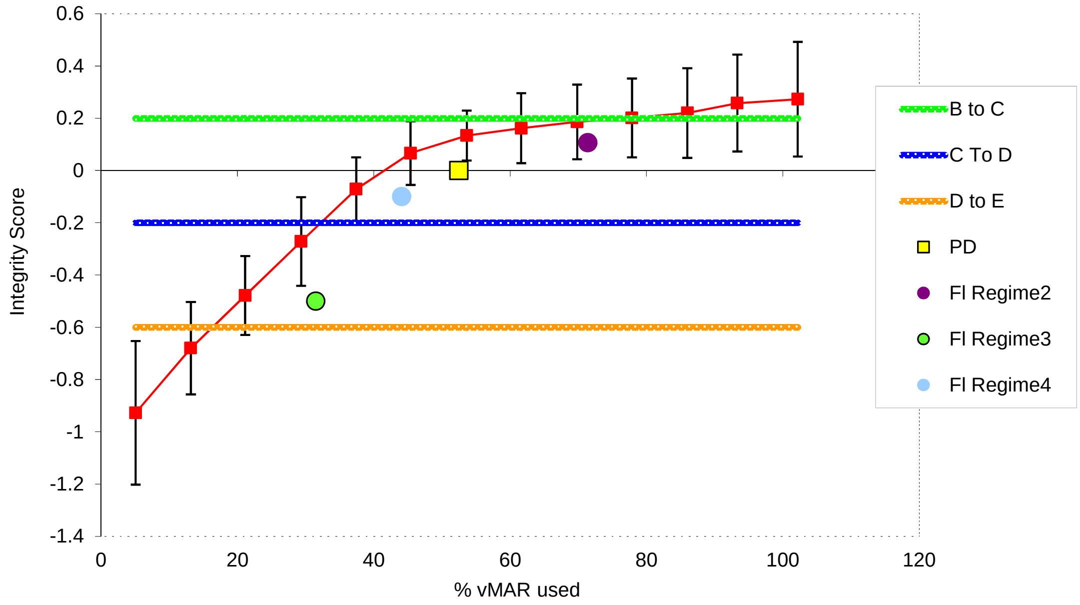
In order to adjust the score from Step 2 so that a 0 score refers to natural rather than present day, the following rules are applied:
If the reach is in an A or A/B category, do not adjust the Integrity score.
If the reach is in a B category, subtract 0.5 from the score.
If the reach is in a C category, subtract 1 from the score.
If the reach is in a D category, subtract 2 from the score.
If the reach is in a E category, subtract 3 from the score.

The resulting scores therefore reflect the integrity relative to natural, and can be compared across disciplines and sites.

B.14. Ecosystem target flow regimes (integrity linked flows)

Generally, in a flow assessment study, several scenarios are created to represent specific options (e.g. degree of development, amount of abstraction, size of a dam, dam operation). These scenarios may also include meeting a specific environmental goal, such as maintaining the river in a particular state of ecological health. A ‘recommended’ flow regime for meeting a specific environmental goal can be determined using the DSS.

Before the development of a time-series approach, this was done using an optimisation procedure that allowed for the design of flow regimes to minimise the impact on the health of the river ecosystem, while meeting certain constraints such as the volume of water used (Brown and Joubert 2003). This was called “DRIFT Solver” and generated the DRIFT-CATEGORY plot that showed the overall integrity scores of optimised flow regimes versus the mean annual runoff (MAR) used (red line in Appendix Figure 24).



Appendix Figure 24 The "DRIFT-CATEGORY" plot created in the old version of DRIFT.

The Category plot also shows the uncertainty associated with the integrity scores (error bars on the red line). Scenarios with less than optimal distribution of flow plotted below the optimised regimes, showing where similar scores could be achieved with small changes in the volume used, but differently allocated. For example, "Fl Regime4" in Appendix Figure 24 has a slightly worse score than the "PD" (present day), but only uses 44% of MAR as opposed to the 52% that PD uses. Thus, scenarios could be adjusted to be closer to the optimised (red) line while meeting a particular environmental target such as maintaining the river in a particular Category.

Optimisation was achieved by trading off Integrity scores against the volume of water needed to provide different parts of the flow regime.

However, this approach did not work when using time-series, because:

- optimisation needs to be done across seasons within each year, and potentially even across years, requiring a powerful optimiser. The MSExcel inbuilt optimiser (Solver) is not powerful enough, and even the commercial optimiser (What'sBest! ®) struggled to deal with such a large optimisation;
- the optimisation requires a trade-off between volume and integrity score, but with the new approach not all flow indicators are linked to volume (e.g. many are linked to the timing); and
- the resulting optimised flow regime would be difficult to operationalise at such a fine level of detail.

Thus, a new approach was needed in order to design flow regimes to meet specific environmental (or other) goals.

The approach adopted was to create a large number of 'synthetic' scenarios representing a wide range of possible volumetric and temporal changes, so that a scenario that delivered river conditions close to the target condition could be found. Two types of scenarios are created:

Intermediate scenarios — a range of flow scenarios that are between the scenario that alters the flow regime the most (the 'Max' scenario) and the reference scenario. The reference scenario is usually present day (PD), but if restoration scenarios are also under consideration, it may be the naturalised flow regime (the 'Min' scenario)[11] (the examples in Sections B.14.1 to B.14.3 use PD);

Mixed scenarios — mixtures between pairs of intermediate scenarios, where, for example below a certain exceedance, the flows from one of the intermediate scenarios are used, while above that value those from another are used.

The steps to create the scenarios are described in the next two sections, followed by a description of how the newly created scenarios are assessed to find the one which is closest to the target condition.

B.14.1. Creating intermediate scenarios

1. Collate existing scenarios' daily discharge time series and choose 'Max' and 'Min' scenarios.
2. Find the difference between Max and Min scenarios for each time step (*Diff*).
3. Choose the desired number of intermediate scenarios between Max and Min (i.e. the number of increments).

   The number of scenarios chosen will depend on the extent of the difference between Max and Min, the refinement required or desired, and the time or budget constraints of a particular project. For simplicity in the examples shown here, five intermediate scenarios were created: i.e. five new flow regimes were created between Max and Min. This also determines the number of mixed scenarios created (see Section B.14.2). If five intermediate scenarios are created then the total number of new (intermediate and mixed) scenarios will be 17 since the mixed scenarios are permutations of the intermediate scenarios. The intermediate scenarios created are labelled Scenario 1 to Scenario 5.
4. Create new flow regimes for each increment (Appendix Figure 25)

   Divide the difference between Max and Min (*Diff*) by the number of increments (+1) to find the amount to add for each successive increment (*IncAdd*).

   For the first increment up from the Max scenario, for each time step (e.g. daily), add *IncAdd*:

   $Dnew^{t}_{1} = Dmax^{t} + IncAdd$

   $Dnew^{t+1}_{1} = Dmax^{t+1} + IncAdd$, etc.

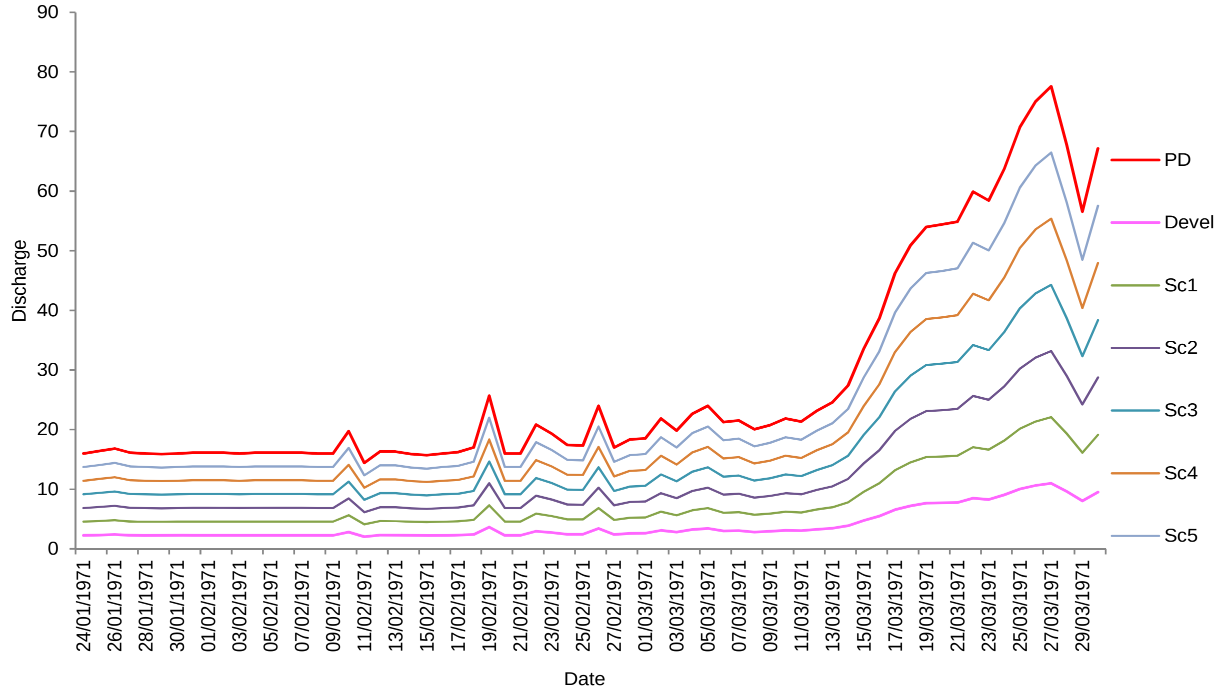
[11] The terms 'Max' and 'Min' are used in the interim, but will be changed once more suitable names have been decided on.

For the next intermediate scenario add (*IncAdd* x 2) at each time step:

$Dnew^{t}_{2} = Dmax^{t} + (IncAdd \times 2)$

$Dnew^{t+1}_{1} = Dmax^{t+1} + (IncAdd \times 2)$, etc.

where *Dnew1* is the first new intermediate scenario's daily discharge values, *Dnew2* is the next intermediate scenario's daily discharge values, etc., and *Dmax* is the Max scenario's daily discharge values.

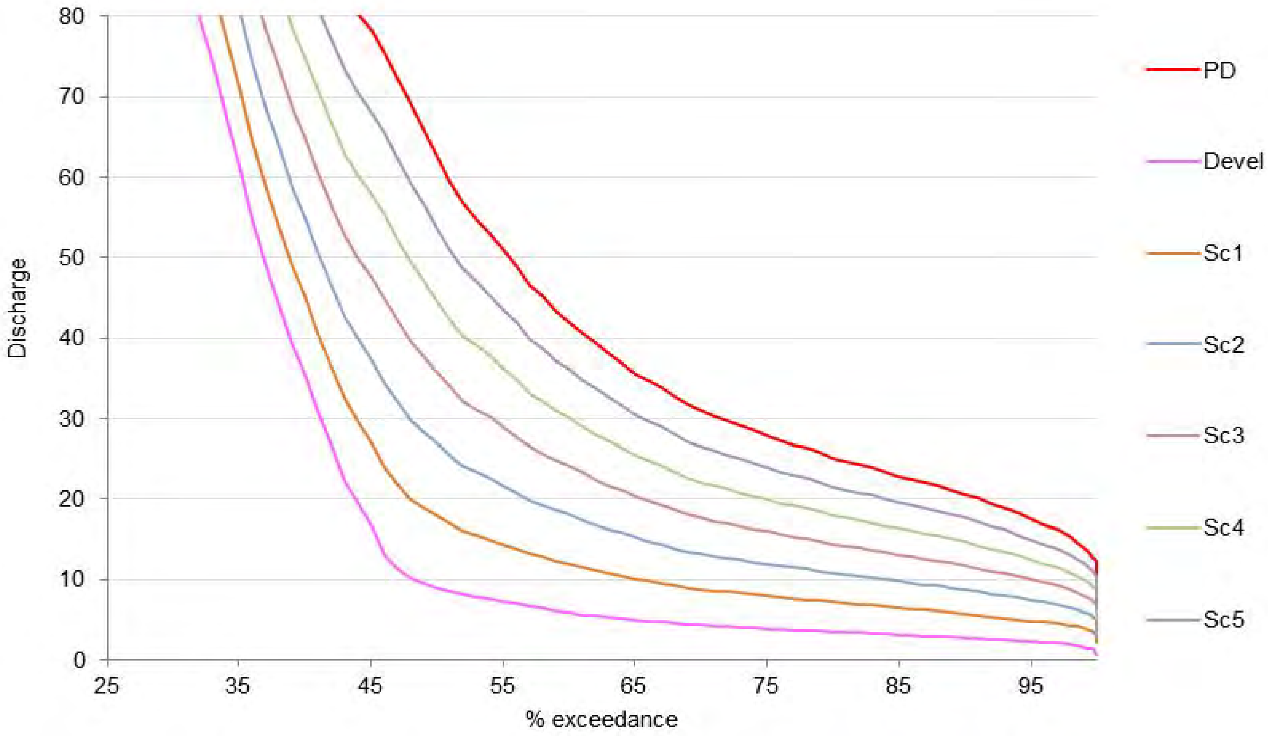


Appendix Figure 25 **A portion of the daily discharge time series for the Min scenario (PD), the Max scenario (Devel), and the intermediate scenarios created between them.**

5. Create FDCs for each new flow regime (Appendix Figure 26)

   FDCs are created in the normal manner. For their creation in the Excel version of the DSS, the function percentile.inc[12] was used and 109 exceedance percentages were used, allowing for finer increments at the higher exceedance / lower flow levels.

[12] The function Percentile.inc is the Office 2007 and 2010 version of Percentile and is reported to be more accurate.



Appendix Figure 26 **A portion of the flow duration curves for the Min scenario (PD), the Max scenario (Devel), and the intermediate scenarios created between them.**

B.14.2. Creating mixed scenarios

Mixed scenarios are created from combinations of pairs of the other scenarios, i.e. Min, Max and the intermediate scenarios created in Section B.14.1.

1. Choose an 'exceedance percentage' (or percentages) based on the shape of the flow duration curve, or some other criterion.

   For example, in the flow duration curves shown in Appendix Figure 26, there is a change in slope somewhere between exceedance 45 and 55, so one might choose an exceedance percentage of, say, 50%. In the test data used in the examples here, for example, the discharge associated with an exceedance percentage of 50%, for the Max scenario in the test data is 8.975.

   The discharge value (DE) corresponding to the exceedance percentage defines a break point above which values for the time series are from one of the scenarios and below which they are from another scenario. Thus, higher flows might be from intermediate Scenario 1, and the lower flows might be from intermediate Scenario 2.

   There are two types of mixed scenarios: (a) those with high flows from a scenario (e.g. Scenario 1) and lower flows from the next increment up (i.e. Scenario 2), and (b) those with the higher flows from a scenario (e.g. Scenario 2) and the lower flows the next increment down (e.g. Scenario 1).
2. Create mixed scenarios of Type (a) (Appendix Figure 27).

Run through the time series for the first scenario in the set of scenarios (i.e. Max). Check at each time step, whether the discharge value is greater or less than the value of *DE* for that scenario (i.e. 8.975 in this case).

If the discharge is greater than *DE*, then use the discharge from the current scenario (Max), else use the discharge from the corresponding time series step, from the next scenario up (Scenario 1). This scenario is called Maxw1lo.

Repeat for the next scenario in the set of scenario, i.e. Scenario 1. In this case the associated *DE* is 16.924, and the scenario which will provide the lower values is Scenario 2. This scenario is labelled 1w2lo.

Continue until the scenario being assessed is the last of the intermediate scenarios, and the next scenario up is therefore Min (called 5wMinlo).

i.e. for each time step, the first mixed scenario of type (a) is created by:

If $Dmax^t$ is >= DE then $DMixa^t_1$ is $Dmax^t$ else $DMixa^t_1$ is $Dnew^t_1$

and for each time step, the second mixed scenario is created by:

If $Dnew^t_1$ is >= DE then $DMixa^t_1$ is $Dnew^t_1$ else $DMixa^t_1$ is $Dnew^t_2$

3. Create mixed scenarios of Type (b) (Appendix Figure 27).

   Run through the time series for the second scenario in the set of scenarios (i.e. Scenario 1). Check at each time step, whether the discharge value is greater or less than the value of *DE* for that scenario (i.e. 16.924 in this case).

   If the discharge is greater than *DE*, then use the discharge from the current scenario (Scenario 1), else use the discharge from the corresponding time series step, from the next scenario down (Max). This scenario is called 1wMaxlo.

   Repeat for the next scenario in the set of scenario, i.e. Scenario 2. This scenario is called 2w1o.

   Continue until the scenario being assessed is the last of the set of scenarios, i.e. Min and the next scenario down is therefore Scenario 5 (called Minw5lo).

   i.e. For each time step, the first mixed scenario of type (b) is created by:

   If $Dnew^t_1$ is >= DE then $DMixb^t_1$ is $Dnew^t_1$ else $DMixb^t_1$ is $Dmax^t$;

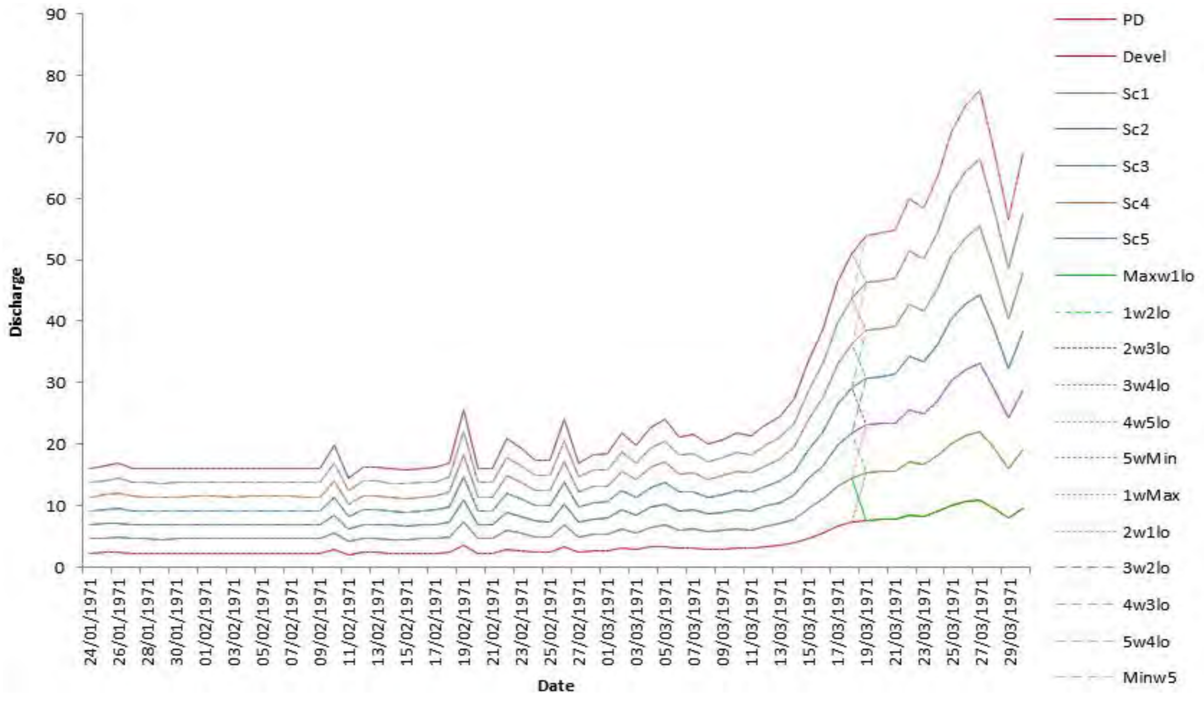
   The second mixed scenario is created by:

   If $Dnew^t_2$ is >= DE then $DMixb^t_2$ is $Dnew^t_2$ else $DMixb^t_2$ is $Dnew^t_1$

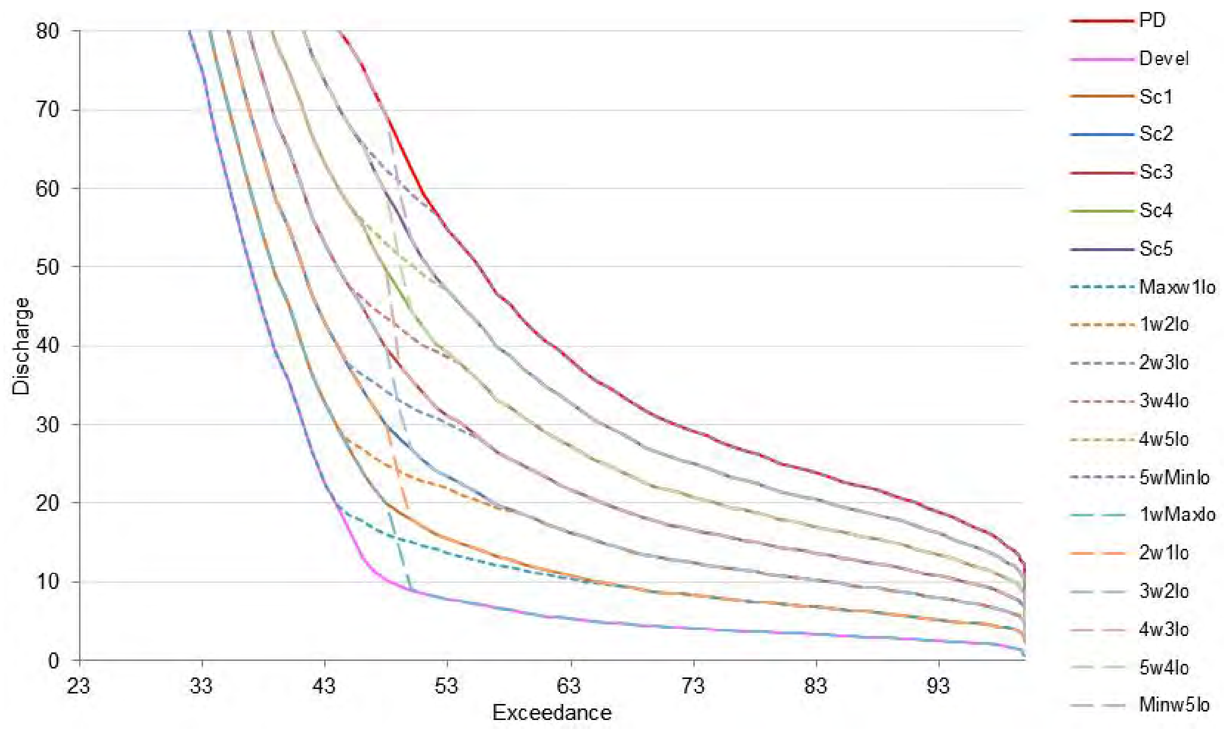
4. Create FDCs for each new flow regime (Appendix Figure 28).

   FDCs are created in the normal manner. For their creation in the Excel version of the DSS, the function percentile.inc[13] was used and 109 exceedance percentages were used, allowing for finer increments at the higher exceedance / lower flow levels.

[13] Percentile.inc is the Office 2007 and 2010 version of Percentile and reportedly more accurate.



Appendix Figure 27 **A portion of the time series of daily discharge for the Min, Max intermediate and mixed scenarios.**



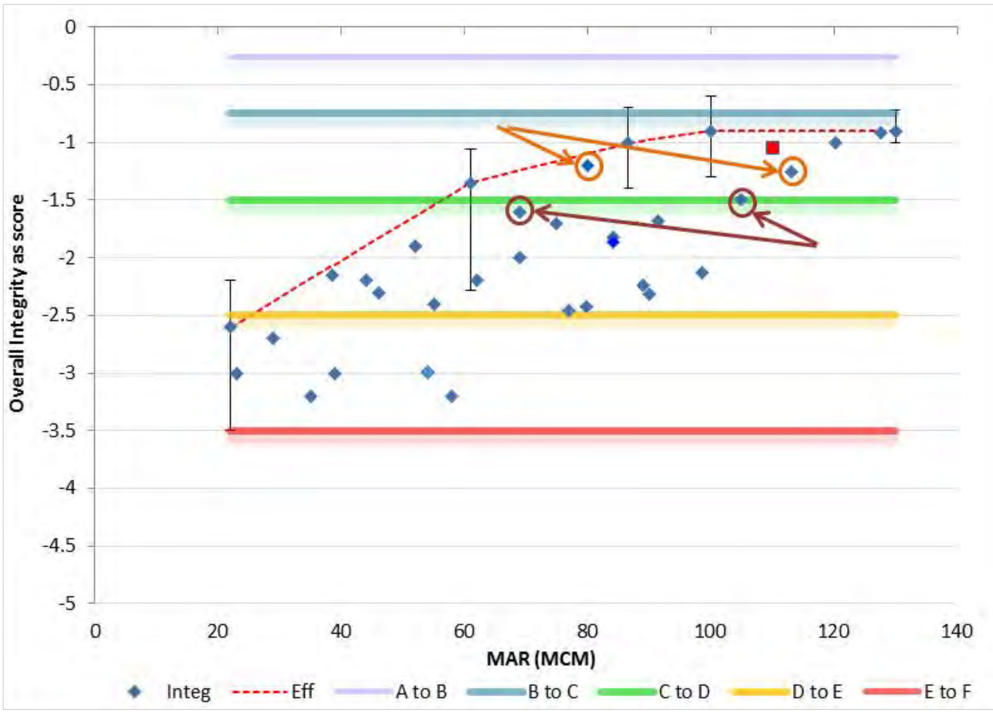
Appendix Figure 28 **A portion of flow duration curves for the Min, Max, intermediate and mixed scenarios.**

B.14.3. Further processing of all new scenarios

Processing at this stage is common to all the synthetic scenarios. The daily flow regimes created need to be analysed to calculate the relevant flow indicators being used in the flow assessment (e.g. onsets and durations of the seasons). This analysis is done in the Flow Indicators module within HYDROLOGY.

The biophysical and socio-economic responses are then evaluated by running the synthetic scenarios through the model. The resulting Integrity scores for each scenario are calculated. A scatterplot is then created showing all the synthetic scenarios' Integrity scores versus the % MAR that they use (or absolute MAR), creating the equivalent of the old DRIFT-CATEGORY plot shown in Appendix Figure 24 (called Category plot). All the synthetic scenarios now sit below the 'efficient frontier' enveloping the points of the scatterplot (Appendix Figure 29). In the same way as previously, the other water-resource development scenarios can also be plotted on this graph.

The results can then be assessed to identify the particular scenario that is closest to the environmental target. For example, the target might be a scenario with an overall Integrity rating is 0.5 less than the PD scenario. In Appendix Figure 29, the two scenarios circled in brown would qualify. The one closest to the efficient frontier could be the one chosen (i.e. correct Integrity score, least MAR required). The two orange circled scenarios, closer to PD, could be candidates for an even lower level of degradation, and again the one closest to the efficient frontier would be the appropriate one to choose.

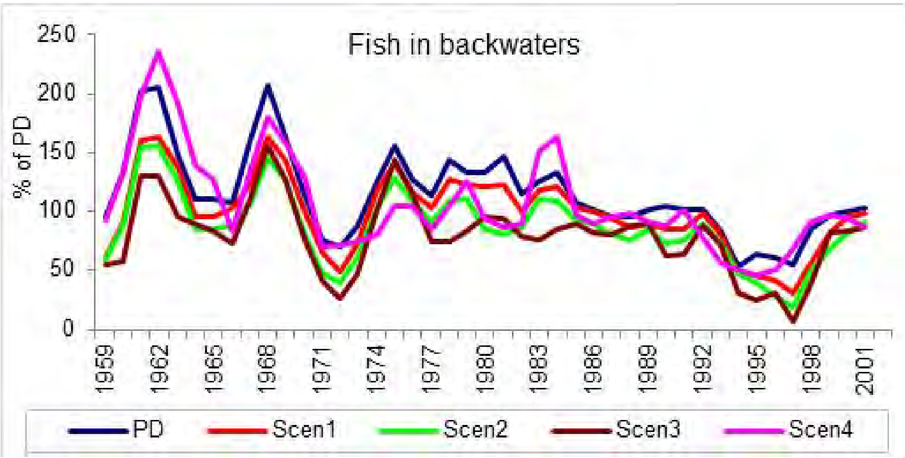


Appendix Figure 29 **Category plot: Integrity of synthetic flow regimes vs. MAR, and ecosystem condition Categories. The present day scenario is shown as the red square. The efficient frontier (red dotted line) reveals? where the highest Integrity score /lowest MAR combination is found.**

B.15. Maps and graphs

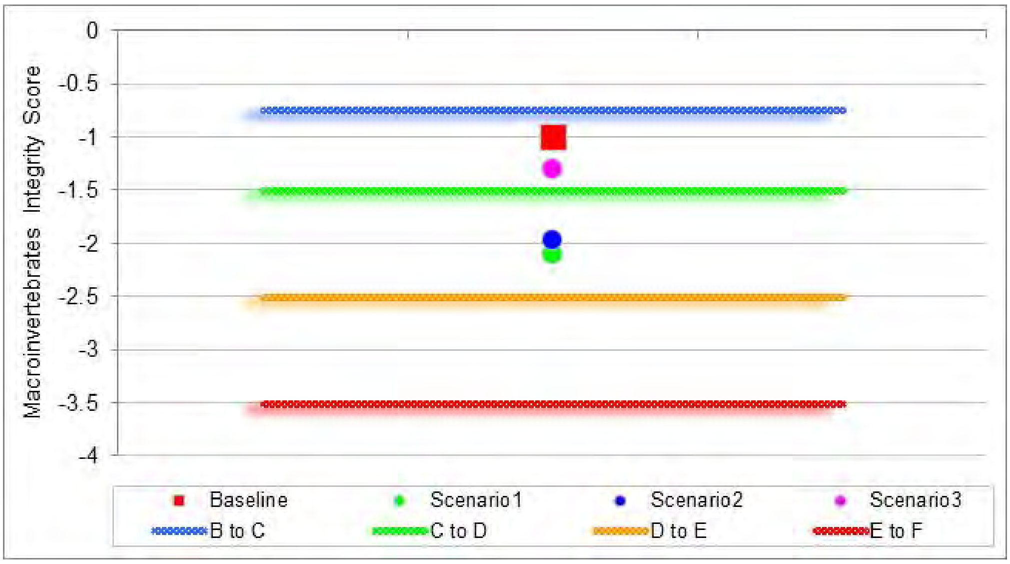
The following are essential visual aids provided in the DSS:

- Response Curves (Appendix Figure 21);
- seasonal and annual time-series graphs on the response curve entry pages (Appendix Figure 23), which show a particular scenario;
- annual time-series graphs showing all the scenarios together for each indicator (Appendix Figure 30);

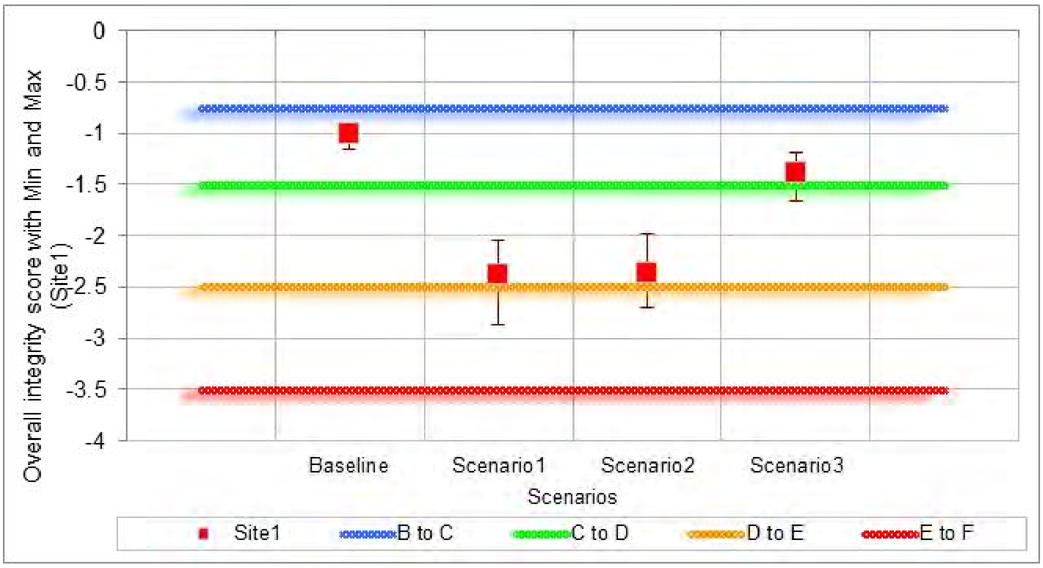


Appendix Figure 30 An example of the summary time-series (end-of-year values) graph for the present day and four scenarios (example for Fish in backwaters).

- ecological Integrity for a discipline for all scenarios at a particular site (Appendix Figure 31);
- Overall Ecological Integrity for a site (Appendix Figure 32);



Appendix Figure 31 An example of an integrity plot for Macroinvertebrates at a particular site.



Appendix Figure 32 **An example of a site-level Integrity plot, with error bars on the Integrity scores.**

- Integrity vs. MAR for synthetic flow regimes when finding the Ecosystem Target scenario (Appendix Figure 29); and
- maps with the biotic and socio-economics zones coloured to indicate integrity / well-being for different scenarios at the indicator or discipline level (Appendix Figure 33).

Appendix Figure 33 **Site and Zone Integrity for an indicator (Fish Species 3) for all scenarios (left), and for a discipline (right).**

B.16. References

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Appendix C. DRIFT-DSS USER MANUAL

Note: The DSS is a beta version. While every effort has been made to ensure that it works correctly, and provides accurate results, Southern Waters Ecological Research and Consulting and the Water Research Commission do not accept any responsibility for any errors it may contain. Similarly, adjustments to existing routines and the addition of new ones are not reflected in the User Manual.

C.1. Introduction

The User Manual describes how to use the DRIFT Decision Support System (DSS) to do an Environmental Flow Assessment (EFA) for a single or for multiple sites (basin-wide).

All hydrological modelling is done outside of the DSS. The DSS is dependent on the outputs of a hydrological model to provide naturalised and present day basin hydrology, and a water-resource model to predict the changes in the flow regime associated with the existing and proposed water-resource developments under the various scenarios.

NOTE: The DRIFT process is described in the Final Report. Technical details are given in Appendix B. Other useful references include, for example, Brown et al. (2008) and King and Brown (2010).

C.2. Layout of the DSS and the User Manual

The DRIFT-DSS has three main sections that align with stages in the DRIFT process described in the Final Report, namely: **SETUP**, **KNOWLEDGE CAPTURE** and **ANALYSIS**. The first two deal with the population of the DSS and the calibration of the relationships that will be used to predict the ecosystem and socio-economic response to changes in flows. The third is used to generate results once the first two have been populated, and to produce the reports and graphics detailing the predictions for the scenarios under consideration.

Before describing the modules themselves, general instructions on conventions used in this manual and on navigation in the DSS are provided in Section C.3. Each module is described, with examples, where relevant.

C.3. General Instructions

C.3.1. Main user interface

The main user interface or opening screen of the DSS is in two parts (Appendix Figure 34):

- the left-hand (or navigation) panel, which shows the **SETUP**, **KNOWLEDGE CAPTURE** and **ANALYSIS** sections. The first (**SETUP**) opens automatically on startup, and the other two appear at the bottom of the navigation panel;

- the main panel, which initially shows the basic system information for the most recently opened project (or may be blank if no project has been loaded).

Clicking on one of the sections will open it up, and display its sub-sections. The sub-sections group modules relating to specific stages of the DRIFT process. For example, clicking on **ANALYSIS** displays: "Integrity linked flows" and "Scenario outcomes".

Appendix Figure 34 **The main user interface, with the navigation panel showing the sections (Setup, Knowledge Capture and Analysis), with Setup open. The main panel shows the project information on startup.**

C.3.2. File structure and installation

The entire DRIFT folder is copied to the hard drive of the user's computer. The most straightforward option is to copy directly into the C:\ drive of the computer into a folder called DRIFT (i.e. the path will be C:\DRIFT). The DRIFT folder contains two sub-folders: C:\DRIFT\Bin and C:\DRIFT\Data.

The C:\DRIFT\Bin\ folder contains two essential files: the executable file Drift2.exe and Drift2.ini. A shortcut to the executable can be pinned to the taskbar.

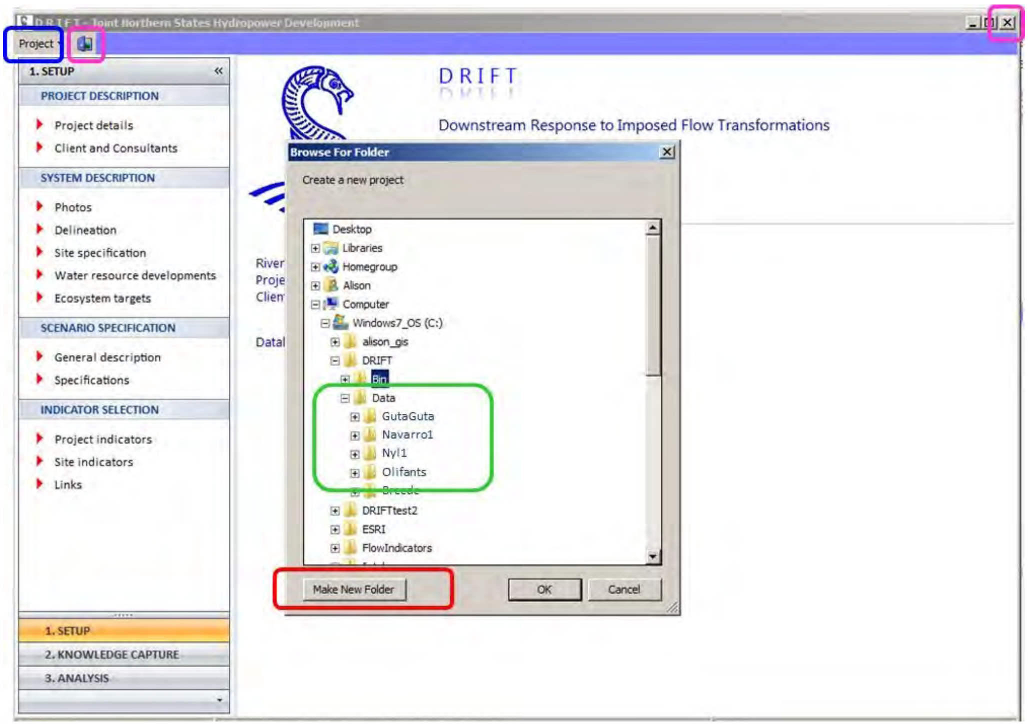
For each new project the DSS creates a unique project folder in C:\DRIFT\Data\. For example, for a project on the Breede River the user might name C:\DRIFT\Data\Breede\. (see the next Section for creating new projects or changing projects).

C.3.3. Starting a new project or opening an existing project

To create a new project: click on <Project><Create a new project> (blue circle, Appendix Figure 35), which will open the browse window shown in Appendix Figure 35. Click on the …\DRIFT\Data subfolder and then click <Make new folder> (red circle, Appendix Figure 35) and type in an appropriate folder name for the new project. Alternatively, select the relevant sub-folder for an existing project (green circle, Appendix Figure 35).

NOTE: When starting a new project or switching from one project to another, it is advisable to select the project (<Project><Select project> or <Create a new project>) and then immediately EXIT the program (click either of the pink encircled icons in Appendix Figure 35). Then re-open the program before continuing. This ensures that all references to the previously opened project are cleared from the DSS.

In addition the user must change the Pan and Zoom parameters in the .ini file in the ...\DRIFT\Bin folder, to ensure that the program goes to the correct location. It is therefore useful to store these parameters in a .txt file in the bin folder, named appropriately for each project. This will be automated at a later stage.



Appendix Figure 35 **The main user interface, creating a new project or opening an existing project.**

When starting a new project, the DSS automatically creates and locates relevant files in locations within the …\DRIFT\Data\ sub-folders. The subfolders within the ..\Data folder, are:

- DB (for DataBase)

- FloodEvents
- FlowIndicators
- Hydrology
- IntegrityFlows
- Map
- Photos
- Testing.

The DSS manages the files and their names, apart from the input hydrology files (which are placed by the user in the folder: …\Data\project_name\Hydrology, see Section C.5.1) and the photographs (which are placed by the user in the folder: …\Data\project_name\Photos). User information can also be entered into the …\Data\project_name\Map folder, but is not referenced by the DSS. The user should familiarise themselves with the location of the different kinds of files. In particular, all information related to sites, indicators, links, response curves, etc. is located in the …\Data\project_name\DB folder.

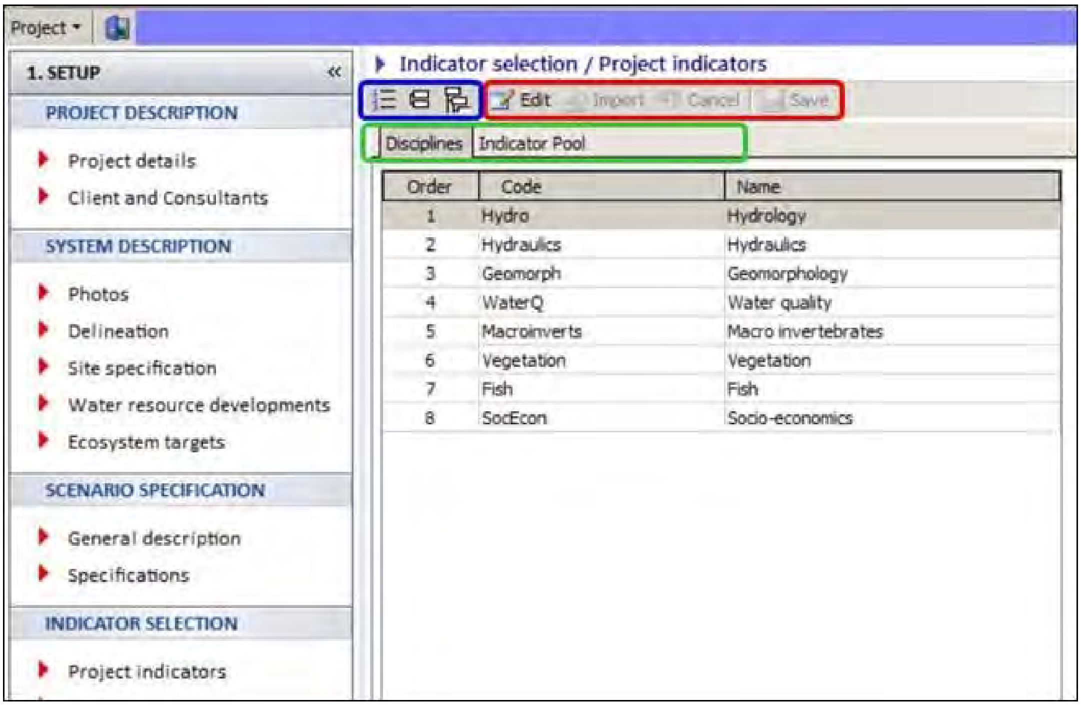
If a particular project is set up on one computer, it can be copied to another computer (provided DRIFT has been installed), by copying the …\Data\project_name sub-folder (e.g. ... \Data\Breede) to the other computer. Subsequently, changes in indicators, links, response curves, and other DSS parameters, can be copied from one computer to another by just copying the relevant ..\Data\project_name**DB**\sub-folder. Where relevant, this can also be done with single files. For instance, Links.nx1 if only a link has been changed.

C.3.4. Conventions used in the descriptions of the DSS

- **SETUP**, **KNOWLEDGE CAPTURE** and **ANALYSIS** refer to the three sections of the DSS.
- Sub-sections within each are designated, e.g. [***Connectivity***], [***Response curves***] within **KNOWLEDGE CAPTURE**.
- Modules within module groups are designated, for example, [*Habitat and biota*], [*Socio-economics*] within the module group [***Response curves***].
- Menu items may appear in the menu-toolbar at the top of the main panel are designated as «*Import*», «*Edit*», and «*Save*» (e.g. Appendix Figure 36, red circle). To the left of these menu items are tools for organising and rearranging the data displayed (e.g. Appendix Figure 36, blue circle);
- Names of tabs that appear in the main panel, depending on the module, are designated as <*Disciplines*> and <*Indicator Pool*> (e.g. Appendix Figure 36, green circle).
- Column headers of columns that appear in a particular tab, are designated as {*Order*}, {*Code*}, {*Name*} (e.g. Appendix Figure 36).
- Folders are designated as <DRIFT> and path names as ...\DRIFT\Data\Breede\.

C.3.5. Displaying and arranging information and menus

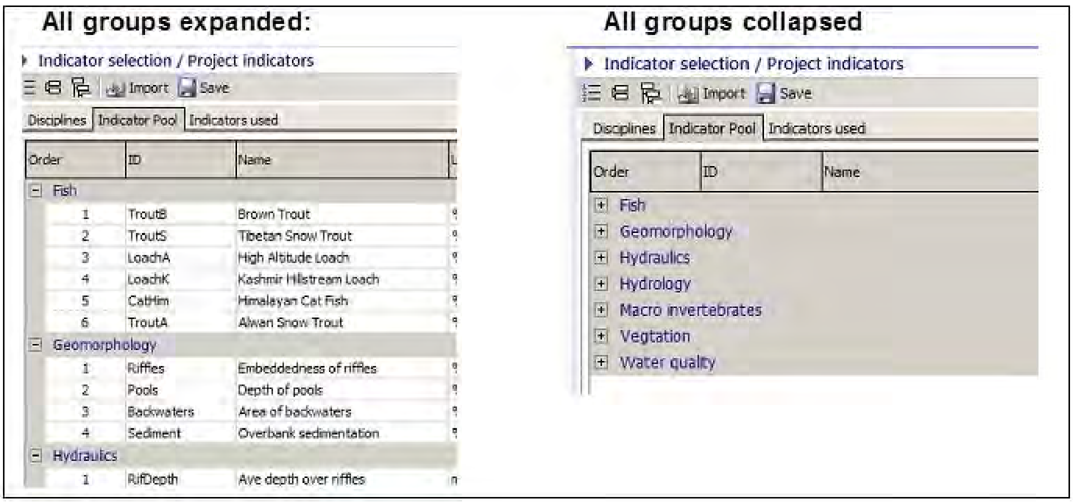
Depending on which menu-item and/or tab is active in the main panel, the toolbar at the top of the main panel will include some or all of the tools shown in the blue circle in Appendix Figure 36 (i.e. Import Save). These can be used for grouping or arranging the data displayed in the main panel, for entering «Edit» mode, to «Import» or «Save», etc.



Appendix Figure 36 **Example of the layout of the DSS displaying the Setup section; Indicator Selection group, Project indicators module. Red circle = menu items, blue circle = tools for arranging information in the tabs, green circle = tabs.**

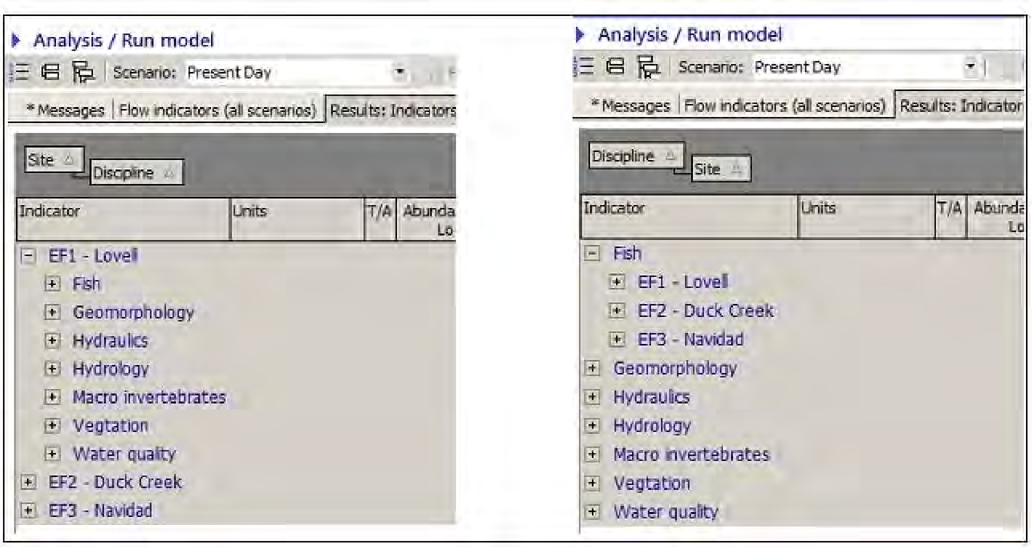
The tools for rearranging information work as follows:

7. Groups can all be "collapsed" using or expanded using . For example, indicators are displayed according to discipline, but this can be collapsed to show only disciplines, as illustrated in Appendix Figure 37.



Appendix Figure 37 **Collapsed and expanded groups.**

8. Columns can be sorted alphabetically by clicking in a particular column header.
9. Information can be grouped in different ways, by firstly pressing , which opens up the "group by" space, and then dragging different column headers into the space to get the desired combination and hierarchy of groupings, e.g. indicators grouped by site and then discipline, or by discipline and then site (as shown in Appendix Figure 38). Groups can be individually expanded using the +sign to the left of each group, or collapsed using the – sign to the left (if expanded).



Appendix Figure 38 Rearranging the groups and hierarchies displayed.

10. If more space is needed in the main panel, the navigation (left) panel can be hidden by pressing the symbol shown in the red circle in Appendix Figure 39.

Appendix Figure 39 Displaying and hiding the navigation panel.

11. The lists of module groups under each Section in the navigation panel can be folded away by clicking on the main Section headings.

C.3.6. *Importing data: Format and naming of imported files*

There are a number of modules that can or must import data from external files. The files need to be formatted and named appropriately before importing so that they can be read by the DSS.

Most of these files are text-comma delimited files (which can be created in Excel by “saving as” a .csv file). Depending on the data contained in the file, the extension then needs to be changed from .csv to an extension that matches the data type required by the DSS. The required extensions are as follows:

For hydrology (daily) time-series:	.day
For hydrology (sub-daily) time-series:	.vts
For water quality (daily or sub-daily) time-series:	.wq
For sediment (daily or sub-daily) time-series:	.sd
For hydraulic parameters:	.tab

All the import files must be named according to the conventions expected by the DSS. The name is a combination of the DSS’s abbreviation for the site name and DSS’s abbreviation for the scenario name. For example, when creating the sites in the DSS, the “long name” for a site might be “EF1 Rito” (as it is near a town called Rito) and the site code might be “RIT”. Any imported files, e.g. hydrology files, relating to this site must have the preface “RIT”. The second part of the name for files relating to scenarios, e.g. for hydrology, must identify the scenario, using the code entered by the user in Setup/Scenario information/General description (see C.4.3.1). For example, the present day scenario, might be given the scenario code “PD”, and a scenario with the most developments (abstractions, dams, etc.) out of the scenarios being examined might have the scenario code “Max”. The site and scenario codes are combined when naming a file: e.g. a daily present day scenario time series for Site 1, would be named: RIT-PD.day (*the hyphen is mandatory*).

In general, imported data needs to be in a text-comma delimited file named:
SITE-SCENARIO.extension, where

- the SITE is the site <u>code</u> given by the user in the DSS;
- the SCENARIO is the scenario code given by the user in the DSS; and
- .extension matches the appropriate extensions given above.

All files should contain two header rows, followed by columns of comma delimited information. The contents of the two header rows differ slightly depending on the type of file, while the contents of the first (date) column differ slightly depending on the time-step of the data concerned.

For **files containing flow data**, the header rows are:

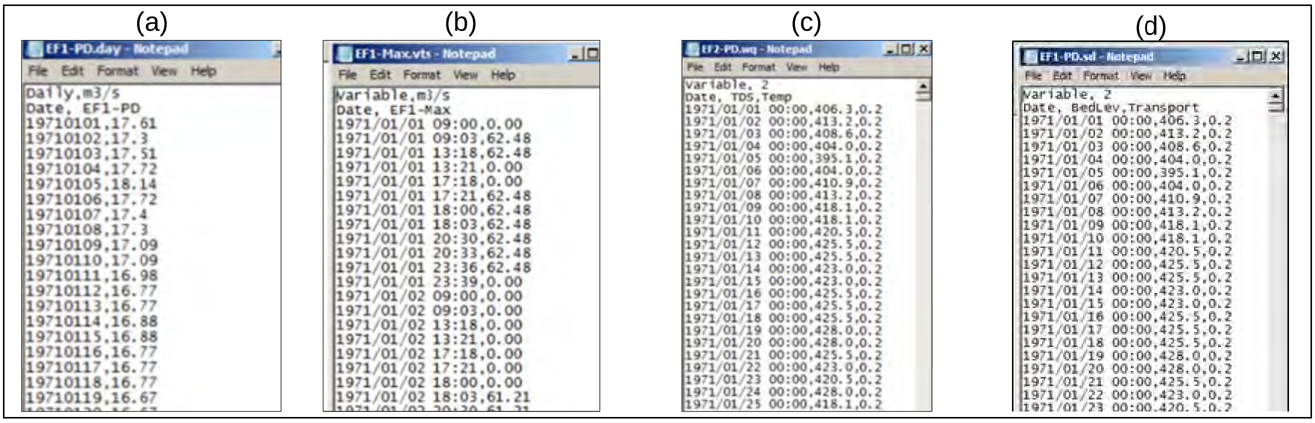
- <u>First part, first row</u>: Either “Daily” or “Variable” (which applies to anything which is not “Daily” even if regular (e.g. hourly data),
- <u>Second part, first row</u>: the units, viz: “m3/s”

- First part, second row: "Date" which says that the first column contains the dates
- Second part, second row: The Site-Scenario code, e.g. "RIT-PD".
- Thus, together Daily,m3/s
  Date, RIT-PD
- OR Variable,m3/s
  Date, RIT-PD

For **files containing other data** (e.g. water quality or sediment sampling data for calculation of water quality and sediment indicators (see Sections C.5.2 and C.5.3), the header rows are:

- First part, first row: Either "Daily" or "Variable" (which applies to anything which is not "Daily" even if regular (e.g. hourly data) – for water quality or sediment sampling data this will usually be "Variable",
- Second part, first row: the number of variables (columns of data other than the date) contained, e.g. "2"
- First part, second row: "Date" which says that the first column contains the dates
- Other part(s), second row: The names of the variables contained e.g. "BedLevel, Transport" when importing those sediment variables.
- Thus together Variable, 2
  Date, BedLevel,Transport

The data that follow the two header rows are comma delimited columns of data with the first column containing the date (Appendix Figure 40). For daily time-step data the date is in the format "yyyymmdd", while for other data / time-steps the format is "yyyy/mm/dd hh:mm".



Appendix Figure 40 **Formats for importing data. (a) Daily flow data, for EF1, PD scenario, (b) Sub-daily (variable) flow data for EF1, Max scenario, (c) Water quality data for three variables at EF2, variable time step, (d) Sediment data for two variables at EF1, variable time step.**

NOTE: When saving or creating files in Excel, be aware that Excel tends to format dates in one of the Excel data / time formats, which are not readable by the DSS (after saving as .csv and changing the file extension). The user should re-enter the dates by formatting the column as "general" and then pasting the dates copied back into the date column as values only.

C.4. Setup

All relevant project information is entered in **SETUP**. The following information is mandatory:

- name of the project and the study rivers;
- the physical layout of the river system (delineation, sites, etc.);
- the position and type of existing and planned water-resource use or infrastructure that will be included in scenarios;
- the indicators that will be used for evaluating the different scenarios;
- the links between indicators.

SETUP comprises of four module groups, [***Project description***], [***System description***], [***Scenario specification***], and [***Indicator selection***], each of which are explained below.

C.4.1. Project description

General information about the project is entered in the [***Project description***] group of modules. Once entered, some of the information will appear on the main panel of DSS (Appendix Figure 34).

The modules are [*Project details*] and [*Clients and consultants*]. The information entered in [***Project description***] is not mandatory.

General information regarding the project is entered in [*Project details*]. This information includes the name of the project, the location, the river names, etc. The entered information is then reflected on the main panel of the DSS and other sections. The client(s) and consultants can be entered in [*Clients and consultants*].

NOTE: Remember to «*Save*» before exiting.

C.4.2. System description

The [***System description***] group of modules is used to capture information relating to the spatial layout of the project and the indicators to be used for scenario evaluation. Much of the information is mandatory.

While [***Project description***] provides the context for the project, the information entered in [***System description***] helps to prepare the DSS for the particular project, by laying out the river network (sites, zones, arcs), describing the scenarios, and selecting the indicators that will be used in the assessment of scenarios.

The information entered in [***System description***] is mandatory, apart from the photographs and ecosystem targets (which are only required for some projects).

The modules are [*Photos*], [*Delineation*], [*Site specification*], [*Water-resource developments*] and [*Ecosystem targets*].

NOTE: The DSS links to a Google component that displays the locations of the study and sites, etc., once these have been entered. If there is no internet link available, click on <*Show map*> to disable the maps (Appendix Figure 44).

Most of the [***System description***] modules require spatial referencing, which needs to be prepared outside of the DSS.

When a new project is created, in order for the map components to “Pan” to the correct location and to “Zoom” by the desired amount, the user must open the .ini file in the \Bin folder in Notepad, and enter the latitude, longitude and zoom parameters.

NOTE: Remember to «*Save*» before exiting.

C.4.2.1 Photos

Photographs of the sites or relevant aspects of the system (e.g. villages, maps) with .jpg extensions can be placed in the sub-folder: ..\DRIFT\Data\Project_name\Photos. These then appear in the photos tab and can be located on the map by entering their coordinates.

C.4.2.2 Delineation and Site specification

Nodes, Arcs, Zones, Sites and Paths are defined in these two modules. Delineation is undertaken first, followed by site selection.

The specification of the physical system determines the kinds of links that can be made between indicators (i.e. which sites’ indicators may influence others: specified in [*Links*] module in [***Indicator selection***]), and allows assessment of connectivity issues between sites (factors affecting connectivity are recorded in [*Specifications*] module in [***Scenario specification***]).

The relationships between Sites, Nodes, Arcs, and biophysical and social Zones are illustrated in Appendix Figure 41:

Sites: All the information in the DSS is linked to and reported in relation to a Sites, each of which represents a Zone. Typically these are locations where biophysical sampling has been done, or for which biophysical information is available.

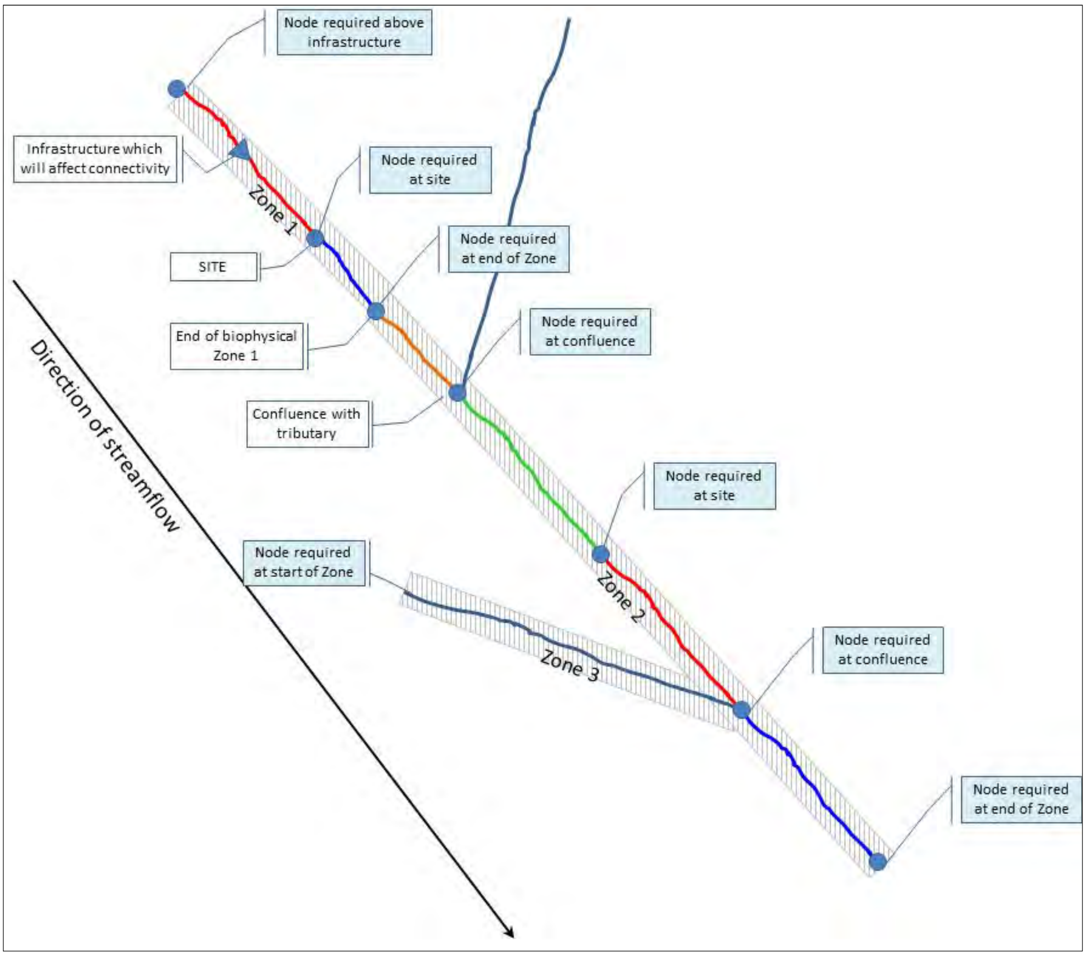
Nodes: Nodes are defined at (Appendix Figure 41):

- sites;
- where zones begin and end (usually between sites);
- tributary confluences; and
- upstream of impoundments or other infrastructure where these are upstream of the study reach if these impact on connectivity.

Sites must correspond to a particular node, but not all nodes will have a site associated with them (there may be more nodes than sites).

Arcs: Arcs are segments of river that join nodes.

Zones: One or more Arcs combine to form a Zone. Socio-economic zones can be represented by different combination of arcs from those forming biophysical zones (e.g. there could be fewer socio-economics zones or more than one site within a social zone: however, the user must specify at which site results will be viewed. It is preferable for each Zone to have a single representative site, and for social and biophysical zones to be harmonised to produce coincident zones).



Appendix Figure 41 **Layout of a hypothetical river with three biophysical zones and two tributaries: Seven nodes were required to define this system. The rectangle indicating each zone has no meaning.**

C.4.2.2.1 Delineation

Within [*Delineation*], the “Nodes” and “Arcs” are defined first, followed by the zones (which are combinations of arcs). Sites are selected in [*Site Selection*] once these tasks have been completed. Nodes and Arcs form the basis of the physical layout of the system within the DSS. Once defined, the relationships between nodes, arcs, sites and zones can be defined. The relationships effectively create a map of the river system. The Arcs or Nodes that are relevant (i.e. reflected in later sections of the DSS) in terms of (a) infrastructure and other water-resource development and (b) links between indicators, are determined by this map.

NOTE: When adding Nodes, Arcs or Zones click «*Edit*», then the + sign in  at the bottom of the screen. A row can be removed by clicking the – sign in .

C.4.2.2.2 Nodes

Nodes are entered by typing in the coordinates of the node in the longitude and latitude column of each node row in the <*Nodes*> tab and providing a node ID (Appendix Figure 42 shows the <*Arcs*> tab, which is similar to that for Nodes). It is recommended, that, as far as possible, the node IDs are ordered from upstream to downstream. It is useful to also provide a description for each node, for later reference (e.g. Node for Site1, Node for Confluence, Node for end of study area).

NOTE: Remember to «*Save*» before exiting.

C.4.2.2.3 Arcs

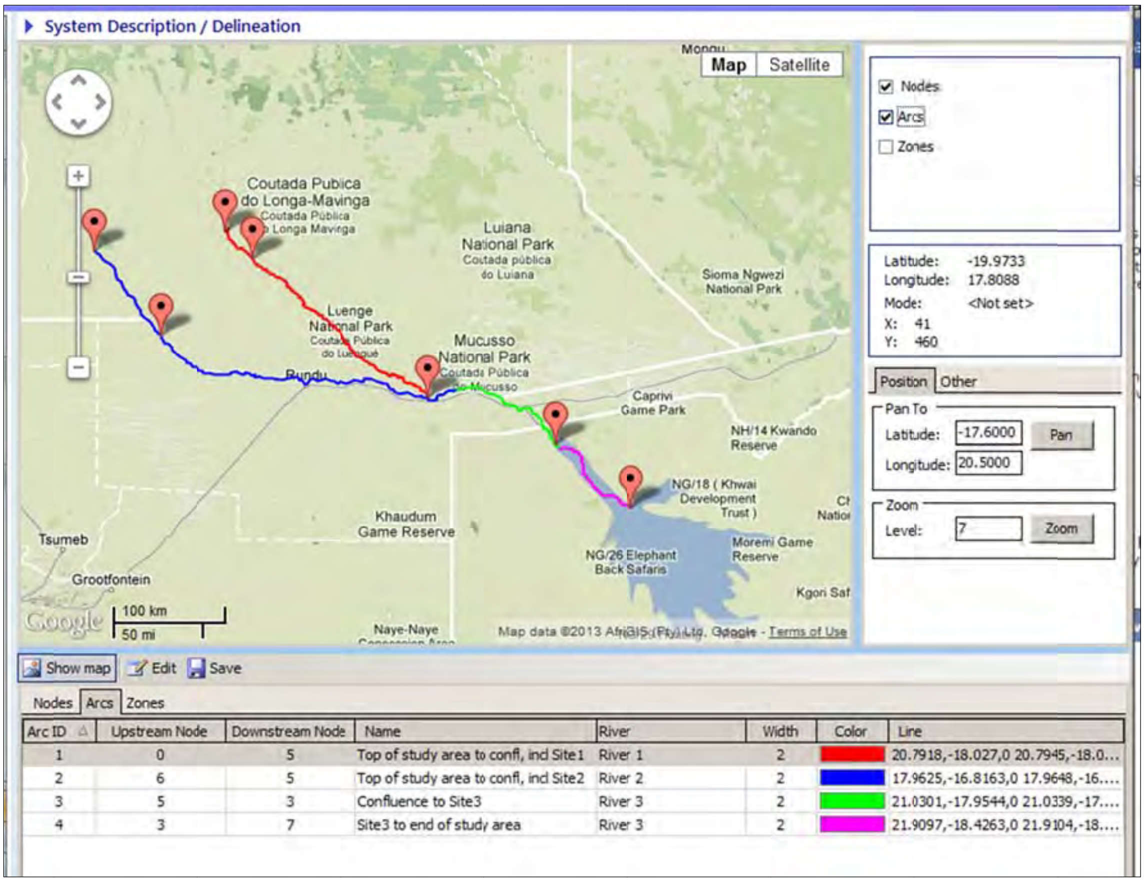
Arcs are entered by choosing the upstream and downstream nodes corresponding to the endpoints of the Arc in the <*Arcs*> tab and providing an Arc ID. As with nodes, it is recommended that the Arc ID’s, as far as possible, are ordered from upstream to downstream. Note that because a site is represented by a node, but a site is *within* a zone rather than at an endpoint, in general, more than one Arc forms a zone.

The string of co-ordinates describing each Arc is entered in the {*Line*} column. Currently, the only way to do this is:

- Display or import an existing .kml or GIS path into Google Earth (remembering this is a path for an Arc – i.e. the river coverage needs to be broken into appropriate reaches);
- Save the path to a .kml (not .kmz) file with an appropriate name (into the …\DRIFT\Data\Map subfolder, for ease of retrieval);
- Open the .kml file in Notepad or other text editor (not Word);
- Select the string of co-ordinates between the .kml markers <coordinates> and </coordinates> (note there may be more than one string of co-ordinates, in which case, they must be sequentially selected and pasted: it is preferable to combine these and ensure they *are* sequential in Google Earth, before importing to DRIFT);
- Paste the selected string into the appropriate Arc row in the {*Line*} column.

In order to view the Arc just entered, you need to choose a colour in column {*Color*} and a line width in [*Width*], and then click on the "Arcs" tick box at the top right of the window (e.g. Appendix Figure 42).

NOTE: If the Arcs are very long, or finely digitised, they may take some time to appear after having clicked the "Arcs" tick box.
Remember to «*Save*» before exiting.



Appendix Figure 42 **Entering "Arcs" in the Delineation window. To see the Arcs entered, choose a colour and width for displaying the line, and tick "Arcs" in the top right of the window.**

C.4.2.2.4 Zones

Zones are defined by listing the Arcs that form them in the <*Zones*> tab. The Arcs are listed as comma-separated numbers, with no spaces. To view the Zones, chose a colour and line width, as described for Arcs, and tick the "Zones" tick box. Deselect Arcs before selecting Zones to view.

NOTE: If the Zones are very long, or finely digitized, they may take some time to appear after having clicked the "Zones" tick box.
Remember to «*Save*» before exiting.

C.4.2.2.5 Site selection

In this module, sites and paths must be entered, each with its own tab. The site representing each Zone must also be added on the Zones tab.

C.4.2.2.6 Sites

Sites (biophysical or social) are entered in this module by typing the site information in the appropriate columns. The key part of this task is to link the site to the correct node (Appendix Figure 43). Sites must be given a full name and a **site code**, for use a reference within the DSS, such as naming relevant data files (see e.g. Section C.3.6). The site code cannot be changed once any other information is linked to a site.

NOTE: When adding Sites, click «*Edit*», then the + sign in  at the bottom of the screen. A row can be removed by clicking the – sign in .

Fields to be entered are:

{*Display*}: this is the order that you want the sites to be displayed in other windows: usually from upstream to downstream starting with site 1.

{*Site code*}: A code used for internal DSS reference to the site, and also used in naming conventions for files which are imported (see Section C.3.6). The Site code must not be changed once any other information linked to sites is entered.

{*Node ID*}: This is the identification number (Node ID) given previously in the Delineation module.

{*Name*}: A short descriptive name should be given: it is useful to include both the site's number and the name of a nearby location (e.g. "Site 1 Rito").

{*Latitude*} and {*Latitude*}: These are automatically filled in when {*Node ID*} is given.

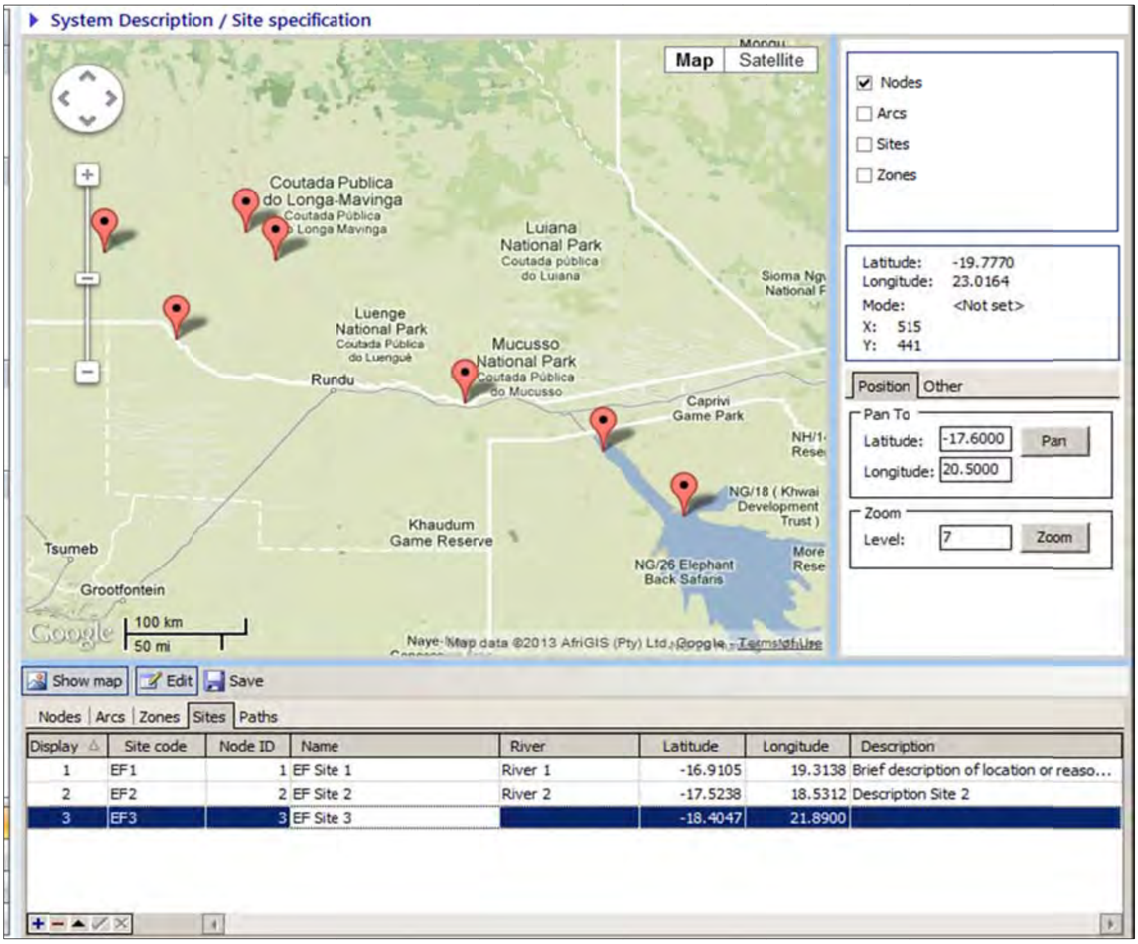
{*Description*}: A short description of the site and / or the reasons for choosing it.

NOTE: Remember to «*Save*» before exiting.

C.4.2.2.7 Paths

Paths are links between sites. These are entered by clicking «*Edit*», then the + sign in  at the bottom of the screen. Then, in the relevant columns, specify the upstream node, downstream Nodes, and the Arcs that represent each Site, separated by commas, with no spaces.

NOTE: Remember to «*Save*» before exiting.



Appendix Figure 43 **<System description><Site selection> window, showing the entering of relevant information for sites, in particular the link to the appropriate node in the Node ID column.**

C.4.2.3 Water-resource developments

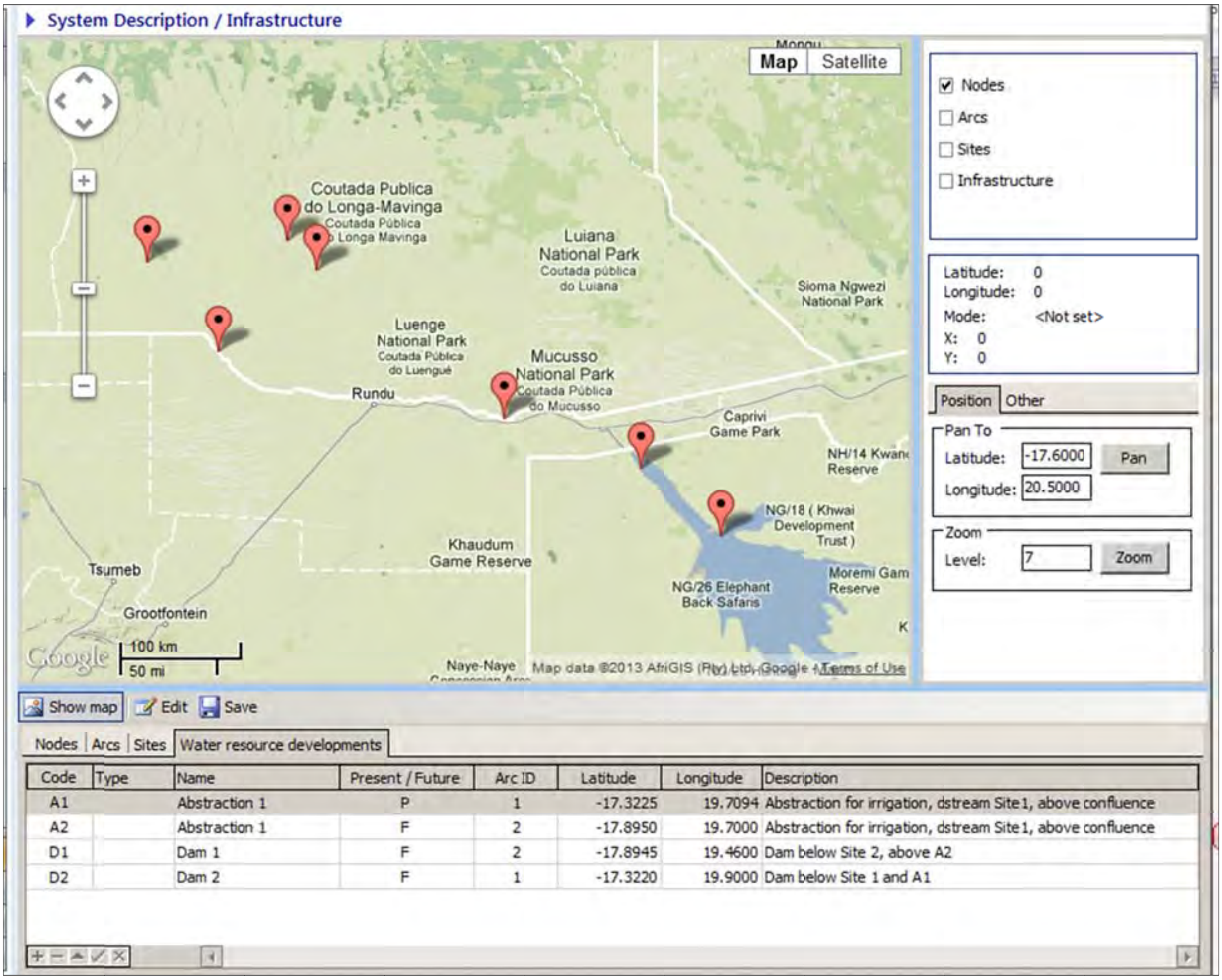
The location of existing or planned infrastructure (such as dams, weirs, hydropower stations or major abstraction points) or other water-resource development options (such as irrigation schemes and associated return flows), etc. that form part of the scenarios, need to be entered into the DSS. Ideally any existing or planned developments that could influence flow, connectivity or water quality should be captured here.

In the DSS, the “water-resource developments” are located on “Arcs”. This is important, as it affects what appears in the [*Specifications*] module where scenarios are defined, and what appears in, and can be dealt with, in the [Connectivity] module.

The user must enter a Code (e.g. A1, D1, R1) and Type (e.g. Abstraction, Dam, Return flow) for each water-resource development, and denote whether it is existing (P for present) or planned (F for future); the Arc on which it is located; the coordinates; and a description in the columns provided. The location of water-resource developments can be viewed by clicking the “Infrastructure” tick-box in the top right of the window.

NOTE: When adding Water-resource developments, click «*Edit*», then the + sign in at the bottom of the screen. A row can be removed by clicking the – sign in .

Remember to «*Save*» before exiting.



Appendix Figure 44 **<System description><Water-resource developments> window, showing where relevant information is entered.**

C.4.2.4 Ecosystem targets

If required, a target ecosystem condition for a particular stretch of river can also be specified (i.e. for a biophysical Site and its representative zone). At this stage, the module does not have any function other than storing this information, as it is not yet linked to the [***Integrity Linked Flows***] group of modules in the **ANALYSIS** section.

C.4.3. Scenario specification

> The [***Scenario specification***] group of modules captures information relating to the scenarios that will be considered in the project. Much of the information is mandatory.

Enter a general description of each scenario in [*General description*]. In [*Specifications*] the existing and planned water-resource developments (infrastructure, outflows, etc.), which are or will be present in scenarios are entered. Only water-resource developments entered in [***System description***], [*Water-resource developments*] will be available for selection for a scenario in [***Scenario specification***][*Specification*s] (see Section C.4.2).

C.4.3.1 General description

Four columns of information are entered, the first three of which are mandatory:

{*Display order*}: the order in which scenarios are displayed in DSS windows, tables, and graphs.

{*Code*}: the code used for each scenario. This code is used internally in the program, as well as for files used for import (e.g. the flow indicators for each scenario-site: see Section C.3.6).

{*Name*}: a short, descriptive name for each scenario.

{*Description*}: a longer description of the details of the scenario.

NOTE: To add Scenarios, click «*Edit*», then the + sign in  at the bottom of the screen. A row can be removed by clicking the – sign in .

It is mandatory to include a scenario (which can be given the display order 0) with the code "Ref" and which has the name "Reference". This scenario is a "placeholder", and is later used in [***Hydrology & Scenarios***] when the user specifies the flow regime to be used for calibration (usually the present day scenario). This becomes the Reference scenario, which is used internally in the DSS.

The Scenario code cannot be changed once any other information linked to scenarios has been entered.

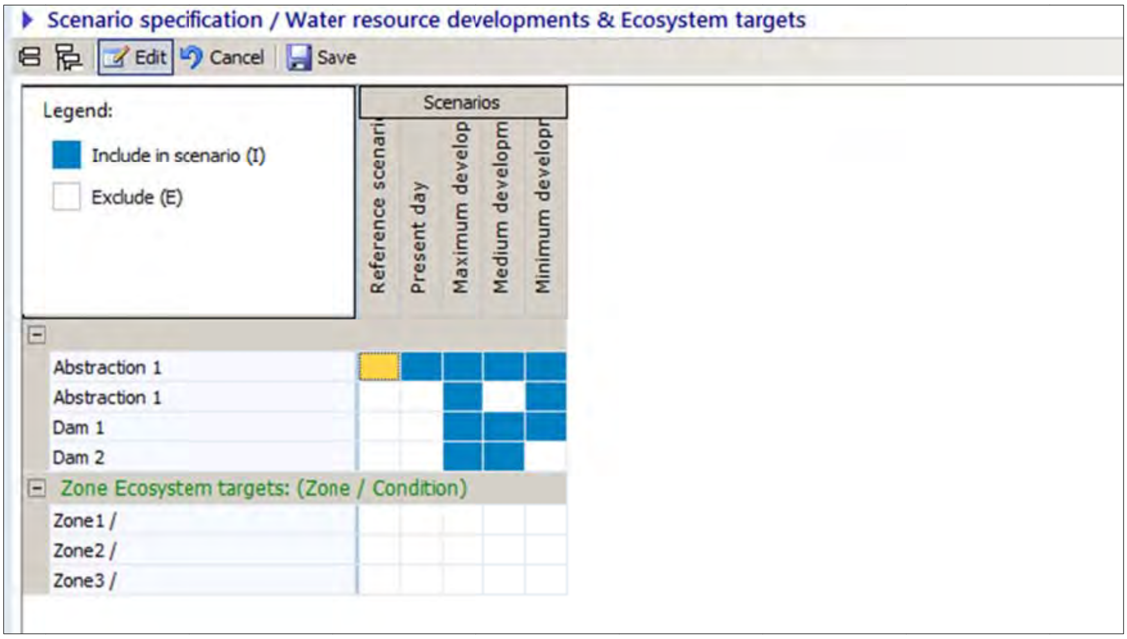
Remember to «*Save*» before exiting.

C.4.3.2 Specifications

Scenarios that comprise various combinations of the existing and planned water-resource developments that were entered into the DSS in [***System description***] and [*Water-resource developments*] are defined in this module.

The entry panel is a matrix of with scenarios across the top, and infrastructure and ecosystem targets down the left. Water-resource developments can be assigned to a scenario by clicking «*Edit*» (Appendix Figure 45) and then typing **I** (for "include") in the relevant matrix cell (or typing **E** to exclude if an error is made).

NOTE: Remember to «*Save*» before exiting.



Appendix Figure 45 **<Scenario specification><Specification> window. Infrastructure and other existing or planned water-resource developments relevant to each scenario are specified. The ecosystem targets are placeholders.**

C.4.4. Indicator selection

The [***Indicator selection***] group of modules captures information relating to the disciplines and indicators relevant to the project. In addition, the links between indicators are specified. Much of the information is mandatory.

There are four modules in this group: [*Project indicators*], [*Site indicators*], [*Composite indicators*] and [*Links*].

C.4.4.1 Project indicators

In this sub-module, all the disciplines and indicators that will be used in the project need to be entered, and the user needs to specify what type of indicator each is.

There are two tabs in the main panel: <*Disciplines*> and <*Indicator Pool*>.

Disciplines and indicators can either be entered manually, or can be imported from an existing Excel file of the appropriate format (see Section C.4.4.1.3).

C.4.4.1.1 Disciplines

Disciplines can be added by first clicking «*Edit*» and then the + sign which appears in the menu bar at the bottom of the screen (). (Disciplines can also be deleted and rearranged using the bar). Disciplines need to be given a Code (an abbreviation used internally in the program) and an Order. The Order needs to reflect the hierarchy in which calculations should proceed, running from the initial drivers of the system (Hydrology should always be 1), to the final responses (e.g. Socio-economics). The only obligatory discipline is Hydrology. The conventional order, depending on which disciplines are relevant, is given in Appendix Table 25.

Disciplines can also be imported as described in Section C.4.4.1.3.

Appendix Table 25 The hierarchy of disciplines that defines the order of the calculations in the DSS.

1.	Hydrology (including hydraulics and sediment if relevant)
2.	Hydraulics (exclude if DSS sediment module is being used)
3.	Sediment (exclude if DSS sediment module is being used)
4.	Geomorphology
5.	Water quality
6.	Periphyton / algae
7.	Macroinvertebrates
8.	Riparian vegetation
9.	Fish
10.	Mammals and birds
11.	Socio-economics

C.4.4.1.2 Indicator pool

Indicators within each discipline can be added or deleted in this tab, using «*Edit*» and the toolbar at the bottom of the page (). As with disciplines, indicators within each discipline require a Code (abbreviation for internal program use) and a calculation order.

In addition, the user must specify what the type of indicator from a drop down list of three options. These are:

- Flow indicators (Flow)
- Ordinary non-flow indicators (Indicator)
- Composite non-flow indicators (Composite)

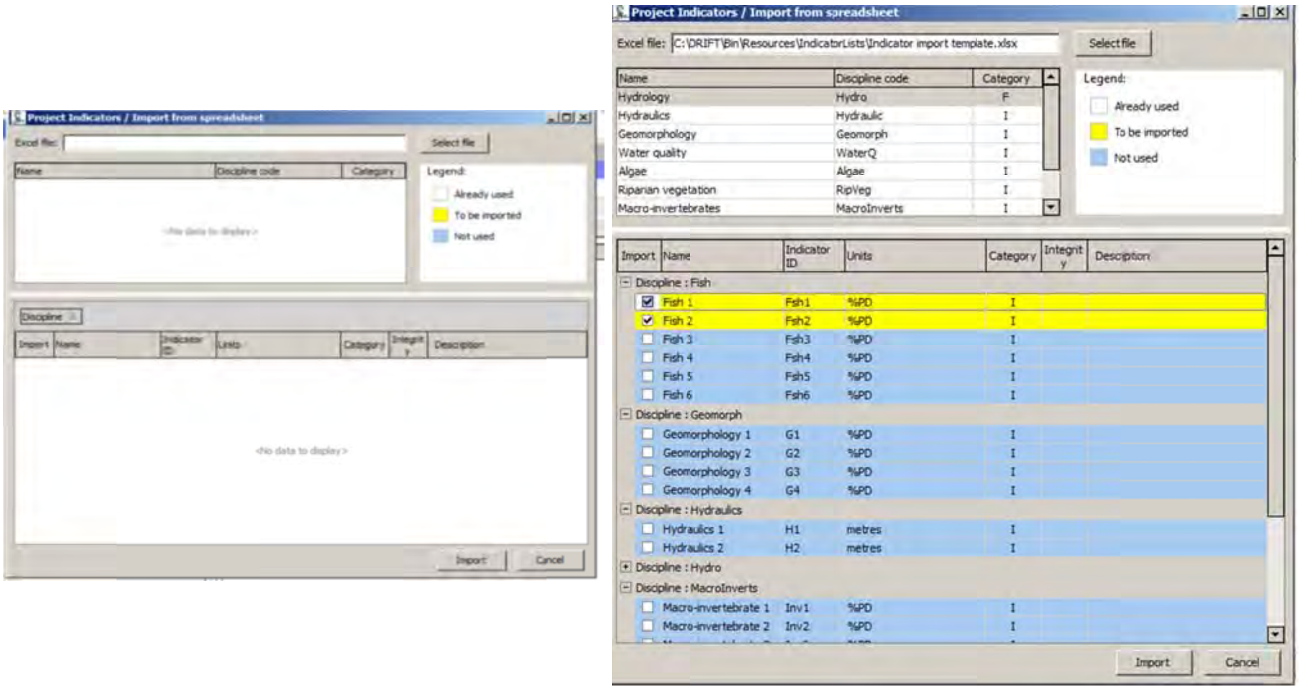
Most non-flow indicators will be ordinary indicators (designated "Indicator"). "Composite" indicators are mainly used for socio-economics (discussed in Section C.4.4.3).

Indicators can also be imported as described in Section C.4.4.1.3.

NOTE: The code **<u>must not</u>** be changed once any other information has been linked to the indicator.
In future versions of the DSS, the flow indicators will not be visible or editable in this module.

C.4.4.1.3 Importing disciplines and/or indicators

Indicators and disciplines can either be entered manually or imported from an appropriately structured Excel file. Click on «*Edit*» and then «*Import*». A screen appears (Appendix Figure 46, left), from which you can browse to find the Excel file containing your indicators. The indicators will appear on a screen (Appendix Figure 46, right), and can be clicked on to select for import (shading them yellow). Indicators that have previously been imported or manually entered (i.e. are already in the DSS database) will be shaded in white, while those not yet selected will be shaded blue. Once all the indicators for import have been selected, click Import.



Appendix Figure 46 Importing indicators from Excel from Project indicators either the Disciplines or Indicator pool tabs: «*Edit*», «*Import*».

The arrangement of the Excel file is given in Appendix Figure 47. There should be two pages, one named [Disciplines] and the other [Indicators]. The discipline page should have columns for (1) abbreviations for the discipline; (2) the discipline name and (3) the type of discipline (used to differentiate between (F) indicators that are imported and summarised, such as flow indicators, (I) indicators that are calculated from response curves; and (C) composite indicators that are a weighted sum of other indicator results. The indicator page have columns for (1) the abbreviated indicator name; (2) the full name; (3) the units in which it is measured; (4) the discipline to which it belongs; and (5) the indicator type (F, I or C).

NOTE: An Excel template is provided in …\DRIFT\Bin\Resources\IndicatorLists\. It is advisable to use this as a basis for page and column names (and locations).

Hydrology **must** be one of the disciplines.

All of the flow indicators currently calculated in the DSS are listed in the template and **must not** be altered. Generally only some will be used as links for other indicators, but the DSS calculated all of them.

The indicators' codes **must not** be changed once any other information has been linked to the indicator.

Remember to «*Save*» before exiting.

Disciplines

DisciplineID	Name	CatID
Hydro	Hydrology	F
Hydraulic	Hydraulics	I
Geomorph	Geomorphology	I
WaterQ	Water quality	I
Algae	Algae	I
RipVeg	Riparian vegetation	I
MacroInverts	Macro-invertebrates	I
Fish	Fish	I
SocEcon	Socio-economics	I

Drift Indicators

IndicatorID	Name	Units	DisciplineID	CatID
MAR	Mean annual runoff	m3/s	Hydro	F
Do	Dry season onset	cal week	Hydro	F
DoR	Dry season relative onset	weeks	Hydro	F
Dd	Dry season duration	days	Hydro	F
Dq	Min 5d dry season Q	m3/s	Hydro	F
Fo	Wet season onset	cal week	Hydro	F
FoR	Wet season relative onset	weeks	Hydro	F
Fq	Max 5d flood season Q	m3/s	Hydro	F
Fv	Flood volume	Mm3	Hydro	F
F_Type	Flood type	Type	Hydro	F
Fd	Wet season duration	days	Hydro	F
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
FqV	Max 5d flood season V	m/s	Hydro	F
FqW	Max 5d flood season WetPerim	m	Hydro	F
FqH	Max 5d flood season Stage	m	Hydro	F
FminQV	Min 5d flood season V	m/s	Hydro	F
FminQW	Min 5d flood season WetPerim	m	Hydro	F
FminQH	Min 5d flood season Stage	m	Hydro	F
H1	Hydraulics 1	metres	Hydraulics	I
H2	Hydraulics 2	metres	Hydraulics	I
WQ1	Water quality 1	%PD	WaterQ	I
WQ2	Water quality 2	%PD	WaterQ	I
G1	Geomorphology 1	%PD	Geomorph	I
G2	Geomorphology 2	%PD	Geomorph	I
G3	Geomorphology 3	%PD	Geomorph	I
G4	Geomorphology 4	%PD	Geomorph	I
RV1	Riparian vegetation 1	%PD	RipVeg	I
RV2	Riparian vegetation 2	%PD	RipVeg	I
RV3	Riparian vegetation 3	%PD	RipVeg	I
Inv1	Macro-invertebrate 1	%PD	MacroInverts	I

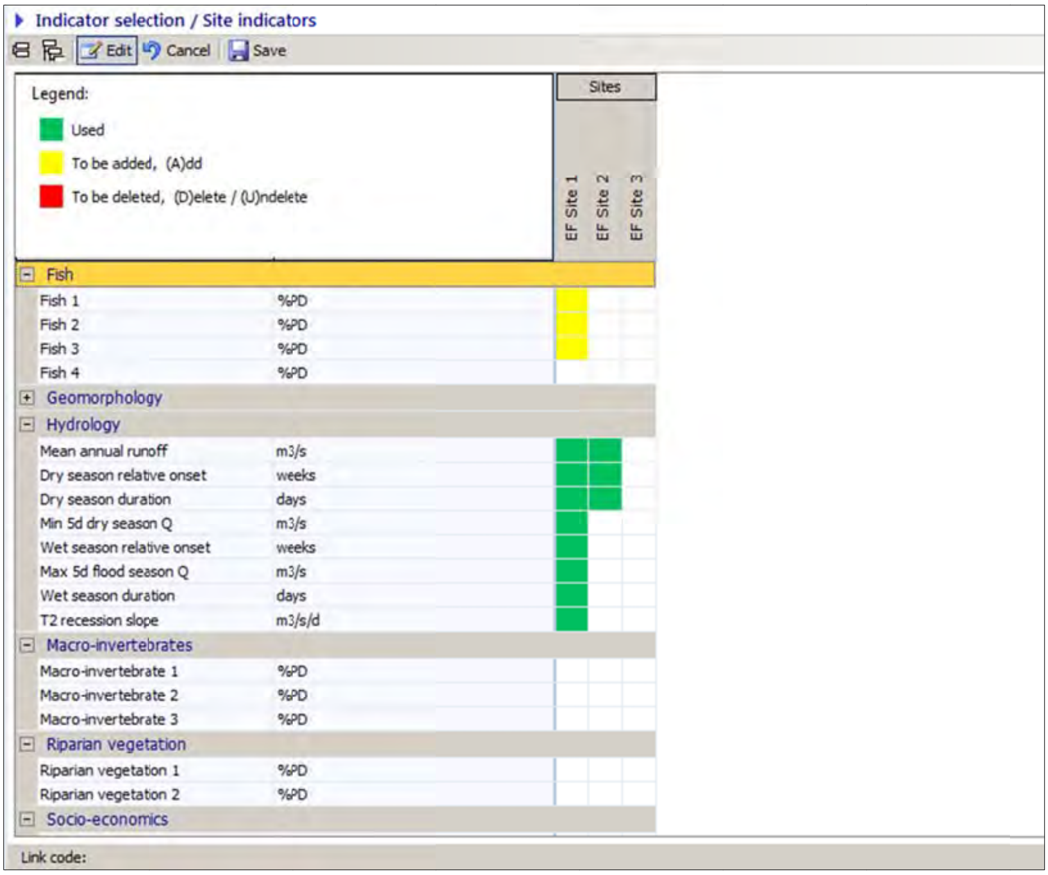
Disciplines | Indicators

Appendix Figure 47 **Arrangement of the Excel file for importing indicators. Left: Discipline page, with three columns (abbreviation, full name, indicator type). "Hydro" and "Hydrology are mandatory. Right: Indicators page with abbreviations, full name, units, discipline and indicator type columns. Shaded is the full list of flow indicators produced by the DSS: a subset of these can be "imported", although all are calculated.**

C.4.4.2 Site indicators

Once disciplines and indicators have been defined for the project, the user needs to specify which indicators are relevant at each site. Click on «*Edit*» in the menu bar of the Site indicator main panel (Appendix Figure 48). Then, at each site, select the relevant site / indicator cell in the matrix and type in "A" to add, or "D" to delete. Cells highlighted in yellow, are those selected for adding: when the user presses «*Save*», these will all change to be shaded green (indicating that those indicators are relevant at that site) (Appendix Figure 48).

NOTE: Remember to «*Save*» before exiting.

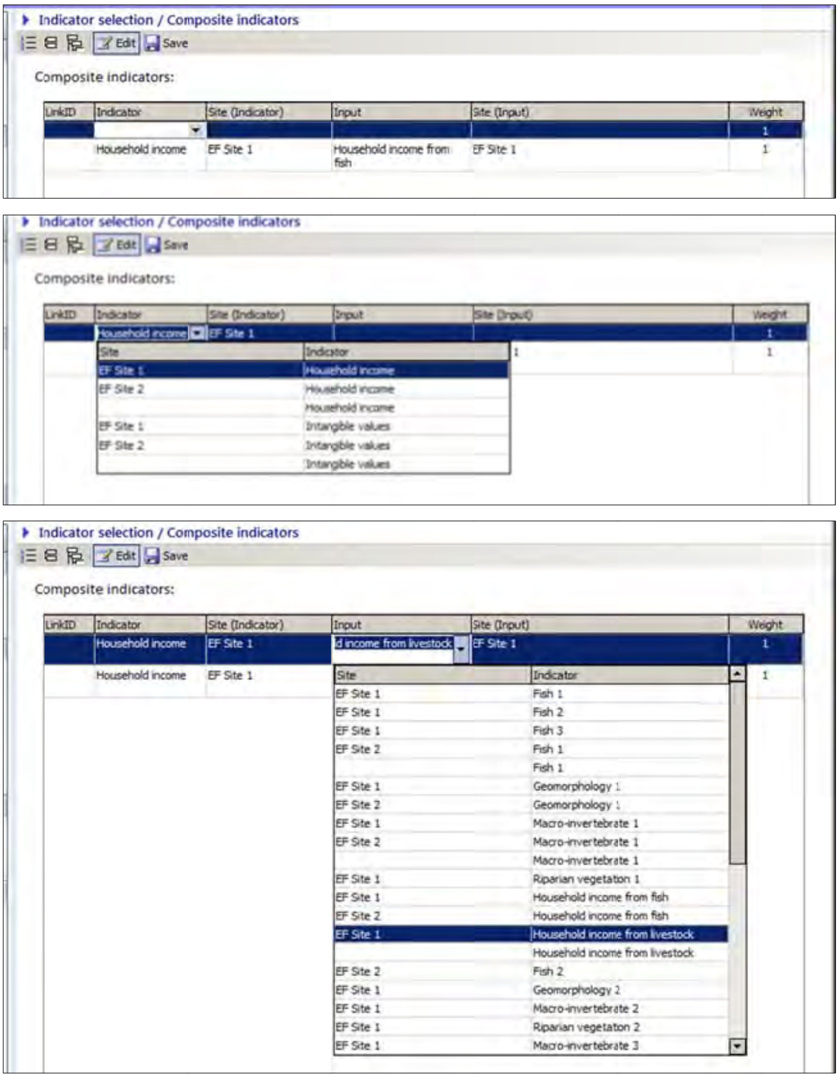


Appendix Figure 48 **<Indicator selection><Site indicators> window.**

C.4.4.3 Composite indicators

Composite indicators are typically only used in socio-economics. For example, several factors may contribute to household income, and so several household income related indicators are defined (e.g. household income from fishing, household income from livestock, household income from crops). Each of these indicators may be influenced by changes in various flow and biophysical indicators, and these relationships are specified in the usual way for ordinary indicators, described in Sections C.4.4.2 (specify site indicators), C.4.4.4 (specify links) and C.5.5 (complete response curves). However, there may be a need to summarise the effect of scenarios on *overall* household income, i.e. the overall effect of the three sources of household income. A Composite indicator, for example "household income", must then be defined (and specified as a Composite indicator in Indicator pool (Section C.4.4.1.2). Household income will then be an aggregation of the three separate contributors, specified in the DSS as a weighted sum. The user, thus, needs to specify weights which reflect the present day contributions of the different sources of income to total income and the result is expressed as an overall change in income relative to present day (i.e. %ofPD).

If an indicator has been designated as a Composite indicator in the Indicator pool (Section C.4.4.1.2), and listed as relevant at a particular site (Section C.4.4.2), it must then be further defined by listing which indicators combine to comprise the Composite indicator. To do this, click the «*Edit*» button and then the + button at the bottom of the screen () to add a new row. The drop-down box in the Indicator column will show the list of indicators defined as Composite in (Section C.4.4.1.2) (Appendix Figure 49). Select one of these, then specify, by choosing indicators from the drop-down list in the Input column, the list of indicators that form the Composite indicator (a new row must be added for each new input). The sites will automatically be completed when the inputs are chosen. Then, in the Weights column, a weight must be given, indicating the relative contribution of each input indicator to the Composite indicator.



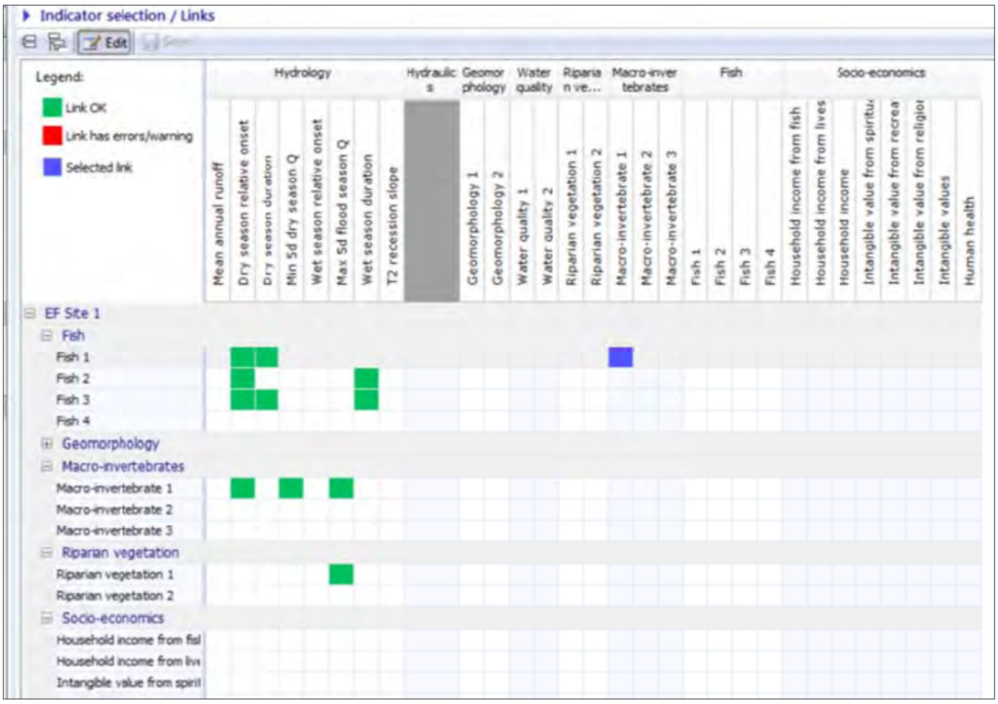
Appendix Figure 49 **Defining a composite indicator. Top: previously defined indicator; Middle: drop down list showing indicators defined as composite in the Indicator pool; Bottom: choosing the inputs to the Composite indicator (from list of all indicators).**

C.4.4.4 Links

Once all the disciplines have been entered, and the indicators relevant at each site have been selected, the links between indicators can be specified. The links table is a two-dimensional matrix, with all the indicators (including Hydrology) across the top, and all the indicators (excluding Hydrology) down the side (Appendix Figure 50). The indicators listed down the left hand side are the responding indicator, and those listed along the top are the driving indicators. Each indicator will be affected by, or respond to, changes in one or more input indicators. For example, there might be a row for Rainbow Trout, which might respond to changes in the “Dry onset” (onset of the dry season), “Dry season duration” (both flow indicators) and “Simuliidae” (a macro-invertebrate indicator) at Site 1 (Appendix Figure 50).

In order to change or add a link:

- press «*Edit*», then
- double click the cell indicating the appropriate link, then
- if the link did not previously exist, a popup-menu will appear with blank drop-down boxes and the defaults active for the other information (“same season”, and “active”) (Appendix Figure 51). In most cases, make sure that the link is established to the same site. Only select a different site if there is an up- or down-stream link for the same indicator (e.g. migration for some fish).



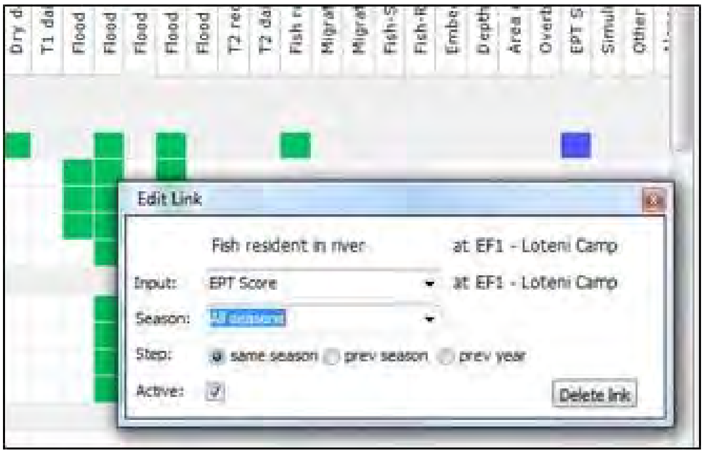
Appendix Figure 50 **The links matrix. Green cells mark active and correct links, while red cells mark links that have been entered incorrectly or which have been deactivated (the specific error is detailed if the link is opened, see text), if in edit mode, the blue cell indicates the link being edited.**

- o In the example illustrated, a link is established between Fish 1 (e.g. Rainbow Trout) and Macroinvertbrate 1 (e.g. Simuliidae) (blue cell in Appendix Figure 51). The user selects the link / site of interest from the first drop-down box (Appendix Figure 51). In the second drop-down box, the user selects in which season the dependency / response is relevant, or selects all seasons. For example, Fish 1 might depend on a

Macro-invertebrate food source only in the dry season, while it depends on another food source all year around.

There are two tick-boxes below the two drop-down boxes: one for selecting the "step"; and one for making the link "active" or "inactive" (Appendix Figure 52). The step will usually be "same season". However, if linked indicator is "lower" in the hierarchy of disciplines (Appendix Table 25) that the indicator that it drives, previous season should be used. For example, if channel width (Geomorphology) is dependent on marginal vegetation (Riparian Vegetation), the "previous season" needs to be selected as the step. This is because in the DSS Geomorphology indicators are calculated before Riparian Vegetation indicators each year.

Appendix Figure 51 **Pop-up menu for establishing a link, with drop-down box shown (left) for selecting linked indicator, and (right) for selecting the season in which the dependency is relevant.**



Appendix Figure 52 **Populated pop-up menu for establishing a link, showing the tick-boxes for selecting the "step" and to make the link "active". The default settings are "same season" and "Active".**

C.5. Knowledge Capture

In **KNOWLEDGE CAPTURE** the flow indicators are calculated and the response curves for other indicators (as defined in **SETUP**) are entered and calibrated. The flow indicators and indicator responses form the "brains" of the DSS.

There are six groups of modules in **KNOWLEDGE CAPTURE**, *viz*. [***Hydrology & Hydraulics***], [***Water quality***], [***Sediment***], [***Connectivity***], [***Response curves***], and [***Integrity***].

C.5.1. Hydrology & Hydraulics

The [***Hydrology & Hydraulics***] group of modules captures information used to calibrate the equations used to calculate the flow indicators, and calculates the time series of indicators for later use in the DSS. It can also be used to calculate the hydraulics indicators.

There are five modules in this group: [*Parameters & time-series data*], [*Delineate flood events*], [*Site calibration*], [*Calculate flow indicators*], and [*Indicator charts*].

Examples of the flow indicators for a "flashy" system are given in Appendix Table 17and those for a "flood pulse" system in Appendix Table 18.

C.5.1.1 Parameters & time-series data

There are two tabs in this module <*Setup parameters*> and <*Indicator options & time-series data*>.

The only information *entered* under [*Parameters & time-series data*] is on the <*Setup parameters*> tab, are includes:

- the starting year of the hydrological time series being imported;
- the starting month of the hydrological time series being imported (not necessarily the same as the "hydrological start month" (see Section C.5.1.3.1); and
- the number of years of data.

<*Time-series data*> shows which data files are currently available: these are automatically updated, as new data / scenarios are added to the …Data\Project\Hydrology folder and new flow indicators are calculated.

Other parameters that required for calculating flow indicators are entered in [*Site calibration*].

If the hydrology represents a flashy system, additional actions are required in [*Delineate flood events*].

C.5.1.2 Delineate flood events

This component is used when the river basin has a "flashy" flow regime. It is not included in this version of the DSS.

C.5.1.3 Site calibration

NOTE: Site calibration should be undertaken by the hydrologist of the EF team.

Before flow indicators can be calculated, information on how the DSS should distinguish between hydrological seasons at each site is needed to calibrate the calculations. This is done using a calibration scenario, which is usually the present day scenario. The various parameters need to be defined, and flow indicators calculated for the "calibration scenario". These are then tested and adjusted for each river system and site, before the flow indicators can be calculated for all scenarios in [*Calculate flow indicators*]. .

Before a site can be calibrated, the calibration scenario hydrology files need to be imported into …\Data\Project\Hydrology folder. These are usually daily data in a comma delimited file with extension .day (or .vts for "variable time-step" if the data are sub-daily). The format of the files is described and shown in Section C.3.6, Appendix Figure 40.

When [*Site calibration*] is opened, the window shows two sections: the top listing the sites, and below that a section with two rows of tabs: the top row (<*Parameters*>, <*Results*>, <*Seasons*>, <*Data*>), and the second row (which are "sub-tabs" to the tab selected in the top row. Under the <*Parameters*> tab, three sub-tabs appear in the second row of tabs: <*General*>, <*Hydrology*> and <*Hydraulics*> (Appendix Figure 53), and the <*General*> tab is initially displayed.

C.5.1.3.1 Edit parameters and calibration

In order calibrate a site and edit parameters for a site (Appendix Figure 53):

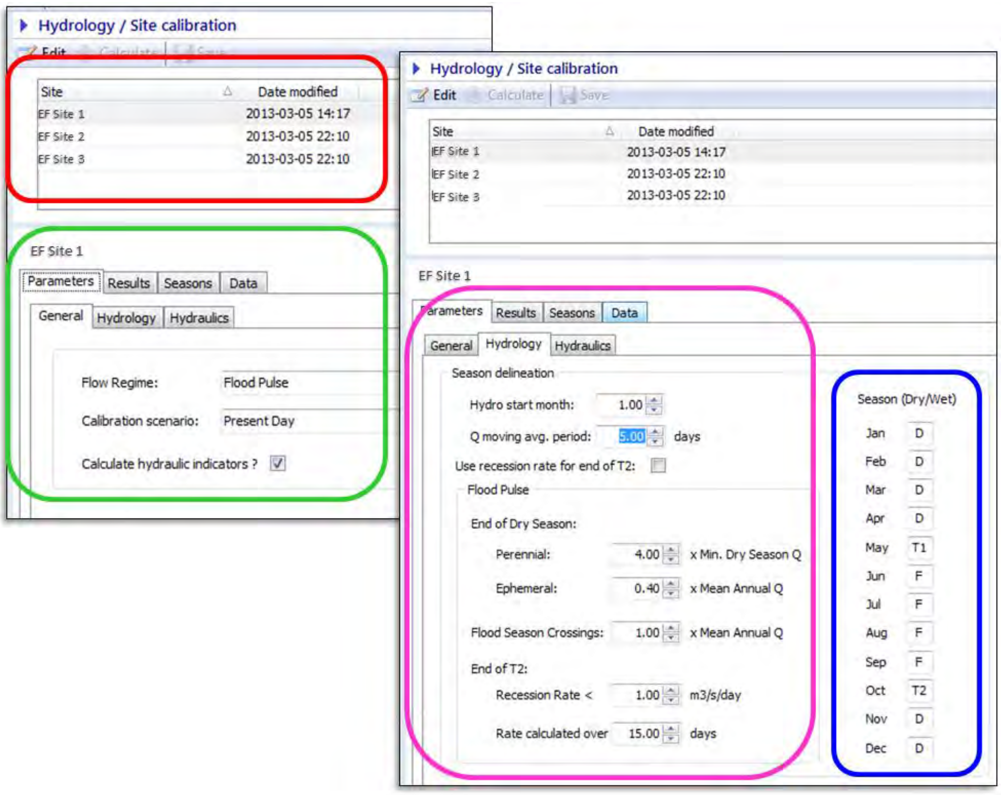
1. Click on the <*General*> tab under the <*Parameters*> tab and:
   - select the site to be calibrated by clicking in the relevant row in the top part of the window (Appendix Figure 53, red circle),
   - click the menu item «*Edit*» at the top of the main panel.
   - select the type of flow regime (flood pulse or flashy) (Appendix Figure 53, green circle),
   - select the calibration scenario (usually the present day).
   - specify whether hydraulic indicators are to be calculated.
   - click «*Save*».

2. Click on the <*Hydrology*> tab under the <*Parameters*> tab in order to set parameters for seasonal delineation in Flood Pulse systems (Appendix Figure 53, pink circle):
   - The starting month of the hydrological year (e.g. 10 for October): this is normally chosen to be somewhere in the middle of the dry season;
   - The number of days to be used in the calculation of moving averages of discharge (e.g. 5 days);
   - The number of times greater than the min dry season discharge (Q) that flow should be to indicate the end of the dry season (for perennial and ephemeral / non-perennial systems) (and start of the first transitional season);

- The number of times greater than the mean annual discharge that the discharge should be in order to indicate the end of the first transitional season and the start of the Wet/ Flood season;
- The recession rate that would indicate a transition from the Wet / Flood season to the second transitional season;
- The number of days over which the above recession rate should be calculated (e.g. 15).
- Click «*Save*».

NOTE: If the study river has a flashy hydrology, a couple more parameters are required to calculate the flow indicators. These are:

- the months that fall in dry, wet or transitional seasons. These are specified in [Delineate flood events], but are also displayed here (Appendix Figure 53, blue circle).
- the number, duration and timing of floods in different flood classes (see Section C.5.1.2).

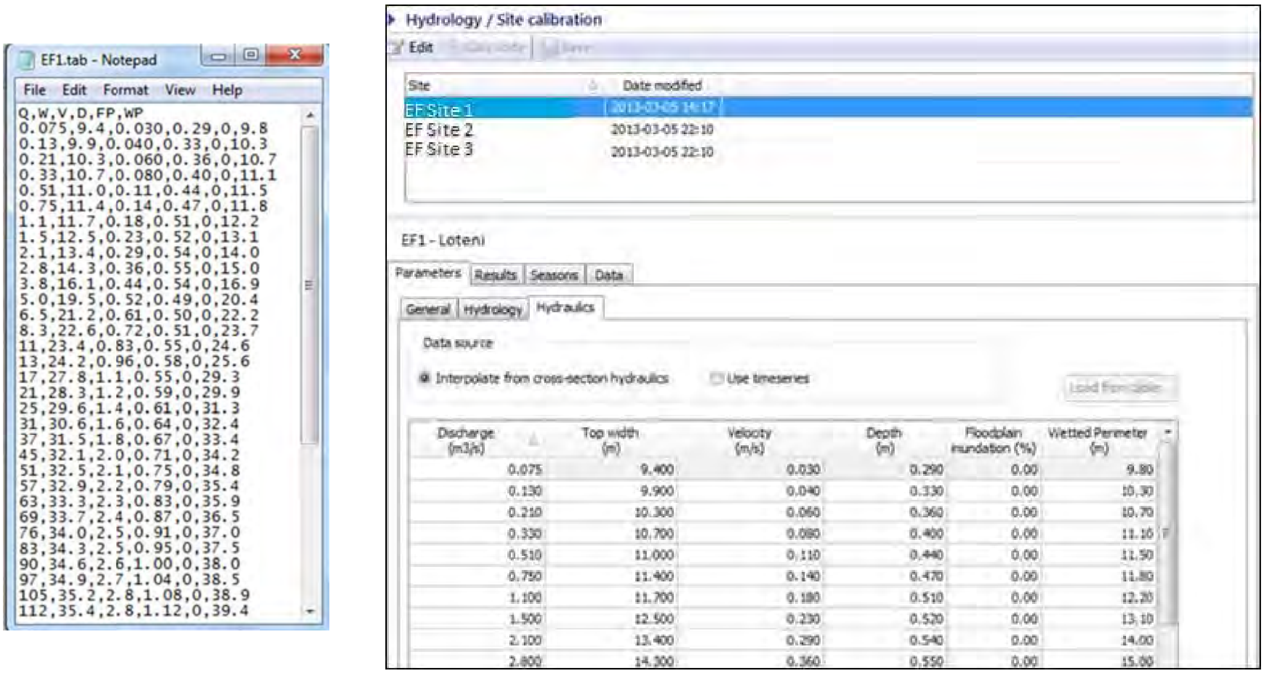


Appendix Figure 53 **The [*Site calibration*] edit window showing the General parameters, and Hydrology parameters tabs.**

3. If the appropriate stage-discharge data are available, hydraulic indicators can also be calculated. Click on the <*Hydrology*> tab under the <*Parameters*> tab:
   - A maximum of two representative cross-sections (e.g. 'Riffles' and 'Pools') can be defined by entering hydraulic properties that relate discharge to top width, velocity, depth, % flood plain inundation (if relevant), and wetted perimeter for each cross section (Appendix Figure 54). These can be imported from a .tab file (text delimeted file,

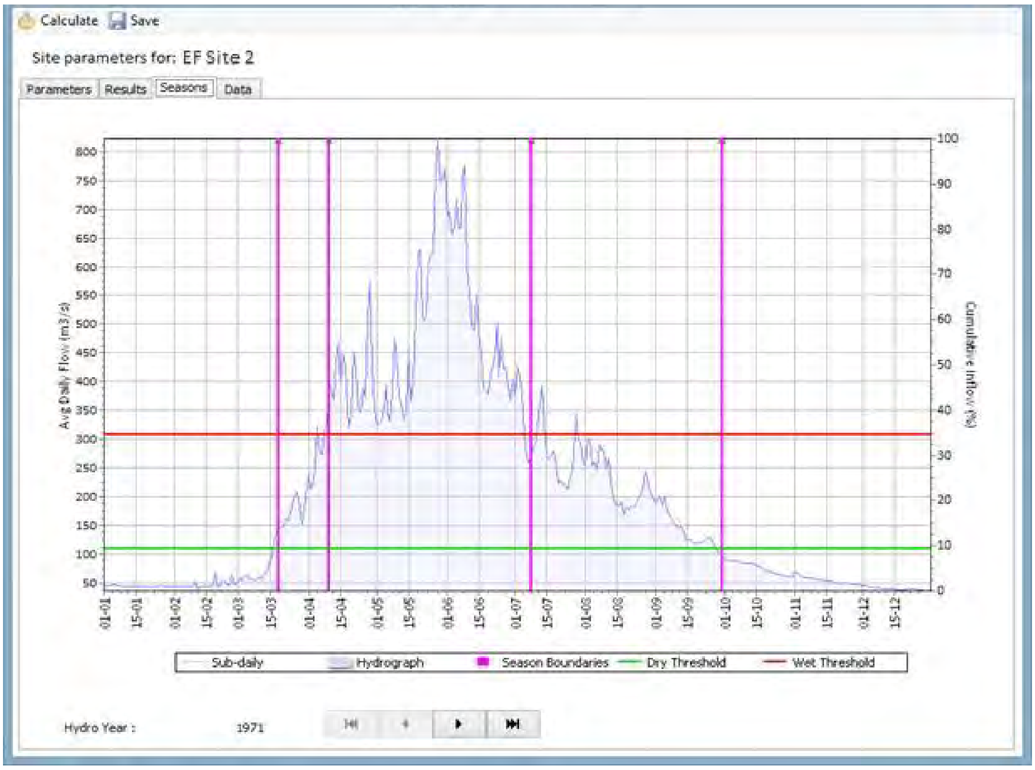
Appendix Figure 54, see also Section C.3.6), by clicking «*Load from table*» and browsing to choose the file.

- Click «*Save*».



Appendix Figure 54 **(Left): Format and content of .tab file of hydraulic data for import, and (Right): Parameters for calculating hydraulic indicators: imported from a .tab file (see also Section C.3.6).**

4. After the site parameters have been entered, the flow indicators are calculated for the calibration scenario by clicking the «*Calculate*» button (only available when «*Edit*» is clicked on).
   - A site is considered calibrated when four delineated flow seasons are present in (almost) every year of the flow sequence (although the DSS allows for seasons to not occur in some years). Calculated hydrology and hydraulic parameters can be viewed on the <*Results*>, <*Seasons*>, and <*Data*> tabs.
   - After calculation the <*Seasons*> tab opens automatically. Flow seasons and the annual hydrographs can be viewed graphically under the <*Seasons*> tab (Appendix Figure 55. (Note: the scale can be altered by dragging the cursor from somewhere near the Y-axis, down and to the right towards the X-axis and vice-versa).

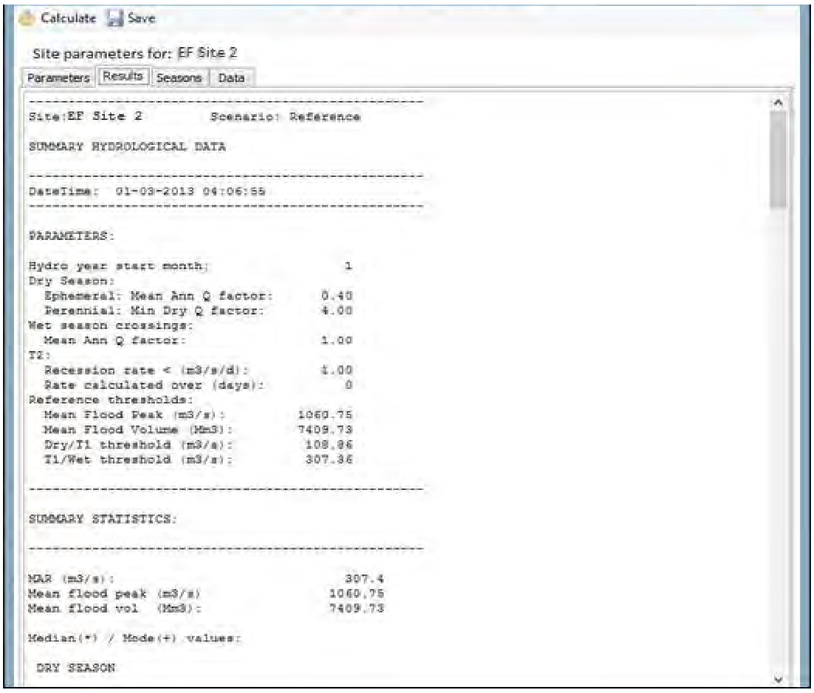


Appendix Figure 55 Graphical display of seasons for the time-series (*Site calibration*].

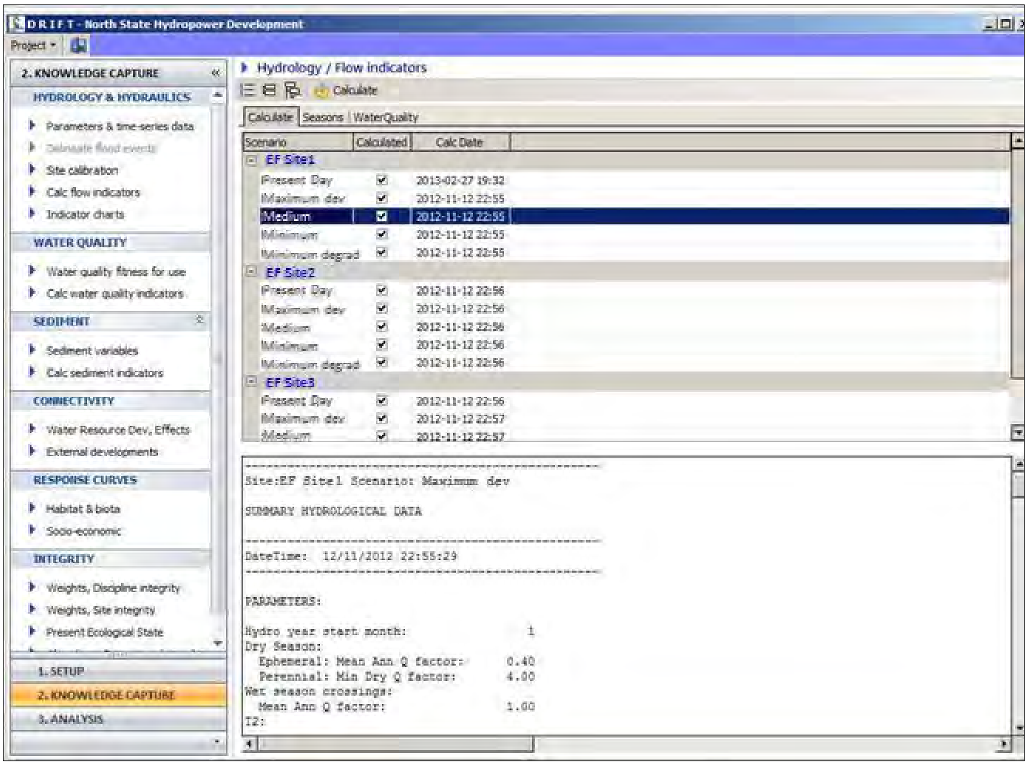
- The calculated indicators can be viewed under <*Results*> (Appendix Figure 56). Note: This is a replica of the text file containing the calculated indicator results which is automatically saved in the \FlowIndicators\ folder. Results files have a **.hst** extension.
- More details about the data and indicators can be viewed under <*Data*>, the "subtabs" being <*Parameters*>, <*Daily flow*>, <*Annual results*>, <*Daily results*>. Note: If difficulties are encountered when trying to calibrate a site, the information in <*Annual results*> is particularly useful to track down issues.
- Accept and store the calibrated parameters in the DSS by clicking the «*Save*» button.

C.5.1.4 Calculate flow indicators

Once the site has been calibrated, flow and hydraulic indicators can be calculated <u>for other scenarios</u>, by switching to the [*Flow indicators*] module, selecting the row indicating the site / scenario of relevance and clicking «*Calculate*». Scenarios whose indicators have already been calculated are marked with a tick (Appendix Figure 57). Once the calculations have been done for each, the flow seasons can be viewed graphically under the <*Seasons*> tab (which is the same as shown in (Appendix Figure 55).



Appendix Figure 56 **Flow and hydraulics parameters <Results> tab.**



Appendix Figure 57 **Calculate flow indicators window, showing sites and scenarios and which have been calculated (ticks).**

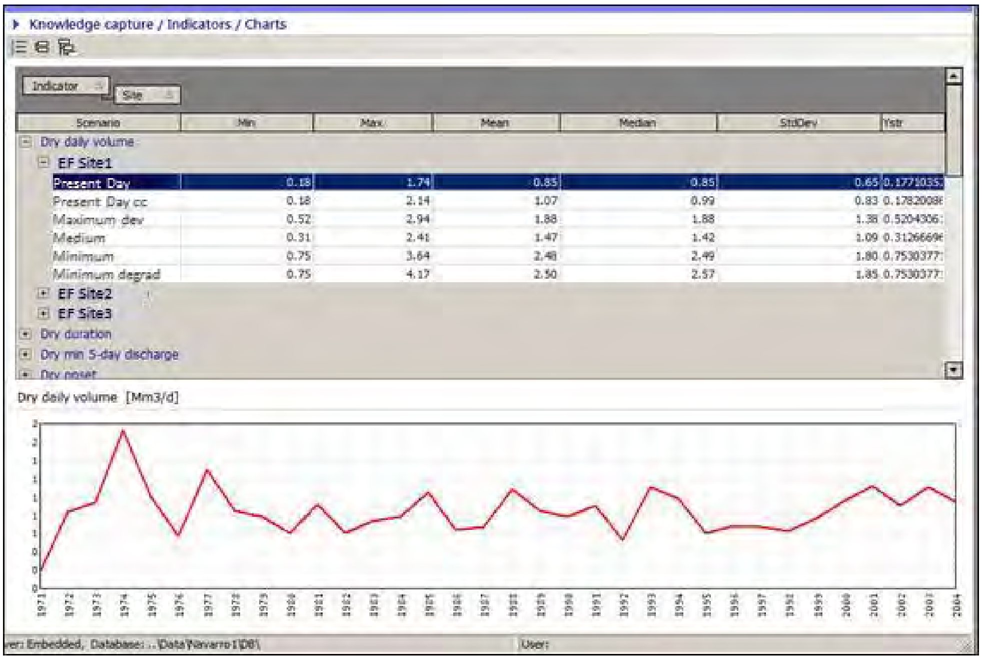
C.5.1.5 Indicator charts

The time-series of flow indicators calculated can be viewed here, by reorganising the information as required (as described in Section C.3.5). Often the most useful view is to group by indicator and then by site (Appendix Figure 58), so the various scenarios at a site can be viewed one indicator at a time.

C.5.2. Water quality

Water quality indicators are based on a "fitness for use" concept. Water quality constituent concentration thresholds can be defined for different uses (e.g. domestic consumption, aquatic ecosystem, agricultural use). Water quality indicators are defined as the percentage of samples that exceed the specified threshold in a particular season (indicators are calculated separately for the Dry and Wet seasons).

Calculation of water quality indicators has two steps before indicators can be calculated: (1) definition of fitness for use classes, and (2) import of a time-series of water quality data from an external source. There are two modules in this group: [*Water quality fitness for use*] and [*Calc water quality indicators*].



Appendix Figure 58 Viewing the time-series of flow indicator values.

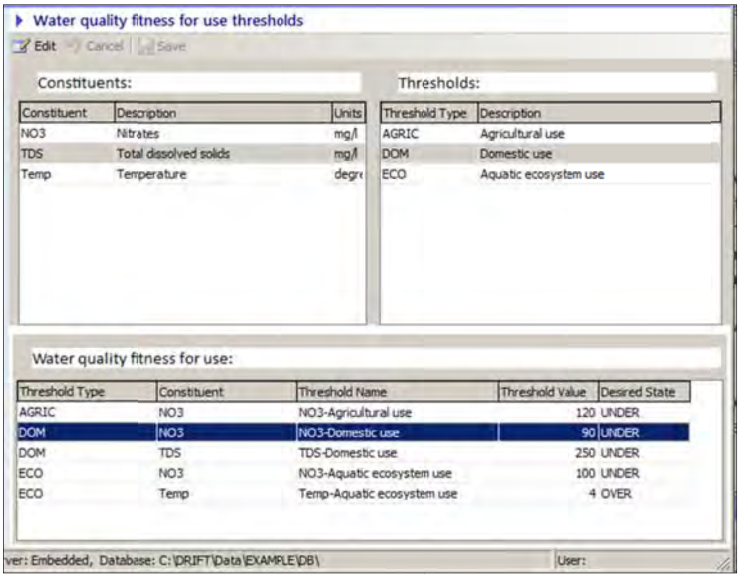
C.5.2.1 Water quality fitness for use

There are three sections to the [*Water quality fitness for use*] module, *viz*.: Constituents, Thresholds and Water Quality fitness for use. The relevant water quality constituents are listed in the Constituents section (with an appropriate abbreviation in the Constituent column and a matching description). The types of fitness for use thresholds are specified in Thresholds.

These might be for example, agricultural, ecosystems, or domestic fitness for use thresholds. Fitness for use (FFU) classes are defined by entering a maximum of three constituents and three threshold (use) types, and combining these to form the FFU classes.

Finally, the constituents and types of thresholds are combined in the Water quality fitness for use window. For example, if nitrates (NO_3) have been specified as a relevant constituent and agriculture as a sector with a fitness for use threshold, then in this window, after clicking «*Edit*» one would choose agriculture from the drop-down list in the threshold type column, and NO_3 from the drop-down in the Constituent column. (Alternatively, if the AGRIC row is highlighted in the Thresholds part of the window, NO_3 in the constituents part of the window, then a row for AGRIC-NO_3 will automatically be added, when adding a row in the fitness for use part of the window). Then, a threshold value (in constituent concentration units) and a "desired state" are specified. The desired state is specified in terms of direction: to be greater than (over) or less than (under) the target.

The combination of three constituents with three threshold / use types can produce up to nine FFU classes. Indicators are calculated separately for the Dry and Wet seasons, meaning that up to 18 water quality indicators can be produced.

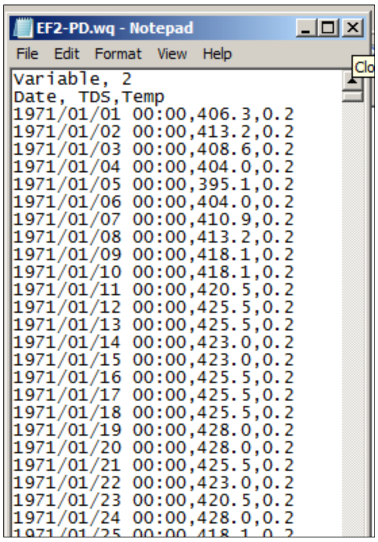


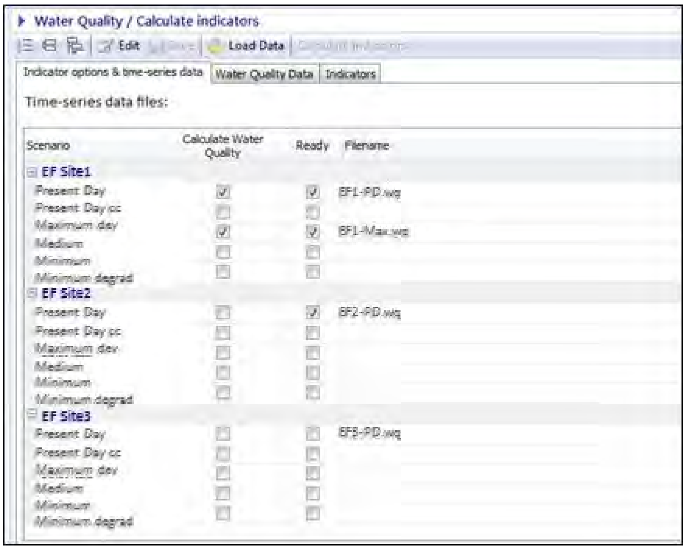
Appendix Figure 59 [*Water quality fitness for use*] module.

C.5.2.2 Calculate water quality indicators

Water quality indicators are calculated by loading a time series of water quality sample data. Data for a maximum of three constituents are read from a comma delimited text file in the format shown in Appendix Figure 60. The first row of the text file header indicates that the time series time step is *variable* and that there are *two* constituents. The second row of the text file header indicates what the columns contain *date* (date time format mandatory), *TDS* and *Temperature* (by way of example – these could be any other constituents, but the colum names should exactly match the constituent abbreviation entered into the Constituent column in Appendix Figure 59).

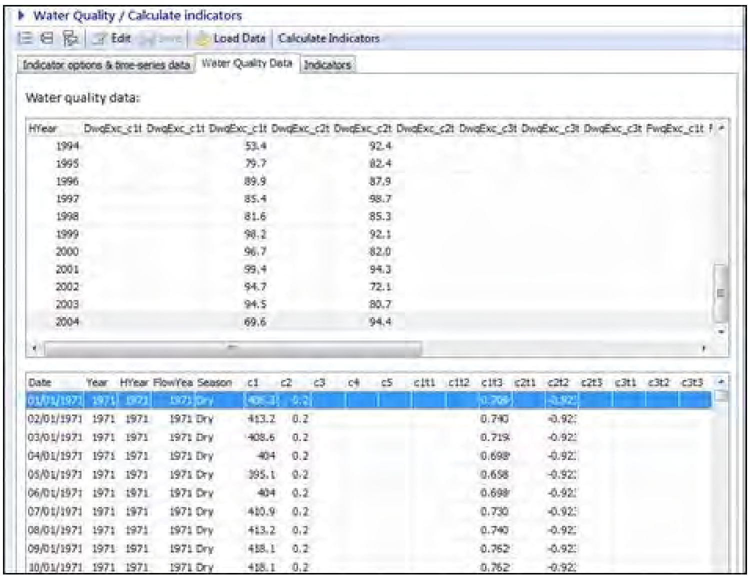
- When clicking on [*Calc water quality indicators*] the window shown in Appendix Figure 60 (right) will open which lists the scenarios, and has three other columns.
- If an appropriately named water quality file is in the ..\Data\project_name\Hydrology sub-folder, the user can click in the “Ready” checkbox and the “Calculate water quality” checkbox, and then click «*Load data*» to import the data into the DSS.





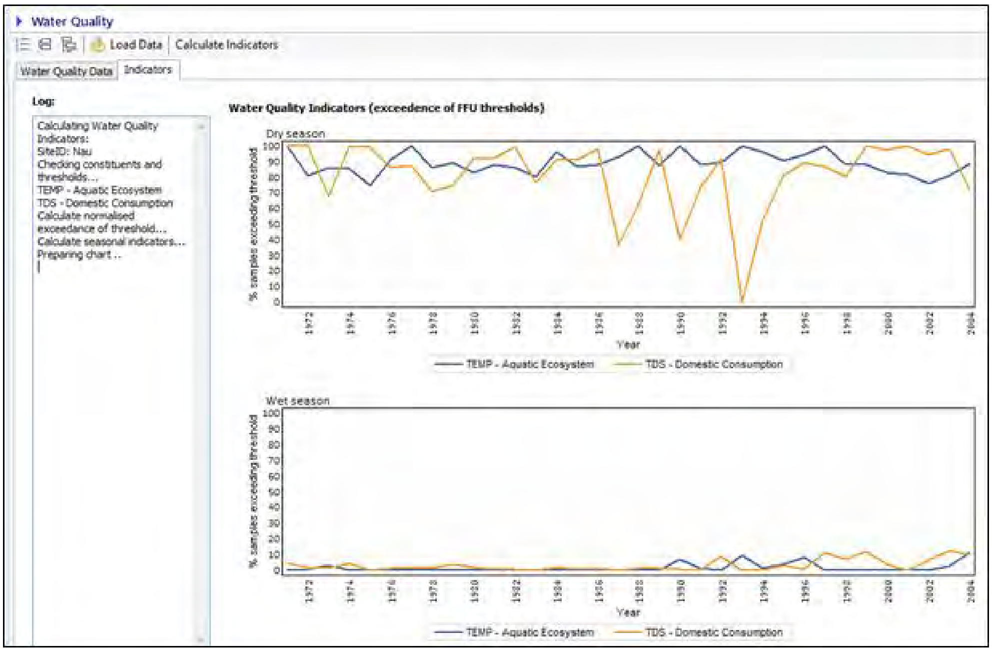
Appendix Figure 60 **Water quality import data format (left) and window for viewing, selecting and loading data, and for calculating indicators.**

- If the data are successfully loaded, it will be displayed as shown in Appendix Figure 61.



Appendix Figure 61 **Successfully imported water quality data.**

- Calculation of indicators by clicking the «*Calculate indicators*» button.
  Seasonal indicator time series are displayed for each FFU class, for the Dry and Wet seasons.



Appendix Figure 62 Calculated water quality fitness for use indicators (seasonal).

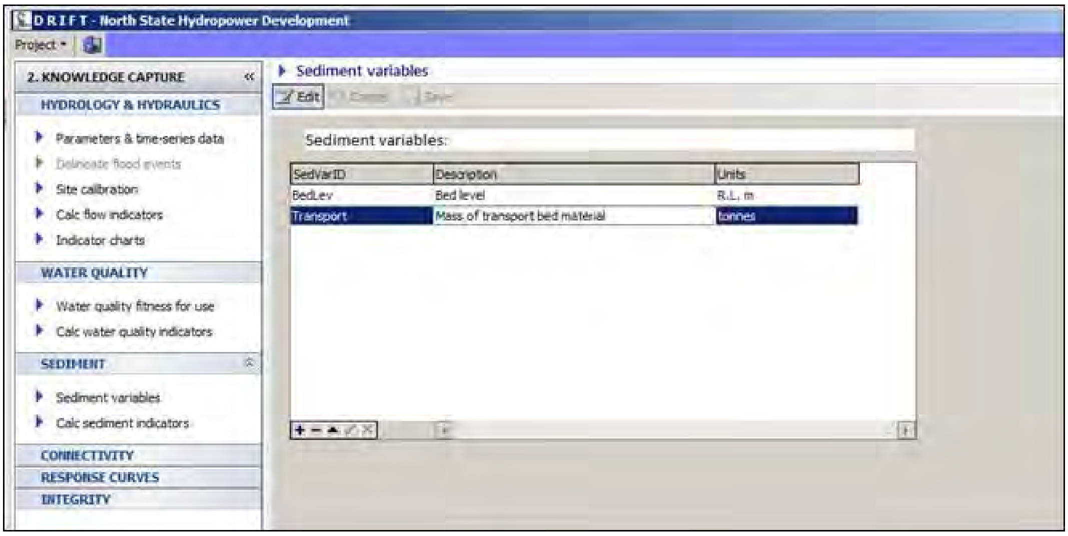
C.5.3. Sediment

Sediment indicators are defined as the maximum, minimum, and mean values of sediment variables recorded or simulated at a site. A maximum of three sediment variables are defined by the user, and time series for these variables are imported into the DSS. Indicators are calculated separately for the Dry and Wet seasons, meaning that a maximum of 18 sediment indicators (3 variables times 3 statistical properties times 2 seasons) can be generated.

As with water quality, there are two steps before sediment indicators can be calculated: (1) definition of sediment variables, and (2) import of a time-series of sediment data from an external source. There are two modules in this group: [*Sediment variables*] and [*Calc sediment indicators*].

C.5.3.1 Sediment variables

Sediment variables are defined in the window that opens by clicking «*Edit*», then the + button at the bottom of the screen () to add a row, and then typing the abbreviation, description and units in the columns provided (Appendix Figure 63).

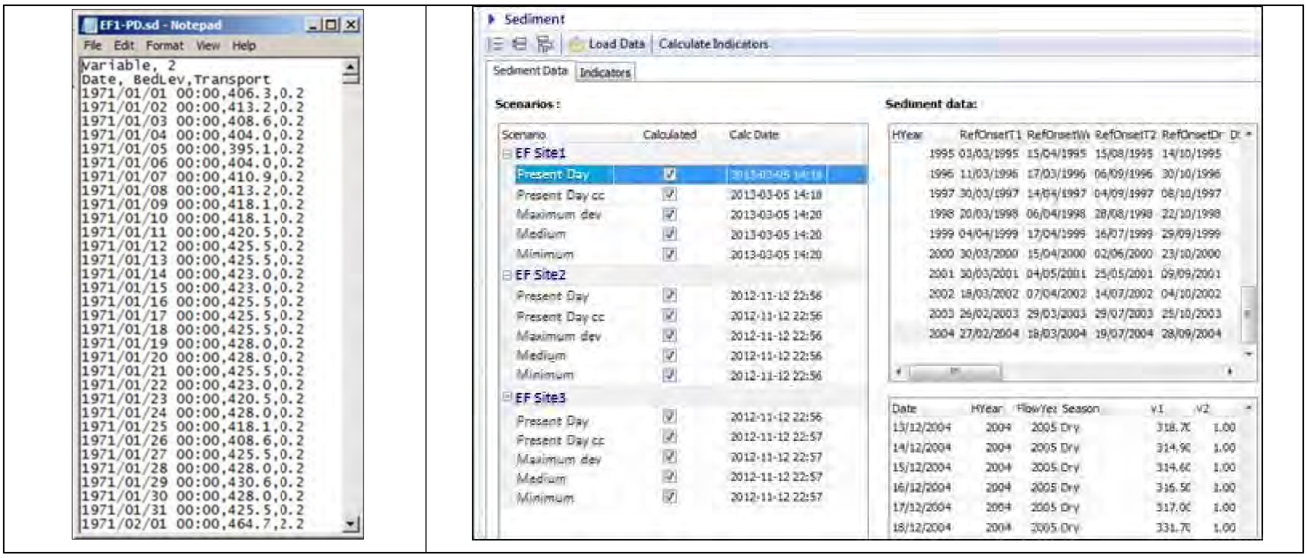


Appendix Figure 63 **Entering sediment indicators.**

C.5.3.2 Calculate sediment indicators

Sediment indicators are calculated by:

- Loading a time series of sediment sample data. Data for a maximum of three variables are read from a comma delimited text file in the format shown in Appendix Figure 64. The first row of the text file header indicates that the time series time step is *variable* and that there are *two* constituents. The second row of the text file header indicates what the columns contain *date* (date time format mandatory), *BedLev* and *Transport* (by way of example – these could be any other constituents, but the header names should match the abbreviations entered when the variables were defined).
- If the data are successfully loaded, it will be displayed as shown in Appendix Figure 64.



Appendix Figure 64 **Sediment import data format (left) and successfully imported sediment data (right).**

- Calculation of indicators by clicking the «*Calculate indicate*» button.
  Seasonal indicator time series are displayed for each sediment variable, for the Dry and Wet seasons (Appendix Figure 65).

Appendix Figure 65 Calculated sediment indicators (seasonal).

C.5.4. Connectivity

The [***Connectivity***] group of modules deals with impairment to important upstream / downstream linkages (e.g. fish migrations). The information is not mandatory.

There are two modules in this group: [*Water-resource development, effects*] and [*External developments*].

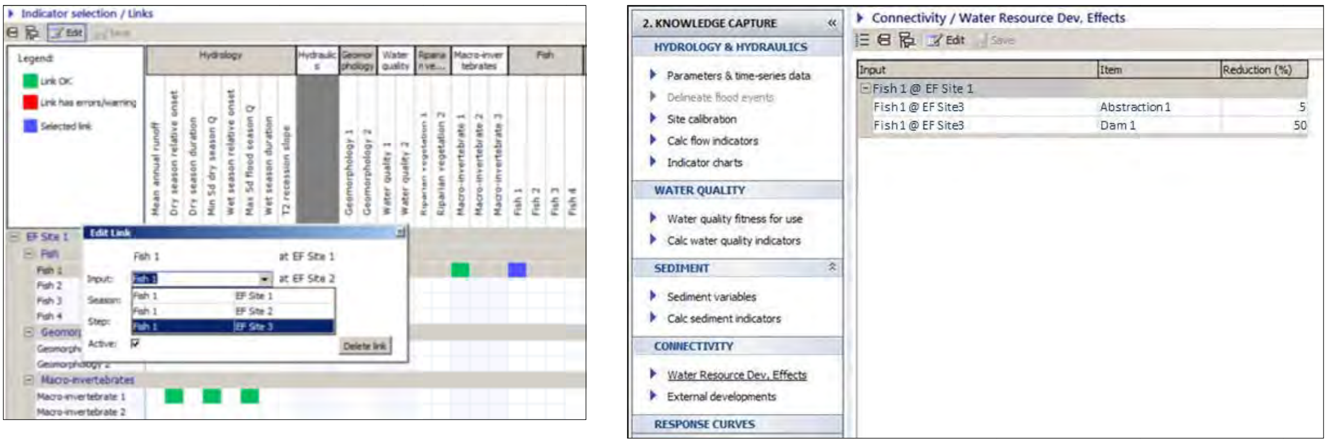
C.5.4.1 Water-resource development, effects

Based on the list of water-resource developments listed in [***Project description***] [***System description***] [*Water-resource developments*] and the list of links specified in [***Indicator selection***] [*Links*], the DSS prepares a list of indicator-links which will be affected by connectivity and the associated water-resource developments (Appendix Figure 66). The types of links which are relevant are where an indicator at one site is affected by the same indicator at another site (e.g. fish migration). In the example shown in Appendix Figure 66, a link was made in [***Indicator selection***] [*Links*] between Brown Trout at Site 1 and Brown Trout at Site 2 (i.e. abundance of Brown Trout at the upper site was influenced by abundance of Brown Trout at the lower site, because of migration upstream).

Because of water-resource developments described in [***System description***] [*Water-resource developments*] (which locates them in the river system), the DSS knows that there are two developments planned between Site 1 and Site 2 (Sharda dam, and Dudhnial abstraction).

The estimated percentage reduction in connectivity, if any, associated with each water-resource development must be entered in the column provided.

NOTE: Currently, if there are developments upstream of Site 1 that affect connectivity, a "dummy" site ((Site 0) must be inserted upstream of this and the necessary indicators at that site defined and links made from downstream sites, e.g. Site 1, to Site 0. Effects of developments upstream of Site 1 on connectivity are handled as for any other connectivity issues.



Appendix Figure 66 **Specifying connectivity effects: Left: In [*Links*] – creating a link where Fish 1 at EF site 1 depends on Fish 1 at EF site 3, Right: In [*Connectivity*] – specifying the effect of a proposed dam on that link.**

C.5.5. Response curves

The Response curve module is the heart of the DSS and the DRIFT process: the collective specialist knowledge and data are captured here. Response curves capture how an indicator will react to a change in an input indicator (e.g. how fish abundance will change in response to a change in the duration of the flood season, or how income from fishing will change in response to changes in the abundance of fish).

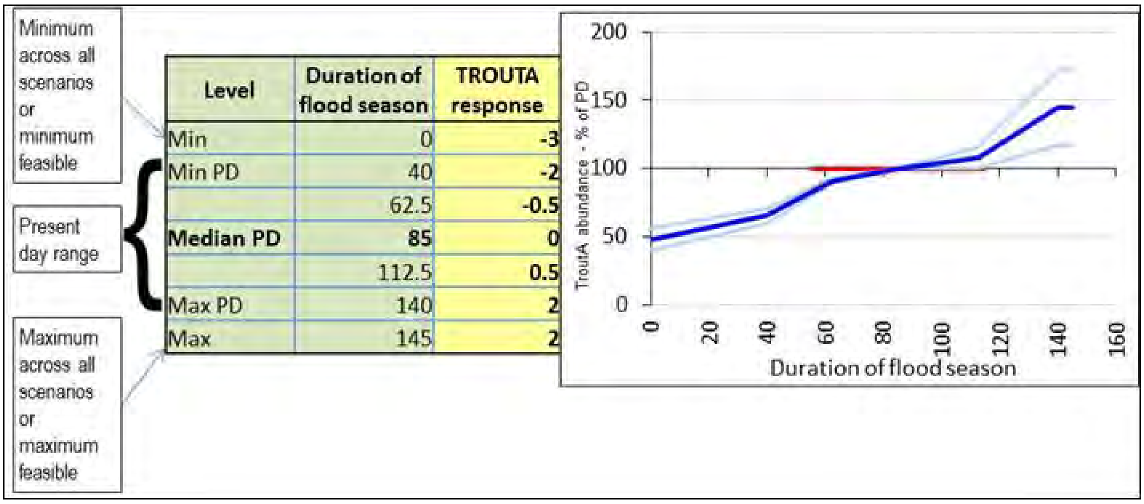
There are two modules in this group, [*Habitat and biota*] and [*Socio-economic*]. These are identical except for the use of weights and composite indicators in the socio-economics module (described in Section C.4.4.3).

The reaction or response of an indicator is expressed in terms of a Severity score, which is related to a percentage change in abundance (Appendix Table 26). The Severity scores are converted in order to express the overall results as a percentage of present day.

Appendix Table 26 Severity ratings

Severity rating	**Severity change**	**Equivalent Loss** (i.e. % abundance retained)	**Equivalent gain** (%increase)
0	None	No change	No change
1	Negligible	80-100	1-25
2	Low	60-79	26-67
3	Moderate	40-59	68-250
4	Large	20-39	251-500
5	Very large	0-19	501-∞ (to pest proportions)

The user is provided with the reference (usually present day) range and median values for each driving indicator. They are also given minimum and maximum values that encompass the likely ranges of the scenarios (see Appendix Figure 67).



Appendix Figure 67 The seven points provided for completion of the response curve with the resulting curve shown on the right, with the lighter blue lines representing the range implied by the severity score. The red horizontal line on the graph is the present day standard deviation.

The Severity score for median present day (the middle of the seven X-axis numbers), is always 0, i.e. no change from present day. The user enters scores from -5 to +5 for all the other values, in order to describe the degree to which the output indicator will change in response to a change in input indicator.

According to the values in Appendix Figure 67, if the duration of the flood season in a particular year is 40, the severity rating will be -2, meaning that 70% of the abundance will be retained (range 60-79%, Appendix Figure 67), i.e. the resulting percentage of present day value will be

70%. For any intermediate values, the response is linearly interpolated (e.g. if the input is 126.25, the severity rating will be 1.25 or a 26.14% increase in abundance).

C.5.5.1 Habitat and biota

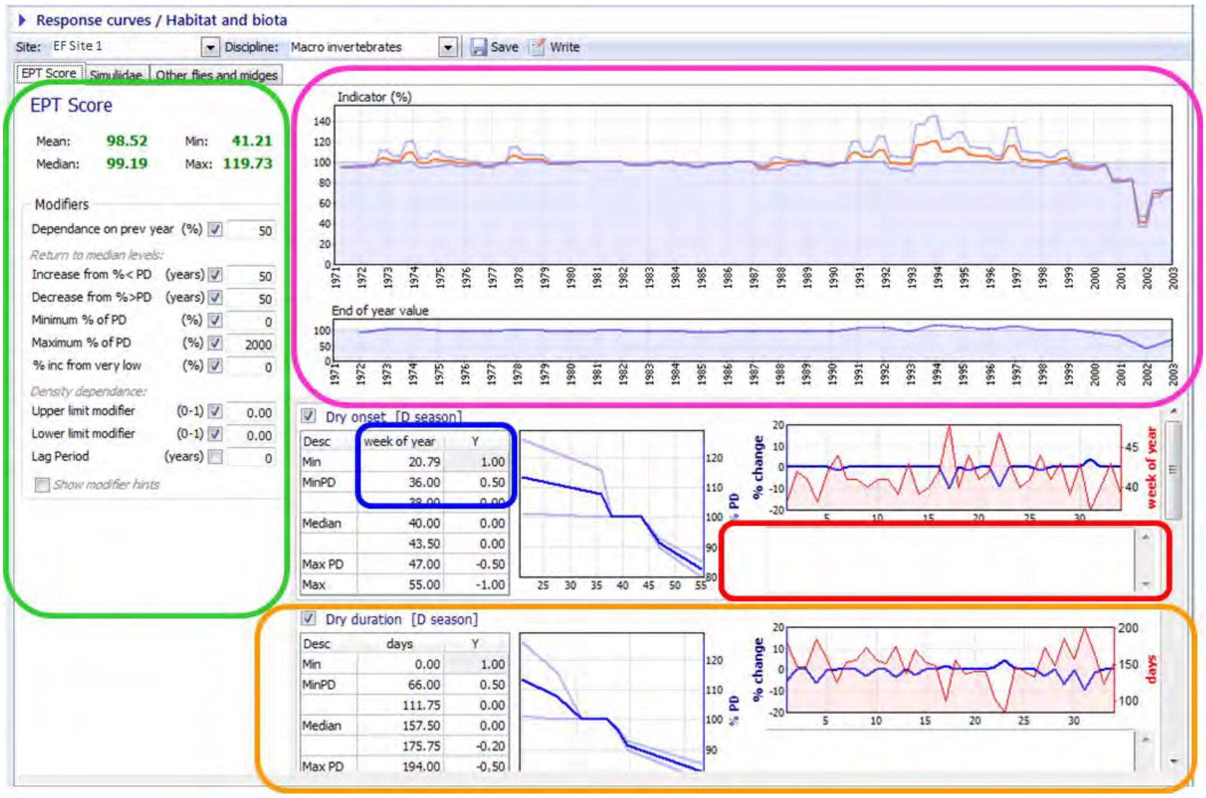
When the Habitat and biota module is opened, the first site and the first indicator are displayed in the main panel. The drop-down boxes at the top of the main panel (Appendix Figure 68) can be used to select the site and discipline of interest (Site 1 and Macroinvertebrates in Appendix Figure 68). Once the site and discipline are chosen, the particular indicator with which you want to work can be chosen by clicking on the relevant tab (Appendix Figure 68 shows three indicator tabs “EPT score”, “Simuliidae” and “Other flies and midges”).

Appendix Figure 68 **Habitat and biota response curve editor. The red circle shows the drop-down boxes for selecting the site and the discipline, and the blue circle the tabs for each of the indicators specified within this discipline at this site.**

The page (Appendix Figure 69) is arranged as follows:

- At the top of the right hand side (pink circle in Appendix Figure 69) is a time-series which is the overall resulting abundance time-series of the indicator. This is an aggregation of the indicators responses as an aggregated response to all the input response curves.
- On the left are the “modifiers” (green circle in Appendix Figure 69). Refer to Appendix B for more details regarding these.

- All input indicators to which the chosen indicator was linked are listed down the page below the aggregate time-series (use the scroll-bar to view down the list). (The orange circle in Appendix Figure 69 highlights one of the response curves and its associated information).



Appendix Figure 69 **Habitat and biota response curve editor. The green circle shows the modifiers, the pink circle the overall time-series response, the orange circle the information relating to a single response curve, the red circle the explanation for the shape of the response curve, and the blue circle, the X-axis values of the driving indicator, and the Y-axis response values which are entered by the user.**

In order to create a response curve:

- The user types the appropriate response in terms of a Severity rating (-5 to +5 (Appendix Table 26) in the appropriate row of the Y column next to the X-axis values. Note that the median PD must have a Severity rating of 0.
- Each Severity rating has a range of percentage change associated with it (Appendix Table 26).

NOTE: Currently only one set of values can be entered. These incorporate a pre-specified range of percentage changes (Appendix Table 26). Future versions of the DSS will include the possibility to specify a wider range of uncertainty.

- An explanation for each response curve must be given in the text box (red circle in Appendix Figure 69) to the right of each response curve (under the individual time series graph associated with that response curve).
- The overall response can be modified with the “Modifiers” shown within the green circle in Appendix Figure 69 (modifiers are described in Appendix B). The modifiers can be clicked on or off using the tick-boxes and the values changed as required. Hints are provided when the mouse hovers over any of the modifiers. Modifiers include:
    - dependency on previous year;
    - tendency back to median levels;
    - minimum percentage of present day;
    - maximum percentage of present day;
    - persistence;
    - density dependence; and
    - lag effect.

NOTE: After any changes are made, the new information must be saved by clicking «*Save*» in the toolbar. Currently the DSS does not give a warning if you have made changes and not saved.

There are a number of graphical displays:

- Immediately to the right of each response curve table, is the response curve graph. The X-axis is the input / linked indicator (e.g. dry season duration in days, for the response curve encircled in orange in Appendix Figure 69). The Y-axis is the response of the indicator, translated into percentage of present day (% PD).
- To the right of each response curve is a time-series that shows the response of the indicator to that single input (blue line) and the time-series of values for the input itself (red line). The X-axis is years. The right hand Y-axis refers to the units of the input indicator (days in the example shown) and the left hand Y-axis is in terms of percentage change (% change) (i.e. how much the response indicator increases or decreases – not expressed as a % of PD). This allows the user to scroll up and down and compare the relative size of the responses to different inputs.
- The overall response of the indicator to all input/linked indicators that are activated (ticked in tick box) is shown at the top of the screen. This shows all four seasons.
- Immediately below the seasonal time-series, is the end-of-year time-series. This shows the end of year value, rather than each season’s variation, and is useful for indicators where seasonal variation is not particularly relevant.

C.5.5.2 Socio-economics

The Socio-economics response curve module operates in essentially the same way as the Habitat and biota module. The differences between the Habitat and Biota and the Socio-economics modules arises due to the possibility, in Socio-economics, of defining "composite indicators" and of using weights at various stages.

C.5.5.2.1 Composite indicators

Experience in previous applications suggested that there might often be the need within the socio-economics part of the EFA to form composite indicators which group together a number of contributing indicators. This might arise, for example, where there a number of livelihood strategies or sources of income, which might be very differently affected by the change flow regime or other factors within the scenarios. Thus, one might want to define these different sources of income as separate indicators, e.g. Household income from fishing, Household income from livestock, Household income from crops. These can be defined to combine to form the composite indicator "Household income". Composite indicators must be specified as such when creating or importing indicators in [***Indicator selection***][*Project indicators*], must be selected for the appropriate sites in [***Indicator selection***][*Site indicators*] and contributors must be defined in [***Indicator selection***][*Composite indicators*] – see Sections C.4.4.1.2, C.4.4.2 and C.4.4.3.

C.5.5.2.2 Aggregation weights

Aggregation of responses

In the habitat and biota module, responses created from a number of different linked indicators (drivers or input indicators) are aggregated to create the overall response for that time season (i.e. season). As all of these responses are measured in terms of Severity scores (translated into % of present day), they should not be weighted when aggregating (the weight is included in the severity score).

However, a slightly different situation may arise within Socio-economics, such that weights are required when aggregating to get the overall time-step response. This is best illustrated using the Socio-economics indicator "Household income from fishing" as an example.

Consider the case where income from fishing is primarily sourced from three fish species (brown trout, rainbow trout and mountain loach). While, as for biophysical response curves, the socio-economist can describe a response curve giving the <u>change in income from each of these fish relative to present day</u>, and the three responses can be aggregated, this does not take into account the original relative abundance of the three fish species. For example, assume the relative abundance (as a percentage) was 80, 15, 5 for brown trout, rainbow trout and mountain loach respectively, and they contributed, respectively, 50, 40 and 10 % of present day income. The relative value "per fish" might then be considered to be 50/80, 40/15 and 5/5 respectively, or 0.625, 3, and 1 respectively.

Either this relative contribution "per fish" could be incorporated within the relative Severity scores, as is done with all biophysical response curves. In this case, the smallest and largest response values of brown trout will be scaled to be 0.625 of those for mountain loach, and rainbow trout 3 times as much as those for mountain loach. However, given that, for example, different nonlinearities (different response curve shapes) might apply in different fisheries, this proof a difficult approach to follow. Therefore the opportunity is given (either approach can be followed), within the socio-economics to:

- consider the response curves independently, i.e. the response is “the Severity of changes in income from brown trout fishing (relative to present day) given changes in brown trout abundance”, rather than “the Severity of changes in fishing income due to changes in brown trout abundance”.
- Weight the contributions to fishing income according to their relative values (0.625, 3 and 1, respectively)

Aggregation of composite indicators

When composite indicators are created, for similar reasons to those discussed above, the individual contributing indicators can weighted for their aggregation to form the composite indicator value.

Considering the example given in Section C.5.5.2.1, the socio-economist would weight household income from fishing relative to other sources of income, in terms of how much fishing contributes to overall household income, and so on.

C.5.6. Integrity

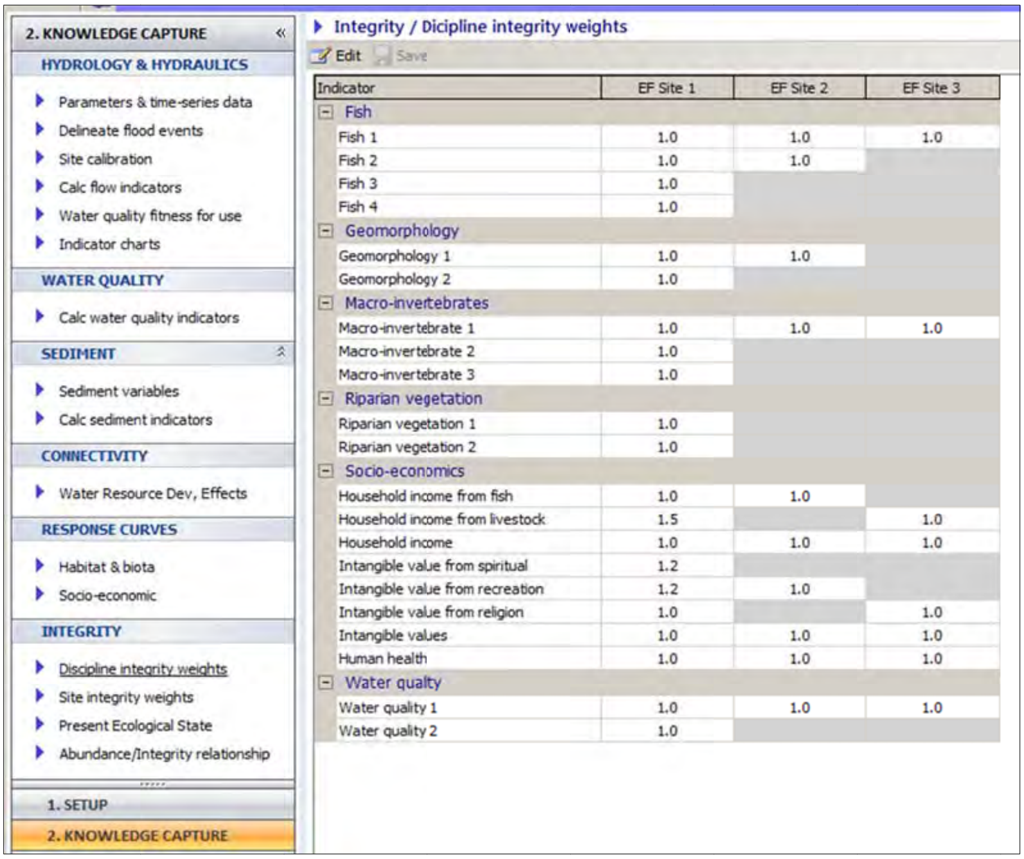
Within each discipline, besides the time-series of responses, which reveal particular patterns and times of interest (e.g. conditions which cause abundance to “crash”), an overall summary of the “performance” of each scenario according to each indicator, discipline and site is created using the concept of “Integrity”. Socio-economic well-being is calculated in exactly the same way as is Ecosystem Integrity as described in these sections.

Briefly, Integrity (or social well-being) is calculated using an average for each indicator over the time-series (all seasons), which is converted back from percentage of present day, to an Integrity Score. The Integrity Score for a discipline I sthe comprised on a weighted sum of the indicator Integrity Scores.

Thereafter, the Overall Ecosystem Integrity score is a weighted sum of biophysical disciplines, and the Overall Social well-being score is the same as the Socioeconomics Integrity score.

C.5.6.1 Discipline integrity weights

Weights are entered by clicking on «*Edit*» and entering the adjusted weight (the default values are all 1). The weights are relative and adjusted to sum to one when integrity / well-being is calculated. For example, in the socio-economics section shown in Appendix Figure 70, the subsistence fishing was considered to contribute twice as much to well-being as livestock grazing.



Appendix Figure 70 Weights for calculating discipline level biophysical integrity and socio-economic. The default values are 1.

C.5.6.2 Site integrity weights

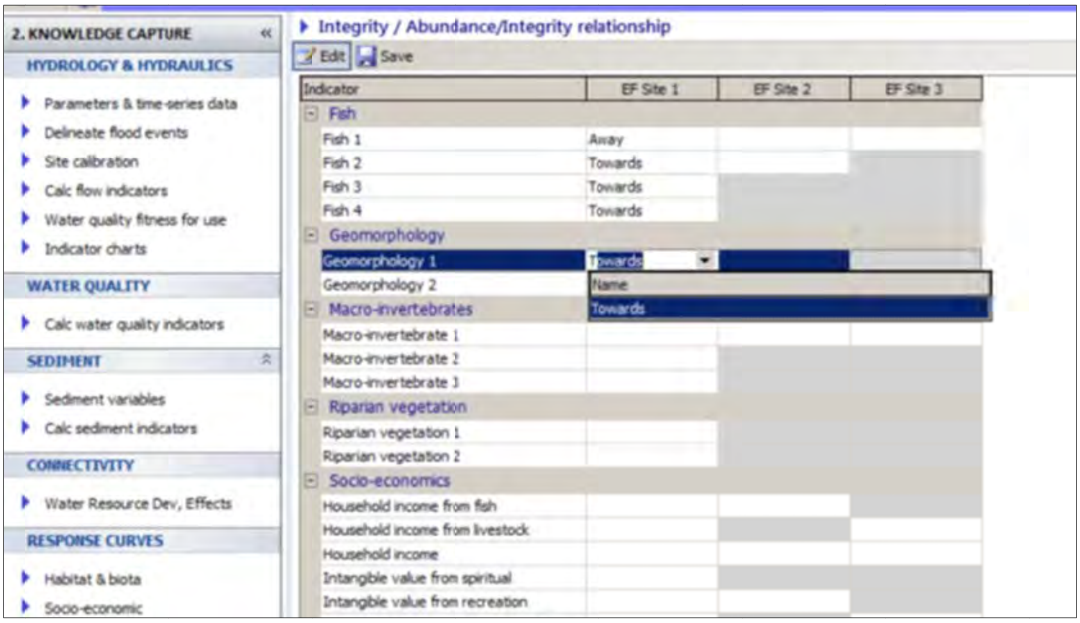
Weights to be applied to disciplines when calculating the overall site Integrity are entered here, in the same way as for discipline Integrity.

C.5.6.3 Present Ecological State

The present ecological status (PES) estimates for each discipline at each site are entered here. The PESs are described in terms of the Categories A to E, including intermediate categories like B/C. These Categories are defined in Kleynhans (1999) and relate to the relationship with the natural state of the river, as shown in Table 2.4. Besides being general information for the project the PES is used in calculations for determining the final Integrity scores for comparison of scenarios.

C.5.6.4 Abundance / Integrity relationships

For each indicator at each site, the user needs to indicator whether an increase or decrease in the abundance of the indicator is an improvement in condition: in the case of biophysical indicators, this is a move towards natural, and in the case of socio-economic indicators this means an improvement in socio-economic terms. This is done by entering clicking «*Edit*», and either typing T (towards will be filled in) or A (away will be filled in) or selecting from the drop-down box (F)



Appendix Figure 71 Specifying the relationship between abundance and Integrity.

C.6. Analysis

ANALYSIS is for comparing the results for the scenarios. It also allows for the creation of synthetic flow scenarios for further analysis should these be required for any reason.

There are two groups of modules in **ANALYSIS**: [***Integrity linked flows***], which is used to generate synthetic flow regimes to meet particular ecosystem targets for further analysis in the system, and in [***Scenario outcomes***], which tabulates and graphs the results.

C.6.1. Integrity linked flows

The "Integrity linked flows" group of modules is used to generate a recommended EF regime to meet a pre-defined target ecosystem integrity.

For example, a particular site / zone might currently be in a B condition (PD category=B), but the operation of a proposed new development (Scenario 1) may result in a new predicted condition of a D (Scenario 1, category = D). In order to facilitate decision making however, it may be necessary to know the EF regime that would maintain the river in a B category and if that would be possible with the proposed new development in place. This group of modules allows for the creation of range of flow regimes to meet a variety of future ecosystem conditions.

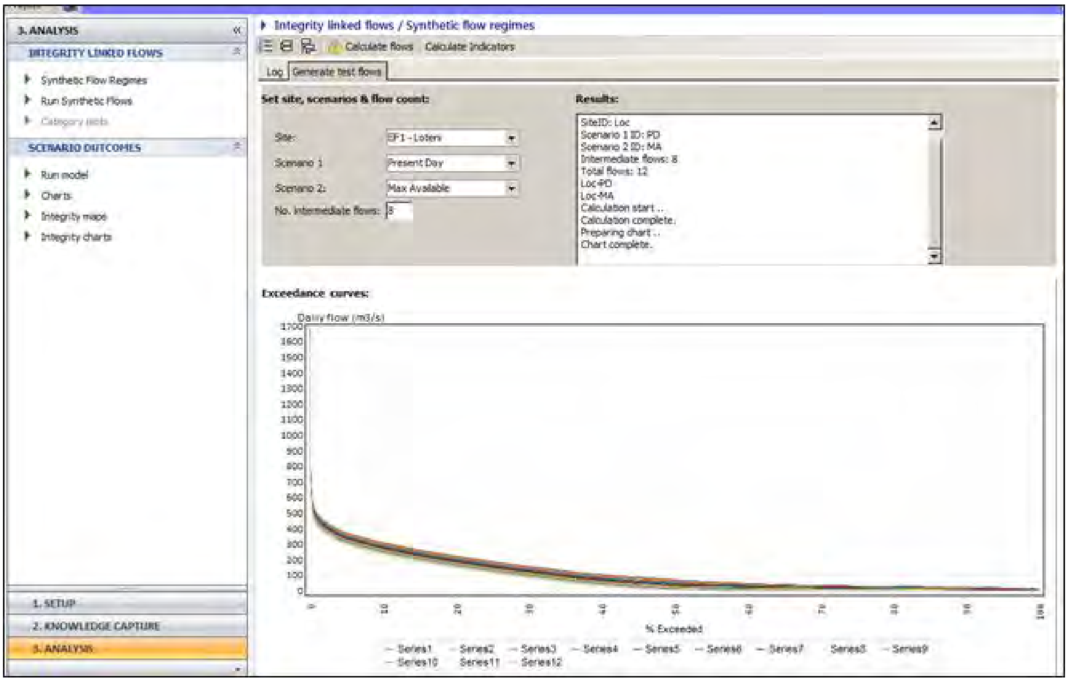
Technical details are provided in Appendix B. This component is not required for every EFA.

C.6.1.1 Synthetic flow regimes

In this module, a range of 'synthetic[14]' flow regimes are created by interpolating between 'worst' case and 'best' (usually natural or close thereto) case flow regimes, and combinations of high and low flows from the interpolated regimes (see Appendix B for details).

To start the process, click on the <*Generate test flows*> tab and select the site from the drop-down box (Appendix Figure 72). Two "starter scenarios" can then be selected which encompass the range of abstraction and / or restorations flow regimes between which new synthetic flow regimes will be created (additional scenarios are also created on either side of these).

Once these have been selected, the synthetic flow regimes are created by clicking «*Calculate flows*». The flow duration curves for all the new scenarios appear in the graph below. The graph can be examined more closely by "zooming" the scale by clicking in the top right corner of the graph, and holding the click down, drag the mouse down and to the right (i.e. forming a rectangle encompassing the zoomed range). If you only want to zoom the y-axis scale then make sure to make the width of the rectangle the same as the length of the x-axis. To zoom out again, reverse the action: i.e. click somewhere in the bottom, left area of the graph, and drag towards the top, right in an appropriately sized rectangle.



Appendix Figure 72 **Selecting sites and starter scenarios for creating synthetic flow regimes from which to choose a flow regime meeting a specified ecological integrity target,**

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[14] Hypothetical, artificially constructed.

Once the synthetic flow regimes have been generated, the flow indicators for them are calculated by clicking on «*Calculate indicators*».

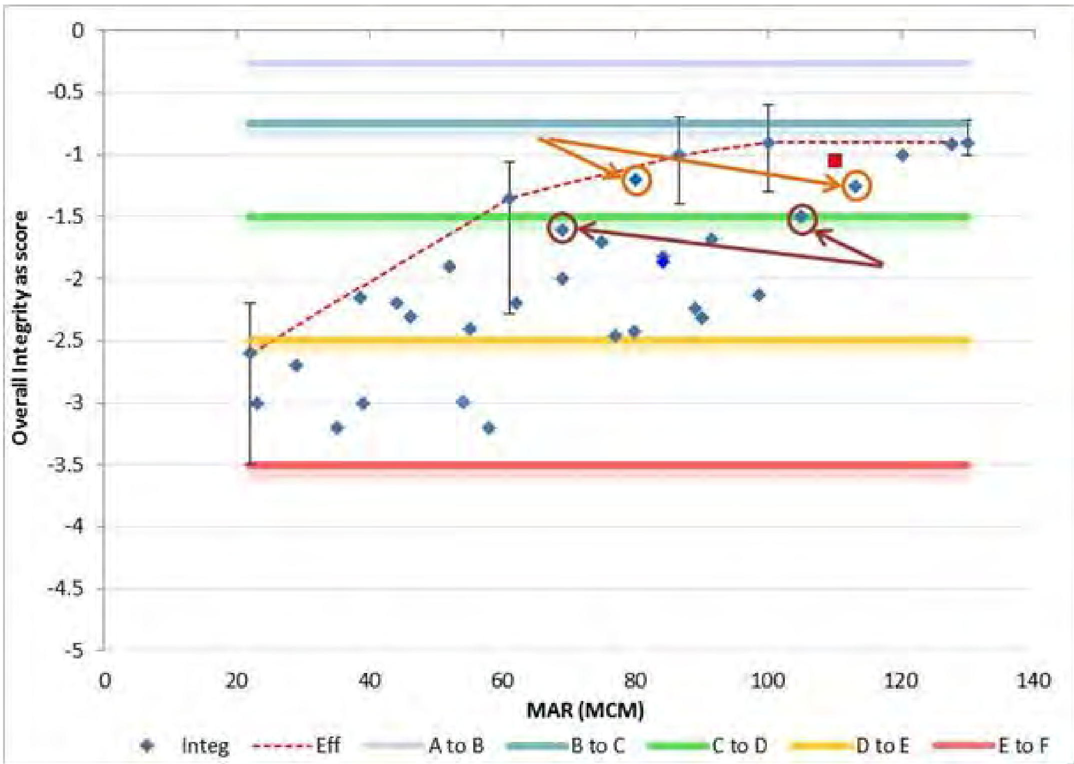
C.6.1.2 Run synthetic flows

Once the synthetic flow regimes have been generated and flow indicators calculated, the synthetic scenarios are 'run' through the response curve module to calculate responses for all regimes in [*Run synthetic flows*]. Abundance and Integrity scores are calculated for each synthetic flow regimes.

C.6.1.3 Category plots

The Integrity results of all the synthetic flow regimes can be viewed in a variation of the "Integrity plot", called a "Category plot" which shows the ecosystem integrity ratings of all the synthetic flow regimes (y-axis) against the MAR of each of those scenarios (x-axis) and includes the horizontal lines showing the transitions from one ecological Category to the next.

By examining this plot, the user can select one which achieves the target category, and uses the least amount of water (lowest MAR) (Appendix Figure 73).



Appendix Figure 73 **Category plot: Integrity of synthetic flow regimes vs. MAR, and ecosystem condition Categories. PD scenario is shown as the red square. The efficient frontier (red dotted line) envelopes where the highest Integrity score /lowest MAR combination is found.**

C.6.2. Scenario outcomes

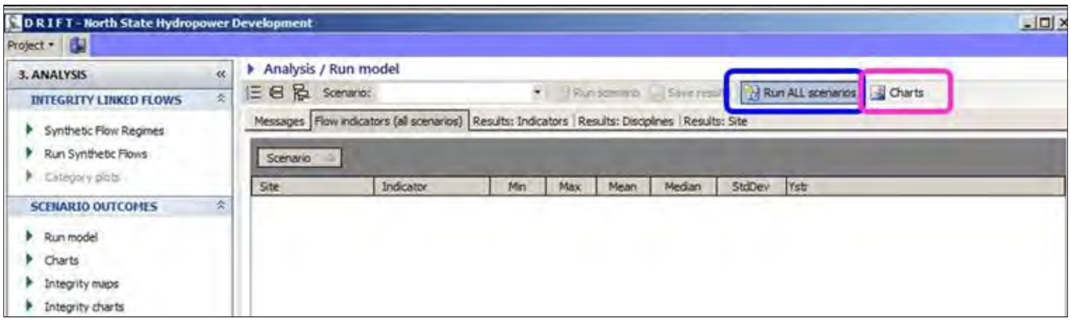
The scenario outcomes group of modules, finally, runs all the information through the model, and, for all scenarios, calculates the time-series of responses (e.g. changes in abundance over time), the changes in ecosystem condition and social well-being and displays this information in a number of different ways.

There are four modules in this group, [*Run model*], [*Charts*], [*Integrity maps*], and [*Integrity charts*].

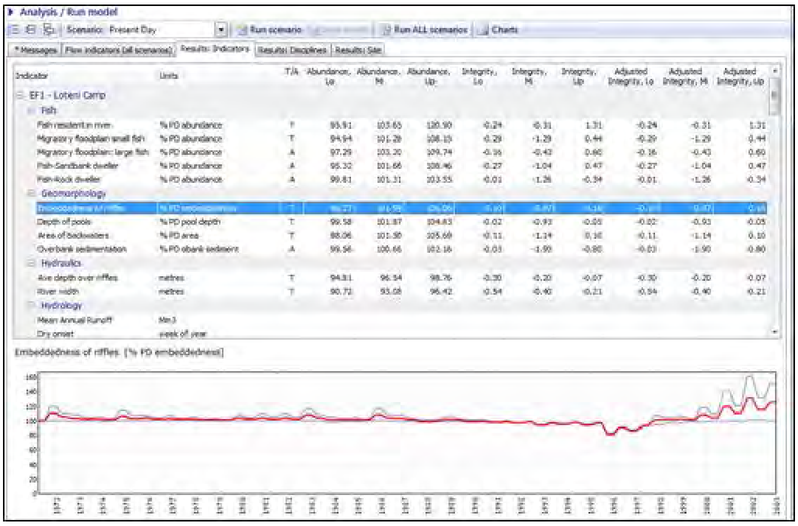
C.6.2.1 Run model

C.6.2.1.1 Run all scenarios

The user needs to click «*Run all scenarios*» in the menu bar (Appendix Figure 74). Tabular results (per scenario) can then be viewed for scenarios, by indicator (also shows time-series), by discipline or by site, by clicking on the appropriate tabs and arranging the information as needed using the menu-items for re-arranging groups, etc. (e.g. Appendix Figure 75).



Appendix Figure 74 **Initial window for ANALYSIS [*Scenario outcomes*] [*Run model*], showing the «Run all scenarios» menu item (blue circle) and the «Charts» menu-item (pink circle).**



Appendix Figure 75 **Results: Indicators tab, showing a particular arrangement of results: the results for one indicator in geomorphology at site 1, for the present day scenario.**

C.6.2.1.2 *Charts*

Often the more interesting way to view results is to view the time-series for one indicator for all scenarios on one graph. This can be done by clicking the «*Charts*» menu item in the menu bar (see Appendix Figure 75 pink circle for the location of the button). When the Charts window opens, the user selects a site from the drop-down list in the menu bar, and the relevant discipline tab, and all indicators' time-series for all indicators can be viewed by scrolling down the window Appendix Figure 76. A second Charts window can be opened from here, allowing the user to view two disciplines at a time, for example.

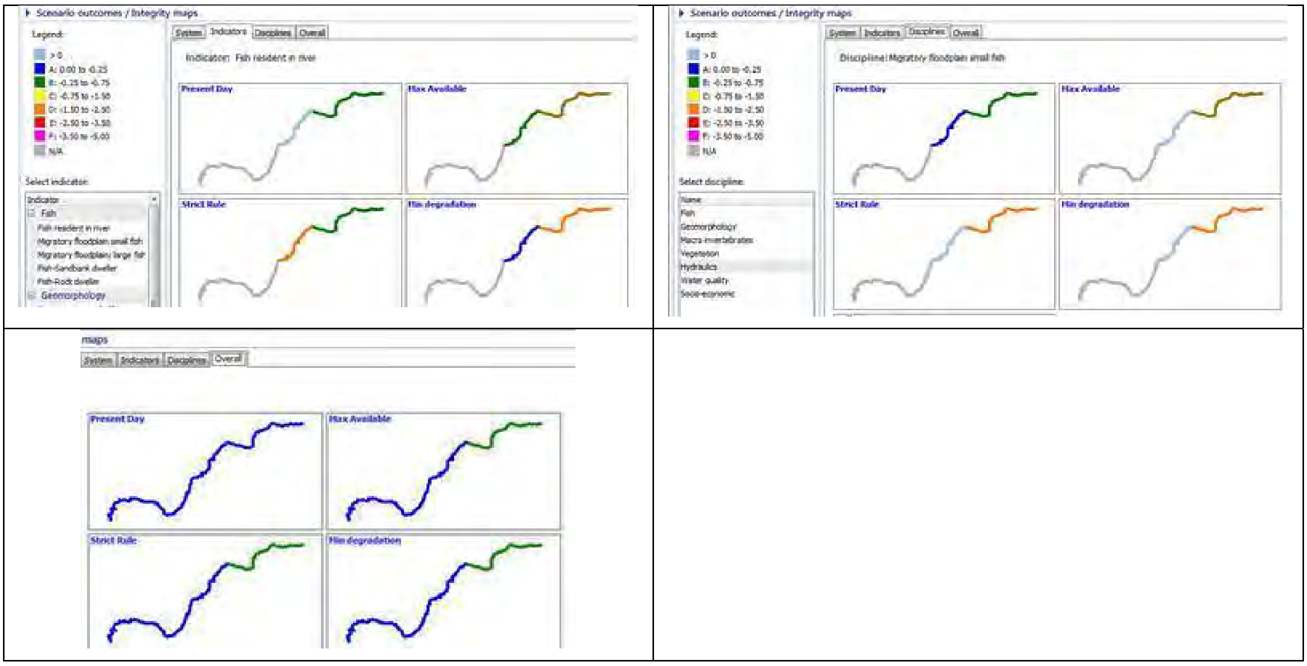
Appendix Figure 76 **[*Run model*] «*Charts*» window showing the result for all scenarios on one graph.**

C.6.2.2 Charts

This sub-module produces the same window as that opened when clicking «*Charts*» as described in Section C.6.2.1.2.

C.6.2.3 Integrity maps

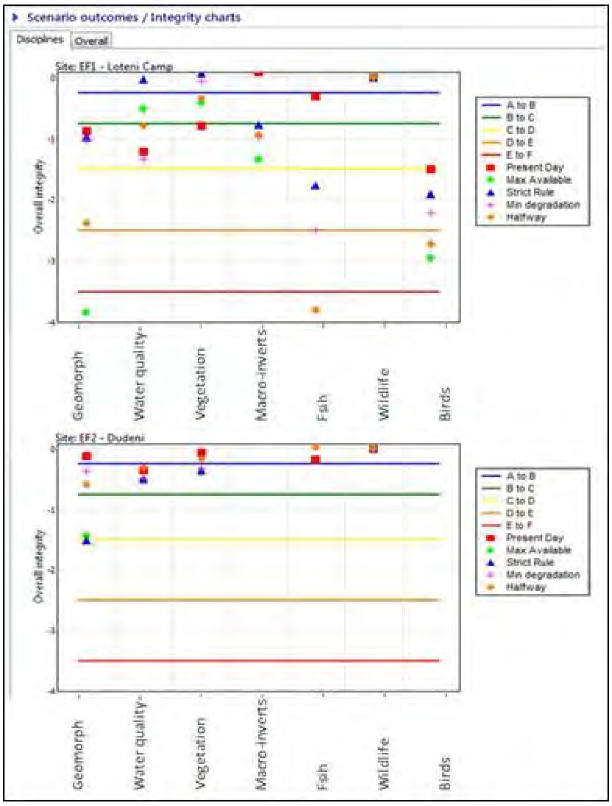
Integrity maps show the Integrity results for all scenarios for the river zones, for each indicator, for each discipline, and for the basin as a whole, by clicking on the different tabs, and scrolling down the list of indicators or disciplines listed on the left hand side of the window (Appendix Figure 77).



Appendix Figure 77 **Integrity maps for indicators (top left), disciplines (top right) and basin (bottom).**

C.6.2.4 Integrity charts

Similarly, Integrity plots can be viewed for disciplines and overall (Appendix Figure 78) by clicking on the relevant tabs under [*Integrity charts*].



Appendix Figure 78 **Integrity plots for disciplines.**

C.7. References

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