ENVIRONMENTAL FLOW ASSESSMENTS FOR RIVERS

A SUMMARY OF
THE DRIFT PROCESS

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GENERAL INFORMATION

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GLOSSARY

Baseflows:	A hydrological term referring to the proportion of the flow in the river contributed by groundwater.
BBM:	The Building Block Methodology (King and Louw 1998).
DRIFT:	Acronym for the EFR Process described in this report. DRIFT = Downstream Response to Imposed Flow Transformations.
Highflows:	Term used in the DRIFT process for peaks in the daily hydrograph relative to the lowflows occurring at that time (see lowflows below).
EFR:	Environmental flow requirements (also referred to as Instream Flow Requirements). This refers to the magnitude, duration, timing and frequency of a range of flows required to facilitate maintenance of a riverine ecosystem in some pre-determined condition.
Lowflows:	Term used in the DRIFT process for the parts of the daily hydrograph between highflows.
MAR:	Mean Annual Runoff.
masl:	Metres above sea level (elevation).
MCM:	Million cubic metres (of water).
Minimum degradation:	The level of water abstraction at which mild effects will occur that are deemed insufficient to materially affect the current functioning of the river ecosystem.
PAR:	Population at Risk; the human community living alongside the river and dependent on it for subsistence.
Q:	Discharge, or the volume of streamflow per unit time past a point ($m^3 s^{-1}$).

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- The LHDA Panel of Experts for Lesotho Highlands Water Project Contract No. LHDA 648.
- The Southern Waters' sub-consultants on the Palmiet River IFA.
- Project Planning Division, South African Department of Water Affairs.
- The South African Water Research Commission.

1 INTRODUCTION

1.1 WHAT IS DRIFT?

DRIFT (an acronym for Downstream Response to Imposed Flow Transformations) is an Environmental Flow Assessment (EFA) process that was developed by Southern Waters for the assessment of environmental flows for the Lesotho Highlands Water Project. It was developed in liaison with SMEC International (Australia) and the team of biophysical and socio-economic specialists brought together for that project (Metsi Consultants 2000). An earlier version of DRIFT was also used to determine the environmental flows for the Palmiet River in the Western Cape, South Africa (Brown *et al*. 2000).

The methodology arose from, and its initial data-collection steps closely approximate those of, the Building Block Methodology (BBM, King and Louw 1998). Like the BBM, DRIFT is a holistic approach, addressing all biophysical aspects of the river of concern. Both employ a multidisciplinary team in a workshop environment to compile a modified flow regime that will help maintain some required river condition.

There are three primary differences between the two processes.

- DRIFT is a scenario-based interactive approach, in which a database is created that can be queried to describe the biophysical consequences of any number of potential future flow regimes (scenarios). It is designed specifically for use in negotiations over water resources. The BBM is a prescriptive approach that requires identification of a single predetermined condition, after which a single flow regime is described to facilitate maintenance of that condition.
- The BBM "builds up" a recommended flow regime from scratch, whereas DRIFT takes the present-day flow regime as a starting point, and describes the consequences for all aspects of the river of further reducing (or, if relevant, of increasing) the flow regime in different ways.
- DRIFT is designed to detail and quantify the links between changing river condition and the social and economic impacts for the riparian people who rely on the river for subsistence (Population at Risk or PAR).

1.2 THIS REPORT

This report provides a summary of the DRIFT process.

It is not intended as an exhaustive description, but rather as a general summary of the concepts and procedures of the process, with an emphasis on the biophysical aspects.

This report assumes that the reader has a working understanding of holistic approaches, such as the BBM. The description of the process presented here commences after the data collection phase. As already mentioned, the earlier phases, *viz.* site selection and data collection, approximate those of the BBM, which are outlined in King and Louw (1998) and Tharme and King (1998), and given in detail in King *et al*. (in press).

1.3 PEER REVIEW OF THE DEVELOPMENT OF DRIFT

Development and application of DRIFT was subject to extensive review by an International Panel of Experts, contracted by the Lesotho Highlands Development Authority, and by the environmental staff of the World Bank.

1.4 PLANS FOR THE FUTURE

At present, Southern Waters is under contract to the South African Water Research Commission to continue the development of DRIFT.

2 OVERVIEW OF DRIFT

2.1 ASSUMPTIONS AND MAIN ACTIVITIES

DRIFT is essentially a data-management tool, allowing data and knowledge to be used to their best advantage in a structured way. Within DRIFT, component-specific methods are used by each specialist to derive the link between river flow and river condition (biophysical), or between changing river condition and social and economic impact (socio-economic).

The central rationale of DRIFT is that different aspects of the flow regime of a river elicit different responses from the riverine ecosystem (Table 2.1). Thus, removal of part or all of a particular element of the flow regime will affect the riverine ecosystem differently than will removal of some other element. Furthermore:

1. it is possible to identify and isolate these elements of the flow regime from the historical hydrological record (Section 3);

Table 2.1 Different kinds of river flow and their importance to ecosystem functioning (from Brown and King in press).

The normal lowflows in the river outside of floods.	Lowflows define the basic seasonality a rivers – its dry and wet season, whether it flows all year or dries out for part of it. The different magnitudes of lowflow in the dry and wet seasons create more or less wetted habitat and different hydraulic and chemical conditions, which directly influence what the balance of species will be in any season.
Freshes: small floods that occur several times within a year.	Defined here as small pulses of higher flow, freshes are usually of most ecological importance in the dry season. Smaller floods stimulate spawning in fish, flush out poor quality water, mobilise sandy sediments, and contribute to flow variability. They re-set a wide spectrum of conditions in the river, triggering and synchronising activities as varied as upstream migration of fish and germination of riparian seedlings.
Large floods that occur less often than once a year.	Large, scouring floods dictate the form of the channel. They mobilise sediments and deposit silt, nutrients and seeds on floodplains. They inundate backwater areas, and trigger the emergence of flying adults of aquatic insects, which provide food for fish, frogs and birds. They maintain moisture levels in the banks, which support trees and shrubs, inundate floodplains, and scour estuaries thereby maintaining the link with the sea.
Flow variability.	Variability of flow is essential for a healthy ecosystem. Different conditions are created through each day and season, controlling the balance of species and preventing dominance by pest species.

2. it is possible to describe the probable biophysical consequences of partial or whole removal of a particular element of the flow regime, in isolation (Sections 4 and 5);
3. once these biophysical consequences have been described, it is possible to combine them in various ways to describe the overall impact on river condition of a range of potential flow regimes (Section 6);
4. once the potential changes in river condition have been described, it is possible to describe their socio-economic implications (Section 7);

The DRIFT process involves a number of river-related biophysical and socio-economic activities. At present these are centered in two major workshops, but it is envisaged that much of the work could eventually be done by the specialists prior to much shorter “wrap-up” workshops.

There are eight main activities in DRIFT (post data collection).

1. Preparation of the hydrological data and derivation of summary statistics.
2. Linkage of the hydrological statistics to cross-sectional river features at a number of representative river sites.
3. Reduction of different flow components in a structured series, and description of the biophysical consequences.
4. Entry of the consequences into a custom-built database.
5. Querying the database to describe the changes in river condition caused by one or more potential flow regimes (scenarios).
6. Identification of the social impacts of each scenario.
7. Calculation of the economic cost of compensation and mitigation for each scenario.
8. Calculation of the impact on system yield for each scenario.

2.2 DISCIPLINES REPRESENTED IN DRIFT

The disciplines represented vary depending on the requirements of the particular project. In general, the biophysical specialist team will consist of representatives of the following disciplines:

- Hydrology
- Hydraulics and physical habitat
- Water quality
- Geomorphology/sedimentology
- Botany
- Macroinvertebrate ecology
- Ichthyology

Specialists in aquatic parasites, algae, aquatic and semi-aquatic mammals and birds, and herpetofauna may also be included on the biophysical team, depending on the specific requirements of the EFA.

Similarly the composition of the socio-economic team is project-specific, and may include specialists in sociology, anthropology, public health, animal heath, resource economics, scheme economics and public participation.

3 PREPARING THE HYDROLOGICAL DATA

For DRIFT, the historical and present-day daily time series for each EFR site are separated into lowflow and highflow datasets, using a suitable technique (software being developed). These data sets are analysed to produce summary statistics.

Several standard hydrological baseflow separation algorithms exist, which create a daily "baseflow" time series, i.e., separate baseflows from flood events (e.g., Nathan and McMahon, 1990; Boughton, 1993; Hughes *et al*., 1994; Chapman and Maxwell, 1996). These algorithms reflect the hydrological definition of baseflow as the flow in the river that is contributed by ground water. Thus, with the first highflow events of the wet season, the algorithms predict very little baseflow contribution (when the catchment is dry) and high baseflow contribution at the end of summer (when the catchment is saturated). DRIFT, however, requires consideration of the actual water levels in the river at any given time, rather than the extent to which that flow was contributed by surface runoff or ground water seepage. Thus, we drew a distinction between the hydrological term “baseflow” and what may be seen as an ecological term “lowflows”, where lowflows are defined as “*the flow residing in the river outside of the highflow events*’’. This entails separation of the hydrological time-series into its lowflow and highflow elements.

After the separation procedure, a number of hydrological statistics are derived.

- The lowflow time series is divided into two (or more) lowflow seasons: a dry lowflow season and a wet lowflow season. These should be chosen after consultation with the specialists.
- The percentage of the time that lowflow conditions prevailed during each season is determined by expressing the number of days of lowflow as a proportion of the total number of days in that season.
- Using these data, flow duration curves are constructed for the lowflow data sets for each season.
- For the highflow events, the month in which each event occurred is recorded, as is its magnitude, volume and duration. All highflow events are then allocated to a within-year group or a group with a return period of 1:2 years. They are then further allocated by size to one of four classes within each group.

As a general rule, halving the magnitude of a highflow event results in a significant change in the physical capabilities of the event in terms of moving sediments (A. Rooseboom, Dept. Civil Engineering, Stellenbosch University, pers. comm.). Thus, the four within-year classes of high flow events are usually identified by consecutive halving of the 1:2 year event, as follows:

Size class 4: 0.5 x magnitude of the 1:2 year - magnitude of the 1:2 year flood.
Size class 3: 0.25 x magnitude of the 1:2 year - 0.5 x magnitude of the 1:2 year flood.
Size class 2: 0.125 x magnitude of the 1:2 year - 0.25 x magnitude of the 1:2 year flood.
Size class 1: upper limit of the minimal degradation dry season lowflow discharge - 0.125 x magnitude of the 1:2 year flood.

The higher-magnitude events are:
Size class 8: greater than or equal to the magnitude of the 1:20 year flood.
Size class 7: magnitude of the 1:10 year flood - magnitude of the 1:20 year.
Size class 6: magnitude of the 1:5 year flood - magnitude of the 1:10 year.
Size class 5: magnitude of the 1:2 year flood - magnitude of the 1:5 year.

At the end of these analyses, summary statistics will be available on:

1. the range of lowflows in each lowflow season
2. the percent of time that any particular lowflow is equalled or exceeded
3. the duration, temporal distribution, average number per year and average volume of all size classes of floods.

4 LINKING HYDROLOGICAL STATISTICS TO CROSS-SECTIONAL RIVER FEATURES

The maximum and minimum values (1st and 99th percentiles) of the dry-season and wet season lowflow duration curves are converted into depths and marked on surveyed cross-sections of each river site (Figure 4.1). The cross-sections also contain information such as vegetation zones and kinds of substrata. Flow duration curves illustrate how often any cross-section feature is exposed or inundated.

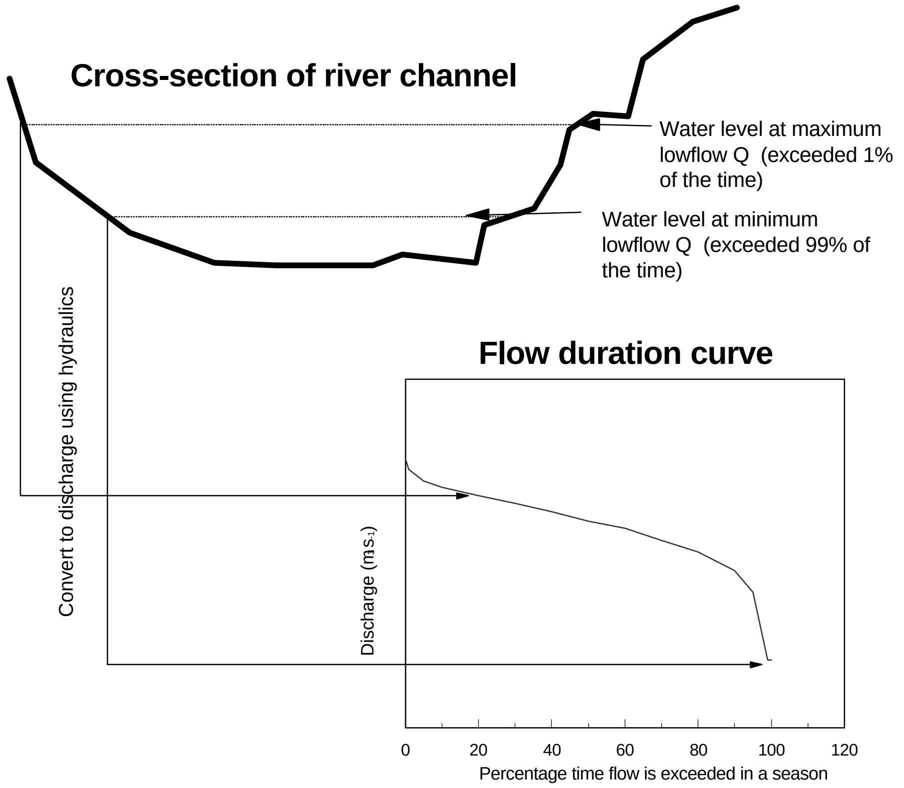

Figure 4.1 The range of lowflow discharges that occur during a wet or dry season, expressed as water depths shown on one or more cross-sections of the river channel at each EFR site. The amount of time that the river was at or above a particular level may be derived from the flow duration curve.

The water depths corresponding to the boundaries of each of the eight highflow size classes are also marked on the cross-sections (Figure 4.2). Pertinent hydraulic statistics associated with each size class, such as average water depth, average velocity, wetted perimeter and wetted area are derived by the hydraulic modeller.

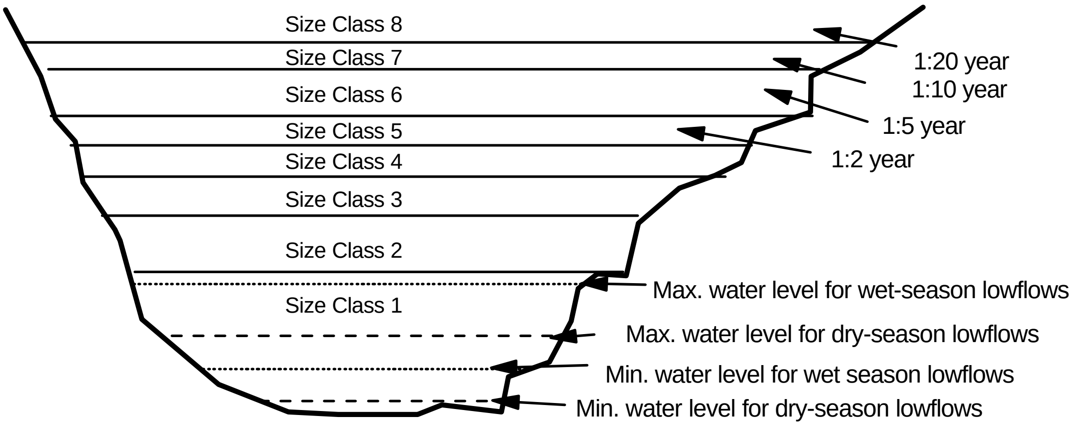

Figure 4.2 An hypothetical example of the range of water depths delineated by the various hydrological statistics, shown on a cross-section of river channel.

5 REDUCTION OF FLOWS AND DESCRIPTION OF BIOPHYSICAL CONSEQUENCES

5.1 FLOW REDUCTIONS

In the biophysical workshop, the various parts of the flow regime are reduced in a structured series and the consequences of each reduction described.

Lowflows are reduced in their **range** and thus **variability**. The reductions are made to the top end of the lowflows with the reduction to minimal degradation level being described first. The predicted biophysical consequences of a further structured series of reductions to the top end of the lowflows are then described. Each consequence is assigned a rating from 1 to 5 indicating severity of change. Uncertainty is expressed through a range of ratings instead of a single value.

High flows are reduced in their **numbers**. Numbers of highflows in each class that could be harvested with minimal degradation to the ecosystem are identified first. The biophysical consequences of further reductions in the number of high flow events are then described, along with their severity ratings.

In summary, the consequences of the following reductions are compiled:

- wet season lowflows – range reduced through four levels, with the first being identified by specialists as “minimum degradation”;
- dry season lowflows – range reduced through four levels, with the first being identified by specialists as “minimum degradation”;
- Size Class 1 of within-year highflow events – number of events per year reduced up to four times, with the first being identified by specialists as “minimum degradation”;
- Size Class 2 of within-year highflow events – number of events per year reduced up to four times, with the first being identified by specialists as “minimum degradation”;
- Size Class 3 of within-year highflow events – number of events per year reduced up to three times, with the first being identified by specialists as “minimum degradation”;
- Size Class 4 of within-year highflow events – number of events per year reduced up to two times, with the first being identified by specialists as “minimum degradation”;
- highflow events with a return period of 1:2 years – present or lost;
- highflow events with a return period of 1:5 years – present or lost;
- highflow events with a return period of 1:10 years – present or lost;
- highflow events with a return period of 1:20 years – present or lost.

5.2 BIOPHYSICAL CONSEQUENCES

A biophysical consequence is the predicted response of a specific sub-component of the riverine ecosystem (e.g., species, community or feature) to a reduction in a single aspect of the hydrological regime. When the consequences of any flow reduction are being described, it is assumed that all other components of the flow regime remain unchanged. These individual descriptions of consequences are used later in different combinations to build scenarios describing the consequences of any potential change in the whole flow regime.

Section 5.2.1 provides a summary of the general procedures used to derive the consequences. The methods adopted by each biophysical specialist to develop flow-related relationships for their discipline are not dealt with here.

5.2.1 Consequences of lowflow reductions

The hydraulic information enables the specialists to assess the variations in depth, velocity and inundation that are occurring over key habitats during a season. Each specialist links this information to data specific to their component that have been collected along the same cross-sections, or elsewhere at the sites, to predict how flow reductions might cause ecosystem change.

The first reduction considered is the degree to which lowflows can be reduced with only minimum degradation of the ecosystem. The specialists use the marked cross-sections to assess how far, if at all, the range of lowflows could be reduced without significant effects on the functioning of the riverine ecosystem (Figure 5.1).

The minimum degradation water level is converted to a discharge value and expressed in terms of how often it is exceeded under present-day conditions. For example, in Figure 5.1, the flow percentile value of the possible minimal degradation level is 30%. The full interpretation of this is that for 30% of the time outside of highflow events in the wet season, this flow is exceeded, and thus for 70% of the same time set, the area above this level is exposed.

Lowflow discharges that occur in the present-day hydrological record and that are lower than the designated minimal degradation water level would continue to occur at the same frequency and thus some flow variability would be maintained. The minimal degradation water level is simply a threshold value, and the volume of water that would have resulted in this threshold being exceeded would (theoretically) be available for abstraction during periods of lowflow (Figure 5.2).

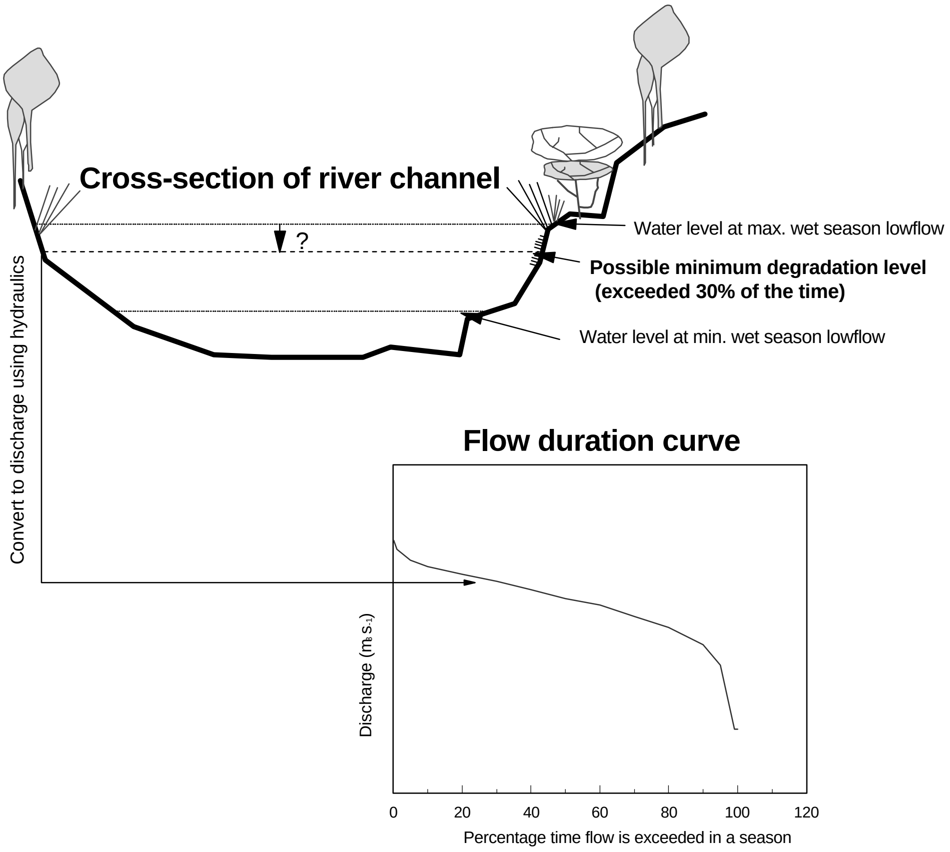

Figure 5.1 Setting the flow reduction level for minimum degradation: the range of wet season lowflows was reduced by eliminating the discharges at the top end of the range. The new maximum discharge was expressed as a flow percentile on the current-day flow duration curve.

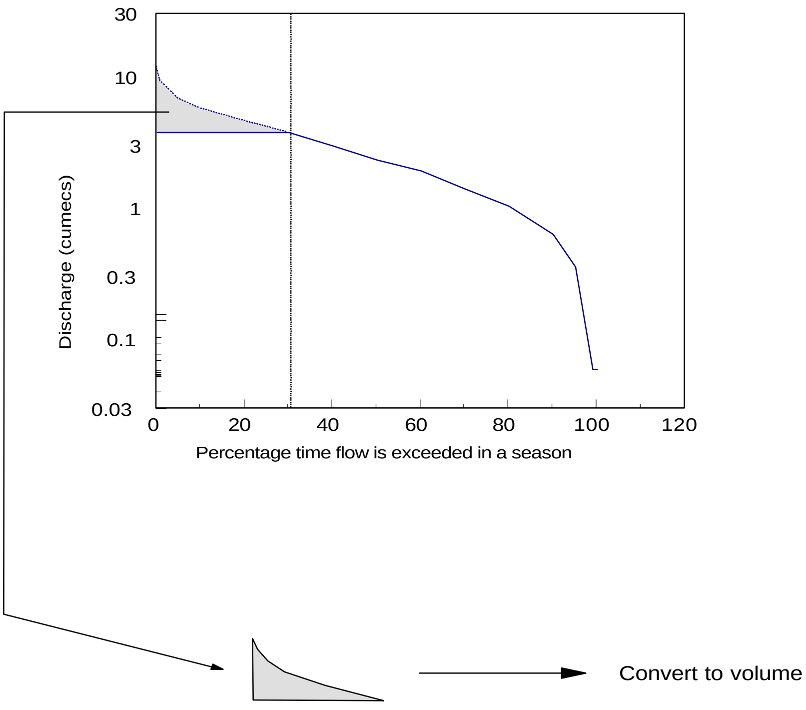

Figure 5.2 Calculation of the water volume involved in a flow reduction level: the volume of water above the threshold would be available for abstraction (see Figure 5.1).

Thereafter, three additional levels of reduction are considered by further reducing the top end of the lowflow range. In each of these reductions, the lowflow discharges that occur in the present day that are lower than the designated reduction level would continue to occur at the same frequency, but the flows above the designated level are considered to be lost.

5.2.2 Consequences of highflow reductions

Initially, the specialists describe how the highflows in each size class affect ecosystem functioning. These effects can be biological, physical or chemical in nature. For instance, whereas the large 1:20 year events may dictate the shape of the channel, the smaller within-year events act as biological cues and have much less effect on channel shape. Once they have described the effects of each size-class flood, the specialists describe the consequences of a reduced frequency of events in each size class and of such events no longer occurring.

For instance, if six Class 3 floods occur on average per year, the consequences are described by each specialist of the following reductions:

- three events instead of six;
- one event instead of six;
- no events instead of six.

At each reduction level the remaining events are allocated to one or a range of calendar months, with reasons.

5.2.3 Generic lists

Consequences are given for every item of concern to each specialist. To ensure structure to this procedure, each specialist develops a generic list of items of concern (Table 5.1). At each flow reduction level, the consequence for each item on each generic list is described.

5.2.4 Severity levels and uncertainty

Each consequence is assigned a severity rating indicating the degree to which the generic-list item is predicted to change in abundance. The direction of change can be an increase or decrease and the ratings range from 0 (no change) to 5 (critically severe change). To make the link through to the socio-economic calculations, the severity ratings are converted to percentages. Each specialist provides his/her individual conversions. For instance, for Specialist A, a severity rating of 3 may refer to a 41-60% change in abundance, whilst for Specialist B it may refer to a 21-50% change.

Table 5.1 Examples of the information provided in the generic lists for different components of the riverine ecosystem

Sub-component	Physical significance	Ecological significance	Social significance
Geomorphology			
Colloidal sediment deposition	Small particles (clay sized) that are carried in colloidal suspension. They will be deposited only in areas where flow velocities are extremely low. Thick deposits can be found especially in enclosed pools adjoining streams. This is the only component of the total sediment load that will pass through a reservoir and hence the colloidal load increases proportionately downstream of dams. Once clay deposits become consolidated then high velocities are required to remobilise these. At times colloidal material may form a 'fluffy' layer at the sediment – water interface.	- Smothers or blankets in-channel habitat areas. - Changes the substratum texture. - Influences nutrient dynamics in pools and backwater areas. - Influences water quality especially turbidity.	Increased mud in a river has a number of deleterious effects: - river crossings are more slippery for people and animals; - the chance of bogging of people and animals will be increased; - mud is an important factor for animal foot rot; reduces the condition of wool and animal fur and is an excellent breeding ground for disease vectors.
Water quality			
pH	pH seldom seemed to be flow related. If metal ion pollution ever became a problem (which is unlikely)- pH governs metal ion availability and therefore toxicity.	Although it is unlikely, fish and macroinvertebrates could be affected if metal ions reach toxic levels.	Impacts related to toxicity of metal ions. Unlikely to be a major issue.
Botany			
Trees in the dry bank zone	Respond to flood events, primarily the large within-year floods, the 1:2 and the 1:5 year events.	Decrease in density with a decrease in floods. Plants at back of zone under increasing water stress; roots unable to develop deeper because of insufficient water at root depth.	Reduction in plant abundance
Macroinvertebrate ecology			
Cheumatopsyche thomasseti	Prefers swift velocities of flow in excess of 1 m s^{-1}.	A filter feeder, which is an important predator of blackflies and in particular *Simulium chutteri*.	Water purification value and a species able to contain population growth of pest blackflies. See 7.

Uncertainty is expressed through the range of severity ratings given for an item. As shown above, each rating already encompasses a range of change. In addition, if the uncertainty is greater than that already contained in the severity rating, a range of severity ratings is provided, e.g., 2-4. This effectively increases the spread of predicted percentage change, e.g., if rating 2 = 5-24%, and rating 4 = 51-75%, then ratings 2-4 would translate to an expected change of anywhere between 5 and 75%.

6 CREATING A BIOPHYSICAL SCENARIO

6.1 NATURE OF A 'CONSEQUENCE' ENTRY IN THE DATABASE

Each biophysical consequence, as entered into the database, consists of (Table 6.1):

- the EFR site under consideration;
- the element of the flow regime under consideration (e.g., wet season lowflows or Size Class 3 highflow events);
- the level of reduction being considered;
- the component of the riverine ecosystem under consideration (e.g., geomorphology);
- the sub-component of the riverine ecosystem under consideration (e.g., formation of sand bars);
- the direction of expected change (i.e., increase or decrease);
- the severity of the expected change;
- the conversion of the severity rating to a percentage range;
- the ecological explanation for the expected change, as well as expected knock-on effects, such as riffle sedimentation leading to possible spawning failure in fish;
- an indication of the possible social implications of the expected change.

Table 6.1 An example of the information contained in a biophysical 'consequence' entry into the database.

Site	Flow aspect	Reduction Level	Component	Sub-component	Result	Sev.	%	Ecological Comment	Social Comment
EFR 7	Size Class 1 – within-year floods	Level 1	Geom.	A reduction in the frequency of inundation of lower bar surfaces.	Decrease	3	25-50	Regular in-channel accumulations of sediment occur within the constrained zone because of lower sediment transport efficiencies. Large, mobile sediment bars are a dominant feature of the in-channel environment, occupying up to 75 % of the active channel.	Important source of coarse (rough) sand and mud for building.

6.2 USING THE DATABASE TO COMPILE A SCENARIO

Biophysical scenarios consist of:

- a potential future flow regime described at the level of daily flows (the EFR);
- a description of river condition under this flow regime, with each ecosystem component described separately;
- the monthly volumes of water (separated into highflows and lowflows) encompassed in that flow regime;

- the monthly volumes of water thus potentially available for abstraction from the river.

At a later stage, the following are added to create a full EFR Scenario (see Section 7):

- the social impacts of that river condition for the Population at Risk (PAR);
- the economic costs of mitigation and compensation for the PAR.

Compilation of biophysical scenarios begins with reaching agreement with the client on the number and nature of possible future flow regimes they would like considered. These flow regimes are simulated at a daily time step and the flow reduction levels that they represent identified. The biophysical consequences of these reduction levels are then selected from the database and combined to give an overall description of the predicted change in river condition. For instance, a future simulated flow regime under Scenario X could indicate that:

- wet season lowflows will be reduced to the Level 2 range;
- dry season lowflows will be reduced to the Level 3 range;
- within-year floods of Size Classes 1 and 2 will be reduced to one of each;
- within-year floods of Size Classes 3 and 4 will be lost completely,
- flood events with a return period 1:2-year will still occur.

The consequences linked to these flow levels would then be combined to create a biophysical scenario.

6.3 TYPES OF BIOPHYSICAL SCENARIOS

Biophysical scenarios are derived from many possible starting points. The following three are common.

TYPE 1: A VOLUME OF WATER (e.g., % of MAR) IS SPECIFIED THAT COULD BE LEFT IN THE RIVER. The flow regime that would provide the best river condition for this volume of water is described.

TYPE 2: A CONDITION IN WHICH THE RIVER SHOULD BE MAINTAINED IS SPECIFIED. In these cases, the amount of water required to facilitate maintenance of the river in the desired condition is described.

TYPE 3: A VOLUME DICTATED BY A MIX OF DESIGN LIMITATIONS OF THE DAM AND OF ABSTRACTION LIMITATIONS IS SPECIFIED. In these cases, flow reduction levels are dictated by release structures and or extant water allocations, and the resultant river condition is described.

6.4 DATA HANDLING AND SCENARIO PREPARATION

A prototype DRIFT biophysical database, designed specifically to handle the quantity and complexity of the biophysical consequence data, has been developed. Because all consequences are entered with individual explanations and severity ratings, the complete extracted data set for any one scenario requires synthesis and interpretation by a river ecologist to provide an overall description of ecosystem change.

7 SOCIO-ECONOMIC IMPLICATIONS OF THE BIOPHYSICAL SCENARIOS

The socio-economic specialists follow their own specialist studies, and link with the biophysical activities at several points.

Before the Biophysical Workshop they ensure that the river scientists are including in their field studies all the river features or species of social importance.

At the Biophysical Workshop, they:

- provide information on the significance of these river features and species, and ensure that they are addressed during the deliberations;
- develop an understanding of the links between river functioning and these river features or species;
- ensure that the biophysical information is produced in a manner that allows them to predict the social implications.

Once the biophysical scenarios have been compiled, they attend a Socio-economic Workshop where they:

- predict the socio-economic consequences of each scenario;
- check to ensure that the links between biophysical and sociological information have been made correctly and are consistent;
- check to ensure that the links between the various sociological disciplines, e.g., sociology, animal and public health, water supply and economics, have been made correctly and are consistent;
- identify appropriate mitigation and compensation measures.

The methods adopted for each socio-economic component are not dealt with here.

The social specialists do not create a database similar to the DRIFT biophysical database. This is because the social implications that are described are scenario specific. The significance of this is that, whereas additional biophysical scenarios can be derived from the DRIFT database, the social implications have to be assessed anew by the social team.

8 CALCULATING THE ECONOMIC COST OF COMPENSATION AND MITIGATION

Once the sociologists have identified the social impacts of the biophysical change, the economist calculates the costs of mitigation of and/or compensation for those impacts. Costs are only calculated for changes that will adversely affect the PAR.

8.1 MITIGATION

Mitigation can be defined as changes to project design, operation or management to reduce impacts. Mitigation is inherent in the scenarios produced. For instance, an EFR scenario that requires a large percentage of the MAR is likely represent a high level of mitigation (but a low system yield), whereas one that requires a small percentage is likely to represent a low level of mitigation (but a high system yield).

For the predicted impacts that are amenable to mitigation, the cost of mitigation programmes can also be provided. For instance, changes that are likely to negatively affect the health of the PAR are obvious candidates for mitigation and the economist, in close liaison with the public health specialist, can design and cost a programme to do this.

8.2 COMPENSATION

Compensation is relevant where mitigation does not entirely reduce the impacts and can be defined as the provision of cash, goods or services to replace lost resources or impeded activities.

For each EFR scenario, data on resource use, the prices attached to those resources and the midpoints of the biophysical consequences are combined to derive the monetary impact of flow changes as follows:

- resource values are first derived by multiplying resource use by prices;
- monetary impacts are then isolated by weighting resource value using biophysical consequences, which provide both the direction and the magnitude of the predicted change.

Thereafter the costs of delivering the compensation to the PAR are calculated.

9 CALCULATING THE IMPACT ON SYSTEM YIELD

The hydrological yield analysis provides the impacts of the various release scenarios on system yield. Standard reservoir and water-routing models are used to calculate how much water would be available as yield in each scenario. The EFR is met at each site through dam releases and catchment contributions. The operation of the scheme is simulated with the EFR as the primary ‘demand’ on the system, and the volume of water available (the yield) once the EFR has been met is then calculated.

10 SUMMARY OF OUTPUTS

The output of DRIFT is a set of EFR scenarios, usually four, that can be used assess a range of options for operation of a particular water resource development. Each scenario quantitatively describes:

- a modified flow regime;
- the resulting condition of the river, or species, whichever is being addressed;
- the likely social impacts of the resulting condition of the river;
- the monetary costs of mitigation of, or compensation for, the negative social
- the effect on yield for offstream users.

The biophysical information used to predict changing river condition is held within a database. This can be queried in a range of ways to describe, for instance, the predicted future river condition resulting from any flow regime, or the flow regime required to maintain a valued species in the river.

10.1 THE MODIFIED FLOW REGIME

The following information is routinely provided:

- the range and required flow duration curve for wet season lowflows;
- the range and required flow duration curve for dry season lowflows;
- the magnitude, duration, number per annum and month of occurrence of required within-year floods;
- the magnitude and duration of required >1:2 year flood events;
- the volumes of water represented by the lowflow and highflow requirements in MCM per annum;
- the lowflow and highflow requirements as a percentage of present-day and natural MAR.
- the total EFR as a percentage of present-day and natural MAR.

10.2 THE CONDITION OF THE RIVER

The predicted river condition is described relative to the present-day condition of the river. Change in condition is provided at several different levels of detail. At the most detailed level, expected change in each river feature or species is described along with its ecological and social significance and an explanation of why such a change would occur. Each change is accompanied by an indication of its direction and extent (as a percentage of present-day condition, e.g., abundance of species A would reduce by 50%). The individual changes are then synthesised into an overall description of river change in a quantitative way and in layman's terms. Finally, this description is provided as an index of river health such as Ecological Status (DWAF 1999).

10.3 THE SOCIAL IMPACTS

The following is provided:

- a description of the present extent of river use by riparian people and, if required, health profiles of them and their livestock;
- details of the social impacts of changes in river resources;
- an explanation of the linkages between river resources and the social impacts.

10.4 MONETARY COSTS OF MITIGATION OR COMPENSATION

The costs of mitigation and compensation are calculated relative to the present day condition, and are only provided for the negative social impacts. Once again, these are provided at different levels of detail ranging from the costs of mitigating against or compensating for the loss or reduction of a single feature or species that is utilised by the PAR, through to the overall costs of a comprehensive mitigation and compensation programme.

10.5 SYSTEM YIELD

The system yield is provided for each of the EFR scenarios. In addition, the components of the EFR that have the biggest impact on system yield are identified, as are the main system constraints in accessing the full volume of the water that is theoretically available for off-stream uses.

10.6 THE DRIFT DATABASE

The database created during the EFA forms an important output of the process as it contains all of the biophysical data in a form that can be queried to describe the biophysical consequences of additional possible flow regimes (scenarios) or subtle variations on the EFR scenarios provided, such as changes to the number and magnitude of large floods. This obviates the need for additional biophysical specialist workshops to discuss such changes.

The DRIFT database, with the accompanying biophysical and socio-economic specialist reports, provides the water-resource manager with an invaluable tool for exploring flow-related responses of the system under consideration.

11 REFERENCES

BOUGHTON, W.C. 1993. A hydrograph-based model for estimating yield of ungauged catchments. Institution of Engineers, Australia. I.E. Aust. Natl. Conf. Publ. No 93/14. Pp. 317 – 324.

BROWN, C.A. AND KING, J.M. In press. Chapter 3: Environmental Flow Requirements and Assessment. In: Water Resources Management In southern Africa: Enhancing Environmental Sustainability. An IUCN/SARDC Publication.

BROWN, C.A., SPARKS, A. AND HOWARD, G. 2000. Proceedings of the IFR Workshop and determination of associated dam yields. Palmiet River Instream Flow Assessment. Unpublished Southern Waters Report to Client: Department of Water Affairs and Forestry. Report No. G400-00-0499. 168 pp.

CHAPMAN, T.G. AND MAXWELL, A. I. 1996. Baseflow separation-comparison of numerical methods with tracer experiments. Institution of Engineers, Australia. I.E. Aust. Natl. Conf. Publ. No 96/05. pp 539-545.

HUGHES, D.A., MURDOCH, K.A. AND SAMI, K. 1994. A hydrological model application system - a tool for integrated river basin management. In: Integrated River Basin Development (ed. C. Kirby & W.R. White), 397-406. Wiley, Chichester, UK.

KING, J.M. AND LOUW, D. 1998. Instream flow assessments for regulated rivers in South Africa, using the Building Block Methodology. Journal of Aquatic Ecosystem Health and Management. Vol 1.

KING, J.M., THARME, R.E. AND DE VILLIERS, M.S. (eds.). In press. Environmental flow assessments for rivers: manual for the Building Block Methodology. Water Research Commission, Pretoria.

METSI CONSULTANTS. 2000. Final Report: Summary of Main Findings. Consulting services for the establishment of the instream flow requirements for river courses downstream of LHWP dams. Unpublished report to Client: Lesotho Highlands Development Authority. Contract LHDA 648. Report No. LHDA 648-F-02. 75 pp.

NATHAN, R.J. AND MCMAHON, T.A. 1990. Evaluation of automated techniques for baseflow and recession analysis. Water Resources Research. 26(7), pp. 1465-1473.

THARME, R.E. AND KING, J.M. 1998. Development of the Building Block Methodology for instream flow assessments and supporting research on the effects of different magnitude flows on riverine ecosystems. Water Research Commission Report No 576/1/98. Pretoria. 452 pp.