Predicting Water Quality and Biotic Response in Ecological Reserve Determinations

Heather Malan and Jenny Day

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Predicting Water Quality and Biotic Response in Ecological Reserve Determinations

Prepared for the Water Research Commission

by

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PREFACE

This document is one of a series of reports arising from the Water Research Commission project K5/956 "Development of numerical methods for assessing water quality in rivers, with particular reference to the environmental flow requirements process". The reports are:

1. *Malan, H.L. and Day, J.A. (2002) Development of numerical methods for predicting relationships between stream flow, water quality and biotic responses in rivers. WRC Report no. 956/1/02.*
This volume details the development of the models and tools produced during the project and outlines the results of several applications of these tools to rivers in South Africa.

2. *Malan, H.L. and Day, J.A. (2002) Linking discharge, water quality and biotic response in rivers: a literature review. WRC Report no. 956/2/02.*
This volume presents a review of literature pertinent to the project in the fields of *inter alia* hydrogeochemistry, water quality modelling, environmental flow assessments and biomonitoring.

3. *Malan, H.L. and Day, J.A. Predicting water quality and biotic response in ecological Reserve determinations. WRC Report no. TT XX.* (This manual).
This volume is a technical guide allowing water resource managers and consultants to use the tools described in (1) above.

Cover page: 1. Berg River, Western Cape, South Africa (photo – Bryan Davies).

2. Zeekoevlei, Cape Town, South Africa (photo – Bryan Davies)

3. Lower Berg River, Western Cape, South Africa (photo – Jenny Day)

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SECTION 1

INTRODUCTION

About this manual

This manual is designed to teach consultants and water resource managers how to use the tools developed in the Water Research Commission project K5/956 “Development of numerical methods for assessing water quality in rivers, with particular reference to the Instream Flow Requirement process”. The numerical method that has been developed (the Q-C modelling method) enables predictions of stream flow (Q)-concentration (C) relationships to be made for some key water quality variables in rivers. These methods have been refined through application to actual Reserve Assessments.

In addition, a set of steps is presented (the “Biotic Protocol”) which aids in inferring the effect that changes in water quality may potentially have on the aquatic biota. The term “aquatic biota” refers to micro-organisms, amphibians, macroinvertebrates, mammals, which live either in a river or within the riparian strip. It also refers to plants in the form of riparian vegetation, macrophytes, and algae. The major focus of the Biotic Protocol, however, is on macroinvertebrates (insects, crustaceans, worms and molluscs).

This manual is set out in the following manner:

Section 1. Introduction:
Section 1 explains why it is important to include predictions of water quality and the resultant effects on the aquatic biota in Reserve determinations.

Section 2. The Q-C modelling method
This section gives instructions for carrying out Q-C modelling, which enables estimates to be made of concentrations of certain water quality constituents that can be expected under a given stream flow. The assumptions and limitations in the method are explained. Another technique for estimating concentration – mass balance modelling is also described.

Section 3: The Biotic Protocol

Section 3 explains the individual steps of the Biotic Protocol, a technique designed to gain estimates of the effect a given water quality scenario is likely to have on the aquatic biota. The assumptions and limitations of the Biotic Protocol are also discussed in this section.

Section 4: How predictions of water quality and biotic effects can be used in reserve determinations

The final section of this manual explains exactly where in the Reserve determination process these tools can be used and how useful information, that will aid in implementation of the Reserve, can be gained.

Why is it necessary to make predictions of the effect of change in flow on water quality and biotic response?

The South African Water Act

The new South African Water Act (Act No. 36, August 1998) recognizes that in order to protect the full range of "goods and services" (e.g. provision of water, disposal of waste, supply of fish, plants, and other biota) provided for humans by rivers, the entire ecosystem must be protected. A basic principle of the Act is that, the *quality*, *quantity* and *reliability* of water required to maintain ecological functioning should be maintained, in order that human use of water does not compromise the long term sustainability of aquatic ecosystems. Thus the Act makes provision (in addition to a "basic human needs Reserve") for an "ecological Reserve". In the rest of this manual, the term "Reserve" refers to the "ecological Reserve".

The "ecological Reserve" is the water *quantity* and *quality* required to protect ecosystems in order to secure ecologically sustainable development and use of the relevant water resource.

The ecological component of the Reserve is considered to consist of four aspects, all of which need to be assessed:

- **water quantity** (the amount, timing and duration of stream flow)
- **water quality** (the concentration of chemical constituents and values of physical variables eg. nitrate concentration, water temperature, that should not be exceeded)
- **habitat** (both instream and riparian eg. the state of the riparian vegetation, condition of instream substrate)
- **aquatic biota** (eg. fish, aquatic macroinvertebrates)

In this manual, section two looks at the relationship between water quantity and water quality and section three considers the relationship between water quality and aquatic biota (chiefly aquatic macroinvertebrates).

Water quality and Reserve determinations

During the course of a Reserve determination, water quality is assessed for each significant water resource in terms of each of three categories of variables, namely:

- toxic substances (e.g. phenol).
- system variables (e.g. pH, temperature).
- nutrients (e.g. nitrates, phosphates).

For each resource, the values of each water quality variable in the un-impacted (natural) state (the Reference Condition; RC) are derived. This may be either using historical data (i.e. pre-impact) from the same site or from a Reference Condition site in the same catchment. These values are compared with the current levels termed the "Present Ecological State" (PES) in order to assess whether the river is degraded with regard to water quality. These values are also compared to those associated with the Ecological Reserve Class (i.e. the class, or condition for which that section of river will be "managed"). Management goals of water quality (resource Quality Objectives) are set at this stage. These represent the values of physical variables (e.g. temperature, pH) and concentration of chemical constituents (e.g. nitrates, mercury, dissolved salts) that should not be exceeded in each river reach. The Reserve process and incorporation of water quality is discussed fully in the manual titled "Resource directed measures for protection of water resources" (DWAF 1999). A useful overview of the process (although not the water quality aspects) is to be found in O'Keeffe (2000). At the time of writing this manual the procedure for the incorporation of water quality into Reserve determinations is under review.

The relationship between stream flow, water quality and biotic response

Changes in stream flow can have a major effect on water quality. The most obvious situation is in rivers where point-sources of pollutants are discharged. If stream flow is decreased significantly, but not the proportion of effluent, the concentration of some constituents is likely to increase. Even in unimpacted catchments, changes in stream flow can frequently lead to changes in the concentration of instream constituents and the values of physical variables.

Furthermore, the animals and plants that live in a water resource (we are specifically considering rivers in this manual) are adapted to the water quality of that stretch of river. Should that water quality be changed, the tolerance limit of some of the organisms may be exceeded so that they can no longer thrive (or in extreme cases, survive) in that river reach.

What does this mean for the Reserve?

Methods have been developed to calculate the quantity and timing of stream flow that is needed in order for riverine ecosystems to function at a pre-determined level. This is currently known in South Africa as the "Instream flow requirement" of a river or the IFR. This involves a workshop situation in which a flow regime (which will maintain a given section of river in a certain state) is devised by specialists from different disciplines (hydrology, hydraulics, riparian vegetation, water quality etc). But because flow and water quality are intimately linked, if the new regime is implemented it may well mean that water quality may be changed. This means that although the correct amount of water is supplied it is quite likely that the water quality may not be of good enough quality, ("not good enough" in the sense that the targets set for water quality may not be met, and that the correct water quality required by the aquatic biota is not achieved).

Because water quality changes with stream flow, it is necessary to ensure that when setting the ecological Reserve with regard to the quantity and timing of flow, the targets (Resource Quality Objectives) with regard to water quality will also be met.

In order to do this, quantitative predictions of the concentrations of chemical constituents and values of physical variables that can be expected for a given flow need to be made. In other words, some form of *water quality modelling* is required. For instance, it can be fairly reliably assumed that if the volume of flow is reduced, the concentration of at least some chemical constituents in the water is likely to increase. But, without water quality modelling the magnitude of this increase cannot be determined.

In this manual, water quality modelling means making quantitative predictions of the concentration of chemical constituents that can be expected in a given river reach at a given stream flow.

Although a flow regime that provides suitable flow conditions for target organisms may be recommended, unless suitable water quality is also provided, the requirements of the biota may not be fulfilled. Then, for example, if one of the objectives of the recommended flow regime was to maintain a given species of insect in a river reach, this might not be achieved due to unsuitable water quality.

The relationships between stream flow, water quality and aquatic organisms

The relationships between stream flow, water quality and biotic response are summarised in Figure 1. The figure shows that a change in stream flow can have an effect on water quality. Both the values of physical variables (e.g. temperature) and the concentration of chemical constituents may well be affected. Since the tools presented in this manual are not able to predict the effect of temperature, we will only consider the concentration of chemical constituents. Change in water quality can potentially have an effect on individual types of aquatic organisms. This is turn may affect ecosystem functioning. Our knowledge of the likely effects on ecosystem processes is limited and are not considered in this manual. Changes in stream flow, apart from the indirect effect on aquatic organisms via altered water chemistry, will also have a direct effect on many aquatic organisms. This is largely through different habitats becoming available/unavailable. For example if a highly reduced flow regime is specified, water at certain times of the year may no longer flow through riffle areas. Thus species that can only live in riffle areas are likely to be severely impacted, over and above potential effects of changed water quality. The direct effect of altered flow on the biota is an important consideration that is evaluated fully by the various specialists (eg. riparian vegetation, macroinvertebrate, fish) at the IFR workshop. It is only considered indirectly in the methods presented in this manual (Section 3: The Biotic Protocol).

The tools (i.e. the predictive methods) discussed in this manual, and the relationships that they address, are also shown in the figure. The Q-C method can be used to predict the instream concentration of a chemical constituent that is likely to arise under a given flow. The Biotic Protocol, on the other hand, has been designed to help infer what effect the altered water quality may have on the aquatic biota.

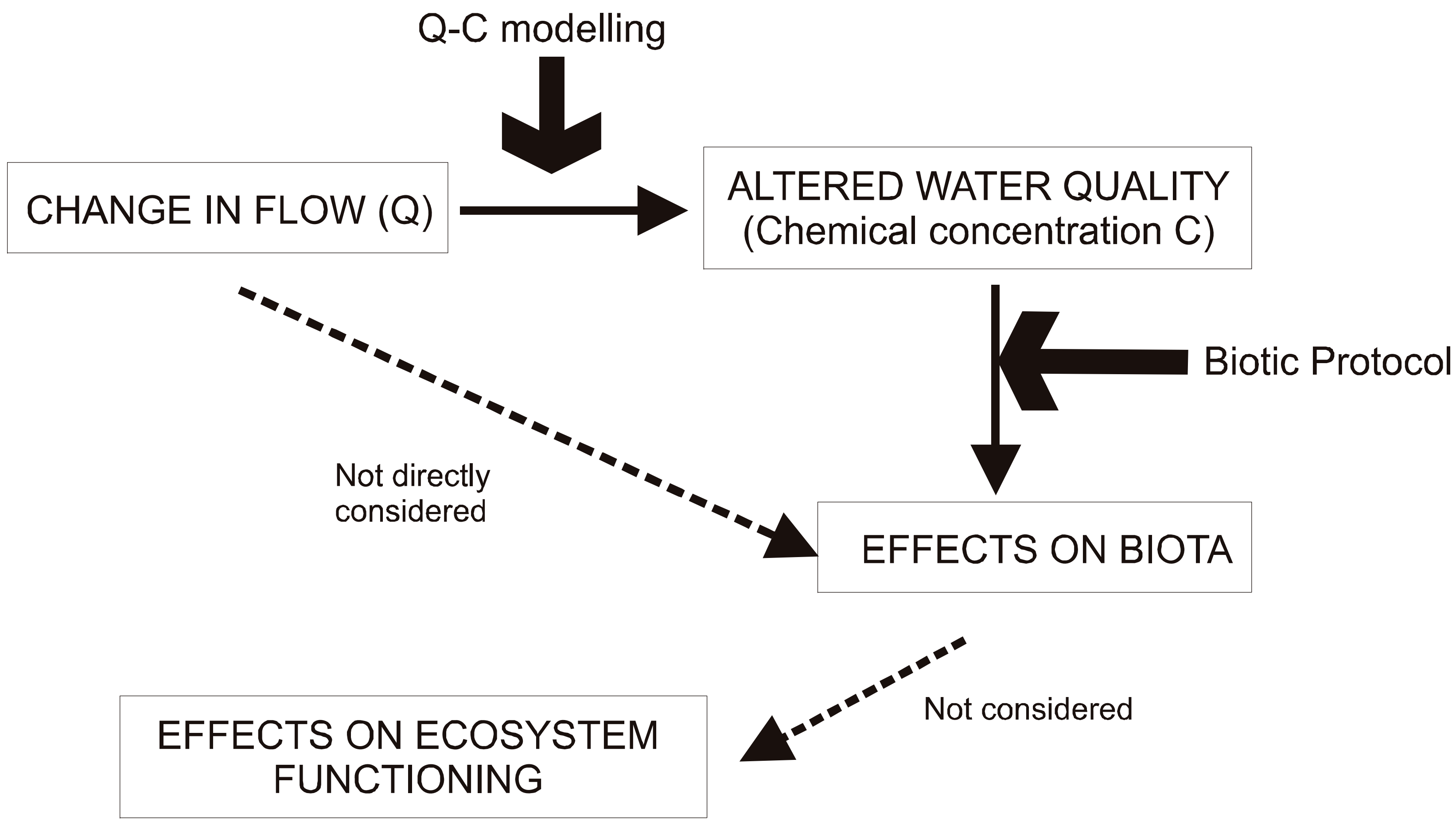


Figure 1 *A summary diagram of the most important relationships between stream flow, water quality and the aquatic biota. The tools used to predict these relationships in this manual are also shown. Aspects that are not addressed in this manual are indicated by dashed arrows.*

SECTION 2

LINKING STREAM FLOW AND WATER QUALITY

What is the Q-C modelling method?

The stream flow-concentration (Q-C) modelling method is a numerical technique that looks at the empirical relationship between flow and water quality at a site on a river. It is based on “rating curves” which have long been used to investigate the relationship between instream concentration of chemical constituents and river flow. The method entails, for a given river reach or site on the river, graphically plotting stream flow against measured concentration for each chemical constituent of concern. The graphs obtained are called “Q-C” plots and are used to predict, for a given flow, what instream concentration of the various chemical constituents can be expected.

Water quality variables

In this manual the definitions of *water quality* and of individual *water quality constituents* are taken from the South African Water Quality Guidelines (DWAF 1996). The Q-C modelling method can be used for:

- Total dissolved solids/salts (TDS).
- Total suspended solids (TSS).
- Individual inorganic ions (eg. K^+, Mg^{2+}).
- Nutrients (e.g. ortho-phosphate, Total phosphate, nitrate, nitrite, ammonia /ammonium).
- Toxins, to a limited extent (e.g. fluoride).

In water quality modelling, it is often necessary to distinguish between *conservative* and *non-conservative* water quality constituents:

- Conservative constituents are those components, such as chlorides, that are essentially unchanged in their progression along a watercourse.

- Non-conservative constituents, which include nutrients, are altered in quantity and form as they progress downstream due to chemical inter-conversions, microbial or biotic activities and interaction with sediments (DWAF 1996).

It is important to remember that for non-impacted rivers, due to varying climate, geology, geomorphology and biota, the natural values of physical variables and concentration of chemical constituents vary from region to region.

What kind of stream flow-concentration (Q-C) plots can be expected?

Concentrations of different chemical constituents commonly (but not always) vary with stream flow in a characteristic manner. This mathematical relationship between flow and solute concentration, or sediment load, varies from river to river and from site to site. The relationship at a given site will also be different for each chemical constituent.

The mathematical relationship between stream flow and concentration is site-specific and chemical constituent-specific.

Stream flow-concentration relationships are complex and influenced by a wide range of factors other than flow, including:

- Antecedent rainfall patterns (i.e. how wet the catchment is).
- The geology of the surrounding catchment (which influences what chemical constituents are available to be carried by rain into the stream).
- Season and climate (which influences, amongst other aspects, the amount and timing of rainfall and the extent of evaporation).
- Anthropogenic effects, such as pollution, land-use and construction of impoundments and weirs.

Some typical Q-C responses are illustrated in Figure 2. Because of the variability in response, the actual relationship of flow and stream chemistry needs to be checked at each site using data measured in the field.

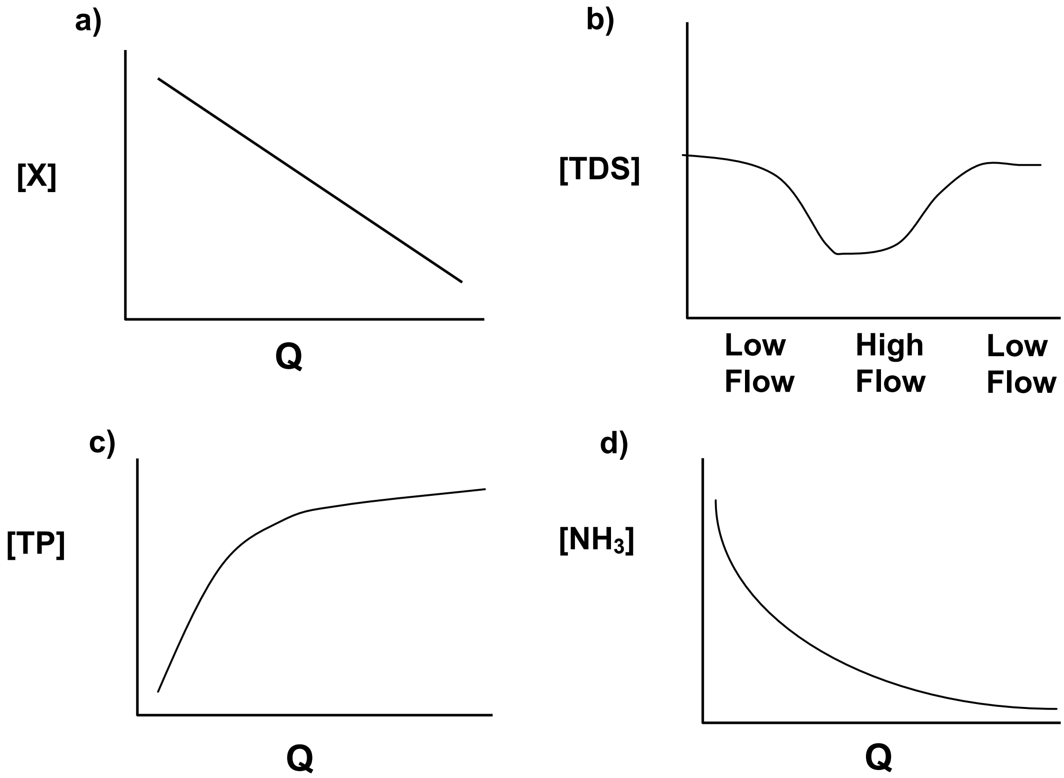


Figure 2 *Characteristic patterns of change in the concentration of selected water quality variables with increasing stream flow (Q).* ***a)*** *A conservative inorganic ion (C).* ***b)*** *Typical changes in TDS concentration throughout the hydrological year.* ***c)*** *Total phosphorus.* ***d)*** *Un-ionised ammonia.*

- The concentration of many variables (e.g. **inorganic ions)** is likely to decrease as flow increases (Figure 2a). This is a result of the fact that river flow during low flows originates largely from groundwater and is usually relatively rich in solutes (particularly inorganic ions). During spates (increased flow due to a rainfall event), this groundwater is diluted by water originating mainly from surface flow. Such water resides for a short length of time in the catchment, consequently the period in which solutes can dissolve in water and the resulting concentration is reduced. The Q-C response may be linear as in Figure 2a or may be more curved (e.g. a logarithmic response).

- The effect of increased flow on **total dissolved solids (TDS)** can be difficult to predict. Due to the high rate of evaporation, in addition to the trends in inorganic ions noted above, in non-impacted catchments (i.e. where there is little pollution), TDS is likely to be maximal during periods of low flow and minimal during periods of high flow. This gives rise to a seasonal pattern as shown in Figure 2b.

  In areas where wash-off of salts from the surface of the surrounding land is likely to be high, a different response for **TDS, and some individual salts** may be seen. For example, in salinised catchments in the winter-rainfall region, at the beginning of winter, TDS may increase with increased flow due to the wash-off of accumulated salts from the soils of the surrounding catchment.

- **Suspended sediments** generally increase with stream flow but the rate of increase may level off at high flows as the amount of erodable substrate becomes limited (Figure 2c). At higher flows than those illustrated in the figure, concentration may well decrease with flow. As a result of limited erodable substances being available, storms occurring early during the wet season are likely to carry heavier loads of sediments compared to storms occurring later in the season (when accumulated sediments have already been washed away).

- **Total phosphorus** often increases with flow. This is because a large portion of the total phosphorus load is bound to sediments and only a small amount is dissolved in the water (as ortho-phosphate). During high-flow events high loads of sediment, and consequently of phosphates, enter the watercourse due to erosion of the surrounding catchment. Even in the absence of rain, an increase in flow, due to releases from an upstream impoundment for example, may result in increased phosphate loads. This is as a result of the churning of sediments with the river releasing phosphate from the banks and river-bed. The Q-C plot in Figure 2 c) shows the concentration of total phosphorus first increasing rapidly with increased flow and then reaching a plateau phase. At very high flows, the concentration of total phosphorus will eventually decrease as dilution becomes the dominant process. Other chemical constituents that sometimes increase in concentration at low flows (e.g. TDS, sediments, nitrates) may also exhibit a similar trend.

- **Un-ionised ammonia** (and other chemical constituents) frequently exhibit a rapid decrease with enhanced stream flow (Figure 2d), a consequence of increased dilution. In the case of, ammonia and other nutrients this may be due to rapid uptake by the biota as the riverbanks become inundated with water.

Water quality is dependent on processes taking place in the entire catchment, which are often poorly understood, and may result in responses that are difficult to predict.

The availability of hydrological and water quality data

The Q-C method makes use of water quality data from the nearest appropriate monitoring station, and flow data which may be either observed (e.g. from a nearby DWAF gauging weir) or may be simulated from a hydrological rainfall-runoff-stream flow model.

The South African Department of Water Affairs and Forestry (DWAF) has an extensive database that includes flow data for many sites. In addition, in some catchments, data are collected by individual water boards (e.g. Umgeni Water, Rand Water). During an Instream flow assessment for a particular river it is important to work closely with the hydrologist who is appointed to the specialist team. This specialist will have a good understanding of the hydrology of the catchment and will be able to advise on where to obtain appropriate flow data for each IFR site that requires modelling.

Water quality samples have been routinely collected and analysed by DWAF since the late 1970's (or more recently in some catchments). The frequency of data collection varies, as does the water quality variables that are covered. Measurements of DO, temperature, sediments and turbidity, pathogens and toxic substances are often lacking.

Water quality data and streamflow data can be requested directly from DWAF via email (see "Useful web site addresses" at the end of this manual). DWAF water quality data are also available on a CD titled "Water Quality on Disk" (WQOD) available from the CSIR (Contact person Derek Hohls; see "Useful web sites"). Water quality data can be down-loaded from the these sources into a commercial spread-sheet or statistical package (e.g. Microsoft Excel or Statistica) and further manipulated from there.

The water quality modeller must work closely with the hydrologists and water quality specialists during a Reserve determination.

How to carry out Q-C modelling

The modelling method is carried out at each IFR site for which appropriate flow and water quality data are available. Each water quality variable is modelled separately. A spreadsheet template (in Microsoft Excel) has been developed into which the stream flow and water quality data can be entered. The required calculations to determine the regression line and confidence limits for the Q-C plots are built into the spreadsheets. A computer disk with a copy of this template is at the back of this manual.

The steps that comprise the basic Q-C modelling method are given below, and are summarised in Figure 3. A worked example is given further on in the manual.

- **i)** *Gather together all available data on water quality, point-sources of pollution, hydrological structures, hydrology, land-use, topography etc. for the water resource. Identify the locations of the IFR sites relative to water quality monitoring stations, flow gauging sites, and any other significant hydrological features. Produce maps indicating the above.*

Figure 3 Summary of the Q-C modelling method

i) *Gather together all available data on water quality, point-sources of pollution, hydrological structures, hydrology, land-use, topography etc. for the water resource. Identify the locations of the IFR sites relative to water quality monitoring stations and flow gauging sites, as well as any other significant hydrological features. Produce maps indicating the above.*

ii) *Identify the different ecoregions through which the river flows according to the method of Kleynhans (1999). Using this information, as well as the location of dams, point-sources of pollution and significant tributaries (hydrological features), delineate river reaches within which water quality would be expected to be uniform.*

iii) *For each water quality reach in which an IFR site is situated, using stream flow and water quality data from the nearest appropriate gauging and water quality monitoring station, correlate mean stream flow values and median concentration values for each water quality variable "X", for each month of the year. This is done:*

i) For the Reference Condition (i.e. the natural or least-impacted state)

ii) For the Present Ecological State

iv) *Examine the relationship between stream flow and the concentration of "X".*

v) *Calculate the concentrations of variable "X" (as given in the regression equation) for the Reference Condition and Present Ecological State for each month under the natural and present day flow regimes.*

vi) *Predict the concentration of "X" for each month of the recommended flow regime and estimate the 95% confidence interval around this prediction.*

vii) *Calculate the extent of deviation of the Present Ecological State values of "X" and of the predicted concentrations of "X" under the recommended flow regime from the Reference Condition.*

viii) Assign the Assessment Category for each month.

- **ii)** *Identify the different ecoregions through which the river flows according to the method of Kleynhans (1999). Using this information, as well as the location of dams, point-sources of pollution and significant tributaries (hydrological features), delineate river reaches within which water quality would be expected to be uniform.*

These first two steps (in addition to the water quality section of step iii) are standard components of the water quality assessment for Intermediate and Comprehensive Reserve determinations and are explained in DWAF (1999). The delineated river reaches in which water quality is considered to be homogeneous are termed "water quality reaches".

- **iii)** *For each water quality reach in which an IFR site is situated, using stream flow and water quality data from the nearest appropriate gauging and water quality monitoring station, correlate mean stream flow values and median concentration values for each water quality variable "X", for each month of the year using the appended spreadsheet template. This is done:*
    - *i) For the Reference Condition (i.e. the natural, or least-impacted state).*
    - *ii) For the Present Ecological State.*

Mean flow and median concentration values, for each month of the year, are entered into a table or spreadsheet. These values represent both the Reference Condition and the Present Ecological State. For sites that are impacted by pollution, an idea of what the water quality would have been like in the natural (the Reference condition) can be deduced in either of two ways. Firstly by looking at the entire set of water-quality data for that site to see if any pre-impact data are available. Secondly by using data from a Reference site in the same area that is expected to exhibit similar water quality to that of the site under consideration in the natural state.

Data from the past five years are used to determine the Present Ecological State (the current condition). The median monthly values of water quality variables are derived according to the rules set out in DWAF (1999). Thus, they must be calculated from a minimum of 60 data points covering the entire hydrological year. Graphs of concentration and flow for each month of the year under natural and present day conditions can also be produced. An examination of the seasonal patterns of these variables can be useful in understanding the dynamics between water quality and quantity at a given site.

- **iv)** *Examine the relationship between stream flow and the concentration of constituent "X".*

This step is carried out separately for both the Reference Condition and for the Present Ecological State, which may or may not be impacted. Graphs are drawn of concentration versus flow. A regression line (called "trendline" in Microsoft Excel) is then drawn through the data points. The "best fit" is chosen by using the relationship that yields the highest value of the coefficient r^2. Where there is little difference between r^2 values the simplest relationship (i.e. linear or logarithmic) is used. Expert judgement is frequently required to choose the most appropriate relationship.

- **v)** *Calculate the concentrations of variable "X" (as given by the regression equation) for the Reference Condition and Present Ecological State for each month under the natural and present day flow regimes.*

The monthly values of the variable X in the Reference Condition are calculated using the Reference Condition regression equation. Likewise, the values of X for the Present Ecological State are calculated from the Present Ecological State regression equation. These values are used to calculate the % deviation from the natural condition (see step vii)

In summary:

The Reference Condition regression relationship is an equation relating the Reference Condition concentration of X ($[X]_{RC}$) to flow (Q)

e.g. $[X]_{RC} = b(Q) + c$ (linear relationship)

The Present Ecological State regression relationship is an equation relating the Present Ecological State concentration of X ($[X]_{pes}$) to flow (Q)

e.g. $[X]_{pes} = b(LogQ) + c$ (logarithmic relationship)

where: b, c are constants (the slope and y-intercept respectively) and [X] represents the concentration of X.

The 95% confidence interval for each monthly predicted value of X is calculated using standard statistical formulae incorporated into the spreadsheet templates. Depending on the mathematical form of the relationship linking flow and concentration, the data may first need to be transformed. These transformations are performed automatically in the spreadsheet templates.

- ***vi)*** *Predict the concentration of constituent "X" for each month of the recommended flow regime and estimate the 95% confidence interval around this prediction.*

The major output of an Instream Flow Requirement (IFR) workshop is a recommended flow regime that is expected to maintain ecosystem functioning in a river reach (typified by an IFR site) at a predetermined level. This flow regime is given in the form of values of the baseflow for each calendar month. A recommended flow regime is prescribed for both normal hydrological years (maintenance low flow) and drought years (drought low flow). Floods are also recommended. Some constituents (e.g. sediments) increase with flow, but the Q-C modelling technique can only be used for those that decrease with flow. Since water quality is worst during low flows, floods are usually ignored in this method. Using the Present Ecological State regression equation, the predicted concentration of each water quality constituent for each month under both the maintenance and drought flow regimes, in addition to the 95% confidence interval, can be calculated.

The recommended flow regime is comprised of:
- **Maintenance flows (for "normal" hydrological years).**
- **Drought flows (for dry years).**
- **Floods (not important for Q-C modelling).**

- **vii)** *Calculate the extent of deviation of the Present Ecological State values of "X" and of the predicted concentrations of "X" from the Reference Condition.*

The Present Ecological State and predicted concentrations can be compared with the concentration of X in the Reference Condition (as calculated from the regression equation) and the difference calculated using the following:

$$\textit{Deviation from RC} = \frac{(\textit{Predicted } [X] - [X]_{RC})}{[X]_{RC}}$$

This step is may not always be necessary, but can be useful to indicate how different the Present Ecological State is from the natural state on a monthly basis. It can also be used to indicate how different water quality (i.e. the concentration of variable X) under the recommended flow regime will be from both the Reference Condition and the Present Ecological State.

viii) *Assign the Assessment Category for each month*.

The predicted Assessment Category (e.g. A – D, or natural – poor), for the water quality variable under consideration, is then assigned for each month under maintenance low flow and drought low flow. The mean category for the entire year is also calculated. The initial guidelines in the Resource Directed Measures manual (DWAF 1999) make use of tables in which percentage deviation from the Reference Condition is linked to the Assessment Category for some variables. For example, if the PES or predicted concentration of TDS will be within 15% of the Reference Condition concentration, then TDS will be in an "A" category. If TDS is predicted to be within 30% - 40% of the Reference Condition value, it will be an "E/F" class. This is indicated by the "Look up table" in the spreadsheet template (cells R90 – S 94). In the case of some water quality variables the class can be derived directly by comparing the predicted concentration with concentrations that represent a boundary value. For example, predicted un-ionized ammonia values of between 0.015-0.030 mg/litre, would mean that the site would be in a C category for ammonia (Table E16, DWAF 1999). At the time of writing this manual, the definitions of Assessment Categories are being reviewed. Sections of the spreadsheet template ("Assessment Category - % deviation method" and "Assessment Category – direct method") that are used to assess the water quality category have been included in the current template to give an example of how "Look up tables" can be used to determine the category. The actual values may need to be changed in future once there is a final decision by DWAF as to how to derive the categories for each water quality variable.

<u>Points to note</u>

1) The Q-C modelling method can be used with both techniques used in South Africa for determining the environmental flow requirement of a river:

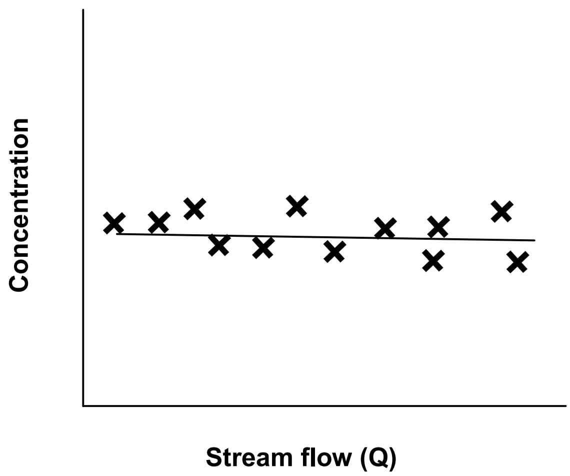
- the Building Block Methodology (BBM)
- DRIFT (Downstream Response to Instream Flow Transformations)

2) The modelling method can also be used in the opposite way i.e. to estimate, under the current pollution loading in the river, the flow that would be required to attain a given concentration, or Assessment Category.

3) Modelling of nutrients is not usually as successful as that of conservative constituents. Considerable scatter of points is often shown when concentration is plotted against flow (due to the many factors that influence instream nutrient concentrations).

4) Monthly mean stream flow values were correlated with median monthly concentration values for each variable. Mean flow values are used because this is the convention in hydrology. Median water quality values are employed since concentrations can range widely and a single extreme event can alter the mean significantly.

5) The Q-C plot for the Reference Condition (and sometimes for the Present Ecological State) at many sites, frequently shows only slight change with flow so that an almost horizontal line may be obtained (see sketch below). Consequently the value of r^2 will be very low. From the point of view of making predictions of concentration resulting from a given flow, the confidence in the predictions from such a relationship is high. The concentration of the given variable is likely to be more or less constant whatever the flow.

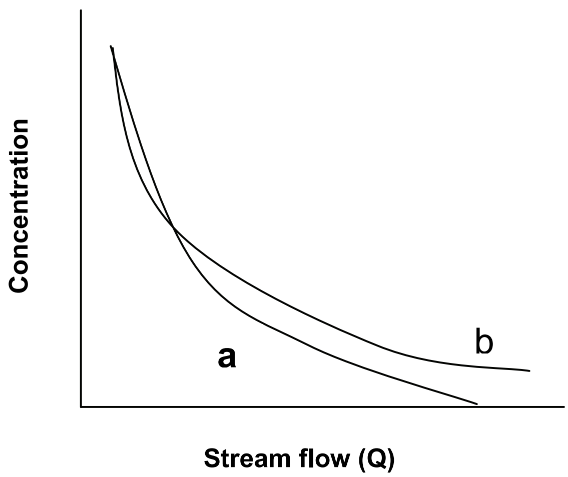


6) The recommended flow regime (as proposed by the specialists) is for low flows - in other words, this represents the minimum flow required in the system to maintain the prerequisite state. Frequently, higher flows would actually be present as a result of floods, freshes or additional flow (i.e. water that is not required for abstraction or impoundment). The predicted concentrations of water quality constituents in the case of those that showed a dilution effect with increased flow, therefore represent the worst-case scenario.

The predicted concentrations for chemical constituents that are negatively correlated with flow represent the worst-case scenario.

7) If a poor correlation between measured data and the regression line is obtained (less than 0.6), the predicted concentrations are not likely to be reliable, and Q-C method should not be used to obtain predictions of water quality.

8) Expert judgement frequently needs to be used when deciding on the best relationship that describes how concentration varies with flow. In the example shown in the sketch below, whilst a higher r^2 value may be obtained using relationship a), relationship b) would be more appropriate since even at very high flows, the background concentration of the variable is not likely to be zero.



Assumptions and limitations in the method

There are some important assumptions and limitations that need to be kept in mind when using the Q-C method:

1) The Q-C method has been designed to be a rapid, user-friendly tool that can be used to screen IFR sites to identify those where water quality is likely to be problematic under the recommended flow regime. Many factors, apart from flow, influence water quality. In addition, as a simplification, monthly median concentrations are plotted against monthly mean flow values. Consequently Q-C modelling is a very simple approach, aimed at providing estimates of predicted water quality rather than precise numerical values.

Q-C modelling is designed to give estimates of expected concentration rather than precise values.

2) It is assumed in the method that, if flow is altered, apart from the concentration of the water quality variable under concern, all other parameters (e.g. the pollution load) will remain constant. In practice, if flow is altered drastically it is likely that the source of the water will be altered (for example by means of the impoundment of tributaries) and therefore the loading of chemical constituents may also be modified. Changes in operation of upstream impoundments may also be involved. In other words, this method does not take into account changes in water quality management scenarios.

Predictions made using Q-C modelling are only valid if the system is operated in the same way as used to derive the flow-concentration relationship.

3) Some constituents are negatively correlated with flow whereas others may increase with flow, at least during low flows, if not during floods. The two different responses are shown in Figure 4. In the case of constituents that are negatively correlated with flow, if flow under the new regime (Q_{IFR}) is reduced compared to the present condition (Q_{PES}), due to a concentration effect, the predicted concentration will be higher than the present instream concentration (Figure 4a).

In the case of constituents that are positively correlated with flow (e.g. TDS in salinised catchments in the winter rainfall region), according to the diagram, reduced flow would result in lower predicted concentrations under reduced flow (Figure 4b). Such predictions in this case are not necessarily reliable. Under the new flow regime, the loading of salts in the soils of the surrounding lands will remain constant, as will the rainfall. As a result, the load of salts entering the river is likely to be the same. If stream flow is reduced, due to a concentration effect the instream levels of TDS must increase, or at least remain the same. Conversely if the predicted flow is greater than under present day, it cannot be assumed that the instream concentration of TDS will be increased.

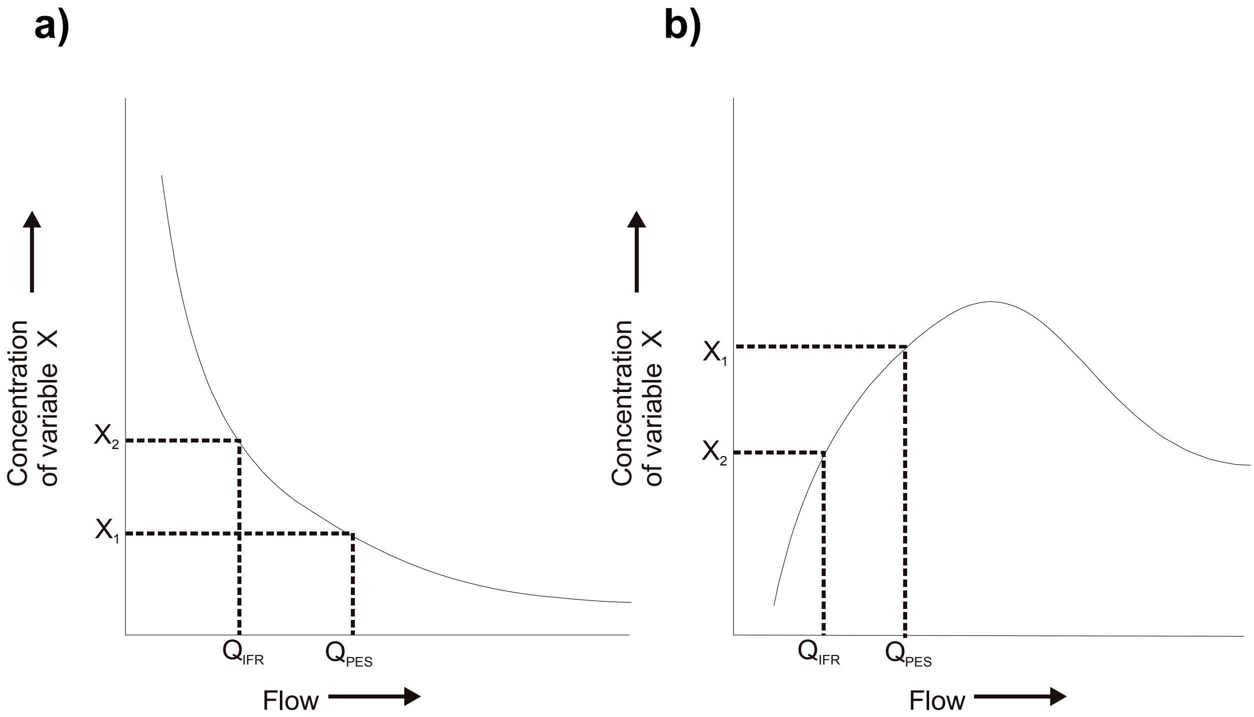


***Figure 4** A schematic representation of predicted concentrations for a given flow.*
***a)** Classical dilution of a point-source of pollution with increasing flow. **b)** Increased concentration with increasing flow. (Q_{IFR} = Instream Flow Requirement, Q_{PES} = Present Ecological State flow)*

Q-C modelling should therefore generally not be used to make predictions of concentrations in cases where a positive correlation with flow is obtained. Except:

- In the case of phosphates and other constituents, where elevated instream levels result from churning of benthic sediments or release from riverbanks, rather than wash-off from the surrounding catchment. In such cases this would represent an instream pollutant source rather than an off-land input and reduced flow may well lead to lower concentrations of some constituents in the water column.
- Where the recommended flow regime falls within the flow range where concentration decreases with flow (Figure 4b).

Q-C modelling should be used with caution to make predictions of concentration in the case of constituents that are positively correlated with flow.

4) Experience and expert judgement is important in the use of this method:

- For understanding the limitations and assumptions of the technique.
- For understanding the dynamics of the Q-C relationships obtained.
- In choosing the monitoring and gauging weirs that are used to provide data for an IFR site (i.e. judging if they are all in the same water quality reach).
- In the derivation of monthly median water quality concentrations, particularly for the Reference Condition where, historical, pre-impact water quality data are often not available. Experience of the natural water quality to be expected in different ecoregions is then required.

The last two points are not unique to Q-C modelling but apply to all water quality assessments undertaken as part of a Reserve determination.

The type of information that can be gained using Q-C modelling

Depending on the availability and reliability of data at each IFR site, the following information can be obtained:

- Flow-concentration relationships for some key water quality variables.
- Estimates as to how many months of the year the water quality component of the Reserve would be attained, as well as the likely Assessment Category (A, B, C etc.), for each water quality constituent of concern;

- In what month the worst water quality would be likely to occur and what concentrations could be expected;
- The extent of deviation of predicted concentrations from those specified under the Reference Condition.
- What flow, in the absence of pollution control, would be required to dilute pollutants in order to attain a required concentration for a given chemical constituent.

The degree of confidence in the accuracy of the predictions for each IFR site can be judged by taking the following factors into consideration:

- The completeness of the data -set used to assess Reference Condition water quality for each chemical constituent, as well as an assessment of how representative that data-set is of the natural state.
- The completeness of the data-set for each water quality variable that is used to assess water quality for the Present Ecological State.
- How representative the water quality data (for both the Reference Condition and the Present Ecological State) are of the IFR site under consideration. This depends largely on how close the monitoring station used as data source is to the IFR site, and if a hydrological feature (e.g. minor tributary, weir etc.) or point-source of pollution, is situated between the IFR site and the data-source site.
- The reliability of the flow data. This can be assessed by consultation with the hydrologist for the project.
- The accuracy of the water quality simulations (i.e. the value of r^2).

Predictions of water quality should not be made using Q-C modelling:

- If the available PES water quality data do not satisfy the requirements as laid out in the Resource Directed Measures manual (DWAF 1999). In the absence of Reference Condition data, predictions of future water quality can still be made, but the extent of deviation from natural can not be assessed.
- If the nearest water quality monitoring station to the IFR site is in a different water quality reach from the site.
- If accurate present day flow data for the water quality reach under consideration are not available.
- If the correlation coefficient between measured and predicted values is less than 0.6, the simulations should be discarded. It can be concluded in such cases that factors

other than flow are influencing instream concentrations. Predictions of water quality in such cases need to be made using a more sophisticated modelling method (e.g. QUAL2E, or possibly a catchment run-off model).

- If the concentration of the water quality variable exhibits a marked *increase* in concentration with increasing flow and if this is likely to be due to wash-off from the surrounding land.

Simple mass-balance equations

Predictions of water quality using Q-C modelling are valid only if the system is operated in the same way as used to derive the flow concentration relationships. If an additional point-source of pollution is added to the system, the Q-C relationship will not be valid and predicted concentrations will no longer describe the real situation. In simple systems (two or three point-sources or tributaries), where only conservative constituents are of concern, an estimate of resultant concentration can be obtained by simple mass balance calculation. An example, might be a situation in which two point-sources of pollution are discharging effluent into a river just upstream of an IFR site. For a given point in time, an estimate of the resultant concentration at the IFR site can be calculated by adding the loads (concentration multiplied by flow) from the respective sources and dividing by total flow:

$$X_{IFR} = \frac{X_m Q_m + X_1 Q_1 + X_2 Q_2}{Q_{IFR}}$$

where:

X_{IFR} = Concentration of constituent X at the IFR site

X_m = Concentration of constituent X in the main channel

X_i = Concentration of constituent X in effluent 1 or 2

Q_{IFR} = Total stream flow at the IFR site

Q_m = Stream flow from main channel

Q_i = Flow from effluent 1 or 2

A WORKED EXAMPLE OF THE Q-C MODELLING METHOD

In this example, the Q-C method is applied to a site (IFR 10) on the lower Steelpoort River (Mpumalanga) in order to make predictions of TDS under the recommended flow regime. The tables and figures that are shown are copied directly from the example on the computer disk at the back of this manual.

- **i)** *Gather together all available data on water quality, point-sources of pollution, hydrological structures, hydrology, land-use, topography etc. for the water resource. Identify the locations of the IFR sites relative to water quality monitoring stations, flow gauging sites, and any other significant hydrological features. Produce maps indicating the above.*

- **ii)** *Identify the different ecoregions through which the river flows according to the method of Kleynhans (1999). Using this information, as well as the location of dams, point-sources of pollution, and significant tributaries (hydrological features), delineate river reaches within which water quality would be expected to be uniform.*

The information for steps i) and ii) are given in Palmer and Rossouw (2000).

- **iii)** *For each water quality reach in which an IFR site is situated, using stream flow and water quality data from the nearest appropriate gauging and water quality monitoring station, correlate mean stream flow values and median concentration values for each water quality variable "X", for each month of the year. This is done:*
  - *i) For the Reference Condition (i.e. the natural, or least impacted state)*
  - *ii) For the Present Ecological State*

These data are taken from the spreadsheet template and are shown as Table 1. The section of the table named "Data Source" indicates which data (i.e. which DWAF monitoring stations) were used to derive water quality for the Reference Condition (RC) and for the Present Ecological State (PES). Although not shown here, it is a good idea to record exactly what time-span of data and the number of samples that were used to calculate the monthly median values. All flow data were simulated, indicating that they were obtained using a hydrological model (by the hydrological specialist). Mean flow and median TDS values (both for the Reference Condition and the Present Ecological State)

Table 1 Correlation of monthly flow data and water quality data for IFR 10 on the Steelpoort River. The section of the table named "Data Source" indicates which data were used to derive water quality for the Reference Condition (RC) and for the Present Ecological State (PES). Mean flow and median TDS values for each month of the year are given in the section of the table named "Data". Both the values calculated from measured samples for the Reference Condition and Present state (RC TDS and PES TDS) are shown as well as the values calculated from the regression equations (RC TDS REGRESS and PES TDS REGRESS).

		DATA SOURCE		
RIVER:	**STEELPOORT RIVER (IFR 10)**			
WQ REACH	LOWER STEELPOORT			
RC WQ DATA FROM:	B4H007 LITTLE SPEKBOOM R. AT POTLOODSPRUIT		RC FLOW DATA FROM:	SIMULATED *
PES WQ DATA FROM:	B4H011 STEELPOORT AT ALVERTON		PES FLOW DATA FROM:	SIMULATED *

			DATA											
1			**OCT**	**NOV**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**
2	**RC**	**FLOW (m^3/sec)**	4.46	17.78	22.95	29.76	31.50	18.96	11.57	6.35	4.11	3.09	2.56	2.54
3		**TDS (mg/litre)**	116	60	43	38	36	38	47	55	75	97	121	131
4		**TDS (mg/litre) REGRESS**	87	46	41	39	39	45	56	74	91	103	113	113
5														
6	**PES**	**FLOW (m^3/sec)**	1.93	14.67	19.37	25.50	27.03	15.17	8.78	3.96	1.75	0.79	0.28	0.42
7		**TDS (mg/litre)**	587	307	183	222	220	189	266	342	348	401	601	504
8		**TDS (mg/litre) REGRESS**	383	241	226	213	213	239	271	325	392	470	594	543

IFR = Instream Flow Requirement, WQ = Water Quality, RC = Reference Condition, PES = Present Ecological State, REGRESS = Regression

* Simulated - data is obtained from a hydrological model (from a hydrologist) rather than observed flow data from a DWAF gauging weir.

for each month of the year, are given in the section of the table named “Data”. The median values calculated from the measured data are indicated as RC TDS and PES TDS, respectively. The values that are calculated from the regression equations are shown as RC TDS REGRESS and PES TDS REGRESS. The last two sets of data are derived in step iv).

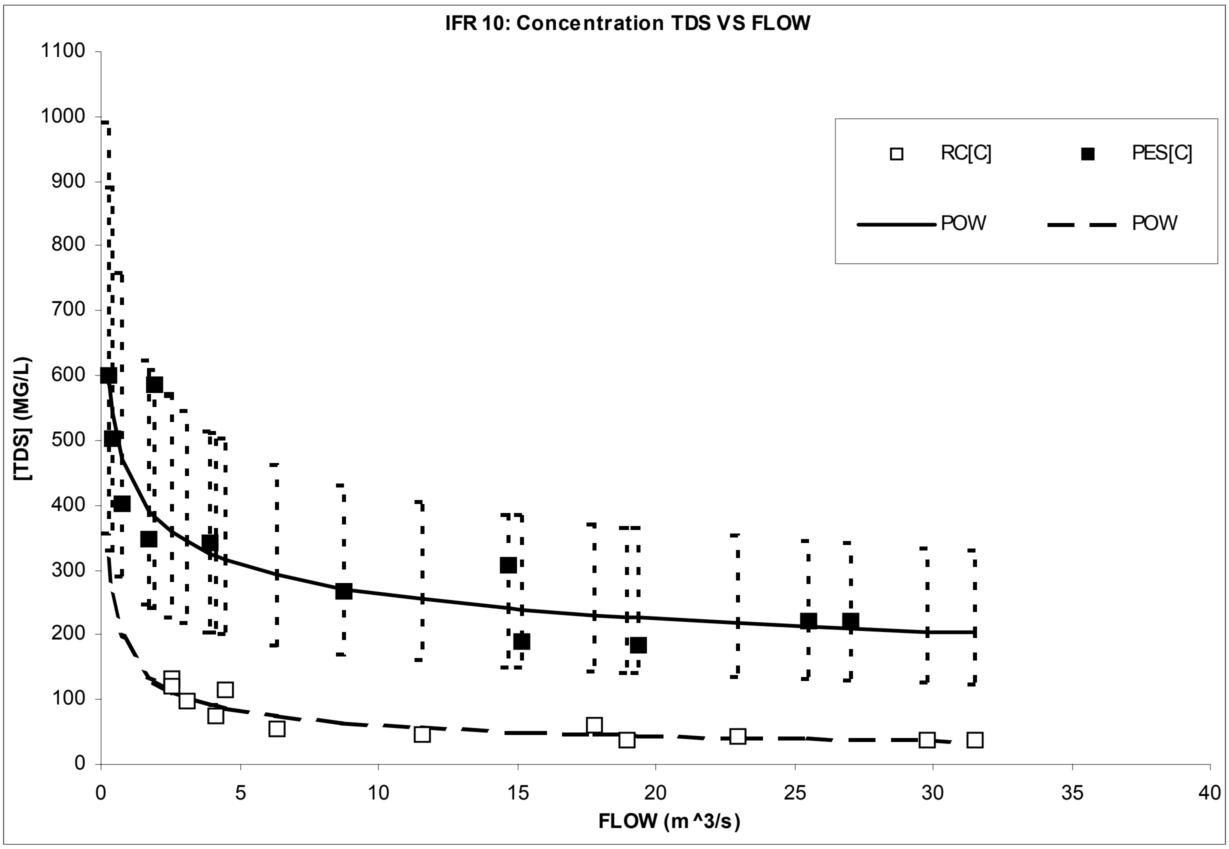
- **iv)** *Examine the relationship between stream flow and the concentration of “X”.*

The data are plotted as shown in Figure 5 and a regression line drawn through the data points. The regression line (trendline) that is chosen is the one that yields the highest value of the regression coefficient r^2. In this example the relationship both for the Reference Condition and for the Present Ecological State between flow and TDS are best described by a power function. A summary table of the r^2 values is also shown in the figure.

It can be seen that in this example, the present state concentrations are higher than the Reference Condition, indicating that there is some degree of impact with regard to salinity at this site. In both the present state and in the Reference Condition, TDS concentrations are high at low flows but are rapidly diluted at higher flows. The regression coefficients for both Reference Condition and Present Ecological State are reasonably good.

- **v)** *Calculate the concentrations of variable “X” (as given by the regression equation) for the Reference Condition and Present Ecological State for each month under the natural and present day flow regimes.*

The first two data lines of Table 2 (the “Flow building blocks” section) show the monthly mean stream flow for the Reference Condition and for the Present Ecological State (the same data as in Table 1). The first two data lines of the lower half of the table (“Water quality corresponding to flow”) show the predicted TDS concentration for those months as calculated from the appropriate regression equation.



R-SQUARE VALUES			
REFERENCE CONDITION		PRESENT STATE	
LINEAR	0.645	LINEAR	0.624
LOG	0.804	LOG	0.774
POWER	**0.859**	POWER	**0.797**
EXPONENTIAL	0.737	EXPONENTIAL	0.692

Figure 5 Q-C plot of TDS concentration with flow for site IFR 10 on the Steelpoort River (Mpumalanga). The median monthly values for the Reference Condition (RC[C]) and the Present Ecological State (PES[C]) are shown in addition to the 95% confidence interval for the latter. Also shown is a summary table of the r^2 values obtained for each of the functions (trendlines).

Table 2 The predicted concentrations of X under the recommended flow regime. The first two data lines show the monthly mean stream flow for the Reference Condition and for the Present Ecological State, followed by the recommended flow regime for Maintenance low flows and drought low flows. The regressed concentrations of variable X for the Reference Condition and Present Ecological State for each month under the natural and present day flow regimes are given in row 7and 8. The lower half of the table ("concentration corresponding to flow") shows the predicted TDS concentration for each month under each flow as calculated from the appropriate regression equation.

		FLOW BUILDING BLOCKS	**MONTHLY MEAN FLOW**												
		MONTH	**OCT**	**NOV**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**MEAN**
1	**RC**	**FLOW (m^3/sec)**	4.46	17.78	22.95	29.76	31.50	18.96	11.57	6.35	4.11	3.09	2.56	2.54	12.97
2	**PES**	**FLOW (m^3/sec)**	1.93	14.67	19.37	25.50	27.03	15.17	8.78	3.96	1.75	0.79	0.28	0.42	9.97
3	**Recommended**	**MAINTENANCE IFR; LOW FLOW**	**3.0**	**15.0**	**20.0**	**26.0**	**28.0**	**17**	**9.0**	**4.0**	**2.0**	**2.0**	**2.0**	**2.0**	**10.83**
4		**MAINTENANCE IFR: FLOODS**													
5		**DROUGHT IFR: LOW FLOW**	**1.8**	**10.0**	**5.0**	**15.0**	**20.0**	**10**	**5.0**	**2.0**	**1.0**	**1.0**	**1.0**	**1.0**	**6.06**
6		**DROUGHT IFR: FLOODS**													
		FLOW BUILDING BLOCKS	**CONCENTRATION CORRESPONDING TO FLOW**												
		MONTH	**OCT**	**NOV**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**MEAN**
7	**RC**	**[TDS] REGRESS**	87	46	41	39	39	45	56	74	91	103	113	113	71
8	**PES**	**[TDS] REGRESS**	383	241	226	213	213	239	271	325	392	470	594	543	343
9	**Predicted**	**MAINTENANCE IFR; LOW FLOW**	**347**	**240**	**225**	**212**	**208**	**233**	**270**	**325**	**380**	**380**	**380**	**380**	**298**
10		**MAINTENANCE IFR: FLOODS**													
11		**DROUGHT IFR: LOW FLOW**	**392**	**263**	**308**	**240**	**225**	**263**	**308**	**380**	**445**	**445**	**445**	**445**	**347**
12		**DROUGHT IFR: FLOODS**													

RC = Reference Condition, PES = Present Ecological State, IFR = Instream Flow Requirement, REGRESS = Regression.

- ***vi)*** *Predict the concentration of X for each month of the prescribed flow regime and estimate the 95% confidence interval around this prediction.*

A prescribed flow regime for normal and drought years is given in data lines 3 and 5 of the “Flow building blocks” section of table 2. Space is left in which the values of recommended floods can be entered if required. (Although since the worst water quality usually occurs under conditions of lowest flow, this is not normally needed). The corresponding monthly TDS concentrations that can be expected under this flow regime (as calculated from the Present Ecological State regression equation) are shown in data lines 9 and 11 of the “Water quality corresponding to flow” section.

The predicted TDS concentrations under the recommended Maintenance IFR low flows (i.e. baseflow during normal hydrological years) are lower, or the same as, water quality under the Present Ecological State. Under the recommended drought low flow conditions, however, TDS levels will be higher.

- **vii)** *Calculate the extent of deviation of the Present Ecological State values of X and of the predicted concentrations of X from the Reference Condition.*

Table 3 shows the percentage deviation from the Reference condition of the Present Ecological State TDS (data line 1) and the predicted TDS concentrations (data lines 2 and 4).

- **viii)** *Assign the Assessment Category for each month*.

The precise details of how to assign the predicted Assessment Category will depend on the method that is finalised by DWAF. As an example, the results that are shown for the site on the Steelpoort River were derived using the method set out in the Resources Directed Methods manual (DWAF 1999). These are shown in Table 3 (data lines 6,7 and 9). Because of considerable change from the Reference Condition concentrations, current TDS levels and those predicted are 40% higher than the Reference Condition. Consequently using the look up table used, an E/F category is predicted for all months under all flow regimes.

Table 3 The percentage deviation of the Present Ecological State TDS and the predicted TDS concentration under recommended maintenance and drought flows (values given in Table 2) from the Reference Condition for each month of the year. The predicted Assessment Category for each month is also shown (see text).

	FLOW BUILDING BLOCKS		**PERCENTAGE DEVIATION FROM REFERENCE CONDITION**												
	MONTH		**OCT**	**NOV**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**MEAN**
1	**PES**	**[TDS]PES REGRESS**	339	425	455	488	495	437	384	339	332	354	427	379	404
2	**Predicted**	**MAINTENANCE IFR; LOW FLOW**	**297**	**422**	**450**	**484**	**490**	**423**	**381**	**338**	**319**	**267**	**237**	**236**	**362**
3		**MAINTENANCE IFR: FLOODS**													
4		**DROUGHT IFR: LOW FLOW**	**346**	**473**	**655**	**563**	**538**	**490**	**450**	**413**	**391**	**330**	**294**	**293**	**436**
5		**DROUGHT IFR: FLOODS**													

	FLOW BUILDING BLOCKS		**ASSESSMENT CATEGORY**												
	MONTH		**OCT**	**NOV**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**MEAN**
6	**PES**	**[TDS] REGRESS**	E/F	E/F	E/F	E/F	E/F	E/F	E/F	E/F	E/F	E/F	E/F	E/F	E/F
7	**Predicted**	**MAINTENANCE IFR; LOW FLOW**	**E/F**	**E/F**	**E/F**	**E/F**	**E/F**	**E/F**	**E/F**	**E/F**	**E/F**	**E/F**	**E/F**	**E/F**	E/F
8		**MAINTENANCE IFR: FLOODS**													
9		**DROUGHT IFR: LOW FLOW**	**E/F**	**E/F**	**E/F**	**E/F**	**E/F**	**E/F**	**E/F**	**E/F**	**E/F**	**E/F**	**E/F**	**E/F**	E/F
10		**DROUGHT IFR: FLOODS**													

PES = Present Ecological State, IFR = Instream Flow Requirement, REGRESS = Regression

SECTION 3

LINKING WATER QUALITY AND BIOTIC RESPONSE

Why is it necessary to link water quality and biotic response?

Not only can altered stream flow have a marked effect on water quality - but water quality can also exert a profound effect on the functioning and abundance of aquatic biota. So, in order to maintain a functioning riverine ecosystem it is necessary to ensure that the aquatic biota are healthy, and this, in turn, requires the provision of suitable water quality (the appropriate concentrations of chemical constituents and values of physical variables). All organisms exhibit tolerance ranges for environmental variables, including those of water quality, within which they can survive and multiply. Outside of these tolerance ranges, processes such as growth, feeding, and reproduction may be impaired. Because the species forming a community in a stream exhibit different tolerance ranges, changes in water quality will affect some species more than others. As the alteration in water quality becomes more pronounced, some species will not be able to survive and will disappear from the community whilst other, more tolerant species, will start to establish themselves.

The Biotic Protocol

The “Biotic Protocol” is a series of steps which represents a structured way for assessing the likely effects of changed water quality on the aquatic biota. These steps are presented in this manual. The method makes use of macroinvertebrates (insects, crustaceans, worms and molluscs), although, if suitable data are available, the same approach could be applied to other biotic groups such as fish. As part of the Biotic Protocol, relevant sources of data or information (listed below and discussed in the following section) are examined in order to assess the implications of the changed water quality. These sources include:

- The South African Water Quality guidelines (DWAF 1996)
- Macroinvertebrate biomonitoring data (i.e. the Biobase and Rivers databases).

- Ecotoxicological data.
- Any other useful sources of information that are currently available or may become available in the future (e.g. the macroinvertebrate section of the starter document if the work is part of a Reserve determination).

Although the Biotic Protocol takes into account documented tolerance ranges from ecotoxicological studies it is based, primarily, on the examination of historical records in which the presence of macroinvertebrate taxa (i.e. families, genera or species) is linked with measurements of water quality variables. The Biotic Protocol can be used either within the Reserve determination process, or in other situations where the effect of altered water quality (for instance resulting from increased effluent discharge) on the biota needs to be assessed.

The complexity of aquatic ecosystems

Because natural ecosystems are complex, it is extremely difficult to predict the effect that changed water quality might have on them, and at best, only general predictions can be made. Furthermore, water quality variables can interact with one another, leading to additive, antagonistic and synergistic effects (e.g. the toxicity of most metals is increased under acidic conditions).

Because aquatic ecosystems are naturally varied and complex, only generalised predictions of the effect changed water quality may have on the aquatic biota can be made using the Biotic Protocol.

Furthermore, because of the complexity of ecological interactions, no single source of information (whether ecotoxicological, or biomonitoring data from the Rivers database) is enough to give a full understanding of the likely consequences of a proposed change in water quality for the biota. By including all useful sources of relevant information, a better prediction of the likely effects can be made.

The availability of tolerance data

Several forms of data linking water quality with the abundance, composition (i.e. presence or absence of taxa) or functioning of aquatic macroinvertebrates are available.

- **The South African Water Quality Guidelines**

The South African Water Quality Guidelines (DWAF 1996) for aquatic ecosystems give recommended ranges of water quality variables (termed the "Target Water Quality Range" (TWQR)). These ranges were derived from consideration of the limited data on indigenous organisms, from examination of the guidelines from other countries and from laboratory-based ecotoxicity data. These ranges represent a very useful tool for initial screening of predicted water quality values.

- **Macroinvertebrate biomonitoring data**

The South African Scoring System (SASS) is a biomonitoring technique that has been developed specifically for South African rivers (Chutter 1994). It is a scoring system for assessing the chemical quality of river water from the composition of the macroinvertebrate fauna (at the family level) and is one of the major components of the River Health Programme. Results from this biomonitoring programme are stored in the Rivers database (Fowler, Dallas and Janssens 2000). Details of the River Health Programme are available from the website and the data are available on a CD from Southern Waters (see "Useful websites" at the end of this manual).

The Chemical-Biological database (Biobase), is a database comprising macroinvertebrate and water quality data obtained from documented studies of riverine ecosystems in South Africa (Dallas, Janssens and Day 1999). Measures of physical attributes and concentrations of chemical constituents are incorporated with associated species assemblages of invertebrates from samples collected over many years throughout the country. The Biobase on CD, in conjunction with a User manual (Dallas and Janssens 1998), is available from the Water Research Commission.

- **Ecotoxicological data**

Ecotoxicological data for aquatic organisms are available from the ECOTOX database developed by the US EPA. This database is of limited use since is difficult to extrapolate the data to the effects on indigenous organisms and does not include system variables (e.g. temperature, DO, TDS). Nevertheless, for assessing the impact of toxic substances it is a useful resource (see "Useful web sites" for the web site address). Values of some ecotoxicological parameters for chemical constituents and indigenous organisms are given in the South African Water Quality Guidelines (DWAF 1996). Currently, few empirical tolerance data exist for southern African organisms or for standard test organisms exposed under local conditions.

Ecotoxicological data that are available in databases are not always easy to interpret, and if possible, a toxicologist should be consulted.

General considerations

There are three sets of stream flow, water quality and biological data involved in the Biotic Protocol. Namely, those for the:

- Reference Condition,
- Present Ecological State
- Future Predicted State (under the recommended flow regime).

Because the Biotic Protocol is time-consuming it is recommended the method be applied only to critical reaches in which either water quality is very poor, or sensitive species are present.

Depending on the frequency of sampling at the site in question or at sites in the same ecoregion and same type of river, 3-5 years worth of biomonitoring data are required. Since the River Health Programme has only been running for a short while, for the majority of sites there are currently few biomonitoring data. It is important to note that this method is still under development and so it is not possible to give guidance as to exact details.

The Biotic Protocol is still under development, therefore the exact details of some parts of the procedure cannot be given and may need to be revised.

How to apply the Biotic Protocol

The Biotic Protocol is a technique that can be used to assess what a water quality scenario will mean for the macroinvertebrate population in a given reach of river. In the case of Reserve determinations, the technique can be applied once predictions of water quality (e.g. from Q-C modelling) have been obtained (and hence once the flow regime has been recommended). The Biotic Protocol is carried out separately for each water quality reach in which a critical site is located. The individual steps are described below, and a summary is given in Figure 6.

- **i)** *Using water quality modelling, tabulate and identify the maximum predicted concentrations for each significant water quality variable. This is carried out separately for the:*
  - *a) Reference Condition,*
  - *b) Present Ecological State*
  - *c) Future Predicted State (i.e. under the predicted water quality conditions)*

Any type of water quality modelling can be used (e.g. Q-C, QUAL2E) providing that monthly values for a given water quality variable are predicted. From these simulations the maximum monthly, predicted concentrations that will occur under the recommended flow regime can be identified.

It is useful to tabulate the minimum, median and maximum monthly values for each of the important water quality variables and for each of the three scenarios.

Figure 6 Summary of the Biotic Protocol

i) *Using water quality modelling, tabulate and identify the maximum predicted concentrations for each water quality variable. This is carried out separately for the;*

a) Reference Condition,
b) Present Ecological State,
c) Future Predicted State.

ii) *Compare the maximum predicted concentrations with the Target Water Quality Range and identify the water quality variables (typically two or three) likely to pose the most serious risk.*

iii) *Compare ecotoxicological parameters, if available, with the maximum predicted concentrations in order to estimate the toxicity of the variable in question.*

iv) *Examine the Biobase and Rivers database for biotic sampling data characteristic of the* ***Reference Condition*** *for;*

a) The specific river in question, and/or
b) similar systems (i.e. in the same ecoregion and type of river).

v) *Examine the Biobase and Rivers database for biotic sampling data characteristic of the* ***Future Predicted State*** *for;*

a) The specific river in question, and/or
b) similar systems (i.e. the same ecoregion, and type of river).

vi) *Compare macroinvertebrate taxa lists for the Reference Condition and Future Predicted State. Derive a theoretical SASS score and a tentative Assessment class for the Future Predicted State.*

vii) *Include input from any other biotic tolerance indices and databases that may be relevant.*

viii) *Synthesize a scenario for the aquatic biota that is likely to be the consequence of the proposed change in flow. Assign the future Assessment Category (A-F).*

- **ii)** *Compare the maximum predicted concentrations with the Target Water Quality Range from the South African Water Quality Guidelines and identify the two or three water quality variables likely to pose the most serious risk at that particular site.*

Target Water Quality Ranges (TWQR) are the recommended limits of concentrations of chemical constituents and values of physical variables for aquatic ecosystems (DWAF 1996). Values that fall within the TWQR, can be considered to pose little risk to the biota, whilst those that fall outside of this range may be harmful. The two or three (more may be selected but may need refinement at a later stage in the process) water quality variables that are considered to be the most critical (most exceed the TWQR range) are selected. The choice as to which water quality variables are likely to pose the most serious threat to the biota requires expert judgement. Toxins are rated as the most important followed by system variables.

- **iii)** *Compare ecotoxicological parameters, if available, with the maximum predicted concentrations in order to estimate the toxicity of the variable in question.*

Check ecotoxicological databases for data on the water quality variables under consideration, both for indigenous organisms, and for laboratory organisms in international databases. Ecotoxicological parameters such as the LOEC (the lowest concentration that brings about an observed effect) and LC_{50} (the concentration that corresponds to a 50% cumulative probability of death of the test population) can be compared with the maximum values predicted for the recommended flow regime. This gives an indication of the toxicity of individual water quality constituents.

- **iv)** *Examine the Biobase and Rivers database for biotic sampling data characteristic of the* ***Reference Condition*** *for:*

  a) the specific river in question;

  b) similar systems (i.e. other rivers of the same type and in the same ecoregion).

The aim of this step is to identify macroinvertebrate taxa that are likely to be present at the IFR site in question under un-impacted conditions. There are two main ways in which this can be done:

- In the Biobase or Rivers database, set the theoretical SASS and ASPT (Average Score Per Taxon) scores equal to values representative of the Reference Condition for that given ecoregion and type of river (see Table 4), and then filter the data in order to identify samples from least-impacted sites.

- Search the databases for sampling occasions in which the median monthly concentrations or values of physical variables are within 15% of the values expected in the Reference Condition.

This task (as well as establishing the taxa currently present in the system) is usually part of the requirements for the macroinvertebrate section of a Reserve determination. It is therefore a good idea to communicate with the specialist for this discipline.

It is important to liaise with both the water quality and macroinvertebrate specialists involved in a Reserve determination during application of the Biotic Protocol.

- **v)** *Examine the Biobase and Rivers database for biotic sampling data characteristic of the* ***Future Predicted State*** *for:*
  - *a) the specific river in question, and/or*
  - *b) similar systems (i.e. other rivers of the same type and in the same ecoregion).*

Extract sampling data where the values of the water quality variable are similar to the maximum predicted concentrations. Data are screened by setting the concentration values in the range of the critical value ± 10%. The value of 10% is an arbitrary value, and is used to ensure that sampling occasions where the concentrations of the key water quality variables are approximately the maximum predicted concentration are included. For example, if the maximum predicted concentration is 300mg/litre then sampling occasions when the concentration of that variable is within the range of 270 – 330 mg/litre will be included in the extraction. Lists are compiled of the macroinvertebrate taxa that can be expected to survive under the predicted water quality conditions. If no data are available in which all water quality variables (i.e. two or three) are similar to the maximum predicted concentration, the databases are again interrogated setting fewer variables equal to 90% of the maximum predicted concentration. A list of invertebrate taxa likely to be found under such a water quality scenario is compiled. A lower confidence can be placed in the predictions in this second case however, since the situation is less representative of the future water quality scenario.

- **vi)** *Compare the lists of taxa obtained for the Reference Condition, Present Ecological State (if required) and Future Predicted State. Derive a theoretical SASS score and a tentative likely Assessment Category for the Future Predicted State.*

From the list of invertebrate taxa obtained in steps iv) and v) tables are drawn up recording the taxa expected under the Reference Condition and Present Ecological State (if required) and under water quality conditions that represent the Future Predicted State. SASS scores from different sites and sampling occasions that are characteristic of a given water quality scenario (i.e. the Reference Condition, Present Ecological State or Future Predicted State), are combined by taking the median and for this reason are referred to as derived or theoretical SASS scores.

A theoretical SASS score for the predicted impacted state can be calculated, and from this a tentative future Assessment Category (see Table 5). Possible shifts in species composition including occurrence of nuisance species and loss of rare/key species should also be noted.

- **vii)** *Include input from any other biotic tolerance databases that may be relevant.*

This step can be included if suitable data and expertise, for example on fish or aquatic vegetation, are available.

- **ix)** *Synthesize a likely scenario for the aquatic biota as a result of the proposed change in stream flow. Assign the future Assessment Category (A-F).*

In this step, expert knowledge of the macroinvertebrates and water quality of the particular river of concern is used to modify the final predicted Assessment Category. Factors that might need to be taken into consideration include:

- The occurrence of vulnerable sites (e.g. spawning sites) in a given water quality reach (the juvenile life stages are often more sensitive to chemical pollutants than the adults, thus potentially lowering the expected Assessment Category).
- The presence of refugia from which river reaches can be recolonised in cases where the future predicted water quality is better than at present.
- Potential effects on the biota of alterations to hydraulic habitat (e.g. it may be predicted that water quality is suitable for a given riffle-dwelling species. If the water

level is reduced so that riffles will no longer be present, that species is not likely to remain).

- Consideration of the representivity of the sampling data that were used to make predictions of the impact. It was explained in step *v*) that the databases are first interrogated to obtain sampling occasions in which three water quality variables are equal to, or greater than 90% of the maximum predicted concentration. If no suitable sampling occasions are available, data are extracted in which two variables fit the required criteria. The fewer variables that represent the Future Predicted State, the lower the confidence in the prediction.

The final step is to reassess the tentative Assessment category assigned in step *vi)* in the light of the information obtained above and to produce a final future Assessment Category.

<u>Points to note</u>

1) SASS and ASPT (Average score per taxon) values used for identifying Reference Conditions vary according to the ecoregion (or Water quality management region; WQMR), and the type of river (Table 4). Those for areas other than the southern and western coast still need further research to confirm the values.

Table 4 *SASS4 score and ASPT values used to identify least impacted (Reference Condition) sampling sites in the Western Cape and for other Water Quality Management Regions (WQMR).*

WQMR	River type	SASS4 score ≥	ASPT ≥
Southern and western coast[1]	Mountain stream	140	7.5
	Foothill	120	7.5
	Transitional	85	6.5
	Lowland	50	5.0
"A" category river[2]		>140	>7.0

[1] Dallas, Day, Musibono and Day (1998)

[2] DWAF (1999)

2) Version 4 of SASS was used in the development of this Biotic Protocol, although version 5 (SASS5) is now available. Both forms are compatible with the Biotic Protocol although in order to compare scores from different sampling occasions accurately it is necessary to first ensure that they are all converted to the same version of the SASS index.

3) A tentative Assessment Category for the Future Predicted State can be derived from the theoretical SASS4 score by using Table 5. As in the case of SASS scores that are characteristic of Reference Condition (Table 4), the values of SASS4 scores that delineate the different Assessment Categories also require further research in order to confirm the exact values.

Table 5 *A comparison of Assessment Category, river condition, and associated SASS4 scores and ASPT values (DWAF 1999).*

Assessment Category	Condition	SASS4 score	ASPT value
A	Excellent	> 140	> 7
B	Very good	121 – 140	6 – 7
C	Good	101 – 120	5 – 6
D	Fair	61 – 100	4 – 5
E	Poor	31 – 60	3 – 4
F	Very poor	< 30	< 3

4) Interactions between water quality variables are taken into account by searching the databases for sampling data where as many variables as possible are simultaneously (approximately) equal to 90% of the predicted maximum concentration. The records obtained are also filtered to ensure that they are obtained from the same ecoregion and type of river.

5) In cases where no modelling data are available but it is known that certain instream contaminants are likely to be present, this information can be used to modify the final Assessment Category (and included as comments in the predicted water quality scenario). The following situations should be considered to be serious:

- A combination of high predicted nitrogen concentrations in combination with high pH (due to the possibility of NH_3 forming which is toxic to most macroinvertebrate species).
- A combination of high predicted concentrations of a metal pollutant in combination with low pH.
- Conditions of high water temperature accompanied by low levels of dissolved oxygen.

6) Many steps in the Biotic Protocol require specialised knowledge of water quality and the macroinvertebrates characteristic of the river under consideration. These include:

- The decision as to which water quality variables are likely to exert the most profound effects on the biota (note that in the worked example a graph of concentration versus SASS score was plotted to help in this decision).
- Identification of potential nuisance species or key species of invertebrates that are likely to be lost to the system.
- Synthesising information on the integrated effects of the proposed water quality scenario on the biota (step ix).

7) As far as possible, given the constraints of the limited data, sampling data from the same time of the year should be compared. This is important since the composition of taxa (and thus the SASS score) will vary during the year.

<u>Assumptions and limitations in the method</u>

The following assumptions and limitations should be kept in mind when using the Biotic Protocol:

1) The databases are patchy and if a given taxon is not found in the database under particular conditions of water quality, this does not necessarily mean that the species cannot tolerate those conditions. It may well be that the organism can survive such water quality but this fact has not been recorded. In a similar manner, a given water quality scenario may not have been recorded in a particular river or catchment. There is a need for the compilation of extensive databases linking water quality and biomonitoring data.

Lack of appropriate data is the most serious limitation to applying the Biotic Protocol.

2) Not only should the concentration of chemical constituents that the biota will be exposed to be considered, but also the length of exposure time. At the moment the Biotic Protocol cannot be used to assess such a change in a water quality scenario.

3) Some of the assumptions that apply to Q-C modelling are also of relevance in application of the Biotic Protocol, namely:

- Predictions are made on the assumption that the pollution load will remain the same as at present.
- Since the recommended maintenance and drought low flows represent the minimum flow for each month, predicted water quality, and therefore the potential impact on the biota, represents the “worst case scenario”.

4) Often because of lack of data, or a significant statistical relationship between flow and concentration, quantitative predictions of a significant water quality constituent cannot be made. If it is suspected that that variable is exerting a major impact, the effect can be incorporated qualitatively by adjusting the final Assessment Category.

A WORKED EXAMPLE OF THE BIOTIC PROTOCOL

In this example, the Biotic Protocol is applied to a site (called “Mamba”) on the lower Olifants River, Mpumalanga. The reasons for choosing this site were:

- Water quality is persistently poor in this reach.
- The site is on the western (upstream) boundary of the Kruger National Park and is therefore ecologically important.
- Reasonably extensive biomonitoring data are available for this region.

The results are presented in the form of the sequential steps of the Biotic Protocol:

- **i)** *Using water quality modelling, tabulate and identify the maximum predicted concentrations for each significant water quality variable. This is carried out separately for the:*
  - *a) Reference Condition*
  - *b) Present Ecological State*
  - *c) Future Predicted State*

The minimum, median and maximum monthly concentrations for each water quality variable that could be expected during the hydrological year are shown in Table 6. This is reported for the Reference Condition, Present Ecological State, and the Future Predicted State. Two different flow regimes are included in the latter, namely the recommended maintenance flow and the drought flow. Both of these flow regimes represent an *increase* in flow compared to the current regime at that site and water quality will be improved more under maintenance low flow than under drought low flow. It was decided that the implications to the biota of the drought low flows should be investigated as this represented the “worst case scenario”. Thus the effect of the following maximum predicted of chemical constituents (expressed in mg/litre) on the biota were investigated:

TDS = 1421
Sulphate = 586
Fluoride = 2.7
Total inorganic nitrogen (TIN) = 0.29
ortho-Phosphate = 0.07

- **ii)** *Compare the maximum predicted concentrations with the Target Water Quality Range and identify the two or three water quality variables likely to pose the most serious risk.*

- The Target Water Quality Range (TWQR) for each of the chemical constituents, as recommended in the South African water quality guidelines (DWAF 1996) is also shown in Table 6. The final column of the table indicates whether or not the maximum value falls within this range. It can be seen that of the five water quality variables modelled, only total inorganic nitrogen (TIN) would be within the limits under the recommended flow regime.

***Table 6** Minimum, median and maximum concentrations (mg/litre) of the water quality variables modelled at IFR 15 on the Olifants River, under the Reference Condition (natural), Present Ecological State (present), and Future Predicted State (maintenance and drought) flow regimes. Concentrations predicted using the Q-C method. The TWQR is indicated and whether the predicted maximum concentration will fall within this range (√) or will exceed it (**X**).*

Variable	Flow regime	Predicted/measured concentration (mg/litre)			TWQR	Max within TWQR?
		Min.	Median	Max.		
TDS	Natural	212	266	300	≤ 15% deviation from Reference Condition	√
	Present	252	816	1541		**X**
	Maintenance	778	956	1074		**X**
	Drought	1167	1323	1421		**X**
Sulphate	Natural	-	-	-	Not in SA Guidelines	-
	Present	52	235	727		-
	Maintenance	217	288	343		-
	Drought	394	499	586		-
Fluoride	Natural	0.274	0.317	0.34	TWQR = 0.75 mg/litre CEV = 1.5 mg/litre AEV = 2.54 mg/litre	√
	Present	0.314	1.5	3.00		**X**
	Maintenance	1.37	1.45	2.00		**X**
	Drought	2.2	2.5	2.70		**X**
TIN	Natural	0.13	0.14	0.17	< 0.5 mg/litre = oligotrophic	√
	Present	0.275	0.28	0.32		√
	Maintenance	0.28	0.28	0.29		√
	Drought	0.28	0.28	0.29		√
ortho-P	Natural	0.016	0.017	0.02	≤ 15% deviation from Reference Condition 0.025-0.25 mg/litre = eutrophic	
	Present	0.023	0.036	0.09		**X**
	Maintenance	0.034	0.041	0.05		**X**
	Drought	0.052	0.063	0.07		**X**

TDS =total dissolved solids, TIN =total inorganic nitrogen, ortho-P =ortho-phosphate. CEV =chronic effect value, AEV =acute effect value. TWQR =Target Water Quality Range as specified in the South African Water Quality Guidelines (DWAF 1996).

Sulphate is not listed in the South African water quality guidelines and in addition, there were no suitable Reference Condition data available for Q-C modelling. It is suspected however, by comparing the values with other sites on the same river system that sulphate levels are considerably elevated at this site. Thus it is likely that this water quality constituent may be exerting a major impact on the biota at that site.

Four of the water quality variables were chosen for further investigation namely;

- TDS
- fluoride
- ortho-phosphate
- sulphate.

- **iii)** *Compare ecotoxicological parameters, if available, with the maximum predicted concentrations in order to estimate the toxicity of the variable in question.*

Relevant ecotoxicological data could be found only for fluoride in the ECOTOX database. The LC_{50} for fluoride (i.e. the concentration resulting in a likelihood of death for 50% of a test population within 24 – 48 hours) was found to range from 26 to 680 mg/litre. This was derived from the data for *Daphnia* and three species of caddisfly. These concentrations are much higher than those predicted to occur at Mamba. A probability of death for 50% of the test population is also an extreme impact. No other useful ecotoxicological information could be found in this database.

The CEV (the chronic effect value) and AEV (acute effect value) for fluoride are reported in DWAF (1996) as 1.5 and 2.54 mg/litre respectively. The maximum predicted concentration for fluoride (2.7 mg/litre) is greater than both these values. The CEV is defined by DWAF (1996), as the (upper) concentration limit that is safe for most populations even during continuous exposure. The AEV is the concentration at, and above which, statistically significant acute adverse effects are expected to occur. These data show that fluoride at the concentrations currently present in the system, and under the recommended drought low flows is likely to exert acutely toxic effects on the biota. It is likely to be a major factor in determining the presence or absence of sensitive taxa in that reach of the river.

- **iv)** *Consult the Biobase and Rivers database for sampling data characteristic of the **Reference Condition** for:*

  a) The specific river in question.

  b) Similar systems (i.e. in the same ecoregion and type of river).

A review of the macroinvertebrate taxa found under present conditions and historically at Mamba is given in Palmer (2000). The author gives eight SASS4 taxa that were historically found at Mamba, but that have not been found subsequently during the biomonitoring programme. These were Perlidae, *Hydra*, Heptageniidae, Pleidae, Nymphulidae, Haliplidae, Hydraenidae and Lymnaeidae.

The Biobase and Rivers databases are then interrogated for sampling data characteristic of the Reference Condition by setting the theoretical SASS score equal to 140. The value of this SASS4 score was chosen after consideration of Table 4. Only sites in the lowveld were examined that were in the foothill, gravel-bed sub-region (i.e. similar river type and same ecoregion as Mamba). Two records were found (one in each database) that fitted this criterion, both from Mamba. These sampling occasions are indicated as records 6 and 13 respectively in Table 7. Mamba is designated as KNP06 in the Biobase and B7OLIF-Mamba in the Rivers database. The taxa found during these sampling occasions that are considered to be representative of the Reference Condition are listed in Table 8.

- **v)** *Consult the Biobase and Rivers database for sampling data characteristic of the **Future Predicted State** for:*

  a) the specific river in question;

  b) similar systems (i.e. the same ecoregion, and type of river).

Three sites in the databases were found to fit the necessary criteria (i.e. in the same ecoregion, and the same type of river with similar water quality conditions). The three sites were Mamba, Vygeboom and Balule. The last two sites are downstream of Mamba on the Olifants River and within the Kruger National Park. Table 7 shows a summary of all the sampling data for the three sites, including the name of the site, the sampling date, and the concentrations of the four water quality variables at the time of sampling (or in the case of the Biobase, at approximately the time of sampling). The derived SASS score and ASPT are indicated, as are the biotopes that were sampled, and the database from which the information was extracted. Graphs were drawn of concentration versus

***Table 7** Summary of the sampling data from Mamba, Vygeboom and Balule stored in the Rivers database and the Biobase. Included are the site name, sampling date, and the concentrations of the significant water quality variables at the time of sampling. The derived SASS score and ASPT, the number of biotopes sampled, as well as the database from which the information was extracted, are given. Sampling occasions used to infer the taxa likely to be present in the Future Predicted State are indicated in bold.*

Record number	Site	Site visit	[F]	[TDS]	$[SO^4]$	[ortho-P]	SASS4 Score	ASPT	No. of Families	No. biotopes sampled	Database
1	**B7OLIF -Mamba**	**7/6/93**	**2.7**	**1572**	**744**	**0.02**	**93**	**4.2**	**22**	**All biotopes**	RIVERS DATABASE
2	**B7OLIF -Mamba**	**29/7/93**	**2.7**	**1383**	**592**	**0.13**	**131**	**4.7**	**28**	**All biotopes**	
3	B7OLIF-Mamba	28/6/94	2.6	1518	660	0.06	-	-	-	All biotopes	
4	B7OLIF-Mamba	19/7/94	3.2	1667	745	0.08	125	5.2	24	All biotopes	
5	B7OLIF-Mamba	1/8/95	3.8	1637	696	0.18	66	5.1	13	All biotopes	
6	B7OLIF-Mamba	7/10/98	0.6	478	115	0.05	157	5.6	28	All biotopes	
7	B7OLIF-Vyge	8/10/98	0.6	448	-	0.02	73	4.9	15	All biotopes	
8	B7OLIF-Balule	6/6/93	1.4	841	262	0.022	78	7.8	15	All biotopes	
9	**B7OLIF -Balule**	**29/7/93**	**2.4**	**1551**	**672**	**0.025**	**81**	**4.8**	**17**	**All biotopes**	
10	**B7OLIF -Balule**	**20/7/94**	**2.6**	**1356**	**542**	**0.028**	**102**	**5.1**	**20**	**All biotopes**	
11	**B7OLIF -Balule**	**1/8/95**	**2.4**	**1481**	**601**	**0.025**	**100**	**5.6**	**18**	**All biotopes**	
12	B7OLIF-Balule	8/10/98	0.8	558	155	0.019	62	4.4	14	All biotopes	
13	KNP06 Mamba	1983-1986/10/03	0.6	225	11	0.05	165	6.1	27	3	BIOBASE
14	KNP06 Mamba	1983-1986/04/09	0.3	288	18	0.04	125	6.0	21	2	

ASPT = average score per taxon, Vyge = Vygeboom.

derived SASS score for each of the chemical constituents (data taken from table 7) in order to decide which were having the most impact on the biota (Figure 7). There is a negative trend between concentration and SASS score for TDS, fluoride and sulphate however, the derived SASS value seemed to be largely independent of the concentration of ortho-phosphate. This is not surprising since the major effect of elevated concentrations of nutrients on aquatic ecosystems, is to alter the trophic state rather than to exert a toxic effect. This variable was therefore not considered further.

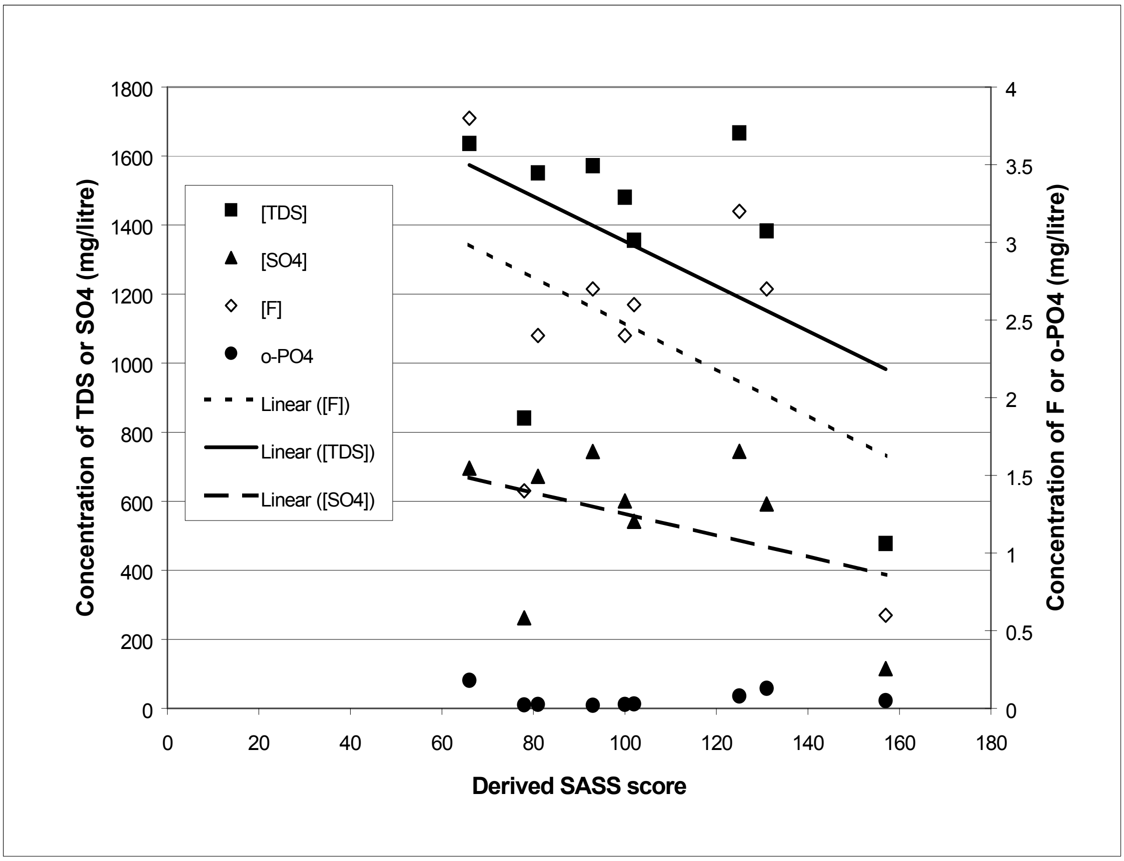


***Figure 7** Graph of concentration plotted against derived SASS score for the four water quality variables (TDS and $SO_4{}^{-2}$ on the left Y-axis and fluoride and ortho-phosphate on the right Y-axis) considered to be the most significant at Mamba on the Olifants River.*

The data in Table 8 were inspected for occasions on which the concentration of the water quality variables were equal to or higher than approximately 90%, but less than 110% of the maximum predicted concentration. Namely:

TDS = 1420 (≈ 1280 – 1560) mg/litre

sulphate = 580 (≈ 525 – 640) mg/litre

fluoride = 2.7 (≈ 2.4 – 3.0) mg/litre

The sampling occasions that were used to infer the taxa likely to be present in the Future Predicted State were records number 1, 2, 9, 10 and 11. These are indicated in bold in Table 7. Records 4 and 5 were considered to representative of the Present Ecological State. The data recorded in the Biobase were not found to be useful for deriving information with regard to the recommended flow regime as the TDS and sulphate levels were too low. Record 3 (from the Rivers database) was ignored because no biological data were collected on that sampling occasion.

- **vi)** *Compare taxa lists for the Reference Condition and Future Predicted State. Derive a theoretical SASS score and Assessment Category for the Future Predicted State.*

Lists of the taxa present on the sampling occasions are indicated in Table 8, which also shows the water quality (the concentration of fluoride, TDS and sulphate), and the derived SASS4 score. The two columns on the left-hand side, show the taxa expected under Reference Conditions. Columns 3 and 4 represent the Present Ecological State water quality at Mamba. Columns 5 - 9 are similar to the maximum predicted concentrations for TDS (1420 mg/litre), fluoride (2.7 mg/litre) and sulphate (580 mg/litre) and are representative of the Future Predicted State.

By comparing the taxa lists representative of the Reference Condition (columns 1 and 2) with those that represent the Present Ecological State (columns 3 and 4) the taxa that have been lost from the system compared to the Reference Condition could be deduced (underlined in Table 8).

These include: Aeshnidae, one type of Hydropsychidae, Hydrozoa, Nantantia, Oligoneuridae, Planariidae, Planorbidae, and Thioridae.

Table 8 *Lists of invertebrate taxa and SASS scores for individual sampling occasions. Taxa that have been lost compared to the Reference Condition are underlined.*
Taxa that may be regained in the system under the Future Predicted State shown in bold.

REFERENCE CONDITION		PRESENT STATE		FUTURE PREDICTED STATE (UNDER DROUGHT BASEFLOW)				
RECORD 13 (KNP06) 1983-1986/10/03 F=0.6, TDS=225, S=11	RECORD 6 (Mamba) 7/10/98 F=0.6, TDS=478, S=115	RECORD 4 (Mamba) 19/7/94 F=3.2, TDS=1667, S=745	RECORD 5 (Mamba) 1/8/95 F=3.8, TDS=1637, S=696	RECORD 11 (Balule) 1/8/95 F=2.4,TDS=1481, S=601	RECORD 9 (Balule) 29/7/93 F=2.4, TDS=1551, S=672	RECORD 10 (Balule) 20/7/94 F=2.6, TDS=1356, S=542	RECORD 1 (Mamba) 7/6/93 F=2.7, TDS=1570, S=744	RECORD 2 (Mamba) 29/7/93 F=2.7, TDS=1383, S=592
AESHNIDAE								
	ANCYLIDAE							ANCYLIDAE
								ATHERICIDAE
BAETIDAE 3 TYPES	BAETIDAE 1 TYPE	BAETIDAE 2 TYPES	BAETIDAE 2 TYPES	BAETIDAE 2 TYPES	BAETIDAE 1 TYPE	BAETIDAE 2 TYPES	BAETIDAE 1 TYPE	BAETIDAE 1 TYPE
	BELASTOMATIDAE				**BELASTOMATIDAE**		**BELASTOMATIDAE**	**BELASTOMATIDAE**
CAENIDAE	CAENIDAE	CAENIDAE	CAENIDAE	CAENIDAE	CAENIDAE	CAENIDAE	CAENIDAE	CAENIDAE
CERATOPOGONIDAE	CERATOPOGONIDAE			**CERATOPOGONIDAE**		**CERATOPOGONIDAE**		
CHIRONOMIDAE	CHIRONOMIDAE	CHIRONOMIDAE	CHIRONOMIDAE	CHIRONOMIDAE	CHIRONOMIDAE	CHIRONOMIDAE	CHIRONOMIDAE	CHIRONOMIDAE
COENAGRIONIDAE	COENAGRIONIDAE	COENAGRIONIDAE		COENAGRIONIDAE	COENAGRIONIDAE	COENAGRIONIDAE	COENAGRIONIDAE	COENAGRIONIDAE
CORDULIIDAE		CORDULIIDAE			CORDULIIDAE	CORDULIIDAE	CORDULIIDAE	CORDULIIDAE
CORIXIDAE	CORIXIDAE	CORIXIDAE		CORIXIDAE			CORIXIDAE	CORIXIDAE
		CULICIDAE			CULICIDAE	CULICIDAE	CULICIDAE	CULICIDAE
		ELMIDAE/DRYOPIDAE						
DYTISCIDAE					DYTISCIDAE		DYTISCIDAE	DYTISCIDAE
ECNOMIDAE					ECNOMIDAE			
ELMIDAE/DRYOPIDAE	ELMIDAE/DRYOPIDAE					ELMIDAE/DRYOPIDAE		
						GERRIDAE	**GERRIDAE**	**GERRIDAE**
GOMPHIDAE	GOMPHIDAE	GOMPHIDAE	GOMPHIDAE	GOMPHIDAE	GOMPHIDAE	GOMPHIDAE	GOMPHIDAE	GOMPHIDAE
GYRINIDAE						**GYRINIDAE**	**GYRINIDAE**	
HIRUDINEA	HIRUDINEA	HIRUDINEA	HIRUDINEA	HIRUDINEA		HIRUDINEA	HIRUDINEA	HIRUDINEA
HYDROPHILIDAE		HYDRACHNELLAE		HYDRAENIDAE	HYDROPHILIDAE			HYDRACHNELLAE
								HYDROPHILIDAE
HYDROPSYCHIDAE 3 TYPES	HYDROPSYCHIDAE 3 TYPES	HYDROPSYCHIDAE 1 TYPE	HYDROPSYCHIDAE 2 TYPES	HYDROPSYCHIDAE 2 TYPES (pH>6.6)	HYDROPSYCHIDAE 1 TYPE		HYDROPSYCHIDAE 1 TYPE	HYDROPSYCHIDAE 1 TYPE
HYDROPTILIDAE	HYDROPTILIDAE		HYDROPTILIDAE					
HYDROZOA								
	LEPTOPHLEBIIDAE (pH>6.6)	LEPTOPHLEBIIDAE (pH>6.6)	LEPTOPHLEBIIDAE (pH>6.6)					
	LIBELLULIDAE	LIBELLULIDAE	LIBELLULIDAE	LIBELLULIDAE	LIBELLULIDAE	LIBELLULIDAE	LIBELLULIDAE	LIBELLULIDAE
	MELANIIDAE	MELANIIDAE					MELANIIDAE	MELANIIDAE
	MUSCIDAE					NAUCORIDAE		MUSCIDAE
	NANTANTIA (SHRIMPS)							
NAUCORIDAE	NAUCORIDAE	NAUCORIDAE						NAUCORIDAE
	NEPIDAE	NEPIDAE			NEPIDAE		NEPIDAE	NEPIDAE
	NOTONECTIDAE					**NOTONECTIDAE**	**NOTONECTIDAE**	**NOTONECTIDAE**
	OLIGONEURIDAE							
OLIGOCHAETA		OLIGOCHAETA	OLIGOCHAETA	OLIGOCHAETA		OLIGOCHAETA		
	PHYSIDAE						**PHYSIDAE**	**PHYSIDAE**
PLANARIIDAE	PLANARIIDAE							
PLANORBIDAE								
SIMULIIDAE	SIMULIIDAE	SIMULIIDAE	SIMULIIDAE	SIMULIIDAE		SIMULIIDAE	SIMULIIDAE	
	SPHAERIDAE	SPHAERIDAE	SPHAERIDAE	SPHAERIDAE		SPHAERIDAE		SPHAERIDAE
TABANIDAE	TABANIDAE	TABANIDAE	TABANIDAE	TABANIDAE	TABANIDAE	TABANIDAE	TABANIDAE	TABANIDAE
THIORIDAE								
TRICHOPTERA (CASE CADDIS 2 TYPES)		TRICHOPTERA (CASE CADDIS 1 TYPE)		TRICHOPTERA (CASE CADDIS 2 TYPES)	TRICHOPTERA (CASE CADDIS 1 TYPE)	TRICHOPTERA (CASE CADDIS 2 TYPES)	TRICHOPTERA (CASE CADDIS 1 TYPE)	TRICHOPTERA (CASE CADDIS 1 TYPE)
TRICHORYTHIDAE	TRICHORYTHIDAE	TRICORYTHIDAE						
	VELIIDAE	VELIIDAE		VELIIDAE	VELIIDAE			VELIIDAE
SASS 165	**157**	**125**	**66**	**100**	**81**	**102**	**93**	**131**

F=fluoride, TDS = total dissolved solids, S= sulphate

A comparison of taxa present during conditions representing the Future Predicted State (columns 5-9) with those present during the poorest water quality (columns 3 and 4) was used to infer the taxa that would likely be regained in the system under the improved water quality scenario. These are shown in bold in Table 8.

Taxa that may be *regained* in the system under the improved water quality scenario include:
Belastomatidae, Ceratopogonidae, Dytiscidae, Gerridae, Gyrinidae, Notonectidae and Physidae.

A tentative derived SASS score was for the Future Predicted State was estimated to be about 100. This value was obtained by taking the median of the SASS scores for columns 5 -9. From Table 5, this would indicate a future Assessment Category of "C/D".

- **vii)** *Include input from any other biotic tolerance indices that may be relevant.*

This step was not attempted.

- **viii)** *Synthesize a scenario for the aquatic biota that is likely to be the consequence of the proposed change in flow. Assign the future Ecological Reserve Class (A-F).*

The Present Ecological State Assessment Category for macroinvertebrates at Mamba was considered to be a D (Palmer 2000). The predicted improvement in Assessment Category from "D" to "C/D" was considered to be conservative. This is because the proposed flow regime represents an increase in the present-day flow and the maximum predicted concentrations were taken from those expected under the drought low flows (expected to be imposed for less than 20% of the time at the site). In addition, the position of the site and potential recolonisation was taken into account. The poor quality water originates to a large extent from the Selati River, which is a few kilometres upstream from Mamba. Water quality in the mainstem Olifants River is considerably better than at Mamba and thus faunal populations exist that would be likely to recolonise Mamba, should the conditions improve. Thus it is considered that under the recommended flow regime, the likely future Assessment Category will be "C".

SECTION 4

HOW PREDICTIONS OF WATER QUALITY AND BIOTIC EFFECTS CAN BE USED IN RESERVE DETERMINATIONS

What is covered in this section

This section covers the following topics:

- The difference between "natural" and anthropogenic water quality impacts (and why it is important to distinguish between them).
- A general framework for the incorporation of predictions of water quality and implications for the biota into the Reserve process (including a short discussion of scenario modelling).

Natural versus anthropogenic water quality impacts

When carrying out the water quality assessment part of a Reserve determination, it is important to distinguish between "anthropogenic " (i.e. man-made) and "natural" water quality problems.

Anthropogenic water quality impairment occurs frequently and is due to pollution from point- and non-point sources of contaminants.

"Natural" water quality impairment is much less frequent than above, and would include instances where, due to the geology of the surrounding catchment, water draining that region is naturally saline resulting in elevated concentrations of salts in the river.

The two types of water quality impairment need to be treated differently in Reserve determinations as explained below:

1. During a Reserve determination, the present day water quality in the system is appraised since this (amongst other factors, such as, habitat availability) will determine what species of fish and invertebrates are currently to be found.

2. At the Instream Flow Requirement workshop, a flow regime is recommended that will provide suitable flows (in terms of hydraulic and geomorphological habitat) for maintenance of a given level of ecosystem functioning.

3. Predictions are then made as to the concentration of chemical components that can be expected under the new, proposed flow regime in the absence of pollution control. These are termed the likely "*water quality consequences*" of the recommended flow regime (Palmer and Rossouw 2000).

4. When setting the environmental flows, in the case of anthropological water quality impairment, *the flow specified for any one month should not be set higher than required by the biota and fluvial geomorphology in order to provide dilution flow*s (Tharme and King 1998). As a management option water can be used to dilute contaminants (rather than reducing them at source), but this "extra" water is NOT part of the water quantity Reserve.

In the case of anthropogenic water quality impacts, water required to dilute pollutants is not part of the water quantity Reserve.

5. In the case of river reaches that are "naturally impaired" with regard to water quality, the aquatic biota in such rivers are adapted to those conditions (e.g. high salinity levels). If the new flow regime represents a reduced flow volume compared to natural, the resulting salinity may well be unsuitable for the biota. In such cases, incorporation of dilution flows into the flow requirement (the water quantity Reserve) would be necessary and acceptable.

In the case of "natural" water quality impacts, water required to dilute naturally occurring chemical constituents to an acceptable level can be considered to be part of the water quantity Reserve.

A framework for incorporating predictions of water quality and effects on the biota into Reserve determinations

A framework has been developed (Table 9) which shows at what stage, predictions of water quality and the likely effects of changed water chemistry on the aquatic biota can be incorporated into the Reserve determination process. Because of the additional time, effort (and therefore cost) involved, Q-C modelling and the Biotic Protocol would be used only in Comprehensive and (possibly) Intermediate Reserve determinations, i.e. those for which a high degree of confidence is required.

The framework is comprised of three phases. Each phase is sub-divided into steps and each step is further divided into work components. The major "product" (with regard to water quality) of each work component is shown as well as where in the Reserve process that product will be used.

The framework is comprised of three major phases:

- *Before* the Instream Flow Requirement (IFR) workshop.
- *At* the IFR workshop.
- *After* the IFR workshop.

The pre-IFR workshop phase:

The first step (**Step A**) entails assessing the water quality of the resource. This is a standard part of determining the water quality component of the Reserve and is described in detail in DWAF (1999). The tasks within this step include:

- Examination of ecoregions, point-sources of pollution and catchment land-use for the water resource under consideration.

Table 9 *Framework for the incorporation of predictions of water quality and the implications of altered water quality for the biota, into Reserve assessments.*

Phase	Step	Work component	Product	Use of product
PRE-INSTREAM FLOW REQUIREMENT WORKSHOP	**Step A:** Water quality assessment	1. Identify resource & delineate boundaries, chose IFR sites etc.	Maps of resource	Used for entire process
		2. Identify ecoregions, significant hydrological features, point sources etc.	WQ reaches	
		3. Determine Reference Condition	Monthly median RC values	**Step B**
		4. Determine Present Ecological State	Monthly median PES values	**Step B**
		5. Assign provisional Ecological Reserve Class		
		6. Assign WQ Reserve	WQ categories and RQOs for each variable and site	**Step C**
		7. Record findings	WQ Starter document	Used for entire process
	Step B: Integration of WQ & quantity (Pre-workshop)	8. Check RC & PES monthly median values for suitability for modelling		
		9. Consult with hydrologist. Obtain appropriate flow data		
		10. Prepare Q-C modelling spreadsheets.	Q-C relationships for each variable at each IFR site	**Step C and Step F**
INSTREAM FLOW REQUIREMENT WORKSHOP	**Step C:** Integration of WQ & quantity (during workshop)	11. Use Q-C modelling to predict concentrations and WQ categories.	"Water quality consequences"	**Step E**
		12. If "natural WQ impacts", use Q-C modelling to motivate for Quantity Reserve	Recommended flow regime that will attain RQOs for water quality	**Step E**
POST-INSTREAM FLOW REQUIREMENT WORKSHOP	**Step D:** Assess implications of predicted WQ for biota	13. Apply Biotic Protocol to key IFR sites, for critical recommended discharges	Predicted derived SASS scores, Ecological Reserve Class, lists of taxa	**Step E**
	Step E: Document Predicitons of WQ and effects on aquatic biota	14. Record results of WQ modelling	Water quality modelling report	
		15. Record results of Biotic Protocol	Report on expected effects on the aquatic biota	

WQ = water quality, RC = Reference Condition, PES = Present Ecological State, RQOs = Resource Quality Objectives, IFR = Instream Flow Requirement.

- Division of the resource into water quality reaches in which the concentrations of chemical constituents and values of physical variables are assumed to be homogeneous.
- Collection and processing of relevant water quality data.
- Determination of the Reference Condition (RC) and Present Ecological State (PES) for individual river reaches.
- Assignment, for each water quality variable of concern, of a numerical value for the Reserve (e.g. the maximum concentration of TDS, or minimum dissolved oxygen concentration, that should be allowed).

All this information is recorded in the water quality section of the IFR starter document. From the point of view of this manual, the major products arising from these activities are the monthly median concentration values (for Reference Condition and Present Ecological State) which are used in Q-C modelling, and the identification of the critical water quality variables at each site.

Although not shown in Table 9, in a similar manner to Step A, the macroinvertebrate communities of the aquatic resource would be investigated. SASS scores and taxa lists for the Reference Condition and Present Ecological State would be determined and the Resource Quality Objectives set for macroinvertebrates in each river reach.

In **Step B**, flow-concentration plots for each chemical constituent of concern are drawn up for each site for which there are data and the spreadsheet templates are prepared for use in the IFR workshop.

The IFR workshop phase:

The second phase of the framework involves the tasks that arise during the IFR workshop itself. Using the Q-C plots, predictions of water quality (the “water quality consequences”) can be made in response to the flow regimes prescribed by the IFR practitioners.

Occasionally, cases of “natural water quality impacts” may be encountered. In such a situation, Q-C modelling can be used to calculate the volume of water required to dilute naturally occurring chemical constituents, so that the water quality component of the

Reserve would be obtained (in other words that the Resource Quality Objectives for each variable will be met).

The post-IFR workshop phase:

The final phase of the process is carried out after the IFR workshop. The implications of the predicted water quality for the biota at key sites can be assessed by applying the Biotic Protocol. The likelihood of the Resource Quality Objectives for aquatic macroinvertebrates being attained under the proposed flow regime and current pollution loading is determined. If at some sites these objectives are not likely to be met these sites can be “flagged”, indicating that attention needs to be given to reduction of pollution in those reaches.

Scenario modelling

The post-IFR workshop phase may, or may not include a comparison of flow scenarios. Presently, such comparisons are made if there are such heavy demands on the system in question that both the ecological Reserve and the demands of existing users in the catchment cannot be satisfied (Louw, Hughes and Birkhead 2000). Different flow scenarios are produced and the ecological consequences are compared. For example two flow regimes may be compared, one in which the recommended drought flows are imposed 5% of the time and another in which they are imposed 10% of the time.

Using the Q-C relationship for a given constituent at a site, different flow time-series can be converted to time-series of concentration. Concentration time-series can be manipulated to produce concentration duration curves which indicate what percentage of the time under a given flow regime the concentration will be equal to, or above a given value. Whilst these percentages are likely to be inaccurate they at least allow different flow time-series (flow scenarios) to be compared and ranked with regard to water quality impacts. This work is still being developed and is discussed in Malan and Day (2002).

One of the major limitations of the Reserve methodology at the moment is that no information is usually available as to how the relative sources of water would change between flow scenarios and therefore how the pollutant loads will vary. In other words, different water quality management scenarios are not compared. If only water quantity is considered this is acceptable, if predictions of water quality are to be made, this is not acceptable, since the concentration of chemical constituents in water will vary depending on where water comes from (e.g. from a non-impacted tributary compared to an impacted main river). As a result, the actual effects on water quality can not be determined, and all predictions are made on the assumption that the source of water for all flow scenarios will be the same as at present. It is important to included qualitative statements in reports (e.g. “the flow from tributary X, which carries good quality water should be maintained in order to ensure that salinity at site Z, downstream of the confluence is not compromised”). This helps to emphasize likely effects on pollutant loading resulting from changes in management of the resource.

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South African Water Act (Number 36). (August 1998) Government Gazette. Volume 398. Number 19182. Government Printers, Pretoria, South Africa.

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USEFUL WEB SITES

Institute for Water Quality Studies (DWAF):

http://iwqs.pwv.gov.za

DWAF water quality database:

http://iwqs.pwv.gov.za/wq/map

River Health Project:

http://www.csir.co.za/RHP

Water Quality on Disk:

http://envweb.csir.co.za/water/wqcd/index.html

Water Research Commission:

http://www.wrc.org.za

US EPA ecotoxicology (ECOTOX) database:

http:/www.EPA.Gov/ecotox

Southern waters Ecological Research and Consulting:

http://southernwaters.co.za

Centre for Aquatic Toxicology (CAT), Institute for Water Research,

http://www.ru.ac.za/institutions/iwr/cat

ABBREVIATIONS AND GLOSSARY OF TERMS

Abbreviations

AEV – acute effect value
ASPT – average score per taxon
BBM – Building Block Methodology
Biobase – Biological and chemical database
C – concentration
CAT-IWR - Centre for Aquatic Toxicology-Institute for Water Research
CD – compact disk
CEV – chronic effect value
CSIR – Council for Scientific and Industrial Research
DO – dissolved oxygen
DRIFT – Downstream Response to Imposed Flow Transformations
DWAF – department of water affairs and forestry
EC – electrical conductivity
IFR – instream flow requirement
LC_{50} – the lethal concentration that corresponds to a cumulative probability of 50% for death of a test population of organisms (DWAF 1996)
LOEC – Lowest Observable Effect Concentration
PES – Present Ecological State
Q – flow
Q-C – flow-concentration
RC – Reference condition
RQO – resource quality objective
SASS – South African scoring system
TIN – total inorganic nitrogen
TP – total phosphorus
TDS – total dissolved solids
TSS – total suspended solids
TWQR – target water quality range
US EPA – United States Environmental Protection Agency
WQ – water quality
WQOD – Water quality on disk
WRC – Water Research Commission

Glossary

Acute Effect Value (AEV) – that concentration or level of a constituent above which there is expected to be a significant probability of acute toxic effects to up to 5% of the species in the aquatic community. (DWAF 1996).

Aquatic biota - the living organisms of an aquatic resource (includes micro-organisms, amphibians, macroinvertebrates, mammals, plants in the form of riparian vegetation, macrophytes, and algae).

Biotic Protocol - a tool, developed in this manual that aids in inferring the effect that changes in water quality may potentially have on the aquatic biota.

Biotopes – an area of uniform environmental conditions.

Chemical-Biological database (Biobase) - a database comprising macroinvertebrate and water quality data obtained from documented studies of riverine ecosystems in South Africa (Dallas, Janssens and Day 1999).

Chronic Effect Value (CEV) – that concentration of a constituent at which there is expected to be a significant probability of measurable chronic effects to up to 5% of the species in the aquatic community (DWAF 1996).

Conservative constituents - those components, such as chlorides, that are essentially unchanged in their progression along a watercourse. Non-conservative constituents, which include nutrients, are altered in quantity and form as they progress downstream due to chemical inter-conversions, microbial or biotic activities and interaction with sediments.

Ecological Reserve is the water *quantity* and *quality* required to protect ecosystems in order to secure ecologically sustainable development and use of the relevant water resource.

ECOTOX is an ecotoxicological database for aquatic organisms developed by the US EPA.

Future Predicted State – the water quality conditions that can be expected if a given flow regime is implemented.

Habitat – the combination of biotopes that makes up the living space of an organism.

Instream flow requirements – the amount and timing of flow that is needed in order for riverine ecosystems to maintain ecological functioning.

LOEC – the lowest concentration that brings about an observed effect on aquatic organisms compared to the controls.

Macroinvertebrates – large animal without a back-bone (insects, crustaceans, worms and molluscs).

Non-conservative constituents – see "conservative constituents".

Present Ecological State (PES) – the current levels of each chemical constituent or physical variable (in the case of water quality) in a river reach. As part of a Reserve determination, the PES is usually described for other components of water resource such as the macroinvertebrates or fish.

QUAL2E is a water quality model (US EPA)

Q-C (stream flow-concentration) modeling - a numerical technique described in this manual which looks at the empirical relationship between flow and water quality at a site on a river and uses this to predict expected concentrations that will occur under a given flow regime.

Reference Condition (RC) – the concentration of each chemical constituent or physical variable (in the case of water quality) that would be expected in a given river reach in the natural or least-impacted condition.

Resource Quality Objectives - management goals of water quality and represent the values of physical variables (e.g. temperature, pH) and concentration of chemical constituents (e.g. nitrates, mercury, dissolved salts) that should not be exceeded in each river reach.

South African Scoring System (SASS) - a system for the rapid bioassessment of water quality of rivers using the composition and abundance of the macroinvertebrate fauna (at the family level).

System variables – water quality variables (e.g. temperature, pH, dissolved oxygen) that are considered to regulate essential ecosystem processes (DWAF 1996).

Target Water Quality Range - recommended ranges of water quality variables as given in the South African Water Quality Guidelines (DWAF 1996) for aquatic ecosystems.

Water quality - the concentration of chemical constituents (eg. nitrates, organic pollutants) and values of physical variables (eg. water temperature) in a given river reach.