A MODEL FOR RAPIDLY ASSESSING THE IMPACT OF WASTE DISCHARGE ON DOWNSTREAM WATER QUALITY

Report to the
Water Research Commission

by

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WRC Report No. 1212/1/10
ISBN 978-1-77005-986-3

August 2010

DISCLAIMER

EXECUTIVE SUMMARY

INTRODUCTION

Background and motivation

DWA Regional Office, Head Office and CMA staff needs a rapid means of assessing the impact of waste load discharge permit applications and the required degree of change to permit conditions to meet water quality objectives. WQ2000 already provides such a tool for salinity. However, non-conservative pollutants are also of paramount importance to water quality managers. This is because human activities typically result in the discharge of nutrients and biological pollutant loads, thereby promoting eutrophication of water bodies and presenting a direct threat to public health. A number of models are available for simulating these impacts. However, they are generally highly complex, data intensive and costly to apply, requiring the services of experts to set up and test each and every option. In practice, the use of such models is usually defeated by shortage of funds, excessive development time delays and the fact that such complex models seldom deliver commensurately adequate results.

Another important factor is that water quality models require naturalised catchment flow data to provide essential input. Processing of this essential hydrological data requires extensive patching and analysis. Typically several years elapse between the major studies required to produce this data. This means that the water quality data collected in the interim cannot be used effectively to answer the key “what if?” questions such as, “what will happen if a new effluent source is introduced?” This is especially important since our water quality data base is relatively short.

This research is aimed at providing a simple to apply evaluation tool capable of making good use of the new water quality data and of simulating the effects of both conservative and non-conservative pollutants, taking account of both point and diffuse inputs. This model requires experts to first set up the model, after which the CMA and Regional Office personnel can use it to rapidly test a range of waste discharge options with minimal input from experts. The objective is to speed up and reduce the cost of processing waste discharge applications and the testing of alternative discharge permits. Departmental personnel and scarce outside experts should then be freed to concentrate on interpreting the model output data, setting appropriate permit levels, filling key data gaps and ensuring compliance with the requirements.

Aims

1. Provide a simple to apply model for rapidly assessing the impact of applications for new waste load discharges, or applications for the modification of old permits.

2. Calibrate and test the model on an existing river system. The Blesbokspruit catchment has been chosen for this purpose.

3. Provide adequate documentation of the model.

Approach

A model has been developed to utilise the most recent flow and water quality data available in standard DWA hydrological and water quality data systems without any need for prior processing or naturalisation. User-friendly screens have been provided to facilitate system setup and the capture of river channel data. The model is self-calibrating. The simulation mode provides a powerful tool for assessing the impact of system changes on the water quality in downstream channel reaches. The statistical properties of the stored calibrated river channel decay values, diffuse input loads and effluent concentrations are used to generate stochastic values that are used in the simulation mode during which concentrations are generated at the ends of each channel reach for a range of flow conditions. The results are then tabulated and plotted against defined water quality objectives.

Applications

Key applications include:

- Rapid assessment of impacts of waste discharge
- Initial testing of management options
- Evaluation of monitoring requirements

WQDOWN MODEL

WQDown is a simple to operate self-calibrating non-conservative variable water quality model that was developed to simulate the effect of applications for new waste discharge permits (or changes to existing permits) on downstream water quality.

Model concept

The main steps in the modelling process are outlined in Figure 1. These are discussed below.

1. Define run: Select an existing project database or create a new one.

2. Set up system: Set up the catchment layout, system network and channel reach characteristics and define the flow and water quality input files. The initial setup requires specialist input, but need not be repeated unless substantial changes are made to the system.

3. Select water quality variable: A selection is made from the water quality variables contained in the data files generated by the DWA's Water Management System (WMS).

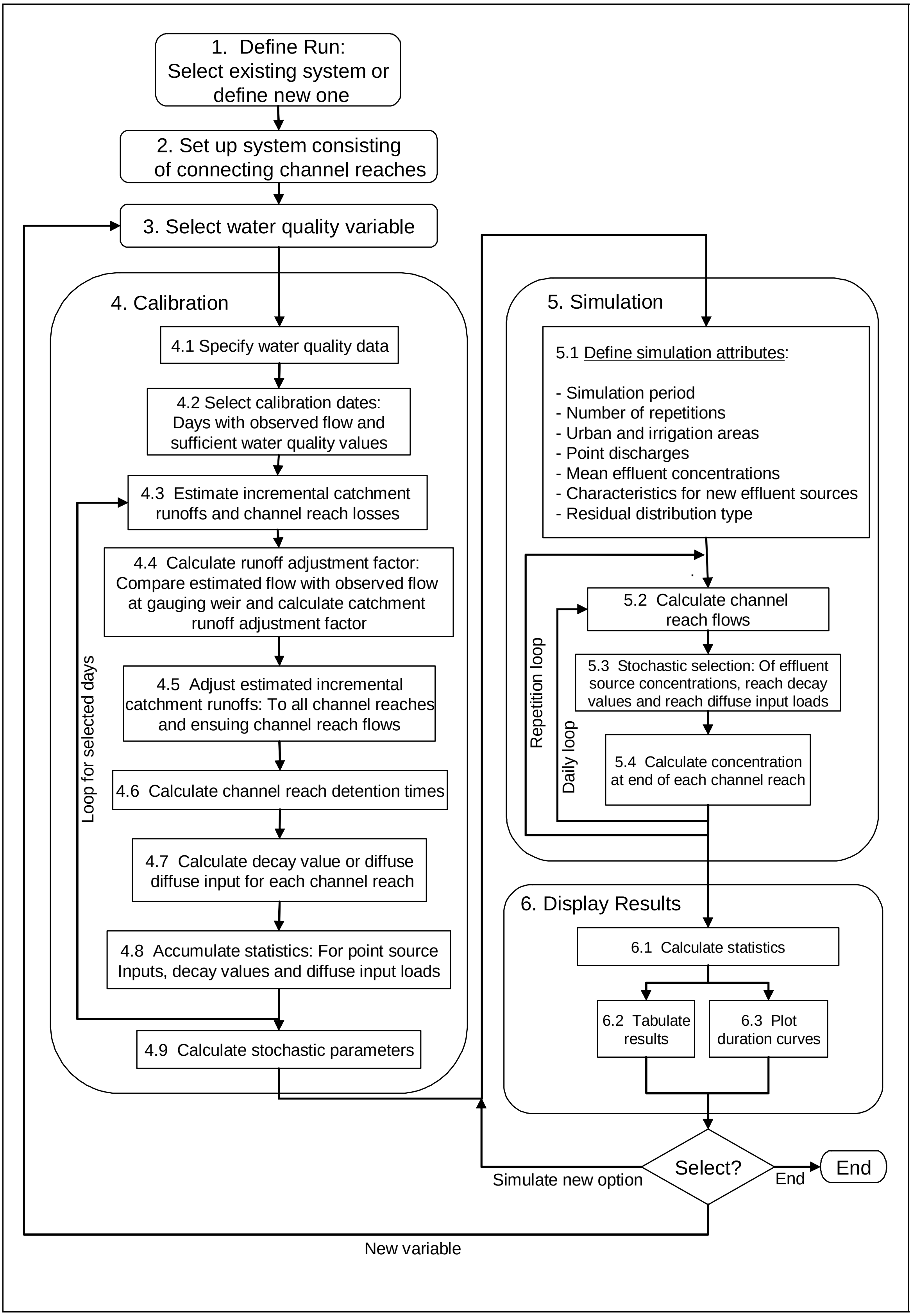

Figure 1: Main steps in the WQDown modelling process

4. Calibration: Define and run model calibration.

Calibration setup includes:

- Specify water quality data and default values
- Select calibration dates based on availability of flow and water quality data.

For each calibration date the model automatically does the following:

- Estimates incremental catchment runoffs and channel reach losses
- Calculates runoff adjustment factor: The initial flow estimate at the downstream end of the channel reach coinciding with the catchment flow gauging station is compared with the observed flow to yield an adjustment factor
- Adjust estimated incremental catchment runoffs: The adjustment factor is applied to all of the previously calculated initial incremental catchment runoffs
- Calculate channel reach detention times
- Calculate decay value or diffuse input for each channel reach
- Accumulate statistics: for decay values and diffuse inputs to each channel reach.

After completion of the main simulation loop the stochastic parameters are calculated for each channel reach and effluent point source and a statistical summary is generated.

5. Simulation: Define and run model simulation.

Simulation setup includes:

- Define simulation attributes: Set up the system attributes defining the simulation run including simulation period, number of repetitions, urbanised and irrigated areas, effluent discharge flow and water quality characteristics, abstraction rates and parameters controlling the handling of the stochastically generated residuals for effluent concentrations and channel reach decay values and diffuse load inputs.

For each iterated day of the simulation period the model automatically does the following:

- Calculate channel reach flows and detention times
- Stochastic selection: of effluent concentration, channel reach decay or diffuse input load for each channel reach
- Calculate concentration at end of each channel reach.

6. Display results: The mean, standard deviation, percentile values and the percentage time that the defined water quality objective is exceeded are calculated and stored at the downstream end of each river reach. The following types of display are provided:

- Tabulate results
- Plot duration curves: for one or more channel reaches, along with the water quality objective.

Model Algorithms

The algorithms used in model calibration and model simulation are described.

DATA REQUIREMENTS

The data requirements for WQDown have been divided into three groups:

- Initial setup
- Periodic updating
- Simulation.

Initial setup

This step should be carried out by persons with expertise in hydrological and water quality modelling. User-friendly screens have been provided to facilitate this. The following information is required for the initial model setup:

- Reference gauge flow data
- Define system network
- Channel reach data:
    - Quaternary location
    - Channel length
    - Channel flow control data
    - Mean monthly values
    - Point discharge and abstraction flow data
    - River sampling water quality data (WMS files)
    - Effluent quality data (WMS files) and default concentrations
    - Controls defining calibration period, default values, etc.
    - Set standard dates

Periodic updating

Periodic updating falls into two classes:

- ***Revision of the setup***: Done after significant catchment changes and requires modelling expertise.
- ***Updating of time series data***: Updating of river flow and WMS water quality time series files and monthly point source discharge and abstraction flow data. It is also desirable to regularly (say each year) re-evaluate the default effluent point source concentration decay values. These updates can be carried out by competent Head Office, Regional Office and CMA personnel who have had appropriate training and is desirable once per year.

Simulation

Model simulation is the intended day by day use of the model by Regional Office and CMA personnel. The data that is required for simulation relates only to the system change being simulated.

TESTING ON BLESBOKSPRUIT CATCHMENT

The model was tested on the Blesbokspruit catchment and the lower portion of the Suikerbosrand River down to its confluence with the Vaal River.

This system was chosen for model testing because it contains all of the main elements used in WQDown, including heavily urbanised, irrigation, wetland and lake features, several effluent point sources, water abstractions, diffuse pollution from a number of areas, several river and effluent water quality monitoring stations of various sampling frequency and duration and a flow gauging station. The catchment is also of great concern due to high pollution load inputs, the Blesbokspruit RAMSAR wetland, the threat posed to informal users who may use the river water for domestic purposes and the impact on the already polluted Vaal Barrage and downstream Middle Vaal River.

Model testing comprised simulation of phosphate for two options:

- Baseline
- Grootvlei Gold Mine effluent ceases.

Cessation of Grootvlei Gold Mine underground effluent results in an 82% increase in the simulated 90-percentile peak phosphate concentration at the Grootvlei Mine bridge (to 0.89 mg/l), with a 70% increase in the mean (to 0.35 mg/l). near the downstream end of the wetland at the R42 road crossing the increase in the simulated 90-percentile peak reduced to 67% and the mean to 39%. Near the mouth of the Suikerbosrand River at weir C2H004 the increase in the 90-percentile rose to 95%, although the absolute magnitude of the peak reduced to 0.76 mg/l, while the mean increased by 34%.

This example demonstrates the potential of WQDown for making rapid initial assessments of the impact of changes in waste discharges on water quality in complex systems.

MODEL CAPABILITIES AND LIMITATIONS

Model capabilities

- ***Rapid initial assessment***: WQDown places a powerful tool in the hands of water resource managers to make rapid “what if?” assessments of the impact of a variety of options on the concentrations of non-conservative and conservative pollutants in complex river systems.

- ***User friendly***: The user-friendly features are designed to permit managers who do not have detailed experience in water quality modelling to apply it.

- ***Automatic calibration***: A particular strength and unique feature of WQDown is that it is self-calibrating and makes full use of the available water quality records and streamflow data routinely processed by the DWA. The technique employed to seamlessly naturalise the hydrology is a strong feature. A third unique feature is the method of switching between the calculation of decay values and diffuse input loads and the use of stochastic modelling to sample these values in the simulation mode. Treating the decay and diffuse loads as stochastic elements, rather than the conventional method of running water quality concentrations through a stochastic generator lifts the model from a blind regression process to a tool that can take account of cause and effect.

- ***Assess complex systems using limited data***: The model has been tested on an extremely complex and highly developed river system and used to evaluate one of a wide variety of options. The test produced plausible results.

Model Limitations

- ***Initial evaluation***: WQDown is intended as an initial rapid assessment tool. It is not meant to replace more comprehensive models. However, it must be stated that more comprehensive models are impractical to apply in most instances due to their insatiable data requirements.

- ***Probabilistic model***: WQDown is a hybrid between process modelling with relatively simple decay and stochastic generation. It telescopes all of the complex in-stream processes into simple decay and, where appropriate, diffuse input. As such the model remains agnostic about the type of channel reach (wetland, lake or normal river channel), sedimentation, sediment uptake, organic cycling, etc. All these are covered by a single decay factor calculated for the entire channel reach.

Comprehensive water quality models require the laborious calibration of fixed decay and other parameter values, resulting in compromise values that fail to simulate observed extremes and therefore inevitably under-estimate the observed variance. By contrast WQDown preserves the variance by treating the calculated decay values as a stochastically changing variable that is a feature of each channel reach. The complex inter-relationship between all of the parameters and processes playing a part in the channel reach often defeats complex modelling. This is because extreme water quality events in a real system tend to be dominated by unanticipated events, such as sewer overflows, illegal discharges, temporary biological failure of a sewage works when unexpected slugs of toxic waste enter the sewers, chlorine dosing plant failure and the like. Even the most sophisticated models cannot hope to replicate such semi-stochastic events. However, the characteristics are contained in the river quality data. WQDown uses this information in such a way that the statistical properties are preserved, but also allows a variety of management options to be simulated in a rational way.

The underlying assumption is that the gross dynamics of the channel reach will remain unchanged. If the channel reach characteristics are radically altered, for example if a wetland is canalised or a lake breached, then the decay down the channel reach will also be altered. The model is flexible enough to permit the assigning of a default decay value for the channel reach that corresponds to the characteristics of another water body. So, for example, if a new lake is developed, then the default decay value for a similar lake can be applied to the channel reach and at the same time the earlier water quality data record for the channel reach (if such exists) can be discarded thereby forcing use of the new default value. Then, as more sampling data is accumulated by the regular data collection programme, the old inapplicable data for the channel reach can be replaced by the new data that represents the altered condition.

USER MANUAL

A user manual dealing with model setup and describing the mechanics of using the model is provided.

CONCLUSIONS

The following conclusions have been drawn.

Aims achieved

- A simple to apply self-calibrating model for rapidly assessing the impact of proposed waste load discharges on river system non-conservative water quality has been provided.
- The model has been calibrated and tested successfully on the highly developed and complex Blesbokspruit catchment.
- The model has been documented.

Data requirements defined

The data requirements of the WQDown model have been defined and differentiated between the needs for:

  - Once-off initial setup by modelling specialists
  - Periodic revision of the setup to reflect changing conditions
  - Ongoing application by Regional Office and CMA personnel.

All of the data is well within the means of the parties concerned to assimilate from readily available sources.

Dissemination and application

Incorporation in the DWA's User Support System and associated training will ensure that the vast potential benefits of this unique modelling tool are fully realised. Catchments where there is already a pressing need to apply the model have been identified.

Further research needs

Beneficial research needs have been identified to further facilitate the application of the model.

RECOMMENDATIONS

Dissemination and application

The primary purpose of WQOWN is to aid in the evaluation of discharge permits and generally assist in assessing catchment management strategies. Accordingly the following actions should be put into effect without undue delay.

- ***Incorporate in User Support System***: WQDOOWN should be incorporated into the DWA's User Support System (USS).

- ***Training***: Training sessions should be set up to ensure that the new technology is widely disseminated..

- ***Application***: There are immediate areas of application where the model can be used, including, but not limited to, the following developed catchments:
  Blesbokspruit
  Klip River
  Rietspruit
  Vaal Barrage
  Waterval River
  Mgeni River
  Crocodile River (West)
  Mooi River

- ***Rationalise water quality monitoring***: The model could be used to rationalise monitoring programmes to better serve the needs of water quality modelling:

Further research

- ***Automatic convergence of default values***: A procedure to automatically reset the default decay values based on the average simulated for the available sample points is desirable.

- ***Include temperature effects***: Temperature plays a significant role in in-stream decay processes and should be incorporated.

- ***Assign decay distributions to unmonitored channel reaches***: At present the decay rates for unmonitored channel reaches are assumed to remain constant at the defined default value. However, a better approach might be to link the unmonitored channel reach to a suitable nearby route that has similar characteristics. In the calibration mode the decay value calculated for the associated channel reach could then be used in place of the default value for dates when data is available for the associated channel reach.

- ***Merge routes for calculating decay values***: It often occurs that two water quality monitoring points are separated by more than one channel reaches to accommodate point inputs or river junctions. Grouping of similar stations along portions of river lengths could facilitate direct calculation of decay values for the entire channel reach.

- ***Increase simulation speed***: Various means are available to increase the simulation speed.

- ***Growth in historical catchment development***: Allowing for growth between specified break point values is recommended.

- ***Introduce variable seasonal effluent flow***: A facility to use the monthly point discharge and abstraction time series calibration data to derive a dimensionless monthly seasonal pattern for use in the simulation mode is recommended.

- ***Track calibration changes***: Checks are required to determine when last the river flow and WMS files and project database were updated and the time and date of the latest calibration run to obviate unnecessary repetition of the calibration step.

- ***Combine water quality records***: It has been observed that the WMS database contains two and sometimes three feature codes for the same monitoring point. Since these split the record over different periods it is important to combine them for the purpose of modelling.

- ***Sensitivity analyses***: Sensitivity analyses are required to determine:
    - The desired number of repetitions of the hydrology to ensure convergence during model simulation
    - The effect that the choice of distribution type (linear, log or observed) has on simulated water quality
    - Determine how seasonality affects the simulation results
    - The effect of eliminating poor and small or redundant records, rather than letting them dilute long channel reaches with default values.

- ***Relate catchment quality to runoff***: The concentration assumed for incremental catchment runoff can affect the modelling of decay rates and diffuse input loads. Derivation of suitable relationships between incremental runoff and runoff quality is desirable.

- ***Test other water quality variables***: The initial model development and testing has focussed on phosphate. Other water quality variables should be tested. This is probably best linked to the practical application of the model, rather than as an academic exercise.

- ***Simulate for exact calibration dates and flow conditions and compare water quality statistics***: Checking for complex systems would be enabled by a facility to run a simulation that exactly replicates the flow conditions of the calibration period, using the identical dates and the corresponding effluent and abstraction discharge rates.

- ***Update WR90 with WR2005 quaternary data***: Replacement of the WR90 values in the database with data from the WR2005 study is recommended, together with the unit paved surface runoff proportions.

- ***Incorporate multiple flow gauges***: The inclusion of multiple flow gauging points is desirable.

- ***Effect of storage***: WQDown is not a dynamic model. Storage effects in large impoundments may warrant investigation.

- ***Integrate with WMS***: Integration of WQDown into the DWA's WMS system bears consideration.

ACKNOWLEDGEMENTS

The research in this report emanated from a project funded by the Water Research Commission and is entitled: "Development of a user-friendly model for assessing the impact of waste discharge applications on downstream water quality".

The Steering Committee responsible for this project consisted of:

Mr HM du Plessis	Water Research Commission (Chairman)
Mr H Maaren	Water Research Commission
Mr M Keet	Department of Water Affairs, Gauteng Region
Mr P Viljoen	Department of Water Affairs, Resource Planning Systems – Water Quality Planning
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Mr F van Wyk	Rand Water
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Dr CE Herold	Stewart Scott Water Quality

The financing of the project by the Water Research Commission and the contribution of the members of the Steering Committee are gratefully acknowledged.

This project was only possible with the co-operation of many individuals and institutions. In this regard the authors wish to record their sincere thanks to Ms R Munnik of the Department of Water Affairs for the provision of water quality data. Mr J van Wyk, C Swanepoel, Ms D Maritz, B Davis and M Erasmus of the Department of Water Affairs also offered valuable advice and information regarding the Water Management System.

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LIST OF ABBREVIATIONS

CMA	Catchment Management Agency
DWA	Department of Water Affairs
USS	User Support System
VRSAU	DWA Vaal River System Analysis Update study
WMS	Water Management System (DWA water quality system)
WQDown	Water quality assessment model developed in this project
WQT	Water Quality TDS (and sulphate) monthly catchment model
WQ2000	User-friendly system for rapidly assessing salinity in quaternary catchments making use of the a pre-calibrated version of the WQT hydro-salinity model
WR2005	Water Resources of South Africa, 2005 study (Middleton and Bailey, 20094)
WR90	Water Resources 90 database and manuals (Midgley *et al*., 1994)

1. INTRODUCTION

1.1 Background and motivation

Personnel involved with water quality management in the Department of Water Affairs (DWA) head office and the Gauteng Regional Office have expressed the concern that they lack a suitable means of determining the impact of permit applications on downstream water quality. The Regional Offices continually have to assess the merits of applications for new waste discharges. Such applications can take the form of new discharge points, increased discharges or altered permit conditions. In the past such applications were dealt with by the application of blanket effluent standards. However, account must now be taken of integrated catchment management. This calls for meeting the requirements of receiving water quality objectives, which in turn are defined by user requirements and lead to the establishment of in-stream water quality requirements. Determination of the in-stream water quality likely to arise in the downstream river system requires suitable modelling tools.

The need for such a water quality management tool is made even more urgent by the establishment of Catchment Management Agencies (CMA's), each of which face similar requirements. Industries and Local Authorities also need a simple means of assessing the likely impact of their own discharge applications, in a manner that will be acceptable to the Authorities.

At present a number of water quality models are available. In the case of salinity, the WQT hydro-salinity model (Allen and Herold, 1988) has already been applied to (or is being set up for) a number of major river catchments in South Africa including the Vaal, Orange, Fish-Sundays, Crocodile, upper Olifants and parts of the Western Cape River systems. In the case of the highly developed Vaal Barrage catchment a daily time step version of this model has also been developed. These models can, and have, been used to evaluate permit conditions. This model requires a high level of skill to set up and operate, with concomitant high costs. Even then, the WQT model can only simulate TDS and sulphate. This model can also be calibrated for other conservative salts (such as sodium, chloride, etc.). However, this would require further calibration of the model for these constituents. The data requirements for rigorous calibration of this model are onerous.

However, non-conservative pollutants are also of paramount importance to water quality managers. This is because human activities typically result in the discharge of nutrients (such as phosphorous, nitrates and ammonia), which can adversely affect aquatic life and lead to eutrophication problems in downstream water bodies. Human habitation can also lead to the release of large biological pollutant loads (such as evidenced by indicators like *E.coli*), thereby presenting a direct threat to public health. Industrial and mining activities can lead to elevated local metal, fluoride and cyanide concentrations. Agriculture can lead to elevated pesticide and herbicide levels. A number of models are available for simulating these impacts. However, they are generally highly complex, data intensive and address only a few of the above elements. As a result, application of these models proves extremely costly and requires the services of experts to set up and test each and every option. Such models also require large amounts of costly data, take a long time to apply and lead to a proliferation of diverse models, the results of which are difficult to compare. In some cases it is also necessary to cascade the results of complex upstream models as input to equally complex downstream models. For example, in the case of nutrients, a detailed land use and river routing model would be required to provide input to a complex downstream reservoir eutrophication model. In practice, however, such use of multiple models is usually defeated by shortage of funds, excessive development time delays and the fact that such complex models seldom deliver commensurately adequate results.

Another important factor is that water quality models require naturalised catchment flow data to provide essential input. Processing of this essential hydrological data requires extensive patching and analysis. Typically several years elapse between the major studies required to produce this data. This means that the water quality data collected in the interim cannot be used effectively to answer the key “what if?” questions such as, “what will happen if a new effluent source is introduced?” This is especially important since our water quality data base is relatively short.

A case in point is the Vaal Barrage catchment. Useful water quality sampling data is available only from about 1975. But load estimation and effective water quality modelling could not proceed until after the hydrology was processed during the two-year Vaal River System Analysis study that ended in 1987. This made it possible to model water quality for the 10 years up to the end of the 1984 hydrological year, but only using monthly time step models. The 10-year water quality record was hardly long enough to span even half of one wet to dry hydrological cycle, resulting in a distinct hydrologically driven trend in the surface water quality. Between 1984 and 1999 the water quality record became more comprehensive and the data period more than doubled. Significantly during this period major changes took place within the catchment. These included the commissioning of the Lesotho Highlands Water Scheme, the cessation of pumping from the Grootvlei Gold mine, the closing of some other gold mines and substantial growth in catchment development and effluent discharges. But the new data could not be used in water quality models since the all important driving hydrological data had not been processed. The task of doing so was too onerous to be funded by smaller sub-catchment studies and had to wait until the Vaal River System Analysis Update study was completed in 1999, which advanced the processed hydrological record by 11 years to 1994. By the time the hydrological data became available it was already out of date and another 5 to 6 years of water quality data had been accumulated, during which time the re-commencement of the Grootvlei Gold mine pumping at unprecedented flow and salinity had radically changed the water quality regime of the Blesbokspruit. Since 1994 another 16 years of water quality data has been accumulated and before a new hydrological study is carried out the grossly under-utilised portion of the water quality record will have doubled yet again. This is a serious oversight given the vast developmental changes that will have taken place during the preceding two decades.

It is therefore essential that an evaluation tool is developed that is capable of making good use of the new water quality data and of simulating the effects of both conservative and non-conservative pollutants. A means of accounting for both point and diffuse inputs is also required, since in many instances diffuse pollution sources play a significant role. The model should also be simple to apply and be able to operate even on scanty input data. Ideally it should be possible for experts to first set up and calibrate the model, after which the CMA and Regional Office personnel can use it to rapidly test a range of waste discharge options with minimal input from experts. The objective is to speed up and reduce the cost of processing waste discharge applications and the testing of alternative discharge permits. Departmental personnel and scarce outside experts, should then be freed to concentrate on interpreting the model output data, setting appropriate permit levels, filling key data gaps and ensuring compliance with the requirements. This study is aimed at fulfilling these requirements.

1.2 Aims

1. Provide a simple to apply model for rapidly assessing the impact of applications for new waste load discharges, or applications for the modification of old permits.

2. Calibrate and test the model on an existing river system.
   The Blesbokspruit catchment has been chosen for this purpose.

3. Provide adequate documentation of the model.

1.3 Approach

A model has been developed to utilise the most recent flow and water quality data available in standard DWA hydrological and water quality data systems without any need for prior processing or naturalisation. User-friendly screens have been provided to facilitate system setup and the capture of river channel data. The model is self-calibrating. The simulation mode provides a powerful tool for assessing the impact of system changes on the water quality in downstream channel reaches. As such it is well placed for assessing the impact of permit applications. The user defines the simulation option, which can include changes to paved catchment areas, changes to effluent discharge rates, effluent quality changes, the introduction of new effluent sources and new or changed abstractions. The statistical properties of the stored calibrated river channel decay values, diffuse input loads and effluent concentrations are used to generate stochastic values that are used in the simulation mode during which concentrations are generated at the ends of each channel reach for a range of flow conditions. The results are then tabulated and plotted against defined water quality objectives.

1.4 Applications

1.4.1 Rapid assessment of impacts of waste discharge

The model that was developed provides a means of rapidly assessing the impact of applications for new or altered waste load discharges. Since receiving water quality often violates water quality targets, it is also essential to assess the degree to which existing effluent permits need to be tightened to meet the targets while also allowing the introduction of new users.

The model has been developed to handle non-conservative water quality variables for which data is available and to make full use of the latest water quality data without the need for prior patching and naturalisation of the hydrology. Conservative pollutants can also be simulated, although the model has not yet been tested for such variables. The minimum requirement is the presence of one river flow gauge within the study catchment. Daily flow data from such stations is readily available from the DWA with a lag time between flow recording in the field that is commensurate with the lag time between water quality sampling, analysis and inclusion in the DWA's Water Management System (WMS).

The model that has been developed is intended as an initial low cost rapid assessment tool that does not replace the judicious application of more sophisticated water quality models.

1.4.2 Initial testing of management options

The model facilitates rapid testing of a range of "what if?" options including increased or decreased effluent discharge volumes and the introduction of new discharge points. Typically the model results would be used to determine if a new discharge application can be accepted or not and the water quality conditions that need to be applied to meet in stream water quality objectives. It is anticipated that in many instances these requirements would be accepted by the applicants. However, in marginal and important cases the DWA may insist on the applicant funding more rigorous modelling. It may also occur that an applicant may seek a more lenient ruling, in which case recourse to more comprehensive modelling may ensue.

Standardisation of the process should also make it possible to evaluate the initial results obtained by a large variety of organisations other than DWA. This would help to reduce the time requirement and cost of studies that have to be made by applicants.

1.4.3 Evaluation of monitoring requirements

The modelling would also assist in identifying critical gaps in monitoring systems and eliminating wasteful redundancies. The testing on the Blesbokspruit has revealed a number of instances where beneficial improvements to the monitoring could be made.

1.5 Structure of report

Chapter 1 introduces the background and motivation, the project aims and approach and applications of the research product.

The main product of the research, the WQDown model, is described in Chapter 2 and Appendix A. This includes the model concept, the model structure and the algorithms used in the calibration and simulation modes.

The data requirements are discussed in Chapter 3.

Chapter 4 and Appendices B, C and D describe the testing of the model on the highly developed and complex Blesbokspruit catchment.

The model capabilities and limitations are discussed in Chapter 5.

Chapter 6 and Appendix E describe the user manual.

The conclusions, including a discussion of the degree to which the project aims were met, is given in Chapter 7.

Recommendations for model application and further research are given in Chapter 8.

References are contained in Chapter 9.

2. WQDOWN MODEL

WQDown is a simple to operate self-calibrating non-conservative variable water quality model that was developed to simulate the effect of applications for new waste discharge permits (or changes to existing permits) on downstream water quality.

2.1 Literature survey

The WQDown model developed in this study embodies requirements for a self-calibrating rapid assessment water quality model.

This model is unique and other models with similar features do not appear to be available. Similar findings arose from another study investigating the need for a simplified water quality model (Heath and Herold, 2007).

2.2 Model concept

The main steps in the modelling process are outlined in Figure 2.1. These are discussed below.

2.2.1 Define run

The project database to be run can be selected from a list of existing databases, an existing database can be used to clone a new one, or a brand new system can be built up from scratch. An existing database can be modified at will during the subsequent steps.

2.2.2 Set up system

During this step the physical channel reach and sub-catchment characteristics such as total and urbanised sub-catchment areas, channel shape and slope, locations of lakes and their outlet controls, wetlands and irrigated areas are set up. If a system already exists, opportunity is given to make modifications. The linkages of observed streamflow and river water quality monitoring points are also defined, along with the historical effluent discharge inputs. Water quality data is read directly from the standard .CSV format files generated by the DWA's WMS database. Likewise, daily streamflow data at the designated flow gauging point is read directly from the files generated by the DWA database. Allowance is also made for the user to define flow data derived from other data sources, such as that provided by Rand Water.

Channel reach linkages can be defined digitally or using a graphical network visualiser.

Channel reaches can be defined either as normal river channel reaches with flow-depth relationships defined by the Manning equation, or as level pool lake channel reaches with outflows controlled by a broad crested weir outlet.

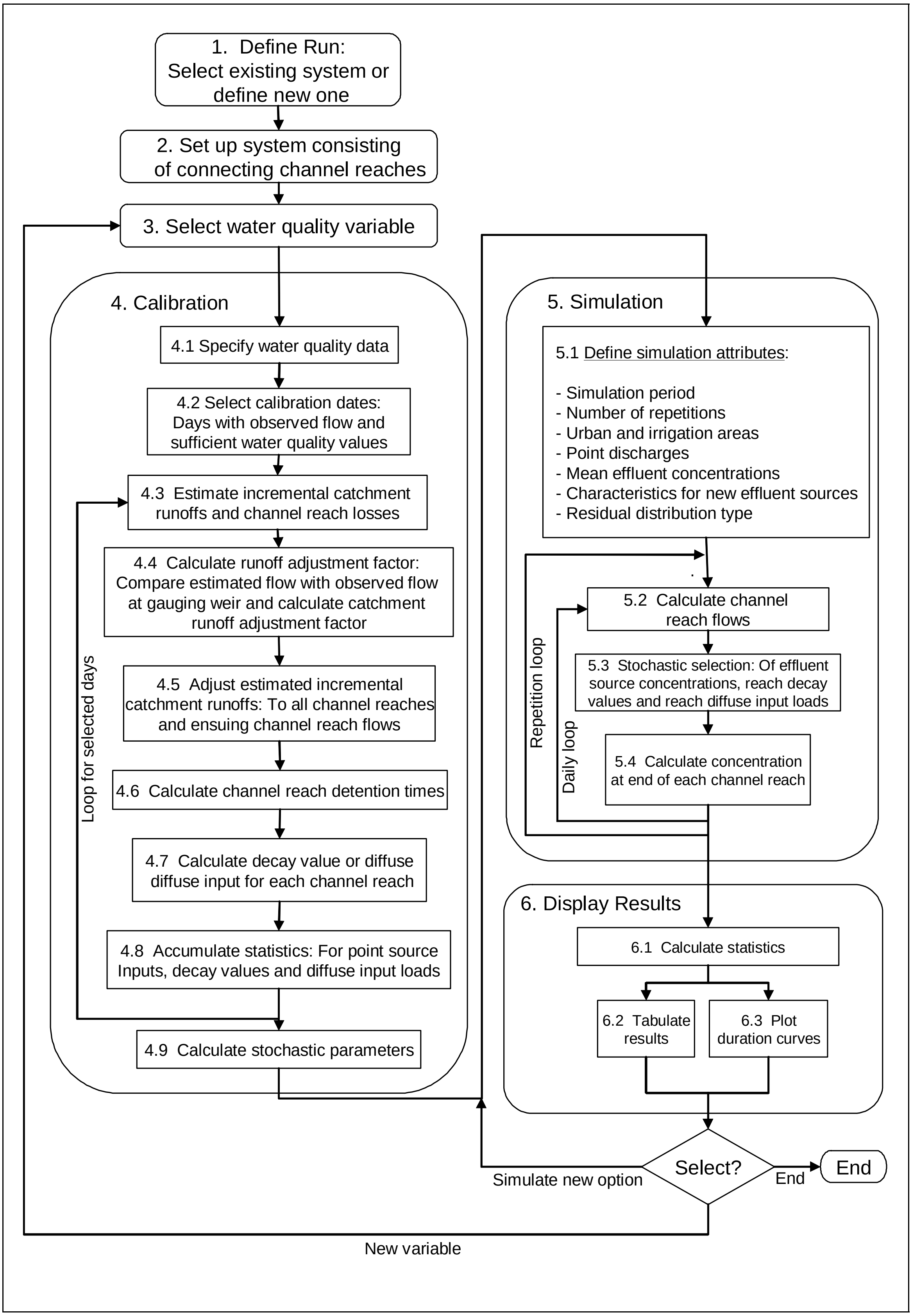


Figure 2.1: Main steps in the WQDown modelling process

The data for each channel reach is stored in a project database.

The initial setup requires specialist input, but once done, need not be repeated unless substantial changes are made to the system.

2.2.3 Select water quality variable

The user may select any of the water quality variables contained in the data files generated by the WMS that are used as input to the model. The default decay values, background catchment runoff concentrations, minimum and maximum allowable concentrations defined for each channel reach are stored in a user defined project database. These values are retained irrespective of how many new variables are selected and their values defined.

This means that it is not necessary to redefine these values when the water quality variables are changed.

2.2.4 Calibration

2.2.4.1 Specify water quality data

The calibration option first allows the user to:

- Define the WMS feature and pathname of the file containing the quality data for each channel reach.

- Define the WMS feature and pathname of the file containing the quality data for each effluent point source and the default effluent concentration to be used on occasions when river quality data is available but there is no effluent quality data.

- Define (for new systems) or modify (for existing systems) the river and effluent point source water quality data files to be used in the calibration for each channel reach.

- Select the range of months (i.e. seasons) to be included in the calibration.

- Define the average catchment runoff concentration.

- Define the default decay values to be used when downstream water quality data is not available or when the downstream concentration is higher than the upstream value and the minimum allowable decay value.

- Define the minimum decay value below which the default value is used and a diffuse input load is calculated.

2.2.4.2 Select calibration dates

The selected dates should coincide with the sampling of water quality at a sufficiently representative number of significant monitoring points. The model provides a useful means of identifying and quickly selecting evaluation dates. An option is also provided to allow automatic grouping of samples taken within a specified number of days before and after the selected sampling date to be treated as if they are part of the same event. The is to allow for the fact that for logistical reasons sample collection rounds are sometimes split into two or more groups collected on successive days. Sometimes a weekend could also intervene between sampling rounds, with the one set sampled on the Friday and the rest the following Monday. During low flow periods the two can logically be treated as one event, although this might break down during wet weather when flow conditions during the second data collection round could differ markedly from those of the first.

For example, if the grouping period is set to (say) three days before or after the selected date (to cover the possibility of a normal week-end splitting the sampling rounds), then if sample points A, B and C correspond exactly with the selected date, then they are obviously included. If point D is sampled only 4 days after the selected date, then it is rejected. If sampling points E and F were sampled two days before, then they are also included. If point G has three samples taken: G1 three days before, G2 one day before and G3 one day after, then the automatic selection procedure will first temporarily select G1, then reject it in favour of G2 since it is closer to the selected date and finally reject sample G3 since it is already represented by a sample that is one day away from the selected target date.

The run calibration option causes the steps outlined in Sections 2.2.4.3 to 2.2.4.8 to proceed automatically using all of the defined dates. Key information is stored in temporary output files. There is usually no need to view these, but they can be accessed external to the model if so desired.

2.2.4.3 Estimate incremental catchment runoffs and channel reach losses

For each sampling date the automatic calibration procedure first solves for the flow mass balance. Irrigation, wetland, lake and river bed losses and impervious and pervious catchment runoffs to the upstream end of, and lateral to, each channel reach are calculated based on simple mean monthly quaternary catchment values stored in the database that have been populated from the WR90 hydrological study (Midgley *et al*, 1994). This is done sequentially from the top to the bottom of the study catchment. This is only a crude initial estimation, since the mean monthly quaternary values can differ widely from the actual daily values.

2.2.4.4 Calculate runoff adjustment factor

The flow thus estimated at the bottom end of the channel reach that coincides with the catchment flow gauging station is compared with the observed flow for that day. This yields an adjustment factor that has to be applied to the crude initial estimate of the catchment runoff.

Steps 2.2.4.3 and 2.2.4.4 are carried out every day in the specified simulation period for which flow data is available, which could be much longer and contain many more daily flow values covering a wide range of historical hydrology than the typically much smaller calibration sample based on available water quality data that confines the selection of the calibration dates. The calculated catchment runoffs adjustment factors are stored in a temporary file for later use in the simulation stage.

2.2.4.5 Adjust estimated incremental catchment runoffs

The adjustment factor is then applied to all of the previously calculated initial incremental catchment runoffs entering each channel reach in the system. This yields new adjusted estimates of the catchment runoffs to each channel reach that result in a flow at the observation point the same as that observed.

2.2.4.6 Calculate channel reach detention times

The flows at the upstream and downstream ends of each channel reach and the channel reach hydraulic characteristics are then used to calculate the channel reach detention times.

2.2.4.7 Calculate decay value or diffuse input for each channel reach

For each date defined for the calibration the concentration at the head of each channel reach, starting with the channel reach located at the upstream end of the catchment, is calculated by mixing the inputs from upstream channel reaches, effluent inflows and incremental catchment runoff. If the downstream end of the channel reach has an observed concentration for the day being calibrated and the downstream concentration is lower that that at the upstream end, then the decay along the channel reach is calculated taking account of the detention time in the channel reach. If there is no water quality data available at the lower end of the channel reach, then the default decay value for that channel reach is used. If the downstream concentration exceeds the upstream concentration then it follows that a diffuse pollutant load must be entering the channel reach. The decay rate for the channel reach on that day is then set equal to the default value and the magnitude of the diffuse input load is calculated assuming that it enters the channel reach at a predefined distance from the lower end of the reach. This distance is usually set equal to half of the channel reach length. However, if the pollution control officer knows the location of an industry, mine dump or other potential source the distance can be set appropriately. This could be important if the source is located near to the upper or lower end of the channel reach since a source near to the lower end would not be subject to in-stream decay, whereas one located near the upstream end would result in a higher calculated diffuse input load to account for full decay during the longer detention period down the reach.

2.2.4.8 Accumulate statistics

The statistics required to calculate the mean and standard deviation of the calculated decay, or where appropriate, diffuse loads are calculated for each of the calibration dates. The mean and standard deviation of the logs of these values are also calculated. The decay and diffuse loads are also stored and later ranked to determine the observed distribution. Similar statistics and observed distributions are also stored for the concentrations of each effluent point source, except that in this case decay and diffuse input loads do not need to be considered. Since effluent quality data is usually collected at a much higher frequency than the river quality data, the statistics and observed distributions for effluent sources are accumulated for the full effluent record between the start and end dates of the calibration period, rather than being restricted only to those dates for which river quality data is available.

2.2.4.9 Calculate stochastic parameters and generate statistical summaries

After the iteration for all if the calibration dates has been completed (steps 2.2.4.3 to 2.2.4.9), the means and standard deviations are calculated for the effluent concentrations, decay values and diffuse load inputs (natural and log values). The effluent concentrations, calculated decay values and diffuse loads are also ranked to yield observed distributions.

The statistics are stored for use in the simulation mode.

A summary showing the sample sizes, natural mean and standard deviation, mean and standard deviation of the logs of the decay values and the diffuse loads is displayed for each channel reach and can be stored and printed.

A summary of the sample sizes and the natural and log mean and standard deviation of the concentrations of each of the effluent point sources is also produced.

2.2.5 Simulation

2.2.5.1 Define simulation attributes

The water quality parameter to be simulated is defined by the previous calibration run. (This is necessary to ensure that external data files have not been updated since the last calibration run.) The user can specify or modify the simulation run period, whether daily or monthly flow data is to be used, the number of repetitions to be simulated and the water quality objective.

The physical characteristics of the modified system are also defined. Initially the catchment characteristics, such as urbanised and irrigated areas, abstraction rates and effluent point source discharges and quality characteristics are automatically defined according to the characteristics of the historical system used in the calibrations.

The whole point of the simulation is to be able to evaluate the changes in water quality that would arise from changes to the system. Therefore the user can change one or more of the characteristics for each channel reach to reflect the option being simulated. Changes can be made to the following characteristics for each channel reach:

- The incremental upstream and lateral urban areas
- Irrigation area
- Point abstraction rate
- Effluent discharge rate
- Effluent discharge mean concentration
- Channel reach number used to define the effluent concentration characteristics. (By default this is set equal to the current channel reach, but in some instances, such as when introducing a new point source for which there is not yet any data it is desirable to assume the same distribution as for an existing effluent source, which will be scaled according to the newly defined target mean concentration.)
- Define which method is to be used to generate decay values and diffuse source loads for each channel reach and the water quality for each effluent point source. Possible selections for each include:
  - Linear (i.e. stochastic generation based on the mean and standard deviation of the natural historical values)
  - Log (i.e. stochastic generation based on the mean and standard deviation of the logs of the historical values)
  - Observed (i.e. random selection constrained by the historical distribution).

  The above three options have been included, because each will have its own effect on the simulation results.

  In the linear case the drawback is that negative stochastic values can be generated, more frequently if the standard deviation is large compared with the mean. Since a negative decay value cannot be tolerated (as this would imply a higher downstream concentration than the upstream one, in which case the decay value should rather be set equal to the default value and a diffuse input load generated), the generated value has to be set to the minimum allowable value. Similarly a negative load is intolerable and has to be set to zero. In both instances this artificially increases the mean value above that derived from the model calibration. This effect is tolerable if the occurrence of negative values is small, but may not be in other cases.

Log values hold the advantage that negative values cannot be generated. This makes the log distribution a more desirable choice. However, a disadvantage of a log distribution is that it can lead to unrealistically high peak values.

Use of the observed distribution holds the advantage that unrealistically high or low values cannot be generated and that the simulated values must tend towards exactly replicating the distribution calculated during the calibration period. However, this depends on the observed distribution being realistic. For example, if the sample size is small the calibrated values may provide an unrealistic distribution and a normal distribution generated stochastically from the mean and standard deviation may be better. Another potential disadvantage is that higher values than those observed cannot be generated.

It is not yet clear how important these considerations are and hence all three options have been included pending further testing.

The above model features facilitate the definition of the option to be simulated, which, for example, may be set to model:

- Present day conditions (but for a more comprehensive range of flow conditions and range of decay values than is encompassed by the more limited historical sample size). This would serve as a baseline against which to compare other options.

- Projected future conditions, with growth in urban areas, abstractions and effluent discharges.

- The effect of introducing one or more new effluent sources.

- The effect on receiving water quality of a change in a proposed new effluent source quality (in order to determine acceptable permit conditions).

- The effect of modifying existing permit conditions to determine what is required to meet in-stream water quality objectives.

Steps 2.2.5.2 to 2.2.5.4 are repeated for each channel reach and for each day in the simulation period. This sequence can be repeated a number of times to increase the size of the stochastic sample.

2.2.5.2 Calculate channel reach flows

The incremental catchment runoffs to each channel reach are calculated using the adjustment factors stored during the calibration step and the urbanised areas defined for the simulation. The defined effluent discharge, abstraction and irrigation areas and the channel reach physical characteristics (including the channel shape, Manning equation or weir outlet control characteristics, bed loss, lake and wetland areas) are then used to calculate the flows into the upstream end of each channel reach, the outflow from its downstream end and the channel reach detention time.

2.2.5.3 Stochastic selection

For each channel reach and day simulated a random number is first generated and compared to the percentage time that the historical data yielded decay values or diffuse input loads to choose if decay values are to be generated. When decay generation is selected, the diffuse load is set to zero. Otherwise the decay value is set to the default value (to be consistent with the procedure adopted during calibration) and a diffuse input load is generated. Two random numbers between 0 and 1 are selected (one to set the sign to +1 or -1) and the other filtered to produce normalised random numbers that are then applied to the calibrated mean and standard deviations (natural or log as selected) to determine the decay (or diffuse input load) value.

Alternatively, if the “observed” historical distribution option has been selected, then only one random number between 0 and 1 is generated. This is then used to find the position in the ranked calibration distribution to pick out the appropriate decay, diffuse load or point concentration value.

2.2.5.4 Calculate concentration at end of each channel reach

The generated effluent concentration and the other upstream inputs are then used to calculate the concentration at the head of the channel reach. The generated decay or diffuse input values are then used to calculate the decay down the channel reach and, when applicable, increase due to a diffuse input load, and finally the concentration at the downstream end of the channel reach. Inputs from upstream channel reaches are passed on to those downstream until the lowermost point is reached.

This procedure is repeated for each daily (or monthly, if so defined) time step in the simulation period. Then the entire process is repeated for the specified number of repetitions.

In practice it is not necessary to specify an excessive number of repetitions to ensure a sufficient sample of stochastically generated decay and diffuse input load values, since the hydrology itself (if daily hydrology has been specified) already contains a large number of repeated flows of similar magnitude, especially in the predominant low flow range. If the river is broken into a number of channel reaches, then this too effectively increases the aggregate sample size. Also, the longer the simulation period, the fewer repetitions are required. Selection of monthly hydrology has the effect of reducing the hydrological sample size by a factor of 30.4, which indicates the need for more repetitions than would be the case for daily sampling.

The concentrations simulated at the downstream end of each channel reach are accumulated.

2.2.6 Display results

2.2.6.1 Calculate statistics

The mean, standard deviation, percentile values and the percentage time that the defined water quality objective is exceeded are calculated and stored at the downstream end of each river reach.

2.2.6.2 Tabulate results

The model simulation results can displayed in tabular form, stored and printed. The first part of the tabulation records the simulation assumptions. This is followed by tabulation of the key statistics of the simulated concentrations for each channel reach. These include simulated percentile values and the mean, with values exceeding the water quality objective shown in bold, and the percentage time that the water quality objective is exceeded.

2.2.6.3 Plot duration curves

User friendly routines have been included to plot duration curves for one or more channel reaches, along with the water quality objective.

2.3 Model structure

2.3.1 Overview

Figure 2.2 shows an overview of the main components of the WQDown model.

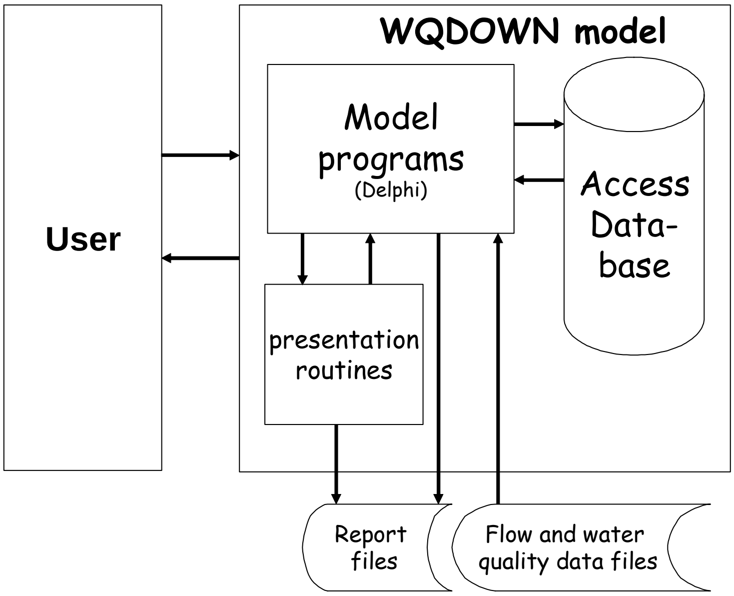


Figure 2.2: Overview of model structure

The model is written in Delphi and interfaces with the user via a system of screen menus. A system screen editor is used to set up, view and modify the system network and to enter channel reach attributes. Other modules calculate sub-catchment runoffs entering each channel reach, read and process point source input flow and water quality and river node data, process it to carry out model calibrations and simulate the system to assess proposed development. WQDown is designed to accept flow and water quality data in the same format as the output from the DWA's Water Management System (WMS). This data is obtained in the form of data files. System network data, channel reach attributes and key calibration information for each water quality variable are stored in an Access database. Reports on input data and model results can be selected. Modules have also been included to graphically display output results.

A description of the main subroutines used in WQDown is given in Appendix A.

2.3.2 Catchment representation

Figure 2.3 shows a typical hypothetical catchment layout.

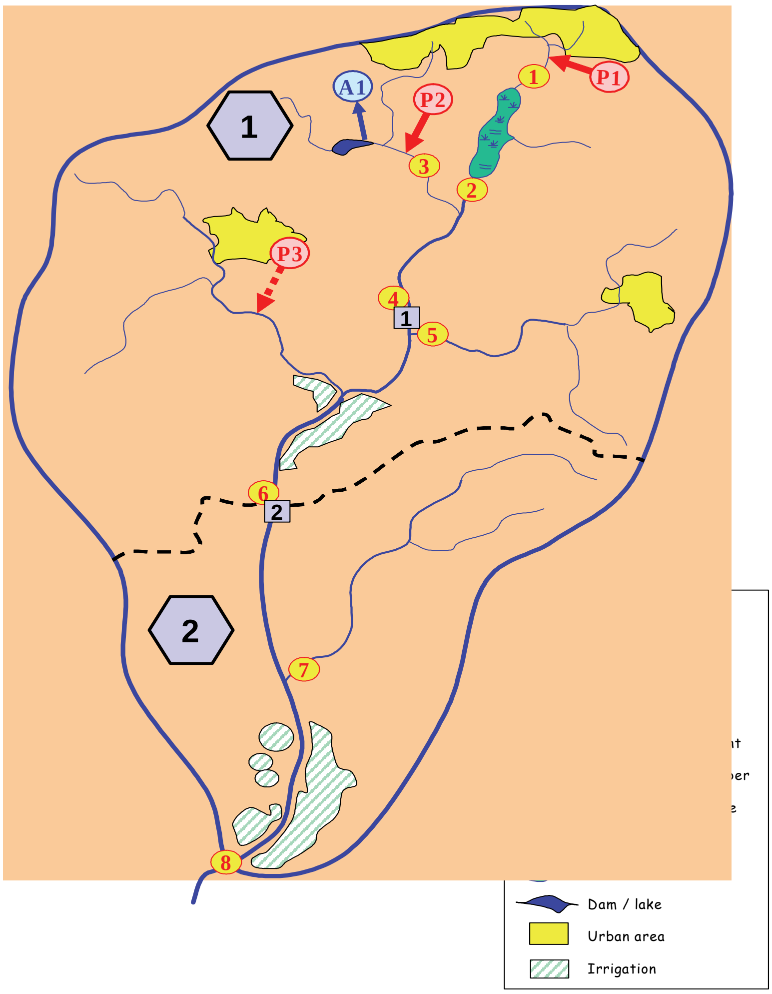


Figure 2.3: Typical catchment layout

The catchment flow gauging site (shown in a square numbered 1), divides the catchment into two main sub-catchments (numbered 1 and 2 denoted by hexagonal boxes), and 8 water quality sampling sites (denoted by numbered circles). Two existing effluent point discharges (P1 and P2) are shown, denoted by arrows entering the river system. A dashed arrow indicates a third potential effluent discharge point (P3). An arrow leaving the river system denotes an abstraction point (A1). The sample catchment includes some urban areas (shaded), a wetland and a lake (dark shaded). Hatched areas denote irrigation.

Figure 2.4 shows the catchment being represented by means of a series of connected channel reaches (named 1 to 13 in this example).

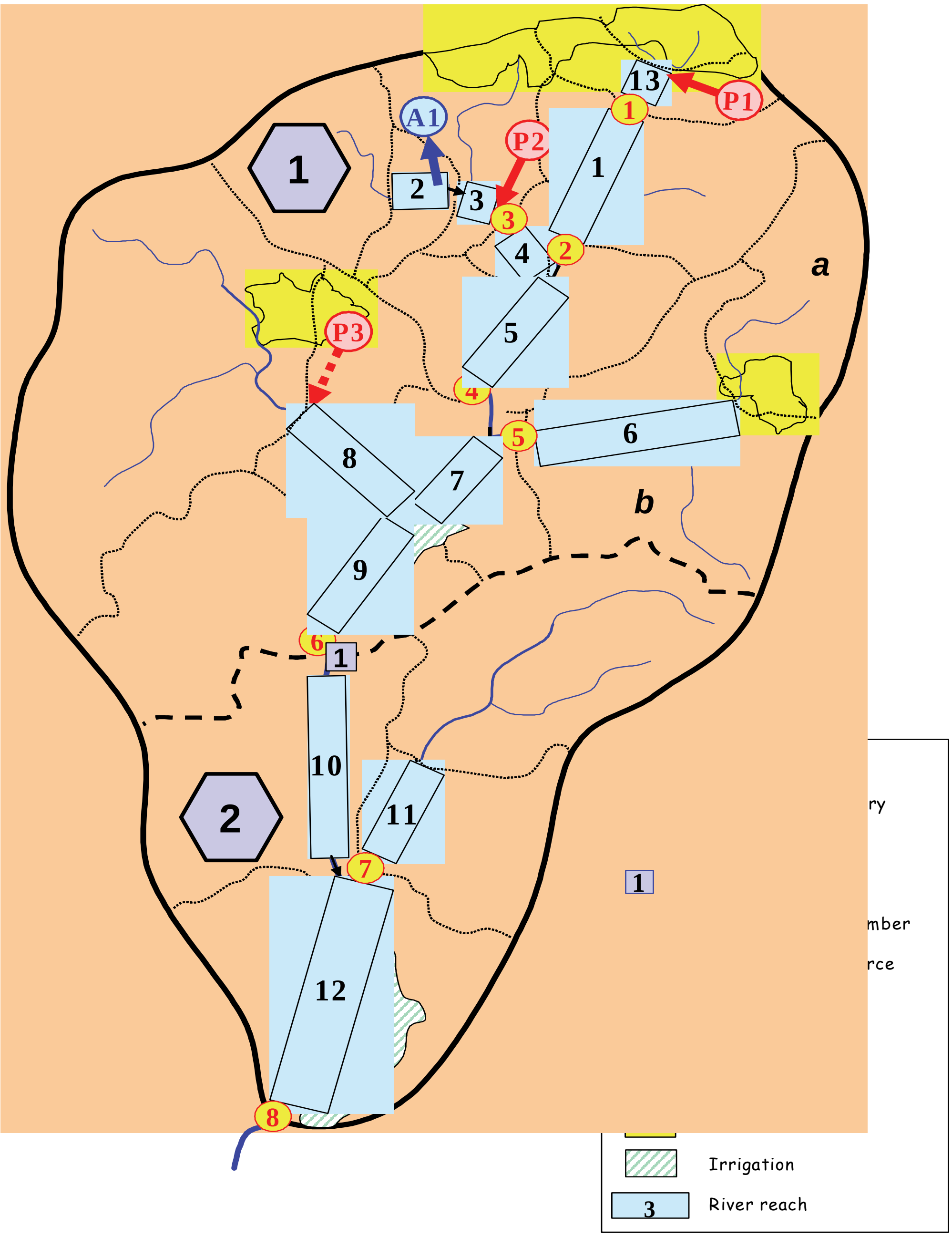


Figure 2.4: Model system configuration

Model channel reaches have been chosen to:

- Connect flow and water quality sampling points
- Represent major river junctions of interest
- Accommodate point source inputs and outputs
- Provide nodes at points where simulated information is required.

Additional sub-catchment boundaries have been included to denote the areas of catchment features upstream of and lateral to each channel reach. This is required to estimate the catchment runoff entering each channel reach, which is assumed to be driven by total catchment area, paved urban area and mean monthly precipitation. The model also uses the area of land irrigated from each channel reach, the wetland areas and lake areas. Provision is made to use estimates of bed loss that may be available from other studies.

2.3.3 Channel reach representation

Figure 2.5 shows the configuration of a generalised channel reach.

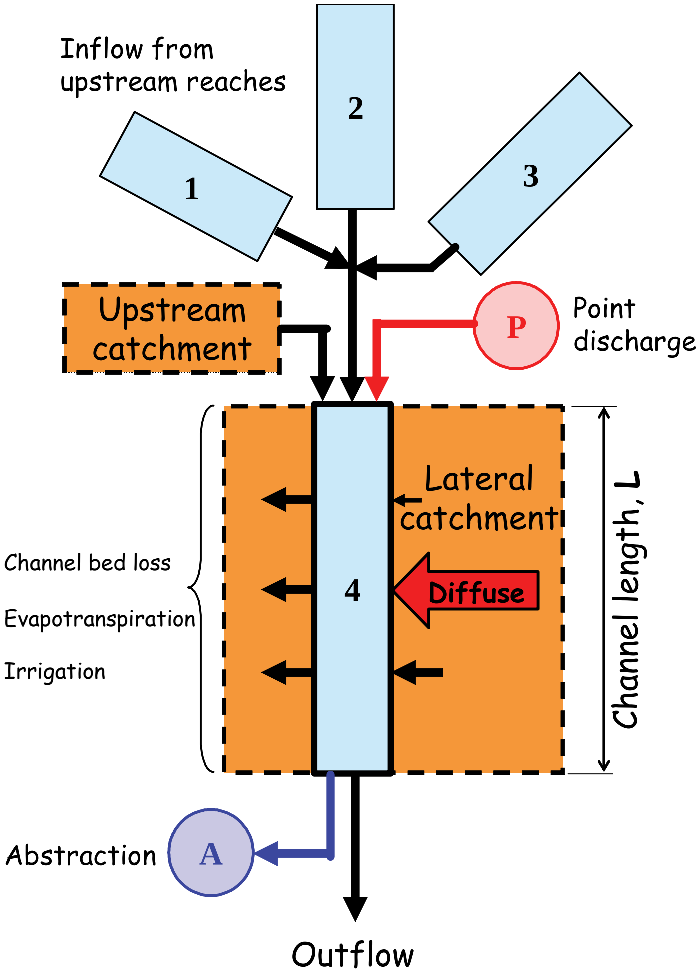


Figure 2.5: Channel reach configuration

Each channel reach can be connected to up to three upstream channel reaches and can accept a point source discharge to its upstream end. Incremental catchment runoff enters partially at the upstream end of the channel reach (this would be particularly important for channel reach 8 in the example – see Figure 3.4) and partially laterally (for example all of the local catchment runoff to channel reach 12 enters by this mechanism).

Irrigation abstraction, riverbed loss, lake and wetland evapotranspiration and point abstraction are assumed to leave the channel reach at its downstream end, as does the remaining outflow.

2.4 Calibration algorithms

The equations and assumptions driving the model are described in the following sections.

2.4.1 Point source inputs and abstractions

Monthly effluent point source (or water importation) flow input to the upstream end of each channel reach can be read in for the entire simulation period. Alternatively values can be specified manually as discrete monthly values, with linear or exponential interpolation between the specified break point values.

Case 1: File of monthly values provided

In the first case the monthly effluent flow data is cut from a spreadsheet and pasted into the model via an input screen. The first column is reserved for the date (Excel format) and the second column for the monthly flow. Appropriate flow units are specified (m^3/day, Mℓ/day or $10^6 m^3$/month). Thereafter the model automatically converts all flows to m^3/day, which are used for all flow units in the calculations.

The effluent flow values specified for each month are as follows:

QP_i = Effluent flow for month i (m^3/day)

For this option the specified data should span each of the months from the starting date to the ending date that is to be simulated.

Hence i1 =< is and in >= ie

Where:
i1 = first month of data
is = specified starting month of calibration
in = last month of data
ie = specified ending month of calibration

Monthly abstractions from the downstream end of the channel reach can also be cut and pasted from a spreadsheet in a similar manner. In this case only abstraction volume (QA_i –

m^3/day) values are specified for each month since the concentration of the abstracted water will be calculated by the model.

The abstraction flow values specified for each month are as follows:

QA_i = Abstraction for month i (m^3/day)

Case 2: Annual break points specified

In the second case the effluent flow values (QP_i) and abstraction rates (QA_i) are provided manually for selected breakpoint months. Linear or exponential interpolation is used to calculate the flow and concentration values for intermediate months:

Linear interpolation:

$$QP_i = QP_{i1} + (I - i1)\cdot(QP_{i2} - QP_{i1})/(i2 - i1) \quad \text{...} \quad (2.1a)$$

Where:
QP_{i1} = Specified point inflow for month i1 (where i1 < i)
QP_{i2} = Specified point inflow for month i2 (where i2 > i)

Exponential interpolation:

If QPi1 > 0.

$$QP_i = QP_{i1}\cdot(QP_{i2}/QP_{i1})^{\{(i - i1)/(i2 - i1)\}} \quad \text{...} \quad (2.1b)$$

Else use linear interpolation over this interval (i.e. equation (2.1.a))

The monthly subscripts have been omitted in the following text to simplify the equations. From here onwards flow and concentration values with no subscripts refer to the current time step.

2.4.2 Channel reach flow

One flow gauging point must be included in the modelled system. But allowance is made for more than one historical flow file to be available at that point. For example, in the case of the Blesbokspruit test catchment, three different flow records are specified for DWA flow gauging point C2H004 at the bottom of the Suikerbosrand. These comprise: a DWA daily flow record, a daily flow record from Rand Water (RW) and a monthly flow record and a patched monthly record derived from the Vaal River System Analysis Update study. The order in which these are specified determines the priority given to each record. The model switches to the next priority record in instances when gaps appear in the higher priority record. Generally a daily flow record is given a higher priority than a monthly record and the reliability of the record also play a role in the priority order.

During calibration the runoff from each sub-catchment during each time step is estimated from the observed flow gauge data and the upstream inflows abstractions and river losses.

Evapotranspiration loss

The net evapotranspiration loss from each channel reach is calculated as:

$$QE_k = QEL_k + QEW_k \quad \text{.......} \quad (2.2)$$

Where:

QE_k = Total net evapotranspiration loss from channel reach k (m^3/day)

QEL_k = Lake net evaporation loss from channel reach k (m^3/day)

QEW_k = Net wetland evapotranspiration loss from channel reach k (m^3/day)

The net evaporation loss from free water surfaces is calculated as:

$$QEL_k = AL_k \cdot \{PL_{q,m} \cdot PES_{q,m} - RAIN_{q,m} \cdot (MAP_k / MAP_q)\} \cdot (10^3/ND_m) \quad \text{.......} \quad (2.2a)$$

Where:

AL_k = Lake surface area for channel reach k (km^2)

$PL_{q,m}$ = Symons pan to lake evaporation conversion factor for month m for the quaternary catchment in which the reach is situated.(-)

$PES_{q,m}$ = Mean Symons pan evaporation for month m for the quaternary catchment within which channel reach k is situated (mm)

$RAIN_{q,m}$ = Mean monthly rainfall for quaternary catchment within which channel reach k is situated (mm)

MAP_q = Mean Annual Precipitation for the quaternary catchment within which the channel reach is situated (mm)

MAP_k = Mean Annual Precipitation for channel reach k (mm)

ND_m = Number of days in month m (-)

The mean monthly quaternary catchment information is contained in the distribution database.

The use of mean monthly rainfall in equation (2.2a) is a simplification necessitated by the practical problem of obtaining and processing catchment daily rainfall data fast enough to facilitate the rapid determination. The objectives are to develop a rapid user-friendly tool that can be applied by Regional Office and CMA staff. Both of these objectives would fail if the user has to first obtain, check and enter the latest daily rainfall data from a second party before they can make use of the latest flow and water quality data that is readily available to them. This approximation is partially mitigated by the fact that an adjustment is later applied to correct the estimated catchment runoffs to match the observed flow at the reference gauge (see equations (2.6) and (2.7)). The approximation is of little consequence during the predominant dry weather, and in wet weather if the evapotranspiration losses are small compared with the effluent discharges and catchment runoffs. This is likely to be the case in catchments where anthropogenic inputs are significant, which applies to most of the instances where this type of modelling will be required to support the evaluation of discharge permits.

The lake surface area, AL_k, is approximated as the normal free water surface area. For normal channel reaches this should be taken as the river surface area for base flow conditions. The approximation should have little influence as the flow in the river will normally be much larger than the free water evaporation loss. For lake sections the normal lake surface area should be used. This should seldom vary much for urban lakes since these are normally maintained at or near their full storage level by upstream effluent discharges.

The net wetland evapotranspiration loss is calculated as:

$$QEW_k = AW_k \cdot \{CFW_{q,m} \cdot PEA_{q,m} - (RAIN_{q,m} \cdot (MAP_k/MAP_q)\} \cdot (10^3/ND_m) \ldots \quad (2.2b)$$

Where:

AW_k = Wetland area for channel reach k (km^2)

$CFW_{q,m}$ = Wetland crop factor for month m for the quaternary catchment within which channel reach k is situated (-)

$PEA_{q,m}$ = A-pan evaporation for month m for the quaternary catchment within which the channel reach is situated (mm)

The wetland area, AW_k, is approximated as remaining constant. This assumption is justified by the propensity of wetland areas in developed catchments to be kept wetted by upstream effluent flows. The nominal most recently mapped wetland area is used for this purpose. The mean monthly wetland crop factors, $CFW_{q,m}$, can be chosen to implicitly account for regular seasonal variation in wetted surface area.

Irrigation use

The net irrigation use from each channel reach (m^3/day) is calculated as:

$$QI_k = AI_k \cdot (CPF_k/EFI_k) \cdot (PEA_{q,m} \cdot CF_{q,m} - ERF_{q,m} \cdot RAIN_{q,m} \cdot (MAP_k/MAP_q) \cdot (100-PIR_k)/(100-TL_k) \cdot (10^3/ND_m) \ldots \quad (2.3)$$

Where:

AI_k = Area irrigated from channel reach k (km^2)

CPF_k = Percentage of potential irrigation area cropped (%)

EFI_k = Irrigation water use efficiency (%)

$CF_{q,m}$ = Monthly crop factor for quaternary catchment within which the channel reach is situated (-)

$ERF_{q,m}$ = Monthly effective rainfall factor for channel reach k (-)

PIR_k = Percentage irrigation return flow (%)

TL_k = Irrigation supply transmission loss e.g. in main canals (%)

Catchment runoff

A theoretical estimate of the catchment runoff entering all of the channel reaches upstream of reference flow gauge is first made from the volumetric balance for the upstream catchment: (m^3/day):

$$QC'_{\lambda} = \sum_{K=1}^{NC}(QUU_k + QPU_k + QUL_k + QPL_k) \dots\dots\dots\dots \quad (2.4)$$

Where:

QC'_{λ} = Estimate of total catchment runoff upstream of gauge λ (m^3/day)

NC = Number of sub-catchments upstream of and including reference gauge λ (= 2 x number of upstream channel reaches)

QUU_k = Preliminary estimate of urban runoff from incremental catchment upstream of channel reach k (m^3/day)
For channel reach 6 of the example (Figure 2.3) sub-catchment ***a*** is the incremental upstream catchment.

QPU_k = Preliminary estimate of pervious surface runoff from incremental catchment upstream of channel reach k (m^3/day)

QUL_k = Preliminary estimate of lateral urban runoff from incremental catchment adjacent to channel reach k (m^3/day)
For channel reach 6 of the example (Figure 2.3) sub-catchment ***b*** is the incremental lateral catchment

QPL_k = Preliminary estimate of lateral pervious surface runoff from the incremental catchment adjacent to channel reach k (m^3/day)

The initial theoretical estimate of the incremental urban runoff to the upstream end of each channel reach is given as:

$$QUU_k = AUU_k \cdot PU_k \cdot \{(MAP_k/MAP_q) \cdot RAIN_{q,m}\} \cdot FU_k \cdot (10^3/ND_m) \dots\dots\dots \quad (2.4a)$$

Where:

AUU_k = Urban area in upstream incremental catchment (km^2)

PU_k = Percentage of urban area that is paved (typically 12 to 20%) (%)
Default values are provided in the model distribution database.

FU_k = Urban runoff factor (proportion of rainfall giving rise to runoff from urban surfaces) (-)
Default values are provided in the model distribution database.

As with evapotranspiration losses, the use of mean monthly rainfall data ($RAIN_{k,m}$) is less accurate than actual catchment rainfall data. Once again this approximation was used for practical reasons to facilitate rapid application of the model without the need to first collect and process catchment rainfall data. This approximation is mitigated by the adjustment that is later applied to correct the estimated catchment runoffs to match the observed flow at the reference flow gauge (see equations (2.6) and (2.7)).

The initial theoretical estimate of the incremental runoff from pervious surfaces to the upstream end of the channel reach is given as:

$$QPU_k = (Qquat_{q,m}/Aquat_q)\cdot(ATU_k - AUU_k\cdot PU_k)\cdot(MAP_k/MAP_q)\cdot(10^3/ND_m) \quad \text{... (2.4b)}$$

Where:

$Qquat_{q,m}$ = Mean monthly runoff from the quaternary catchment within which the channel reach is situated ($10^6 m^3$) This information is provided from the WR90 database.

$Aquat_q$ = Quaternary catchment area (km^2)

ATU_k = Total area of incremental catchment of channel reach k (km^2)

The initial theoretical estimate of the incremental lateral urban runoff to the channel reach is given as:

$$QUL_k = AUL_k\cdot PU_k\cdot\{(MAP_k/MAP_q)\}\cdot RAIN_{k,m}\}\cdot FU_k\cdot(10^3/ND_m) \quad \text{.............. (2.4c)}$$

Where:

AUL_k = Urban area in incremental catchment adjacent to channel reach k (km^2)

The initial theoretical estimate of the incremental runoff from pervious surfaces entering the channel reach laterally is given as:

$$QPL_k = (Qquat_{k,m}/Aquat_k)\cdot(ATL_k - AUL_k\cdot PU_k)\cdot(MAP_k/MAP_q)\cdot(10^3/ND_m) \quad \text{... (2.4d)}$$

Where:

ATL_k = Total area of incremental catchment adjacent to channel reach k (km^2)

The total catchment runoff upstream of the reference gauge is next calculated taking account of the observed flow at the reference gauge and the known upstream inputs and outputs. From the catchment water balance:

$$QC_\lambda = 86400\cdot QG_\lambda - \sum_{K=1}^{NRG}(QP_k - QE_k - QI_k - QA_k - QB_k) \quad \text{......................... (2.5)}$$

If the calculated value of $QC_\lambda < 0$, then set $QC_\lambda = 0$.

Where:

QC_λ = Calculated total catchment runoff upstream of gauge λ, excluding

point inputs and losses
86400 = Number of seconds in a day (s)
QG_λ = Observed flow rate at reference gauge λ (m^3/s)
NRG = Number of channel reaches upstream of reference flow gauge (-)
QP_k = Point source inflow to channel reach k (m^3/day)
QA_k = Point abstraction from channel reach k (m^3/day)
QB_k = Bed seepage loss from channel reach k (m^3/day)

It is implicitly assumed in equation (2.5) that changes in channel storage can be ignored. Hence accurate results may not be achieved when significantly large changes in channel storage occur between sampling intervals. This would be particularly the case when major dams are involved. However, in such instances storage and detention times are generally so large as to render most decay processes spurious. Small urban lakes tend to be maintained at sensibly constant storage, except during large storms.

The calculated value obtained from equation (2.5) is taken as the coarse theoretical estimate of the total runoff upstream of the reference gauge. An adjustment factor, FA_λ, is then calculated from equations (2.4) and (2.5) as:

$$FA_\lambda = QC_\lambda / QC'_\lambda \tag{2.6}$$

The theoretical estimates given in equations (3.4a) to (3.4d) are then used to make the adjusted estimate of the upstream and lateral incremental catchment runoff to each channel reach:

$$QCUP_k = (QUU_k + QPU_k) \cdot FA_\lambda \tag{2.7}$$

$$QCLAT_k = (QUL_k + QPL_k) \cdot FA_\lambda \tag{2.8}$$

Where:
$QCUP_k$ = Catchment runoff to upstream end of channel reach k (m^3/day)
$QCLAT_k$ = Catchment runoff to upstream end of channel reach k (m^3/day)

Upstream flow

The flow at the upstream end of each channel reach (see Figure 3.4) is calculated as:

$$QS_k = QCUP_k + QP_k + \sum_{j=1}^{NUP}(QOUT_{j,k}) \tag{2.9}$$

Where:
QS_k = Inflow at start of channel reach k (m^3/day)
NUP = Number of channel reaches connected to upstream end of reach k
$QOUT_{j,k}$ = Outflow from jth upstream channel reach connected to head of channel reach k (m^3/day)

Downstream flow

The flow reaching the downstream end of the channel reach is given by:

$$QD_k = QS_k + QCLAT_k - QB_k - QE_k - QI_k \qquad (2.10)$$

Where:

QD_k = Flow at bottom end of channel reach k (m^3/day)

If $QD_k < 0$, then set $QD_k = 0$.

Abstraction

If $QD_k < QA_k$, then adjust QA_k value to $QA_k = QD_k$

Outflow to downstream channel reaches:

$$QOUT_k = QD_k - QA_k \qquad (2.11)$$

2.4.3 Velocity – flow relationship

Two basic channel reach types are accommodated:

- Normal river reach
- Lake

Normal river reach

A parabolic channel shape has been assumed of the form:

$$h_k = a_k \cdot b_k^2 \qquad (2.12)$$

Where:

h_k = height above channel bottom (m)

b_k = channel width at height h (m)

a_k = constant (m^{-1})

For a measured height H_k (m) and width B_k (m) for channel reach k:

$$a_k = H_k/B_k^2 \qquad (2.12a)$$

For a parabolic shape the cross sectional area, Ax_k (m^2), is given by:

$$Ax_k = \tfrac{2}{3} b_k \cdot h_k \qquad (2.13)$$

From (2.9), (2.9a) and (2.10) the cross section area for channel reach k is given by:

$$Ax_k = \tfrac{2}{3}(B_k/H_k^{\frac{1}{2}})\cdot h_k^{1.5} \quad \text{.......} \quad (2.13a)$$

For b >> h, the wetted perimeter, P_k (m), can be approximated as:

$$P_k = b_k \quad \text{.......} \quad (2.14)$$

The hydraulic radius, R_k (m), is given by:

$$R_k = Ax_k/P_k \quad \text{.......} \quad (2.15)$$

From (3.13), (3.14) and (3.15):

$$R_k = \tfrac{2}{3}h_k \quad \text{.......} \quad (2.15a)$$

The Manning equation is assumed to govern the flow-depth relationship for a normal channel reach:

$$V_k = (1/n_k)\cdot R_k^{\frac{2}{3}}\cdot S_k^{\frac{1}{2}} \quad \text{.......} \quad (2.16)$$

Where:
V_k = Flow velocity (m/s)
n_k = Manning friction factor (-)
S_k = channel slope (-)

The discharge, Q_k (m^3/day), is calculated as:

$$Q_k = 86400\cdot V_k\cdot Ax_k \quad \text{.......} \quad (2.17)$$

From (3.13a), (3.15a), (3.16) and (3.17):

$$Q_k = 86400\cdot(\tfrac{2}{3})^{5/3}\cdot(1/n_k)\cdot(B_k/H_k^{\frac{1}{2}})\cdot S_k^{\frac{1}{2}}\cdot h_k^{13/6} \quad \text{.......} \quad (2.17a)$$

$$h_k = \{(3/2)^{5/3}\cdot(Q_k\cdot n_k)/(86400\cdot S_k^{\frac{1}{2}})\cdot(H_k^{\frac{1}{2}}/B_k)\}^{6/13} \quad \text{.......} \quad (2.17b)$$

The cross sectional area is derived from equations (2.13) and (2.17b) as:

$$Ax_k = (3/2)^{2/13}\cdot(B_k/H_k^{\frac{1}{2}})^{4/13}\cdot\{(Q_k\cdot n_k)/(86400\cdot S_k^{\frac{1}{2}})\}^{9/13} \quad \text{.......} \quad (2.18)$$

Lake

The main body of a lake channel reach is also assumed to have a parabolic cross section. However, the outlet is assumed controlled by a broad-crested weir. Figure 2.6 shows the assumed lake outlet shape.

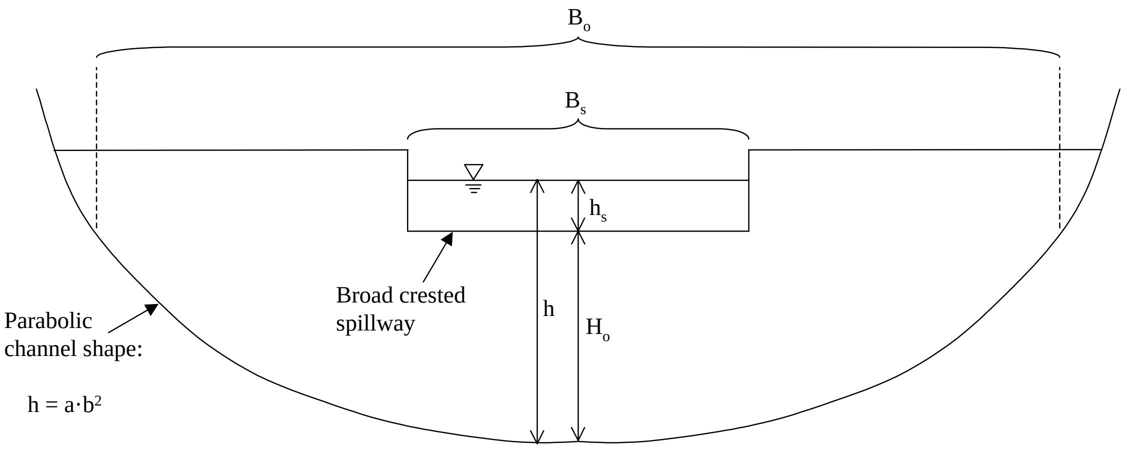


Figure 2.6 : Lake outlet section

The assumption is made that the lake remains full. Hence if $Q_k = 0$, the lake level is assumed to not drop below Ho_k (m). This is a reasonable assumption for most urban lakes which tend not to drop much below full storage level since they are usually adequately supplied from local effluent discharges and urban runoff and are usually devoid of significant abstractions. Recreational use of such amenities also requires a relatively constant water level.

Equation (2.18) describes the assumed parabolic channel cross section.

A broad crested weir equation describes the outflow when the outlet weir is overtopped:

$QOUT_k =$ $86400 \cdot 1.706 \cdot Bs_k \cdot hs_k^{1.5}$ .... (2.19)

Where:

$1.706 =$ Weir coefficient ($m^{½}/s$)
$Bs_k =$ Spillway length (m)
$hs_k =$ Lake level above spillway level (m)

Hence:

$hs_k =$ $\{QOUT_k/(86400 \cdot 1.706 \cdot Bs_k)\}^{⅔}$ ....(2.19a)

The lake volume is given as:

$VOL_k =$ $Ax_k \cdot L_k \cdot 1000$ .... (2.20)

Where:
$VOL_k =$ Storage volume for channel reach k (m^3)
$L_k =$ Average lake length for channel reach k (km)

From equation (3.13a), (3.20) and Figure 3.5 the lake volume can be expressed as:

$$VOL_k = 1000\cdot(2/3)\cdot L_k\cdot(Bo_k/Ho_k^{1/2})\cdot(Ho_k + hs_k)^{1.5} \quad \text{..................................(2.20a)}$$

Where:

Bo_k = Average lake breadth at full storage level for channel reach k (m)

Ho_k = Average lake full storage depth for channel reach k (m)

From equations (2.19a) and (2.20a):

$$VOL_k = 1000\cdot(2/3)\cdot L_k\cdot(Bo_k/Ho_k^{1/2})\cdot\{Ho_k + [QOUT_k/(1.706\cdot Bs_k)]^{2/3}\}^{1.5} \quad \text{......(2.20b)}$$

2.4.4 Detention time

The detention time in the channel reach has a significant impact on the estimated decay (attenuation) of non-conservative water quality variables.

Two cases can arise:

- Zero outflow at bottom of channel reach
- Positive outflow at bottom of channel reach

When flow at the downstream end ceases, the theoretical detention time becomes infinity and therefore cannot be calculated. Nor can the water quality variable concentration be calculated. However, in such cases a small discrete flow may still have occurred and a water quality sample may have been obtained. In such instances the sample remains valid. Such discrepancies between actual and estimated flows can arise since the method of estimating flows at all upstream channel reaches is only an approximation (flows are generally not directly measured at all sampling points). Moreover, the model is not dynamic and does not keep track of changes in storage and flow events that might have arisen between sampling dates. For example, much of the routine sampling is at weekly or even monthly intervals. Hence excess water from preceding events could still be passing through the channel. In the case of a lake, zero outflow can also occur when the water level is below the spillway crest. Clearly a valid sample can still be taken in the body of water behind the dam wall.

Allowance has been made to use a nominal maximum detention period, $Tmax_k$ (days) during events when there is no outflow from the channel reach. Judgement needs to be exercised in choosing this value, which should be based on knowledge of the system. The sampling interval and the duration of low or zero flow periods between runoff events would influence the choice.

The calculation of the detention period when the channel outflow is positive is discussed below.

Normal channel reach

The cross-sectional area at the upstream end of channel reach k, Axu_k (m^2), is calculated from equation (3.18) as:

$$Axu_k \quad = \quad (3/2)^{2/13} \cdot (B_k/H_k^{½})^{4/13} \cdot \{(QS_k \cdot n_k)/(86400 \cdot S_k^{½})\}^{9/13} \tag{2.21a}$$

And that at the downstream end of the channel reach, Axd_k (m^2), is calculated as:

$$Axd_k \quad = \quad (3/2)^{2/13} \cdot (B_k/H_k^{½})^{4/13} \cdot \{(QOUT_k \cdot n_k)/(86400 \cdot S_k^{½})\}^{9/13} \tag{2.21b}$$

The average volume of water in the channel reach, VOL_k (m^3) is then obtained as:

$$VOL_k \quad = \quad ½ \cdot (Axu_k + Axd_k) \cdot L_k \cdot 1000 \tag{2.22}$$

The average detention time for a particle of water to move from the top to the bottom of the channel reach, T_k (days), is given by:

$$T_k \quad = \quad VOL_k/QOUT_k \tag{2.23}$$

Lake

For a lake channel reach the detention time is also obtained from equation (2.23), but with the values for VOL_k and $QOUT_k$ obtained from equations (2.20b) and (2.19).

2.4.5 Water quality at head of channel reach

Effluent water quality data is derived from a .CSV file generated by the DWA's WMS system, for which the WMS flow line code must be specified.

The water quality variable concentration at the head of each channel reach is calculated from the load balance:

$$CS_k \quad = \quad \{ QP_k \cdot CP_k + QCUP_k \cdot CCAT_k + \sum_{J=1}^{NUP} (QOUT_{j,k} \cdot COUT_{j,k}) \} / QS_k \tag{2.24}$$

Where:

CS_k = Water quality variable concentration at head of channel reach k (appropriate units)

CP_k = Water quality variable concentration in point source discharge to head of channel reach k (appropriate units)

$CCAT_k$ = Water quality variable concentration in catchment runoff to channel reach k (appropriate units)

$COUT_{j,k}$ = Water quality variable concentration in outflow from downstream end of jth channel reach directly connected to head of reach k (appropriate units)

In the calibration mode the point input water quality variable concentration, CP_k, is known from the observed data.

The simplifying assumption is made that the catchment runoff water quality variable concentration, $CCAT_k$, remains constant. This concentration is applied to the upstream ($QCUP_k$) and lateral catchment runoff ($QCLAT_k$). The $CCAT_k$ value should be chosen to correspond to estimated natural catchment runoff conditions. Added diffuse source runoff due to catchment development or under-estimation of the natural catchment runoff is accommodated by the calculated diffuse source input discussed in section 3.2.6. This assumption is justified by the fact that for most polluted catchments the anthropogenic input via point and diffuse sources is very much higher than that of the natural catchment runoff. Instances where this is not the case will be less relevant, since this would either reflect undeveloped catchments were water quality is not problematic or a problematic undeveloped area where little can be done to manage the catchment anyway. In either case there would be little incentive to use this model or most others.

2.4.6 In-stream attenuation between pairs of points

In the calibration mode the water quality variable concentration at the downstream end of the connected upstream channel reaches ($COUT_{j,k}$) can be obtained from either of two sources. In the first instance, if an in-stream sampling point is located at the downstream end of the channel reach, then the observed value is used. If there is no such sampling point, or there is no data for the date in question, the concentration at the bottom of the channel reach is calculated assuming a default decay parameter value.

The simplifying assumption is made that all of the inputs and outputs occur at the nodes at the head and tail of each channel reach. This assumption is reasonable if the flow through the channel reach is large compared to the lateral inflow and losses, which for relatively short channel reaches is likely, especially in systems where base flows are dominated by effluent discharges.

First order decay along the channel reach yields the following relationship:

$$CD_k = CS_k \cdot e^{-DEC_k \cdot T_k} \quad \text{...} \quad (2.25)$$

Where:

DEC_k = Decay constant to describe attenuation of the constituent (day^{-1})

The decay value is calculated from equation (2.25) as:

$$DEC_k = - \{ \ln[CD_k/CS_k] \}/ T_k \quad \text{...} \quad (2.25a)$$

A minimum permissible decay value, $DMIN_k$, (d^{-1}) is specified for each channel reach. If the calculated value falls below this minimum (i.e. if the downstream concentration is unreasonably high relative to the upstream concentration) then the attenuation is recalculated assuming that a diffuse load enters the channel reach. A specified default decay value, DEF_k, is then adopted. The diffuse input load is assumed to enter the channel reach LED km from the upstream end of the channel reach.

Figure 2.7 illustrates this process.

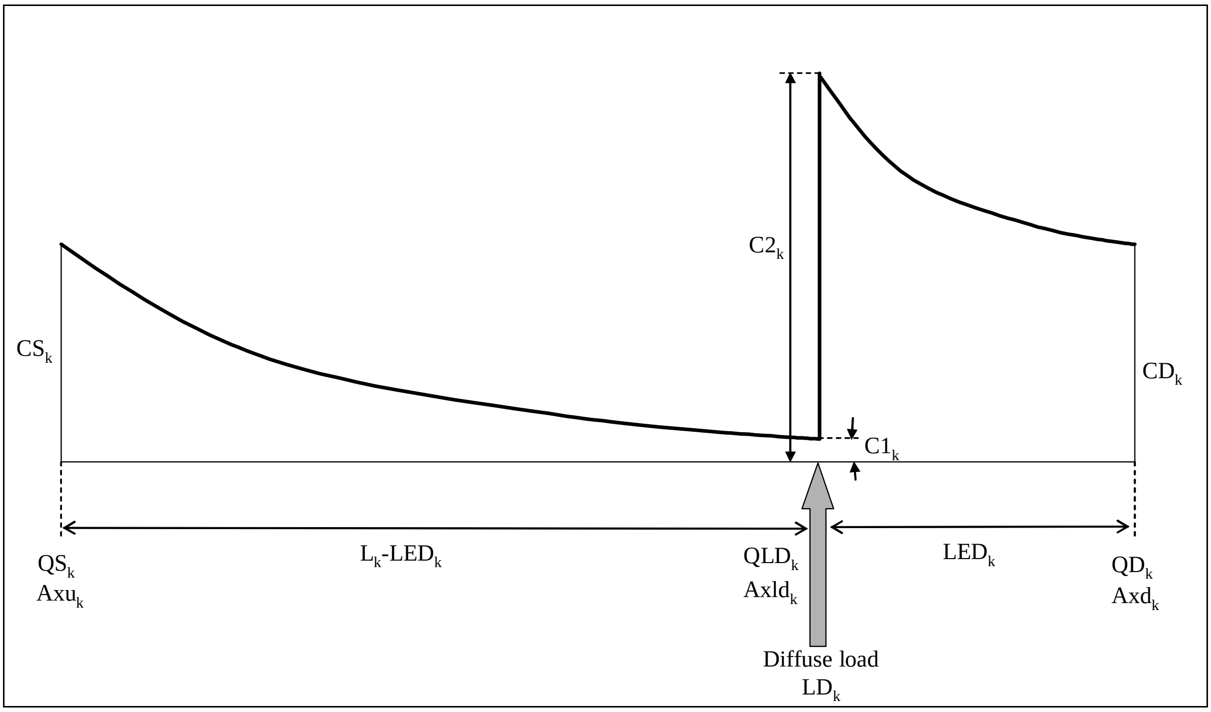


Figure 2.7 : Decay with introduction of diffuse input load

When $DEC_k < DMIN_k$ the default decay rate $DDEF_k$ is adopted and the concentration at the point just before the introduction of the diffuse load is calculated as:

$$C1_k = CS_k \cdot e^{-DDEF_k \cdot T1_k} \quad \text{.......} \quad (2.26)$$

Where:

$C1_k$ = Concentration in the channel reach just before the point of Introduction of the diffuse load (appropriate units)

$DDEF_k$ = Default decay value for channel reach k (d^{-1})

$T1_k$ = Detention time from start of channel reach until just upstream of diffuse input (d).

For a lake $T1_k$ is calculated as a simple proportion of the total detention time as:

$$T1_k = T_k \cdot (L_k - LED_k)/ L_k \quad \text{.......} \quad (2.27)$$

Where LED_k is distance of the diffuse input from the bottom of channel reach k (km).

For a channel reach the cross-sectional area is assumed to vary linearly between Axu_k at the upstream end to Axd_k at the downstream end. The cross sectional area at the point at which the diffuse load enters, $Axld_k$ (m^2), is therefore given as:

$$Axld_k \quad = \quad Axu_k + (Axd_k - Axu_k) \cdot (L_k - LED_k) / L_k \quad \text{...} (2.28)$$

Similarly the flow at the point of input of the diffuse load, QLD_k (m^3/day), is calculated as:

$$QLD_k \quad = \quad QS_k + (QD_k - QS_k) \cdot (L_k - LED_k) / L_k \quad \text{..} (2.29)$$

The concentration in the channel reach just below the point of introduction of the diffuse load is obtained from the load balance:

$$C2_k \quad = \quad C1_k + LD_k / QD_k \quad \text{..} (2.30)$$

Where:

$C2_k$ = Concentration just below the mid-point of channel reach k (appropriate units)

LD_k = Diffuse load entering channel reach k (appropriate units)

After decay in the lower half of the channel reach the final concentration is given by:

$$CD_k \quad = \quad C2_k \cdot e^{-½\cdot DDEF_k \cdot T_k} \quad \text{..} (2.31)$$

And:

$$C2_k \quad = \quad CD_k \cdot e^{½\cdot DDEF_k \cdot T_k} \quad \text{...} (2.31a)$$

From equations (3.26), (3.27) and (3.28a):

$$LD_k \quad = \quad \{CD_k \cdot e^{½\cdot DDEF_k \cdot T_k} - CS_k \cdot e^{-½\cdot DDEF_k \cdot T_k}\} \cdot QD_k \quad \text{........................} (2.32)$$

Each channel reach can be assigned one water quality sampling point at its downstream end. However, the observed water quality data may be missing at one or more such points. This can occur when sampling problems prevent sample analyses on some occasions. Some channel reaches may also have been included simply to connect river junctions or upstream point sources and may not be sampled at all. In such instances the specified default decay value for the channel reach is used to calculate the downstream concentration:

$$CD_k \quad = \quad CS_k \cdot e^{-DDEF_k \cdot T_k} \quad \text{...} (2.33)$$

The decay value calculated for the next downstream channel reach that has sampling data will therefore implicitly compensate for any errors arising from the use of default values for upstream channel reaches that do not have sampling data.

Once the first calibration run has been completed the tabulated calibration results should be examined to compare the average decay value for each channel reach with the previously specified default value. The default value for the channel reach should then be adjusted to the calibrated mean. The average of the mean values for all channel reaches grouped together according to their type (river, wetland or lake) should also be calculated and this average value used to define the default values for channel reaches of similar type that do not have any decay samples. This procedure may have to be repeated more than once since some channel reaches that do have a positive calibrated decay value sample size may also have occurrences when diffuse loads were calculated, thereby affecting the average value tabulated for the channel reach. At a later stage this procedure should be automated.

2.4.7 Accumulation of statistics

The sample size, mean and standard deviation of the calculated decay values are calculated for each channel reach, as are the mean and standard deviation of the logs of the decay values. Similar statistics are calculated for the calculated diffuse loads entering each channel reach and the effluent point source concentrations (for channel reaches receiving effluent discharges).

In addition the decay values, diffuse input loads and effluent concentrations for each reach are ranked and probabilities in the range 0 to 1 assigned to the ranked values.

2.5 Simulation algorithms

2.5.1 Initialisation

The attributes of the system condition to be simulated are defined, as discussed in Section 2*.2.5.1*.

2.5.2 Run simulation

A check is in place to prevent execution of a simulation run unless the system has first been calibrated during the current computer session. This is to ensure that no changes have been made to the input files since WQDown was last used to carry out the calibration.

The algorithms for model simulation follow closely on those for calibration. The main differences are that:

- The point source and abstraction input files use single defined flow rates (representing a specified level of development), rather than reading in a historical time series. This affects most of the flow algorithms discussed in Section 3.3.2.

- The catchment runoff flow reduction factor (Equation 3.6) does not have to be calculated in the simulation mode since an array of these values has already been simulated and stored for each channel reach during model calibration. Hence equations (3.4) and (3.5) are no longer required.

- The velocity-flow relationships based on channel characteristics given in Section 3.3.3, the calculation of channel reach detention time (Section 3.3.4) and the water quality at the head of each channel reach (Section 3.3.4) also remain unchanged.

- The main changes occur in Section 3.3.5 where the effluent point source quality concentrations are no longer read from file and channel reach decay and diffuse load values are no longer calculated from the observed channel reach concentrations. Instead these values are calculated stochastically from the stored statistical data.

2.5.2.1 Simulation of effluent concentrations

During simulation setup the user defined one of three options for calculating the effluent point source concentrations for each channel reach, namely, “Linear”, “Log” and “Observed”.

<u>Linear distribution type</u>

Selection of this option results in the generation of two random numbers, RAND and RAND2, in the range 0 to 1. These are passed to a routine to filter the random number RAND to derive a random number, NORM, conforming to a normal distribution. RAND2 is used to define the sign of the residual. The normalised random number has a mean of zero and can now exceed 1 or be smaller than -1 in conformity with the bell shaped normal distribution.

For each time step the sampled concentration of the point source discharged to the channel reach is calculated as:

$$CP_k = CPS_k \bullet (1. + COVCP_k) \bullet RNORM \qquad \text{(2.34)}$$

Where:

CPS_k = Average concentration of point source defined for the simulation for channel reach k (appropriate units)

$COVCP_k$ = Coefficient of variation for the historical point source concentrations for the channel reach selected to represent channel reach k (appropriate units)

RNORM = Normalised random number.

Since the effluent concentration cannot be negative, if the CP_k value thus calculated is below zero, then the concentration is set to the minimum allowable value (typically zero) for channel reach k. This can only happen when the “Linear” type is specified for calculating the residuals.

Warning: Setting negative concentration values to zero or a small positive minimum value will result in over-estimation of the simulated average value. This is especially serious if the observed standard deviation is large compared with the mean.

Log distribution type

The sampled logarithm of the concentration of the point source discharged to the channel reach is calculated as:

$$LCP = CPS_k \bullet (1. + COVCP_k) \bullet RNORM \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2.35)$$

Where:

LCP = Average of logs of concentration of point source defined for the simulation for channel reach k.

And CPS_k is the specified average of the logarithms of point source concentration and $COVCP_k$ is the coefficient of variation of the log of the concentrations for the point source discharged to the channel reach selected to represent channel reach k (appropriate units)

The natural concentration of the effluent discharge used in the calculations is then calculated as:

$$CP_k = e^{LCP} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2.36)$$

Use of the log option prevents the generation of negative concentrations. However, the log distribution can result in unrealistically high concentrations. It should also be noted that the mean of the log values, when converted back to a concentration value leads to a different estimate of the mean concentration. For example, a sample consisting of three concentration values of 1.0, 2.0 and 3.0 concentration units has a true sample mean of 2.0, whereas the average of the natural logs comes to 0.59725, which converts back to 1.8171 concentration units. Hence a log distribution can also skew the average concentration.

Observed distribution type

If the observed distribution is selected, then the concentration of the point source discharge is calculated as:

$$CP_k = \{RANKP_{k,i-1} + \frac{(RANKP_{k,j}-RANKP_{k,j-1})\bullet(RAND-PROBP_{k,j-1})}{(PROBP_{k,j}-PROBP_{k,j-1})}\} \bullet \frac{CPS_k}{AVECP_k} \quad \ldots\ldots \quad (2.37)$$

Where:

$PROBP_{k,j}$ and $PROBP_{k,j-1}$ = Probabilities on either side of the randomly generated probability RAND (values between 0 and 1)

$RANKP_{k,j}$ and $RANKP_{k,j-1}$ = Ranked calibrated effluent concentrations corresponding to probabilities $PROBP_{k,j}$ and $PROBP_{k,j-1}$ (appropriate units)

$AVECP_k$ = Average observed concentration for effluent discharge to the channel reach used to define the distribution for channel reach k (appropriate units).

Use of the actual observed distribution should preserve the sample mean, thereby obviating the problems associated with the linear and log distribution options. A potential drawback is that this method cannot generate concentrations that lie outside the observed range. This is not a serious drawback if the sample size is large, but if the sample size is small then the full range of possible concentrations will not be generated. Small sample sizes would also force the generated concentrations to comply with an unrealistic distribution shape, whereas values generated stochastically (linear or log) from the observed mean and standard deviation would at least follow a normal distribution.

2.5.2.2 Simulation of decay values

A random number, RAND, between 0 and 1 is first sampled for each channel reach to determine if decay values or diffuse loads are to be calculated.

If $RAND > NVALL_k/NVAL_k$ then a decay value is calculated.

Where

$NVALL_k$ = Number of effluent quality samples for the calibration period for which diffuse Loads were calculated

$NVAL_k$ = Total number of effluent quality samples for the calibration period for which either a decay value or a diffuse load was sampled.

The diffuse load, LDD_k (appropriate load units), is then set to zero.

<u>Linear distribution type</u>

The sampled decay value for the channel reach is calculated as:

$$DECC_k = AVED_k + STDD_k \bullet RNORM \quad \text{.....} \quad (2.38)$$

Where:

$DECC_k$ = Simulated decay value for channel reach k (day^{-1})

$AVED_k$ = Average decay value for calibration period for reach k (day^{-1})

$STDD_k$ = Standard deviation of calibrated decay values reach k (day^{-1})

Once again negative decay values cannot be tolerated since these would imply growth rather than decay and a diffuse input load has already been accounted for (see Section 2.4.2.3).

Log distribution type

The logarithm of the sampled decay value for the channel reach is calculated as:

$$\text{LDEC} = \text{LAVED}_k + \text{LSTDD}_k \bullet \text{RNORM} \tag{2.39}$$

Where:

LDEC = Log of decay value for channel reach k.

LAVED_k = Average of calibrated logs of decay values for channel reach k

STDD_k = Standard deviation of logs of calibrated decay values for channel reach k

The simulated decay value is then calculated as:

$$\text{DECC}_k = e^{\text{LDEC}} \tag{2.40}$$

Observed distribution type

If the observed distribution is selected, then the decay value is calculated as:

$$\text{DECC}_k = \text{RANKD}_{k,j-1} + \frac{(\text{RANKD}_{k,j}-\text{RANKD}_{k,j-1})\bullet(\text{RAND}-\text{PROBD}_{k,j-1})}{(\text{PROBD}_{k,j}-\text{PROBD}_{k,j-1})} \tag{2.41}$$

Where:

$\text{PROBD}_{k,j}$ and $\text{PROBD}_{k,j-1}$ = Probabilities on either side of the randomly generated probability RAND (values between 0 and 1)

$\text{RANKD}_{k,j}$ and $\text{RANKD}_{k,j-1}$ = Ranked calibrated decay values corresponding to probabilities $\text{PROBD}_{k,j}$ and $\text{PROBD}_{k,j-}$ (day^{-1}).

2.5.2.3 Simulation of diffuse loads

If RAND (as calculated in Section 2.4.2.2) =< $\text{NVALL}_k/\text{NVAL}_k$ then a diffuse load is calculated and the decay value, DECC_k, is set equal to the default decay value, DDEF_k.

Linear distribution type

The sampled diffuse input load for the channel reach is calculated as:

$$LDD_k = AVEL_k + STDL_k \bullet RNORM \quad \text{.......} \quad (2.42)$$

Where:

LDD_k = Simulated diffuse load entering channel reach k (appropriate units)

$AVEL_k$ = Average diffuse load for calibration period for channel reach k (appropriate units)

$STDL_k$ = Standard deviation of calibrated diffuse loads for channel reach k (appropriate units).

Negative diffuse input loads cannot be tolerated and have to be set to zero.

Log distribution type

The logarithm of the sampled diffuse load entering the channel reach is calculated as:

$$LLD = LAVEL_k + LSTDL_k \bullet RNORM \quad \text{.......} \quad (2.43)$$

Where:

LLD = Log of diffuse load entering channel reach k

$LAVEL_k$ = Average of calibrated logs of diffuse loads entering channel reach k

$LSTDL_k$ = Standard deviation of logs of calibrated diffuse loads entering channel reach k.

The simulated decay value is then calculated as:

$$LDD_k = e^{LDD} \quad \text{.......} \quad (2.44)$$

Observed distribution type

If the observed distribution is selected, then the diffuse load is calculated as:

$$LDD_k = RANKL_{k,j-1} + \frac{(RANKL_{k,j}-RANKL_{k,j-1})\bullet(RAND-PROBL_{k,j-1})}{(PROBL_{k,j}-PROBL_{k,j-1})} \quad \text{.........,......} \quad (2.45)$$

Where:

$PROBL_{k,j}$ and $PROBL_{k,j-1}$ = Probabilities on either side of the randomly generated probability RAND (values between 0 and 1)

$RANKL_{k,j}$ and $RANKL_{k,j-1}$ = Ranked calibrated diffuse loads corresponding to probabilities $PROBL_{k,j}$ and $PROBL_{k,}$ (appropriate units).

2.5.2.4 Calculation downstream concentration

The concentration at the point in the channel reach where the diffuse load enters is calculated as:

$$C1 = CS_k \bullet e^{-DECC_k \bullet T1_k} \quad \ldots\ldots (2.46)$$

Where:

C1 = concentration at the point where the diffuse load is set to enter channel reach k (appropriate units)

After the diffuse load has entered the decayed concentration at the downstream end of the channel reach is then calculated as:

$$COUT_k = \{\frac{LDD_k}{QLD_k} + C1\} \bullet e^{-DECC_k \bullet T2_k} \quad \ldots\ldots (2.47)$$

The concentration at the downstream end of each channel reach then defines the input to the linked downstream channel reach, together with point discharges and incremental catchment runoff.

2.5.3 Presentation of results

The simulated concentrations at the downstream end of each channel reach are then ranked to yield percentile values and the average is calculated. Exceedances of the water quality objective are highlighted and the percentage time that the water quality objective is exceeded is calculated. These results are tabulated and displayed.

The option of plotting duration curves at one or more nodes is provided.

3. DATA REQUIREMENTS

The data requirements for WQDown have been divided into three groups:

- Initial setup
- Periodic updating
- Simulation.

The levels of expertise required for these three groups of tasks differ widely. The end result is aimed at making the simulation task widely assessable to Regional Office and CMA personnel and to organisations making permit applications.

3.1 Initial setup

User-friendly screens have been provided to facilitate entry of the initial system setup. Nevertheless it is recommended that this step be carried out by persons with expertise and experience in hydrological and water quality modelling.

The following information is required for the initial model setup:

3.1.1 Reference gauge flow data

One or more files of historical daily or monthly flow data files need to be obtained for a key flow gauging station in the study catchment. Pathnames and data flow units for each file must be defined and the order of priority set for the automatic selection of the best available file. Daily flow data collected by the Directorate of Hydrology is likely to be the first choice for most catchments. In some instances Water Boards may have more comprehensive detailed information. It is important to evaluate the flow gauge and data record to ensure that misleading information is not used.

3.1.2 Define system network

The linkages between channel reaches need to be defined and nodes chosen to accommodate the location of river junctions, point effluent and abstraction points, river quality sampling points, flow reference gauging sites, significant features such as wetlands, lakes and irrigated areas and potential points at which new effluent discharge or abstraction points are anticipated.

A screen is provided for the user to graphically build the desired network. This screen builder automatically creates database entries for the required channel and point source features, which then have to be populated.

3.1.3 Channel reach data

The following data is required for each channel reach:

- Quaternary catchment within which the channel reach is situated (e.g. C21D)

- Total channel reach length (m)

- Channel reach friction type: i.e. Manning or lake

  For a normal river channel reach the following is required:
    Channel slope (m/m)
    Manning's n friction factor
    Representative channel width and depth for a typical cross-section assuming a parabolic channel shape (m)

  For a lake reach the following is required:
    Length of the broad crested spillway (m)
    Water depth at full capacity (i.e. just before overflow occurs) (m).

- The most likely distance from the downstream end of the channel reach to a diffuse load input (km)

- Mean monthly values derived from WR90 and other sources:
    Symons pan evaporation (mm)
    Class A pan evaporation (mm)
    Irrigation crop factor relative to A-pan evaporation (aggregated for all crops)
    Wetland crop factor relative to A-pan evaporation
    Symons pan to lake evaporation factor
    Effective rainfall factor
    Quaternary catchment rainfall (mm)
    Quaternary catchment runoff (10^6m^3)

    Default values for all of the above are inserted automatically from the WQDown database, but modifications are required to suite the characteristics of each channel reach. This is because quaternary catchments are quite large and more specific information may be available for individual channel reaches.

- Point source flow data
    Historical monthly flow data (break point data or complete patched record)
    Definition of the flow units
    Interpolation type (linear or power) to be used between break points.

- Point abstraction data
    Historical monthly flow data (break point data or complete patched record)
    Definition of the flow units
    Interpolation type (linear or power) to be used between break points.

- River sampling water quality data.
  - WMS .CSV file pathname
  - WMS feature number

- Point source input quality data.
  - Constant point source concentration (required for all of the water quality variables that are to be simulated), or
  - WMS .CSV file pathname
  - WMS feature number
  - Default concentration to be used when there are gaps in the effluent water quality record (appropriate flow units). This is required for all of the water quality variables that are to be simulated.

- Calibration controls:
  - Set calibration period. The selected period should be long enough to embrace a representative range of hydrological conditions, since it also defines the limits of the simulation period
  - Define acceptable data error (days). This is the range before or after the specified calibration dates in which additional channel reach sample data will be accepted as applying to the nominal date.
  - Natural catchment runoff concentration (appropriate units)
  - Maximum allowable concentration (appropriate units)
  - Minimum allowable decay value (appropriate units), below which the default decay value is used and a diffuse input load is calculated
  - Default decay value (appropriate units).

- Set standard dates to be used in the calibration. A suitable screen is provided showing channel reaches for which quality data is available for each date for which one or more samples are available. Care has to be exercised in selecting calibration dates so as to ensure that:
  - There are enough samples to represent the system. This is important since all of the channel reaches for which there is no data will be represented by the default values. For example, if there are 10 channel reaches in series and nine of them are sampled at monthly intervals and the last is sampled weekly and all of the dates are accepted, then for 9-tenths of the possible calibration dates nine of the channel reaches will have default decay values with the calculated decay value for the 10th channel reach having to compensate for the errors arising from the upstream channel reaches within the last channel reach. This would distort the calibration by lending too much weight to the default values for the upstream channel reaches, thereby flattening their distributions, and cause far too much variance in the calculated values for the last channel reach. A better result would ensue from simply eliminating those dates for which only one sample is available, (despite reducing the sample size at the last point by 90%). The above example is not unrealistic. A case in point is the Blesbokspruit, where the

Regional Office sampling frequency is monthly, which accounts for most of the 25 upstream river sampling points. Conversely the DWA National monitoring system gathers weekly samples at station C2H004 near the outlet of the Suikerbosrand catchment.

These considerations also have a bearing on the selection of system channel reaches (i.e. Section 4.2.2). It may be better to eliminate a sampling point with very few samples entirely if it commands a long channel reach in favour of a nearby downstream monitoring station that has a better record.

There are also implications for the design and operation of monitoring systems. Fewer well selected monitoring points that are consistently sampled are much more valuable for modelling than many sampling points that operate only for limited blocks of time, or where the sampling frequency is erratic.

Care also needs to be exercised in selecting the length of the calibration period to ensure that it does not span a discontinuity in the physical system. For example, if a lake is constructed the decay values for the erstwhile channel reach will not be compatible with the lake formed after construction. Under such circumstances it might be better to only do the calibration for the period after the lake is built. Alternatively, if the overall system for which water quality records are available is significantly bigger and a reduction in the sample size for all of the other sampling points is undesirable, it might be more appropriate to remove the record for just the affected monitoring station prior to the date of construction.

3.2 Periodic updating

Periodic updating falls into two classes:

- Revision of the setup
- Updating of time series data.

3.2.1 Revision of setup

The first of these classes comprises a review of the initial setup (see Section 4.1) and as such requires modelling expertise. Setup revision need be done only after catchment changes are significant enough to justify revision of catchment characteristics. Sometimes this may only be required for those parts of the system affected by the changes. However, it is recommended that a full revision is carried out at less frequent intervals to capture changes in catchment development and re-examine field conditions.

3.2.2 Updating of time series data

The second class involves the periodic updating of river flow and WMS water quality time series files and monthly point source discharge and abstraction flow data. This task can be carried out by competent Head Office, Regional Office and CMA personnel who have had appropriate training on using the model. This should be done once per year to ensure that the recently collected readily available data is assimilated. It is not onerous to replace the old WMS and daily flow files with the latest available. Updating the monthly effluent flow data should be facilitated by the monthly returns that dischargers are required to return anyway in terms of their discharge permits. Only 12 monthly flow values are required to be entered per year and this is a good discipline to ensure that the essential flow records are updated regularly.

It is also desirable to regularly (say each year) re-evaluate the default effluent point source concentration decay values for each channel reach. This can be done by running a data calibration, replacing the default values with the simulation averages, and repeating the calibration until convergence is reached. This is desirable since the sample size available at each monitoring point will become more comprehensive than that which was available when the model was first set up, resulting in better estimates of the default values. This could assume even greater importance if the recommendations regarding the sampling programme are followed.

3.3 Simulation

Model simulation is the intended day by day use of the model by Regional Office and CMA personnel.

The additional data that is required for simulation relates only to the system change being simulated. For example, if a new effluent discharge is being contemplated, then it is necessary to determine the discharge rate and the average effluent quality. If the sewage treatment works is to be similar to an existing one, then it might be reasonable to assume a distribution of effluent quality values similar to the existing works, but perhaps with a revised average effluent concentration to reflect a different target level. This is considered more realistic than simply assuming a fixed concentration at the target level, since even in the best run entities occasional plant failures will still occur or clients will discharge a slug of pollutants that will disrupt biological processes for a period of time. Nevertheless WQDown does provide the option of simply specifying a constant effluent concentration.

The current version of WQDown does not provide for simulating a variable effluent discharge rate. A seasonal flow distribution feature could easily be added.

If a new future time horizon is to be simulated (or if the growth in urban and irrigated areas during the calibration period was long enough for the present day values to be substantially different), then it would be necessary to define new urban and irrigated areas and point effluent discharge and abstraction flow rates. Changes in current urban and irrigated areas can be obtained from satellite imagery supported by suitable ground truthing. Projections of future areas would require hydrological and other expertise.

The data required to support simulation comprises:

- Set the simulation period (which must lie within the limits of the total calibration period)

- Select either daily or monthly flow data
- Set the number of data repetitions
- Set the water quality objective (appropriate units)
- For each channel reach define:
    - Incremental upstream and lateral urban areas (km^2)
    - Irrigation area (km^2)
    - Average point abstraction rate (m^3/day)
    - Average effluent point discharge rate (m^3/day)
    - Number of the channel reach to be used to represent the distribution of residuals for the local effluent point source
    - Average effluent point source concentration (appropriate units)
    - Distribution type to be used to simulate stochastic effluent point source concentrations (“Linear”, “Log” or “Observed”)
    - Distribution type to be used to simulate stochastic channel reach decay values (“Linear”, “Log” or “Observed”)
    - Distribution type to be used to simulate stochastic channel reach diffuse input loads (“Linear”, “Log” or “Observed”).

4. TESTING ON BLESBOKSPRUIT CATCHMENT

4.1 Introduction

During the development phase extensive testing was carried out using a simple hypothetical system that included most of the model element types. Comprehensive spreadsheets were developed to assist in this process and ensure that the model produced expected results.

Once everything was working satisfactorily the model was applied to the complex Blesbokspruit system, the results of which are discussed in the following sections.

4.2 Catchment overview

The Blesbokspruit was chosen for testing and Figure 4.1 shows the main features of the Blesbokspruit / Suikerbosrand River catchment. Figures 4.2, 4.3 and 4.4 are enlargements of the north-west, central and south western sections of the catchment.

The study catchment includes the lower portion of the Suikerbosrand River down to its confluence with the Vaal River.

This system was chosen for model testing because it contains all of the main elements used in WQDown, including heavily urbanised, irrigation, wetland and lake features, several effluent point sources, water abstractions, diffuse pollution from a number of areas, several river and effluent water quality monitoring stations of various sampling frequency and duration and a flow gauging station. The catchment is also of great concern due to high pollution load inputs, the Blesbokspruit RAMSAR wetland, the threat posed to informal users who may use the river water for domestic purposes and the impact on the already polluted Vaal Barrage and downstream Middle Vaal River.

4.2.1 Initialisation

The following details apply to the Blesbokspruit test setup:

Database name:	WQDBlesbok.mdb
Project name:	Blesbokspruit
Calibration period:	1991/01 – 2002/01

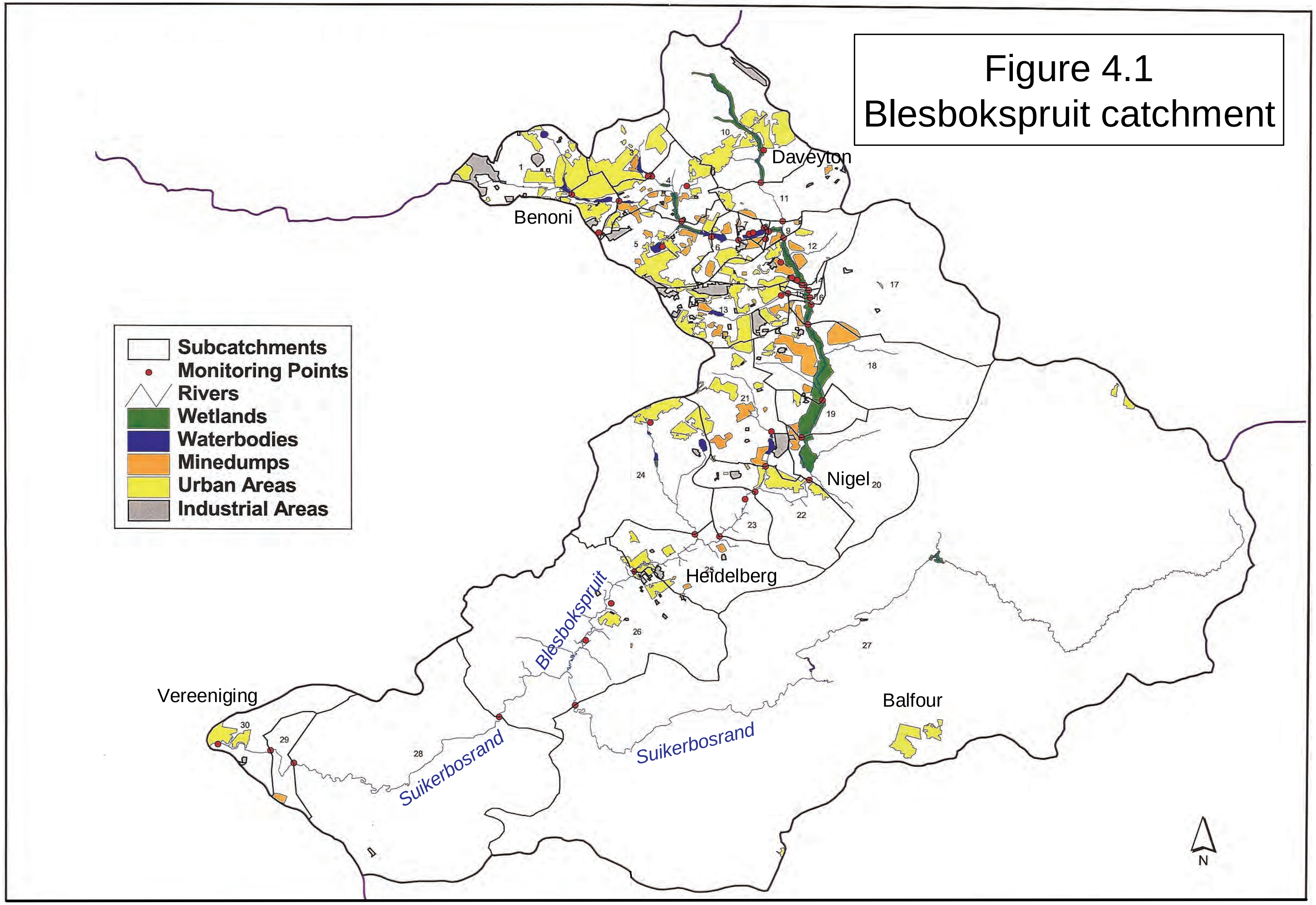


Figure 4.1
Blesbokspruit catchment

Figure 4.2
North-West section of
Blesbokspruit catchment

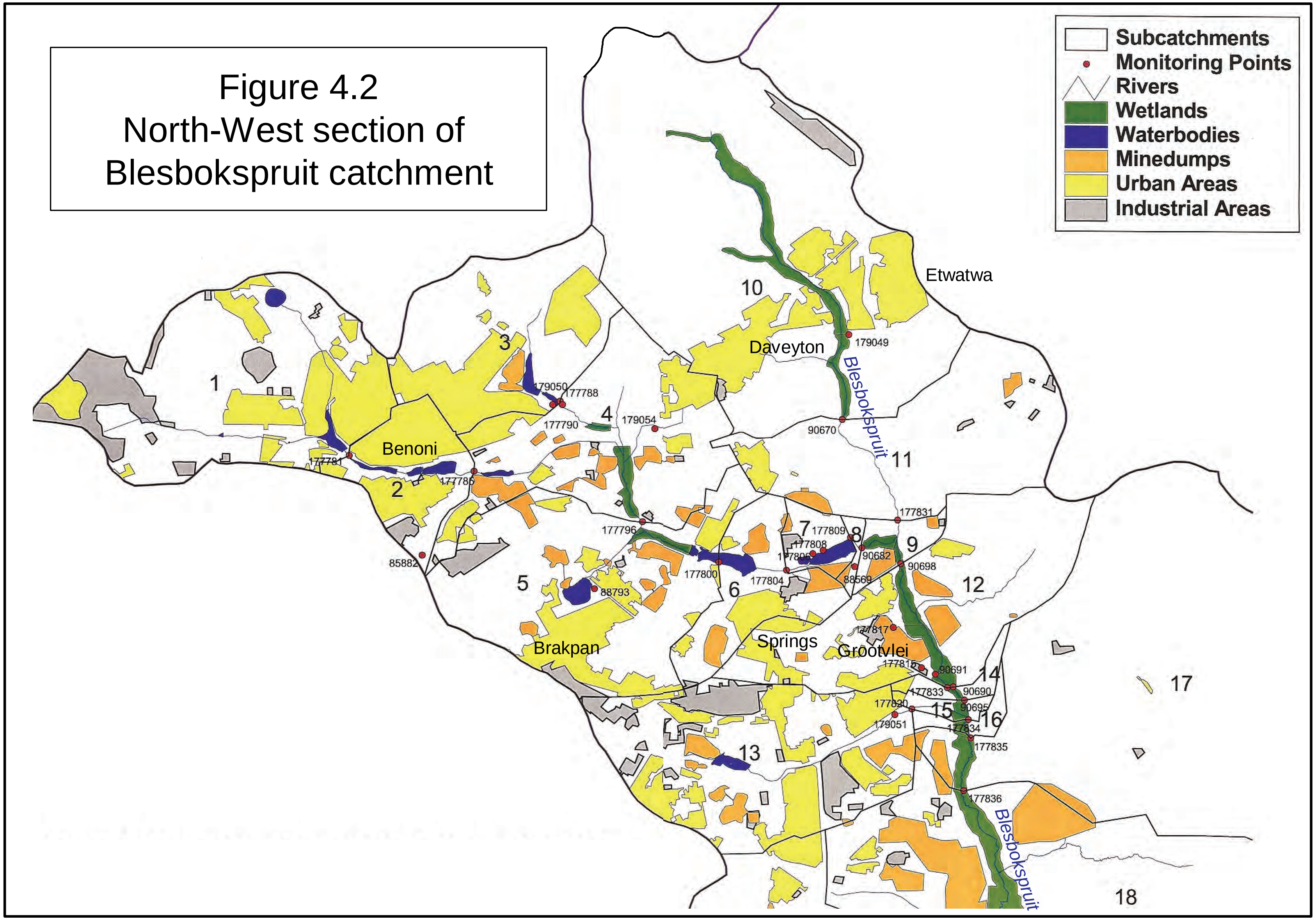


Figure 4.3
Central section of Blesbokspruit catchment

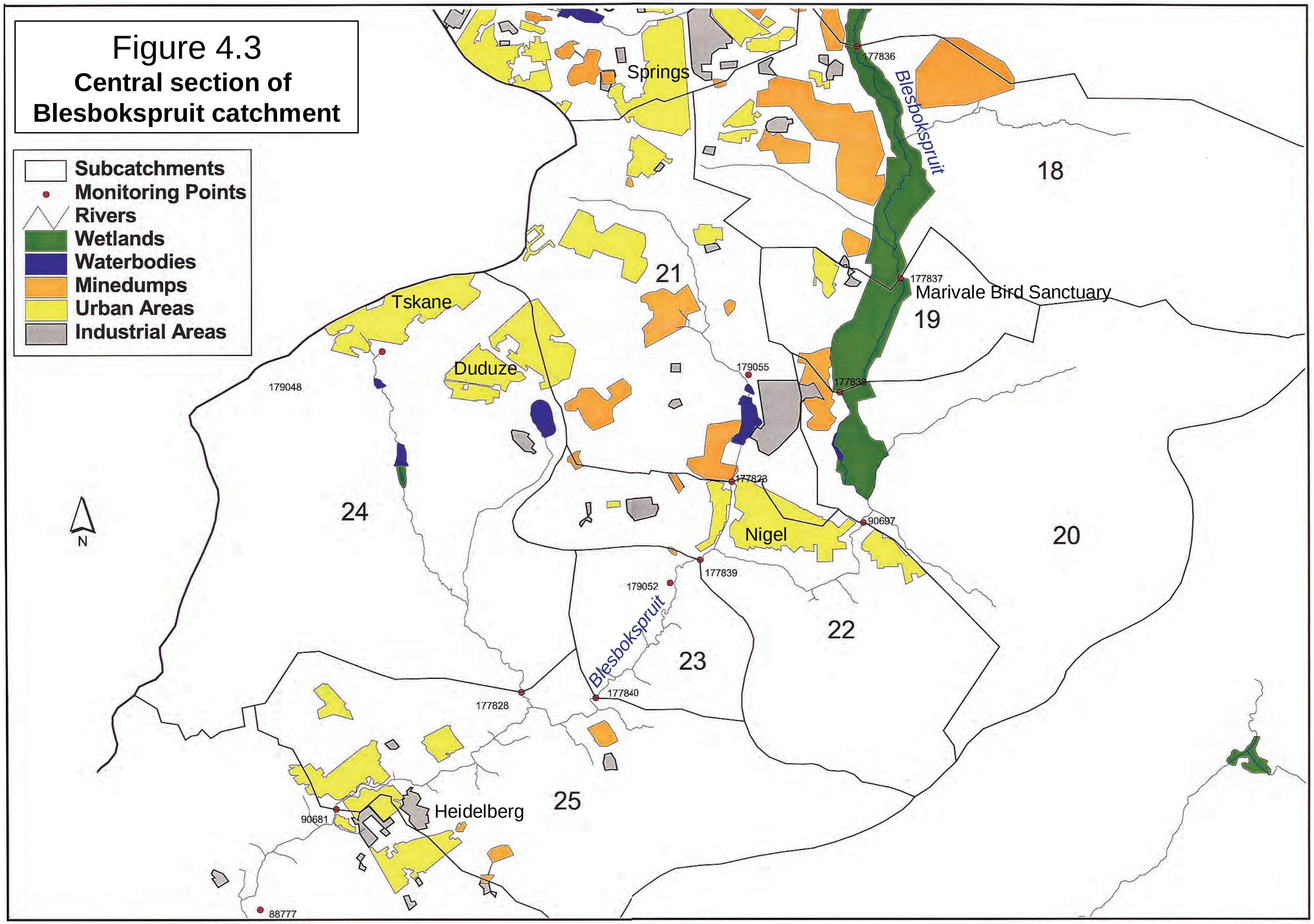
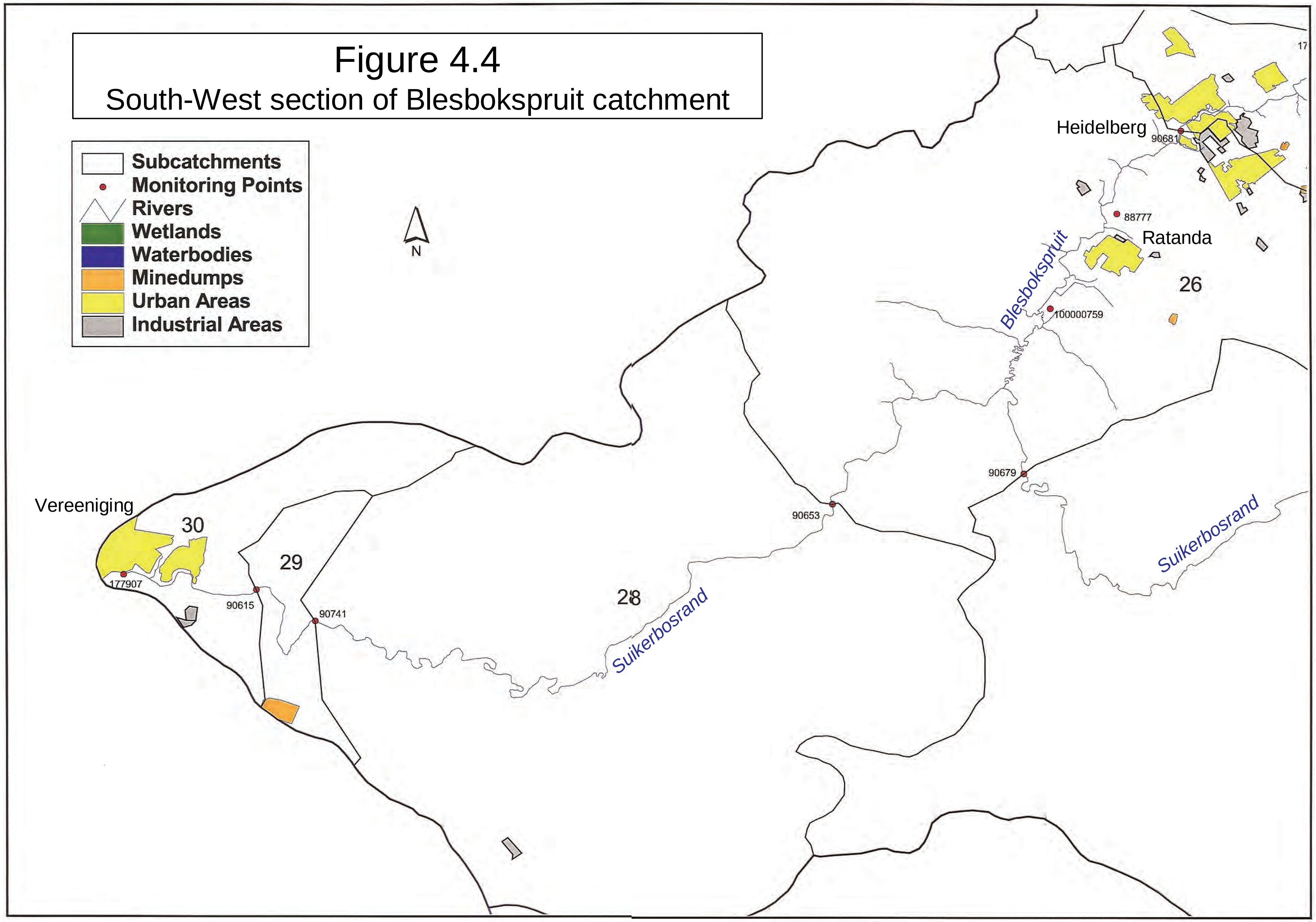


Figure 4.4
South-West section of Blesbokspruit catchment



4.2.2 Reference flow gauge

Streamflow station C2H004 located on the Suikerbosrand River upstream of its confluence with the Vaal River was taken as the reference flow gauge. The downstream end of channel reach 54 was chosen to coincide with this weir. Three flow records are available at this site:

1) Adjusted daily flow data collected by Rand Water
2) DWA daily flow data, and
3) Patched monthly flow data.

This was taken as the priority order, since hydraulic modelling was undertaken to extend the Rand Water rating curves to cater for flows beyond the 50 m^3/s modular limit of the weir.

4.2.3 System network

The WQDown system network representing the Blesbokspruit is shown in Figure 4.5.

The network comprises 54 interconnected channel reaches of various types (lake, wetland and channel reaches), 27 sampling points for which data is included in the DWA's WMS database, 15 effluent point source inputs for which data is also contained in the WMS and two abstraction points.

4.2.4 Channel reach attributes

The attributes of the channel reaches used in WQDown are summarised in Table 4.1.

4.2.5 Channel reach quality data

The sources of the water quality data and phosphate input values used in the model calibrations is summarised in Table 4.2.

4.2.6 Point source data

A summary of the point effluent discharge and abstraction data and the sources of the point source water quality data are also contained in Table 4.2.

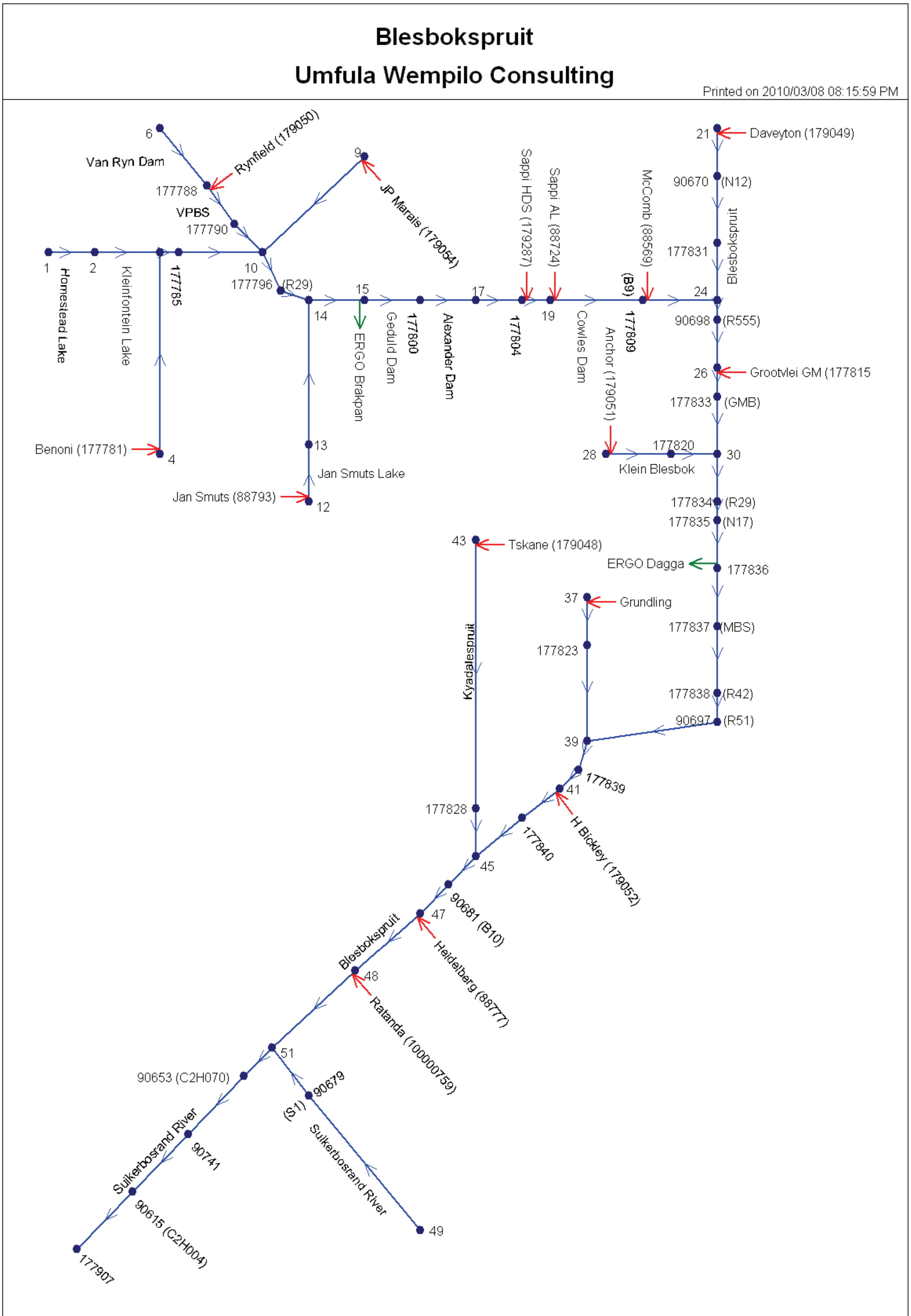


Figure 6.5: Blesbokspruit catchment system network

Table 4.1: Attributes of Blesbokspruit system network

ID	Description	Quat.	LE	LED	S	Mann	B	H	BS	B0	H0	QB	AL	AW	AI	ATU	ATL	AUU	AUL	PU	FU	MAP	CPF	EFI	PIR	TL	TMX
			km	km	m/m		m	m	m	m	m	Mℓ/d	km2	km2	km2	km2	km2	km2	km2	(-)	(-)	mm	%	%	%	%	d
1	Homestead Lake	C21D	1.78	0.89	0	0	234	2	20	234	2	0	0.4	0	0	56	4.5	20	3.9	0.13	0.88	698	57	65	10	0	30
2	Kleinfontein Lake	C21D	4.08	2.04	0	0	142	2	20	142	2	0	0.7	0	0	0	14	0	11	0.13	0.88	698	57	65	10	0	30
3	Stream from Benoni STW	C21D	3.20	1.60	0.001	0.1	3	0.3	0	0	0	0	0.3	0	0	0.1	1.3	0	0	0.13	0.88	698	57	65	10	0	30
4	Benoni canal above Snake Road	C21D	0.78	0.39	0.004	0.1	11	0.3	0	0	0	0	0	0	0	0	1.2	0	0	0.13	0.88	698	57	65	10	0	30
5	Benoni canal below Snake Road	C21D	6.17	3.09	0.0026	0.1	11	0.3	0	0	0	0	0.2	0	0	0	9.7	0	0.5	0.13	0.88	698	57	65	10	0	30
6	Van Ryn Dam	C21D	1.53	0.77	0	0	273	2	20	273	2	0	0.4	0	0	32	1	12	0	0.13	0.88	698	57	65	10	0	30
7	Victor Penning Bird Sanctuary	C21D	0.83	0.41	0	0	159	1	10	159	1	0	0.1	0	0	0	3.9	0	0.6	0.13	0.88	698	57	65	10	0	30
8	Below VPBS	C21D	3.60	1.80	0.0028	0.2	1.3	0.2	0	0	0	0	0	0.2	0	0	1.3	0	0	0.13	0.88	698	57	65	10	0	30
9	From JP Marais	C21D	1.73	0.86	0.0023	0	3.7	0.3	0	0	0	0	0	0	0	8.8	6	2.7	0	0.2	0.88	698	57	65	10	0	30
10	Wetland to R29	C21D	2.50	1.25	0.0004	0.3	15	0.3	0	0	0	0	0	1.1	0	6.7	8.4	0	3.5	0.13	0.88	698	57	65	10	0	30
11	Wetland below R29	C21D	0.60	0.30	0.0008	0.3	275	0.3	0	0	0	0	0	0	0	0	0.4	0	0	0.13	0.88	698	57	65	10	0	30
12	Jan Smuts Lake	C21D	0.96	0.48	0	0	667	2	10	667	2	0	0.6	0	0	12	2	10	1.2	0.13	0.88	698	57	65	10	0	30
13	Stream from Jan Smuts	C21D	2.92	1.46	0.0041	0.1	0.4	0.3	0	0	0	0	0	0	0	0	30	0	2.4	0.13	0.88	698	57	65	10	0	30
14	Benoni canal	C21D	1.91	0.96	0.0008	0.3	275	0.3	0	0	0	0	0	0.6	0	0	5	0	0	0.13	0.88	698	57	65	10	0	30
15	Geduld Dam	C21D	1.16	0.58	0	0	284	2	40	284	2	24	0.3	0	0	0	6.9	0	0.2	0.13	0.88	698	57	65	10	0	30
16	Alexander Dam	C21D	1.47	0.73	0	0	503	2	40	503	2	0	0.7	0	0.3	0	11	0	2.5	0.13	0.88	698	57	65	10	0	30
17	Enstra Road	C21D	1.15	0.58	0.0052	0.1	18	0.1	0	0	0	0	0	0	0	0	6.6	0	0.5	0.13	0.88	698	57	65	10	0	30
18	Cowles Dam upper	C21D	0.94	0.47	0	0	341	2	45	341	2	0	0.1	0	0	0	2.1	0	0.3	0.2	0.88	698	57	65	10	0	30
19	Cowles Dam	C21D	1.81	0.91	0	0	341	2	45	341	2	0	0.6	0	0	0	3.2	0	0	0.2	0.88	698	57	65	10	0	30
20	Blesbok canal below Cowles Dam	C21D	1.60	0.80	0.0006	0.3	200	0.3	0	0	0	0	0	0.5	0	0	1.3	0	0	0.2	0.88	698	57	65	10	0	30
21	Blesbok: Daveyton to N12	C21D	3.17	1.59	0.0013	0.3	15	0.3	0	0	0	0	0	1	0.8	109	16	18	1	0.2	0.88	698	57	65	10	0	30
22	Blesbokspruit: N12 to Welgedacht	C21D	4.58	2.29	0.0009	0.1	15	0.3	0	0	0	0	0	0	0	0	45	0	2	0.2	0.88	698	57	65	10	0	30
23	Blesbokspruit: Welgedacht to confluence	C21D	0.64	0.32	0.0016	0.1	15	0.3	0	0	0	0	0	0	0	0	1.7	0	0	0.2	0.88	698	57	65	10	0	30
24	R555 - Benoni Bird Sanctuary	C21D	0.95	0.47	0.001	0.3	200	0.3	0	0	0	0	0	0.2	0	0	1.2	0	0	0.2	0.88	698	57	65	10	0	30
25	Blesbokspruit above Grootvlei Mine	C21D	4.54	2.27	0.0004	0.3	400	0.5	0	0	0	6	0.7	2.1	0.4	0	43	0	7.3	0.2	0.88	691	57	65	10	0	30
26	Grootvlei Mine bridge	C21E	0.77	0.39	0.0004	0.3	400	0.5	0	0	0	0	0	0.4	0	0	1.9	0	0.1	0.2	0.88	691	57	65	10	0	30
27	GMB to Klein Blesbok confluence	C21E	1.13	0.56	0.0015	0.3	400	0.5	0	0	0	0	0	0.3	0	0	3.5	0	0.3	0.2	0.88	691	57	65	10	0	30
28	Klein Blesbokspruit	C21E	0.70	0.35	0.0029	0.1	18	0.3	0	0	0	0	0	0	0	50	0.6	22	0	0.2	0.88	691	57	65	10	0	30
29	Klein Blesbok to Blesbokspruit	C21E	2.27	1.14	0.0018	0.1	18	0.3	0	0	0	0	0	0	0	0	1.1	0	0.2	0.2	0.88	691	57	65	10	0	30

ID	Description	Quat.	LE	LED	S	Mann	B	H	BS	B0	H0	QB	AL	AW	AI	ATU	ATL	AUU	AUL	PU	FU	MAP	CPF	EFI	PIR	TL	TMX
			km	km	m/m		m	m	m	m	m	Mℓ/d	km2	km2	km2	km2	km2	km2	km2	(-)	(-)	mm	%	%	%	%	d
30	Blesbokspruit: Klein Blesbok to R29	C21E	0.24	0.12	0.0022	0.3	400	0.5	0	0	0	0	0	0.2	0	0	0.4	0	0	0.13	0.88	691	57	65	10	0	30
31	Blesbokspruit: R29 to N17	C21E	0.42	0.21	0.0053	0.3	400	0.5	0	0	0	0	0	0.3	0	0	2.4	0	0	0.13	0.88	691	57	65	10	0	30
32	Blesbokspruit: N17 to Daggafontein	C21E	2.38	1.19	0.0004	0.3	400	0.5	0	0	0	0	0	1.1	0	0	152	0	0.4	0.2	0.88	691	57	65	10	0	30
33	Blesbokspruit: Dagga to MBS causeway	C21E	8.23	4.11	0.0006	0.3	400	0.5	0	0	0	0	0.4	6.4	2.3	0	115	0	1.9	0.2	0.88	691	57	65	10	0	30
34	Blesbokspruit: MBS to R42	C21E	4.36	2.18	0.0002	0.3	400	0.5	0	0	0	0	0.1	4.6	0	0	25	0	0.8	0.13	0.88	691	57	65	10	0	30
35	Blesbokspruit: R42 to R51	C21E	5.02	2.51	0.0006	0.1	10	0.5	0	0	0	0	0.1	0	0.6	0	102	0	0.3	0.13	0.88	691	57	65	10	0	30
36	Blesbokspruit: R51 to stream from Nigel Dam	C21E	7.19	3.60	0.0023	0.1	10	0.5	0	0	0	0	0	0	0	0	45	0	0	0.13	0.88	691	57	65	10	0	30
37	Nigel Dam + outlet canal	C21E	3.24	1.62	0	0	217	2	10	217	2	0	0.7	0	0	44	26	8.7	2.6	0.15	0.88	691	57	65	10	0	30
38	Stream below Nigel Dam	C21E	2.06	1.03	0.0029	0.1	8	1.5	0	0	0	0	0	0	0	0	8.2	0	2.3	0.15	0.88	691	57	65	10	0	30
39	Blesbokspruit: Confluence to Noycedale	C21E	0.68	0.34	0.0023	0.1	10	0.5	0	0	0	0	0	0	0	0	13	0	4.9	0.13	0.88	691	57	65	10	0	30
40	Blesbokspruit: Noycedale to H Bickley STW	C21E	1.44	0.72	0.0014	0.1	10	0.5	0	0	0	0	0	0	0	0	6.3	0	0	0.13	0.88	691	57	65	10	0	30
41	Blesbokspruit: H BICKLEY to Poortjie	C21E	5.68	2.84	0.0014	0.1	10	0.5	0	0	0	0	0	0	0	0	17	0	0	0.13	0.88	704	57	65	10	0	30
42	Blesbokspruit: Poortjie to Kaydalespruit	C21F	3.35	1.68	0.0009	0	10	0.5	0	0	0	0	0	0	0	0	34	0	0	0.13	0.88	704	57	65	10	0	30
43	Kaydale - Stream from Tskane	C21F	13.31	6.65	0.0043	0.1	10	0.2	0	0	0	0	0.3	0.2	0	9.7	113	5	4.5	0.2	0.88	704	57	65	10	0	30
44	Kaydale to Blesbokspruit	C21F	0.71	0.36	0.0043	0.1	10	0.2	0	0	0	0	0	0	0	0	0.5	0	0	0.2	0.88	704	57	65	10	0	30
45	Blesboksruit: Kaydale to B10	C21F	8.49	4.25	0.0009	0	10	0.5	0	0	0	0	0	0	1.6	0	52	0	5.7	0.13	0.88	704	57	65	10	0	30
46	Blesbokspruit: B10 to Heidelberg STW	C21F	4.94	2.47	0.0031	0	20	0.5	0	0	0	0	0	0	0	0	96	0	2.7	0.13	0.88	704	57	65	10	0	30
47	Blesbokspruit: Heidelberg STW to Ratanda STW	C21F	4.69	2.34	0.0031	0	20	0.5	0	0	0	0	0	0	3.2	0	33	0	1.8	0.2	0.88	704	57	65	10	0	30
48	Blesbokspruit: Ratanda STW to Suikerbosrand confluence	C21F	7.80	3.90	0.0011	0	20	0.5	0	0	0	0	0	0	3.2	0	78	0	0	0.13	0.88	704	57	65	10	0	30
49	Suikerbosrand River above S1	C21C	4.75	2.37	0.0008	0.1	20	0.5	0	0	0	0	0	0	0	1549	13	7.9	0	0.13	0.87	674	57	65	10	0	30
50	Suikerbosrand above Blesbokspruit confluence	C21C	4.12	2.06	0.0004	0.1	20	0.5	0	0	0	0	0	0	0	0	7.2	0	0	0.13	0.87	674	57	65	10	0	30
51	Suikerbosrand: Blesbok to C2H070	C21G	11	5.33	0.001	0	24	1.3	0	0	0	0	0	0	0	0	58	0	0	0.13	0.87	667	57	65	10	0	30
52	Suikerbosrand: C2H070 to Badfontein	C21G	32	15.82	0.0012	0	24	1.3	0	0	0	0	0	0	12	0	337	0	0.2	0.2	0.87	667	57	65	10	0	30
53	Suikerbosrand: C2H070 to C2H004	C21G	5.10	2.55	0.0006	0	24	1.3	0	0	0	0	0	0	0	0	20	0	0	0.13	0.87	667	57	65	10	0	30
54	Suikerbosrand: C2H004 to Vaal	C21G	6.03	3.02	0.0004	0	24	1.3	0	0	0	0	0	0	0	0	43	0	5.3	0.13	0.87	667	57	65	10	0	30

The key for the column headings used in Table 4.1 is as follows:

Code	Description
ID	Channel reach number
LE	Channel reach length (km)
LED	Distance from downstream end of channel reach to diffuse input
QUAT	Quaternary number
TYPE	Reach type: River (Manning friction factor) or Lake (level pool outlet control)
S	Channel slope (m/m)
MANN	Manning n friction factor
B	Measured river cross-section breadth (m)
H	Corresponding measured river cross-section depth (m)
BS	Lake outlet broad crested weir spill way length (m)
B0	Lake width (m)
H0	Lake full storage depth (m)
QB	Bed loss (m^3/day)
AL	Lake area (km^2)
AW	Wetland area (km^2)
AI	Irrigated area (km^2)
ATU	Total incremental catchment area entering upstream end of channel reach (km^2)
ATL	Total incremental catchment area entering channel reach laterally (km^2)
AUU	Urbanised area entering upstream end of channel reach (km^2)
AUL	Urbanised area entering channel reach laterally (km^2)
PU	Proportion of urban area paved
FU	Unit runoff from paved surfaces (proportion of rainfall)
MAP	Mean Annual Precipitation (mm)
CPF	Percentage of irrigation area cropped (%)
EFI	Irrigation efficiency (%)
PIR	Irrigation return flow (%)
TL	Transmission loss between channel reach and irrigated area (%)
TMAX	Maximum number of days detention time in channel reach (days)

Table 4.2: Phosphate and point source input and abstraction data

ID	Channel reach description	WMS Feature	CCAT mg/l	CMAX mg/l	CMIN mg/l	DDEF 1/day	Point source description	QA Mℓ/d	QP Mℓ/d	WMS Feature	CPD mg/l
1	Homestead Lake	177781	0.05	10	0	0.04					
2	Kleinfontein Lake		0.05	10	0	0.04					
3	Stream from Benoni STW		0.05	10	0	2.48	Benoni STW		9065		0.45
4	Benoni canal above Snake Road	177785	0.05	10	0	28.9					
5	Benoni canal below Snake Road		0.05	10	0	2.48					
6	Van Ryn Dam	177788	0.05	10	0	0.03					
7	Victor Penning Bird Sanctuary	177790	0.05	10	0	0.16	Rynfield STW		7129	179050	1.21
8	Below VPBS		0.05	10	0	2.48					
9	From JP Marais		0.05	10	0	2.48	JP Marais		24839	179054	0.89
10	Wetland to R29	177796	0.05	10	0	2.48					
11	Wetland below R29		0.05	10	0	2.48					
12	Jan Smuts Lake		0.05	10	0	0.04	Jan Smuts STW		7774	88793	1.03
13	Stream from Jan Smuts		0.05	10	0	2.48					
14	Benoni canal		0.05	10	0	2.48		800			
15	Geduld Dam	177800	0.05	10	0	0.06					
16	Alexander Dam		0.05	10	0	0.14					
17	Enstra Road	177804	0.05	10	0	2.48					
18	Cowles Dam upper		0.05	10	0	0.14	Sappi HDS		25800	177806	0.36
19	Cowles Dam	177809	0.05	10	0	0.23	Sappi FL		0	177808	0.36
20	Blesbok canal below Cowles Dam		0.05	10	0	0.91	McComb STW		9677	88569	2.29
21	Blesbok: Daveyton to N12	90670	0.05	10	0	0.91	Daveyton STW		20968	179049	,877
22	Blesbokspruit: N12 to Welgedacht	177831	0.05	10	0	0.91					
23	Blesbokspruit: Welgedacht to confluence		0.05	10	0	0.91					
24	R555 - Benoni Bird Sanctuary	90698	0.05	10	0	4.39					
25	Blesbokspruit above Grootvlei Mine		0.05	10	0	3.52					
26	Grootvlei Mine bridge	177833	0.05	10	0	2.66	Grootvlei Mine		120000	177815	0.19
27	GMB to Klein Blesbok confluence		0.05	10	0	3.52					
28	Klein Blesbokspruit	177820	0.05	10	0	178	Anchor STW		28194	179051	0.53
29	Klein Blesbok to Blesbokspruit		0.05	10	0	3.52					
30	Blesbokspruit: Klein Blesbok to R29	177834	0.05	10	0	32.6					
31	Blesbokspruit: R29 to N17	177835	0.05	10	0	1.63					
32	Blesbokspruit: N17 to Daggafontein	177836	0.05	10	0	0.48		5800			
33	Blesbokspruit: Dagga to MBS causeway	177837	0.05	10	0	0.2					
34	Blesbokspruit: MBS to R42	177838	0.05	10	0	0.26					
35	Blesbokspruit: R42 to R51	90697	0.05	10	0	3.02					
36	Blesbokspruit: R51 to stream from Nigel Dam		0.05	10	0	4.36					
37	Nigel Dam + outlet canal	177823	0.05	10	0	4.36	Grundling STW		3581		0.6
38	Stream below Nigel Dam		0.05	10	0	4.36					
39	Blesbokspruit: Confluence to Noycedale	177839	0.05	10	0	29.2					
40	Blesbokspruit: Noycedale to H Bickley STW		0.05	10	0	3.33					
41	Blesbokspruit: H BICKLEY to Poortjie	177840	0.05	10	0	3.93	H Bickley STW		10323	179052	1.72
42	Blesbokspruit: Poortjie to Kaydalespruit		0.05	10	0	4.36					
43	Kaydale - Stream from Tskane	177828	0.05	10	0	1.89	Tskane STW		9355	179048	0.24
44	Kaydale to Blesbokspruit		0.05	10	0	1.89					
45	Blesboksruit: Kaydale to B10	90681	0.05	10	0	6.24					
46	Blesbokspruit: B10 to Heidelberg STW		0.05	10	0	4.36					

ID	Channel reach description	WMS Feature	CCAT mg/l	CMAX mg/l	CMIN mg/l	DDEF 1/day	Point source description	QA Mℓ/d	QP Mℓ/d	WMS Feature	CPD mg/l
47	Blesbokspruit: Heidelberg STW to Ratanda STW		0.05	10	0	4.36	Heidelberg STW		5161	88777	0.57
48	Blesbokspruit: Ratanda STW to Suikerbosrand confluence		0.05	10	0	4.36	Ratanda STW		2903	1E+08	0.65
49	Suikerbosrand River above S1	90679	0.05	10	0	3.28					
50	Suikerbosrand above Blesbokspruit confluence		0.05	10	0	3.28					
51	Suikerbosrand: Blesbok to C2H070	90653	0.05	10	0	3.84					
52	Suikerbosrand: C2H070 to Badfontein	90741	0.05	10	0	2.1					
53	Suikerbosrand: C2H070 to C2H004	90615	0.05	10	0	4.73					
54	Suikerbosrand: C2H004 to Vaal	177907	0.05	10	0	3.56					

The key for the column headings used in Table 4.2 is as follows:

Code	**Description**
ID	Channel reach number
WMS feature	WMS system sampling station code
CCAT	Catchment runoff phosphate concentration (mg/l)
CMAX	Maximum simulated phosphate concentration (mg/l)
CMIN	Minimum simulated phosphate concentration (mg/l)
DDEF	Default decay value (day^{-1})
QA	Point abstraction from reach at end of calibration period (m^3/day)
AP	Point discharge to reach at end of calibration period (m^3/day)
CPD	Default point source inflow phosphate concentration (mg/l)

4.3 Calibration results

The results of the model calibration for phosphate are given in Appendix B. These then provide the statistical values required to simulate options.

4.4 Model simulations

Two options have been simulated:

- Baseline
- Grootvlei Gold Mine effluent ceases.

4.4.1 Baseline

The Baseline option reflects 2002 conditions at the end of the calibration period. The results of the Baseline simulation are tabulated in Appendix C.

Note that the Baseline option is not identical to the calibration period since growth in pollution inputs loads occurred throughout the calibration period. Another major change was to the Grootvlei Gold Mine's effluent discharge. During the first year of the calibration period Grootvlei Gold mine discharged only about 10 Mℓ/day at a relatively low salt concentration. Thereafter pumping from Grootvlei's underground workings ceased entirely for the next 4 years. Dewatering resumed in February 1996 at a much higher discharge rate than before, which peaked at about 120 Mℓ/d and at a much higher TDS concentration.

The observed distribution of residuals was used to generate decay and diffuse load values, since this option should most closely replicate the calibration conditions.

Figure 4.6 shows simulated duration curves of phosphate concentrations at key points in the Blesbokspruit system.

The SA Water quality guidelines do not give a target for phosphate. This is because the development of eutrophication problems is a complex function of factors such as nutrient loading, turbidity, detention time, temperature, etc. In general the Blesbokspruit behaves as a river, although flow velocities drop in some lake and wetland channel reaches. Phosphate loads that would lead to severe algal blooms in a slower moving body of water like Vaal Barrage and the Vaal River impoundments at the North West Water and Sedibeng Water intakes may not cause similar problems in tributaries that have shorter detention times. Given these complexities, the water quality objective of 0.5 mg/l used in the simulation tables and plots is an arbitrary choice and should only be used as a benchmark for comparing one plot with another.

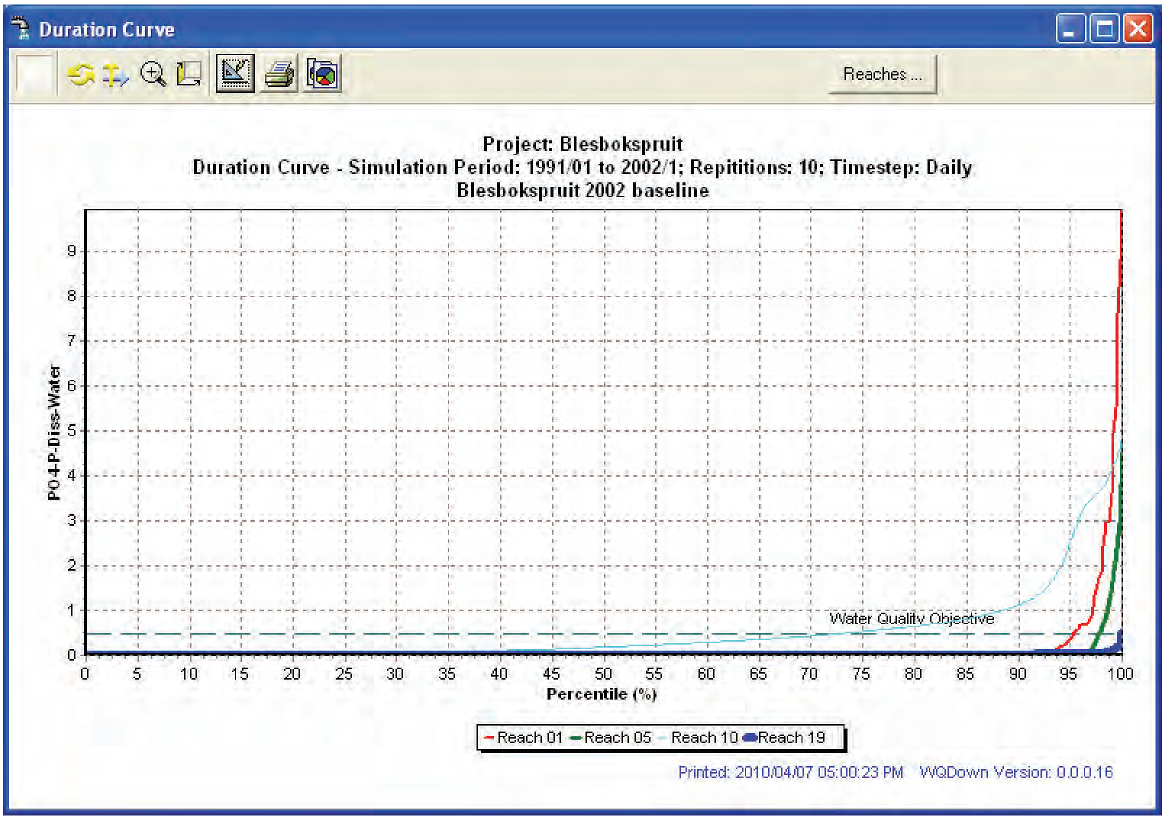


Figure 4.6: Duration curves of phosphate along the Benoni Canal

Figure 4.6 shows that phosphate concentrations remain low for most of the time in Homestead Lake, although high peak concentrations can arise for about 5% of the time and reduce further by the end of channel reach 5. Concentrations rise significantly at the R29 road crossing (end of channel reach 10) below the confluence with the stream below Rynfield Dam and the Victor Penning Bird Sanctuary. This is due to effluent inflows from the Rynfield and JP Marais sewage treatment works (STW). Thereafter phosphate concentrations drop steeply due to the deposition of phosphorus as the flow passes through a chain of wetlands and lakes comprising Geduld Dam, Alexander Dam and Cowles Dam. At the outlet from Cowles Dam at Rand Water monitoring point B9 (channel reach 19) the phosphate concentrations dropped to negligible levels.

Figure 4.7 shows baseline phosphate concentrations in the upper Blesbokspruit between Daveyton and the R555 road crossing at the start of the main part of the Blesbokspruit wetland.

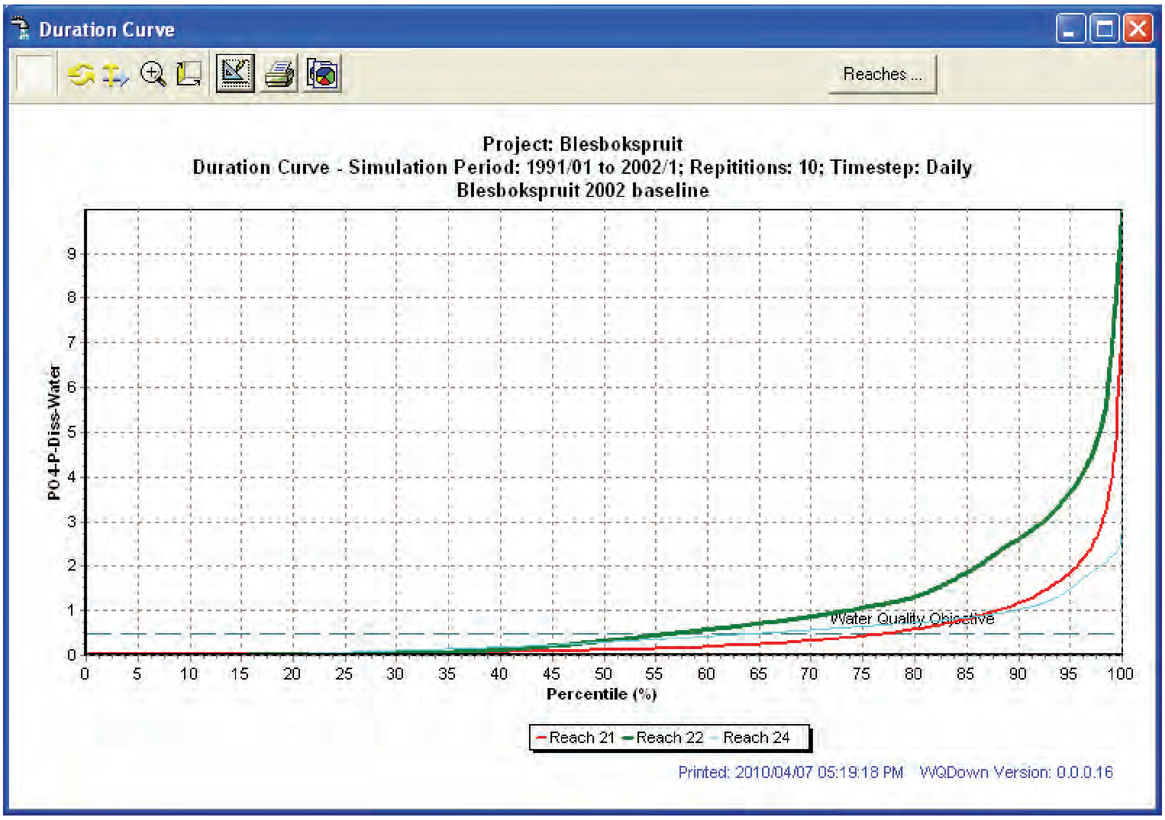
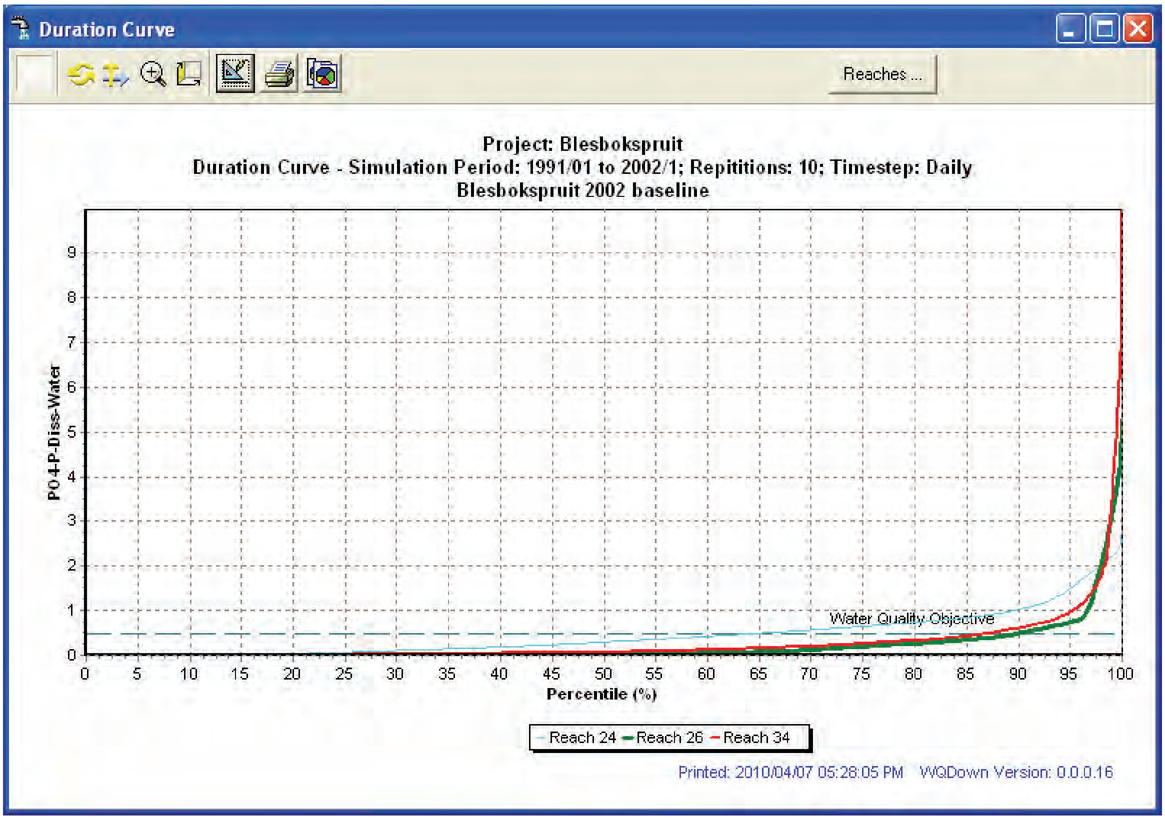


Figure 4.7: Phosphate in the upper Blesbokspruit – Baseline option

Phosphate concentrations start high at the N12 road crossing at the end of channel reach 21. This is due to effluent from the Daveyton STW. There is a distinct increase in concentrations by the end of channel reach 22. There is no point source that can account for this since the calibration period pre-dates discharges from the Welgedacht STW. The increase may be attributable to a diffuse input load of about 65 kg/day entering channel reach 22 (as evidenced by the calibrated diffuse input load tabulated in Appendix C). Phosphate concentrations drop somewhat at the R555 road crossing (end of channel reach 29), partially due to deposition in the reed beds and also due to mixing with the low concentration outflow from Cowles Dam.

Figure 4.8 shows the baseline phosphate concentrations in the Blesbokspruit wetland.



Project: Blesbokspruit
Duration Curve - Simulation Period: 1991/01 to 2002/1; Repititions: 10; Timestep: Daily
Blesbokspruit 2002 baseline

Printed: 2010/04/07 05:28:05 PM WQDown Version: 0.0.0.16

Figure 4.8: Phosphate in the Blesbokspruit wetland – Baseline option

Phosphate concentrations drop appreciably between the R555 road and the Grootvlei mine bridge at the end of channel reach 26, although for about 2% of the time the peak concentrations exceed those at the R555. There is little change until the end of the wetland at the R42 road crossing (end of channel reach 34).

Figure 4.9 shows the simulated phosphate concentrations in the Blesbokspruit from the wetland to the Suikerbosrand weir C2H004.

Figure 4.9 shows remarkably little change in phosphate concentration between the R42 road and weir C2H004 on the lower Suikerbosrand River.

4.4.2 Grootvlei Gold Mine discharge ceases

Appendix D shows the effect on phosphate concentrations of cessation of the discharge from Grootvlei Gold Mine. Grootvlei Gold Mine's underground water is discharged into the head of channel reach 26, so the first point at which the effect can be observed is at the downstream end of this channel reach near the Grootvlei mine bridge.

Figure 4.10 shows duration curves of simulated phosphate concentrations in the Blesbokspruit wetland assuming cessation of the effluent discharge from Grootvlei Gold Mine.

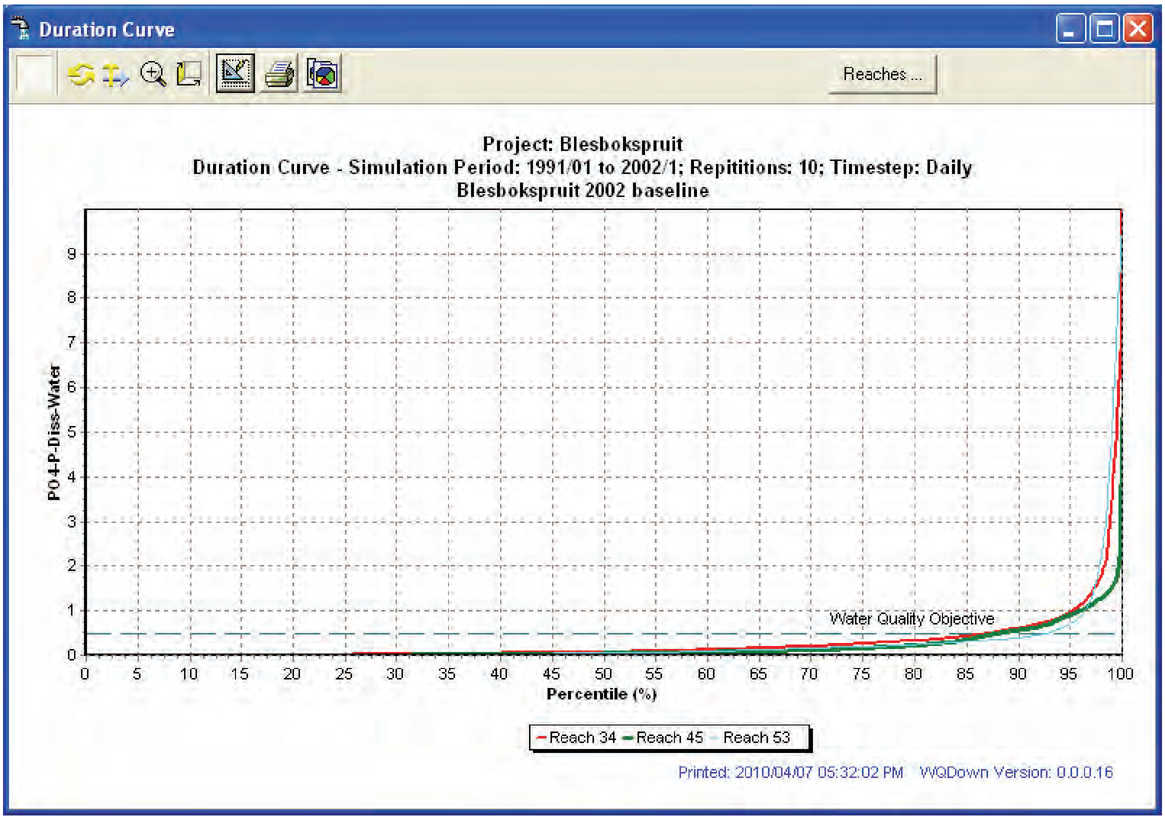


Figure 4.9: Phosphate in the lower Blesbokspruit and Suikerbosrand River – Baseline option

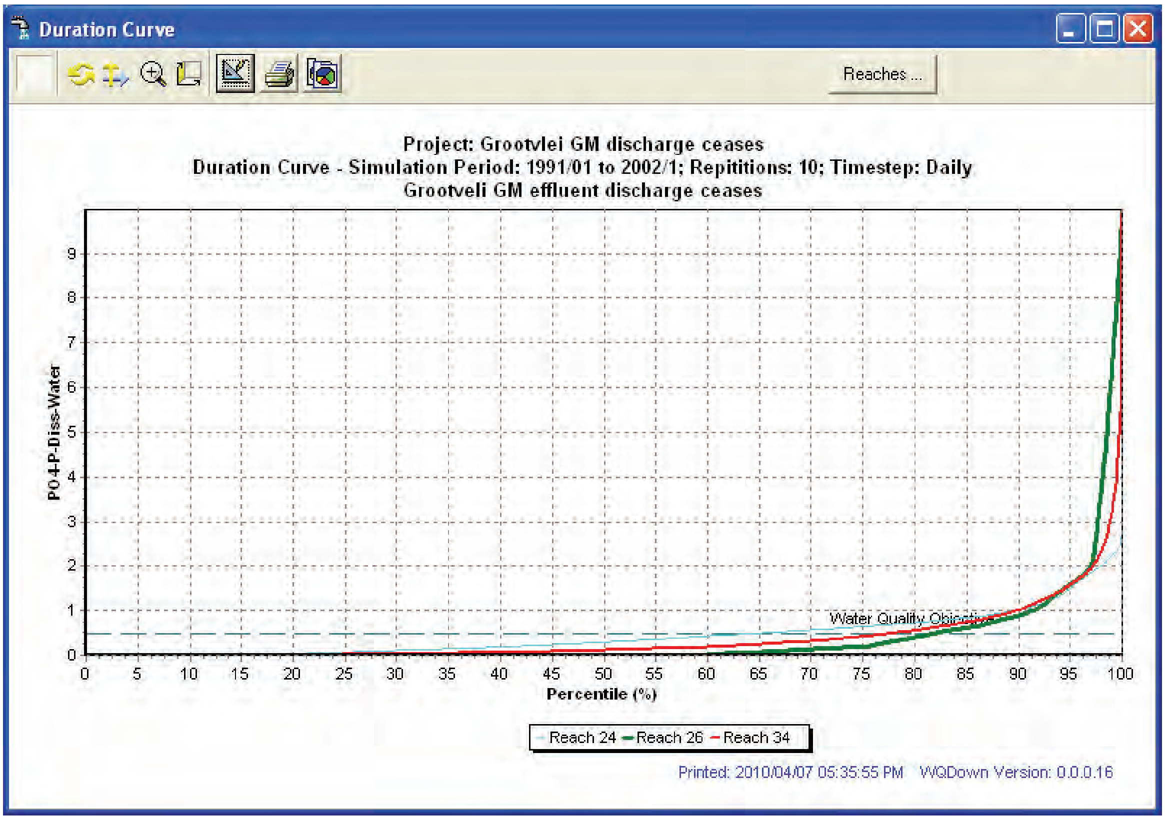


Figure 4.10: Phosphate in the Blesbokspruit wetland – After cessation of discharge from Grootvlei Gold Mine

Figure 4.10 shows more frequent exceedance of the water quality objective at the Grootvlei Mine bridge, with a wider peak concentration tail to the duration curve. The change is mainly attributable to the reduction in dilution afforded by the Grootvlei mine discharge. This may be partially offset by a change in the detention time in the wetland. Similar changes are evident at the R52 road bridge at the lower end of the wetland, although the extreme peaks are of shorter duration.

Figure 4.11 shows duration curves of simulated phosphate concentrations in the Blesbokspruit downstream of the wetland and in the lower Suikerbosrand River.

Similar changes are evident to those in the Blesbokspruit wetland, although the magnitude of the increases is smaller.

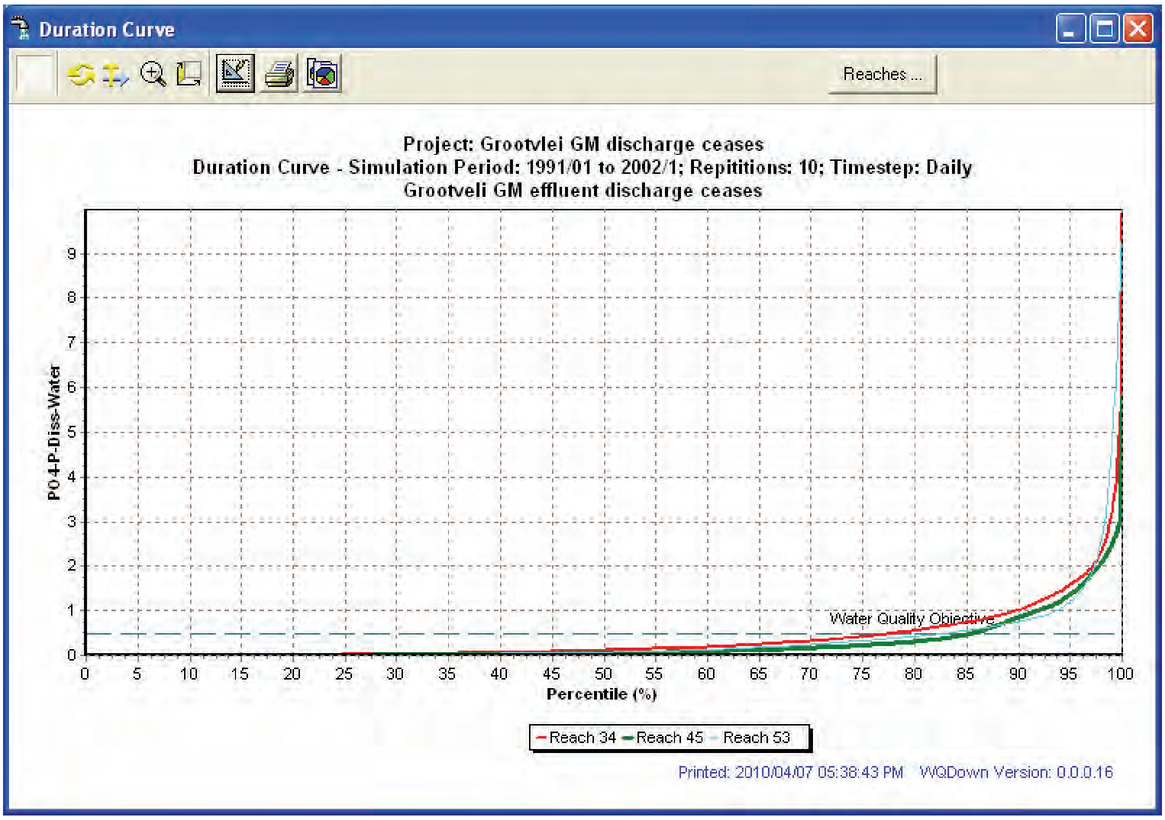


Figure 4.11: Phosphate in the lower Blesbokspruit and Suikerbosrand River – After cessation of discharge from Grootvlei Gold Mine

A comparison between the phosphate concentrations for the Baseline and Grootvlei discharge cessation options is given in Table 4.3.

Table 4.3: Changes in phosphate concentration after cessation of Grootvlei discharge

Channel reach	Option	% time >WQO	Mean	Max.	Percentile			
					95%	90%	75%	50%
26 Grootvlei bridge	Baseline	9.81	0.203	5.28	0.74	0.49	0.20	0.03
	Mine	18.06	0.346	9.99	1.59	0.89	0.20	0.00
	Change	8%	70%	89%	115%	82%	0%	-100%
34 R42 bridge	Baseline	12.58	0.262	9.98	0.97	0.61	0.26	0.08
	Mine	21.84	0.364	9.88	1.58	1.02	0.42	0.12
	Change	9%	39%	-1%	63%	67%	62%	50%
45 B10 weir	Baseline	11.79	0.180	5.31	0.90	0.56	0.16	0.05
	Mine	14.30	0.260	5.80	1.36	0.85	0.23	0.06
	Change	3%	45%	9%	51%	52%	44%	20%
53 C2H004 weir	Baseline	7.34	0.248	9.99	0.71	0.39	0.20	0.06
	Mine	17.11	0.331	9.99	1.20	0.76	0.33	0.08
	Change	10%	34%	0%	69%	95%	65%	33%

This example demonstrates the potential of WQDown for making rapid assessments of the impact of changes in waste discharges on water quality in complex systems.

5. MODEL CAPABILITIES AND LIMITATIONS

It is important to appreciate the capabilities and limitations for the WQDown model. These are discussed below.

5.1 Model capabilities

5.1.1 Rapid initial assessment

WQDown places a powerful tool in the hands of water resource managers to make rapid "what if?" assessments of the impact of a variety of options on the concentrations of non-conservative and conservative pollutants in complex downstream river systems.

5.1.2 User friendly

The model has been designed to be user-friendly so that managers who do not have detailed experience in water quality modelling can apply it. Although it is easy to apply, the underlying technology is complex, taking account of flow processes and the interaction between flow and water quality variable mass balances such as detention time, in-steam decay processes and diffuse source inputs.

5.1.3 Automatic calibration

A particular strength and unique feature of WQDown is that it is a self-calibrating water quality model. The model makes full use of the available water quality records and streamflow data routinely processed by the DWA Directorate of Hydrology. The technique employed to seamlessly naturalise the hydrology is a particularly strong feature. A third unique feature is the method of switching between the calculation of decay values and diffuse input loads and the use of stochastic modelling to sample these values in the simulation mode. Treating the decay and diffuse loads as stochastic elements, rather than the conventional method of running water quality concentrations through a stochastic generator lifts the model from a blind regression process to a tool that can take account of cause and effect.

5.1.4 Assess complex systems using limited data

The model has been tested on an extremely complex and highly developed river system and used to evaluate one of a wide variety of options. The test produced plausible results.

5.2 Model Limitations

5.2.1 Initial evaluation

WQDown is intended as an initial rapid assessment tool. It is not meant to replace more comprehensive models. However, it must be stated that more comprehensive models are impractical to apply in most instances due to their insatiable data requirements. In particular, the application of such models needs to be preceded by detailed hydrological modelling, which due to the study length and cost involved perforce can only be carried out infrequently.

5.2.2 Probabilistic model

WQDown is a hybrid between process modelling with relatively simple decay and stochastic generation. It telescopes all of the complex in-stream processes into simple decay and, where appropriate, diffuse input. As such the model remains agnostic about the type of channel reach (wetland, lake or normal river channel), sedimentation, sediment uptake, organic cycling, etc. All these are covered by a single decay factor calculated for the entire channel reach. It could be argued that this is inferior to detailed modelling that takes account of a host of in-stream processes.

Comprehensive water quality models require the laborious calibration of fixed decay and other parameter values, resulting in compromise values that fail to simulate observed extremes and therefore inevitably under-estimate the observed variance. By contrast WQDown preserves the variance by treating the calculated decay values as a stochastically changing variable that is a feature of each channel reach. The complex inter-relationship between all of the parameters and processes playing a part in the channel reach often defeats complex modelling. This is because extreme water quality events in a real system tend to be dominated by unanticipated events, such as sewer overflows, illegal discharges, temporary biological failure of a sewage works when unexpected slugs of toxic waste enter the sewers, chlorine dosing plant failure and the like. Even the most sophisticated models cannot hope to replicate such semi-stochastic events. However, the characteristics are contained in the river quality data. WQDown uses this information in such a way that the statistical properties are preserved, but also allows a variety of management options to be simulated in a rational way.

The underlying assumption is that the gross dynamics of the channel reach will remain unchanged. If the channel reach characteristics are radically altered, for example if a wetland is canalised or a lake breached, then the decay down the channel reach will also be altered. The model is flexible enough to permit the assigning of a default decay value for the channel reach that corresponds to the characteristics of another water body. So, for example, if a new lake is developed, then the default decay value for a similar lake can be applied to the channel reach and at the same time the earlier water quality data record for the channel reach (if such exists) can be discarded thereby forcing use of the new default value. Then, as more sampling data is accumulated by the regular data collection programme, the old inapplicable data for the channel reach can be replaced by the new data that represents the altered condition. In the case of effluent inputs the current version of the model allows the concentration distribution of an existing effluent source located elsewhere in the system to be used for a proposed new discharge point or an unmonitored old one. This could be extended to assign the decay characteristics of one channel reach to another which would facilitate the generation of more variance in the altered channel reaches.

6. USER MANUAL

A user manual showing the model screens is given in Appendix E.

This manual is intended purely to describe the mechanics of using the model. It does not purport to teach best practice to users.

7. CONCLUSIONS

The following conclusions have been drawn.

7.1 Aims achieved

The aims of the project have been achieved:

- A simple to apply self-calibrating model for rapidly assessing the impact of proposed waste load discharges, or modification of old permits, on river system non-conservative water quality has been provided.

- The model has been calibrated and tested successfully on the highly developed and complex Blesbokspruit catchment.

- The model has been documented.

7.2 Data requirements defined

The data requirements of the WQDown model have been defined and differentiated between the needs for:

- Once-off initial setup by modelling specialists
- Periodic revision of the setup to reflect changing conditions
- Ongoing application by Regional Office and CMA personnel.

All of the data is well within the means of the parties concerned to assimilate from readily available sources.

7.3 Dissemination and application

Incorporation in the DWA's User Support System and associated training of DWA Head Office, Regional Office and CMA staff will ensure that the vast potential benefits of this unique modelling tool are fully realised. Catchments where there is already a pressing need to apply the model have been identified.

7.4 Further research needs

Beneficial research needs have been identified to further facilitate the application of the model.

8. RECOMMENDATIONS

8.1 Dissemination and application

The primary purpose of WQDown is to aid in the evaluation of discharge permits and generally assist in assessing catchment management strategies.

Accordingly the following actions should be put into effect without undue delay.

8.1.1 Incorporate in User Support System

WQDown should be incorporated into the DWA's User Support System (USS) to achieve the following:

- Preserve the model coding
- Provide access to new program versions
- Ensure backup, maintenance and further development
- Facilitate training
- Provide adequate program version control.

8.1.2 Training

Training sessions should be set up to ensure that the new technology is widely disseminated, with special emphasis on the needs of the DWA Head Office, Regional Offices and embryonic CMAs.

A two-pronged approach is envisaged:

- Initial training sponsored by the WRC
- Further training aimed at the DWA regions.

8.1.3 Application

There are immediate areas of application where the model can be used.

8.1.3.1 Blesbokspruit

The Blesbokspruit is the obvious choice for immediate application of the model since the system has already been set up and there are many unanswered questions that need to be addressed.

8.1.3.2 Klip River

The Klip River catchment must be high in the order of priority since this catchment is complex and is the most highly developed in South Africa. Since the model works for the Blesbokspruit there is every reason to expect that it will perform as well, if not better for the Klip River seeing as it is not as dominated by wetlands.

8.1.3.3 Rietspruit

Water quality in the Rietspruit is adversely affected by STWs, informal settlements, conventional urban areas and industries. WQDown could play a useful role in the evaluation of waste load discharge permits and in helping to identify significant pollution sources.

8.1.3.4 Vaal Barrage

The Klip, Suikerbosrand and Riet Rivers are the main sources of pollutant loads entering Vaal Barrage. In addition, there are a number of sources located around Vaal Barrage itself. It is well worth investigating how well WQDown performs on a slow moving body of water like Vaal Barrage. If the results are adequate, then it could provide a means of linking the models for the main tributaries and investigating their impact on Vaal Barrage itself. This would be a particularly important breakthrough since to date non-conservative water quality investigations have had to stop short at the tributary mouths for want of a means of assessing their combined impact on Vaal Barrage.

8.1.3.5 Waterval

The upper Waterval catchment is affected by a number of saline pollution sources. In addition there are a number of STWs and informal settlements that can contribute to non-conservative pollution levels.

8.1.3.6 Mgeni River

Non-conservative pollution is of particular concern due to the preponderance of informal settlements and STWs. Faecal pollution is a particular concern.

8.1.3.7 Crocodile River

The upper Crocodile West catchment is seriously affected by pollution sources, with most of the flow entering the highly eutrophic Hartbeespoort Dam emanating from sewage effluent. WQDown could be applied with effect to the Jukskei River catchment, as well as to other portions the catchment around Pretoria.

8.1.3.8 Mooi River

WQDown could be applied to portions of the Mooi River catchment that are affected by non-conservative pollutant inputs. It may be of only limited use in investigating the effect of radionuclides, since these appear to be dominated by accumulation in sediments, which are not addressed by WQDown.

8.1.4 Rationalise water quality monitoring

Experience gained from the application of WQDown to the Blesbokspruit catchment suggests ways that the regular water quality monitoring programme could be rationalised to better serve the needs of water quality modelling:

- Consistent regular sampling at fewer key points is better than the proliferation of infrequent sampling at many points.

- Sampling at two points located close together serves little purpose unless it is to isolate a significant input load or point source.

- It is much better if all of the samples are collected on the same day.

- If logistical reasons make it necessary to split the sampling programme over two days, then two successive days is best so that the two data sets can be grouped. Moreover, within each day the sampling should proceed in the direction of flow from upstream to downstream to increase the likelihood that the same body of water is tracked through the system. For the same reason the first day's sampling should be at the upstream end of the catchment, followed by the downstream portion the following day.

Sample sizes in the test catchment were found to be remarkably small. For example, the Blesbokspruit calibration period spanned nearly 11 years, during which time a maximum of only 42 samples could be found at any one point on dates when there were enough samples at other monitoring stations to warrant analysis. This is less than 4 samples per year! This means that decades would have to elapse before sufficient data could be accumulated to even get a reliable seasonal distribution, by which time flow and catchment development conditions would have changed considerably, thereby invalidating the seasonal distribution anyway. The radical changes in the flow rate and water quality of the Grootvlei Gold Mine discharge over this period is a case in point (see Section 6.3.1). By contrast the national water quality monitoring system collects weekly samples at several points, which is barely adequate for load calculation. The support of modelling at a smaller catchment scale requires a similar, if not even better, sampling frequency since at the smaller scale flood peaks rise and fall much more rapidly than is the case for bigger catchments. It is clear then that the Regional Office sampling is geared primarily to meet the needs of compliance, rather than modelling. It is doubtful if an effective sampling frequency of less than three months is adequate for this purpose either. Much better use could be made of the much more frequent sampling undertaken by the dischargers in the area, many of whom are required to render returns of their sampling upstream and downstream of their points of discharge. This data should be digitised (preferably obtained from source in digital form) and the data made available for modelling.

8.2 Further research

8.2.1 Automatic convergence of default values

Default decay values are very important since these are used on all occasions when sampling is not available at a station. These important values need to be optimised since they are unknown before the model is used and poor choice of starting values can have a profound influence on the calibration results. For example, on occasions when the downstream concentration exceeds that at the head of the channel reach the decay value is set equal to the default value before calculating the diffuse input load. If this default decay value is too high, the calculated diffuse load could become unrealistically high. This may not be too serious if the channel reach characteristics and the upstream point discharges remain unaltered since the compensating errors between the assumed default decay rate and the diffuse loads will compensate for one another and still produce an acceptable concentration result at the downstream end of the channel reach and hence for the input to the downstream system. However, if the upstream pollutant point input load were to increase the exaggerated decay rate could result in under-estimation of the load passed to the downstream system. Conversely, under estimation of the default decay value would artificially increase the portion of the increased load passed downstream and may also lead to a large diffuse pollution source being overlooked.

A procedure to automatically reset the default decay values based on the average simulated for the available sample points would greatly facilitate this. An automatic procedure would also reduce the likelihood of this important manual procedure being overlooked.

A defined default decay value is used for those channel reaches where there is no water quality monitoring. A procedure to link each such channel reach to one or more gauged channel reaches would facilitate automatic calculation of appropriate default values. (This was done manually for the Blesbokspruit test catchment described in Section 6.)

8.2.2 Include temperature effects

Temperature plays a significant role in in-stream decay processes for variables such as bacteria or viruses. Even water quality variables that do not physically decay (like phosphate), but mimic this process by being removed from the water column by sedimentation and organic uptake, will exhibit seasonal changes related to the density of aquatic growth. While these effects are seasonal in nature, temperature remains a good seasonal indicator. Modelling could therefore be improved by including mean monthly temperature data and including temperature effects in the decay equations. This will not in any way inhibit the automatic calibration procedures that have been developed.

8.2.3 Assign decay distributions to unmonitored channel reaches

At present the decay rates for unmonitored channel reaches are assumed to remain constant at the defined default value. However, a better approach might be to link the unmonitored channel reach to a suitable nearby route that has similar characteristics. In the calibration mode the decay value calculated for the associated channel reach could then be used in place of the default value for dates when data is available for the associated channel reach.

The simplest case would arise when the associated channel reach is solved before (i.e. is located upstream of) the unmonitored channel reach. However the unmonitored channel reach can also lie upstream of the associated monitored channel reach. The general solution procedure therefore requires an iterative process whereby default decay values are first applied to all unmonitored channel reaches to facilitate solving for the downstream channel reaches. The associated decay values at monitored channel reaches would then provide replacements for the default decay values. Iteration would cease when the difference between the successive decay values for all channel reaches are sufficiently close for convergence to have occurred. The decay value statistics for the channel reaches borrowing data from associated monitored channel reaches would then be calculated as if the data were its own. By this means the channel reach would have the required statistical values to compile a decay value distribution to drive stochastic generation in the later simulation mode.

8.2.4 Merge routes for calculating decay values

It often occurs that two water quality monitoring points are separated by more than one channel reaches to accommodate point inputs or river junctions.

For example, in the Blesbokspruit channel reaches 46, 47, 48 and 51 lie between monitoring station B10 at Heidelberg and station C2H070 below the Blesbokspruit-Suikerbosrand confluence (see Figure 6.5). The first three channel reaches are unmonitored, necessitating the use of default decay values. This means that during calibration default values are used for the first two- thirds of the 28 km river length. In addition a further 4 km channel reach of the Suikerbosrand River is situated between monitoring station S1 and the confluence with the Blesbokspruit. Consequently the flow of these two major rivers is first decayed using crude constant default values before the entire remaining error is applied to the calculations for the last channel reach, which can lead to large compensating errors. If, for instance, the default decay values are too large, this will result in decay to an unrealistically low concentration at the head of channel reach 51 that might be lower than the concentration measured at C2H070. This would necessitate the generation of a large diffuse input load to compensate for the unnaturally low concentration at the head of the channel reach. Aside from indicating the presence of a diffuse input that does not really exist, this effectively places a discontinuity between any changes in the water quality upstream of B10 and the values modelled at C2H070. In point of fact there is some evidence of this happening in the study catchment, with over estimation of the decay in unmonitored channel reaches followed by a compensating introduction of a large diffuse load to the last channel reach that has monitored data.

Similar problems arise on occasions when monitoring data is unavailable at some stations, either because they are monitored less frequently, or there are gaps in the record.

Grouping of similar stations along portions of river lengths could facilitate direct calculation of decay values for the entire channel reach. For example the four channel reaches between B10 and C2H070 could be treated as one channel reach for the purpose of calculating a single decay value, with point input flows and loads entering at the nodes for the Heidelberg STW, Ratanda STW and the inflow from the Suikerbosrand River. The decay value applied to all thee channel reaches could then be solved using a suitable iterative solution procedure. However, keeping track of which stations do or do not have data on any given day would greatly complicate the solution procedure.

A much simpler solution is provided by the procedure recommended in Section 8.2.3, which would incidentally cater for this problem for all channel reaches in the system. Recommendations 8.2.3 and 8.2.4 should therefore be addressed together.

8.2.5 Increase simulation speed

Recommendation 9.1.3 will require a number of iterations during the calibration stage. However, currently the model runs much slower than is necessary. This is because:

a) The model writes a great deal of data to output files to facilitate model testing. This can easily be eliminated as the need for further testing is eliminated.
b) The original coding was written in DOS FORTRAN which had severe memory constraints, necessitating the writing of large arrays of data to temporary files, which are again read to facilitate later operations. The translated Delphi code still retains these procedures. This repeated input and output can be eliminated by storing the information that is generated in memory arrays or by writing to memory rather than to slower disk files.
c) Much of the channel reach data is stored in an Access database to preserve project data for future simulations. However, database input/output is rather slow, especially when data is retrieved by individual calls. It should be possible to speed up the processing by reading all of the relevant information from the database in one read statement and storing it in memory arrays for use in smaller chunks as required during the simulation. Similarly, all of the data to be stored permanently can be written to the database in one step once the processing is complete.

8.2.6 Growth in historical catchment development

The current model version assumes constant urban and irrigated areas throughout the calibration period. However, this assumption becomes coarser the longer the calibration period due to growth in catchment development. It is therefore recommended that urban and irrigated areas be specified for breakpoint years with interpolation between them for intermediate years. This is already in place for effluent discharges and point abstractions and should be relatively easy to implement.

8.2.7 Introduce variable seasonal effluent flow

In the simulation mode the assumption is made that effluent discharges and abstractions remain constant. This is consistent with the requirement to simulate conditions at a fixed time horizon and level of development (e.g. present day, a time horizon 10 or 20 years into the future, etc.) In principle this is in keeping with the requirements. However, sewage discharges typically vary with season, being higher in wet weather. It is therefore recommended that a facility be included to use the monthly point discharge and abstraction time series data used during calibration to derive a dimensionless monthly seasonal pattern that can be scaled according to the average point flows specified in the simulation mode.

8.2.8 Track calibration changes

At present the calibration is required to be repeated when the simulation parameters are changed, or if the model is closed after simulation and later restarted. This is to protect against the possibility of some key element being changed between the calibration and simulation steps. However, the changes recommended to the calibration procedure could result in quite long calibrations, especially early on before the default decay values have been optimised.

It is therefore recommended that checks be entered to determine when last the river flow and WMS files and project database were updated and the time and date of the latest calibration run to obviate unnecessary repetition of the calibration step. It is also necessary to ensure that all of the information required for the model simulation step is securely stored in project files after model calibration.

8.2.9 Combine water quality records

It has been observed that the WMS database contains two and sometimes three feature codes for the same monitoring point. Since these split the record over different periods it is important to combine them for the purpose of modelling.

One option is to combine the WMS datasets for the different feature code representing the same point. However, it has been found that once a so-called standard .CSV file generated by the WMS is edited and saved again (purportedly as a .CSV file generated by MS Excel), it no longer has the same file attributes and no longer works in many programs. It is therefore unwise to manually concatenate such files. These files could be concatenated by the DWA and fixed within the WMS. However, this would be a long term process since identifying duplicated stations could be time consuming.

An easier approach that would yield immediate dividends would be to adjust the WQDown coding to allow more than one WMS attribute to be assigned to a channel reach monitoring station or effluent point source.

8.2.10 Sensitivity analyses

Sensitivity analyses are required to determine:

- The desired number of repetitions of the hydrology to ensure convergence during model simulation. The desired number of repetitions would be inversely proportional to the length of the hydrological record and should be smaller when daily flow data is used, as opposed to monthly data. An increased number of monitoring points in series should also help reduce the required number of repetitions.

- The effect that the choice of distribution type (linear, log or observed) has on simulated water quality should also be investigated and compared with the observed to give guidelines on which type of distribution is the most appropriate.

- The model makes provision for the data to be partitioned seasonally. However, the sample sizes available for the calibration period were too small to justify partitioning the data into monthly or even seasonal groupings. Sensitivity analyses should be carried out to determine how seasonality affects the simulation results.

- The problems discussed in sections 8.2.3 and 8.2.4 suggest the need to eliminate small or redundant records, rather than letting them dilute long channel reaches with default values. The effect of eliminating poor records bears investigation.

8.2.11 Relate catchment quality to runoff

The concentration assumed for incremental catchment runoff can affect the modelling of decay rates and diffuse input loads. For example, too low a catchment runoff concentration could result in the calculated concentration at the head of the channel reach being too small. This in turn would result in unrealistically low calculated decay rates and may also result in the need to specify a diffuse input load to compensate for the under-estimate of the catchment runoff contribution. It would be instructive to set a low runoff concentration at points where there is no plausible diffuse source and then regress the resulting diffuse input load values against catchment runoff rate to derive a means of relating catchment runoff quality to catchment flow rate. This could help provide a means of improving the modelling of catchment runoff quality.

It may also be worth while to test the regression of the calibrated decay values against incremental catchment runoff and against in-stream flow rate to try to identify a usable relationship. If such is found, then a regression relationship with flow could be used to reduce the magnitude of the residuals that have to be generated stochastically.

8.2.12 Test other water quality variables

The initial model development and testing has focussed on phosphate. However, a number of other non-conservative pollutants are of concern, including E-coli, ammonia, nitrates, chemical oxygen demand (COD), etc.

These need to be tested as well, although this is probably best linked to the practical application of the model, rather than as an academic exercise (see Section 8.1).

8.2.13 Simulate for exact calibration dates and flow conditions and compare water quality statistics

For complex systems it is difficult to compare the calibration and simulation periods because the latter uses all of the dates for which flow data is available, while the calibration period is restricted to the selected dates for which a large enough number of monitoring station have quality data. The simulation is also for a fixed time horizon, while the calibration period uses observed historical growth in point discharges and abstractions. Therefore checking would be enabled by a facility to run a simulation that exactly replicates the flow conditions of the calibration period, using the identical dates and the corresponding effluent and abstraction discharge rates.

8.2.14 Update WR90 with WR2005 quaternary data

The WQDown database contains mean monthly data derived from the WR90 database for each quaternary of the Vaal Barrage catchment (Midgley *et al*, 1994). This has not yet been populated for other catchments, although this can be done relatively easily. There is merit in updating the database with the more recent WR2005 data (Middleton and Bailey, 2009). However, this is not critical since the extra 15 years of hydrological data may not change the mean monthly values too drastically. And even where they do it should have little effect on the WQDown results since the mean monthly quaternary data is used only to make a first approximation of incremental channel reach runoff, which is adjusted to match the observed flow at the reference gauge anyway.

What could be more important are the PU values (see Table 6.1) that define the proportion of the rainfall on paved surfaces that is assumed to give rise to urban runoff. These values were derived for all of the quaternary catchments of the Vaal River primary catchment for use in the WQ2000 model (Herold and Le Roux, 2004). This required simulation of the WRSM2000 model (Pitman et al, 2007) for each quaternary catchment assuming a unit urban area. Populating this data for catchments other the then Vaal River would require additional hydrological modelling. However, the output could be used in WQ2000 as well as in WQDown.

8.2.15 Incorporate multiple flow gauges

The present system makes use of only one flow gauge in the study catchment. However, the Blesbokspruit catchment has another flow gauging station at B10 near Heidelberg and the earlier records could also benefit from flow gauging at C2H070 (which has since been washed away). The algorithms could be modified to allow more than one flow gauge.

However, this would require some care since one or more of the flow gauges can be out of operation at any time, thereby complicating the modelling procedure.

8.2.16 Effect of storage

WQDown is not a dynamic model. Hence it assumes steady state flow conditions during each selected sampling date. However, when the detention time exceeds the sampling frequency, the water quality observed at the outlet could originate from upstream loads that entered the head of the channel reach during previous sampling dates. These effects might bear investigation for large storage elements such as urban lakes.

8.2.17 Integrate with WMS

When the project commenced the intention was to eventually integrate WQDown into the DWA's WMS system. This could still be investigated, although there are also good reasons to run WQDWN as a stand alone model that uses WMS data files as one of many other data input sources.

9. REFERENCES

Allen, RB and Herold, CE, (1988). *Water quality modelling Volume A: Water quality calibration model. Vaal River System Analysis.* DWA Report P C000/00/7086. BKS report to Directorate of Planning, Department of Water Affairs, Pretoria.

Heath, R and Herold, CE (2007). *Business analysis for a simple model to assess management scenarios.* Business support for water quality planning systems. Report by PDNA to Water Resources Planning Systems, Department of Water Affairs and Forestry, Pretoria.

Herold, CE and Le Roux, PJ (2004). *WQ2000: Development of an interactive surface water quality information and evaluation system for South Africa.* WRC Report No. 950/1/04, Water Research Commission, Pretoria.

Middleton, BJ and Bailey, AK (2009). Water resources of South Africa, 2005 study (WR2005). Report TT 380/08. Water Research Commission, Pretoria.

Midgley, DC, Pitman, WV and Middleton, BJ (1994). *Surface water resources of South Africa 1990.* WRC Report 298/1/94. Water Research Commission, Pretoria.

Pitman, WV, Kakebeeke, JP and Bailey, AK (2007): *WRSM2000 (Enhanced): Water Resources Simulation model for windows: User Manual*, June 2007.

APPENDIX A

WQDOWN SUBROUTINES

A.1 NESTING OF SUBROUTINES

Figure A.1 shows the nesting of the main computational subroutines used in WQDown.

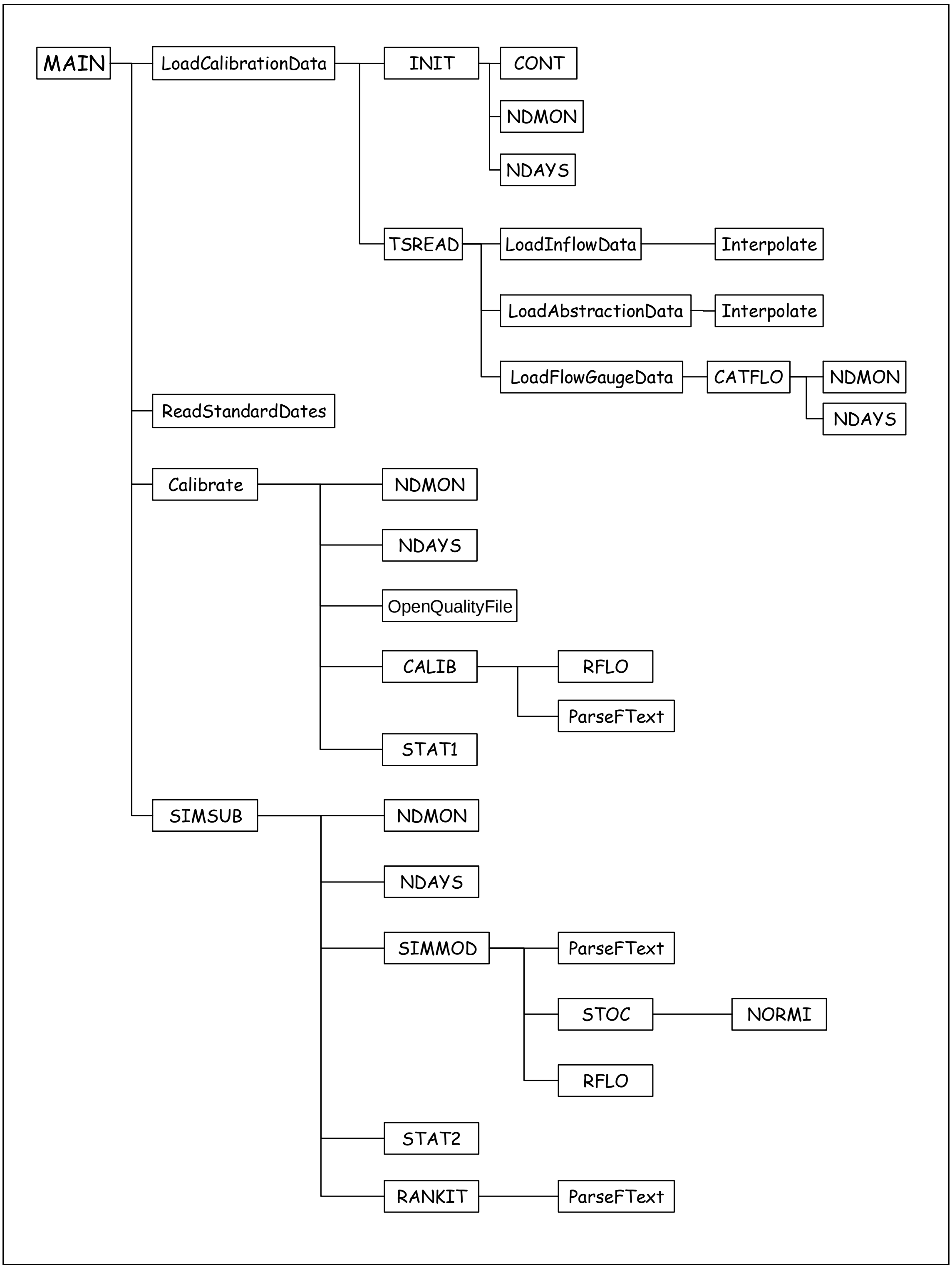


Figure A.1: WQDown – nesting of subroutines

A.2 DESCRIPTION OF SUBROUTINES

The main subroutines are described below.

MAIN

This is the main program to which the subroutines are linked.

LoadCalibrationData

Carries out initial checks on the input data and controls data initialisation process.

INIT

INIT controls initialisation of the program, including defining channel reach linkages and attributes.

CONT

Calculates reach solution order, determines how many reaches are upstream of each reach and the upstream reach numbers

NMON

Calculate the number of days in the month.

NDAYS

Calculate the number of days from the start of a reference year to a specified date and time.

TSREAD

Reads time series flow data.

LoadInflowData

Load monthly effluent flow data from database for the simulation period.

Interpolate

Carry out linear or power interpolation between specified effluent flow or abstraction break point values.

LoadAbstractionData

Load monthly abstraction data from database.

LoadGaugeData

Load observed flow gauge data from file.

CATFLO

Calculate incremental catchment flows to each channel reach.

Calibrate

Calibrate on historical flow and water quality data.

ReadStandardDates

Assists user to select standard dates to be used in the model calibration

OpenQualityFile

Reads water quality data from .CSV files generated by the DWA’s WMS system.

CALIB

This is the main calibration loop that extracts channel reach flow data, checks for missing observed river flow and water quality data. Channel reach decay values and diffuse input loads are calculated and statistical values are accumulated for each channel reach.

RFLO

This calculates the concentration at the head of a channel reach and solves for the channel reach flows and detention time.

ParseFText

Parses a line of text read from a file into model variables.

STAT1

Calculate statistics for calibration period

SIMSUB

This is the main simulation routine. The simulation start and end dates and number of repetitions are set along with the attributes for each channel reach that define the simulation option. Te simulation loops are controlled. The simulation results are stored.

SIMMOD

This subroutine calculates channel reach flows for the defined simulation conditions. Downstream concentrations are calculated using stochastically generated decay values and diffuse input loads. Statistical values are accumulated.

STOC

STOC sample stochastic point inflow concentrations, decay values and diffuse input loads. These can be based on linear or log normalised distributions or on the observed distribution.

NORMI

NORMI generates a normalised random number from specified random number.

STAT2

STAT2 calculates simulation statistics.

RANKIT

Ranks simulated concentrations for each channel reach and calculates percentile values.

PERC

APPENDIX B

WQDOWN CALIBRATION RESULTS FOR BLESBOKSPRUIT

WQDown - Umfula Wempilo Consulting

Blesbokspruit

Reach Calibration Results

Page 1
Date: 2010/03/09

Water quality variable: PO4-P-Diss-Water
Calibration period: 1991/01 to 2002/01 for months January to December

Reach No	Reach Name	Decay Values Sample Size	Diffuse Load Sample Size	Decay Value [/day] Average	Decay Value [/day] StdDev.	Decay Value [/day] COV	Diffuse Input Load Average	Diffuse Input Load StdDev.	Diffuse Input Load COV	Log of Decay Value Average	Log of Decay Value StdDev.	Log of Decay Value COV	Log of Diffuse Input Load Average	Log of Diffuse Input Load StdDev.	Log of Diffuse Input Load COV
01	Homestead Lake	15	7	0.0418	0.0773	1.8491	2414	5100	2.1132	-6.01873	4.41188	-0.73302	-0.50524	8.02278	-15.87922
02	Kleinfontein Lake			0.0371	0.0000	0.0000	-1	0	0.0000	-3.29549	0.00000	0.00000	-1.00000	0.00000	0.00000
03	Stream from Benoni STW			2.4763	0.0000	0.0000	-1	0	0.0000	0.90677	0.00000	0.00000	-1.00000	0.00000	0.00000
04	Benoni canal above Snake Road	25	5	27.6001	18.8397	0.6826	95800	164468	1.7168	2.95849	1.12755	0.38112	10.02795	1.93755	0.19321
05	Benoni Canal			2.4763	0.0000	0.0000	-1	0	0.0000	0.90677	0.00000	0.00000	-1.00000	0.00000	0.00000
06	Van Ryn Dam	1	15	0.0323	0.0000	0.0000	10172	33225	3.2663	-3.43415	0.00000	0.00000	4.53874	6.13827	1.35241
07	VPBS	6	21	0.1644	0.1964	1.1946	72361	62420	0.8626	-2.41818	1.19786	-0.49536	10.89663	0.77226	0.07087
08	Below Victor Penning Bird Sanctuary			2.4763	0.0000	0.0000	-1	0	0.0000	0.90677	0.00000	0.00000	-1.00000	0.00000	0.00000
09	Below JP Marais STW			2.4763	0.0000	0.0000	-1	0	0.0000	0.90677	0.00000	0.00000	-1.00000	0.00000	0.00000
10	Wetland - R29 bridge	16	16	2.4104	2.3087	0.9578	95337	111063	1.1649	0.28851	1.32265	4.58447	10.85703	1.21400	0.11182
11	Below R29 road bridge			2.4763	0.0000	0.0000	-1	0	0.0000	0.90677	0.00000	0.00000	-1.00000	0.00000	0.00000
12	Jan Smuts Lake			0.0371	0.0000	0.0000	-1	0	0.0000	-3.29549	0.00000	0.00000	-1.00000	0.00000	0.00000
13	from Jan Smuts Lake			2.4763	0.0000	0.0000	-1	0	0.0000	0.90677	0.00000	0.00000	-1.00000	0.00000	0.00000
14	Benoni canal: wetland below R29			2.4763	0.0000	0.0000	-1	0	0.0000	0.90677	0.00000	0.00000	-1.00000	0.00000	0.00000
15	Geduld Dam	3	19	0.0789	0.0727	0.9215	33206	72806	2.1926	-3.28464	1.91026	-0.58157	8.91523	1.59463	0.17887
16	Alexander Dam			0.1435	0.0000	0.0000	-1	0	0.0000	-1.94142	0.00000	0.00000	-1.00000	0.00000	0.00000
17	Enstra Road		4	2.4763	0.0000	0.0000	31947	58789	1.8402	0.90677	0.00000	0.00000	8.70132	2.06402	0.23721
18	Cowles Dam upper			0.1435	0.0000	0.0000	-1	0	0.0000	-1.94142	0.00000	0.00000	-1.00000	0.00000	0.00000
19	Cowles Dam	1		0.2371	0.0000	0.0000	-1	0	0.0000	-1.43912	0.00000	0.00000	-1.00000	0.00000	0.00000
20	Wetland below Cowles Dam			0.9071	0.0000	0.0000	-1	0	0.0000	-0.09750	0.00000	0.00000	-1.00000	0.00000	0.00000
21	Blesbokspruit: Daveyton to N12		2	0.9071	0.0000	0.0000	43670	10325	0.2364	-0.09750	0.00000	0.00000	10.67025	0.23867	0.02237
22	Blesbokspruit	3	27	0.9250	0.8516	0.9206	65392	73302	1.1210	-0.99591	2.23137	-2.24053	10.67372	0.89486	0.08384
23	Blesbokspruit: below Welgedacht			0.9071	0.0000	0.0000	-1	0	0.0000	-0.09750	0.00000	0.00000	-1.00000	0.00000	0.00000
24	Blesbokspruit wetland: Confluence	15	25	4.4182	4.8901	1.1068	113538	71916	0.6334	0.71144	1.44792	2.03519	11.48091	0.56025	0.04880

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Blesbokspruit

Reach Calibration Results

Reach No	Reach Name	Decay Values Sample Size	Diffuse Load Sample Size	Decay Value [/day] Average	Decay Value [/day] StdDev.	Decay Value [/day] COV	Diffuse Input Load Average	Diffuse Input Load StdDev.	Diffuse Input Load COV	Log of Decay Value Average	Log of Decay Value StdDev.	Log of Decay Value COV	Log of Diffuse Input Load Average	Log of Diffuse Input Load StdDev.	Log of Diffuse Input Load COV
	to R555														
25	Blesbokspruit wetland: R555 to Grootvlei HDS			3.5217	0.0000	0.0000	-1	0	0.0000	1.25894	0.00000	0.00000	-1.00000	0.00000	0.00000
26	Blesbokspruit wetland: Grootvlei GM to GMB	5	22	2.6554	2.0164	0.7594	103655	154133	1.4870	0.53338	1.25523	2.35335	10.86979	1.19808	0.11022
27	Wetland: Grootvlei bridge to Klein Blesbokspruit			3.5217	0.0000	0.0000	-1	0	0.0000	1.25894	0.00000	0.00000	-1.00000	0.00000	0.00000
28	Klein Blesbok	19	9	177.8278	739.0889	4.1562	3879981	4457934	1.1490	1.76112	2.63701	1.49735	14.71545	0.98029	0.06662
29	Klein Blesbokspruit			3.5217	0.0000	0.0000	-1	0	0.0000	1.25894	0.00000	0.00000	-1.00000	0.00000	0.00000
30	Blesbokspruit wetland: Klein Blesbok to R29	6	22	30.0527	18.5025	0.6157	202951	368902	1.8177	3.16531	0.86438	0.27308	11.34544	1.37816	0.12147
31	Blesbokspruit wetland: R29 to N17	2	3	1.6344	2.3114	1.4142	154345	163252	1.0577	-2.86167	5.72203	-1.99954	11.55509	1.07790	0.09328
32	Blesbokspruit wetland: N17 to Daggafontein	9	18	0.4763	0.3086	0.6480	52464	82171	1.5662	-1.10717	1.17863	-1.06454	10.11503	1.22977	0.12158
33	Blesbokspruit wetland: Marivale Bird Sanctuary	15	16	0.2003	0.5331	2.6616	291398	878962	3.0164	-5.90980	5.30949	-0.89842	10.77390	1.57387	0.14608
34	Blesbokspruit: wetland below MBS to R42	19	21	0.2621	0.4721	1.8015	40716	49055	1.2048	-3.36363	2.68432	-0.79804	9.73727	1.48094	0.15209
35	Blesbokspruit: R42 to R51 bridges	12	7	2.9782	5.3031	1.7806	45064	32921	0.7305	-1.81771	3.91739	-2.15512	10.47340	0.77542	0.07404
36	Blesbokspruit below R51			4.3629	0.0000	0.0000	-1	0	0.0000	1.47314	0.00000	0.00000	-1.00000	0.00000	0.00000
37	Nigel Dam			4.3629	0.0000	0.0000	-1	0	0.0000	1.47314	0.00000	0.00000	-1.00000	0.00000	0.00000
38	Stream below Nigel Dam			4.3629	0.0000	0.0000	-1	0	0.0000	1.47314	0.00000	0.00000	-1.00000	0.00000	0.00000
39	Blesbokspruit above Noycedale	4	28	30.6511	14.7101	0.4799	192500	637228	3.3103	3.31274	0.57916	0.17483	10.45590	1.57717	0.15084
40	Blesbokspruit: Noycedale to H Bickley STW			3.3349	0.0000	0.0000	-1	0	0.0000	1.20444	0.00000	0.00000	-1.00000	0.00000	0.00000
41	Blesbokspruit: H Bickley STW to Poort	23	19	3.5607	3.0605	0.8595	731677	2945379	4.0255	0.84806	1.00804	1.18864	10.45620	1.76126	0.16844
42	Blesbokspruit: Poortjie to Kaydalespruit confluenc			4.3629	0.0000	0.0000	-1	0	0.0000	1.47314	0.00000	0.00000	-1.00000	0.00000	0.00000
43	Kyadalespruit	20	22	1.8893	1.0153	0.5374	43930	49625	1.1296	0.41092	0.93599	2.27779	10.03219	1.26530	0.12612

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Blesbokspruit

Reach Calibration Results

Reach No	Reach Name	Decay Values Sample Size	Diffuse Load Sample Size	Decay Value [/day] Average	Decay Value [/day] StdDev.	Decay Value [/day] COV	Diffuse Input Load Average	Diffuse Input Load StdDev.	Diffuse Input Load COV	Log of Decay Value Average	Log of Decay Value StdDev.	Log of Decay Value COV	Log of Diffuse Input Load Average	Log of Diffuse Input Load StdDev.	Log of Diffuse Input Load COV
44	Kaydalespruit: Bridge to Blesbokspruit			1.8893	0.0000	0.0000	-1	0	0.0000	0.63621	0.00000	0.00000	-1.00000	0.00000	0.00000
45	Blesbokspruit: |Kaydalespruit to B10	10	18	6.3312	6.5120	1.0286	156960	166226	1.0590	1.36720	1.04066	0.76117	11.26220	1.37292	0.12191
46	Blesbokspruit: B10 to Heidelberg STW			4.3629	0.0000	0.0000	-1	0	0.0000	1.47314	0.00000	0.00000	-1.00000	0.00000	0.00000
47	Blesbokspruit: Heidelberg STW to Ratanda STW			4.3629	0.0000	0.0000	-1	0	0.0000	1.47314	0.00000	0.00000	-1.00000	0.00000	0.00000
48	Blesbokspruit			4.3629	0.0000	0.0000	-1	0	0.0000	1.47314	0.00000	0.00000	-1.00000	0.00000	0.00000
49	Suikerbosrand River	16	17	3.2774	2.9904	0.9124	181896	538949	2.9629	-1.20019	4.01337	-3.34395	10.22303	1.95392	0.19113
50	Suikerbosrand River: S1 to Blesbokspruit confluenc			3.2774	0.0000	0.0000	-1	0	0.0000	1.18705	0.00000	0.00000	-1.00000	0.00000	0.00000
51	Suikerbosrand River: Blesbokspruit to C2H070	8	34	3.9925	2.5409	0.6364	172658	291826	1.6902	1.13954	0.84993	0.74586	11.19089	1.35740	0.12129
52	Suikerbosrand: C2H070 to Badfontein	11	3	2.1129	1.4125	0.6685	151525	199740	1.3182	0.51274	0.75420	1.47091	11.28249	1.36062	0.12060
53	Suikerbosrand River: Badfontein to C2H004	8	42	4.8260	6.2220	1.2893	167941	675952	4.0249	0.76150	1.58657	2.08346	10.12206	1.75976	0.17385
54	Suikerbosrand River		1	3.5568	0.0000	0.0000	128793	0	0.0000	1.26886	0.00000	0.00000	11.76597	0.00000	0.00000

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Blesbokspruit

Point Inflow Calibration Results

Date: 2010/03/09

Water quality variable: PO4-P-Diss-Water
Calibration period: 1991/01 to 2002/01 for months January to December

Reach No	Point Inflow Name	Sample Size	Point Concentration Average	Point Concentration StdDev.	Point Concentration COV	Log of Point Concentration Average	Log of Point Concentration StdDev.	Log of Point Concentration COV
03	Benoni (177781)	1	0.450	0.000	0.00000	-0.79851	0.00000	0.00000
07	Rynfield (179050)	1214	1.205	1.474	1.22373	-0.55844	1.41390	-2.53187
09	JP Marais (179054)	1250	0.894	1.393	1.55726	-1.04231	1.56194	-1.49854
12	Jan Smuts (88793)	2029	1.034	2.527	2.44422	-0.45404	0.95709	-2.10796
18	Sappi HDS (179287)	0	-1.000	0.000	0.00000	-1.00000	0.00000	0.00000
19	Sappi AL (88724)	38	0.361	0.382	1.05569	-1.53512	1.19366	-0.77757
20	McComb (88569)	1163	2.289	1.129	0.49328	0.58052	0.89406	1.54009
21	Daveyton (179049)	1172	0.877	1.804	2.05720	-1.22924	1.45377	-1.18266
26	Grootvlei GM (177815	49	0.118	0.230	1.94081	-2.81895	0.99859	-0.35424
28	Anchor (179051)	1243	0.528	0.793	1.50356	-1.10553	1.01730	-0.92019
37	Grunding	1	0.600	0.000	0.00000	-0.51083	0.00000	0.00000
41	H Bickley (179052)	874	1.715	21.823	12.72499	-0.73726	1.34267	-1.82117
43	Tskane (179048)	608	0.240	0.217	0.90404	-1.80481	0.87753	-0.48622
47	Heidelberg (88777)	1512	0.565	1.113	1.97084	-1.31695	1.15712	-0.87864
48	Ratanda (100000759)	70	0.654	1.881	2.87776	-1.60952	1.34443	-0.83530

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Blesbokspruit

Reach Calibration Results

Reach No	Reach Name	Decay Values Sample Size	Diffuse Load Sample Size	Decay Value [/day] Average	Decay Value [/day] StdDev.	Decay Value [/day] COV	Diffuse Input Load Average	Diffuse Input Load StdDev.	Diffuse Input Load COV	Log of Decay Value Average	Log of Decay Value StdDev.	Log of Decay Value COV	Log of Diffuse Input Load Average	Log of Diffuse Input Load StdDev.	Log of Diffuse Input Load COV
44	Kaydalespruit: Bridge to Blesbokspruit			1.8893	0.0000	0.0000	-1	0	0.0000	0.63621	0.00000	0.00000	-1.00000	0.00000	0.00000
45	Blesbokspruit: |Kaydalespruit to B10	10	18	6.3312	6.5120	1.0286	156960	166226	1.0590	1.36720	1.04066	0.76117	11.26220	1.37292	0.12191
46	Blesbokspruit: B10 to Heidelberg STW			4.3629	0.0000	0.0000	-1	0	0.0000	1.47314	0.00000	0.00000	-1.00000	0.00000	0.00000
47	Blesbokspruit: Heidelberg STW to Ratanda STW			4.3629	0.0000	0.0000	-1	0	0.0000	1.47314	0.00000	0.00000	-1.00000	0.00000	0.00000
48	Blesbokspruit			4.3629	0.0000	0.0000	-1	0	0.0000	1.47314	0.00000	0.00000	-1.00000	0.00000	0.00000
49	Suikerbosrand River	16	17	3.2774	2.9904	0.9124	181896	538949	2.9629	-1.20019	4.01337	-3.34395	10.22303	1.95392	0.19113
50	Suikerbosrand River: S1 to Blesbokspruit confluenc			3.2774	0.0000	0.0000	-1	0	0.0000	1.18705	0.00000	0.00000	-1.00000	0.00000	0.00000
51	Suikerbosrand River: Blesbokspruit to C2H070	8	34	3.9925	2.5409	0.6364	172658	291826	1.6902	1.13954	0.84993	0.74586	11.19089	1.35740	0.12129
52	Suikerbosrand: C2H070 to Badfontein	11	3	2.1129	1.4125	0.6685	151525	199740	1.3182	0.51274	0.75420	1.47091	11.28249	1.36062	0.12060
53	Suikerbosrand River: Badfontein to C2H004	8	42	4.8260	6.2220	1.2893	167941	675952	4.0249	0.76150	1.58657	2.08346	10.12206	1.75976	0.17385
54	Suikerbosrand River		1	3.5568	0.0000	0.0000	128793	0	0.0000	1.26886	0.00000	0.00000	11.76597	0.00000	0.00000

APPENDIX C

WQDOWN SIMULATION RESULTS FOR BLESBOKSPRUIT BASELINE CONDITION

WQDown - Umfula Wempilo Consulting

Blesbokspruit

Reach Simulation Results

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Water Quality Variable: PO4-P-Diss-Water
Calibration Period: 1991/01 to 2002/01 for months January to December
Simulation Period: 1991/01 to 2002/1
Number of Repitions: 10
Simulation Time Step: Daily
Water Quality Objective: 0.50
Scenario Name: Baseline

Reach No.	Upstream Urban Area (km²)	Lateral Urban Area (km²)	Upstream Irrigation Area (km²)	Abstraction (m³/day)	Point Discharge (m³/day)	Point Source Concentration Average (mg/l)	Point Source Concentration Coefficient of Variation	Point Source Concentration Reference Reach	Point Source Quality Residual Calculation Type	Decay Value Residual Calculation Type	Diffuse Load Residual Calculation Type
01	20	4	0	0	0	0.0000	0.0000	**01**	Observed	Observed	Observed
02	0	11	0	0	0	0.0000	0.0000	**02**	Observed	Observed	Observed
03	0	0	0	0	9065	0.4500	0.0000	**03**	Observed	Observed	Observed
04	0	0	0	0	0	0.0000	0.0000	**04**	Observed	Observed	Observed
05	0	0	0	0	0	0.0000	0.0000	**05**	Observed	Observed	Observed
06	12	0	0	0	0	0.0000	0.0000	**06**	Observed	Observed	Observed
07	0	1	0	0	7129	1.2047	**-2.5319**	**07**	Observed	Observed	Observed
08	0	0	0	0	0	0.0000	0.0000	**08**	Observed	Observed	Observed
09	3	0	0	0	24839	0.8942	**-1.4985**	**09**	Observed	Observed	Observed
10	0	4	0	0	0	0.0000	0.0000	**10**	Observed	Observed	Observed
11	0	0	0	0	0	0.0000	0.0000	**11**	Observed	Observed	Observed
12	10	1	0	0	7774	1.0337	**-2.1080**	**12**	Observed	Observed	Observed
13	0	2	0	0	0	0.0000	0.0000	**13**	Observed	Observed	Observed
14	0	0	0	800	0	0.0000	0.0000	**14**	Observed	Observed	Observed
15	0	0	0	0	0	0.0000	0.0000	**15**	Observed	Observed	Observed
16	0	3	0	0	0	0.0000	0.0000	**16**	Observed	Observed	Observed
17	0	1	0	0	0	0.0000	0.0000	**17**	Observed	Observed	Observed
18	0	0	0	0	25800	0.3615	-0.7776	**19**	Observed	Observed	Observed

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Blesbokspruit

Reach Simulation Results

Reach No.	Upstream Urban Area (km²)	Lateral Urban Area (km²)	Upstream Irrigation Area (km²)	Abstraction (m³/day)	Point Discharge (m³/day)	Point Source Concentration Average (mg/l)	Point Source Concentration Coefficient of Variation	Point Source Concentration Reference Reach	Point Source Quality Residual Calculation Type	Decay Value Residual Calculation Type	Diffuse Load Residual Calculation Type
19	0	0	0	0	0	0.3615	**-0.7776**	**19**	Observed	Observed	Observed
20	0	0	0	0	9677	2.2886	**1.5401**	**20**	Observed	Observed	Observed
21	18	1	1	0	20968	0.8770	**-1.1827**	**21**	Observed	Observed	Observed
22	0	2	0	0	0	0.0000	0.0000	**22**	Observed	Observed	Observed
23	0	0	0	0	0	0.0000	0.0000	**23**	Observed	Observed	Observed
24	0	0	0	0	0	0.0000	0.0000	**24**	Observed	Observed	Observed
25	0	7	0	0	0	0.0000	0.0000	**25**	Observed	Observed	Observed
26	0	0	0	0	120000	0.1183	**-0.3542**	**26**	Observed	Observed	Observed
27	0	0	0	0	0	0.0000	0.0000	**27**	Observed	Observed	Observed
28	22	0	0	0	28194	0.5275	**-0.9202**	**28**	Observed	Observed	Observed
29	0	0	0	0	0	0.0000	0.0000	**29**	Observed	Observed	Observed
30	0	0	0	0	0	0.0000	0.0000	**30**	Observed	Observed	Observed
31	0	0	0	0	0	0.0000	0.0000	**31**	Observed	Observed	Observed
32	0	0	0	5800	0	0.0000	0.0000	**32**	Observed	Observed	Observed
33	0	2	2	0	0	0.0000	0.0000	**33**	Observed	Observed	Observed
34	0	1	0	0	0	0.0000	0.0000	**34**	Observed	Observed	Observed
35	0	0	1	0	0	0.0000	0.0000	**35**	Observed	Observed	Observed
36	0	0	0	0	0	0.0000	0.0000	**36**	Observed	Observed	Observed
37	9	3	0	0	2581	0.6000	0.0000	**37**	Observed	Observed	Observed
38	0	2	0	0	0	0.0000	0.0000	**38**	Observed	Observed	Observed
39	0	5	0	0	0	0.0000	0.0000	**39**	Observed	Observed	Observed
40	0	0	0	0	0	0.0000	0.0000	**40**	Observed	Observed	Observed
41	0	0	0	0	10323	1.7150	**-1.8212**	**41**	Observed	Observed	Observed
42	0	0	0	0	0	0.0000	0.0000	**42**	Observed	Observed	Observed

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Blesbokspruit

Reach Simulation Results

Reach No.	Upstream Urban Area (km²)	Lateral Urban Area (km²)	Upstream Irrigation Area (km²)	Abstraction (m³/day)	Point Discharge (m³/day)	Point Source Concentration Average (mg/l)	Point Source Concentration Coefficient of Variation	Point Source Concentration Reference Reach	Point Source Quality Residual Calculation Type	Decay Value Residual Calculation Type	Diffuse Load Residual Calculation Type
43	5	4	0	0	9355	0.2405	**-0.4862**	**43**	Observed	Observed	Observed
44	0	0	0	0	0	0.0000	0.0000	**44**	Observed	Observed	Observed
45	0	6	2	0	0	0.0000	0.0000	**45**	Observed	Observed	Observed
46	0	3	0	0	0	0.0000	0.0000	**46**	Observed	Observed	Observed
47	0	2	3	0	5161	0.5650	**-0.8786**	**47**	Observed	Observed	Observed
48	0	0	3	0	2903	0.6536	**-0.8353**	**48**	Observed	Observed	Observed
49	8	0	0	0	0	0.0000	0.0000	**49**	Observed	Observed	Observed
50	0	0	0	0	0	0.0000	0.0000	**50**	Observed	Observed	Observed
51	0	0	0	0	0	0.0000	0.0000	**51**	Observed	Observed	Observed
52	0	0	12	0	0	0.0000	0.0000	**52**	Observed	Observed	Observed
53	0	0	0	0	0	0.0000	0.0000	**53**	Observed	Observed	Observed
54	0	5	0	0	0	0.0000	0.0000	**54**	Observed	Observed	Observed

Non-default values for Point Source Concentration Coefficient of Variation and Point Source Concentration Reference Reach are indicated in bold.

Reach No.	% Time WQO Exceeded	Mean	Standard Deviation	Percentile (%)								
				Max	95	90	75	50	25	10	5	Min
01	**4.61**	0.1218	0.6394	**9.94**	0.36	0.05	0.05	0.05	0.01	0.00	0.00	0.00
02	**1.25**	0.0376	0.1844	**3.21**	0.05	0.02	0.02	0.02	0.00	0.00	0.00	0.00
03	0.00	0.0000	0.0001	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
04	**2.81**	0.1143	0.7410	**10.00**	0.26	0.01	0.00	0.00	0.00	0.00	0.00	0.00
05	**2.18**	0.0415	0.2757	**4.53**	0.08	0.01	0.00	0.00	0.00	0.00	0.00	0.00
06	**11.09**	0.2309	0.9050	**9.97**	**1.54**	**0.56**	0.03	0.02	0.02	0.02	0.02	0.02
07	**49.09**	1.2733	1.7799	**10.00**	**5.60**	**3.25**	**2.05**	0.46	0.04	0.00	0.00	0.00

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Blesbokspruit

Reach Simulation Results

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Reach No.	% Time WQO	Mean	Standard Deviation	Percentile (%)								
				Max	95	90	75	50	25	10	5	Min
08	**39.43**	0.6741	0.9444	**5.97**	**2.92**	**1.73**	**1.06**	0.25	0.02	0.00	0.00	0.00
09	**41.76**	0.7278	0.9297	**9.90**	**2.73**	**1.97**	**0.99**	0.36	0.09	0.04	0.04	0.00
10	**26.93**	0.4849	0.8294	**5.00**	**2.51**	**1.12**	**0.54**	0.19	0.04	0.01	0.01	0.00
11	**12.00**	0.2507	0.4211	**2.47**	**1.34**	**0.58**	0.28	0.10	0.02	0.00	0.00	0.00
12	**11.47**	0.2664	0.3286	**9.45**	**0.84**	**0.55**	0.30	0.18	0.10	0.05	0.03	0.00
13	**9.54**	0.2325	0.2861	**8.16**	**0.73**	0.48	0.26	0.16	0.08	0.05	0.03	0.00
14	0.00	0.0350	0.0487	0.40	0.18	0.08	0.04	0.02	0.01	0.00	0.00	0.00
15	**6.85**	0.2296	0.8173	**6.00**	**0.97**	0.26	0.06	0.02	0.00	0.00	0.00	0.00
16	0.36	0.0108	0.0487	**0.69**	0.05	0.02	0.00	0.00	0.00	0.00	0.00	0.00
17	**3.19**	0.1323	0.8225	**9.93**	0.15	0.05	0.01	0.00	0.00	0.00	0.00	0.00
18	**2.77**	0.1619	0.2666	**3.11**	0.18	0.15	0.14	0.13	0.11	0.07	0.05	0.02
19	0.00	0.0075	0.0212	**0.51**	0.02	0.02	0.01	0.00	0.00	0.00	0.00	0.00
20	**0.53**	0.2025	0.1161	**0.94**	0.38	0.35	0.29	0.21	0.11	0.04	0.02	0.00
21	**22.59**	0.4251	0.8048	**9.88**	**1.85**	**1.16**	0.43	0.11	0.05	0.03	0.03	0.01
22	**43.37**	0.8712	1.3686	**9.99**	**3.66**	**2.60**	**1.07**	0.32	0.03	0.01	0.00	0.00
23	**42.27**	0.8346	1.3100	**9.59**	**3.50**	**2.49**	**1.03**	0.31	0.03	0.01	0.01	0.00
24	**34.96**	0.4438	0.4840	**2.93**	**1.49**	**1.03**	**0.65**	0.30	0.08	0.01	0.01	0.00
25	0.00	0.0004	0.0007	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
26	**9.81**	0.2027	0.4997	**5.28**	**0.74**	0.49	0.20	0.03	0.01	0.01	0.01	0.00
27	**2.88**	0.0777	0.1894	**1.90**	0.27	0.19	0.08	0.01	0.00	0.00	0.00	0.00
28	**20.12**	0.4413	0.8082	**9.89**	**1.59**	**0.85**	0.43	0.22	0.09	0.03	0.00	0.00
29	**8.04**	0.2161	0.4036	**4.71**	**0.79**	0.41	0.21	0.10	0.04	0.01	0.00	0.00
30	**8.33**	0.2222	0.6808	**6.62**	**0.88**	0.39	0.16	0.03	0.01	0.00	0.00	0.00
31	**10.65**	0.2353	0.6304	**7.90**	**1.22**	**0.56**	0.17	0.03	0.01	0.00	0.00	0.00

WQDown - Umfula Wempilo Consulting

Blesbokspruit

Reach Simulation Results

Reach No.	% Time WQO	Mean	Standard Deviation	Percentile (%)								
				Max	95	90	75	50	25	10	5	Min
32	**11.62**	0.2219	0.4742	**5.70**	**1.21**	**0.59**	0.18	0.05	0.01	0.00	0.00	0.00
33	**12.28**	0.3029	0.8711	**9.98**	**1.30**	**0.64**	0.22	0.07	0.01	0.00	0.00	0.00
34	**12.58**	0.2623	0.6566	**9.98**	**0.97**	**0.61**	0.26	0.08	0.01	0.00	0.00	0.00
35	**8.35**	0.1917	0.4976	**9.98**	**0.71**	0.45	0.20	0.05	0.01	0.00	0.00	0.00
36	**2.64**	0.0909	0.2421	**4.64**	0.33	0.21	0.09	0.02	0.00	0.00	0.00	0.00
37	0.00	0.0000	0.0000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
38	0.00	0.0000	0.0000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
39	**9.04**	0.2553	0.8617	**10.00**	**0.73**	0.46	0.15	0.06	0.01	0.00	0.00	0.00
40	**7.62**	0.2269	0.7666	**9.00**	**0.65**	0.41	0.14	0.05	0.01	0.00	0.00	0.00
41	**6.85**	0.2362	0.7001	**9.98**	**0.79**	0.36	0.17	0.08	0.03	0.01	0.01	0.00
42	**5.35**	0.1657	0.4993	**8.07**	**0.55**	0.25	0.12	0.06	0.02	0.01	0.01	0.00
43	**27.80**	0.7775	1.6163	**10.00**	**4.70**	**2.43**	**0.72**	0.09	0.02	0.01	0.00	0.00
44	**27.27**	0.7162	1.4851	**9.16**	**4.34**	**2.25**	**0.67**	0.08	0.02	0.01	0.01	0.00
45	**11.79**	0.1799	0.3366	**5.31**	**0.90**	**0.56**	0.16	0.05	0.01	0.00	0.00	0.00
46	**6.53**	0.1194	0.2253	**3.90**	**0.59**	0.37	0.11	0.04	0.01	0.00	0.00	0.00
47	**2.83**	0.0869	0.1538	**2.90**	0.40	0.25	0.08	0.03	0.01	0.00	0.00	0.00
48	0.23	0.0370	0.0655	**1.57**	0.15	0.10	0.04	0.01	0.01	0.00	0.00	0.00
49	**15.66**	0.3912	1.1422	**9.92**	**2.76**	**1.12**	0.11	0.04	0.01	0.00	0.00	0.00
50	**4.39**	0.1097	0.3603	**5.26**	0.43	0.21	0.04	0.01	0.01	0.00	0.00	0.00
51	**12.89**	0.2542	0.6063	**5.79**	**0.82**	**0.59**	0.24	0.06	0.01	0.01	0.00	0.00
52	**4.08**	0.0892	0.2414	**3.34**	0.41	0.21	0.06	0.01	0.00	0.00	0.00	0.00
53	**7.34**	0.2476	0.8324	**9.99**	**0.71**	0.39	0.20	0.06	0.01	0.00	0.00	0.00
54	**3.68**	0.1223	0.4027	**5.39**	0.39	0.19	0.10	0.03	0.01	0.00	0.00	0.00

Percentage and percentile values exceeding the water quality objective are indicated in bold.

APPENDIX D

WQDOWN SIMULATION RESULTS FOR BLESBOKSPRUIT GROOTVLEI GOLD MINE DISCHARGE CEASES

WQDown - Umfula Wempilo Consulting

Grootvlei GM discharge ceases

Reach Simulation Results

Water Quality Variable: PO4-P-Diss-Water
Calibration Period: 1991/01 to 2002/01 for months January to December
Simulation Period: 1991/01 to 2002/1
Number of Repitions: 10
Simulation Time Step: Daily
Water Quality Objective: 0.50
Scenario Name: Grootveli GM effluent discharge ceases

Reach No.	Upstream Urban Area (km²)	Lateral Urban Area (km²)	Upstream Irrigation Area (km²)	Abstraction (m³/day)	Point Discharge (m³/day)	Point Source Concentration Average (mg/l)	Point Source Concentration Coefficient of Variation	Point Source Concentration Reference Reach	Point Source Quality Residual Calculation Type	Decay Value Residual Calculation Type	Diffuse Load Residual Calculation Type
01	20	4	0	0	0	0.0000	0.0000	**01**	Observed	Observed	Observed
02	0	11	0	0	0	0.0000	0.0000	**02**	Observed	Observed	Observed
03	0	0	0	0	9065	0.4500	0.0000	**03**	Observed	Observed	Observed
04	0	0	0	0	0	0.0000	0.0000	**04**	Observed	Observed	Observed
05	0	0	0	0	0	0.0000	0.0000	**05**	Observed	Observed	Observed
06	12	0	0	0	0	0.0000	0.0000	**06**	Observed	Observed	Observed
07	0	1	0	0	7129	1.2047	**-2.5319**	**07**	Observed	Observed	Observed
08	0	0	0	0	0	0.0000	0.0000	**08**	Observed	Observed	Observed
09	3	0	0	0	24839	0.8942	**-1.4985**	**09**	Observed	Observed	Observed
10	0	4	0	0	0	0.0000	0.0000	**10**	Observed	Observed	Observed
11	0	0	0	0	0	0.0000	0.0000	**11**	Observed	Observed	Observed
12	10	1	0	0	7774	1.0337	**-2.1080**	**12**	Observed	Observed	Observed
13	0	2	0	0	0	0.0000	0.0000	**13**	Observed	Observed	Observed
14	0	0	0	800	0	0.0000	0.0000	**14**	Observed	Observed	Observed
15	0	0	0	0	0	0.0000	0.0000	**15**	Observed	Observed	Observed
16	0	3	0	0	0	0.0000	0.0000	**16**	Observed	Observed	Observed
17	0	1	0	0	0	0.0000	0.0000	**17**	Observed	Observed	Observed
18	0	0	0	0	25800	0.3615	**-0.7776**	**19**	Observed	Observed	Observed

WQDown - Umfula Wempilo Consulting

Grootvlei GM discharge ceases

Reach Simulation Results

Reach No.	Upstream Urban Area (km²)	Lateral Urban Area (km²)	Upstream Irrigation Area (km²)	Abstraction (m³/day)	Point Discharge (m³/day)	Point Source Concentration Average (mg/l)	Point Source Concentration Coefficient of Variation	Point Source Concentration Reference Reach	Point Source Quality Residual Calculation Type	Decay Value Residual Calculation Type	Diffuse Load Residual Calculation Type
19	0	0	0	0	0	0.3615	**-0.7776**	**19**	Observed	Observed	Observed
20	0	0	0	0	9677	2.2886	**1.5401**	**20**	Observed	Observed	Observed
21	18	1	1	0	20968	0.8770	**-1.1827**	**21**	Observed	Observed	Observed
22	0	2	0	0	0	0.0000	0.0000	**22**	Observed	Observed	Observed
23	0	0	0	0	0	0.0000	0.0000	**23**	Observed	Observed	Observed
24	0	0	0	0	0	0.0000	0.0000	**24**	Observed	Observed	Observed
25	0	7	0	0	0	0.0000	0.0000	**25**	Observed	Observed	Observed
26	0	0	0	0	0	0.1183	**-0.3542**	**26**	Observed	Observed	Observed
27	0	0	0	0	0	0.0000	0.0000	**27**	Observed	Observed	Observed
28	22	0	0	0	28194	0.5275	**-0.9202**	**28**	Observed	Observed	Observed
29	0	0	0	0	0	0.0000	0.0000	**29**	Observed	Observed	Observed
30	0	0	0	0	0	0.0000	0.0000	**30**	Observed	Observed	Observed
31	0	0	0	0	0	0.0000	0.0000	**31**	Observed	Observed	Observed
32	0	0	0	5800	0	0.0000	0.0000	**32**	Observed	Observed	Observed
33	0	2	2	0	0	0.0000	0.0000	**33**	Observed	Observed	Observed
34	0	1	0	0	0	0.0000	0.0000	**34**	Observed	Observed	Observed
35	0	0	1	0	0	0.0000	0.0000	**35**	Observed	Observed	Observed
36	0	0	0	0	0	0.0000	0.0000	**36**	Observed	Observed	Observed
37	9	3	0	0	2581	0.6000	0.0000	**37**	Observed	Observed	Observed
38	0	2	0	0	0	0.0000	0.0000	**38**	Observed	Observed	Observed
39	0	5	0	0	0	0.0000	0.0000	**39**	Observed	Observed	Observed
40	0	0	0	0	0	0.0000	0.0000	**40**	Observed	Observed	Observed
41	0	0	0	0	10323	1.7150	**-1.8212**	**41**	Observed	Observed	Observed
42	0	0	0	0	0	0.0000	0.0000	**42**	Observed	Observed	Observed

WQDown - Umfula Wempilo Consulting

Grootvlei GM discharge ceases

Reach Simulation Results

Reach No.	Upstream Urban Area (km²)	Lateral Urban Area (km²)	Upstream Irrigation Area (km²)	Abstraction (m³/day)	Point Discharge (m³/day)	Point Source Concentration Average (mg/l)	Point Source Concentration Coefficient of Variation	Point Source Concentration Reference Reach	Point Source Quality Residual Calculation Type	Decay Value Residual Calculation Type	Diffuse Load Residual Calculation Type
43	5	4	0	0	9355	0.2405	**-0.4862**	**43**	Observed	Observed	Observed
44	0	0	0	0	0	0.0000	0.0000	**44**	Observed	Observed	Observed
45	0	6	2	0	0	0.0000	0.0000	**45**	Observed	Observed	Observed
46	0	3	0	0	0	0.0000	0.0000	**46**	Observed	Observed	Observed
47	0	2	3	0	5161	0.5650	**-0.8786**	**47**	Observed	Observed	Observed
48	0	0	3	0	2903	0.6536	**-0.8353**	**48**	Observed	Observed	Observed
49	8	0	0	0	0	0.0000	0.0000	**49**	Observed	Observed	Observed
50	0	0	0	0	0	0.0000	0.0000	**50**	Observed	Observed	Observed
51	0	0	0	0	0	0.0000	0.0000	**51**	Observed	Observed	Observed
52	0	0	12	0	0	0.0000	0.0000	**52**	Observed	Observed	Observed
53	0	0	0	0	0	0.0000	0.0000	**53**	Observed	Observed	Observed
54	0	5	0	0	0	0.0000	0.0000	**54**	Observed	Observed	Observed

Non-default values for Point Source Concentration Coefficient of Variation and Point Source Concentration Reference Reach are indicated in bold.

Reach No.	% Time WQO Exceeded	Mean	Standard Deviation	Percentile (%)								
				Max	95	90	75	50	25	10	5	Min
01	**4.64**	0.1333	0.6780	**9.91**	0.42	0.05	0.05	0.05	0.01	0.00	0.00	0.00
02	**2.69**	0.0399	0.1936	**3.21**	0.18	0.03	0.02	0.02	0.00	0.00	0.00	0.00
03	0.00	0.0000	0.0001	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
04	**2.92**	0.1172	0.7467	**9.99**	0.27	0.02	0.00	0.00	0.00	0.00	0.00	0.00
05	**2.31**	0.0425	0.2789	**4.63**	0.08	0.01	0.00	0.00	0.00	0.00	0.00	0.00
06	**12.54**	0.2251	0.8798	**9.86**	**2.10**	**0.81**	0.03	0.02	0.02	0.02	0.02	0.02
07	**48.59**	1.2741	1.7874	**10.00**	**5.71**	**3.28**	**2.05**	0.44	0.04	0.00	0.00	0.00

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Grootvlei GM discharge ceases

Reach Simulation Results

Reach No.	% Time WQO	Mean	Standard Deviation	Percentile (%)								
				Max	95	90	75	50	25	10	5	Min
08	**39.35**	0.6742	0.9477	**6.00**	**2.93**	**1.74**	**1.06**	0.23	0.02	0.00	0.00	0.00
09	**41.68**	0.7266	0.9212	**9.92**	**2.71**	**1.96**	**0.99**	0.36	0.09	0.04	0.04	0.00
10	**27.24**	0.4919	0.8354	**5.28**	**2.53**	**1.14**	**0.54**	0.19	0.04	0.01	0.01	0.00
11	**12.19**	0.2542	0.4239	**2.61**	**1.36**	**0.59**	0.28	0.10	0.02	0.01	0.00	0.00
12	**11.35**	0.2681	0.3390	**9.90**	**0.85**	**0.56**	0.30	0.18	0.10	0.05	0.03	0.00
13	**9.60**	0.2339	0.2948	**8.57**	**0.74**	0.48	0.25	0.16	0.09	0.05	0.03	0.00
14	0.00	0.0354	0.0489	0.44	0.18	0.08	0.04	0.02	0.01	0.00	0.00	0.00
15	**6.94**	0.2358	0.8349	**5.98**	**1.10**	0.27	0.06	0.02	0.01	0.00	0.00	0.00
16	0.36	0.0108	0.0484	**0.68**	0.05	0.02	0.00	0.00	0.00	0.00	0.00	0.00
17	**3.25**	0.1325	0.8165	**9.99**	0.15	0.05	0.00	0.00	0.00	0.00	0.00	0.00
18	**2.86**	0.1618	0.2653	**3.18**	0.18	0.15	0.14	0.13	0.11	0.07	0.05	0.02
19	0.00	0.0075	0.0218	**0.53**	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00
20	**0.54**	0.2032	0.1157	**0.94**	0.38	0.35	0.29	0.21	0.11	0.04	0.02	0.00
21	**23.65**	0.4343	0.7981	**9.93**	**1.91**	**1.20**	0.45	0.12	0.05	0.03	0.03	0.01
22	**43.67**	0.8663	1.3444	**9.98**	**3.59**	**2.59**	**1.09**	0.33	0.03	0.01	0.01	0.00
23	**42.91**	0.8300	1.2869	**9.61**	**3.43**	**2.47**	**1.04**	0.32	0.03	0.01	0.01	0.00
24	**34.88**	0.4441	0.4843	**2.88**	**1.50**	**1.01**	**0.65**	0.30	0.07	0.01	0.01	0.00
25	0.00	0.0004	0.0006	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
26	**18.06**	0.3456	1.0210	**9.99**	**1.59**	**0.89**	0.20	0.00	0.00	0.00	0.00	0.00
27	**3.19**	0.0950	0.2732	**2.65**	0.42	0.24	0.07	0.00	0.00	0.00	0.00	0.00
28	**20.42**	0.4431	0.8157	**9.89**	**1.58**	**0.85**	0.44	0.22	0.09	0.02	0.00	0.00
29	**7.96**	0.2168	0.4060	**4.71**	**0.78**	0.41	0.21	0.10	0.04	0.01	0.00	0.00
30	**13.05**	0.3416	1.0620	**10.00**	**1.55**	**0.65**	0.23	0.03	0.00	0.00	0.00	0.00
31	**14.24**	0.3748	1.0324	**9.88**	**1.95**	**0.86**	0.24	0.04	0.00	0.00	0.00	0.00

WQDown - Umfula Wempilo Consulting

Grootvlei GM discharge ceases

Reach Simulation Results

Reach No.	% Time WQO	Mean	Standard Deviation	Percentile (%)								
				Max	95	90	75	50	25	10	5	Min
32	**16.20**	0.3560	0.7715	**8.81**	**2.04**	**0.95**	0.29	0.07	0.01	0.00	0.00	0.00
33	**19.33**	0.3913	0.8622	**9.95**	**1.89**	**0.98**	0.36	0.10	0.01	0.00	0.00	0.00
34	**21.84**	0.3641	0.6680	**9.88**	**1.58**	**1.02**	0.42	0.12	0.02	0.00	0.00	0.00
35	**16.44**	0.2651	0.5095	**9.78**	**1.17**	**0.76**	0.30	0.07	0.00	0.00	0.00	0.00
36	**3.29**	0.1002	0.2003	**5.31**	0.42	0.28	0.12	0.03	0.00	0.00	0.00	0.00
37	0.00	0.0000	0.0000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
38	0.00	0.0000	0.0000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
39	**13.12**	0.3100	0.8514	**9.98**	**1.29**	**0.76**	0.23	0.08	0.01	0.00	0.00	0.00
40	**12.10**	0.2660	0.7354	**8.98**	**1.09**	**0.65**	0.19	0.06	0.01	0.00	0.00	0.00
41	**11.80**	0.2826	0.6458	**10.00**	**0.88**	**0.55**	0.27	0.11	0.04	0.02	0.01	0.00
42	**5.60**	0.1803	0.4291	**7.79**	**0.55**	0.34	0.17	0.07	0.03	0.01	0.01	0.00
43	**27.50**	0.7760	1.6148	**9.98**	**4.76**	**2.44**	**0.70**	0.09	0.02	0.01	0.01	0.00
44	**27.03**	0.7148	1.4840	**9.14**	**4.38**	**2.25**	**0.65**	0.09	0.02	0.01	0.00	0.00
45	**14.30**	0.2600	0.4990	**5.80**	**1.36**	**0.85**	0.23	0.06	0.01	0.00	0.00	0.00
46	**10.34**	0.1546	0.2915	**4.55**	**0.81**	**0.52**	0.14	0.04	0.01	0.00	0.00	0.00
47	**5.02**	0.1043	0.1742	**3.62**	**0.50**	0.32	0.10	0.04	0.01	0.01	0.00	0.00
48	0.14	0.0372	0.0599	**2.10**	0.16	0.10	0.04	0.01	0.01	0.00	0.00	0.00
49	**16.25**	0.3852	1.1410	**9.99**	**2.84**	**1.16**	0.14	0.04	0.01	0.00	0.00	0.00
50	**4.63**	0.1080	0.3629	**5.56**	0.46	0.22	0.05	0.01	0.01	0.00	0.00	0.00
51	**20.48**	0.4300	1.1031	**9.97**	**1.55**	**1.06**	0.35	0.08	0.01	0.00	0.00	0.00
52	**6.22**	0.1256	0.3776	**5.10**	**0.61**	0.29	0.07	0.01	0.00	0.00	0.00	0.00
53	**17.11**	0.3308	0.8319	**9.99**	**1.20**	**0.76**	0.33	0.08	0.02	0.00	0.00	0.00
54	**4.70**	0.1363	0.3661	**5.25**	0.47	0.27	0.13	0.04	0.01	0.00	0.00	0.00

Percentage and percentile values exceeding the water quality objective are indicated in bold.

APPENDIX E

USER MANUAL

USER MANUAL

Introduction

WQDown was developed under WRC Project 1212 – A model for rapidly assessing the impact of waste discharge on downstream water quality.

Note that in this appendix the words “reach” and “channel reach” are used interchangeably.

System requirements

The minimum system requirements for installing and running WQDown are:

- A personal computer with Windows XP or compatible
- 200 MB hard disk space for program and initial data files
- Super VGA screen, minimum 800 x 600 resolution
- 512 MB RAM
- CD-ROM (only required for drive installation)

Installation

Read the ReadMe.txt file on the WQDown Setup CD for new changes not applied to the manual.

To install the WQDown software and data files:

1. Install the WQDown Setup CD-ROM into the CD drive. The CD AutoRun Index screen should appear automatically. If not, manually start the AutoRun.exe program on the CD.

2. Select Setup WQDown, and follow the prompts on the screen. The program files will be installed in the directory C:\Program Files\WQDown, unless another destination directory is specified. A WQDown icon will be placed on the desktop.

3. WQDown can then be started by clicking on the WQDown icon.

Uninstalling WQDown

To remove a WQDown installation from the computer:

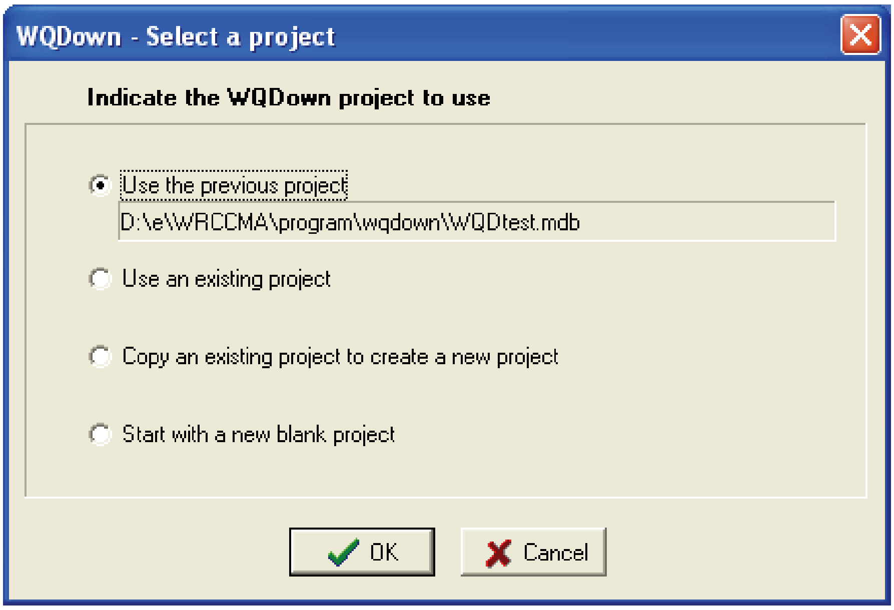
1. Make a backup of all projects that you may want to archive.

2. Select Windows Start | Settings | Control Panel | Add/Remove Programs, select WQDown and click Add/Remove.

3. The above steps will only remove files stored on the hard drive by the Setup program. Projects created afterwards have to be deleted manually. Use Windows Explorer and delete the C:\Program Files\WQDown directory with all it's sub-directories and files.

Creating a New WQDown Project

On starting WQDown the **Select a Project** screen will appear:



WQDown - Select a project

Indicate the WQDown project to use

● Use the previous project
D:\e\WRCCMA\program\wqdown\WQDtest.mdb

○ Use an existing project

○ Copy an existing project to create a new project

○ Start with a new blank project

The user can select to:

- Use the previous project
  This will open the project that was last used. It is important to note that any modification made to the system will permanently over-write the previous project.

- Use an existing project

  This option will provide a drop down list of existing projects from which a selection can be made. As with the first option, any modifications will over-write the original project.

- Copy an existing project to create a new project

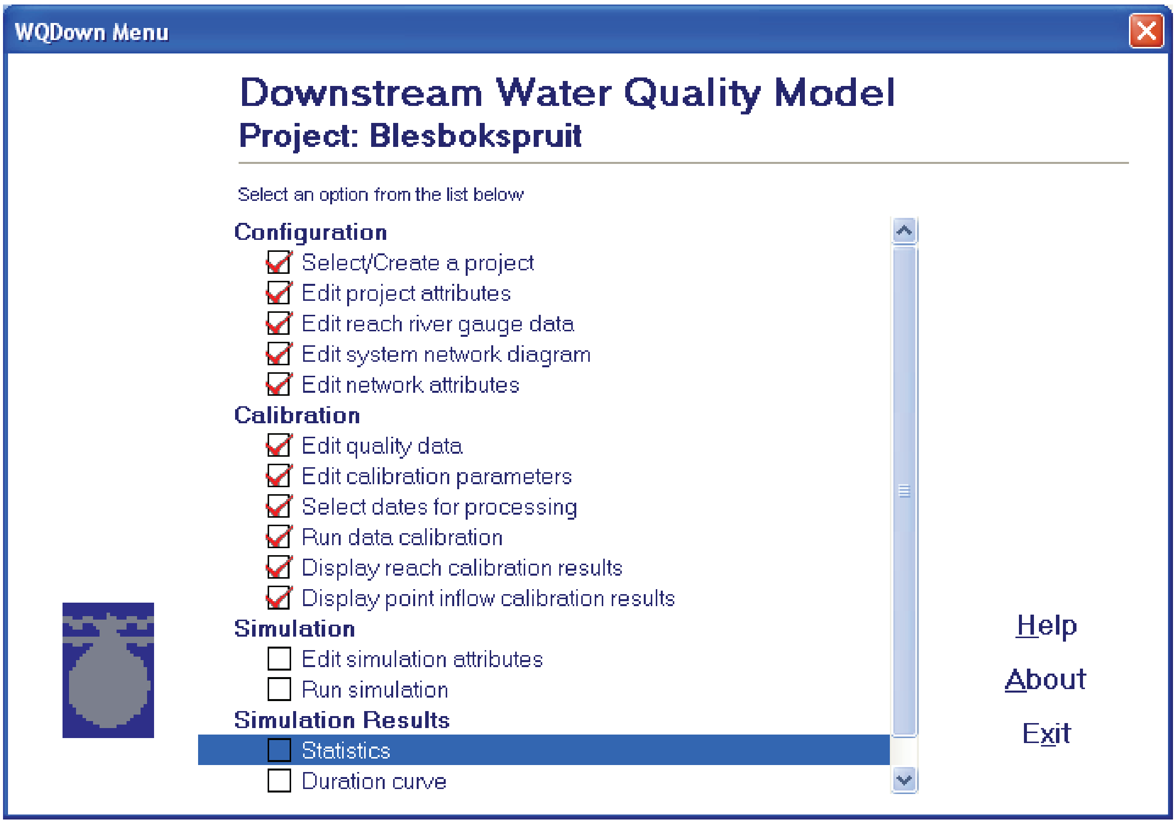
  This option differs from the first two in that the original project will remain unchanged. A new project name will be solicited.

- Start with a new blank project.

  This option requires a brand new project to be built up from scratch.

Main Screen

Once a project has been selected the main **Menu** screen will be displayed.



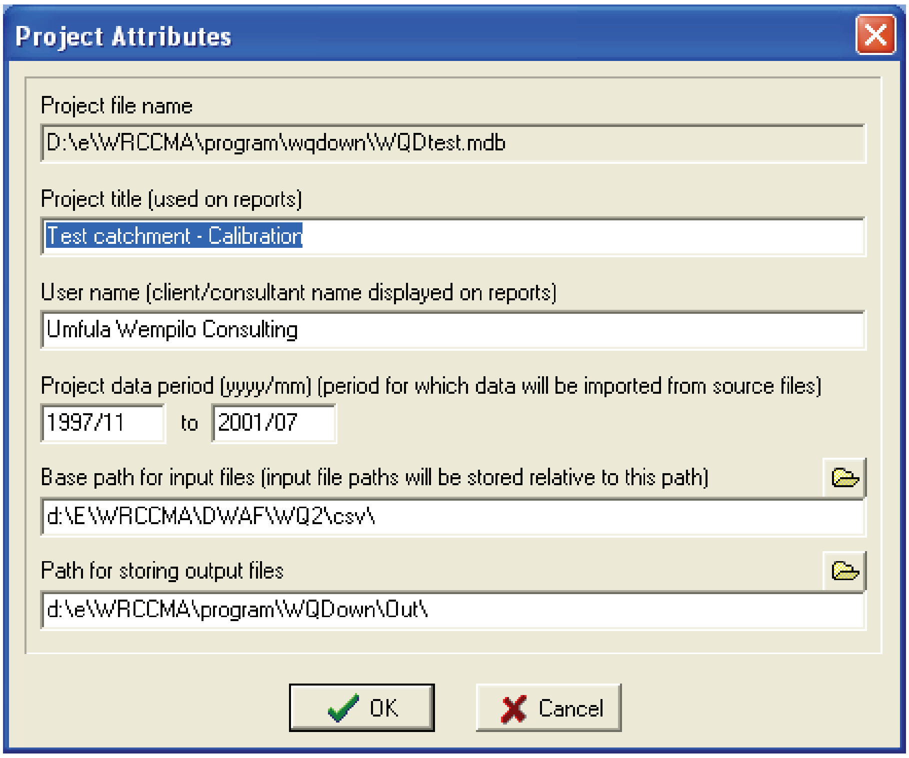
Selecting the first menu option (“Select/Create a project”) will revert to the previous screen to facilitate creation or selection of another project. Similarly at any stage an earlier option can be selected to modify data. However, certain steps cannot be run unless preceding steps have been completed. For example, a calibration cannot be run until the setup steps have been completed. Similarly a simulation cannot be run unless it has been preceded by calibration of the same system.

Select/Create a Project

Selection of this main menu option brings up the “Select/Create a Project” screen that appears when the model is first started.

Edit Project Attributes

Selecting “Edit Project Attribute” from the main menu produces the **Project Attributes** screen.



Project file name
D:\e\WRCCMA\program\wqdown\WQDtest.mdb

Project title (used on reports)
Test catchment - Calibration

User name (client/consultant name displayed on reports)
Umfula Wempilo Consulting

Project data period (yyyy/mm) (period for which data will be imported from source files)
1997/11 to 2001/07

Base path for input files (input file paths will be stored relative to this path)
d:\E\WRCCMA\DWAF\WQ2\csv\

Path for storing output files
d:\e\WRCCMA\program\WQDown\Out\

This allows the user to specify or modify:

- The project title

- The user name

- The project period

  This defines the starting and ending dates that encapsulate both the calibration and simulation periods. The period must be at least one year, and must start on or after 1950/01.

- The base path in which input files are stored is the most common path under which most input files are stored. If for example data is stored in c:\MyFiles\WQData and c:\MyFiles\WMS, then c:\MyFiles is the common path, and should be the path entered here. Input file names will be stored relative to this path. This field may be left blank. Any files that are not stored under this path will also be handled correctly.

  E.g. a file name "C:\MyFiles\WMS\Somefile.txt" will be stored as "..\WMS\Somefile.txt".

  The purpose of this field is to simplify maintenance. If you move this path in future, you only need to update the base path on this dialog, instead of updating each input file name in the database.

- The path for storing output files. If you are only interested in the reports produced by WQDown, this path is of no relevance and can be left as the default.

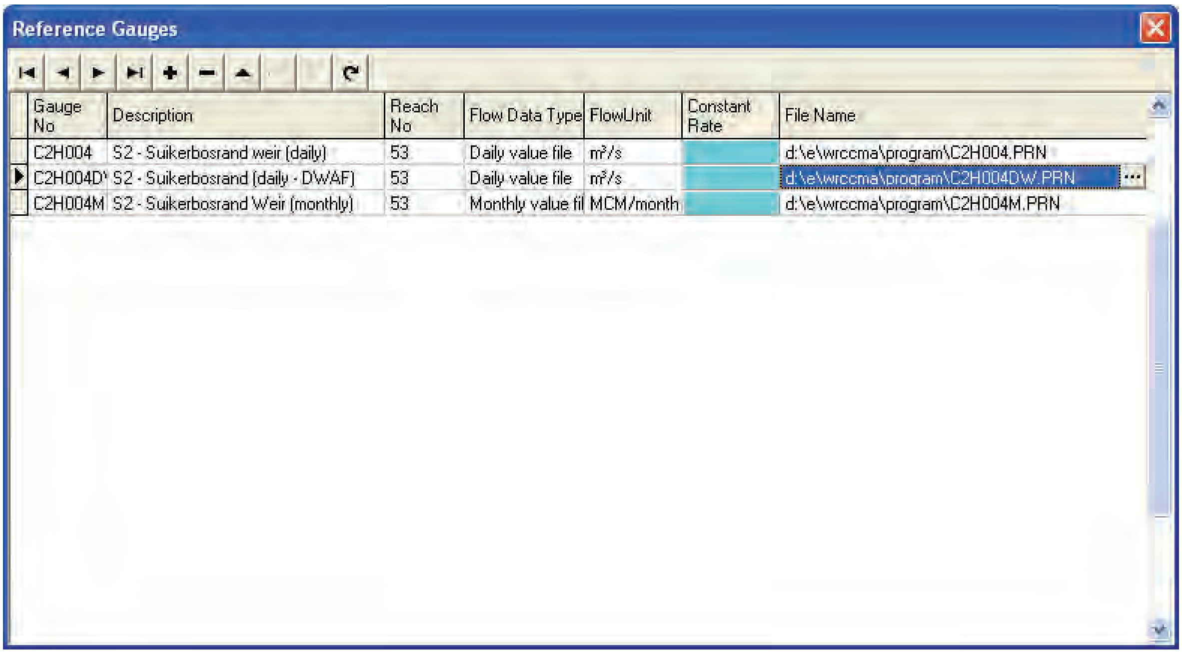
Edit Reach River Gauge Data

This menu option opens the **Reference Gauges** screen.

This allows specification and modification of the flow gauge details for one or more flow data files at the flow gauging point. More than one file can be specified for the point, since alternative data sources spanning different periods can arise. The priority of the flow files is defined by the order in which they are entered. In this example file C2H004.PRN is the first choice. On days when there is no data in this file, then recourse will be made to file C2H004W.PRN, and so on. In its present form WQDown permits only one flow observation location (i.e. at the bottom of channel reach 53 in this example), but provision has been made in the input screen for the eventual provision of multiple flow gauging points at different localities. The information provided for each flow file comprises:

- Gauge code number (alphanumeric)

- Gauge description



Gauge No	Description	Reach No	Flow Data Type	FlowUnit	Constant Rate	File Name
C2H004	S2 - Suikerbosrand weir (daily)	53	Daily value file	m³/s		d:\e\wrccma\program\C2H004.PRN
C2H004D	S2 - Suikerbosrand (daily - DWAF)	53	Daily value file	m³/s		d:\e\wrccma\program\C2H004DW.PRN
C2H004M	S2 - Suikerbosrand Weir (monthly)	53	Monthly value fil	MCM/month		d:\e\wrccma\program\C2H004M.PRN

- Number of the channel reach with the downstream end corresponding to the flow observation point.

- Flow data type

  A drop down menu is provided allowing the following choices:
  - Constant value (in which case the last field (File Name) is closed)
  - Daily value(in which case the second last field (Constant Rate) is closed)
  - Monthly value (In which case the second last field (Constant Rate) is closed).

- Flow units

  A drop down menu is provided from which the following units can be specified:
  - m^3/s
  - MCM/month (Million cubic meters per month)
  - MCM/year (Million cubic meters per month)
  - Mℓ/d (million litres per day)
  - Mℓ /month (million litres per month).

- Constant rate

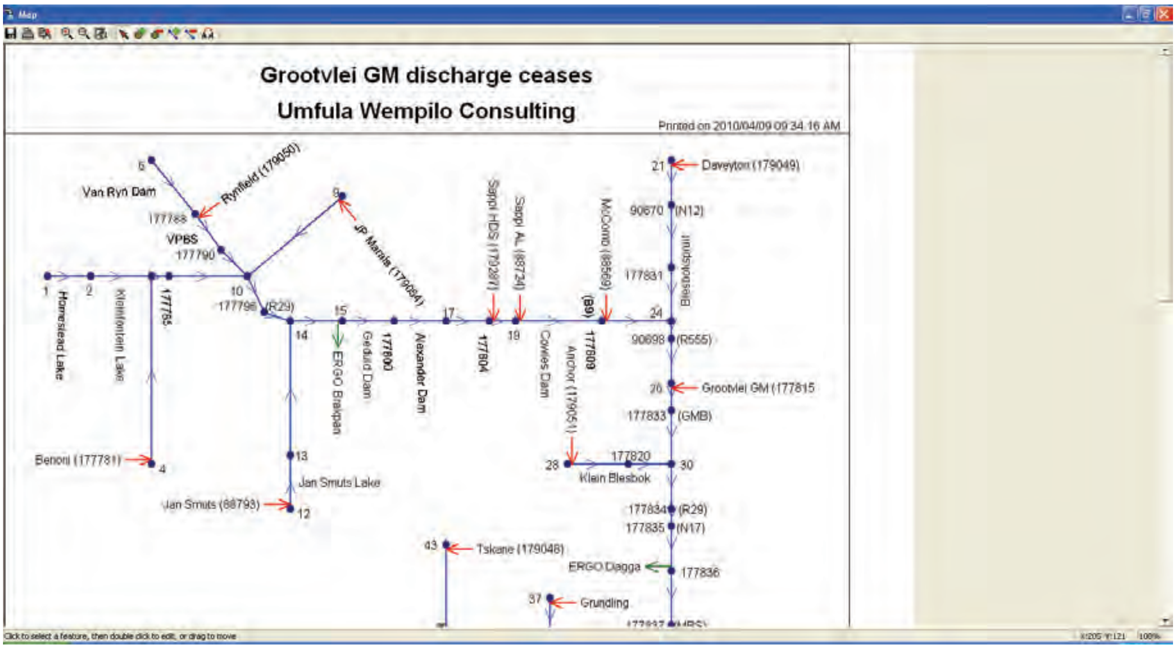
  This allows a constant flow rate to be specified instead of specifying a flow file. As such it is a last resort, which is not recommended.

- File name

The file pathname may be typed in manually or can be browsed for. Ideally this file should have been copied to the *Input Data Path* specified on the *Project Attributes* window. If this is the case, the full path will not be displayed in this field. If the file is stored in another location, you may have to update this field for each reach if the project is copied to another computer. *See How to copy a project* .

Edit System Network Diagram

This main menu option opens the interactive **Map** screen. This screen allows the user to build a system network by specifying (or deleting) and moving nodes and their connected channel reaches.



Icons at the top left of the screen allow the user to:

- Save the image to file
- Print the image
- Copy the image to the clipboard
- Zoom in
- Zoom out

- Redraw

- Select a feature

  In this mode it is possible to:

  - Click on any node an move it
  - Double click on a note to display its attributes, which can be modified to:
    - Change the node name
    - Elect to show this name on the plot
    - Change the node description
  - Double click on a channel reach, which brings up the **Reach Data** screen to permit editing of reach attributes.

- Add node

- Delete node

  This removes all reaches entering or leaving the node as well.

- Add reach

  The heads and tails of new reaches are clicked on to existing nodes.

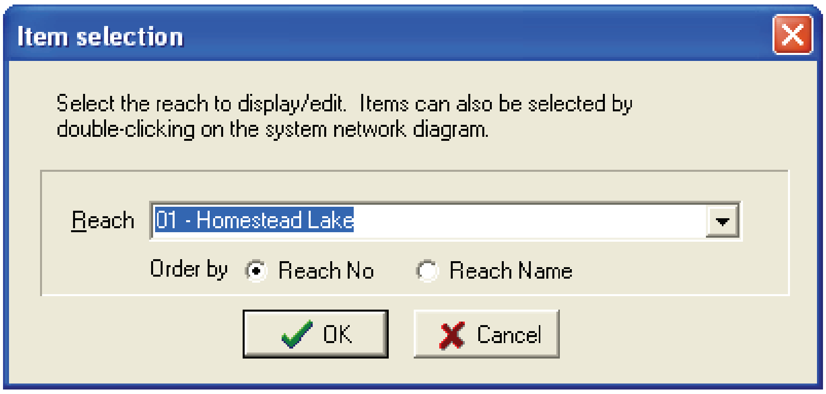
- Delete reach

- Move and rotate labels

  This permits the re-positioning of reach and point source labels.

Edit network attributes

Selection of this main menu option opens the **Item Selection** screen.



Item selection

Select the reach to display/edit. Items can also be selected by double-clicking on the system network diagram.

Reach: 01 - Homestead Lake

Order by ● Reach No ○ Reach Name

This allows selection of a channel reach by its alphanumeric number or its description.

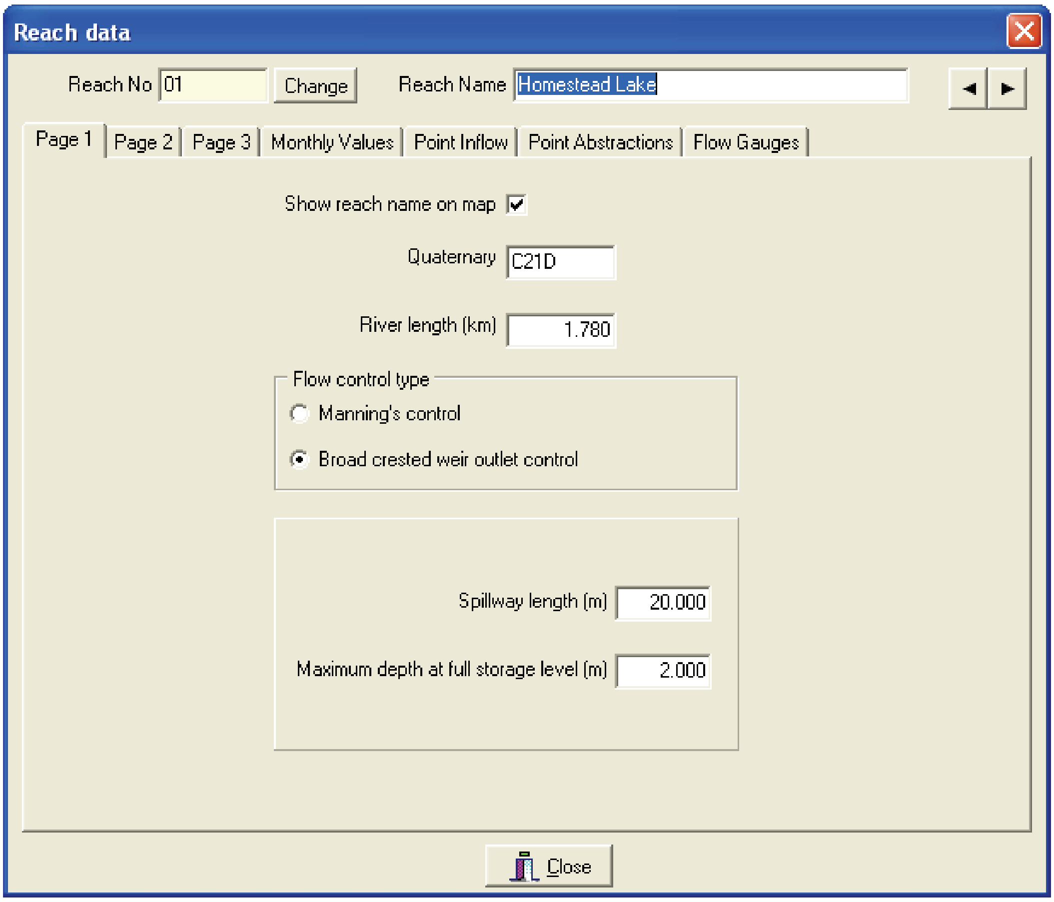
Once a channel reach is selected the first page of the Reach Data screen is opened to permit editing of the reach data. This screen can also be opened from the **Map** screen (see the preceding Edit System Network Diagram option in the main menu) by double clicking on the appropriate channel reach.

The **Reach Data** screens for other reaches can be opened by navigating forwards or backwards using the buttons at the top right of the screen. Doing so will open the same tab as the one from which the change of reach was selected.

Click the *Change* or *Rename* button to edit the reach number. This must be a unique 10 character alphanumeric number

The reach name can be changed in the input field. A maximum of 50 characters is allowed. This name is only for reference and is not used by the program.

The first tab, **Page 1** opens the following screen:



Reach No 01

Reach Name Homestead Lake

Show reach name on map ☑

Quaternary C21D

River length (km) 1.780

Flow control type
○ Manning's control
● Broad crested weir outlet control

Spillway length (m) 20.000

Maximum depth at full storage level (m) 2.000

This controls the following:

- Selection to show the reach name on the map. If unselected, the label is not shown on the system network diagram.

- Quaternary code.
  The 4-diget alphanumeric code denoting the quaternary catchment within which the channel reach resides.

- Define the river length (km)

- Set the flow control as:
    - Manning friction equation (i.e. normal river reach), or
    - Broad crested weir outlet control (i.e. lake reach).

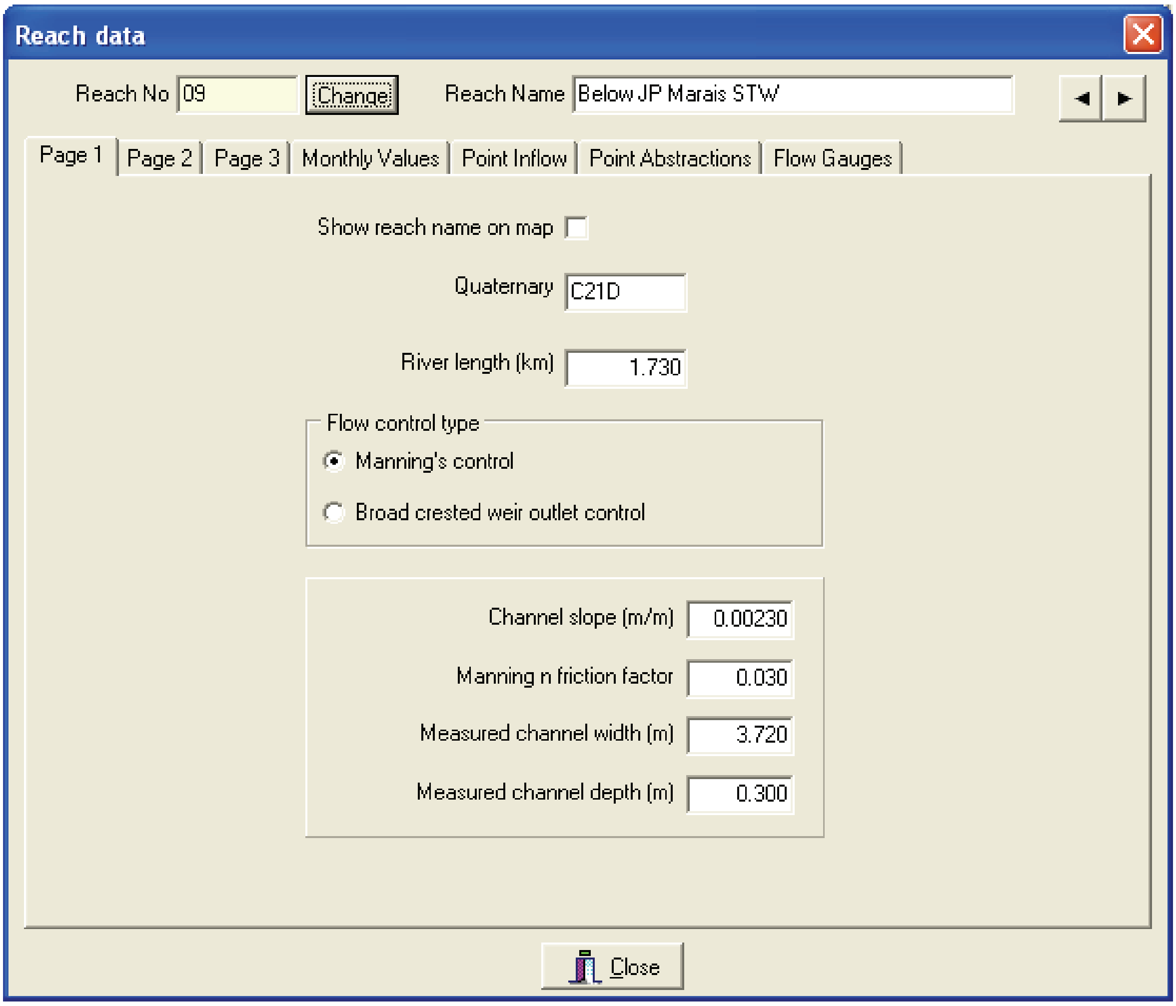
- For a broad crested weir outlet control define:
    - Spillway length (m)
    - Maximum depth at full supply level (m)

If the Manning equation is specified, then the following parameters are specified:

Channel slope (m/m)
Manning n friction factor
Measured channel width (m)
Measured channel width (m)

A parabolic channel cross section is assumed. It is therefore necessary to specify only one typical channel width and depth.

When the Manning equation is specified the **Page 1** screen looks as follows:



Reach No 09

Reach Name Below JP Marais STW

Show reach name on map ☐

Quaternary C21D

River length (km) 1.730

Flow control type

● Manning's control

○ Broad crested weir outlet control

Channel slope (m/m) 0.00230

Manning n friction factor 0.030

Measured channel width (m) 3.720

Measured channel depth (m) 0.300

<u>The second tab (**Page 2**)</u>:

The following channel reach characteristics are entered in this page:

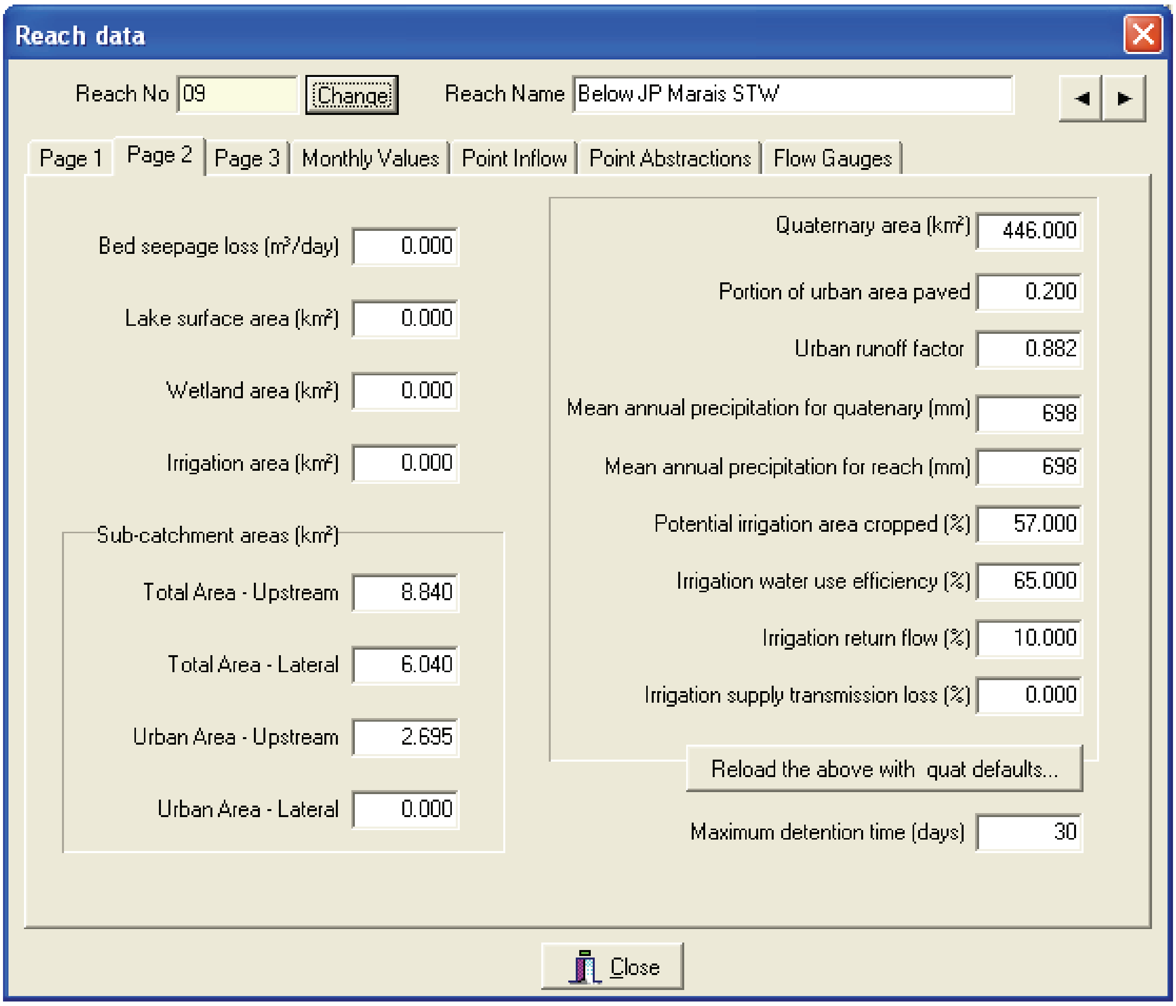
- Bed seepage loss (m^3/day)

  Usually this is unknown and is set to zero, but specific information may be available from previous detailed studies.

- Lake surface area (km^2)

  Note that a channel reach can be partially covered by lake and wetland

- Wetland area (km^2)



Reach No 09

Reach Name Below JP Marais STW

Bed seepage loss (m^3/day) 0.000

Lake surface area (km^2) 0.000

Wetland area (km^2) 0.000

Irrigation area (km^2) 0.000

Sub-catchment areas (km^2)

Total Area - Upstream 8.840

Total Area - Lateral 6.040

Urban Area - Upstream 2.695

Urban Area - Lateral 0.000

Quaternary area (km^2) 446.000

Portion of urban area paved 0.200

Urban runoff factor 0.882

Mean annual precipitation for quatenary (mm) 698

Mean annual precipitation for reach (mm) 698

Potential irrigation area cropped (%) 57.000

Irrigation water use efficiency (%) 65.000

Irrigation return flow (%) 10.000

Irrigation supply transmission loss (%) 0.000

Maximum detention time (days) 30

- Irrigation area (km^2)

  Riparian irrigation adjacent to the channel reach.

- Total upstream incremental sub-catchment area (km^2)

- Total lateral incremental sub-catchment area (km^2)

- Upstream incremental urban area (km^2)

- Lateral incremental urban area (km^2)

Default values for the following parameter values are obtained directly from the data base, most of which are obtained from the WR90 quaternary database. Selecting the reload button restores the default values in all of these fields.

- Quaternary catchment area (km^2)

  Area of the quaternary catchment within which the channel reach is situated.

- Portion of urban area paved

  The paved area directly linked to the drainage system. Typically 0.125 for a normal residential area, but can be higher for high density housing, central business districts and some industrial areas.

- Urban runoff factor

  This is the proportion of the rainfall giving rise to runoff from paved areas. The database has been populated with values for each quaternary catchment derived from running the WRSM90 rainfall-runoff model.

- Mean annual precipitation for quaternary catchment (mm)

- Mean annual precipitation for channel reach (mm)

  This value is applied to the channel surface area, wetlands, lakes and adjacent irrigated areas. The default is set equal to the quaternary rainfall, but allowance is made to specify a reach-specific MAP since the MAP can sometimes vary significantly across a quaternary catchment.

- Potential irrigation area cropped (%)

  Diffuse irrigation is often opportunistic and the full nominal crop area is not always irrigated.

- Irrigation water use efficiency (%)

  This varies according to the type of irrigation (flood, sprinkler and drip).

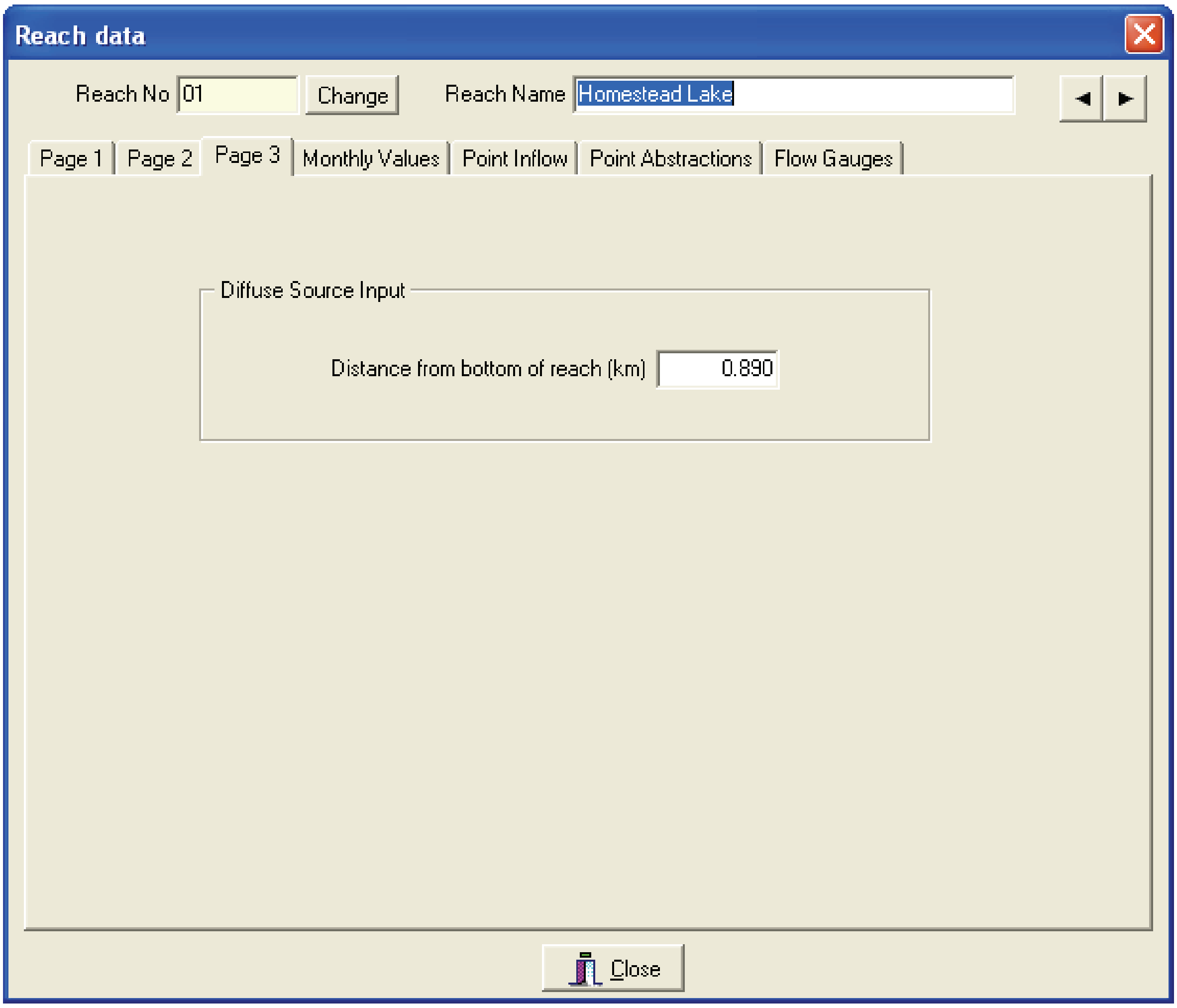
- Irrigation return flow (%)

  The irrigation return flow to the channel as a percentage of the irrigation supply.

- Irrigation supply transmission loss (%)

  Typically riparian irrigation is pumped from the river and conveyed in pipes. In such instances the transmission loss is close to the default value of zero. Larger losses are applicable when the water is transferred via earthen channels.

The third **Reach Data** tab (**Page 3**) is shown below:



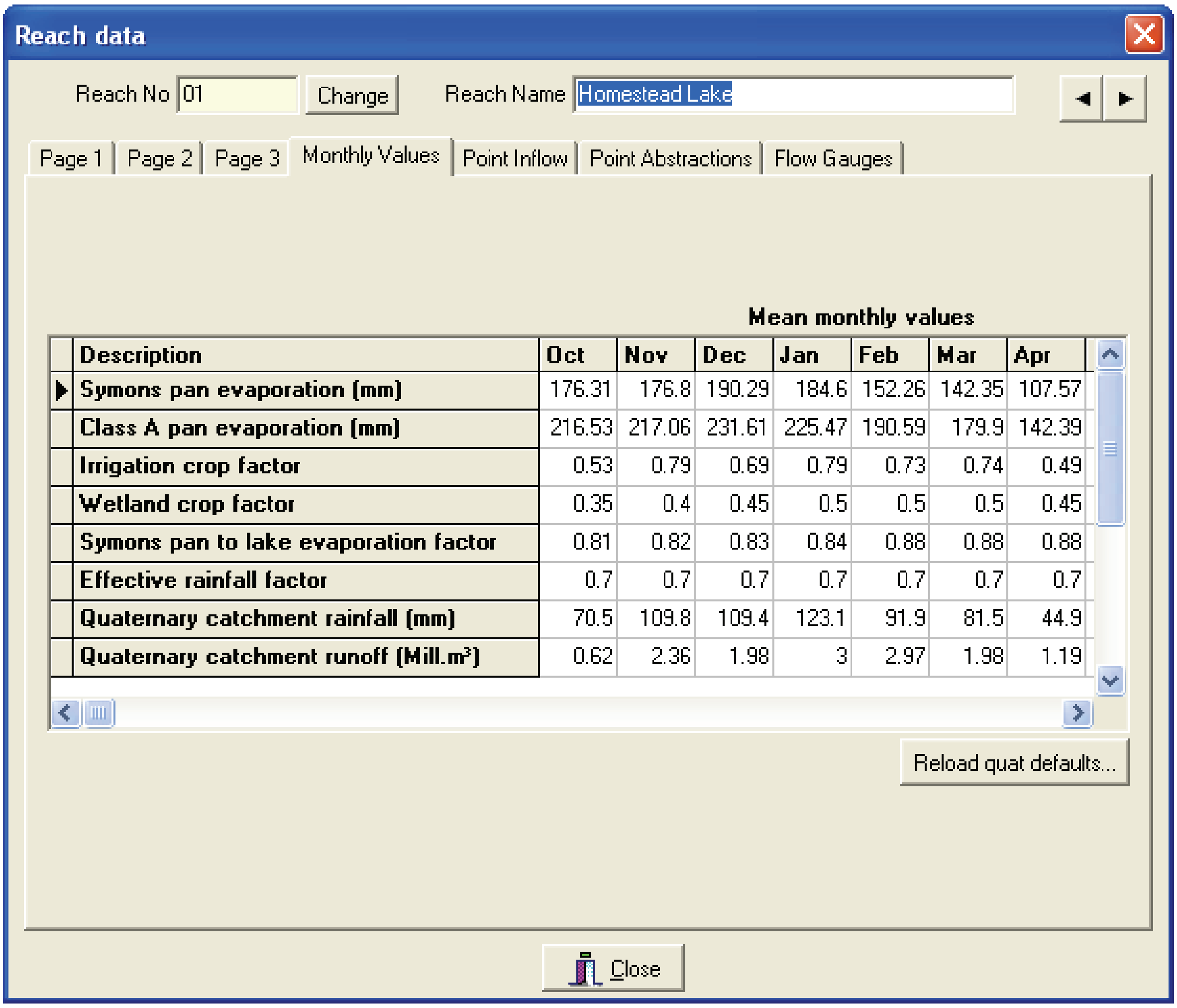
Reach No: 01

Reach Name: Homestead Lake

Distance from bottom of reach (km): 0.890

- This field defines the distance upstream from the downstream end of the reach at which an un-gauged diffuse input load can be anticipated. If no such point can be identified it is normally set as half of the channel length.

The fourth **Reach Data** tab (**Monthly values**) is shown below:



Reach No 01

Reach Name Homestead Lake

Mean monthly values

Description	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Symons pan evaporation (mm)	176.31	176.8	190.29	184.6	152.26	142.35	107.57
Class A pan evaporation (mm)	216.53	217.06	231.61	225.47	190.59	179.9	142.39
Irrigation crop factor	0.53	0.79	0.69	0.79	0.73	0.74	0.49
Wetland crop factor	0.35	0.4	0.45	0.5	0.5	0.5	0.45
Symons pan to lake evaporation factor	0.81	0.82	0.83	0.84	0.88	0.88	0.88
Effective rainfall factor	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Quaternary catchment rainfall (mm)	70.5	109.8	109.4	123.1	91.9	81.5	44.9
Quaternary catchment runoff (Mill.m³)	0.62	2.36	1.98	3	2.97	1.98	1.19

Default values of these mean monthly values are all derived from the WR90 quaternary database and are stored in the WQDown standard database. These values can be modified if so desired. Selecting the “Reload quat defaults” button restores the default values.

The following mean monthly values are entered:

- Symons pan evaporation (mm)
- Class A pan evaporation (mm)
- Irrigation crop factor

  Multiplying this factor by the Class A pan evaporation gives the monthly crop demand.

- Wetland crop factor

- Symons to lake evaporation factor

  The shading effect of the reeds can reduce the wetland evapotranspiration loss to less than lake evaporation, especially for an established reed bed during the dormant period.

- Effective rainfall factor

  Used in the calculation of irrigation crop demand.

- Quaternary catchment rainfall (mm)

- Quaternary catchment runoff (10^6m^3)

The fifth **Reach Data** tab (**Point inflow**) is shown below.

The following entries are made:

- Define if the reach has a point inflow

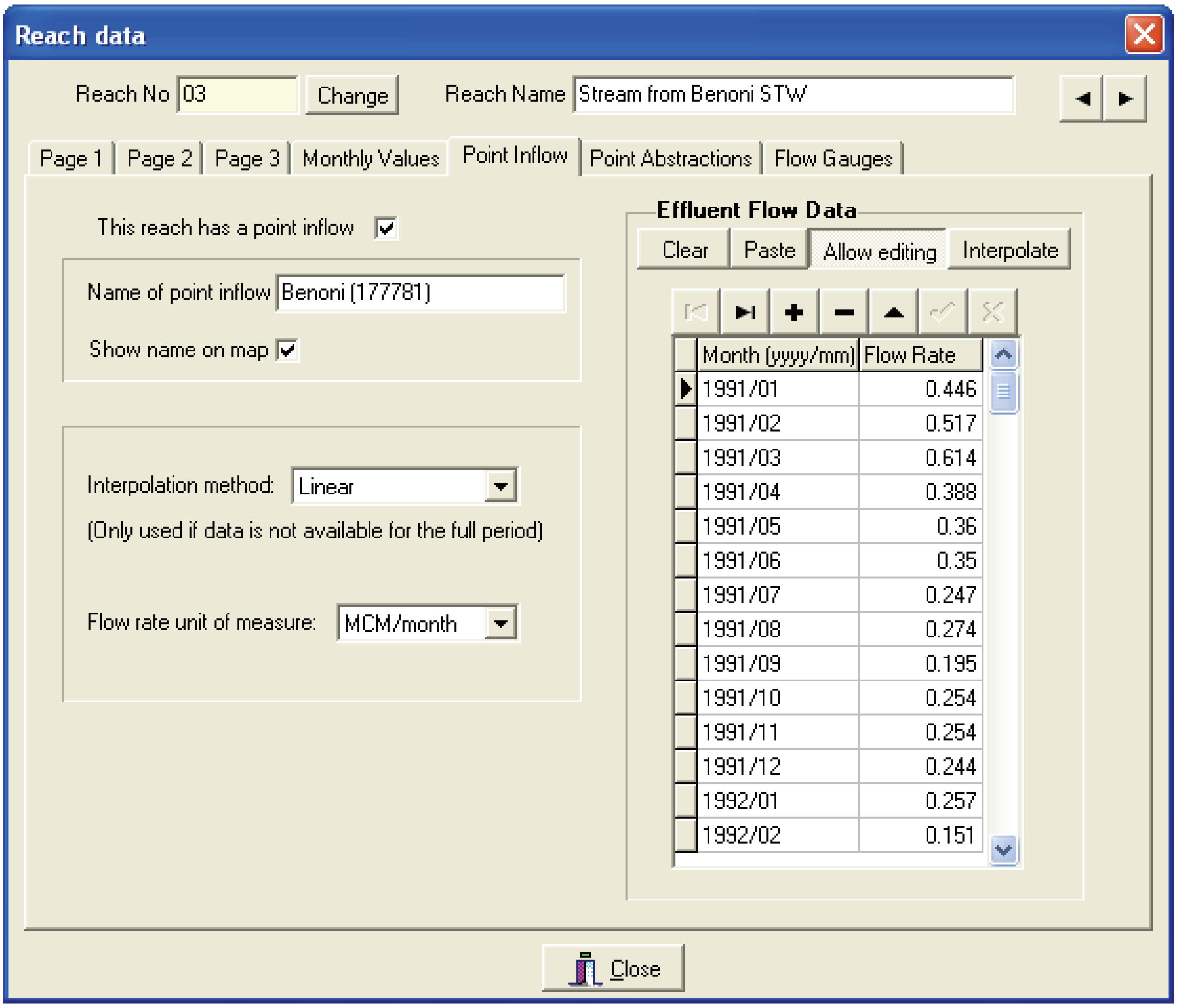
- Name of the point inflow

- Specify if the label is to be shown on the map (see the **Edit System Network Diagram** main menu item)

- Specify the interpolation type to be used to patch gaps between the specified effluent flow data values. Linear or exponential interpolation can be chosen.

- Flow rate units. The following types can be selected:

  m^3/day
  m^3/s
  MCM/month (million cubic metres per month)
  Mℓ/day
  Mℓ/month



Reach No 03

Reach Name Stream from Benoni STW

This reach has a point inflow ☑

Name of point inflow Benoni (177781)

Show name on map ☑

Interpolation method: Linear

(Only used if data is not available for the full period)

Flow rate unit of measure: MCM/month

Effluent Flow Data

Month (yyyy/mm)	Flow Rate
1991/01	0.446
1991/02	0.517
1991/03	0.614
1991/04	0.388
1991/05	0.36
1991/06	0.35
1991/07	0.247
1991/08	0.274
1991/09	0.195
1991/10	0.254
1991/11	0.254
1991/12	0.244
1992/01	0.257
1992/02	0.151

- The right hand portion of the screen allows the user to paste in monthly effluent flow data from an Excel spreadsheet. The spreadsheet data should be in two columns, the first containing the month and the second the monthly flow rate. The data can contain gaps, can be shorter than the modelling period, or can be longer than the modelling period. A full date may be supplied instead of the month.

  The “Clear” button clears all of the data from the screen

  The “Paste” button is used as follows:

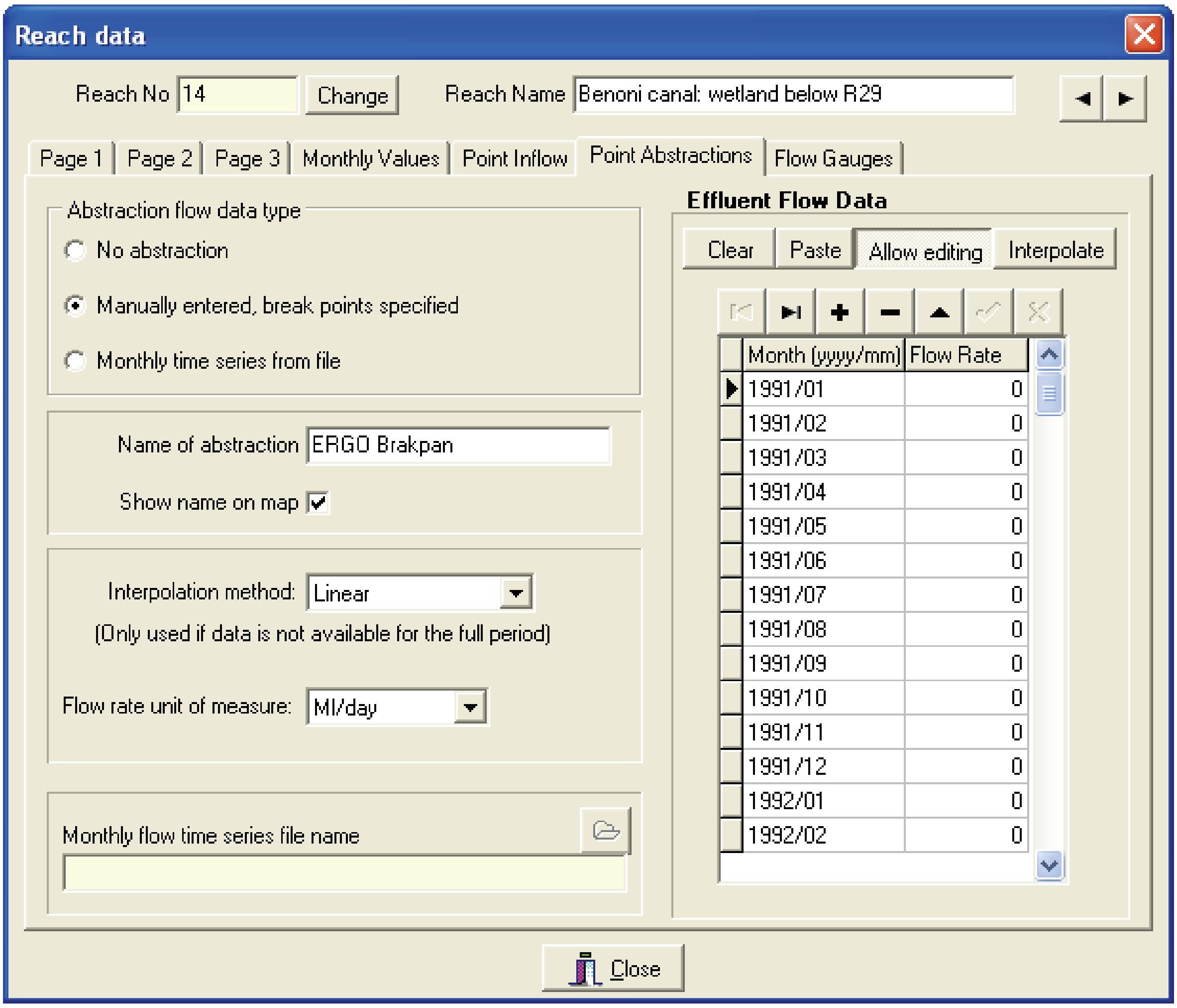
  - Block the appropriate cells in the spreadsheet and copy them to the clipboard
  - In this screen select the “Paste” button

    This will paste the data into the window.

  Selecting the “Allow editing” button permits manual entries to be made and to edit any of the cells.

  Selecting the “Interpolate” button automatically patches gaps in the data.

The sixth **Reach Data** tab (**Point abstractions**) is shown below:



Reach No 14

Reach Name Benoni canal: wetland below R29

Abstraction flow data type

○ No abstraction

● Manually entered, break points specified

○ Monthly time series from file

Name of abstraction ERGO Brakpan

Show name on map ☑

Interpolation method: Linear

(Only used if data is not available for the full period)

Flow rate unit of measure: Ml/day

Monthly flow time series file name

Effluent Flow Data

Month (yyyy/mm)	Flow Rate
1991/01	0
1991/02	0
1991/03	0
1991/04	0
1991/05	0
1991/06	0
1991/07	0
1991/08	0
1991/09	0
1991/10	0
1991/11	0
1991/12	0
1992/01	0
1992/02	0

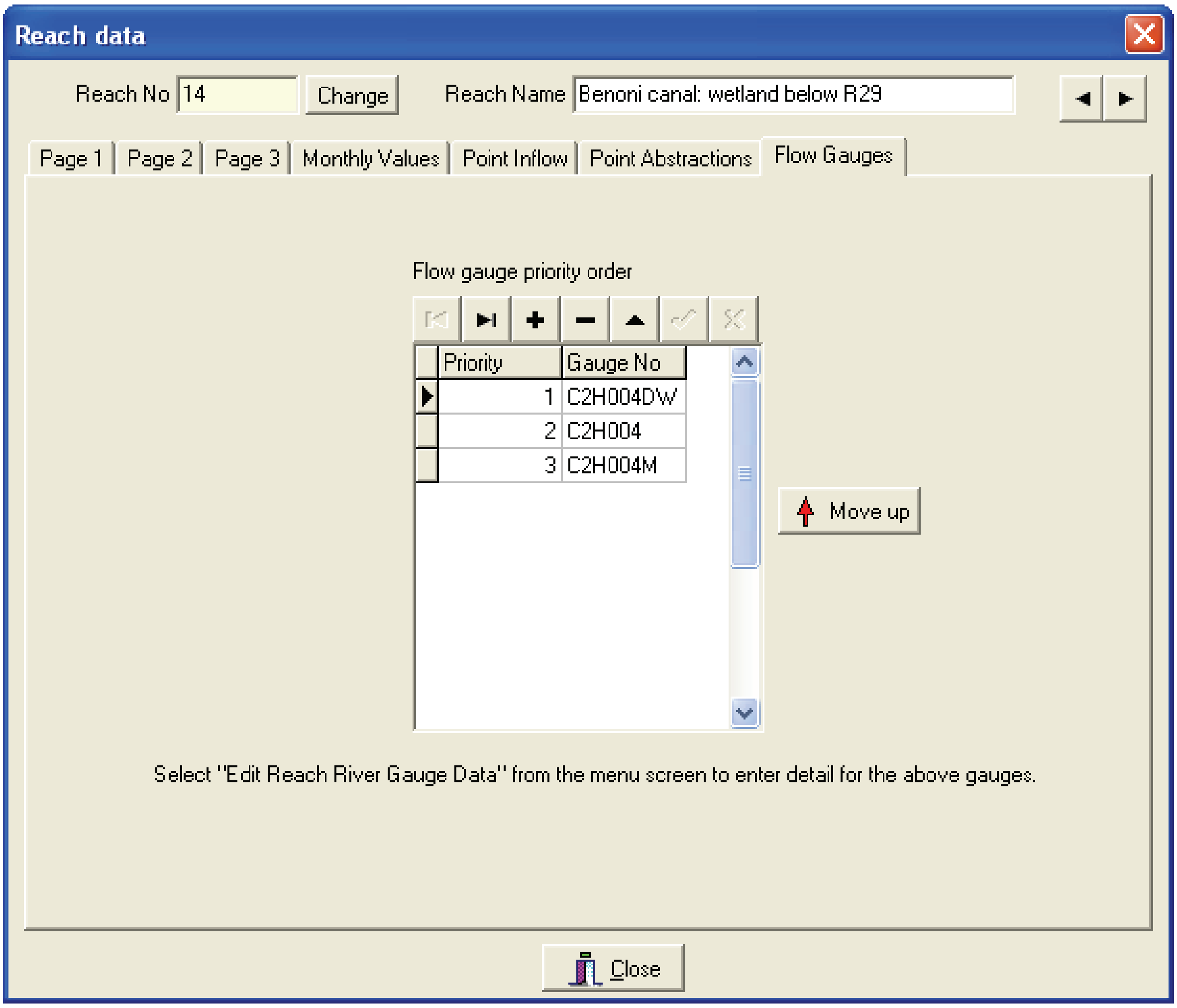
This screen has identical fields to that for point inflows. In addition, an option has been included to enter the monthly time series adapt from a file.

When specifying break point data for point input or point abstractions, the full reporting period specified for the project should be covered. If data is not available for the full period, enter realistic values for the first and last months. If no period start or end values are specified, the extrapolation routine may produce unrealistic values.

The seventh **Reach Data** tab (**Flow gauges**) is shown below:

This screen allows the priority of the flow gauges to be defined for each channel reach. For the present application only one flow observation point is allowed. Hence all of the channel reaches should specify the same observation data sets with the same order of priority.

However, provision has been made to accommodate more than one flow observation point. For example, if two observation points were used, then the channel reaches upstream of and adjacent to the upstream flow gauging point would specify the first gauging point as the first priority, with the second more remote gauging point having a lower priority.



Reach No 14

Reach Name Benoni canal: wetland below R29

Flow gauge priority order

Priority	Gauge No
1	C2H004DW
2	C2H004
3	C2H004M

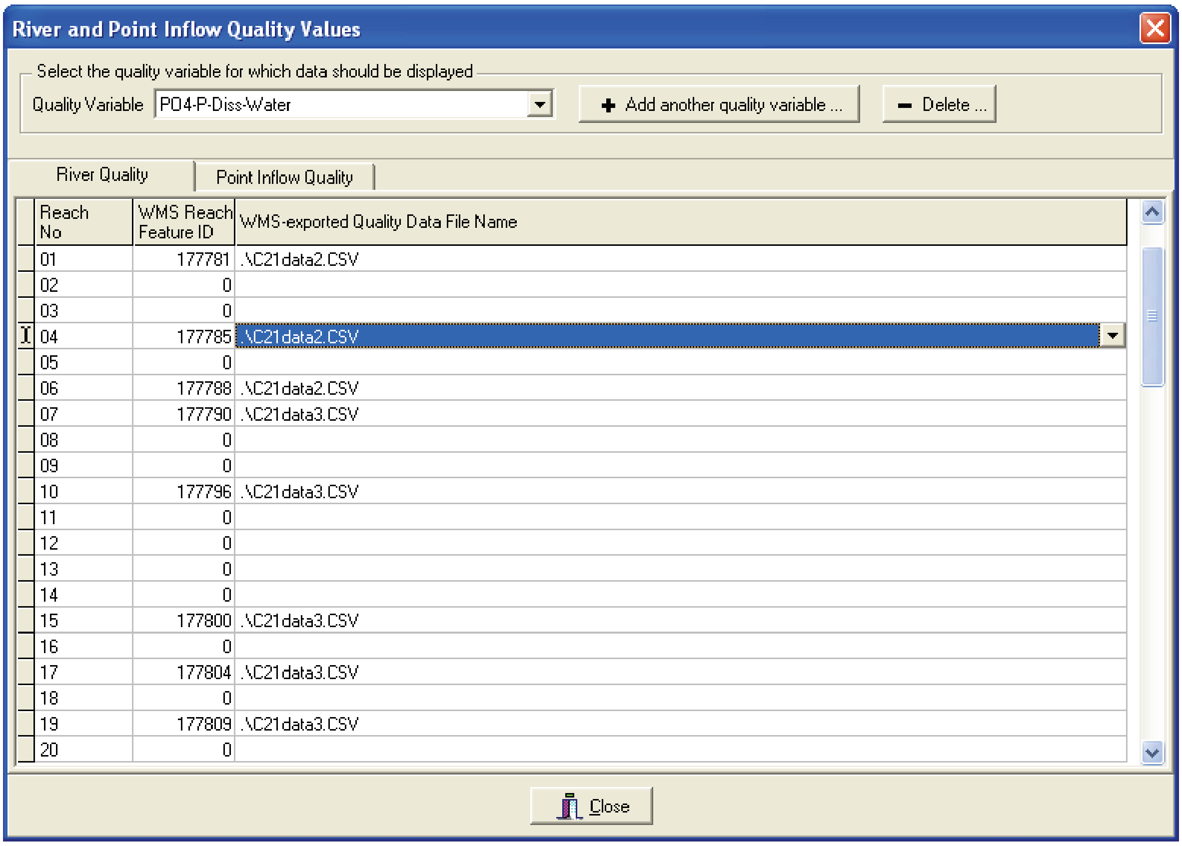
Select "Edit Reach River Gauge Data" from the menu screen to enter detail for the above gauges.

Edit Quality Data

Selection of this main menu option opens the **River and Point Inflow Quality Values** screen.

The first **River and Point Inflow Quality Values** tab (**River Quality**) is shown below

The following items are specified for each channel reach in this screen:



Quality Variable PO4-P-Diss-Water

Reach No	WMS Reach Feature ID	WMS-exported Quality Data File Name
01	177781	.\C21data2.CSV
02	0	
03	0	
04	177785	.\C21data2.CSV
05	0	
06	177788	.\C21data2.CSV
07	177790	.\C21data3.CSV
08	0	
09	0	
10	177796	.\C21data3.CSV
11	0	
12	0	
13	0	
14	0	
15	177800	.\C21data3.CSV
16	0	
17	177804	.\C21data3.CSV
18	0	
19	177809	.\C21data3.CSV
20	0	

- WMS reach feature ID

  This is the code used to denote a water quality monitoring point in the DWA's WMS database. (Not all channel reaches will have such data.)

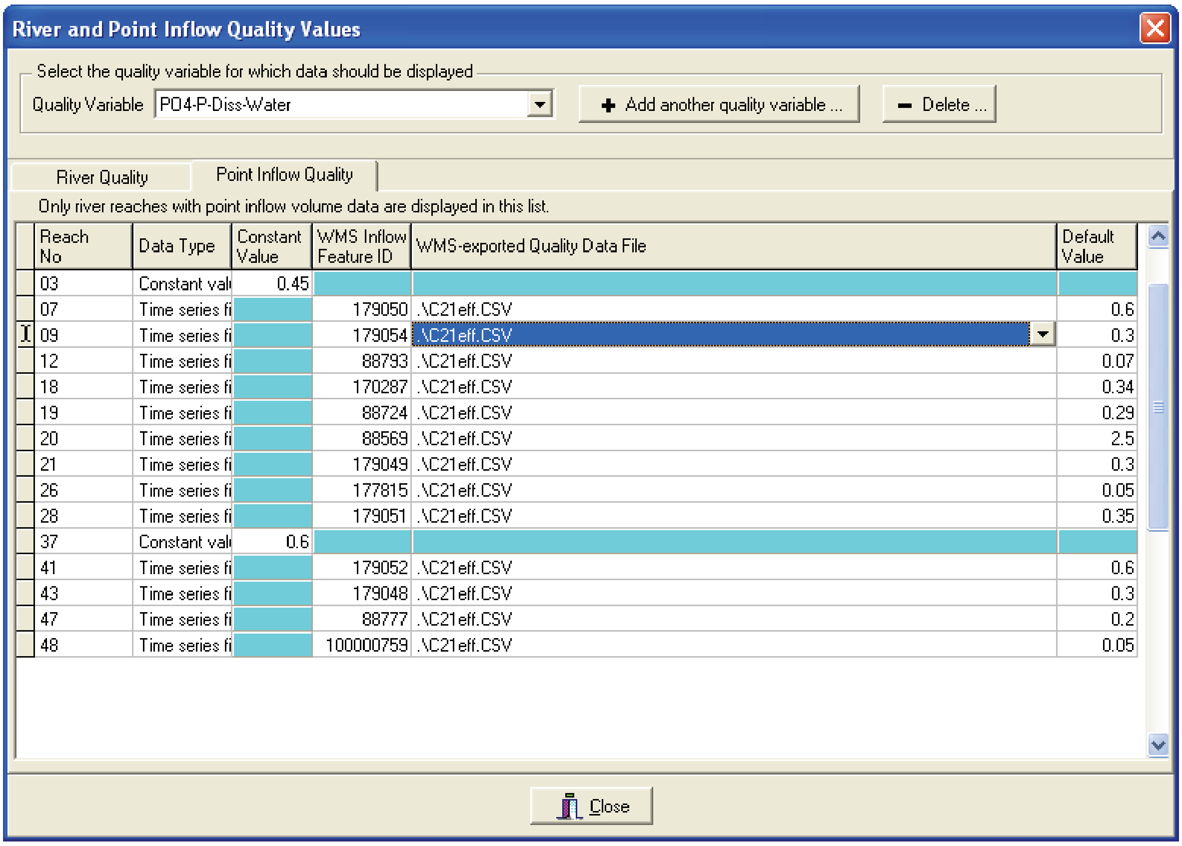
- Quality variable

  The water quality variable is selected from a drop down menu of standard parameter descriptions found in the WMS files.

- WMS exported quality data file name

  This is the name of the .CSV data file containing the water quality data for this channel reach. By default the preceding path name is taken as that specified in the project attributes screen. However, the user can browse for a file in some other directory. The water quality data for all of the monitoring points could be contained in the same WMS file, or as in the example, the data could be contained in more than one file. However, all of the data for a monitoring point should be contained in only one file since the present application does not have a facility to concatenate monitoring point records.

The second **River and Point Inflow Quality Values** tab (**Point Inflow Quality**) is shown below



Select the quality variable for which data should be displayed

Quality Variable: PO4-P-Diss-Water

Only river reaches with point inflow volume data are displayed in this list.

Reach No	Data Type	Constant Value	WMS Inflow Feature ID	WMS-exported Quality Data File	Default Value
03	Constant val	0.45			
07	Time series fi		179050	.\C21eff.CSV	0.6
09	Time series fi		179054	.\C21eff.CSV	0.3
12	Time series fi		88793	.\C21eff.CSV	0.07
18	Time series fi		170287	.\C21eff.CSV	0.34
19	Time series fi		88724	.\C21eff.CSV	0.29
20	Time series fi		88569	.\C21eff.CSV	2.5
21	Time series fi		179049	.\C21eff.CSV	0.3
26	Time series fi		177815	.\C21eff.CSV	0.05
28	Time series fi		179051	.\C21eff.CSV	0.35
37	Constant val	0.6			
41	Time series fi		179052	.\C21eff.CSV	0.6
43	Time series fi		179048	.\C21eff.CSV	0.3
47	Time series fi		88777	.\C21eff.CSV	0.2
48	Time series fi		100000759	.\C21eff.CSV	0.05

The following items are specified for each effluent point discharge to the channel reach:

- Quality variable
- Data type. This data can be specified as:
  Constant value, or
  Time series file
- If a constant value is specified, then this is entered into the open cell ("Constant Value") It is important that the units used are exactly the same as those used in the WMS database. For example, for phosphate WMS uses units of mg/ℓ. It would therefore be incorrect to use μg/ℓ for the specified constant value.

If a time series file is specified, then the following fields are filled:

- WMS Feature ID (the WMS monitoring point code for the point source)

- WMS exported quality data .CSV file name

- Default Value

  The default effluent concentration to be used when there are gaps in the record for chosen calibration dates. The initial choice of these default values can be modified after the first and subsequent calibration run to reflect the sample average. Constant values for unmonitored channel reaches can be set equal to the average for monitored point sources having similar characteristics.

Edit Calibration Parameters

Selection of this main menu option opens the **Calibration Parameters** screen.

<u>The first **Calibration Parameters** tab (**General parameters**)</u>

This screen is used to set the following:

- Start and end tears of the calibration period

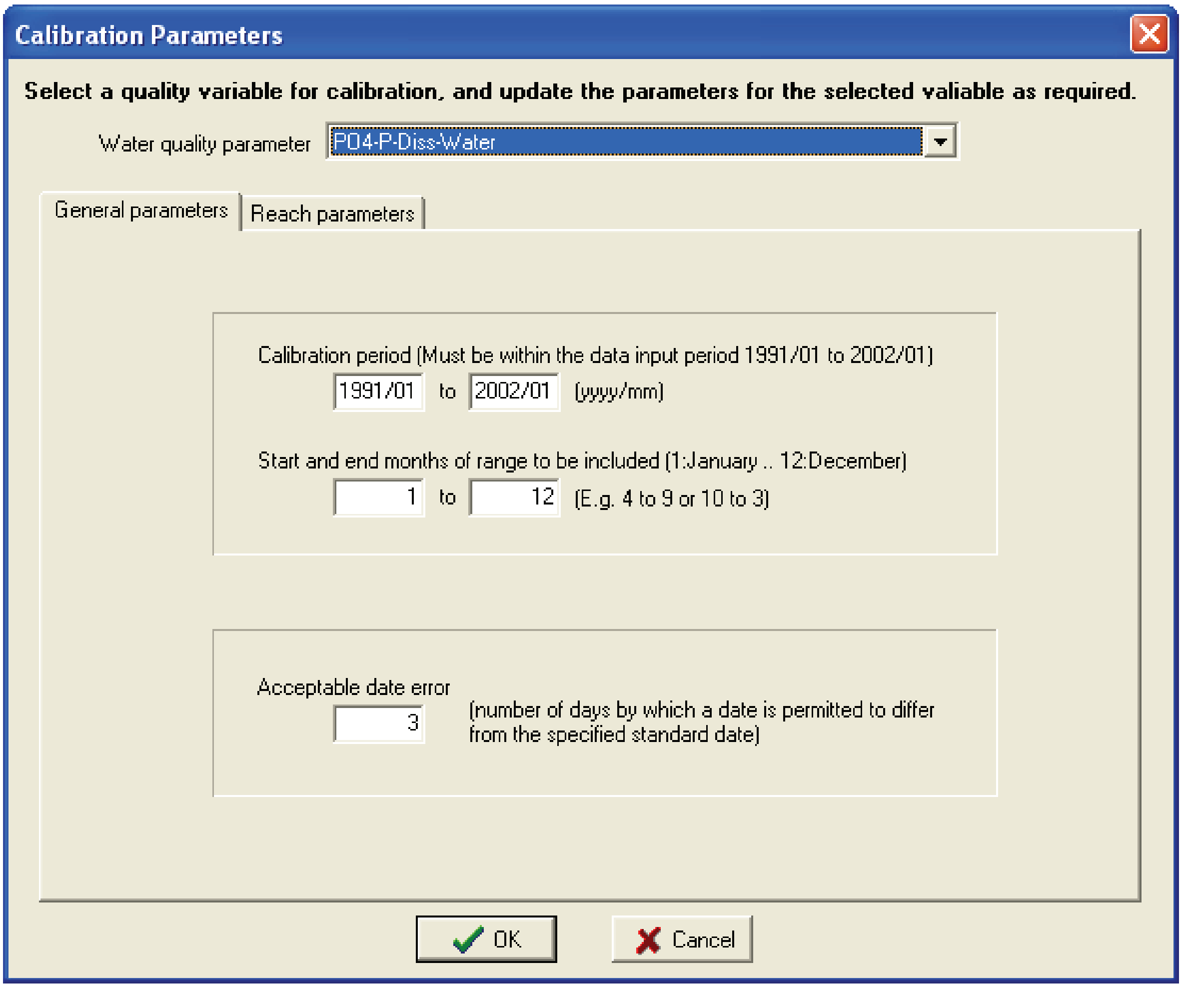
  This period must lie between the start and end dates set in the **Project Attributes** screen (see the main menu option **Edit Project Attributes**)

- Set the seasonal range

  This allows seasonal partitioning of the data. For example, if only the low flow season flows are to be examined, then the range of months 4 to 9 would mean that only the winder months from April to September are used.

- Set acceptable date error

  This is the range of days (before and after each selected calibration date) that will be accepted as being essentially the same sample. A fuller explanation is given in Section 2.2.4.2 of the main report.



Calibration Parameters

Select a quality variable for calibration, and update the parameters for the selected valiable as required.

Water quality parameter: PO4-P-Diss-Water

Calibration period (Must be within the data input period 1991/01 to 2002/01)
1991/01 to 2002/01 (yyyy/mm)

Start and end months of range to be included (1:January .. 12:December)
1 to 12 (E.g. 4 to 9 or 10 to 3)

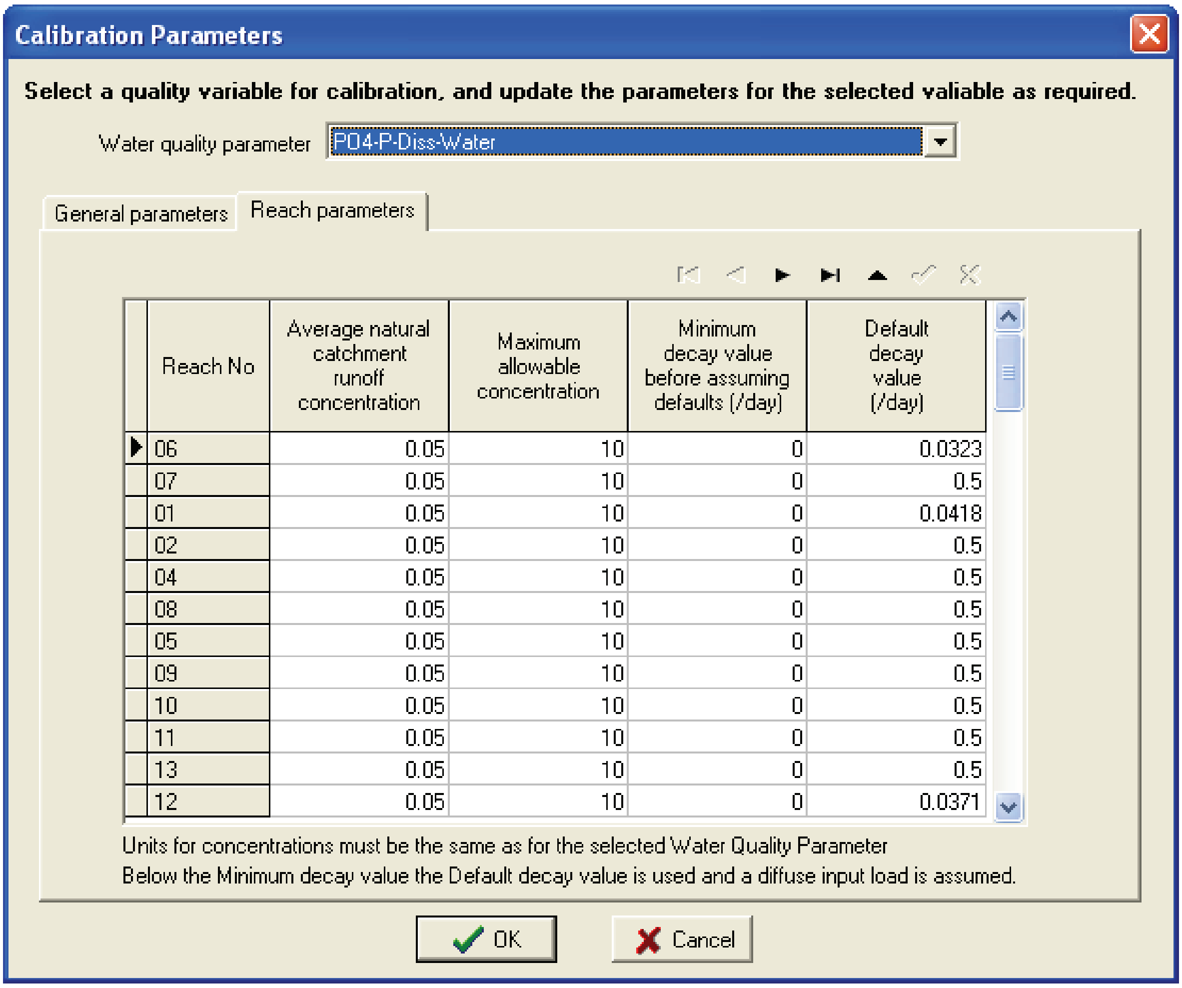
Acceptable date error
3 (number of days by which a date is permitted to differ from the specified standard date)

<u>The second **Calibration Parameters** tab (**Reach parameters**)</u>

This screen is used to set the following:

- Average natural catchment runoff concentration
- Maximum allowable concentration
- Minimum decay value before assuming defaults (day^{-1})
- Default decay value (day^{-1})

Again, the default values can be modified after the first and successive calibration runs to reflect the average for the channel reach (or for a nearby reach with similar characteristics if only default values were used for the channel reach.)



Select a quality variable for calibration, and update the parameters for the selected valiable as required.

Water quality parameter PO4-P-Diss-Water

Reach No	Average natural catchment runoff concentration	Maximum allowable concentration	Minimum decay value before assuming defaults (/day)	Default decay value (/day)
06	0.05	10	0	0.0323
07	0.05	10	0	0.5
01	0.05	10	0	0.0418
02	0.05	10	0	0.5
04	0.05	10	0	0.5
08	0.05	10	0	0.5
05	0.05	10	0	0.5
09	0.05	10	0	0.5
10	0.05	10	0	0.5
11	0.05	10	0	0.5
13	0.05	10	0	0.5
12	0.05	10	0	0.0371

Units for concentrations must be the same as for the selected Water Quality Parameter

Below the Minimum decay value the Default decay value is used and a diffuse input load is assumed.

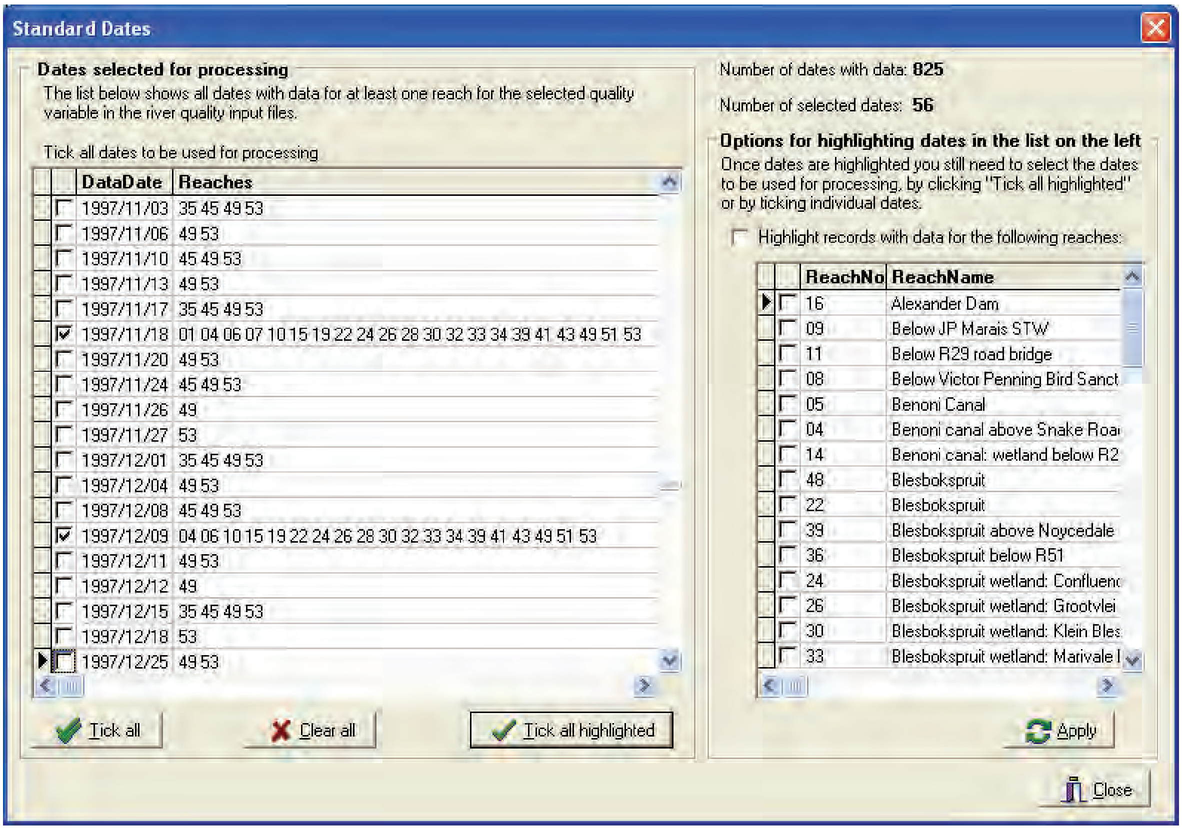
Select Dates for Processing

Selection of this main menu option opens the **Standard Dates** screen.

The model automatically populates this screen with all of the dates for which there is one or more river water quality sample and a flow data at the observation flow gauge. The numbers of all channel reaches for which there is water quality data are shown to aid the user in selecting calibration dates.

- Dates can be selected by checking the boxes in the left hand column.
- The user can also check the most important sampling points in the right hand set of boxes and check the “Highlight records..” option. This causes all of the dates in the left hand box that contain one or more of the selected reaches to be highlighted. Selecting

the “Tick all highlighted” button will then automatically select these dates. This is not the recommended method of selection since it will include dates for which only one of the identified reaches has data. However, highlighting the records is a useful means of identifying potential calibration dates that can then be selected manually if there is sufficient data from other stations.



Dates selected for processing

The list below shows all dates with data for at least one reach for the selected quality variable in the river quality input files.

Tick all dates to be used for processing

	DataDate	Reaches
☐	1997/11/03	35 45 49 53
☐	1997/11/06	49 53
☐	1997/11/10	45 49 53
☐	1997/11/13	49 53
☐	1997/11/17	35 45 49 53
☑	1997/11/18	01 04 06 07 10 15 19 22 24 26 28 30 32 33 34 39 41 43 49 51 53
☐	1997/11/20	49 53
☐	1997/11/24	45 49 53
☐	1997/11/26	49
☐	1997/11/27	53
☐	1997/12/01	35 45 49 53
☐	1997/12/04	49 53
☐	1997/12/08	45 49 53
☑	1997/12/09	04 06 10 15 19 22 24 26 28 30 32 33 34 39 41 43 49 51 53
☐	1997/12/11	49 53
☐	1997/12/12	49
☐	1997/12/15	35 45 49 53
☐	1997/12/18	53
☐	1997/12/25	49 53

Number of dates with data: **825**

Number of selected dates: **56**

Options for highlighting dates in the list on the left

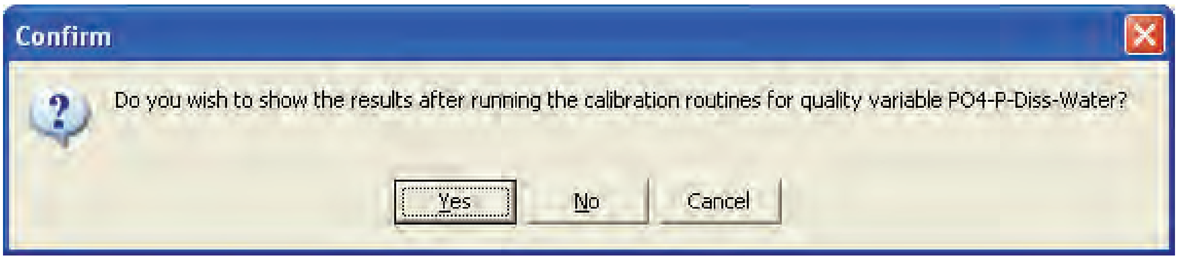
Once dates are highlighted you still need to select the dates to be used for processing, by clicking "Tick all highlighted" or by ticking individual dates.

☐ Highlight records with data for the following reaches:

	ReachNo	ReachName
☐	16	Alexander Dam
☐	09	Below JP Marais STW
☐	11	Below R29 road bridge
☐	08	Below Victor Penning Bird Sanct
☐	05	Benoni Canal
☐	04	Benoni canal above Snake Roa
☐	14	Benoni canal: wetland below R2
☐	48	Blesbokspruit
☐	22	Blesbokspruit
☐	39	Blesbokspruit above Noycedale
☐	36	Blesbokspruit below R51
☐	24	Blesbokspruit wetland: Confluen
☐	26	Blesbokspruit wetland: Grootvlei
☐	30	Blesbokspruit wetland: Klein Bles
☐	33	Blesbokspruit wetland: Marivale

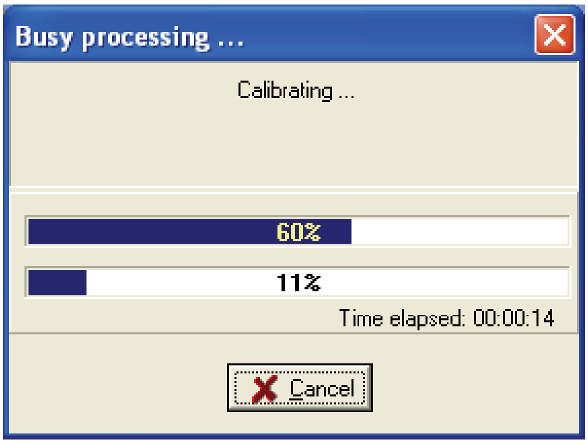
Run Data Calibration

This main menu option opens the **Confirm** screen, asks if the user wants the results screens to be displayed automatically on completion of the calibration run.



Do you wish to show the results after running the calibration routines for quality variable PO4-P-Diss-Water?

Thereafter the **Busy Processing** screen is opened, which indicates the elapsed time and the current operation that is in progress.

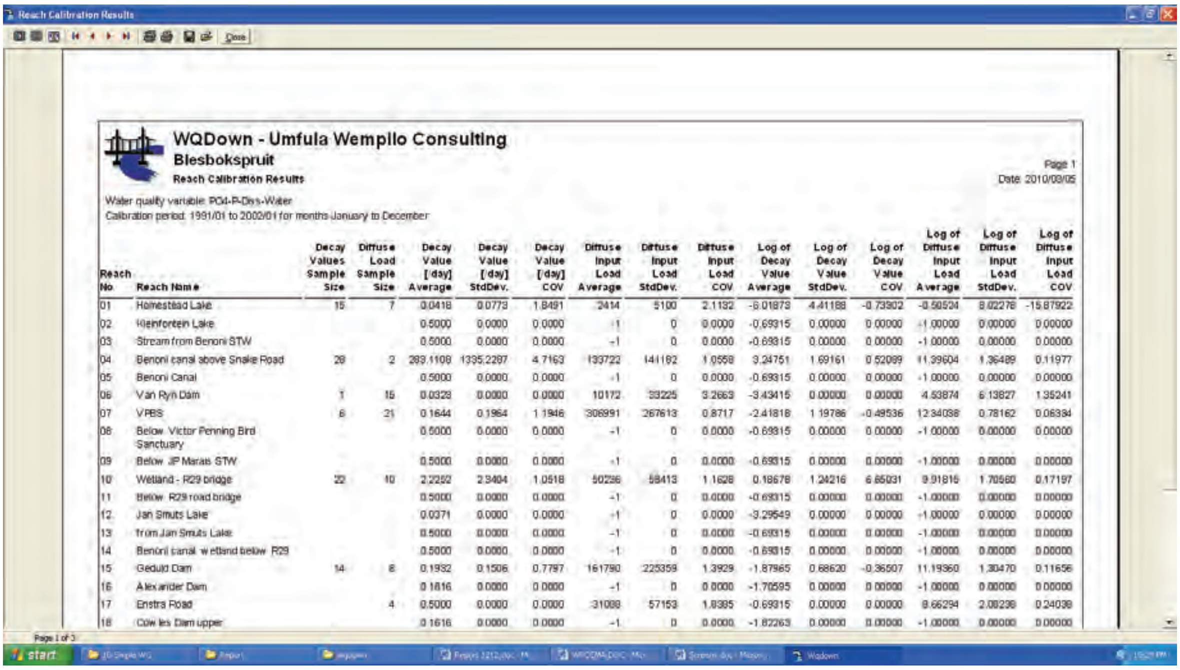


Calibrating ...

Time elapsed: 00:00:14

Display Reach Calibration Results

Selection of this main menu option opens the **Reach Calibration Results** report.



WQDown - Umfula Wempilo Consulting
Blesbokspruit
Reach Calibration Results

Page 1
Date: 2010/03/05

Water quality variable: PO4-P-Diss-Water
Calibration period: 1991/01 to 2002/01 for months January to December

Reach No	Reach Name	Decay Values Sample Size	Diffuse Load Sample Size	Decay Value [/day] Average	Decay Value [/day] StdDev.	Decay Value [/day] COV	Diffuse Input Load Average	Diffuse Input Load StdDev.	Diffuse Input Load COV	Log of Decay Value Average	Log of Decay Value StdDev.	Log of Decay Value COV	Log of Diffuse Input Load Average	Log of Diffuse Input Load StdDev.	Log of Diffuse Input Load COV
01	Homestead Lake	15	7	0.0418	0.0773	1.8491	2414	5100	2.1132	-6.01873	4.41188	-0.73302	-0.50524	8.02276	-15.87922
02	Kleinfontein Lake			0.5000	0.0000	0.0000	-1	0	0.0000	-0.69315	0.00000	0.00000	-1.00000	0.00000	0.00000
03	Stream from Benoni STW			0.5000	0.0000	0.0000	-1	0	0.0000	-0.69315	0.00000	0.00000	-1.00000	0.00000	0.00000
04	Benoni canal above Snake Road	28	2	283.1108	1335.2287	4.7163	133722	141182	1.0558	3.24751	1.69161	0.52089	11.39604	1.36489	0.11977
05	Benoni Canal			0.5000	0.0000	0.0000	-1	0	0.0000	-0.69315	0.00000	0.00000	-1.00000	0.00000	0.00000
06	Van Ryn Dam	1	15	0.0323	0.0000	0.0000	10172	33225	3.2663	-3.43415	0.00000	0.00000	4.53874	6.13827	1.35241
07	VPBS	6	21	0.1644	0.1964	1.1946	306991	267613	0.8717	-2.41818	1.19786	-0.49536	12.34038	0.78162	0.06334
08	Below Victor Penning Bird Sanctuary			0.5000	0.0000	0.0000	-1	0	0.0000	-0.69315	0.00000	0.00000	-1.00000	0.00000	0.00000
09	Below JP Marais STW			0.5000	0.0000	0.0000	-1	0	0.0000	-0.69315	0.00000	0.00000	-1.00000	0.00000	0.00000
10	Wetland - R29 bridge	22	10	2.2252	2.3404	1.0518	50236	58413	1.1628	0.18678	1.24216	6.65031	9.91816	1.70560	0.17197
11	Below R29 road bridge			0.5000	0.0000	0.0000	-1	0	0.0000	-0.69315	0.00000	0.00000	-1.00000	0.00000	0.00000
12	Jan Smuts Lake			0.0371	0.0000	0.0000	-1	0	0.0000	-3.29549	0.00000	0.00000	-1.00000	0.00000	0.00000
13	from Jan Smuts Lake			0.5000	0.0000	0.0000	-1	0	0.0000	-0.69315	0.00000	0.00000	-1.00000	0.00000	0.00000
14	Benoni canal wetland below R29			0.5000	0.0000	0.0000	-1	0	0.0000	-0.69315	0.00000	0.00000	-1.00000	0.00000	0.00000
15	Geduld Dam	14	6	0.1932	0.1506	0.7797	161790	225359	1.3929	-1.87965	0.68620	-0.36507	11.19360	1.30470	0.11656
16	Alexander Dam			0.1816	0.0000	0.0000	-1	0	0.0000	-1.70595	0.00000	0.00000	-1.00000	0.00000	0.00000
17	Enstra Road		4	0.5000	0.0000	0.0000	31088	57153	1.8385	-0.69315	0.00000	0.00000	8.66294	2.08238	0.24039
18	Cowles Dam upper			0.1616	0.0000	0.0000	-1	0	0.0000	-1.82263	0.00000	0.00000	-1.00000	0.00000	0.00000

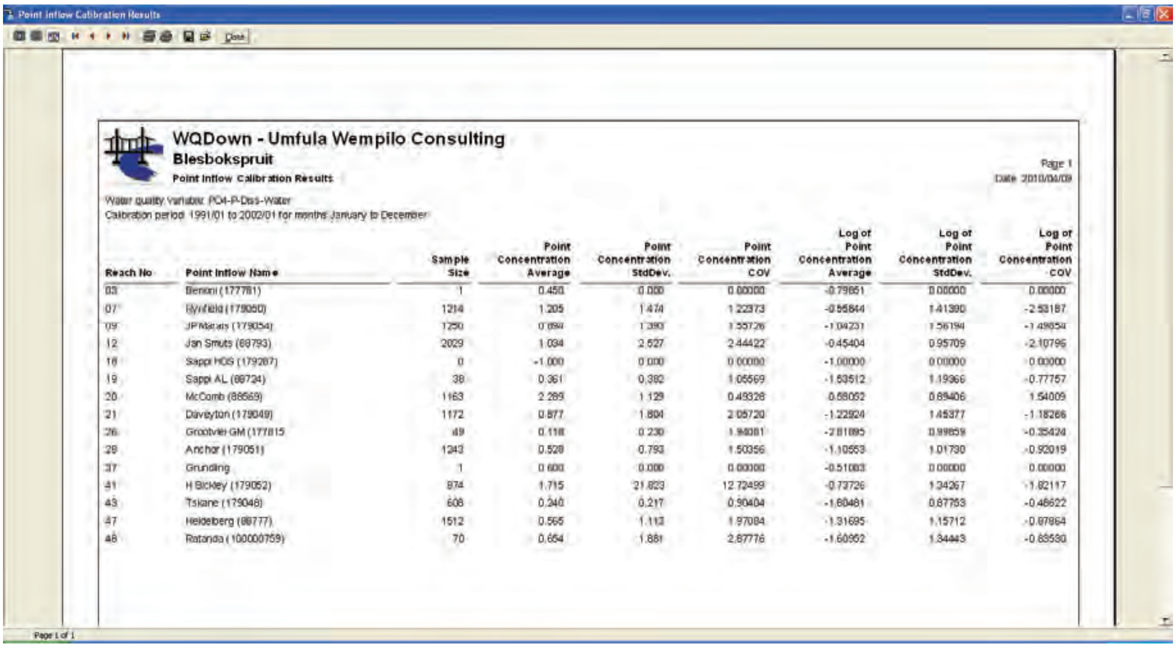
The report records the water quality variable used, the calibration period and the date when the report was generated. The following parameter values are displayed in this report for each channel reach:

- Channel reach number and name
- Decay value sample size
- Diffuse load sample size
- Average of calculated decay values (day^1)
- Standard deviation of calculated decay values (day^1)
- Coefficient of variation of calculated decay values
- Average of calculated logs of decay values
- Standard deviation of calculated logs of decay values
- Coefficient of variation of calculated logs of decay values
- Average of calculated daily diffuse load inputs (appropriate units)
- Standard deviation of calculated daily diffuse load inputs (appropriate units)
- Coefficient of variation of calculated daily diffuse load inputs
- Average of calculated logs of daily diffuse load inputs
- Standard deviation of calculated logs of daily diffuse load inputs
- Coefficient of variation of calculated logs of daily diffuse load inputs.

Display Point Inflow Calibration Results

Selection of this main menu option opens the **Point Inflow Calibration Results** report.

This report records the water quality variable used, the calibration period and the date when the report was generated. The following parameter effluent water quality parameter values are displayed in this report for each channel reach:



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Blesbokspruit
Point Inflow Calibration Results

Page 1
Date 2010/04/09

Water quality variable: PO4-P-Diss-Water
Calibration period 1991/01 to 2002/01 for months January to December

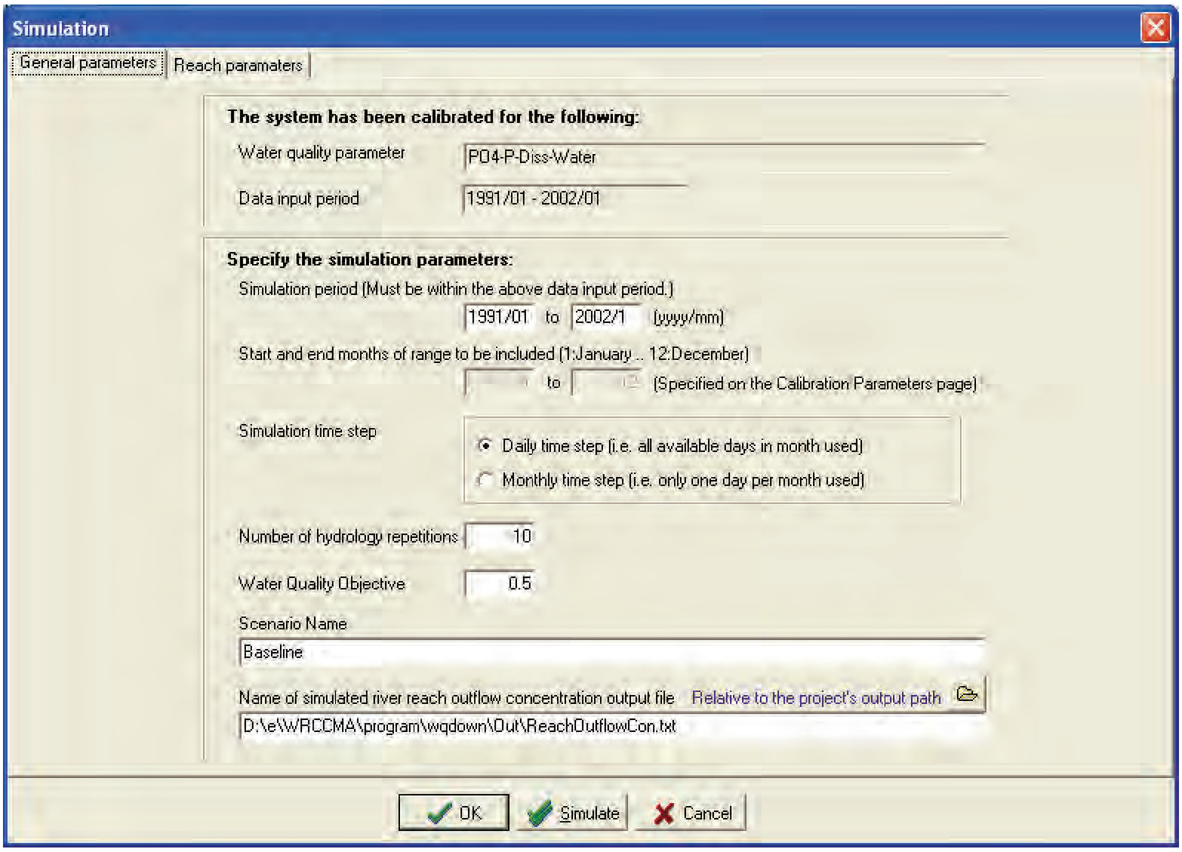
Reach No	Point Inflow Name	Sample Size	Point Concentration Average	Point Concentration StdDev.	Point Concentration COV	Log of Point Concentration Average	Log of Point Concentration StdDev.	Log of Point Concentration COV
03	Benoni (177781)	1	0.450	0.000	0.00000	-0.79851	0.00000	0.00000
07	Rynfield (179050)	1214	1.205	1.474	1.22373	-0.55844	1.41390	-2.53187
09	JP Marais (179054)	1250	0.894	1.390	1.55726	-1.04231	1.56194	-1.49854
12	Jan Smuts (88793)	2029	1.034	2.527	2.44422	-0.45404	0.95709	-2.10796
16	Sappi HOS (179287)	0	-1.000	0.000	0.00000	-1.00000	0.00000	0.00000
19	Sappi AL (88724)	38	0.361	0.382	1.05569	-1.53512	1.19366	-0.77757
20	McComb (88569)	1163	2.289	1.129	0.49328	0.58052	0.89406	1.54009
21	Daveyton (179049)	1172	0.877	1.804	2.05720	-1.22924	1.45377	-1.18266
26	Grootvlei GM (177815	49	0.118	0.230	1.94081	-2.81895	0.99859	-0.35424
29	Anchor (179051)	1243	0.528	0.793	1.50356	-1.10553	1.01730	-0.92019
37	Grundling	1	0.600	0.000	0.00000	-0.51083	0.00000	0.00000
41	H Bickley (179052)	874	1.715	21.823	12.72499	-0.73726	1.34267	-1.82117
43	Tsiane (179048)	608	0.240	0.217	0.90404	-1.80481	0.87753	-0.48622
47	Heidelberg (88777)	1512	0.565	1.113	1.97084	-1.31695	1.15712	-0.87864
48	Ratanda (100000759)	70	0.654	1.881	2.87776	-1.60952	1.34443	-0.83530

- Channel reach number and name
- Water quality data sample size
- Average of the observed water quality analyses (appropriate units)
- Standard deviation of the observed water quality analyses (appropriate units)
- Coefficient of variation of the observed water quality analyses
- Average of the logs of the observed water quality analyses (appropriate units)
- Standard deviation of the logs of the observed water quality analyses (appropriate units)
- Coefficient of variation of the logs of the observed water quality analyses.

Edit Simulation Attributes

Selection of this main menu option opens the **Simulation** screen.

The first **Simulation** screen tab (**General parameters**) is shown below



The system has been calibrated for the following:

Water quality parameter: PO4-P-Diss-Water

Data input period: 1991/01 - 2002/01

Specify the simulation parameters:

Simulation period (Must be within the above data input period.)
1991/01 to 2002/1 (yyyy/mm)

Start and end months of range to be included (1:January .. 12:December)
1 to 12 (Specified on the Calibration Parameters page)

Simulation time step
● Daily time step (i.e. all available days in month used)
○ Monthly time step (i.e. only one day per month used)

Number of hydrology repetitions: 10

Water Quality Objective: 0.5

Scenario Name: Baseline

Name of simulated river reach outflow concentration output file — Relative to the project's output path
D:\e\WRCCMA\program\wqdown\Out\ReachOutflowCon.txt

This screen is used to set the following:

- Simulation period

  The data input period is specified to assist in selecting a simulation period, which must lie within this range.

- Simulation time step

  The simulation time step can be defined as daily or monthly.

- Number of hydrology repetitions

  This defines the number of iterations of the hydrological sequence.

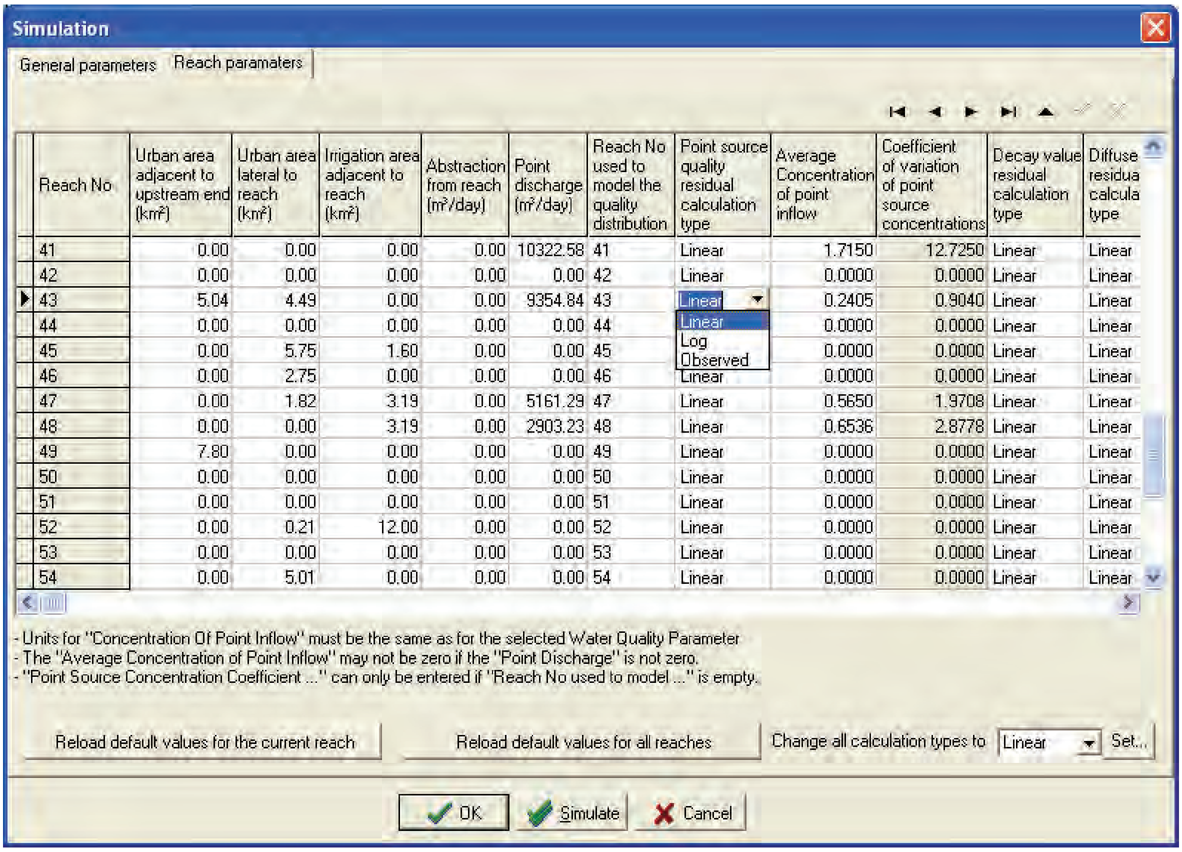
- Water quality objective

  This benchmark is shown in the generated duration curves and is also shown in the tabulated output.

- Name of simulated river reach outflow concentration output file

  The default path root is defined in the **Project Attributes** screen.

The second **Simulation** screen tab (**Reach parameters**) is shown below



Reach No	Urban area adjacent to upstream end (km²)	Urban area lateral to reach (km²)	Irrigation area adjacent to reach (km²)	Abstraction from reach (m³/day)	Point discharge (m³/day)	Reach No used to model the quality distribution	Point source quality residual calculation type	Average Concentration of point inflow	Coefficient of variation of point source concentrations	Decay value residual calculation type	Diffuse residua calcula type
41	0.00	0.00	0.00	0.00	10322.58	41	Linear	1.7150	12.7250	Linear	Linear
42	0.00	0.00	0.00	0.00	0.00	42	Linear	0.0000	0.0000	Linear	Linear
43	5.04	4.49	0.00	0.00	9354.84	43	Linear	0.2405	0.9040	Linear	Linear
44	0.00	0.00	0.00	0.00	0.00	44		0.0000	0.0000	Linear	Linear
45	0.00	5.75	1.60	0.00	0.00	45		0.0000	0.0000	Linear	Linear
46	0.00	2.75	0.00	0.00	0.00	46	Linear	0.0000	0.0000	Linear	Linear
47	0.00	1.82	3.19	0.00	5161.29	47	Linear	0.5650	1.9708	Linear	Linear
48	0.00	0.00	3.19	0.00	2903.23	48	Linear	0.6536	2.8778	Linear	Linear
49	7.80	0.00	0.00	0.00	0.00	49	Linear	0.0000	0.0000	Linear	Linear
50	0.00	0.00	0.00	0.00	0.00	50	Linear	0.0000	0.0000	Linear	Linear
51	0.00	0.00	0.00	0.00	0.00	51	Linear	0.0000	0.0000	Linear	Linear
52	0.00	0.21	12.00	0.00	0.00	52	Linear	0.0000	0.0000	Linear	Linear
53	0.00	0.00	0.00	0.00	0.00	53	Linear	0.0000	0.0000	Linear	Linear
54	0.00	5.01	0.00	0.00	0.00	54	Linear	0.0000	0.0000	Linear	Linear

- Units for "Concentration Of Point Inflow" must be the same as for the selected Water Quality Parameter
- The "Average Concentration of Point Inflow" may not be zero if the "Point Discharge" is not zero.
- "Point Source Concentration Coefficient ..." can only be entered if "Reach No used to model ..." is empty.

This screen defines the nature of the option to be simulated by defining the attributes of each river reach. The fields are initially populated with default values based on the values for the last month of the calibration period, therefore approximating the present day conditions pertaining to the end of the calibration period. Any of these default values may be modified to define the option to be simulated.

The following values may be specified for each reach in this screen:

- Urban area (incremental) adjacent to upstream end of channel reach (km^2)
- Urban area (incremental) lateral to channel reach (km^2)
- Irrigation area adjacent to (and supplied from) channel reach (km^2)
- Abstraction from channel reach (m^3/day)

  A constant discharge rate is assumed for the simulation mode.

- Point discharge to channel reach (m^3/day)

  A constant abstraction rate is assumed.

- Reach number used to model point source water quality distribution

  This feature allows the attributes defining the distribution of the point source concentrations to be set identical to those for a point source entering another reach. Thus, for example, if a new point source is to be introduced, the distribution of a similar existing effluent source (that was included in the calibration) can be used. The range of concentration of the new source will be scaled in proportion to the specified mean concentration and that of the point source used in the calibration. (That is why the non-dimensional coefficient of variation is used instead of the standard deviation.)

- Point source quality residual calculation type. Three choices are available:

  Linear (residual distribution based on mean and coefficient of variation of concentrations)
  Log (residual distribution based on mean and coefficient of variation of logs of concentrations)
  Observed (effluent concentration sampled from the observed distribution during the calibration period, suitably scaled to account for the specified mean concentration)

- Average concentration of point inflow (appropriate units)

- Coefficient of variation of point source concentrations

- Decay value residual calculation type (Linear, log or Observed):

  Linear (residual distribution based on mean and standard deviation of calculated decay values)
  Log (residual distribution based on mean and standard deviation of logs of calculated decay values)
  Observed (decay values sampled from the observed distribution during the calibration period)

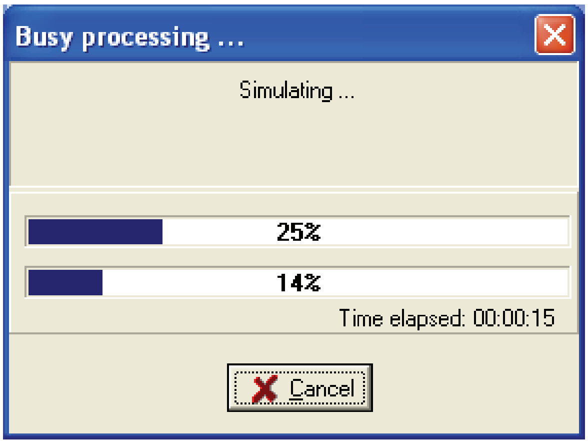
- Diffuse load residual calculation type. (Linear, log or Observed):

  Linear (residual distribution based on mean and standard deviation of calculated diffuse input loads)
  Log (residual distribution based on mean and standard deviation of logs of calculated diffuse input loads values)
  Observed (diffuse input loads sampled from the observed distribution during the calibration period)

- Options are provided to:
  Reload default values for the current reach
  Reload default values for all reaches
  Change all residual calculation types (to Linear, Log or Observed).

Run Simulation

This main menu option opens the **Busy processing** screen, which indicates the elapsed time and the current operation that is in progress.



Simulating ...

25%

14%

Time elapsed: 00:00:15

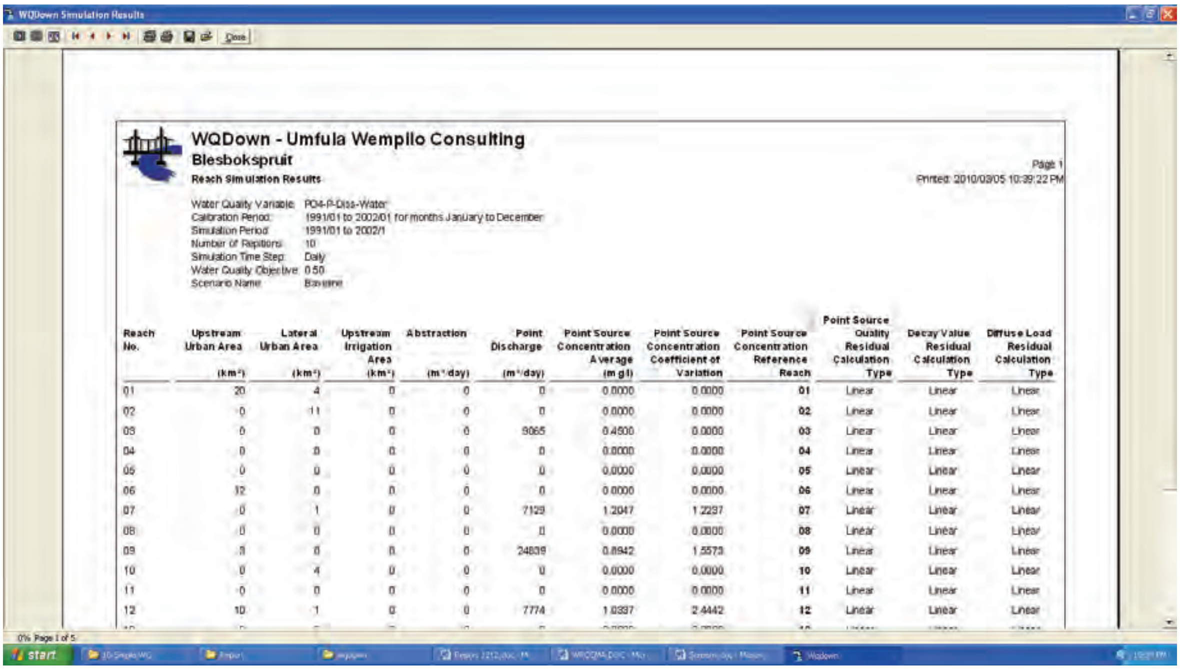
Statistics

Selection of this main menu option opens the **Reach Simulation Results** report.

This report records:

- Details defining the simulation:
  Option title
  Date and time of generation
  Calibration period
  Range of months included
  Simulation period
  Number of repetitions
  Simulation time step (Daily or Monthly)
  Water quality objective
  Scenario name

All of the variables set for each channel reach in the **Reach Parameter** tab of the **Simulation** screen are recorded in the first part of the report to uniquely define the option.



WQDown - Umfula Wempilo Consulting
Blesbokspruit
Reach Simulation Results

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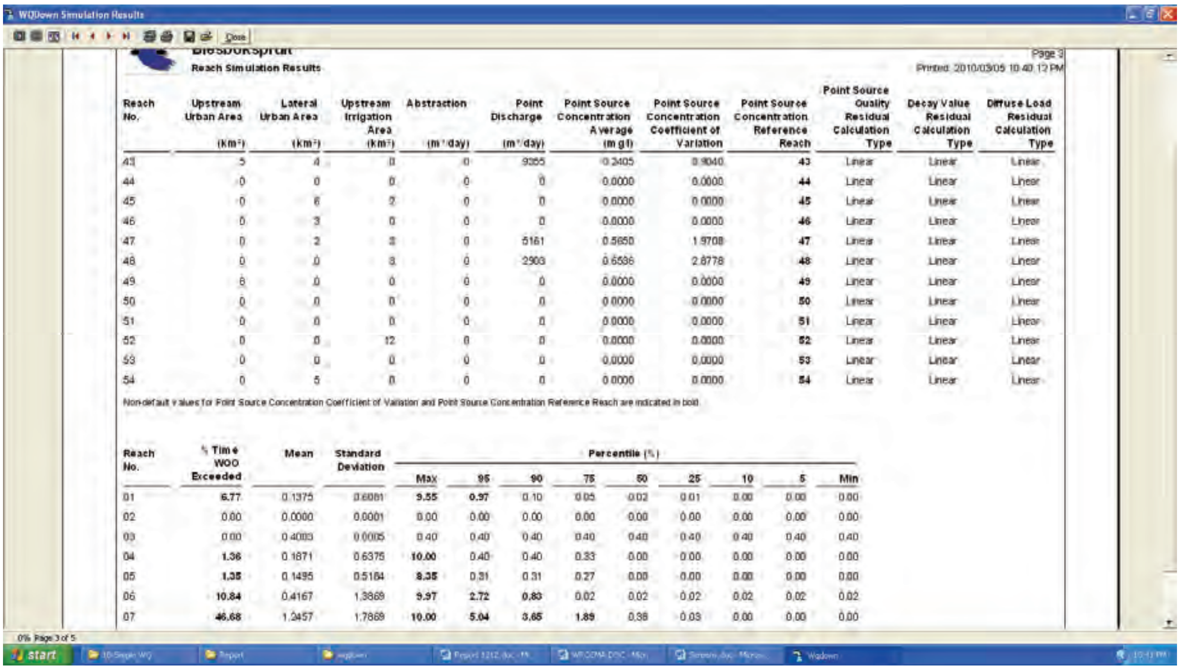
Water Quality Variable: PO4-P-Diss-Water
Calibration Period: 1991/01 to 2002/01 for months January to December
Simulation Period: 1991/01 to 2002/1
Number of Repitions: 10
Simulation Time Step: Daily
Water Quality Objective: 0.50
Scenario Name: Baseline

Reach No.	Upstream Urban Area (km²)	Lateral Urban Area (km²)	Upstream Irrigation Area (km²)	Abstraction (m³/day)	Point Discharge (m³/day)	Point Source Concentration Average (mg/l)	Point Source Concentration Coefficient of Variation	Point Source Concentration Reference Reach	Point Source Quality Residual Calculation Type	Decay Value Residual Calculation Type	Diffuse Load Residual Calculation Type
01	20	4	0	0	0	0.0000	0.0000	**01**	Linear	Linear	Linear
02	0	11	0	0	0	0.0000	0.0000	**02**	Linear	Linear	Linear
03	0	0	0	0	9065	0.4500	0.0000	**03**	Linear	Linear	Linear
04	0	0	0	0	0	0.0000	0.0000	**04**	Linear	Linear	Linear
05	0	0	0	0	0	0.0000	0.0000	**05**	Linear	Linear	Linear
06	12	0	0	0	0	0.0000	0.0000	**06**	Linear	Linear	Linear
07	0	1	0	0	7129	1.2047	1.2237	**07**	Linear	Linear	Linear
08	0	0	0	0	0	0.0000	0.0000	**08**	Linear	Linear	Linear
09	3	0	0	0	24839	0.8942	1.5573	**09**	Linear	Linear	Linear
10	0	4	0	0	0	0.0000	0.0000	**10**	Linear	Linear	Linear
11	0	0	0	0	0	0.0000	0.0000	**11**	Linear	Linear	Linear
12	10	1	0	0	7774	1.0337	2.4442	**12**	Linear	Linear	Linear

- The second part of the report gives the simulation results for each channel reach:

Reach number
Percentage time that the water quality objective was exceeded (values greater than zero are highlighted in bold)
Mean concentration at downstream end of the reach
Standard deviation of all of the simulated concentrations
Maximum, 95%, 90%, 75%, 50%, 25%, 10% and 5% percentiles and minimum simulated concentrations. (Values exceeding the water quality objective are shown in bold.)



Blesbokspruit
Reach Simulation Results

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Reach No.	Upstream Urban Area (km^2)	Lateral Urban Area (km^2)	Upstream Irrigation Area (km^2)	Abstraction (m^3/day)	Point Discharge (m^3/day)	Point Source Concentration Average (mg/l)	Point Source Concentration Coefficient of Variation	Point Source Concentration Reference Reach	Point Source Quality Residual Calculation Type	Decay Value Residual Calculation Type	Diffuse Load Residual Calculation Type
43	5	4	0	0	9365	0.2405	0.9040	**43**	Linear	Linear	Linear
44	0	0	0	0	0	0.0000	0.0000	**44**	Linear	Linear	Linear
45	0	6	2	0	0	0.0000	0.0000	**45**	Linear	Linear	Linear
46	0	3	0	0	0	0.0000	0.0000	**46**	Linear	Linear	Linear
47	0	2	3	0	5161	0.5650	1.9708	**47**	Linear	Linear	Linear
48	0	0	3	0	2903	0.6536	2.8778	**48**	Linear	Linear	Linear
49	6	0	0	0	0	0.0000	0.0000	**49**	Linear	Linear	Linear
50	0	0	0	0	0	0.0000	0.0000	**50**	Linear	Linear	Linear
51	0	0	0	0	0	0.0000	0.0000	**51**	Linear	Linear	Linear
52	0	0	12	0	0	0.0000	0.0000	**52**	Linear	Linear	Linear
53	0	0	0	0	0	0.0000	0.0000	**53**	Linear	Linear	Linear
54	0	5	0	0	0	0.0000	0.0000	**54**	Linear	Linear	Linear

Non-default values for Point Source Concentration Coefficient of Variation and Point Source Concentration Reference Reach are indicated in bold

Reach No.	% Time WQO Exceeded	Mean	Standard Deviation	Percentile (%)								
				Max	95	90	75	50	25	10	5	Min
01	**6.77**	0.1375	0.6081	**9.55**	**0.97**	0.10	0.05	0.02	0.01	0.00	0.00	0.00
02	0.00	0.0000	0.0001	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
03	0.00	0.4003	0.0005	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
04	**1.36**	0.1871	0.6375	**10.00**	0.40	0.40	0.33	0.00	0.00	0.00	0.00	0.00
05	**1.35**	0.1495	0.5184	**8.35**	0.31	0.31	0.27	0.00	0.00	0.00	0.00	0.00
06	**10.84**	0.4167	1.3869	**9.97**	**2.72**	**0.83**	0.02	0.02	0.02	0.02	0.02	0.02
07	**46.68**	1.2457	1.7869	**10.00**	**5.04**	**3.65**	**1.89**	0.38	0.03	0.00	0.00	0.00

Duration Curve

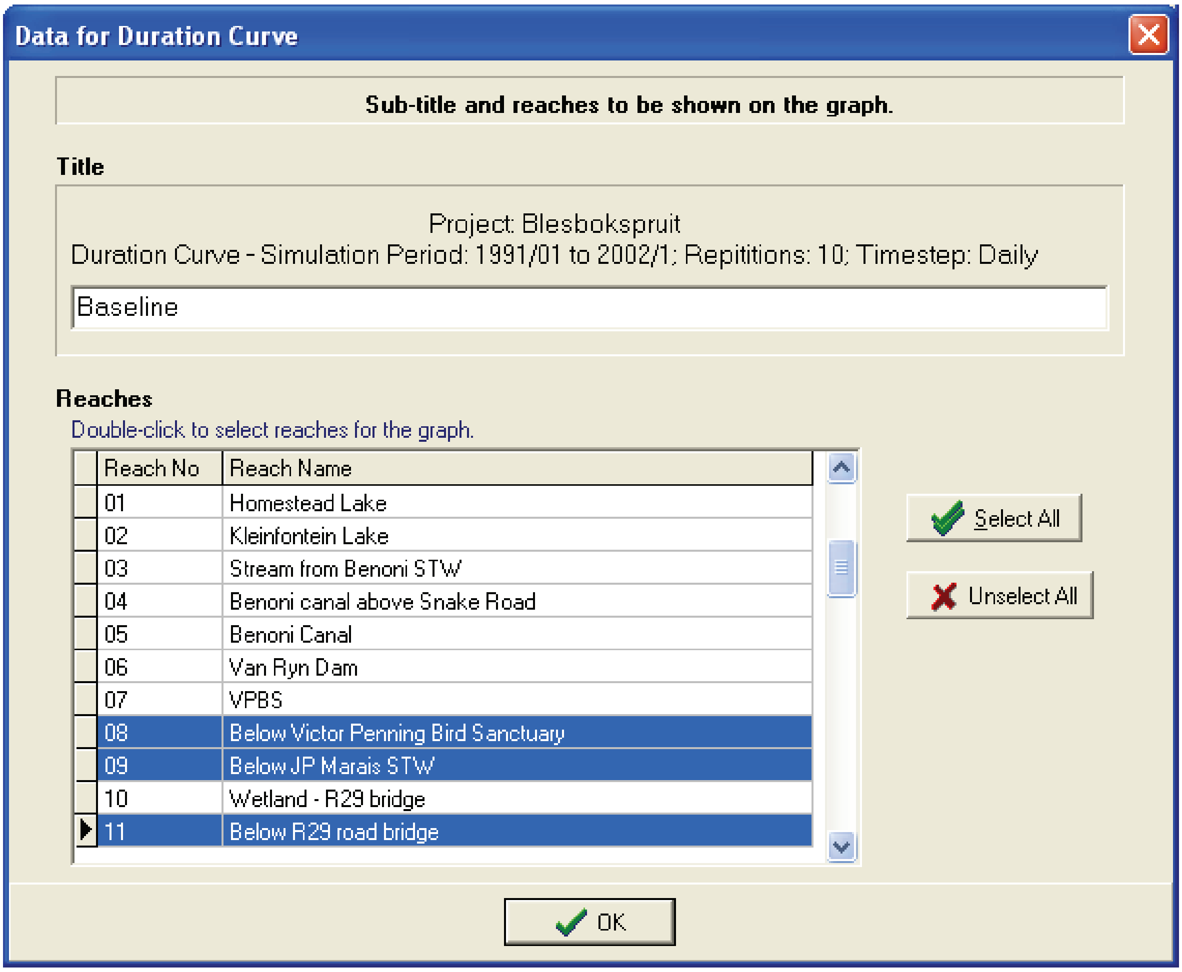
Selection of this main menu option opens the **Data for Duration Curve** screen.

This screen allows:

- Specification of the plot title
  The sub-title will default to the scenario description entered on the *Simulation* screen.

- Selection of one or more channel reaches to be plotted
  Provision is made to select all of the channel reaches for plotting or to unselect all reaches

- Selection of OK button generates the duration curve plot.



Sub-title and reaches to be shown on the graph.

Title

Project: Blesbokspruit
Duration Curve - Simulation Period: 1991/01 to 2002/1; Repititions: 10; Timestep: Daily

Baseline

Reaches

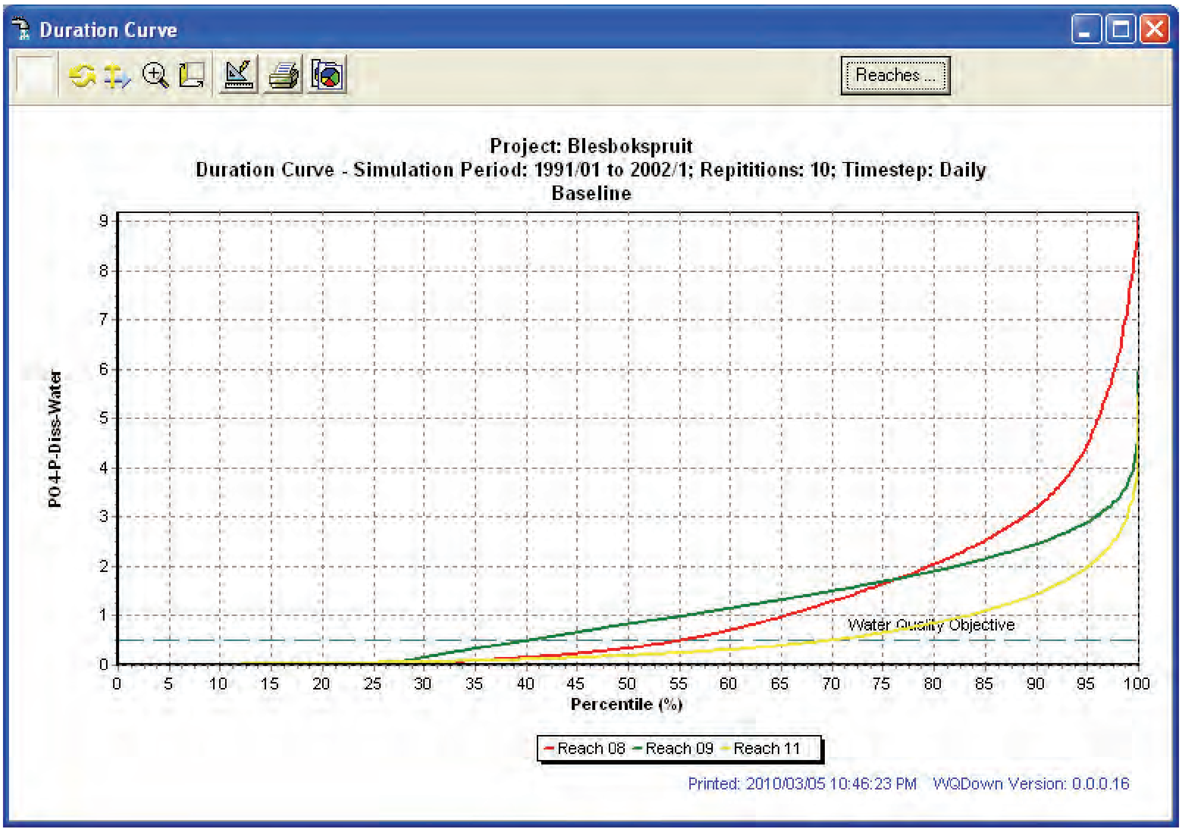
Double-click to select reaches for the graph.

Reach No	Reach Name
01	Homestead Lake
02	Kleinfontein Lake
03	Stream from Benoni STW
04	Benoni canal above Snake Road
05	Benoni Canal
06	Van Ryn Dam
07	VPBS
08	Below Victor Penning Bird Sanctuary
09	Below JP Marais STW
10	Wetland - R29 bridge
11	Below R29 road bridge

Plot output

An example of a generated duration curve is shown below.

The top task bar allows control over line colours and thicknesses.
The “Reaches” button returns control to the previous screen so that a new plot can be defined.


Duration Curve
Reaches ...
Project: Blesbokspruit
Duration Curve - Simulation Period: 1991/01 to 2002/1; Repititions: 10; Timestep: Daily
Baseline
PO4-P-Diss-Water
0
1
2
3
4
5
6
7
8
9
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
Percentile (%)
Water Quality Objective
Reach 08
Reach 09
Reach 11
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WQDown Version: 0.0.0.16