

# WAIORA User Guide

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*Water Allocation Impacts On River Attributes (Version 2.0)*



# User Guide

Version 2.0

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## USER MANUAL & HELP FILES

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Hoteo River at Gubbs, Auckland.

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## INTRODUCTION

### What does WAIORA stand for?

The Revised Dictionary of Modern Maori (Ryan 1989) defines WAI as the word for water and ORA the word for life, well, full and alive. Combined, WAIORA is the Maori word for health but it also means a fountain or well. Fountains and wells are considered good/healthy/sacred to the Maori people as the water from these two sources is considered pure and therefore fit for human and animal consumption (Dean Grace pers. com.). As an acronym for the computer package, WAIORA stands for Water Allocations Impacts On River Attributes.

### What does WAIORA do?

WAIORA Water Allocation Impacts on River Attributes, is a decision support system designed to provide guidance on whether a flow change could have adverse impacts on the following environmental parameters: Dissolved Oxygen, Total Ammonia, Water Temperature and Habitat for aquatic life.

WAIORA uses information on stream geometry and numerical models to estimate the effects of flow on these parameters, and compares the predictions to environmental guidelines that can be specified by the user to determine if an adverse effect is likely to occur. A number of assumptions have been made during model development and these are detailed in this manual and Help Files. The outputs of

WAIORA reflect the nature of these assumptions and the quality of the data entered by the user. The models are better at predicting the relative amount of change associated with flow scenarios than at predicting absolute changes. Some guidance on the expected accuracy of models and “comfort zones” associated with guideline thresholds is provided in the Help Files and the Summary Plots.

WAIORA provides:

- information on environmental criteria that can be used;
- predictions of the absolute and relative change associated with a flow change and whether specified environmental guideline thresholds are exceeded;
- where possible, predicted effects of avoidance/mitigation options and
- an audit trail of the procedures followed.

To use WAIORA you should:

have knowledge of the existing stream conditions above and below the proposed abstraction, and either collect data from two site visits to assess changes in habitat or carry out a more detailed instream habitat survey and calibration using RHYHABSIM.

## **Purpose and process**

WAIORA is a decision support system that can be used to assess the effects of flow changes on instream habitat, water temperature, dissolved oxygen concentration and ammonia concentration. WAIORA applies to a section of river, along which the stream conditions (e.g., geometry, flow, gradient, shade, and aquatic flora) are reasonably consistent.

The steps in the assessment process are:

1. select parameters to evaluate (stream geometry is required for all)
2. data collection
3. calibration (water temperature and DO models)
4. calculation of effects
5. evaluation of effects

The quality and scope of the stream habitat survey data will determine the reliability of the results, particularly the degree to which you can extrapolate beyond the flows that were surveyed. Two levels of survey are available. For quick assessments, stream widths and depths can be measured at two flows in at least 3 locations in each habitat type (e.g., pool, run, and riffle). Stream habitat is then estimated assuming logarithmic hydraulic relationships (Jowett 1998). In cases where you want to extrapolate to flows higher or lower than those surveyed, cross-section data can be collected and calibrated in RHYHABSIM. The normal procedure is to survey at least 5 cross-sections in each habitat type (e.g., pool, run, and riffle) and remeasure water levels at least two other flows.

Calibration data can also be collected for water temperature and dissolved oxygen models. These calibration data should be collected at times of maximum stress, normally mid summer. DataSondes can be deployed to measure diurnal variation in water temperature and dissolved oxygen concentration and inexpensive temperature loggers are available. Water temperatures are required at both the start and end of the section of river for calibration of the water temperature model. Although it is possible to model water temperature and dissolved oxygen without calibrated models, calibration is desirable to calculate appropriate parameters and coefficients for the dissolved oxygen models and to set appropriate initial water temperatures for the water temperature model.

Once the models have been calibrated, WAIORA calculates how instream habitat, water temperature, and dissolved oxygen and ammonia concentrations vary with flow and displays the values of these parameters for the index flow and the new flow that will result from the proposed abstraction or flow discharge.

## **Management objectives**

The evaluation of the effect of flow change on habitat, temperature, oxygen and ammonia is the final and most difficult step in the WAIORA process.

Although WAIORA provides some guidelines for this evaluation process, but it is not possible to provide guidelines for all situations. This is because instream flow management is a complex process, usually involving a combination of technical, public, and legal considerations. To be effective, the instream flow management process should consider the present status of the river and its ecosystem, and then, in consultation with public and institutional organisations, set goals and objectives before establishing appropriate flow requirements.

Conventionally, we recognise instream values and instream uses - those that are associated with water that is flowing in a channel - and out-of-stream values and uses - those that are enjoyed when the water is taken from the channel for use elsewhere. The "social, economic and cultural" values referred to in Section 5 of the

Resource Management Act (RMA) may be either instream or out-of-stream values. For example, water used for irrigated agriculture has out-of-stream value, whereas the water used by a commercial rafting enterprise has instream value. The attributes listed in Sections 6 and 7 of the RMA generally are instream values.

WAIORA helps to quantify the requirements of instream uses in terms of water quality and hydraulic parameters. The two volumes of Flow guidelines for instream values (Ministry for the Environment 1998) provide a very much more comprehensive coverage than is possible here.

A basic principle established in the Flow guidelines is that instream values and their requirements must be identified and appraised within the context of definite Instream Management Objectives. Resource management objectives have been defined by regional councils in their various regional policy statements, and an increasing number of councils are developing more specific objectives in regional or catchment water resources management plans.

An important decision is the level at which instream values are to be maintained. Where there are established water quality standards, such as for dissolved oxygen and ammonia, this is relatively simple. However, acceptable levels of instream habitat and even water temperature are more difficult to decide. The Flow guidelines suggest that the level of maintenance should reflect the merits of instream values in a particular river - the quality of a recreational fishery, the biological diversity of a stream ecosystem, the conservation status of a breeding bird population on a river bed, the proximity to a large population centre of a kayaking river, the availability of alternatives or means of mitigation, etc.

## GETTING STARTED

### System requirements

Before you install WAIORA make sure your computer meets the minimum hardware and software requirements:

- Any IBM compatible machine with an 80486 processor or higher.
- A hard disk with a minimum of 3 megabytes available space for a full installation.
- Windows 98 or higher.

WAIORA will not run properly if your computer does not meet these requirements.

### Installing

WAIORA is installed simply by creating a directory such as c:\Program Files\WAIORA and then copying the files WAIORA.EXE, WAOIRA2.HLP, and WAIORA2.CNT into it.

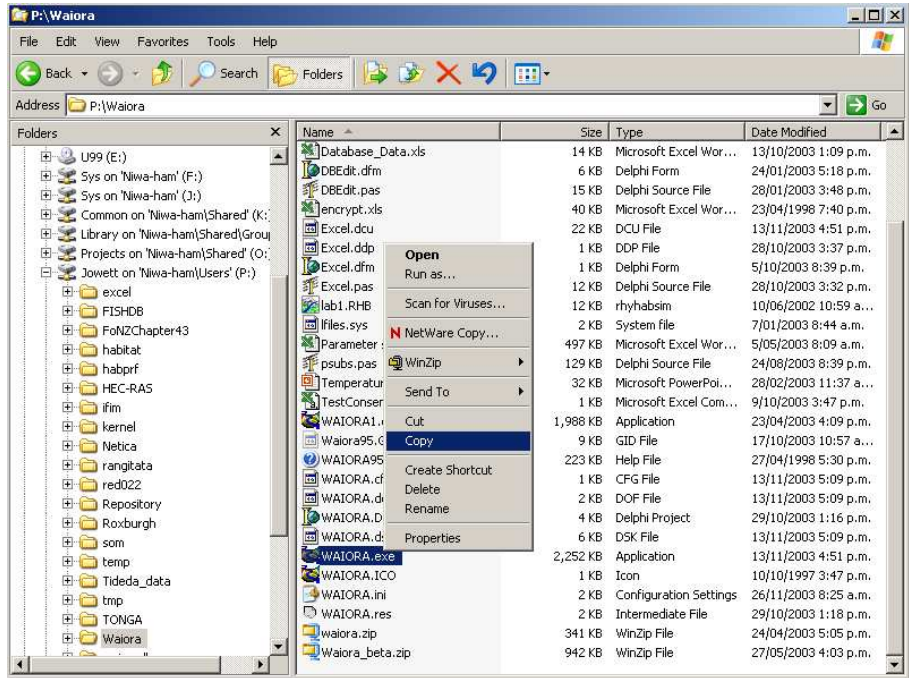
The programme METDATA.EXE, and its associated data file METDATA.FDA, is an accessory that shows a map of New Zealand with the distribution of climate recording sites, the data that are collected, and the period of record (until December 2003).

You can make the program accessible by:

#### CREATING A WAIORA SHORTCUT

1. Run Windows Explorer (Choose Start Menu | Programs | Windows Explorer).
2. Choose the directory that contains the WAIORA program (e.g., c:\Program Files\WAIORA). Click on WAIORA.EXE with the right button and select Copy.
3. Move the mouse cursor so that it over the desktop or Quicklaunch bar, click the right button, and select Paste shortcut.
4. Alternatively, click on WAIORA.EXE and then drag it over to the desktop or Quicklaunch bar.





Desktop showing the WAIORA icon on the desktop and in the Quicklaunch bar.

**Uninstalling WAIORA**

To uninstall WAIORA simply delete the program directory (normally C:\Program Files\WAIORA and any directories and database files (WAIORA.MDB) that you have created.

## Login

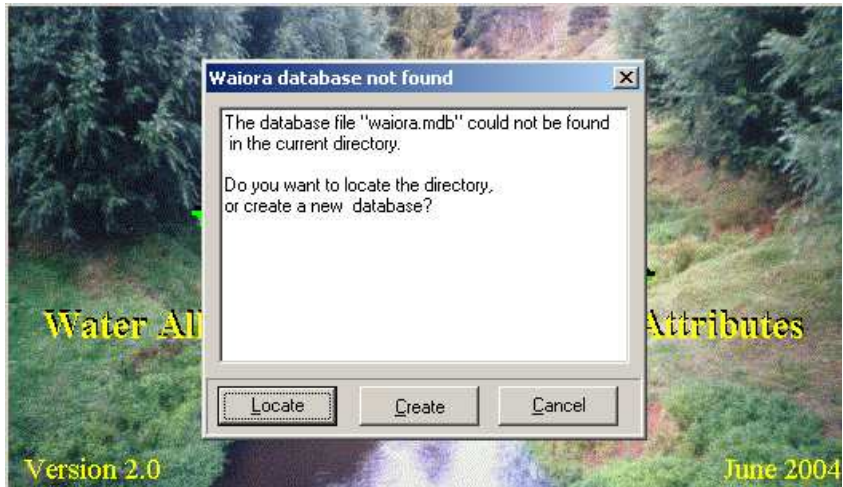
### FIRST LOGIN

The first time that WAIORA runs, the WAIORA Microsoft Access database (WAIORA.MDB) will not be found and you will see the following message:

#### Don't worry!

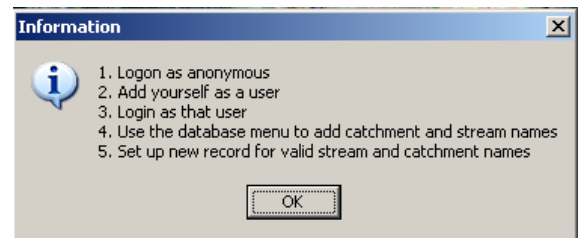
For a new installation press Create and a new database (WAIORA.MDB) will be created in the directory that you select. If you subsequently run WAIORA, and you receive the message

“database .. not found” as above, you can Locate the appropriate directory. Alternatively, you can create WAIORA databases in different directories and select the appropriate directory (Options/Select database) for any stream evaluation.



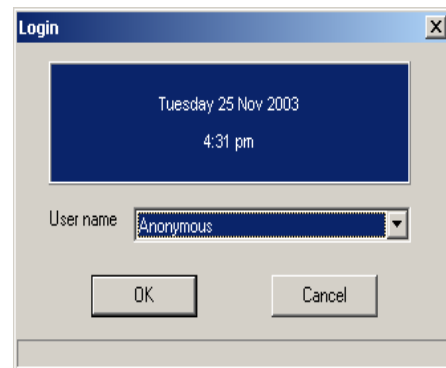
After the new database is created, you are then given instructions on how to proceed:

1. Login as ANONYMOUS
2. Add yourself as user
3. Login as user
4. Set up catchment database
5. Start stream evaluation process.



1. Select Anonymous from the User name drop-down box.
2. Click the OK button.

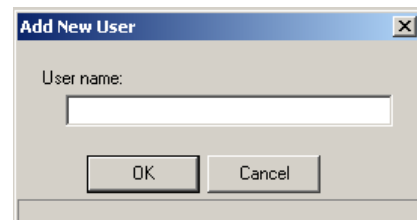
Some features of WAIORA are limited when you are an anonymous user. For example, an anonymous user cannot edit or delete records belonging to other users and database access is restricted. Therefore, you should add yourself as a user (File/Add User) when logged on as ANONYMOUS and then login (File/Login) under that name.



### ADDING A NEW USER

Any user may register a new user (with a name of 3 characters or more that is not already registered). To add a new user:

1. Select Add User... from the File menu (ALT+F+U).
2. Enter the new user name in the User name text box of the Add New User dialog window.

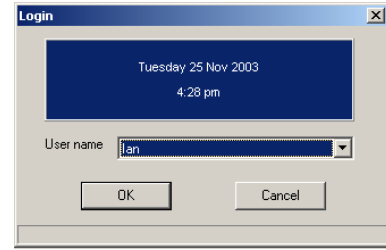


3. Click the OK button or push ENTER.

**NORMAL LOGIN**

Once WAIORA has been run for the first time, the user is prompted to enter a user name when the program is started. The last user will be displayed as the default. To continue:

1. If the correct name is not displayed, select your user name from the User name drop-down list box
2. Click the OK button or push ENTER.

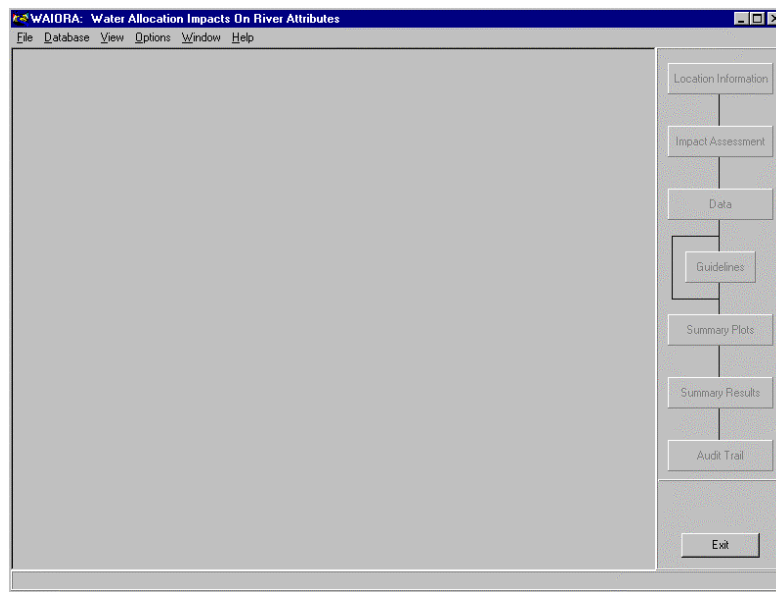


**Main window**

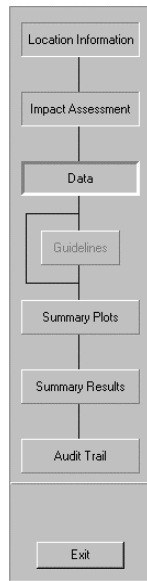
This section describes the elements of the main window. These help you manoeuvre/navigate around WAIORA. Many of the elements are consistent with windows applications, such as a control-menu box, the title bar and menus (see the section on Windows Features in WAIORA).

When you are running WAIORA your work takes place on a surface similar to a desktop, (the screen space WAIORA occupies). On this surface, you can move work items (windows) around, open new windows and remove those you do not need.

When WAIORA is started the Main Window appears (shown here).



## Flow chart navigation



The flow chart, located at the far right of the main window, allows the user to visually identify where the currently active window is relative to the other windows

Any open windows will be depressed, while all other unopened windows will be raised. The active window will have a bold border. Any unavailable windows will have grey text rather than black. All windows are unavailable if there are no records open.

To access the next window the user can either press the Next button on the active window or press the subsequent button on the flow chart navigator.

In the example shown here, the Location Information, Impact Assessment and Data windows are open with the Data window being the focus (active). The Summary Plots, Summary Results and Audit Trail windows are not available until data has been entered. The Guidelines window is unavailable and cannot be accessed until the appropriate check box has been activated in the Impact Assessment window.

The Exit button allows the user to close the program.

## USING WAIORA

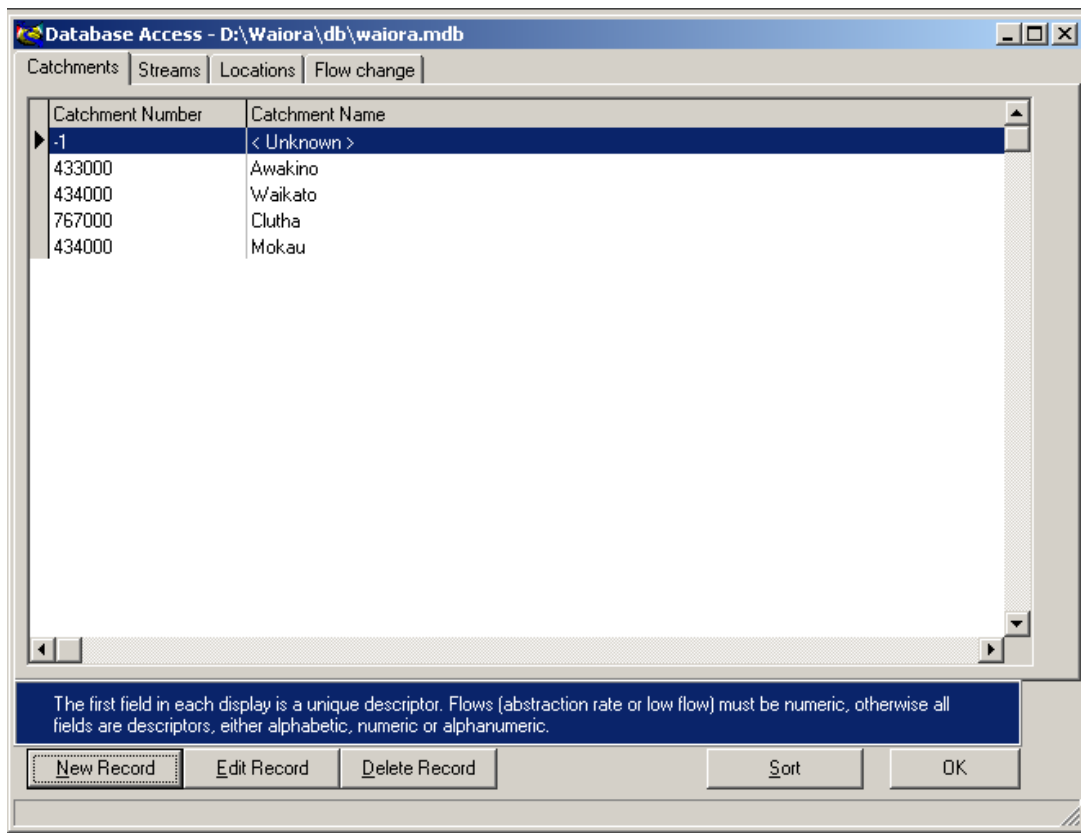
The previous section outlined the basic functionality of the program. This section presents each of the windows in WAIORA and describes more fully how to use this package.

### Database

The WAIORA database (WAIORA.MDB) is a Microsoft Access database that contains information on users who have been added to the database, catchment, stream, location, and flow change information, as well as the records of impact assessments. Catchment, stream, site, location and flow change details are stored in the WAIORA database and can be accessed from the View/edit database on the Database menu.

The catchment, stream, location, and flow change information can be edited directly under the database menu. Records of stream assessments are retrieved and saved under the File menu, as described previously.

The Database Access window (shown here) enables users to view database records and sort records by columns. The database file (WAIORA.MDB) also contains information on registered users, guidelines, evaluation data and audit trail information.



Location Reference	Location Name
N345546	Oterahanga
S12:768356	
s342876	Bridge
Mokauiti Power Scheme	below dam

Grids display tabled information from the WAIORA database.

To adjust the Column Width, select the column whose width you want to adjust and drag the border at the right of the column heading until the column is the width you want.

Registered users may add, edit and delete catchment, stream, site, location, and flow change details and load and save them from or to a csv or xls file. Note: import and export of xls files is only supported when Microsoft Excel is installed.

#### ADDING A NEW DATABASE ENTRY

1. Select the table to which you want to add the new record.
2. Select the New Record button or push ALT+N.
3. Enter the new information into the text boxes and drop-down list boxes provided.
4. Accept the entry by selecting the Save button or by pushing ENTER.

When a catchment is chosen from the drop-down list provided, the streams provided are limited to those located within the selected catchment.

#### EDITING A DATABASE ENTRY

1. Select the table and record that you want to edit.
2. Select the Edit Record button or push ALT+E.
3. Enter the amended information into the text boxes and drop-down list boxes provided.
4. Accept the changes by selecting the Save button or by pushing ENTER.

For the site and location tables, when a catchment is chosen from the drop-down list provided, the streams provided are limited to those located within the selected catchment.

#### DELETING A DATABASE ENTRY

1. Select the field that holds the record you want to delete.
2. Select the record you want to delete.
3. Select the Delete Record button or push ALT+D.
4. Accept the deletion by pushing the Yes button on the Confirm dialog window or selecting Y on the keyboard.

All other records that refer to this record will also be deleted. For example, if you delete a catchment, all streams, locations, and flow change details in that catchment will be deleted.

LOADING DATABASE FROM FILE

Database information can be loaded directly into the WAIORA database from a comma delimited (.csv) file or and Excel spreadsheet (.xls) by selecting Database/Import database from file or pressing ALT+D+I. Note: import and export of xls files is only supported when Microsoft Excel is installed.

The file requires headings and should be in the following order, but they are not case sensitive. All headings must be present but entries can be blank. The headings are:

- Catchment number
- Catchment name
- Stream number
- Stream name
- Location reference
- Location name
- Index flow
- Flow statistic
- Flow data source
- Flow change description
- Abstraction rate

An example spreadsheet is:

Catchment number	Catchment name	Stream number	Stream name	Location reference	Location name	Index flow	Flow statistic	Flow data source	Flow change description	Abstraction rate
434567	Waikato	434002	Waipa	Z34:456765	Te Kuiti	145	malf		123	35
432000	Awakino	567003	Makatinui	D45:642896	Farm	90			New One	50

Database entries are checked as they are added to the database to ensure that flows and abstraction rates are valid numbers and that catchment and stream numbers are unique.

Saving the existing database to a file is the reverse procedure.

**Records**

In WAIORA, a record holds location information, impact assessment information, data and environmental guidelines for a given scenario. This allows the user to retrieve previously run scenarios and modify settings if desired.

CREATING A NEW RECORD

- 7 8
- From the File menu on the main WAIORA desktop, select New Record with the mouse or press ALT+F+N.

This action opens a blank Location Information form (shown below). The user is then able to select an existing Catchment and Stream. These must already exist in the Database. To add a catchment and stream to the database, select Database then View/edit database or press ALT+D+V. The location reference (usually a map reference) and name can be entered directly or selected from those already in the database. The Location reference is **mandatory**. The catchment, stream, and location names can be specified as <Unknown>, if required. The value of the index flow **must** also be specified because this is the baseline for impact assessment. A flow change description is also required. All other fields are optional, although a default abstraction/discharge of 0 will be used.

**Location Information**

Location

Catchment name:  Location reference:

Stream name:  Location name:

Flow information

**WAIORA will predict the absolute and proportional change associated with a change in flow and whether a specified guideline threshold is exceeded at that flow**

The index flow specified here is a flow to which changes in habitat and water temperature are compared. For example, the effect of an abstraction can be judged by the % change in stream width.

WAIORA recommends the use of the 1-day median annual low flow as the current low flow. If the current low flow is not known, it can be estimated using standard hydrological methods.

Index flow is  of  L/s derived by

Details of flow change

Description:  Proposed abstraction or discharge rate (L/s):

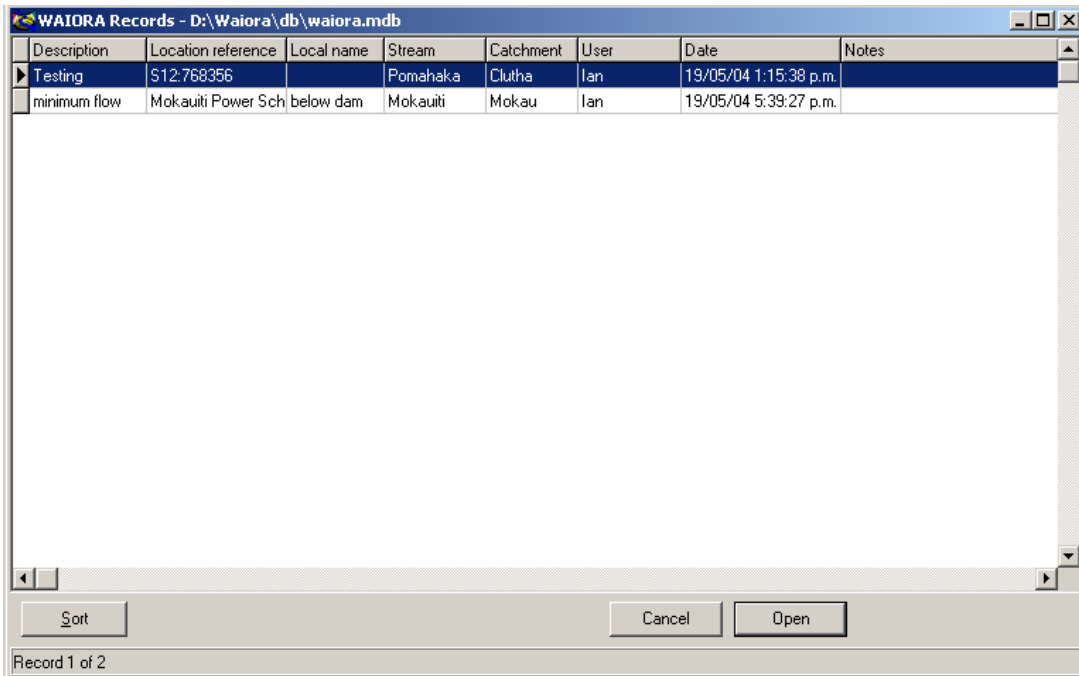
If a record is open, the user is unable to open a new record without closing the original first by selecting **File/Close record** or pressing **ALT+F+C**.

#### SELECTING AN EXISTING RECORD

7 8

1. From the **File** menu on the main WAIORA desktop, **Select Record** or press **ALT+F+S**. This action opens a window that lists all records that have been saved in the database.
2. Select a record you wish to open using the scroll bar and mouse, the **PAGE UP** and **PAGE DOWN** keys or the **UP** and **DOWN ARROW** keys. The selected record is highlighted in blue.
3. Select the **Open** button or press **ENTER**.





The Sort button allows the user to sort saved records by one or two fields. Fields are chosen from the drop-down lists provided on the Sort Records dialog window.

If a record is open, the user is unable to open another existing record without closing the current record first.

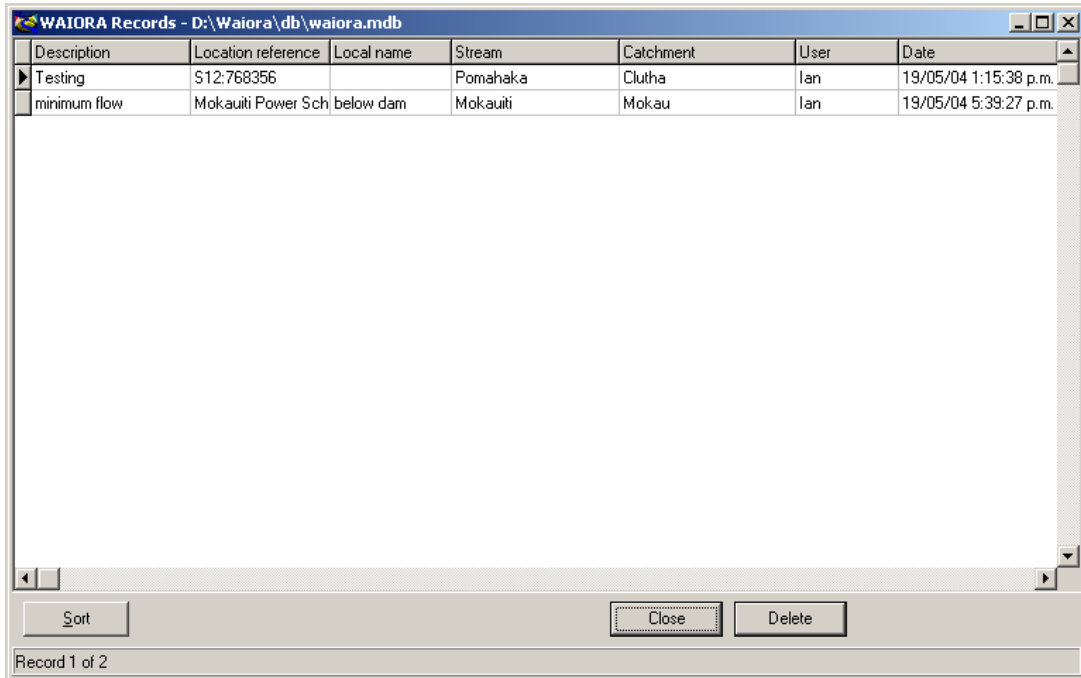
**CLOSING A RECORD**

- 7 8 • From the File menu on the main WAIORA desktop, select Close Record with the mouse or press ALT+F+C.

This must be done before another record can be opened. If the record has not been saved the user is prompted to save it.

**DELETING A RECORD**

- 7 8 1. From the File menu on the main WAIORA desktop, select Delete Records... or press ALT+D. This action opens the Delete Record window.
- 2. Select a record you wish to delete using the scroll bar and mouse, the PAGE UP and PAGE DOWN keys or the UP and DOWN ARROW keys. The selected record is highlighted in blue.
- 3. Selected the Delete button or press ENTER.



The screenshot shows a window titled "WAIORA Records - D:\Waiora\db\waiora.mdb". It contains a table with the following data:

Description	Location reference	Local name	Stream	Catchment	User	Date
Testing	S12:768356		Pomahaka	Clutha	Ian	19/05/04 1:15:38 p.m.
minimum flow	Mokauti Power Sch	below dam	Mokauti	Mokau	Ian	19/05/04 5:39:27 p.m.

Below the table, there are three buttons: "Sort", "Close", and "Delete". At the bottom left, it says "Record 1 of 2".

If a user is logged in as anonymous, the delete option is unavailable. Registered users are only able to delete records created by themselves.

The Sort button allows the user to sort saved records by one or two fields. Fields are chosen from the drop-down lists provided on the Sort Records dialog window. This option is not available while a record is currently open.

## Location information

Location, flow, and flow change information is entered into the Location Information window shown here.

**Location Information**

Location

Catchment name: Mokau | Location reference: Mokauti Power Scheme

Stream name: Mokauti | Location name: below dam

**Flow information**

**WAIORA will predict the absolute and proportional change associated with a change in flow and whether a specified guideline threshold is exceeded at that flow**

The index flow specified here is a flow to which changes in habitat and water temperature are compared. For example, the effect of an abstraction can be judged by the % change in stream width.

WAIORA recommends the use of the 1-day median annual low flow as the current low flow. If the current low flow is not known, it can be estimated using standard hydrological methods.

Index flow is: 1-day median annual low flow of 80 L/s derived by guess

**Details of flow change**

Description: minimum flow | Proposed abstraction or discharge rate (L/s): 55

Buttons: Help, Cancel, Next

## Location

The user can select any catchment and stream that already exist in the Database. To add a catchment and stream to the database, select Database/View/edit database or press ALT+D+V. The catchment name and stream name must be selected from the drop-down lists. If unknown, <Unknown> can be chosen from the list.

The location reference (usually a map reference) and name can be entered directly or selected from those already in the database. The Location reference is mandatory and can either be chosen from the drop-down list or typed in. If the user selects a known location with the dropdown box, the flow and flow change details of that location will be displayed. These details may then be changed by the user. The location name is not required but can be used to identify assessments that are made at the same location.

## Flow information

Index flow is: 1-day median annual low flow of 80 L/s derived by guess

The Index flow must also be provided by the user because it is used as a baseline for impact assessment. There are several index flow information statistics available. The user can choose from the drop-down list, leave them blank, or type in information.

WAIORA recommends the use of the 1-day median annual low flow (MALF). Estimates of MALF can be derived from a flow recorder at the location or by correlation with records at other locations. Local hydrological recording authorities should be contacted for these analyses. Several national methods (Hutchinson 1990; Pearson 1995) of deriving estimates of 5-year low flow and mean annual low flow have

been derived. These can be used in the absence of flow information or flow correlations for the site. Methods of low flow estimation based on GIS data are being developed.

### Flow change details

The user must also to enter a description of the flow change that is being assessed and the proposed abstraction or discharge. Note: At this stage, the rate (in litres per second) can be either the removal of water from the river or the addition of water to the river and the value is always positive.

## Impact assessment

The Impact Assessment window allows the user to enter assessment details.

### Scenarios

The user can evaluate the parameters for the index flow (evaluate status quo) or can compare the assessment status for the index flow to that with the new flow (less than the index flow where water is abstracted and greater where water is discharged).

### Parameters for evaluation

The four categories below are available to the user to be evaluated.

- Habitat
- Water Temperature
- Dissolved Oxygen
- Total Ammonia

For each of the parameters selected WAIORA will predict the magnitude of change associated with the new flow and the relative change. The assessment of total ammonia uses data from the habitat and temperature assessment so all three categories are automatically selected when you click Total Ammonia. Similarly, habitat and water temperature data are used in the assessment of dissolved oxygen, and will be automatically selected when you click on dissolved oxygen.

### Use of environmental guidelines

Specify environmental guideline thresholds

To identify whether an new flow exceeds environmental guidelines, the user will need to specify guideline thresholds.

To specify environmental guideline thresholds tick the check box (shown here). When unchecked, the Guideline window is unavailable.

### Data

The data window shows data tabs for each of the categories that were selected in the previous window. In the example below, habitat, water temperature, dissolved oxygen, and total ammonia were all selected.

The screenshot shows the 'Data' window with the following fields and values:

Parameter	Value
Date 1 [dd/mm/yy]	
Flow 1 [L/s]	30
Width 1 [m]	2
Mean depth [m]	.05
Date 2 [dd/mm/yy]	
Flow 2 [L/s]	70
Width 2 [m]	2.2
Mean stage change [m]	.02

Radio buttons:  Specify survey data at two flows,  Use instream habitat survey (RHYHABSIM) file

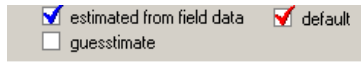
Buttons: Stream Geometry, Water Temperature, Notes, Help, Cancel, Back, Next

Status bar: Press F9 to reset defaults, Press F1 for help on data items,  estimated from field data,  guesstimate,  default,  guesstimate

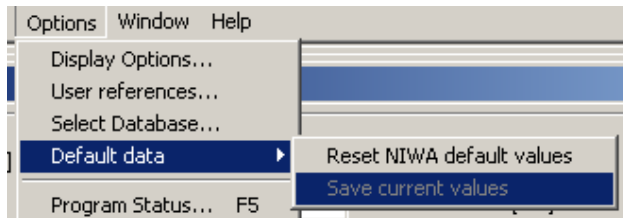
The user enters data into the active edit boxes. If the user holds the cursor over an edit box, an additional description of the edit box will appear. Pressing F1 while in the edit box will open the help file at the page that describes the appropriate parameter and operation.

All data are recorded in the Audit Trail, along with an assessment of the status of the data used in the impact assessment. The status is shown in the checkbox to the right of an edit box. When the checkbox is first displayed, it contains the default data and there is a red tick in the checkbox. When the user changes the default value, the tick disappears from the checkbox to indicate that the value is a guesstimate. If confident

about a value, the user should click the checkbox and a blue tick will appear to indicate that the data value is reliable.



Default values for the data sheet currently displayed can be restored by pressing F9. Values that have been entered in all of the category tabs can be saved as default values by selecting Options/Default data/Save current values.



The habitat, water temperature, dissolved oxygen, and ammonia models in WAIORA are all single station models, in that it is assumed that they apply to a single reach along which there is negligible variation in stream conditions.

## Habitat data

Habitat data are required by all evaluation categories. Habitat data can be entered in two ways. Either by measuring the average stream depth and width at two flows, flow 1 and flow 2. Note that the mean depth mean is entered for the first measurement at flow 1, but the mean stage change is entered for the second. This is because it is not necessary to measure the average depth on the second visit. In fact, it is more accurate and easier to install temporary staff gauges in the stream and measure the change in water level between flow 1 and flow 2.

The temporary staff gauge can be a survey stake, reinforcing rod, or waratah driven into the streambed. The cross-section should be clearly identified so that the site can be found easily on a return visit. The temporary staff gauge should be placed so that any change in water level in the main channel is reflected by changes on the gauge. Usually the gauge should not be in very shallow water near the stream edge where local obstructions can cause localised water level differences. If the gauge is likely to be disturbed, the top of the gauge can be referenced to a datum peg driven to ground level on the bank.

Repeat measurements of stream width should be taken at exactly the same location. The two flow and level measurements should be sufficiently different to define the change in level with discharge accurately. A change in level of 25 mm or 15% change in flow is a minimum. When taking repeat measurements of either width or water level, record the second set of measurements on the original data sheet and check that any change in width or level is consistent with the earlier measurements and with other measurements in the reach.

All data fields, except the date fields, must be entered if the “Specify survey data at two flows” button is selected. Data status checkboxes are not shown with habitat data because it is assumed that these data are measured and therefore reliable.

Date 1 [dd/mm/yy]		Date 2 [dd/mm/yy]	
Flow 1 [L/s]	892	Flow 2 [L/s]	568
Width 1 [m]	2.34	Width 2 [m]	2.1
Mean depth [m]	0.48	Mean stage change [m]	0.09

Specify survey data at two flows

### DATE

Date 1 and Date 2 are the dates in the format dd/mm/yy on which the measurements of average stream width, depth and flow were carried out. It is not necessary to specify these dates but they do record information that is useful for checking and audit purposes.

### FLOW

Flow should be gauged at the best flow measuring site in the reach. Usually the change in level for flow is relatively consistent along a stream and is controlled by the reach geometry, particularly riffles. Flow measurements should be to high accuracy (3%). Normal gauging standards should be used with 20 measurements of velocity and depth across the section, 40 second counts, and measurements of velocity at more than one point in the vertical in deep water or where the vertical velocity distribution is not uniform.

The accuracy of predictions made from a survey will decrease if the flow impacts that are being examined are for flows that differ greatly from the flows at which the measurements are made. Thus, it is better to limit the amount of extrapolation from measured flows by making measurements at a flow that is close to the flow of interest, usually low summer flow.

### WIDTH

The stream width (metres) is the water surface width and excludes islands and any protruding items, such as boulders. Ideally, stream depths and widths should be measured in as many locations as possible. Five cross-

sections in runs would be a minimum requirement, and three cross-sections in pools, runs and riffles (total of 9) would give a better measure of the stream average.

#### MEAN DEPTH AND STAGE CHANGE

The mean stream depth (metres) is the best possible estimate of average stream depth, and is best calculated as the cross-section area divided by the water surface width. The mean stage change is the average change in water level that occurred when the flow changed from flow 1 to flow 2. It is best measured by installing temporary staff gauges at each of the cross-sections and measuring the height of the water surface below the top of the gauge at flow 1 and flow 2, subtracting these 2 readings and averaging to give the mean stage change. The mean stage change is always entered as a positive number and it is assumed that the water level falls as the flow reduces, and vice versa.



In situations where multiple readings are made in the field and an average value is required, the user can access a data entry window by pushing the averaging button. The user is then able to enter up to five values in the Enter values window (shown here). These values are automatically averaged and entered into the Data window once the user pushes the OK button.

#### INSTREAM HABITAT SURVEY

To use instream habitat survey data instead of widths and depths surveyed at two flows, select the “Use instream habitat survey” button and then press the Habitat file button. This will display a file open dialog in which you select the folder and file that you want to use to describe the stream geometry and habitat. This file must be a calibrated instream habitat model produced by RHYHABSIM. The survey and calibration procedures in RHYHABSIM mean that this will be a more accurate reflection of the stream geometry and will give better predictions of stream width, depth and velocity than the two flow method when predicting beyond the range of flow 1 and flow 2 (Jowett 1998).



## Water temperature data

Water temperatures may affect aquatic systems in many ways, ranging from acute lethal effects, to modification of behavioural cues, to chronic stresses, to reductions in overall water quality. Water temperature modelling is included to help predict the consequences of stream manipulations, either flow or shade, on water temperatures.

Parameter	Value	Checkbox
Reach length [m]	2000	<input checked="" type="checkbox"/>
Mean daily air temperature [°C]	18	<input checked="" type="checkbox"/>
Maximum daily air temperature [°C]	23	<input checked="" type="checkbox"/>
Mean daily total solar radiation [MJ/m <sup>2</sup> /d]	20	<input checked="" type="checkbox"/>
Time of max temp [h]	13	<input checked="" type="checkbox"/>
Wind velocity [m/s]	0.5	<input checked="" type="checkbox"/>
% possible sun hours [%]	100	<input type="checkbox"/>
Mean relative humidity [%]	90	<input checked="" type="checkbox"/>
Day number	0	<input checked="" type="checkbox"/>
Latitude [°]	35	<input checked="" type="checkbox"/>
Elevation [m]	20	<input checked="" type="checkbox"/>
<b>Stream shade</b>		
Topographic angle [°]	35	<input checked="" type="checkbox"/>
Canopy angle [°]	35	<input checked="" type="checkbox"/>
Fraction through canopy	0.45	<input checked="" type="checkbox"/>
<b>Stream bed</b>		
Bed conductivity [J/m/s/°C]	10	<input checked="" type="checkbox"/>
Bed thickness [m]	1	<input checked="" type="checkbox"/>
Bed temperature [°C]	17	<input checked="" type="checkbox"/>

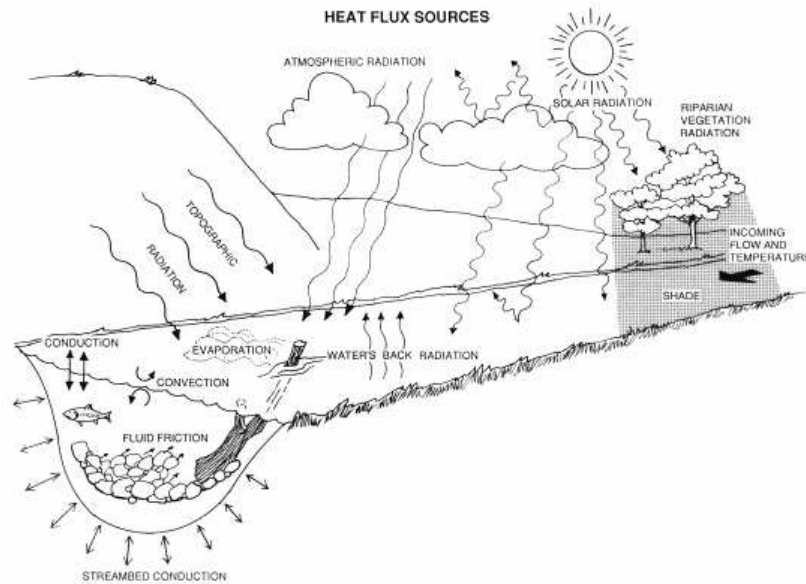
Advanced settings can be used to alter the following default assumptions:

- The upstream water temperature has reached equilibrium with shade and bed conditions the same as in the study reach
- There is no tributary flow that influences water temperature

Advanced settings

Stream Geometry | Water Temperature | Dissolved Oxygen | Ammonia | Notes

Water temperature data (above) describe the meteorological, hydrological, shading and streambed conditions. The model is a one-dimensional heat transport model that predicts the daily mean and maximum water temperatures from the abstraction point as a function of stream distance downstream and environmental heat flux. In general terms, WAIORA calculates the heat gained or lost from a parcel of water as it passes through a stream segment. This is accomplished by simulating the various heat flux processes that determine that temperature change (see figure below). These physical processes include convection, conduction, evaporation, as well as heat to or from the air (long wave radiation), direct solar radiation (short wave), and radiation back from the water. WAIORA first calculates the solar radiation and how much is intercepted by shading. This is followed by calculations of the remaining heat flux components for the stream segment.



The heat transport model tracks heat and water fluxes downstream. It assumes that mean daily temperature and radiation data can be represented by sinusoidal variation about the average, and that other meteorological and hydrological variables can be represented by average values.

Water temperatures are modelled downstream of the abstraction point. The water flowing downstream will then increase or decrease in temperature until a dynamic equilibrium is established between the diurnal pattern of incoming radiation and the diurnal heat losses from the river through radiation and evaporation. This final state, when there is no further change in the diurnal variation of water temperature with distance downstream, is known as the equilibrium condition. The magnitude and rate of change in water temperature will depend on meteorological conditions such as radiation, air temperature, shade and flow.

Air temperatures, solar radiation, wind velocity and relative humidity should be measured for accurate water temperature model calibration. These meteorological parameters may be obtained from the National Institute of Water and Atmospheric Research for a meteorological station near your site.

Limitations/assumptions:

- The characteristics of the selected reach represent the characteristics of a longer section of river and do not change with lateral inflow.
- The model does not handle rapidly fluctuating flows.
- Turbulence is assumed to thoroughly mix the stream vertically and transversely (i.e., no microthermal distributions).

### REACH LENGTH

The reach length, specified in metres, is the length of the stream that is being evaluated for changes in habitat, water temperature and dissolved oxygen. It is assumed that the hydraulic geometry (flow, stream width, depth, and velocity) and other characteristics, such as meteorology, shade, and stream bed conditions, are constant along the reach. Water temperature and dissolved oxygen concentration apply to the end of reach, whereas habitat conditions apply throughout the length of the reach.

Because water temperature usually increases with distance downstream until the equilibrium temperature is reached, the reach length should usually be long enough to ensure that the equilibrium temperature is reached. The variation in water temperature with distance below the abstraction point can be viewed to determine an appropriate reach length. The exception to this would be when the reach is close to the sea or when a large tributary joins the river below the abstraction point.

AIR TEMPERATURE

All temperatures are in degrees Centigrade. Daily means are usually the average of the daily maximum and daily minimum temperatures. The daily maximum/minimum air temperature is usually the maximum/minimum recorded on a max/min thermometer over a 24 h (9am to 9am) period.

Air temperatures should be measured for accurate water temperature model calibration. This and the other meteorological parameters may be obtained from the National Institute of Water and Atmospheric Research for a meteorological station near your site.

The adiabatic lapse rate can be used to correct for elevation differences:

$$Ta = To + Ct * (Z - Zo)$$

where  $Ta$  = air temperature at elevation  $Z$  (°C)

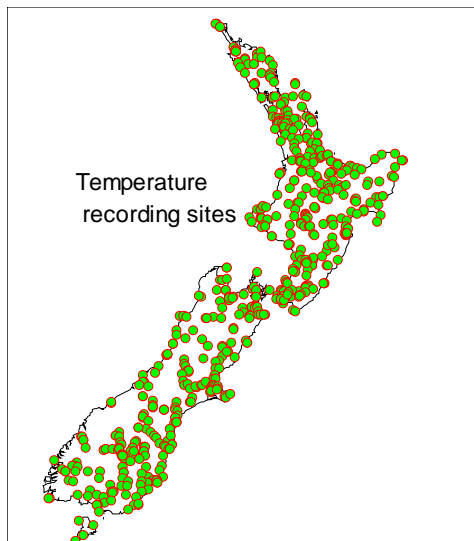
$To$  = air temperature at elevation  $Zo$  (°C)

$Z$  = mean elevation of stream (m)

$Zo$  = elevation of met. station (m)

$Ct$  = moist-air adiabatic lapse rate (-0.00656 °C /m)

NOTE: Air temperature, radiation, and shade are usually the most important factors in determining water temperature.



Daily maximum air temperature (°C) from selected sites. Data are monthly averages of daily maxima for the 1971-2000 period for locations having at least 5 complete years of data.

Location	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
KAITAIA	23.9	24.5	22.9	20.8	18.5	16.3	15.6	15.7	16.8	18.1	19.6	22
WHANGAREI	24.4	24.2	23	20.4	18	16	15.1	15.6	16.8	18.3	20.6	22.6
AUCKLAND	23.3	23.7	22.4	20	17.4	15.2	14.5	15	16.2	17.8	19.6	21.6
TAURANGA	23.9	23.8	22.3	19.9	17.1	14.9	14.3	14.9	16.3	18	20	21.9
HAMILTON	23.8	24.3	22.7	19.9	16.6	14.1	13.6	14.6	16.2	17.9	20	22
ROTORUA	23	23	21.1	18.3	15.1	12.6	12.1	13	14.7	16.7	19	20.9
GISBORNE	24.9	24.2	22.6	19.9	17.1	14.7	14.1	14.9	16.8	19	21.3	23.3
TAUPO	23.3	23.3	20.9	17.6	14.1	11.8	11.2	12.1	14.1	16.5	19	21.3
NEW PLYMOUTH	21.8	22.3	21.1	18.7	16	14	13.3	13.9	15	16.3	18.1	19.9

NAPIER	24.4	24.1	22.6	19.9	17.1	14.5	14.1	14.8	16.9	19.2	21	23
WANGANUI	22.4	22.7	21.3	18.8	16	13.8	13.2	13.8	15.3	17	18.8	20.7
PALMERSTON NORTH	22.4	22.9	21.1	18.4	15.3	13.1	12.5	13.3	14.9	16.7	18.5	20.7
MASTERTON	23.9	23.9	21.8	18.7	15.2	12.8	12	13	15.1	17.3	19.5	21.9
WELLINGTON	20.3	20.6	19	16.7	14.2	12	11.4	12	13.5	15	16.6	18.5
NELSON	22.4	22.4	20.8	18.1	15.2	12.9	12.4	13.1	14.9	16.8	18.7	20.5
BLenheim	23.8	23.6	22	19	15.8	13.3	12.8	13.8	16	18.1	20.1	22
WESTPORT	20	20.4	19.5	17.2	14.7	13	12.6	13.2	14.3	15.3	16.9	18.6
KAIKOURA	20.6	20	18.8	16.6	14.1	11.6	10.9	11.5	13.6	15.3	16.9	19.1
HOKITIKA	19.4	20	18.7	16.7	14.2	12.3	12	12.5	13.9	15.1	16.6	18.1
CHRISTCHURCH	22.5	22.2	20.4	17.8	14.6	11.7	11.3	12.4	14.9	17.4	19.2	21.2
MT COOK	20.3	20.8	17.9	14.5	10.8	7.3	6.4	8.4	11.6	14	16.2	18.2
LAKE TEKAPO	21.5	21.6	18.7	15	10.8	6.9	5.9	8.1	11.7	14.6	17	19.3
TIMARU	21.1	20.9	19.3	16.6	13.3	10.6	10.1	11.4	14.2	16	18.3	19.9
MILFORD SOUND	18.9	19.5	18	15.6	12.3	9.5	9.1	11.2	13.1	14.4	16	17.6
QUEENSTOWN	22.6	22.7	19.9	16.1	11.9	8.6	8.2	10.3	13.5	16.2	18.6	20.7
ALEXANDRA	23.5	23.8	21.5	17.5	12.4	7.5	7.9	11.4	15	17.5	20.2	22.1
MANAPOURI	20.7	20.8	18	14.6	12	8.3	8.2	9.6	12.6	14.9	16.1	18.9
DUNEDIN	18.9	18.7	17.2	15.5	12.6	10.2	9.8	11	12.8	14.6	16.1	17.4
INVERCARGILL	18.6	18.8	17.2	15	12.2	9.7	9.5	11	12.9	14.4	15.8	17.5
CHATHAM ISLANDS	17.8	18.1	17.1	15.1	12.8	11.1	10.4	10.9	11.8	13.1	14.5	16.5

Daily average air temperature (°C) at selected sites. Data are monthly averages of daily values for the 1971-2000 period for locations having at least 5 complete years of data

LOCATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
KAITAIA	19.7	20.0	18.6	16.9	14.8	12.7	12.2	12.1	13.1	14.5	15.8	17.9
WHANGAREI	19.9	20.0	19.0	16.5	14.0	12.2	11.2	11.7	12.9	14.3	16.4	18.2
AUCKLAND	19.3	19.8	18.5	16.2	13.7	11.6	10.8	11.3	12.6	14.1	15.8	17.8
TAURANGA	19.2	19.2	17.9	15.4	12.5	10.4	9.7	10.5	12.1	13.6	15.6	17.5
HAMILTON	18.3	18.7	17.1	14.5	11.6	9.4	8.7	9.8	11.4	13.1	15.0	16.8
ROTORUA	17.8	17.9	16.4	13.5	10.5	8.4	7.6	8.7	10.4	12.3	14.3	16.1
GISBORNE	19.2	18.9	17.4	14.8	12.0	10.0	9.3	10.2	11.8	13.8	15.9	17.8
TAUPO	17.4	17.5	15.6	12.5	9.6	7.6	6.7	7.6	9.4	11.5	13.6	15.7
NEW PLYMOUTH	17.7	17.9	16.9	14.7	12.1	10.3	9.4	10.1	11.5	12.7	14.4	16.1
NAPIER	19.5	19.3	17.7	15.1	12.1	9.7	9.3	10.0	12.0	14.3	16.1	18.2
WANGANUI	18.2	18.3	17.1	14.7	12.3	10.2	9.4	10.0	11.7	13.3	14.9	16.7
PALMERSTON N	17.9	18.2	16.6	14.1	11.3	9.2	8.6	9.3	11.0	12.7	14.3	16.3
MASTERTON	17.8	17.6	16.1	13.3	10.4	8.2	7.5	8.4	10.3	12.1	14.0	16.1
WELLINGTON	16.9	17.1	15.8	13.8	11.5	9.5	8.8	9.2	10.6	12.0	13.4	15.3
NELSON	17.7	17.7	16.1	13.1	10.1	7.7	7.0	8.1	10.2	12.3	14.2	16.2
BLenheim	18.2	17.9	16.7	13.7	10.4	7.9	7.4	8.5	10.8	12.8	14.9	16.7
WESTPORT	16.2	16.5	15.7	13.5	11.0	9.2	8.6	9.3	10.7	11.8	13.4	15.1
KAIKOURA	16.7	16.4	15.3	13.3	10.9	8.7	8.0	8.5	10.1	11.7	13.4	15.4
HOKITIKA	15.6	16.0	14.7	12.5	10.0	8.0	7.5	8.2	9.8	11.3	12.7	14.3
CHRISTCHURCH	17.4	17.1	15.5	12.8	9.6	6.9	6.6	7.7	10.0	12.3	14.0	16.0
MT COOK	14.6	14.8	12.5	9.4	6.1	3.0	2.2	3.7	6.6	8.9	10.8	12.8
LAKE TEKAPO	15.2	15.1	12.7	9.5	6.0	2.5	1.7	3.4	6.6	9.1	11.1	13.3

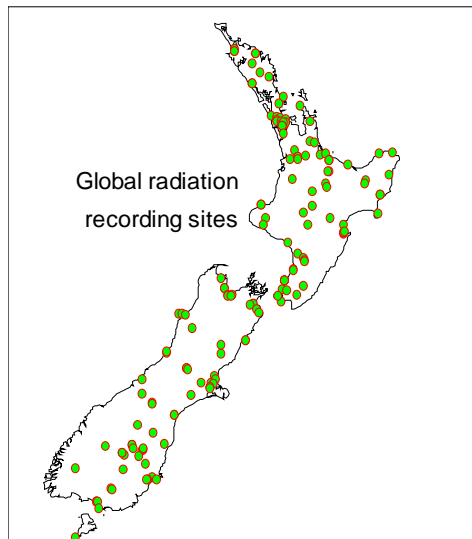
TIMARU	16.2	16.0	14.7	11.9	8.6	6.0	5.7	6.8	9.4	11.2	13.4	15.1
MILFORD SOUND	14.7	15.0	13.5	11.2	8.3	5.7	5.2	6.7	8.5	10.1	11.7	13.4
QUEENSTOWN	16.7	16.6	14.4	11.1	7.6	4.6	4.1	5.8	8.6	10.9	13.0	15.1
ALEXANDRA	17.1	17.1	15.1	11.3	7.0	2.9	3.0	5.5	8.9	11.5	13.9	16.0
MANAPOURI	14.5	14.3	11.8	9.2	7.2	4.2	3.9	4.7	7.1	9.4	10.3	12.8
DUNEDIN	15.2	15.1	13.7	11.9	9.2	7.0	6.5	7.5	9.3	10.9	12.4	13.9
INVERCARGILL	14.0	13.9	12.5	10.4	8.0	5.6	5.2	6.4	8.3	10.0	11.3	13.0
CHATHAM ISLANDS	14.7	15.1	14.2	12.5	10.2	8.7	8.0	8.5	9.3	10.5	11.8	13.7

RADIATION

The daily total radiation is one of the most important factors affecting water temperature. Daily total radiation is highest in mid-summer and lowest in winter, and is measured in units of megajoules per square metre.

The intensity (or rate) of radiation is usually expressed in (W/m<sup>2</sup>). One watt is equal to one joule of work per second. A megawatt (MW) is the same as 1000000 watts. One langley/min is equivalent to 697.3 W/m<sup>2</sup> or 697.3 J/sec/m<sup>2</sup>.

Radiation is usually measured continuously with a pyrometer as a rate in MJ/sec/m<sup>2</sup> or MW/m<sup>2</sup>. This is integrated over the day to give the daily total radiation in MJ/m<sup>2</sup>.



Daily total radiation (megajoules/square metre) from selected sites around New Zealand. Data are monthly averages of daily totals for the 1971-2000 period for locations having at least 5 complete years of data.

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
KAITAIA	21.7	19.4	16.4	11.6	8.5	7.0	7.7	10.1	13.5	16.9	19.9	22.1
WHANGAREI	20.8	18.4	15.5	11.3	8.4	7.1	7.4	10.3	13.7	16.9	18.8	20.4
TAURANGA	23.0	20.2	16.4	11.4	8.1	7.0	7.1	9.8	13.7	17.2	20.4	22.6
ROTORUA	22.5	19.6	16.0	11.1	8.0	6.3	6.7	9.4	12.9	16.6	19.5	21.6
AUCKLAND	23.1	20.1	16.0	11.7	8.3	6.6	7.9	10.0	13.8	17.5	20.9	23.1
HAMILTON	21.7	19.2	15.8	11.1	7.7	6.2	6.7	9.0	12.7	15.9	19.9	22.0
NEW PLYMOUTH	23.2	20.9	16.3	10.8	7.6	6.1	6.7	9.7	13.0	16.7	20.9	22.6

MASTERTON	21.7	19.0	15.2	9.7	7.0	5.5	5.9	8.6	12.6	17.0	20.6	22.5
GISBORNE	22.6	19.4	15.4	10.8	7.9	6.6	6.8	10.0	13.9	18.5	20.7	23.0
NAPIER	22.1	19.4	15.5	10.8	7.8	6.3	6.8	9.7	13.6	18.4	20.8	22.5
PALMERSTON NORTH	21.9	19.2	14.7	10.1	6.8	5.2	5.9	8.4	11.8	15.7	19.0	20.9
WELLINGTON	23.6	19.9	15.1	10.3	6.6	4.9	5.7	8.1	12.3	16.9	20.9	22.6
WANGANUI	23.8	21.5	15.6	10.9	7.7	6.1	6.9	9.3	13.3	17.1	21.2	23.7
WESTPORT	20.9	18.7	14.5	9.2	6.5	4.8	5.7	8.2	11.6	14.4	19.5	20.0
HOKITIKA	20.7	18.1	13.8	9.2	5.8	4.5	5.3	7.7	11.5	14.9	19.2	20.5
NELSON	23.4	20.5	15.6	11.2	7.6	5.7	6.2	8.8	13.2	17.2	21.0	22.9
BLENHEIM	23.1	19.8	15.9	11.1	7.5	5.8	6.5	9.0	12.9	17.5	20.8	22.5
KAIKOURA	21.3	18.7	14.9	10.1	7.1	5.3	6.1	9.1	12.8	17.8	21.1	22.4
CHRISTCHURCH	21.9	18.6	13.9	9.5	6.1	4.6	5.1	7.7	12.1	16.8	20.6	22.2
TIMARU	20.0	17.3	14.4	9.3	6.2	5.5	6.2	8.9	13.0	16.7	20.4	21.2
DUNEDIN	18.5	17.2	12.3	8.1	4.9	3.6	4.5	6.8	11.0	14.3	17.1	18.9
MANAPOURI	21.4	18.5	13.6	8.4	5.0	3.7	4.2	7.2	11.4	15.8	19.9	22.5
QUEENSTOWN	23.9	20.8	15.5	10.2	6.3	4.7	5.7	8.6	13.0	18.0	21.7	24.3
CLYDE	22.2	19.2	15.0	10.0	5.9	4.3	4.7	8.0	12.3	17.5	21.3	22.8
INVERCARGILL	20.4	17.5	12.6	7.9	4.6	3.6	4.3	7.0	11.1	15.5	19.8	21.5
CHATHAM ISLAND	20.0	16.9	12.8	8.6	5.1	4.0	4.7	7.2	10.9	15.2	18.9	20.7

#### TIME OF MAXIMUM TEMPERATURE

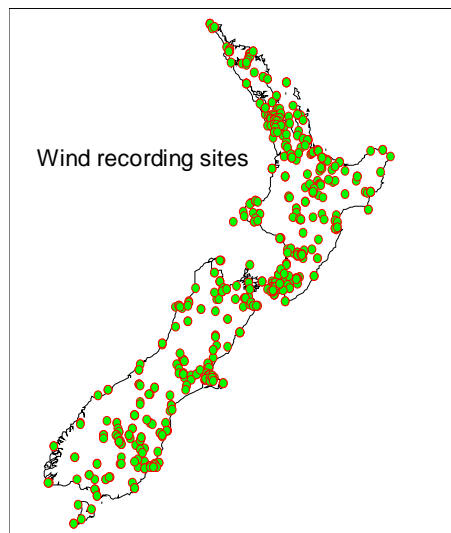
The time of maximum temperature is used to describe the sinusoidal variation in air temperature. It is specified in hours using the 24h clock. This is not a particularly important parameter for water temperature modelling, but can be relevant for calibration of water temperature models. The maximum air temperature usually occurs between 14h and 16h.

#### WIND VELOCITY

The average daily wind velocity over the water surface in m/s. Readings of wind velocity at meteorological stations are often higher than those at water surface level. Adjustment of wind velocity (and shade) can be used to calibrate a water temperature model to known downstream water temperatures. Wind velocity increases evaporative cooling of water as it flows downstream and in some situations can actually result in water temperatures decreasing in a downstream direction.

Daily average wind velocity (m/s) and sunshine hours at selected New Zealand sites. Data are mean annual values 1971-2000.

Location	hours	m/s
KAITAIA	5.7	4.2
WHANGAREI	5.4	4.4
AUCKLAND	5.6	4.7
TAURANGA	6.2	4.4
HAMILTON	5.5	3.3
ROTORUA	5.8	3.6
GISBORNE	6.0	4.2
TAUPO	5.4	3.6
NEW PLYMOUTH	6.0	5.6
NAPIER	6.0	3.9
WANGANUI	5.6	5.0
PALMERSTON	4.7	4.7



MASTERTON,	5.2	3.1
WELLINGTON	5.7	6.1
NELSON	6.6	3.3
BLLENHEIM	6.6	3.6
WESTPORT	5.0	3.1
KAIKOURA	5.7	4.2
HOKITIKA	5.1	3.1
CHRISTCHURCH	5.8	4.2
MT COOK	4.2	2.8
LAKE TEKAPO	6.0	1.9
TIMARU	5.0	3.3
MILFORD SOUND	4.9	2.5
QUEENSTOWN	5.3	3.3
ALEXANDRA	5.5	1.7
MANAPOURI	4.7	2.8
DUNEDIN	4.3	4.2
INVERCARGILL	4.4	5.0
CHATHAM ISLANDS	3.9	6.9

#### POSSIBLE SUNSHINE HOURS

This parameter is an indirect measure of cloud cover. It is expressed as the percentage of maximum possible sunshine hours and is measured with a pyrometer or can be calculated from cloud cover (decimal) as:

$$\text{Percent possible sun hours} = (1 - \text{Cloud}^{(5/3)}) * 100$$

Both sunshine hours and total cloud cover are recorded at New Zealand meteorological sites, but there are more sites recording total cloud than sunshine hours.

MEAN MONTHLY SUNSHINE (hours)												
Data are mean monthly values of total bright sunshine hours for the 1971-2000 period for locations having at least 5 complete years of data												
Station details are available in separate table												
Location	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
KAITIA	212	201	197	155	140	123	137	159	162	182	187	219
WHANGAREI	227	182	158	144	139	110	134	144	154	175	192	209
AUCKLAND	229	201	180	162	142	111	140	144	149	181	187	225
TAURANGA	253	211	197	175	164	132	152	161	164	201	215	232
ROTORUA	241	205	191	167	148	116	132	148	149	187	202	221
TAUPO	227	200	176	157	129	99	120	129	140	183	194	211
HAMILTON	231	199	185	164	131	103	121	138	145	176	197	221
NEW PLYMOUTH	244	223	202	173	144	118	134	154	160	190	204	228
MASTERTON	231	203	167	147	121	96	107	122	141	186	197	213
GISBORNE	241	201	185	156	148	124	130	154	173	210	215	234
NAPIER	242	201	193	163	153	124	138	159	172	208	213	232
PALMERSTON NORTH	208	190	170	139	105	84	103	117	120	147	171	181
WELLINGTON	246	209	191	155	128	98	117	136	156	193	210	226
WANGANUI	243	215	188	155	125	101	121	136	145	183	206	221
WESTPORT	212	189	164	143	113	102	123	127	141	160	174	191
HOKITIKA	211	184	170	142	116	102	121	137	142	158	182	194
FRANZ JOSEF	118	113	109	97	94	79	100	105	99	95	101	87
NELSON	266	229	212	188	173	143	157	171	186	212	225	245
BLLENHEIM RESEARCH	256	224	224	193	177	152	159	184	183	225	228	254
KAIKOURA	231	195	179	164	141	120	133	149	167	201	203	209
MT COOK	180	168	147	120	89	68	75	110	123	143	156	166
CHRISTCHURCH	230	196	183	161	142	119	124	148	165	198	215	221
LAKE TEKAPO	256	233	203	159	131	97	109	150	175	199	229	240
TIMARU GARDENS	185	168	150	140	126	118	118	134	150	173	184	181
DUNEDIN	178	153	140	121	100	86	101	114	129	147	161	169
TE ANAU	196	179	156	118	85	64	68	112	137	170	192	184
QUEENSTOWN	228	206	189	141	91	75	87	121	158	189	208	227
ALEXANDRA	228	213	193	153	112	83	93	146	165	192	213	220
INVERCARGILL	180	165	136	110	80	76	91	119	134	155	176	186

## RELATIVE HUMIDITY

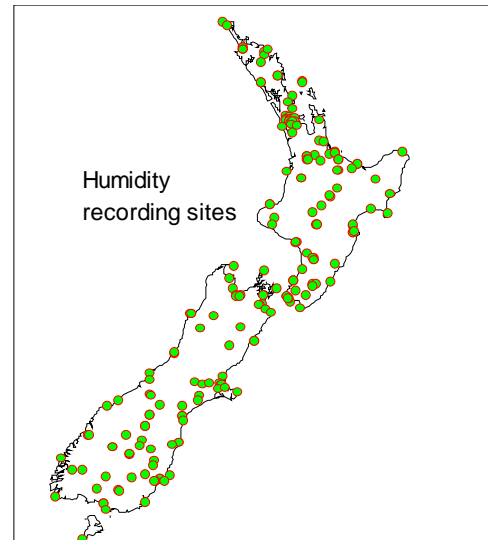
The relative humidity is specified as a percentage. The relative humidity increases the rate at which heat is transferred between the air and water, and an increase in humidity will increase water temperature. Correct for elevation differences by:

$$Rh = Ro * (1.0640^{(To-Ta)}) * ((Ta+273.16)/(To+273.16))$$

where

- $Rh$  = relative humidity for temperature  $Ta$  (decimal)
- $Ro$  = relative humidity at station (decimal)
- $Ta$  = air temperature at stream (deg C)
- $To$  = air temperature at met. station (deg C)

Relative humidity (%) at selected sites around New Zealand. Data are monthly averages of 9am relative humidity for the 1971-2000 period for locations having at least 5 complete years of data.



Location	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
KAITAIA	85.1	86.0	84.5	85.4	87.1	88.9	88.7	87.1	85.3	84.3	83.0	83.8
WHANGAREI	80.7	83.6	83.8	86.4	87.4	89.0	88.0	84.6	80.2	81.2	77.9	78.5
AUCKLAND	77.1	78.3	79.0	82.2	85.2	89.0	88.5	85.7	80.2	76.8	76.3	75.9
TAURANGA	74.2	75.9	77.8	80.8	83.0	85.6	83.5	79.8	75.9	76.1	72.0	72.1
ROTORUA	77.9	80.0	80.3	81.9	84.9	85.0	84.9	83.4	79.0	78.4	76.2	78.1
TAUPO	77.1	78.2	79.4	81.6	85.6	87.6	87.5	84.3	80.4	78.4	74.8	76.0
HAMILTON	79.4	82.4	82.4	85.1	88.5	90.2	89.7	87.0	81.5	79.6	78.7	78.8
NEW PLYMOUTH	82.3	83.8	80.4	80.3	83.4	84.6	84.1	82.9	80.4	80.4	77.3	80.7
MASTERTON	67.2	73.0	73.2	75.3	80.4	82.2	79.6	78.1	72.2	70.3	69.2	67.8
GISBORNE	69.6	76.7	75.7	78.2	78.9	80.1	80.6	76.4	71.7	69.9	68.0	66.7
NAPIER	68.4	73.2	73.6	76.8	77.3	81.0	79.6	77.1	69.9	67.3	66.2	66.3
PALMERSTON NORTH	76.5	78.2	78.2	80.5	85.6	87.7	87.5	84.4	78.9	77.9	76.4	76.6
WELLINGTON	80.3	83.0	81.9	83.3	84.9	87.0	86.3	84.9	81.8	80.9	80.1	80.4
WANGANUI	74.8	78.3	78.1	80.5	83.4	84.7	85.1	82.3	77.5	74.6	73.7	74.1
WESTPORT	82.7	86.2	84.1	84.6	86.5	85.9	83.3	84.2	81.7	83.9	78.8	82.0
HOKITIKA	83.3	86.1	84.3	86.0	87.6	86.6	85.7	83.4	81.7	81.3	80.6	82.2
MILFORD SOUND	90.3	92.3	92.8	94.3	93.9	93.5	93.6	92.3	91.8	90.5	87.9	87.8
NELSON	71.8	75.1	76.4	77.6	80.9	83.2	83.9	81.2	79.6	76.3	72.1	71.5
BLenheim	71.2	76.8	76.2	78.0	80.9	82.8	82.7	80.1	75.8	74.8	67.8	67.7
KAIKOURA	74.0	76.1	75.5	73.2	70.5	71.6	69.8	70.4	71.9	72.3	73.4	73.7
MT COOK	73.1	75.9	77.8	79.3	81.3	82.8	82.3	80.6	72.9	70.6	73.2	74.3
CHRISTCHURCH	72.9	79.7	79.0	83.2	85.6	87.0	87.3	85.0	78.7	73.5	71.9	71.5
LAKE TEKAPO	65.4	72.8	74.8	77.6	79.3	84.5	83.4	81.9	73.3	66.6	65.0	65.3
TIMARU	79.0	81.4	78.7	79.7	83.2	84.2	84.6	79.9	78.0	76.0	75.1	76.0
DUNEDIN	73.1	77.0	76.3	77.2	78.0	79.0	80.2	78.1	74.2	71.8	71.4	73.1
MANAPOURI	78.7	84.0	84.5	87.6	88.8	88.9	87.4	89.2	84.9	81.9	76.8	74.7
QUEENSTOWN	71.8	76.0	75.8	78.5	81.3	83.7	82.6	78.1	70.7	71.1	69.9	70.4



ALEXANDRA	69.8	76.0	76.2	85.0	85.9	88.6	90.5	86.5	75.6	67.8	68.0	68.2
INVERCARGILL	80.8	83.5	84.3	86.3	86.9	88.4	88.9	86.4	82.2	78.9	78.7	79.0
CHATHAM ISLAND	80.1	83.1	81.7	82.6	84.1	84.3	84.5	83.2	82.9	83.5	80.2	80.3

#### DAY NUMBER AND LATITUDE

The day number is the Julian day number with January 1<sup>st</sup> being 1 and 31 December 365. The day number and latitude are used to calculate the sun angle (solar elevation) at different times of day and hence the times at which the stream is shaded by topography or riparian vegetation. They are also used to calculate the time between sunrise and sunset for the time of year.

#### ELEVATION

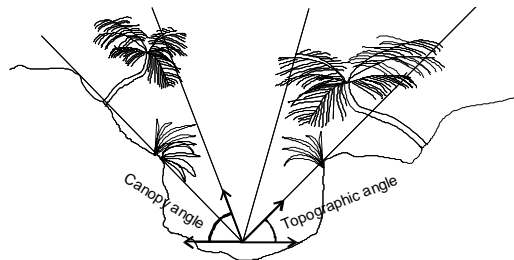
The elevation in metres above sea level at the abstraction point (start of the stream reach to be modelled). This is used to calculate atmospheric pressure for convection heat flux:

$$Pressure = 1013 * ((288 - 0.0065 * Elevation) / 288)^{5.256}$$

#### STREAM SHADE

Every stream or river is shaded by the banks and surrounding hills and vegetation. Shade has a large influence on water temperature and it is important to make reliable estimates of stream shade. The shade angle is estimated as the average angle of sky visible in around the 360 deg horizon. A shade angle of 90 deg is 100% shading. Shade represents the proportion of the incoming solar radiation that does not reach the water. The amount of shade can be determined either by a trial and error calibration procedure to a known downstream water temperature or by measurement where the elevation angles of the trees, banks and/or hillsides are measured and the fraction of radiation penetrating the canopy estimated.

The topographic angle is the average angle of the tops of hills and other solid objects on the horizon, the canopy angle is the average angle of the tops of riparian vegetation, and the fraction through canopy is the fraction of radiation penetrating the vegetation canopy, as shown below.



The total shade fraction is calculated as topographic shade plus canopy shade.

$$Topographic\ shade = 1 - (Cos(topographic\ angle))^{0.5}$$

$$Canopy\ shade = (1 - Fraction\ penetrating\ Canopy) * ((Cos(topographic\ angle))^{0.5} - (Cos(canopy\ angle))^{0.5})$$

The canopy and topographic angles are values between 0 and 90, and the canopy angle must always be equal to (no vegetation) or greater than the topographic angle.

We have found it difficult to estimate shade angles in the field and suggest that shade angles can be varied (within reason) in the process of calibrating a water temperature model.

#### STREAM BED

Heat from the water is lost and gained from the streambed. The streambed acts as a long-term buffer or heat store, effectively damping the response of water temperature to meteorological variations. For this reason, mean monthly air temperatures can be used as bed temperatures if measurements of ground temperature are not available.

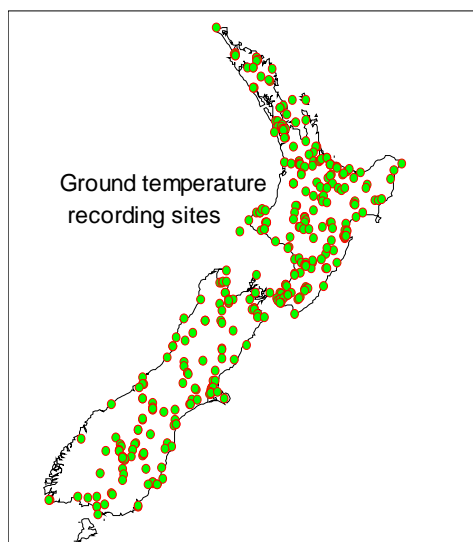
In the model, heat is transferred between the streambed and water according to:

$$\text{Heat transfer} = \text{bed conductivity} * (\text{bed temperature} - \text{water temperature}) / \text{bed thickness}$$

An estimate of the bed temperature can be obtained from measurements of ground temperature taken at climatological stations. If possible, ground temperatures measured at 1.0 m below ground level should be used. In such cases, 1 m would be the streambed depth. Measurements at lesser depths can be used if 1 m depth ground temperature measurements are not available.

The conductivity of the streambed (J/m/sec/°C) is often considered to be 1.65 for water-saturated sands and gravel mixtures. However, the heat transfer process is often more complicated than a simple conductive model because water flows in to and out of the streambed, thus effectively increasing conductivity. For this reason, we suggest a default value of 10 J/m/sec/°C.

Streambed temperatures and bed conductivity can also be used to calibrate water temperature models (see calibration).



#### INITIAL WATER TEMPERATURE

The initial water temperature is the temperature of the water flowing into the upstream end of the reach. Its units are degrees Centigrade. The initial water temperature at the abstraction point can be either specified directly or calculated from the stream characteristics upstream of the reach by assuming that the water temperature has reached equilibrium temperature. The initial water temperatures and upstream characteristics can be specified in Advanced settings. The default assumption is to use the equilibrium temperature calculated from upstream characteristics that are the same as the reach characteristics. These assumptions can be altered by selecting Advanced settings. The change in water temperature is then calculated as the water flows downstream using the sinusoidally varying water temperature at the abstraction point (beginning of the reach).

By default, the initial water temperature is the equilibrium temperature calculated assuming an infinitely long upstream channel with a flow equal to the index flow and the same characteristics as the reach, including shade. If this default assumption is true, there will be little change in temperature with flow and distance downstream.

Note that differences in the amount of shade between upstream and downstream reaches will invalidate the default assumption of equilibrium.

The default assumptions can be changed by altering the characteristics of the upstream channel in Advanced settings as illustrated below:

**Water temperature parameters**

Upstream

**Shading**

US topographic angle [°]  35 **Upstream water temperature**

US canopy angle [°]  35  Use equilibrium temperature

US fraction through canopy  0.45 US mean water temperature [°C]  18

US elevation [m amsl]  50 US max water temperature [°C]  23

**Stream bed**

US bed conductivity [J/m/s/°C]  10

US bed thickness [m]  1  Lateral or tributary flow present

US bed temperature [°C]  17

Close

or clicking on the “Use equilibrium temperature” checkbox and specifying initial upstream daily mean and daily maximum water temperatures.

**Water temperature parameters**

Upstream

**Shading**

US topographic angle [°]  35 **Upstream water temperature**

US canopy angle [°]  35  Use equilibrium temperature

US fraction through canopy  0.45 US mean water temperature [°C]  18

US elevation [m amsl]  50 US max water temperature [°C]  23

**Stream bed**

US bed conductivity [J/m/s/°C]  10

US bed thickness [m]  1  Lateral or tributary flow present

US bed temperature [°C]  17

Close

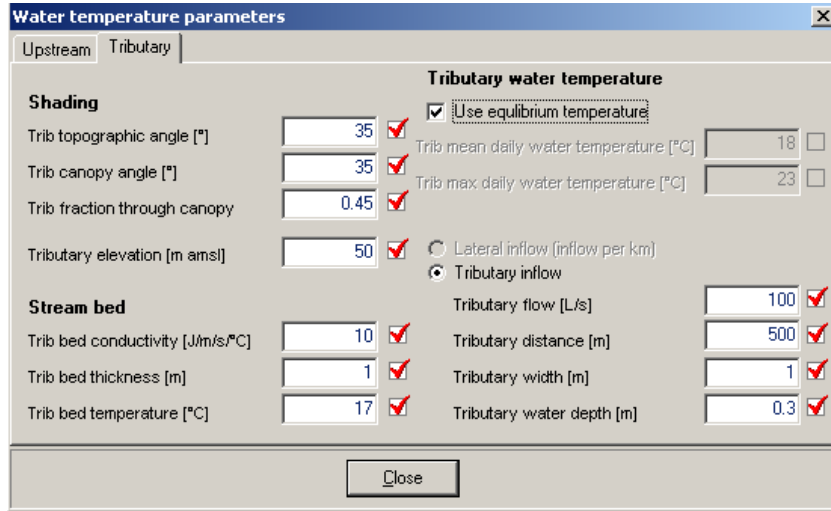
## LATERAL AND TRIBUTARY FLOWS

Water entering the stream reach below the abstraction point can be accounted for in the water temperature model either as a tributary inflow or as a uniformly distributed lateral inflow, such as would occur if groundwater were seeping into the stream along the length of the reach. Thus, the inflow (or outflow if negative) can be either uniformly apportioned through the length of the reach (i.e., by selecting lateral inflow) or can flow into the reach at a point (i.e., by selecting tributary inflow).

The location of a point tributary inflow is specified by its distance below the abstraction point and that value is entered as the tributary distance. The temperature of tributary inflows is specified in the same way as upstream water temperatures, either an equilibrium water temperature calculated from the tributary stream shade and bed conditions or by specifying the daily mean and maximum water temperature.

The temperature of the uniformly distributed lateral inflow generally should be the same as groundwater temperature. Groundwater temperature may be approximated by the mean monthly air temperature. Exceptions may arise in areas of geothermal activity.

Lateral or tributary flow present

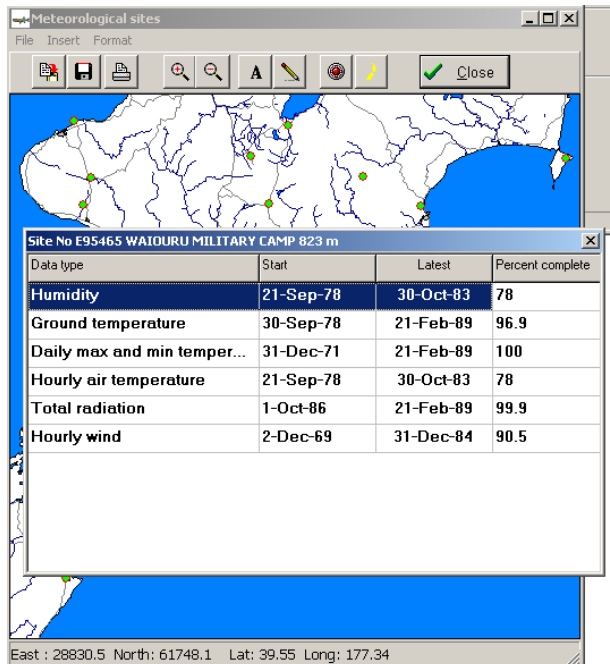


**Calibration of water temperature model**

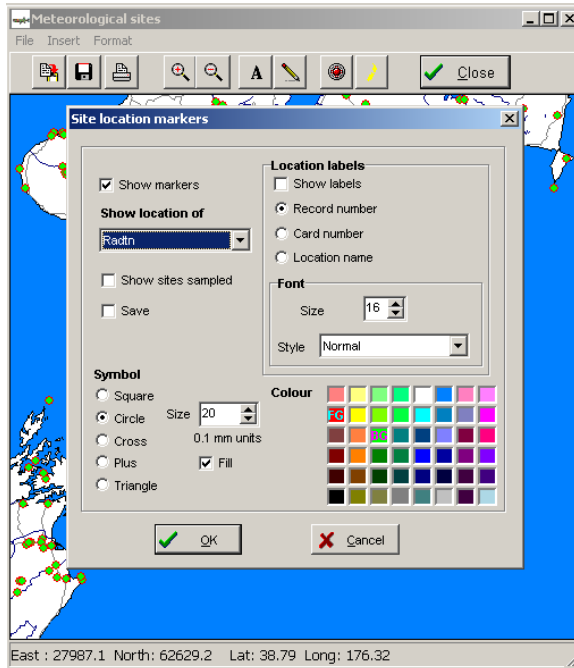
A water temperature model should be calibrated, although this is not necessary in order to get a rough idea of the temperature changes that will be caused by a change in flow.

Actual meteorological and water temperature data are required to calibrate a water temperature model. Ideally, these are recorded on site, but at times it is necessary to obtain meteorological data from nearby climate stations. Such data can be obtained from NIWA’s National Climate Database. <http://www.niwa.co.nz/services/clidb/>

It is often difficult to find out the nearest climate stations and the data that they record. WAIORA includes an interactive program METDATA that shows the distribution of all climate stations, the type of data they contain and record period. To find a site, simply open the program, display the map of New Zealand and zoom in on the location you are interested in. The climate stations are shown as symbols on the map. If you right click on a symbol the Site number and name will be displayed along with details of the data that are collected there.



The distribution maps of recording sites were generated by this program and you display locations of, say radiation stations, by pressing the Marker options button or selecting Format markers and then select the data type you want to display in the drop down box labelled “Show location of.”



It may be easiest to set the index flow as the flow used for calibration of the water temperature model. The appropriate meteorological parameters are then entered. Values of shade and wind velocity can be varied to try and match measured daily mean and maximum water temperatures. If this procedure does not correctly predict both mean and maximum water temperatures, or if the values of shade and wind velocity are unreasonable, the conductivity and temperature of the streambed may need calibration.

The bed temperature can be adjusted by trial and error until observed and predicted daily mean water temperatures match. Bed conductivity can then be adjusted until observed and predicted daily maximum water temperatures match. Using this procedure, the value of bed conductivity can be up to 50 J/m/s/°C and its value will increase with bed thickness. An assumed bed thickness of 1 m is suggested when calibrating bed conditions.

### Dissolved oxygen data

Three important parameters, as well as habitat and water temperature data, are required to calculate flow effects on dissolved oxygen concentration. These are:

- daily community respiration rate (the average rate of oxygen consumption by aquatic plants and micro-organisms),
- production/respiration ratio (ratio of the daily rates of photosynthetic production of oxygen to daily oxygen respiration by plants and micro-organisms), and
- reaeration coefficient (the coefficient that describes the rate at which oxygen is exchanged between the atmosphere and the stream).

The WAIORA DO model applies to streams with a reasonably homogenous distribution of aquatic plants (which can include algae) in a reach. Three main assumptions are invoked:

- a single reach analysis is appropriate - this assumes that while DO at a site exhibits substantial time variation, at any time spatial gradients of DO along the stream are minimal. This is tenable if there is a homogenous distribution of plants over a reach upstream of the site.
- the mass of plants present is not affected by changes in the low flows - this means that rates of photosynthesis and respiration rates are inversely related to flow.
- water temperature is constant over 24 hours - if water temperature varies throughout the day three aspects of the DO balance are affected. These are: reaeration, respiration and the saturation DO concentration. Experience to date in applying both constant-temperature and varying-temperature models to the same data indicate that the combined effect of water temperature variations on these three processes is small, so long as the diurnal water temperature variation is also "small" (say < 5°C). This is a reasonable assumption for most deep, incised lowland streams. If variation is greater than this, a more complicated model would have to be used.

WAIORA assumes that diurnal DO is affected by these three fundamental processes: reaeration, plant and bacterial respiration, and photosynthesis, as described by the following equation for the rate of change in dissolved oxygen,  $dC/dt$ :

$$dC/dt = k(C_s - C) + P - R$$

where  $C$  is the dissolved oxygen concentration at time  $t$ ,  $C_s$  is the saturation value for dissolved oxygen (and depends on water temperature),  $k$  is the reaeration coefficient, and  $P$  and  $R$  are the instantaneous rates of photosynthetic production and respiration by plant and microorganisms at time  $t$ , respectively. Dissolved oxygen is expressed in units of grams of oxygen per cubic metre of water ( $\text{g}(\text{O}_2)/\text{m}^3$ ), or the equivalent milligrams of oxygen per litre of water ( $\text{mg}(\text{O}_2)/\text{L}$ ).

The dissolved oxygen data entry form (below) has three sections. The first section sets the reference conditions. These conditions apply to either the diurnal DO field measurements in the second section or the DO parameters that are entered in the third section.

The default assumption is that field measurements will be used to calculate oxygen parameters. If you change this by de-selecting  Use field measurements of diurnal DO variation, Use field measurements of diurnal DO variation, and the second section (Diurnal DO measurements) will become inactive and grey, and the DO parameter section will become active and values for the parameters can be entered.

Accurate estimates of the parameters describing the three fundamental processes are essential for prediction of dissolved oxygen and we suggest that these parameters should be determined from field measurements, rather than estimated. However, whether oxygen parameters are derived by calibration or based on experience of calibration in similar streams, it is necessary to specify the following stream reference conditions.

## REFERENCE FLOW DO

The reference flow ( $Q_{ref}$ ) is the flow (L/s) at which calibration measurements are carried out or the flow to which the estimated oxygen parameters apply. The reference flow (and its associated velocity and depth calculated using the habitat component of WAIORA) is used to establish a reference reaeration coefficient ( $k_{ref}$ ) so that the reaeration coefficient ( $k$ ) can be calculated for another flow with an associated *Velocity* and *Depth* according to:

$$k = k_{ref} * (Velocity)^{0.5} / (Depth)^{1.5}$$

Respiration rates and photosynthetic production are also adjusted for flow. The method of adjustment depends on the plant biomass present. If the stream is dominated by macrophytes, respiration and production rates are directly proportional to the flow; if benthic algae dominate respiration rates are directly proportional to stream depth (calculated from flow using the WAIORA habitat component). Thus, for a macrophyte dominated reach, the respiration rate  $R$  at flow  $Q$  is :

$$R = R_{ref} * Q_{ref} / Q$$

where  $R_{ref}$  is the reaeration rate at the reference flow  $Q_{ref}$ . In a stream dominated by algae, the flow terms are replaced by the stream depth at the reference flow.

### RATIO OF RESPIRATION RATES 10°C APART

The ratio of the respiration rates 10°C apart ( $Q_{10}$ ) is used to adjust respiration rates either to a standard temperature or to the predicted temperature for a particular flow.

The adjustment for temperature is according to:

$$R^{(20)} = R * Q_{10}^{(2-0.17)}$$

where  $R^{(20)}$  is the respiration rate at 20°C,  $R$  is the respiration rate at  $T$  the daily mean water temperature (°C), and  $Q_{10}$  is the ratio of respiration rates 10°C apart. We expect that  $Q_{10}$  should lie between 1 and 2. The daily mean water temperature is predicted using the WAIORA water temperature model when assessing flow effects or is specified by the user when calibrating oxygen parameters.

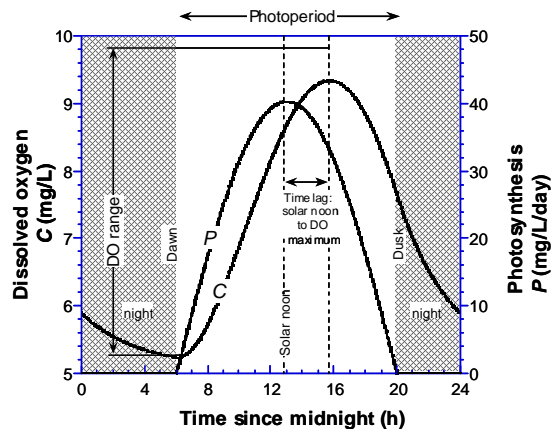
### PLANT BIOMASS

This specifies if the stream is dominated by macrophytes or benthic algae. This is used to determine whether respiration and production rates should be scaled by flow or average stream depth.

### Field measurements of dissolved oxygen parameters

Diurnal variation of dissolved oxygen concentration and water temperature during periods of stable weather and stream flow can be used to calculate reaeration, respiration and production rates. The data must be collected by DataSonde, or similar recorder, during a period of steady flow, such as base flow or during a recession period. The 24-h period used for analysis should exclude measurements made at the start and end of the DataSonde deployment because they are often affected by odd electrode responses that occur during the transfer to the stream site, and generally 24-h periods should start at midnight. Most importantly, it is important to establish a pattern in the diurnal variations and choose the one 24-h period that best represents that whole data set.

Diurnal curve analysis can be used to determine these parameter values. WAIORA uses a simple, direct analytical solution procedure advanced by Chapra & Di Toro (1991), and explained in McBride *et al.* (1998).



The following data are required for this calculation:

Diurnal DO Measurements			
Date DO [dd/mm/yy]	12/3/03	Location	
Time lag between DO max and solar noon [h]	3.9	<input checked="" type="checkbox"/>	Average daily DO [mg(O <sub>2</sub> )/L]
DO range [Observed max to min] [mg(O <sub>2</sub> )/L]	8.4	<input checked="" type="checkbox"/>	Daily mean water temperature [°C]
			20 <input checked="" type="checkbox"/>



## DATE OF OXYGEN MEASUREMENTS

The date (dd/mm/yy) of the measurement of 24 h period of diurnal oxygen variation is used to calculate the photoperiod (hours of day light). Because the hours of daylight are unlikely to alter significantly throughout the deployment of a DataSonde, the date need not specify the exact 24-h period used for analysis.

## LOCATION

The location at which field measurements are carried out will be listed in the audit report. However, it is not essential to enter any data in this field.

## TIME LAG BETWEEN DO MAX AND SOLAR NOON.

The time lag between the maximum dissolved oxygen concentration and solar noon can be estimated from plots of diurnal oxygen variation. Generally, it will be necessary to examine a number of periods of 24-h to determine this value.

The DO maximum should always occur after solar noon for correct calculation of oxygen parameters. Solar noon is the mid-point between sunrise and sunset. The Royal Astronomical Society of New Zealand lists sunrise and sunset times for major centres [www.rasnz.org.nz/SRSStimes.htm](http://www.rasnz.org.nz/SRSStimes.htm).

The following table gives the times of sunrise and sunset for four centres in New Zealand. These can be used for any year as times will not vary by more than a minute or two on the same date from year to year. Times are for a horizon level with the observer and do not allow for hills or mountains obscuring the horizon. New Zealand Standard Time (NZST) is used in the winter months and New Zealand Daylight Time (NZDT) is used in the summer months. NZDT starts on the first Sunday in October and ends on the third Sunday in March. Times in the table are in NZST or NZDT, as is appropriate.

Date	Auckland		Wellington		Christchurch		Dunedin	
NZDT	Rise	Set	Rise	Set	Rise	Set	Rise	Set
Jan 1	06:05	20:43	05:51	20:57	05:52	21:14	05:51	21:31
Jan 11	06:13	20:43	06:01	20:56	06:02	21:12	06:02	21:29
Jan 21	06:24	20:40	06:12	20:51	06:14	21:06	06:15	21:23
Jan 31	06:35	20:33	06:25	20:43	06:28	20:57	06:30	21:12
Feb 10	06:46	20:24	06:38	20:32	06:42	20:45	06:45	20:59
Feb 20	06:56	20:12	06:50	20:18	06:55	20:30	07:00	20:43
Mar 2	07:06	19:59	07:02	20:03	07:09	20:14	07:14	20:25
Mar 12	07:16	19:45	07:14	19:47	07:21	19:57	07:28	20:07
Date	Auckland		Wellington		Christchurch		Dunedin	
NZST	Rise	Set	Rise	Set	Rise	Set	Rise	Set
Mar 22	06:25	18:30	06:25	18:30	06:33	18:39	06:42	18:47
Apr 1	06:34	18:15	06:36	18:14	06:45	18:21	06:55	18:28
Apr 11	06:42	18:01	06:46	17:57	06:57	18:04	07:08	18:10
Apr 21	06:51	17:48	06:57	17:42	07:09	17:47	07:21	17:52
May 1	07:00	17:36	07:07	17:28	07:20	17:32	07:34	17:36
May 11	07:08	17:26	07:18	17:16	07:32	17:20	07:46	17:22
May 21	07:16	17:18	07:27	17:07	07:42	17:10	07:58	17:11
May 31	07:24	17:13	07:36	17:01	07:51	17:03	08:08	17:03
Jun 10	07:30	17:11	07:42	16:58	07:58	16:59	08:15	16:59
Jun 20	07:33	17:11	07:47	16:58	08:03	16:59	08:20	16:59
Jun 30	07:35	17:14	07:48	17:01	08:04	17:02	08:21	17:02
Jul 10	07:33	17:19	07:46	17:07	08:01	17:09	08:18	17:09
Jul 20	07:29	17:26	07:40	17:15	07:55	17:17	08:11	17:18
Jul 30	07:22	17:33	07:31	17:24	07:46	17:27	08:01	17:29

Aug 9	07:12	17:41	07:20	17:33	07:33	17:37	07:47	17:40
Aug 19	07:00	17:50	07:07	17:43	07:19	17:48	07:32	17:52
Aug 29	06:47	17:58	06:52	17:53	07:03	17:59	07:14	18:05
Sep 8	06:33	18:06	06:35	18:03	06:45	18:10	06:56	18:17
Sep 18	06:18	18:14	06:18	18:13	06:27	18:21	06:36	18:29
Sep 28	06:02	18:22	06:01	18:23	06:09	18:32	06:17	18:42
<b>Date</b>	<b>Auckland</b>		<b>Wellington</b>		<b>Christchurch</b>		<b>Dunedin</b>	
<b>NZDT</b>	<b>Rise</b>	<b>Set</b>	<b>Rise</b>	<b>Set</b>	<b>Rise</b>	<b>Set</b>	<b>Rise</b>	<b>Set</b>
Oct 8	06:47	19:30	06:44	19:34	06:51	19:44	06:58	19:55
Oct 18	06:33	19:39	06:28	19:45	06:34	19:56	06:39	20:08
Oct 28	06:21	19:49	06:14	19:57	06:18	20:09	06:22	20:22
Nov 7	06:10	20:00	06:01	20:09	06:05	20:22	06:07	20:37
Nov 17	06:02	20:10	05:51	20:21	05:54	20:36	05:55	20:51
Nov 27	05:57	20:20	05:44	20:33	05:46	20:48	05:46	21:05
Dec 7	05:55	20:30	05:41	20:43	05:42	20:59	05:42	21:17
Dec 17	05:56	20:37	05:42	20:51	05:43	21:08	05:42	21:26
Dec 27	06:01	20:42	05:47	20:56	05:48	21:13	05:47	21:30

## DO RANGE

The DO range is the difference between the maximum and minimum dissolved concentration recorded over a selected 24-h period. The selected 24-h period should be within a period of stable weather and stream flow and show a regular pattern of diurnal oxygen and temperature variation.

## AVERAGE DAILY DO

This is the average dissolved oxygen concentration over the 24-h period for the daily mean water temperature, described below. WAIORA uses this value to calculate the average daily oxygen deficit at the average temperature as the saturation oxygen concentration less the daily average dissolved oxygen concentration.

## DAILY MEAN WATER TEMPERATURE

The daily mean water temperature is the average water temperature in °C over the day on which the average DO and DO range were measured. This temperature is used for the calculation of saturation oxygen concentration and standardising values of reaeration coefficient and respiration rate to 20°C. The daily mean water temperature can be approximated simply by averaging the maximum and minimum daily water temperatures.

## Dissolved oxygen parameters

Accurate estimates of the parameters describing the three fundamental processes are essential for prediction of dissolved oxygen and we suggest that these parameters should be determined from field measurements, rather than estimated. However, in some streams it may be possible to estimate oxygen parameters based on experience and calibration through field measurements.

DO Parameters at 20 C and reference flow			
	Estimated values		Calculated from diurnal DO measurements
Daily community respiration [g(O <sub>2</sub> )/m <sup>2</sup> /d]	<input type="text" value="6"/>	<input checked="" type="checkbox"/>	<input type="text" value="20.51"/>
Daily production/respiration ratio	<input type="text" value="0.5"/>	<input checked="" type="checkbox"/>	<input type="text" value="0.99"/>
Reaeration coefficient [1/day]	<input type="text" value="3.5"/>	<input checked="" type="checkbox"/>	<input type="text" value="3.13"/>

The parameters used to characterise stream reaches are: the daily community respiration rate ( $R$ ) at 20°C; the daily production/respiration ratio ( $P/R$ ) being the 24-h average value for the ratio of  $P$  to  $R$ , where  $P$  is the maximum daily rate of photosynthetic production of oxygen and the reaeration coefficient  $k$  at 20°C.

Note that in any particular application the stream temperature will not be 20°C, but the values of the reaeration coefficient ( $k$ ) and respiration rate ( $R$ ) do depend on temperature. For this reason when  $k$  and  $R$  are calibrated, their values are adjusted, using standard formulae, to a reference temperature (20°C). This enables us to more simply compare these values from one stream to another.

#### REAERATION COEFFICIENT

The stream reaeration coefficient inferred from a single-station diurnal oxygen curve analysis is a function only of the photoperiod duration and of the time lag between solar noon and oxygen maximum—it is independent of rates of primary production and respiration. The reaeration coefficient  $k$  is an important way of characterising a stream's capacity to exchange oxygen with the atmosphere. It is a "first-order" coefficient, meaning that the overall rate of reaeration (or deaeration in super-saturated conditions) is proportional to the oxygen deficit (or surplus), with the coefficient being the constant of proportionality. The process it describes is not connected to other biologically mediated processes and is commonly approximated by functions of velocity, depth and slope. Streams that are sluggish and weedy will have low  $k$  values and, correspondingly, wide diurnal variations in DO. If the respiration rate is also high then we can expect low daily DO minima during summer low flows. The most accurate way of measuring  $k$  is by the gas tracer method but this can be labour intensive.

When using field measurements to establish dissolved oxygen parameters, WAIORA uses the following equation (McBride 2002; McBride & Chapra submitted) to calculate  $k$ :

$$k = 7.5 \left[ \frac{5.3 \left( \frac{\text{photoperiod}}{14} \right)^{0.75} - \text{timelag}}{\left( \frac{\text{photoperiod}}{14} \right)^{0.75} * \text{timelag}} \right]^{0.85}$$

where  $k$  is in reciprocal days, the photoperiod is the day length, and the time lag is the time between noon and the dissolved oxygen maxima.

The reaeration coefficient ( $k$ ) for the 20°C reference temperature is calculated from a standard formula as:

$$k^{(20)} = (1.0241^{T-20}) * k$$

where again  $T$  is daily average water temperature (°C). The reaeration coefficient is also adjusted for the depth and velocity at reference flow:

$$k_{ref} = k * (\text{Depth})^{1.5} / (\text{Velocity})^{0.5}$$

#### DAILY PRODUCTION/RESPIRATION RATIO

The daily production/respiration ratio ( $P/R$ ) is the total production of oxygen by photosynthesis over a 24-hour period divided by the total consumption of oxygen by respiration in that period. It is thus the daily average quotient of the rates of these two processes, with "daily" meaning 24-hours.

An analysis of 28 Waikato lowland streams found  $R^{(20)}$  values between 3.5 and 55.0 g O<sub>2</sub>/m<sup>3</sup>/day, and  $P/R$  values between 0.07 and 1.87. Four main groups of streams were identified in this analysis and the mean values for these groups provide some general guide for estimating values of  $R^{(20)}$  and  $P/R$  for use in WAIORA in absence of direct field measurement.

1. Deep streams with low shade and slow-flowing water:  $R^{(20)}$  10;  $P/R$  1.0

These streams were typically wide, deep (>1m) and sluggish with moderate plant biomass. They were considered particularly susceptible to small reductions in flow and have a high risk of DO deficit stress.

2. Deep streams with low shade and moderate-flowing water:  $R^{(20)}$  38;  $P/R$  0.4

These streams typically had high plant biomass and high amounts of decomposing organic matter. Mean depths were usually  $>0.8$  m. Higher current velocities allowed for higher than average reaeration. These streams were considered to have a moderate risk of DO stress.

3. Streams with high shade and low-moderate depths:  $R^{(20)}$  8;  $P/R$  0.3

These streams typically had low plant biomass due to shade often provided by riparian trees, and mean depths  $<0.8$  m. They were considered to constitute a low DO stress risk, although low reaeration during droughts could reduce night time DO levels.

4. Streams with low-moderate shade and low-moderate depths:  $R^{(20)}$  24;  $P/R$  0.2

These streams were typically cool and had high respiration rates indicating large amounts of decomposing organic matter. Reaeration was high indicating moderate-fast current velocities and low-moderate mean depths ( $<0.8$  m). They were considered to have a low risk of incurring large DO deficits.

## Total ammonia data

WAIORA calculates the total ammonia concentration at the end of the reach, assuming an ammonia concentration at the start of the reach, and the number of point source discharges uniformly distributed along the reach, each with a flow (L/s) and ammonia concentration.

The predicted ammonia concentrations at the end of the reach are compared to guideline standards. Habitat and water temperature data are required in total ammonia assessment for the assessment of guideline ammonia concentrations.

## Ammonia data requirements

### NUMBER OF POINT SOURCE DISCHARGE INFLOWS

This is the number of point inflows discharging into the reach. It is assumed that the point sources are uniformly distributed along the reach, so that the modelling distance is the reach length divided by the number of point sources.

The ammonia reach length can be different from the reach length specified for the water temperature model, because it describes the length along which there are ammonia discharges, with maximum ammonia concentration at the end of this reach.

### POINT SOURCE DISCHARGE

This is the flow rate (L/s) of the point source discharge. The flow rate of the point source times the total ammonia concentration of the point source is its ammonia loading in mg(N)/s. WAIORA provides a default value of 0.1 L/s based on the following assumptions:

- average daily flow for modern dairy sheds of 80 L/cow/d (Hickey et al. 1989)
- summer pond evaporation factor of 0.7 (C. Hickey, NIWA, pers. comm.)
- average dairy herd size of 170 cows.

### TOTAL AMMONIA OF EACH INFLOW

This is the total ammonia concentration (mg(N)/L) of each of the point sources. The median concentration of total ammonia in dairy shed oxidation ponds in the Manawatu and Southland was 75 mg/l (Hickey et al. 1989). Sixty percent of values were between 30 and 100 mg(N)/L. WAIORA uses the 80%-ile value of 100 mg(N)/L as a default, but this can be changed if more appropriate information exists.

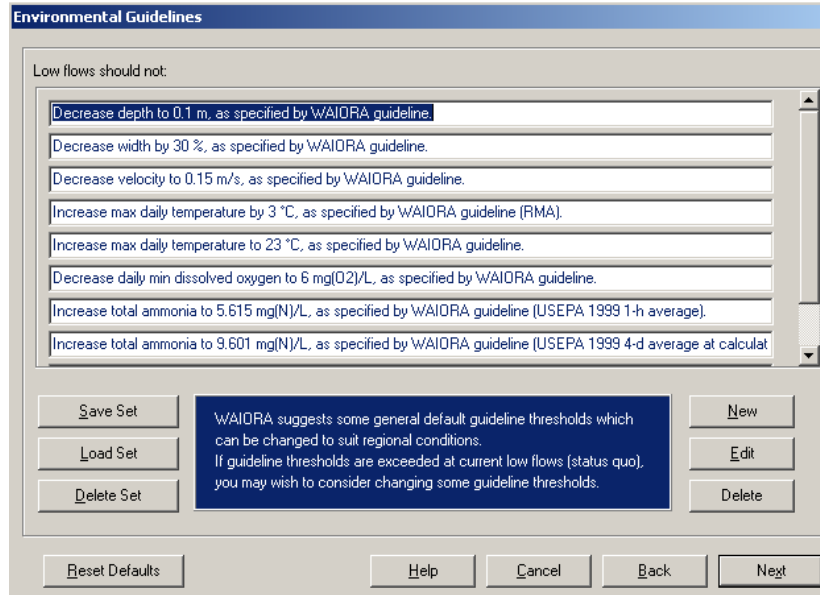
### TOTAL AMMONIA AT TOP OF REACH

This is the total ammonia concentration at the top of the reach before any of the point source discharges. Total ammonia concentrations at the top of a reach are best derived from local records for the site under

study or analysis of water samples as reported values are highly variable (e.g., 0-3.60 mg/L for Waikato streams). The average value for 187 Waikato streams sites was 0.227 mg(N)/L.

## ENVIRONMENTAL GUIDELINES

WAIORA uses a set of guidelines to evaluate the compliance or non-compliance of scenarios. While WAIORA has a set of default guidelines, users can select their own guideline sets. These sets consist of groups of guidelines usually corresponding to the parameters being assessed. The Environmental Guidelines window (shown here), allows the user to access individual guidelines and sets of guidelines. Individual guidelines can be created and edited using the guideline builder, which is accessed through the Edit and New buttons. The methods for adding, editing and deleting guidelines are described in the Appendix.



### Resetting defaults



The default WAIORA guidelines are reloaded by clicking the Reset Defaults button.

## EVALUATING EFFECT OF FLOW CHANGES

WAIORA predicts how stream parameters change with flow, and in particular, it predicts how the conditions under one state, the index flow, will change with additional abstraction or discharge of water. As discussed in the section on management objectives and levels of maintenance the decision on whether the change is acceptable or not depends on environmental, economic and socio-political factors. In this section, we try to give some guidance on the environmental considerations.

### Stream habitat

The velocity and depth of water are an essential characteristic of streams and these two factors are the primary determinants of the aquatic community and instream uses. The velocity and depth of water in a stream depend upon the flow, gradient and substrate, as given by well-known hydraulic formulae (e.g., Manning and Chezy equations). These factors are all inter-related. For example, substrate size depends upon gradient and flow, with large substrate elements in steep rivers and fine substrate in low gradient slow flowing streams and rivers. The morphology of the stream or river is shaped by its flood flows and the surrounding geology that provides the sediment that is transported by the river.

When the flow in a river is reduced, the water velocity and depth usually reduces. Studies of at-a-station geometry in 73 New Zealand rivers (Jowett 1998) indicate that the general relationships between flow ( $\text{m}^3/\text{s}$ ) and depth (m), velocity (m/s), and width (m) are:

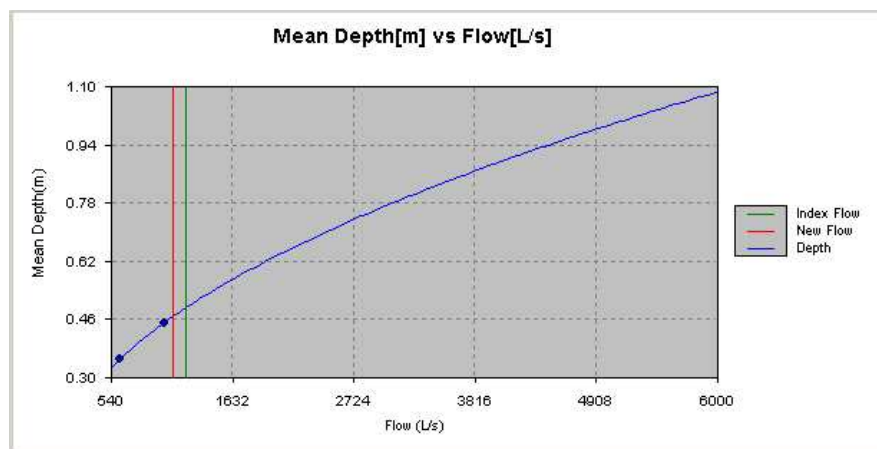
$$\text{Width} = 15.8 \times \text{Flow}^{0.175}$$

$$\text{Depth} = 0.31 \times \text{Flow}^{0.30}$$

$$\text{Velocity} = 0.24 \times \text{Flow}^{0.425}$$

There is considerable variation in these relationships between rivers, especially the depth and velocity relationships, and it is advisable to collect field data that are able to describe how the hydraulic geometry of a river changes with flow.

If habitat curves have been derived by the hydraulic geometry (two flow) method, the two calibration flows can be shown on the graphs, by selecting the appropriate graph display option.



Changes in stream habitat with flow are examined to determine if physical habitat at low flow is being reduced to the extent that it might compromise biota and instream use. This requires knowledge of the ecosystem and the physical requirements of stream biota. The basic premise is that if suitable physical habitat is absent, then the species cannot exist. However, if there is physical habitat available for a given species, then that species may or may not be present, depending on other factors not directly related to flow. In other words, habitat can be used to set the 'outer envelope' of suitable living conditions for the target biota.



The minimum water depth and velocity requirements depend on the function or aquatic community of the stream, which in turn is determined by the character of the stream – its flow regime and depth, velocity and substrate at normal flow. Thus, average velocities of less than 0.05 m/s are suitable, and even necessary, for macrophyte dominated streams, whereas velocities of more than 0.15 m/s are ideal for trout streams (Table 1).

Table 1. Average stream conditions for the maintenance of aquatic communities. Locations in streams and rivers that are less than 100 m amsl are considered lowland, and locations at elevations greater than 100 m amsl are considered upland. Streams are generally less than 5 m in width.

Stream type	Function/community	Depth range (m)	Velocity range (m/s)
Lowland stream	Macrophyte	>0.2	<0.05
Lowland stream	Whitebait	>0.2	0.02-0.08
Lowland stream	Banded kokopu	>0.2	<0.05
Lowland river/stream (gravel bed)	Native fish	>0.05	0.05-0.3
Lowland stream (gravel bed)	Diverse benthic invertebrates	>0.05	0.15-0.5
Lowland river (gravel bed)	Diverse benthic invertebrates	>0.1	0.15-1
Upland stream (gravel bed)	Native fish	>0.05	0.05-0.15
Upland stream (gravel bed)	Trout spawning	>0.2	0.15-0.5
Upland river (gravel bed)	Adult trout	>0.4	0.15-1

#### Generalised instream flow models

Habitat methods and instream habitat models have been used for many minimum flow studies in the last two decades. Conventional instream habitat models link a traditional hydraulic engineering model to habitat suitability curves for water depth, velocity and bed particle size. The hydraulic model predicts the values of point habitat variables (velocity, depth, particle size) for the discharge in a stream reach. Suitability curves are used to calculate point habitat values for each combination of point habitat variables. Their product is a habitat value (HV, ranging between 0 and 1), and when summed over the reach surface area, HV gives the 'weighted usable area' (WUA). Therefore, the major reach-scale outputs of these models are relationships between WUA and discharge.

Applying conventional instream models in a stream reach requires considerable field effort and experience. It involves a complete survey of bed topography and precise measurements of current velocities and water depths along several geo-referenced cross-sections, depending on the form of hydraulic model. The hydraulic model also requires calibration for which cross-section water levels need to be measured at 2 or more flows.

Several approaches have been proposed for reducing this effort. Some are based on a simplification of the hydraulic complexity within the reach by using hydraulic geometry relationships and considering point velocities as equal to their average (Jowett 1998), or simplifying their statistical distribution. Lamouroux and Capra (2002) proposed to model directly the output of conventional instream habitat model using simplified

and cost-effective reach descriptions (depth- and width-discharge relationships, particle size, median flow). The advantage of the resulting generalised habitat models is that no simplifying hypothesis is made on the distribution of hydraulic variables within reaches. Their use requires little experience and field effort, and the models provide HV and WUA curves which can be interpreted in a similar way as conventional ones.

Tests of generalised models in France (Lamouroux and Capra 2002) and New Zealand (Lamouroux & Jowett in press) found that habitat values for taxa were predictable from simplified hydraulic data. Reach hydraulic geometry (mean depth and mean width-discharge relationships), average bed particle size and mean natural annual discharge could be used to provide reliable estimates of habitat values in natural stream reaches. Key physical variables driving habitat values were found to be similar in New Zealand and in France. The Reynolds number of reaches (discharge per unit width) governs changes in habitat value of all species within-reaches. The Froude number at the mean natural discharge, which indicates the proportion of riffles in stream reaches, was generally the major variable governing overall habitat value in the different reaches. This is consistent with the preference of the benthic fauna, such as many of the native New Zealand fish species and benthic invertebrates, for riffles (Jowett and Richardson 1995; Jowett 2000), and the non-benthic aquatic fauna for runs or pools (e.g., Jowett 2002).

The generalised habitat models were robust. Tests of the French models of Lamouroux and Capra (2002) in New Zealand rivers were very satisfactory, and most New Zealand models gave reasonable accuracy when applied in rivers larger or smaller than those used to calibrate them (with some loss of accuracy for some taxa). This suggests that the generalised model equations can be used to model habitat quality anywhere in the world for taxa with comparable microhabitat suitability, at least within their calibration range. Generalised models necessarily lose some information compared to conventional models such as PHABSIM. This loss must be balanced against requirement for field work and experience in conventional modelling. In particular, hydraulic geometry relationships in reaches can be easily obtained from field measurements made at two different discharges or using regional models (Jowett 1998; Lamouroux et al. 1998). By combining generalised models and hydraulic geometry relationships, estimating habitat values in multiple streams is possible from few field measurements; detailed topographies of stream reaches, associated velocity measurements and hydraulic model calibration are not required.

Generalised habitat models suggest general, simple rules can be used to improve flow management or to estimate regulation impacts over whole river networks. An example of such a rule is that a discharge value of about  $Q = 0.3 \times \text{Width}$  would provide optimal habitat values for several freshwater taxa in New Zealand.

#### **Derivation and application of a generalised method**

The generalised model takes the form:

$$HV = a \times \left( \frac{Q}{W} \right)^c \times e^{-k \frac{Q}{W}}$$

The values  $c$  and  $k$  describe the shape of the curve, whereas the parameter  $a$  is a scaling factor that varies from reach to reach. The values  $c$  and  $k$  are of most interest, because the assessment of flow requirements is based on the shape of the curve, rather than the absolute values. The equation has a maximum at  $c/k$ , so that this ratio specifies the discharge per unit width that provides maximum habitat.

The values of model coefficients for each taxa were derived from a dataset of 99 reaches. The reaches in this dataset have mean flows varying from 0.6 m<sup>3</sup>/s to 53.8 m<sup>3</sup>/s (the same data were used by Lamouroux & Jowett (in press)). Lamouroux & Jowett (in press) fitted a non-linear mixed effects model to these data for habitat and flows ranging from 0.05 times the mean flow to the mean flow. This model described a common shape for each taxa (i.e.,  $c$  and  $k$  were held constant), but  $a$  was allowed to vary between reaches.

For some taxa, generalised curves could not be developed by the method used in Lamouroux & Jowett (in press) because the flow range that was modelled did not include the flow that provided maximum habitat. An alternative method of deriving generalised curves was used to avoid the problem of modelling an inappropriate flow range. Instead of fitting one value of  $c$  and  $k$  to all reaches, values of  $c$  and  $k$  were fitted to each reach. Values for  $c$  and  $k$  were then examined and reaches with negative values and outlying values of  $c/k$  were excluded.

The median values of  $c$  and  $k$  are shown in Table 2. These were then used to calculate the likely range of optimum flows for each taxon using average New Zealand at-a-station hydraulic geometry relationships from Jowett (1998) as follows:

$$\begin{aligned} \text{Minimum Flow/width} &= \text{Flow} / (15.8-1 \text{ sd}) \times \text{Flow}^{(0.176-1 \text{ sd})} \\ &= \text{Flow}^{0.89} / 8.3 \end{aligned}$$

The lower bound of flow range is where minimum flow/width =  $c/k$ .

$$\text{Hence, Flow} = (8.3 \times c/k)^{1.1236}$$

$$\text{Similarly, maximum flow/width} = \text{Flow} / (15.8+1 \text{ sd}) \times \text{Flow}^{(0.176+1 \text{ sd})}$$

$$\text{And the upper bound of flow range} = (23.3 \times c/k)^{1.316}$$

The origins of the habitat suitability curves used for the calculation of generalised curves are shown in Table 3.

Table 2. Generalised habitat models used to predict habitat values (HV) from average characteristics of stream reaches. Model parameters  $c$  and  $k$  are developed for each reach and the median value selected, excluding reaches with negative values of  $c$  and  $k$  and outlying values of  $c/k$ .

Species	C	k	Optimum discharge per unit width (m <sup>2</sup> /s)	Optimum flow range (m <sup>3</sup> /s)	
				Min.	Max.
Inanga	0.19	19.74	0.01	0.06	0.14
Shortjaw kokopu <sup>+</sup>	0.19	16.35	0.01	0.07	0.18
Upland bully	0.11	8.63	0.01	0.08	0.21
Crans bully	0.09	6.84	0.01	0.09	0.22
Banded kopopu (juvenile)	0.19	13.3	0.01	0.09	0.23
<i>Galaxias vulgaris</i>	0.03	2.29	0.01	0.09	0.25
Roundhead galaxias	0.31	10.64	0.03	0.21	0.61
Flathead galaxias	0.28	9.11	0.03	0.21	0.64
Longfin eel (< 30cm)	0.07	2.07	0.03	0.24	0.72
Lowland longjaw galaxias	0.33	9.35	0.04	0.25	0.77
Redfin bully	0.26	7.39	0.04	0.25	0.77
Shortfin eel (< 30cm)	0.13	2.32	0.05	0.41	1.37
Common bully	0.39	6.51	0.06	0.46	1.55
Brown trout fry	0.86	10.21	0.08	0.67	2.42
Brown trout yearling	0.4	4.18	0.09	0.76	2.82
<i>Nesameletus</i> <sup>*</sup>	0.26	2.62	0.1	0.8	2.98
Brown trout spawning	1.24	9.89	0.13	1.05	4.11
Bluegill bully	1.01	6.13	0.16	1.42	5.88
Rainbow trout spawning	1.49	8.78	0.17	1.47	6.12
<i>Deleatidium</i> <sup>*</sup>	0.33	1.92	0.17	1.5	6.25
Torrentfish	0.88	4.05	0.22	1.95	8.49
Brown trout adult	1.17	4.35	0.27	2.46	11.18
Food producing habitat	1.19	4.25	0.28	2.57	11.77
Rainbow trout feeding (30-40 cm)	0.93	2.89	0.32	3.02	14.19
<i>Coloburiscus humeralis</i> <sup>*</sup>	1.35	4.17	0.32	3.02	14.22
<i>Aoteapsyche</i> <sup>*</sup>	1.44	3.17	0.45	4.44	22.29
<i>Zelandoperla</i> <sup>*</sup>	1.71	3.4	0.5	4.97	25.43

\* large river habitat suitability curves (see Jowett 2000).

<sup>+</sup> suitability for cover locations only

Table 3. Source of suitability criteria used for the development of generalised habitat curves.

Species	Reference
<i>Aoteapsyche</i>	Jowett et al. 1991
Banded kopopu (juvenile)	McCullough 1998
Bluegill bully	Jowett & Richardson 1995
Brown trout adult	Hayes & Jowett 1994
Brown trout fry	Raleigh et al. 1984
Brown trout spawning	Shirvell & Dungey 1983
Brown trout yearling	Raleigh et al. 1984
<i>Coloburiscus humeralis</i>	Jowett et al. 1991
Common bully	Jowett & Richardson 1995
Crans bully	Jowett & Richardson 1995
<i>Deleatidium</i>	Jowett et al. 1991
Flathead galaxias	Baker et al. 2003
Food producing habitat	Waters 1976
<i>Galaxias vulgaris</i>	Jowett & Richardson 1995
Inanga	Jowett 2002
Longfin eel (< 30cm)	Jowett & Richardson 1995
Lowland longjaw galaxias	Baker et al. 2003
<i>Nesameletus</i>	Jowett et al. 1991
Rainbow trout feeding (30-40 cm)	Bovee pers. comm..
Rainbow trout spawning	Jowett et al. 1996b
Redfin bully	Jowett & Richardson 1995
Roundhead galaxias	Baker et al. 2003
Shortfin eel (< 30cm)	Jowett & Richardson 1995
Shortjaw kokopu	McDowall et al. 1996
Torrentfish	Jowett & Richardson 1995
Upland bully	Jowett & Richardson 1995
<i>Zelandoperla</i>	Jowett et al. 1991

Instream habitat data from the Kuratau River (18.53 m wide at a flow of 5.58 m<sup>3</sup>/s) are used to illustrate an application of the generalised method.

The average NZ hydraulic geometry relationship between width  $W$  and discharge  $Q$   $W = cQ^{0.176}$  is used to calculate the width for flows of 0 to 10 m<sup>3</sup>/s. The generalised model is then applied in the following steps:

1. the hydraulic geometry width constant  $c$  is calculated as  $W/Q^{0.176}$  or 13.69.
2. the width is then calculated for each flow as  $13.69Q^{0.176}$
3. the discharge per unit width ( $Q/W$ ) is calculated for each flow
4. the habitat value (HV) is calculated for each flow using the appropriate values of  $c$  and  $k$  for each species

$$HV = \left( \frac{Q}{W} \right)^c \times e^{-k \frac{Q}{W}}$$

5. the values are then normalised so that the maximum value is 1.

The habitat value (HV) is the dimensionless habitat value and is equivalent to expressing weighted usable area as the proportion of river width. The habitat value (HV) can be converted to the equivalent of WUA in  $\text{m}^2/\text{m}$  by multiplying by the river width at each flow.

Figure 1 shows the curves of dimensionless HV predicted using the generalised relationship compared to those predicted using the instream habitat data and RHYHABSIM and Figure 2 shows the same set of curves with HV multiplied by the river width at each flow.

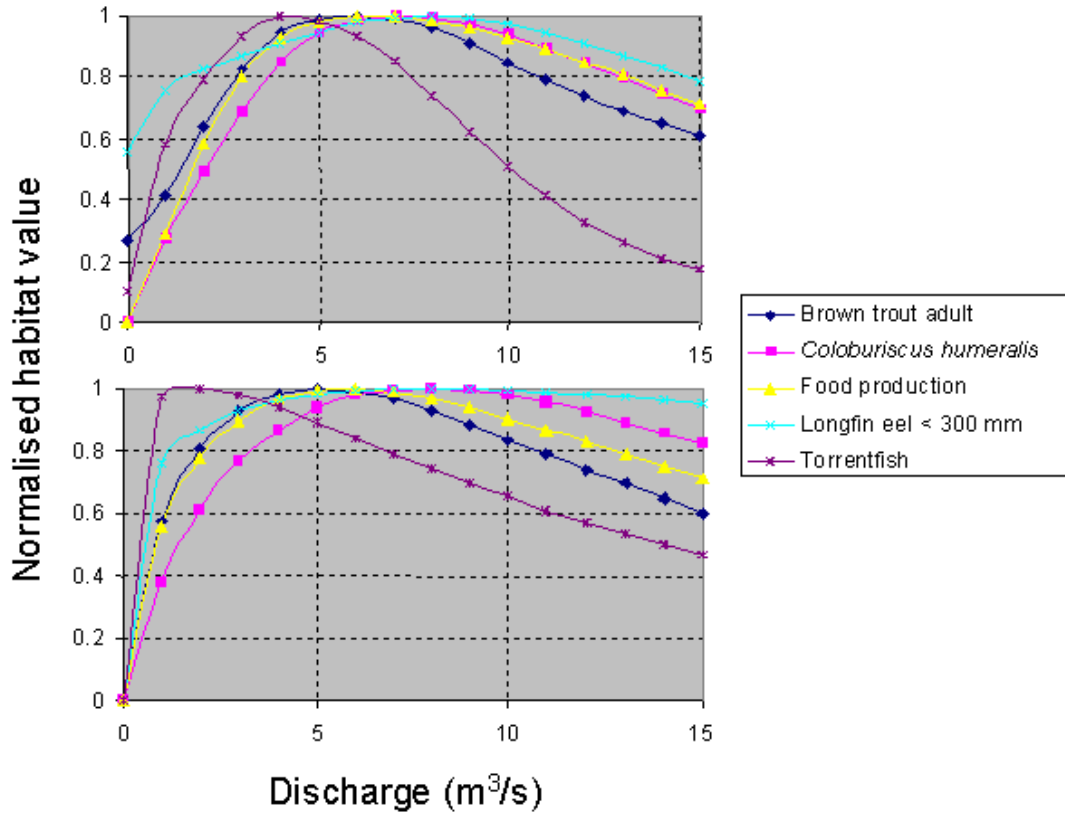


Figure 1. Comparison of normalised habitat per unit width predicted by habitat modelling in RHYHABSIM (above) and the generalised method (below).

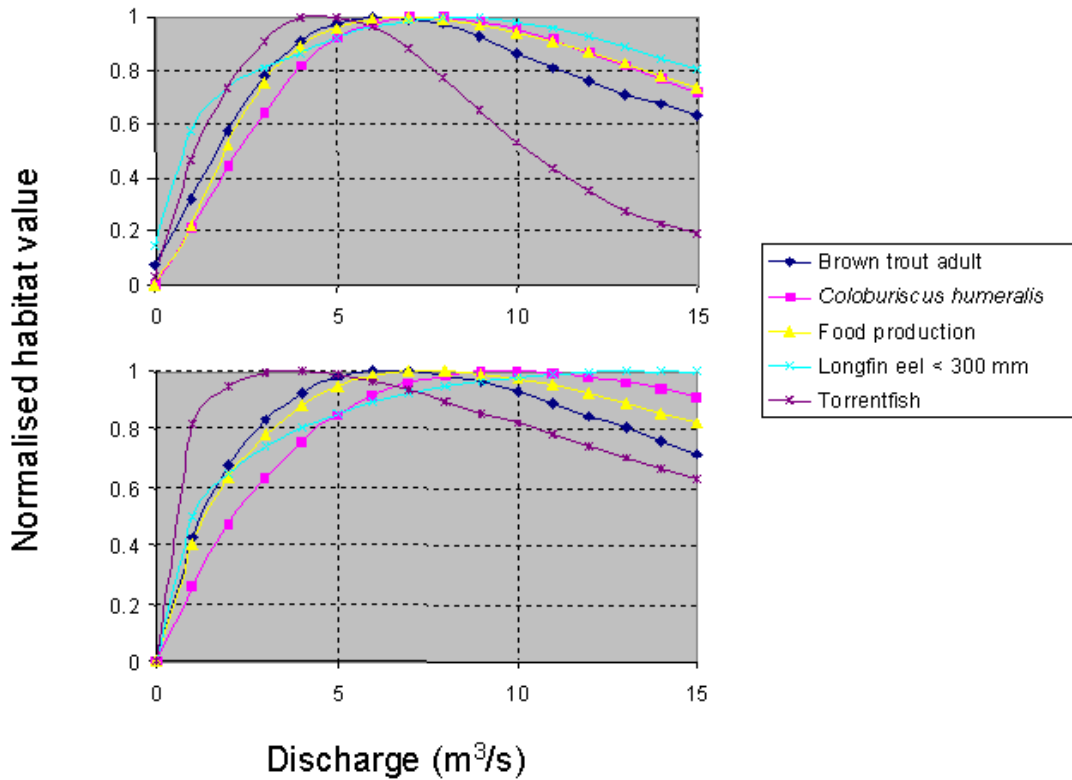
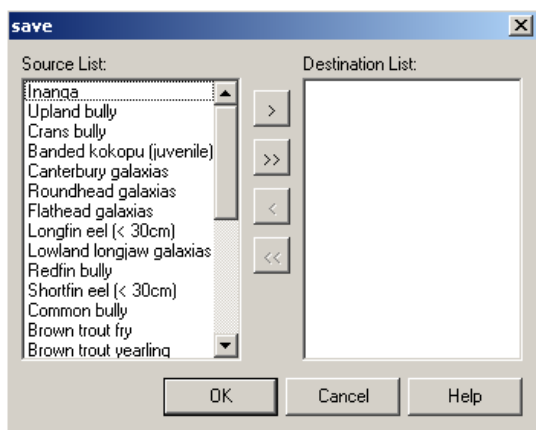
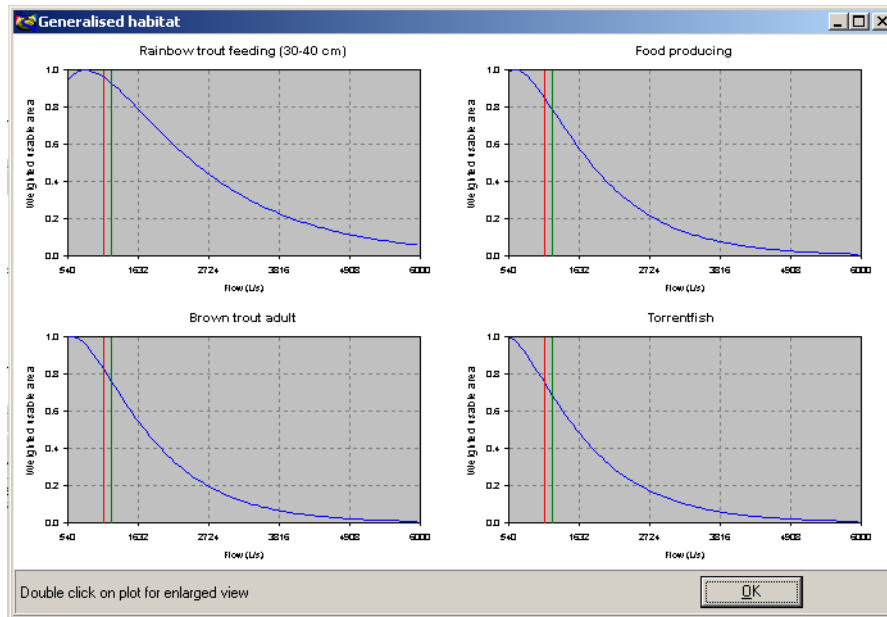


Figure 2. Comparison of normalised habitat area predicted by habitat modelling in RHYHABSIM (above) and the generalised method (below).

Changes in instream habitat for fish and benthic invertebrates can be evaluated using the generalized method. Curves of habitat quality versus flow are displayed for the selected species. The species for which there are generalized curves are listed and the user can select, one, several or all. The species are listed in order of velocity preference, so that the first species are most appropriate for small slow flowing streams and the species listed towards the end are most appropriate for large swift rivers.





The maximum y-ordinate of these curves is 1 and is normalized by dividing the area of suitable habitat (WUA) at each flow by the maximum area of habitat.

The duration of low flows will also need to be taken into consideration when assessing the effect of a flow change. In most situations, a reduction in stream habitat for a short time will have less effect than a reduction for a period of several months or more. Thus, the flow (depth and velocity) requirements of a river that is diverted will generally be greater than the requirements in a river where water is abstracted.



## Water temperature

Water temperature can limit aquatic communities. Some species of benthic invertebrates are restricted to cool waters and trout have a definite limit to their distribution that is believed to be related to incubation water temperature requirements in winter.

Predicted 'typical' daily maximum and mean water temperature can be compared with temperature criteria derived from laboratory tests. The laboratory results usually specify either a 4-day average temperature criterion (i.e., the temperature at which 50% of test organisms die after exposure for 4 days) or a critical thermal maximum (CTM, the temperature at which movement becomes erratic). In this approach the thermal tolerances are reduced by a 'safety factor' (estimated to be 3-4°C) to derive a 'safe' temperature. Quinn et al. (1994) found that the maximum temperatures at which several invertebrates occurred in the field were 3-4°C lower than those measured in laboratory tests.

Cox and Rutherford (2000) found that the upper thermal tolerance under diurnally varying temperatures was less than at a constant temperature, at least for a mayfly and snail species. At constant temperature, 50% of test organisms died after exposure for 4 days at 24.2°C for mayflies and 31°C for snails. However with diurnally varying temperatures (daily amplitude 10°C), 50% mortality occurred when the daily mean temperature was 21.9°C (mayflies) and 28.6°C (snails), 2.5°C lower than the constant temperature. Cox and Rutherford suggest that temperature limits should be applied to a temperature midway between the daily average and the daily maximum of a diurnal profile.

There are two possible criteria against which to assess predictions:

- temperature increase
- actual temperature

The first criterion stems from the Resource Management Act and its predecessors (which limit temperature increase to +3°C).

The second criterion places an upper limit on temperature. For example, field observations indicate trout deaths at water temperatures above 26°C (brown) and 28°C (rainbow), and 26°C has been used as a maximum temperature for the sustainability of smelt and inanga populations below the Huntly Power Station in the Waikato River. Published temperature limits for fish and invertebrates are summarised below; invertebrates tend to be more sensitive than fish.

Meteorological conditions must be specified to predict maximum water temperatures. In selecting meteorological conditions, you should consider the likelihood of all meteorological conditions occurring together with the low flow. Daily average meteorological conditions for each month are given in this manual. These can be used to predict average summer water temperatures. A more detailed analysis of meteorological data is required to determine the conditions that are likely to result in extreme water temperatures.

WAIORA uses default guidelines of a 23°C maximum temperature and a +3°C maximum increase; these can be changed if desired. Alternative thresholds include:

- daily maximum temperature      20°C    if 'sensitive' organisms present;
- daily maximum temperature      26°C    if native fish present but trout absent.

'Sensitive' organisms include stoneflies and mayflies.

If the predicted temperature midway between the daily average and the daily maximum of a diurnal profile exceeds the temperature criterion then there is a significant risk of an adverse effect. If the daily maximum

just complies with the temperature criterion then there is a very low risk of an adverse effect. Temperature criteria should be appropriate to the duration that they persist. For example, it makes no sense to compare a predicted daily maximum water temperature (which may only persist for 1 hour) with a 4-day average temperature criterion if the species being considered can tolerate high temperatures for short periods.

The following steps can be followed:

Step 1: compare the maximum temperature rise from the abstraction point to the bottom of the study reach with the limit +3°C. If the temperature increase exceeds +3°C it is unlikely to be acceptable. Nevertheless it is advisable to proceed to the next step.

Step 2: compare the highest daily maximum equilibrium temperature (i.e., maximum far field temperature) with the criteria 20°C for 'sensitive' streams or 26°C for 'native fish' streams. If these criteria are NOT breached there is a low risk of an adverse effect and there is no need to proceed to the next step. If these criteria ARE breached a further step is necessary.

Step 3: compare the highest daily mean temperature in the study reach (i.e., maximum near field temperature) with the criteria 20°C for 'sensitive' streams or 26°C for 'native fish' streams. If these criteria are breached there is significant risk of an adverse effect.

The following table lists various measures of the temperature preference and tolerance for some fish and invertebrates. **CTM** Critical Thermal Maxima; i.e., the thermal point at which movement becomes erratic and the animal loses its ability to escape from conditions that will promptly lead to its death. The animal is exposed to water heated at a continuous and rapid rate in this test. **LT<sub>50</sub>** the constant temperature at which half of the test animals die within the test period. **FP** final preference, the long-term preferred temperature. **ND** no data.

Fish Species	Life stage/size	Acclimated temp. (°C)	Upper lethal temp. (°C) and method	Preferred temp. (and quartiles) (°C)	Source
Shortfinned eel ( <i>Anguilla australis</i> )	Glass eel	15	28.0 LT <sub>50</sub>	-	Jellyman 1974
	Elver	12-28	33.4-38.1 CTM	-	Simons 1986
	Elver	15	35.7 LT <sub>50</sub>	26.9 (25.6-	Richardson <i>et al.</i> 1994
	Adult	15	39.7 LT <sub>50</sub>	28.5)	Richardson <i>et al.</i> 1994
Longfinned eel ( <i>A. dieffenbachii</i> )	Glass eel	15	25.0 LT <sub>50</sub>	-	Jellyman 1974
	Elver	15	34.8 LT <sub>50</sub>	24.4 (22.6-	Richardson <i>et al.</i> 1994
	Adult	15	37.3 LT <sub>50</sub>	26.2)	Richardson <i>et al.</i> 1994
Cran's bully ( <i>Gobiomorphus basalis</i> )	mixture	12,20	32.3,33.9 CTM	-	Simons 1984
		15	30.9 LT <sub>50</sub>	21.0 (19.6-	Richardson <i>et al.</i> 1994
Common bully ( <i>G. cotidianus</i> )	mixture	12,20	32.7,34 CTM	-	Simons 1984
		15	30.9 LT <sub>50</sub>	20.2 (18.7-	Richardson <i>et al.</i> 1994
Upland bully ( <i>G. breviceps</i> )	Juvenile	15	32.8 CTM	-	Teale 1986
Torrentfish ( <i>Cheimarrichthys fosteri</i> )	Adult	15	30.0 LT <sub>50</sub>	21.8 (20.1-	Richardson <i>et al.</i> 1994
Inanga ( <i>Galaxias maculatus</i> )	Whitebait	15	-	18.8 (18.0-	Richardson <i>et al.</i> 1994
	Whitebait	20	33.1 CTM	19.8)	Simons 1986
	Juvenile	12-26.5	30.5-35.4 CTM	-	Simons 1986
	Juvenile	15	-	-	Richardson <i>et al.</i> 1994
Giant kokopu ( <i>G. argenteus</i> )	Whitebait	16	30.0 CTM	-	Main 1988
		16	29.0 LT <sub>50</sub>	-	Main 1988
Shortjawed kokopu ( <i>G. postvectis</i> )	Juvenile	16	30.0 CTM	-	Main 1988
		16	29.0 LT <sub>50</sub>	-	Main 1988

Banded kokopu ( <i>G. fasciatus</i> )	Whitebait	14-26	30.6-34	CTM	-	Simons 1986
	Whitebait	15	-	-	16.1 (14.8-	Richardson <i>et al.</i> 1994
		16	30.0	CTM	17.7)	Main 1988
		16	29.0	LT <sub>50</sub>	-	Main 1988
	Adult	15	28.5	LT <sub>50</sub>	-	Richardson <i>et al.</i> 1994
					17.3 (16.3-	
					18.3)	
Koaro ( <i>G. brevipinnis</i> )	Juvenile	16	28.0	CTM	-	Main 1988
		16	27.0	LT <sub>50</sub>	-	Main 1988
Common smelt ( <i>Retropinna retropinna</i> )	Adult	15	28.3	LT <sub>50</sub>	16.1 (15.1-	Richardson <i>et al.</i> 1994
		20	31.9	LT <sub>50</sub>	17.4)	Richardson <i>et al.</i> 1994
		20,20.5	31.8,33.4	CTM	-	Simons 1984
Grey mullet ( <i>Mugil cephalus</i> )	78-122 mm	21	27-29	CTM	-	Sylvester <i>et al.</i> 1974
	Juvenile	20	34.3	CTM	-	Davenport & Simons 1985
Brown trout <sup>1</sup> ( <i>Salmo salar</i> )	Adult	-	-	FP	14-16	
	Juvenile	-	-	FP	17.4-17.6	
Rainbow trout ( <i>Oncorhynchus mykiss</i> )	Adult	-	-	FP	13-21	
	Juvenile	-	-	FP	15-22	

<sup>1</sup> Preferred temperatures derived from a 1989 literature review conducted by Boubee, NIWA.

Invertebrate Species	Life stage/size (mm)	Acclimated temp. (°C)	Upper lethal temp. (°C) and method	Preferred temp. (and quartiles) (°C)	Source
Freshwater shrimp ( <i>Paratya curvirostris</i> )	4.5-6.5mm	12,20	28.9,32.6 CTM	-	Simons 1984
	Adult	20	26-27 LT <sub>50</sub> <sup>2</sup>	-	Davenport & Simons 1985
	Adult	15	25.7-27.4	-	Quinn <i>et al.</i> 1994
Freshwater crayfish ( <i>Paranephrops planifrons</i> )	12-23mm	12,20	28.8,31.9 CTM	-	Simons 1984
	6-22mm				
<i>Paracalliope fluviatilis</i>	mid-late instar	15	24.1-27.5 LT <sub>50</sub> <sup>2</sup>	-	Quinn <i>et al.</i> 1994
<i>Deleatidium</i> spp.	mid-late instar	15	22.6-26.8 LT <sub>50</sub> <sup>2</sup> 24.2 LT <sub>50</sub>	-	Quinn <i>et al.</i> 1994 Cox & Rutherford 2000
<i>Zephlebia dentata</i>	mid-late instar	15	23.6-26.9 LT <sub>50</sub> <sup>2</sup>	-	Quinn <i>et al.</i> 1994
<i>Zelandobius furcillatus</i>	mid-late instar	15	ND-c.28 LT <sub>50</sub> <sup>2</sup>	-	Quinn <i>et al.</i> 1994
<i>Aoteapsyche colonica</i>	mid-late instar	15	25.9-27.8 LT <sub>50</sub> <sup>2</sup>	-	Quinn <i>et al.</i> 1994
<i>Pycnocentroides aureola</i>	mid-late instar	15	32.4 LT <sub>50</sub> <sup>2</sup>	-	Quinn <i>et al.</i> 1994
<i>Pyconocentria evecta</i>	mid-late instar	15	25.0-30.4 LT <sub>50</sub> <sup>2</sup>	-	Quinn <i>et al.</i> 1994
<i>Hydora</i> sp.	mid-late instar	15	32.6->34 LT <sub>50</sub> <sup>2</sup>	-	Quinn <i>et al.</i> 1994
<i>Potamopyrgus antipodarum</i>	medium-large	15	32.4-32.4 LT <sub>50</sub> <sup>2</sup> 31 LT <sub>50</sub>	-	Quinn <i>et al.</i> 1994 Cox & Rutherford 2000
<i>Sphaerium novaezelandiae</i>	medium-large	15	30.5-32.8 LT <sub>50</sub> <sup>2</sup>	-	Quinn <i>et al.</i> 1994
<i>Lumbriculus variegatus</i>	ND	15	26.7-30.1 LT <sub>50</sub> <sup>2</sup>	-	Quinn <i>et al.</i> 1994

<sup>2</sup> 96 hour - 24 hour LT<sub>50</sub> values.

**Dissolved oxygen**

The Third Schedule of the Resource Management Act specifies that dissolved oxygen shall exceed 80% of saturation concentration for freshwaters being managed for aquatic ecosystem purposes (Class AE), fishery purposes (Class F), and fish spawning purposes (Class FS). The USEPA (1986) identifies four levels of impairment for salmonid embryos and other life stages. Slight impairment to non-embryo life stages of the fishery was considered to occur  $6 \text{ g/m}^3$ , moderate impairment at  $5 \text{ g/m}^3$ , and severe impairment at  $4 \text{ g/m}^3$ . For salmonid embryos, USEPA consider intra-gravel dissolved oxygen to be at least  $3 \text{ g/m}^3$  lower than the oxygen concentration in the water. The Australian Water Quality Guidelines (1992) recommend that dissolved oxygen should not normally be permitted to fall below  $6 \text{ g/m}^3$  or 80-90% saturation determined over at least one diurnal cycle and preferably over several days.

Recent work on juvenile life stages of some native fish species suggests that they can be tolerant of low levels of constant dissolved oxygen over periods up to 48 hours (Dean & Richardson, 1997). Juvenile smelt are the most sensitive native fish species and respond similarly to juvenile rainbow trout which succumbed to DO levels of  $3 \text{ g/m}^3$  at  $15^\circ\text{C}$  over 24–36 h. Some of the native galaxiid species studied have shown the ability to alter behaviour in response to low oxygen levels (e.g., surface gulping, leaving the water). Fluctuating dissolved oxygen levels also need to be considered. High water temperatures can increase the adverse effects of low dissolved oxygen on fish, and the additive effects of these two potential stressors is an important consideration.

## Ammonia

Recent studies of headwater streams show that ammonia is removed from stream water primarily through assimilation by photosynthetic (unicellular algae, filamentous algae and bryophytes) and heterotrophic (bacteria and fungi) organisms and by sorption to sediments, and secondarily by nitrification. At higher flows, some of these processes may be inhibited by shear, or slowed because of lower stream temperatures. In addition, the surface area-to-volume ratio is reduced so that ammonia molecules do not come into contact as often with surfaces and attached organisms.

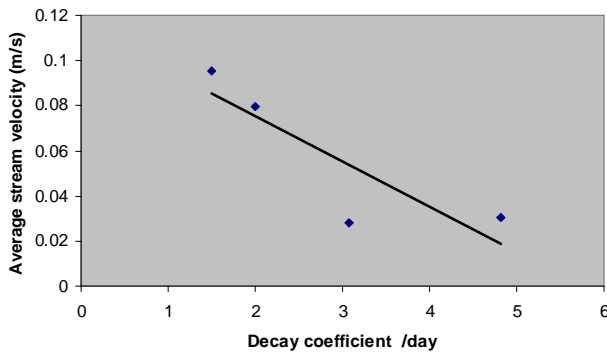
Much confusion can arise in the usage of the term "ammonia". In WAIORA, we adopt the following definitions:

- Total ammonia is ammonia ( $\text{NH}_3$ ) plus ammonium ( $\text{NH}_4^+$ ). This is the USA terminology. It is sometimes also called "ammoniacal-nitrogen" in New Zealand. Because this module uses USEPA toxicity limits, WAIORA uses the term "total ammonia" exclusively.
- Ammonia ( $\text{NH}_3$ ) is "free ammonia" or "un-ionised ammonia" or "non-ionised ammonia". It is sometimes used interchangeably with "total ammonia", but not here.

The USEPA (1999) report total ammonia as mg(N)/L and we use that terminology here.

Measurements in Auckland streams at summer low flows indicate that stream values of the total ammonia removal rate (decay) coefficient increase as water velocity decreases. WAIORA assumes that the decay coefficient is constant at 2 /day, but increases linearly with water velocity ( $V$ ), when velocities are less than 0.08 m/s.

$$\text{Decay coefficient} = 5 - 36.8 * V \text{ for } V < 0.08$$



Relationship between total ammonia decay coefficients measured in the Kumeu and Waiwera rivers.

### Calculation of ammonia concentration

With only one point source discharge, the calculation of ammonia concentration is relatively simple. With a point source discharge of  $q_{in}$  L/s and total ammonia concentration of 100 mg(N)/L and a total ammonia concentration of 0.1 mg(N)/L at the top of the reach, the ammonia concentration at the end of the reach ( $C$ ) for a flow  $Q$  is simply the conservation (dilution) equation:

$$C = (Q * 0.1 + 100 * q_{in}) / (Q + q_{in})$$

With more than one point source, the calculation of ammonia concentration is more complicated and the decay constant is used to reduce the ammonia concentration through the reach.

$$c = \frac{\left( \frac{1-\alpha^n}{1-\alpha} \right) q + \alpha^{n-1} c_{top}}{1+nq}$$

where:

$c = C/C_{in}$  is the ratio of total ammonia concentration at the downstream end of the reach ( $C$ ) that contains  $n$  evenly-spaced inflows of concentration  $C_{in}$ ,  $q$  is the ratio of the discharge of each point source ( $q_{in}$ ) to the reach discharge ( $Q$ ), and  $c_{top}$  is that ratio of the total ammonia concentration at the upstream end of that segment to that of each point source inflow;

$\alpha = e^{-k\Delta x/V}$  is the “total ammonia decay number”, with  $\Delta x$  being the distance between each equally-spaced inflow and  $V$  is the reach average water velocity.

### Ammonia guidelines

Water temperature and pH values are used to interpret appropriate ammonia toxicity criteria for streams. Both water temperature and pH values can show marked diurnal variation. Maximum and daily average pH are specified by the user and the daily mean temperature is calculated by WAIORA.

For lowland streams with incised channels about 1–5 m wide, such as those in many parts of the Waikato and Northland, the pH of stream water typically varies between 6.8 and 8.5 during a 24-hour period. This is equivalent to a maximum 1-hr pH of around 8.5 and a 4-day average pH of 7.7.

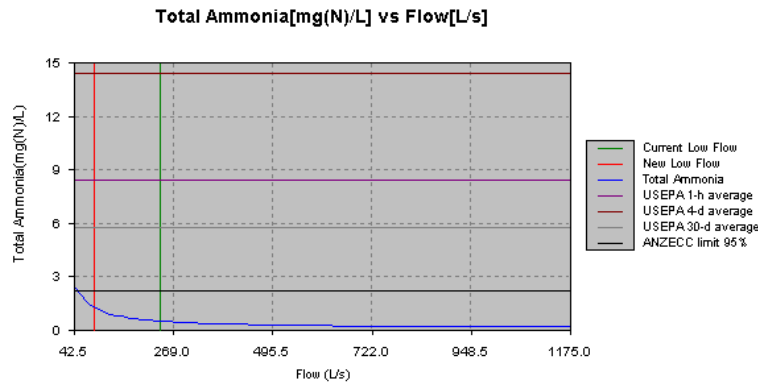
For shallow, shingle streams with channels >10 m wide and <0.5 m deep, the pH of water in streams typically varies between 6.8 and 9.5 during a 24-hour period. This is equivalent to a maximum 1-hr pH of around 9.5 and a 4-day average pH of 8.0.

If you have access to a pH meter, you could do some in-situ pH measurements when you do your site visits to see how well they correspond to expected values. Stream pH is usually at a maximum during the late afternoon. Maximum values are affected by the amount of plant and algal biomass present upstream.

WAIORA uses the latest (1999) USEPA guidelines for acute toxicity to aquatic organisms. The acute toxicity values are criteria for maximum concentration (CMC), and are the same in the 1998 and 1999 editions of the USEPA guidelines and refer to the maximum 1-h average not to be exceeded once in three years. The maximum 1-h average concentration is varied according to the maximum daily stream pH. USEPA guidelines are also given for chronic 4-day and 30-day average total ammonia concentrations. The 4-day and 30-day average guidelines are criteria for continuous concentration (CCC) at the average daily pH, with the 4-day average guideline equal to 2.5 times the 30-day guideline value. Allowable acute (1-h) concentrations in the USEPA guidelines depend on whether salmonids are present. Allowable acute toxicity levels in streams with salmonids present are about one third of those in streams without salmonids. If early life stages of fish are present, the allowable chronic total ammonia concentration 30-day guideline may be reduced, depending on the average water temperature.

ANZECC ammonia guidelines are used as well as the USEPA guidelines. The ANZECC guidelines specify chronic concentrations of ammonia and these concentrations increase as protection levels decrease. The ammonia concentration at the ANZECC 80% protection level is similar to the concentration specified by the USEPA 30-day guideline.

The USEPA guideline standards for 1-h, 4-day and 30-day, as well as the ANZECC guideline for the selected protection level, are given in WAIORA results and on plots as shown below.



### Ammonia effects

Toxicity to aquatic organisms concerns ammonia, not ammonium, but laboratory tests measure total ammonia. The proportion of the total ammonia that is free (non-ionised) is a function of the water pH and temperature, so that the higher these variables are the more toxic a sample becomes. Therefore, stream pH and temperature are important variables in assessing stream toxicity.

Most toxicity studies on native organisms in New Zealand are not reported as total ammonia. An exception is for the native finger-nail clam *Sphaerium novaezelandiae* which had LC50 values over 30-60 days of 3.8 mg(N)/L (pH 7.5) (Hickey & Martin 1999). Reproductive success was influenced by total ammonia values of 0.80 mg(N)/L. Mesocosm studies for freshwater invertebrate sensitivity to ammonia are also reported as total ammonia values (Hickey et al 1999).

As there is a paucity of data on the response of native organisms to total ammonia, WAIORA uses the USEPA and ANZECC total ammonia toxicity criteria. These are calculated internally based on pH and water temperature, but other guideline thresholds can be entered if desired.

The toxicity of ammonia is largely dependent on the concentration of un-ionised ammonia present, which is dependent on the pH and temperature of the solution. For this reason, water quality guidelines generally have tables of pH and temperature values for acute (short-term) and chronic (long-term) protection. While earlier tables were presented as values for un-ionised ammonia with conversion tables from the generally measured total ammonia, more recent guideline derivations provide tables based on total ammonia nitrogen. This change in format is prone to introduce confusion for comparison of guidelines or 'criteria' values, while also making it difficult to compare the published sensitivity data for some native species.

Both the ANZECC and USEPA guidelines are adjusted for pH. For example the ANZECC guidelines, adjust pH = 8 allowable concentrations by the daily average pH according to:

$$\frac{0.0676}{1 + 10^{(7.688 - pH_{Av})}} + \frac{2.91}{1 + 10^{(pH_{Av} - 7.688)}}$$

The US EPA criteria have both acute and chronic data but do not include consideration of any data for ammonia sensitivity of species not resident in North America. The recent ANZECC revisions use only chronic sensitivity data and include most recent New Zealand studies (Hickey and Martin 1999, Hickey et al 1999).

A number of studies have been undertaken which examine the sensitivity of New Zealand native freshwater invertebrates and fish to ammonia. Comparison of the relative sensitivity of species from these studies requires conversion of the sensitivity data to a common pH value. The relative sensitivity of native invertebrate and fish species is compared in Table 4 with the inclusion of rainbow trout. This indicates that two invertebrate species, amphipod and snail, are more sensitive than rainbow trout. Rainbow trout are the most acutely sensitive species in the USEPA criteria derivation.



### Adjustment of guidelines

The USEPA criteria were revised in 1998, with a further revision in 1999 to incorporate temperature sensitivity. Table 5 shows the USEPA (1999) acute criteria table with adjusted New Zealand data.

The USEPA acute Criterion Maximum Concentration (CMC) data is derived from the most sensitive species, rainbow trout, sensitivity value divided by a factor of 2. Thus the trout acute value (AV) of 11.28 mg(N)/L at pH 8 (Table 4) becomes the guideline value of 5.62 mg(N)/L (Table 5). Converting this to New Zealand data uses the same factor of 2 applied to the most sensitive species, the amphipod, with an AV of 7.2 mg(N)/L (Table 4), giving an adjusted value of 3.6 mg(N)/L (Table 5). This indicates that NZ species are 36% more sensitive and all pH related values are adjusted by this factor.

ANZECC 2000 guidelines incorporate a risk-based calculation procedure with total ammonia guidelines in relation to pH. The ANZECC (2000) guidelines include chronic data for three native NZ invertebrate species. The fingernail clams (Hickey and Martin 1999) and artificial streams studies with invertebrate communities showed high sensitivity for the mayfly *Deleatidium* sp. (Table 6), together with the mayfly *Coloburiscus humeralis* (Hickey et al. 1999). The ANZECC dataset includes data for 16 species ranging in sensitivity from 0.54 mg(N)/L (at pH 8.0) to 19.8 mg(N)/L. The ANZECC trigger value for 95% protection at pH 8.0 is 0.90 mg(N)/L. Comparison of this value with the fingernail clam value (pH 8, EC<sub>20</sub> 0.42 mg(N)/L, Table 6) indicates that some slight adverse effect may occur for these species.

Examination of the mesocosm community responses to chronic ammonia exposure (Hickey et al. 1999) provides an indication of the sensitivity of both individual species and of various species groups. The results showed that: (i) macroinvertebrates were generally tolerant of ammonia exposure, with biodiversity indices such as taxa richness and the number of taxa in the orders Ephemeroptera, Plecoptera and Trichoptera (EPT) showing no significant reduction for <11X ANZECC guideline (i.e., <10.1 mg(N)/L at pH 8.0); (ii) abundance measures were more sensitive with mayfly abundance the most sensitive group; (iii) snail abundance was also strongly affected at 11X ANZECC guideline; (iv) trichoptera (caddisflies) were a particularly tolerant group and showed no marked reduction in species diversity (from 15 species to 13 species) or abundance.

Comparison of the NZ invertebrate data (Table 6) with the USEPA (1999) chronic 30 day guideline of 2.3 mg(N)/L for fish early life stages present at 15°C indicates that insufficient protection would be provided for both mayfly and finger nail clams. This showed that both the mayflies and fingernail clams were more sensitive, by 1.8X and 5.5X respectively. USEPA data also indicates that fingernail clams are among the most sensitive species. This data suggests that if mayflies or fingernail clams are present in a receiving water then US EPA guideline values should be adjusted by a factor of 2 or 6 respectively (Hickey et al. 1999).

**Table 4.** The sensitivity of New Zealand native freshwater invertebrates and fish to ammonia. All concentrations are mg(N)/L total ammonia with exposures at 15°C and 96h (except \* = 48h). Bold indicates the most sensitive species in the lower 25%ile of the species used to derive USEPA water quality criteria. - = no data. (After Hickey 2000, with rainbow trout sensitivity added).

Species: common name	Species: scientific name	AV <sup>a</sup> (mg(N)/L)	EPA %ile <sup>b</sup>	Rank of NZ species
<b>Amphipod</b>	<b><i>Paracalliope fluviatilis</i></b>	<b>7.2*</b>	<b>&lt;1</b>	<b>1</b>
<b>Snail</b>	<b><i>Potamopyrgus antipodarum</i></b>	<b>9.8</b>	<b>&lt;1</b>	<b>2</b>
<b>Rainbow trout</b>	<b><i>Oncorhynchus mykiss</i></b>	<b>11.23</b>	<b>1</b>	
<b>Caddisfly</b>	<b><i>Pycnocentria evecta</i></b>	<b>16.3</b>	<b>9</b>	<b>3</b>
<b>Snail</b>	<b><i>Potamopyrgus antipodarum</i></b>	<b>16.5</b>	<b>9</b>	<b>4</b>
<b>Mayfly</b>	<b><i>Deleatidium</i> spp.</b>	<b>17.5</b>	<b>9</b>	<b>5</b>
<b>Fingernail clam</b>	<b><i>Sphaerium novaezelandiae</i></b>	<b>22.2</b>	<b>15</b>	<b>6</b>
<b>Shrimp</b>	<b><i>Paratya curvirostris</i></b>	<b>22.4</b>	<b>15</b>	<b>8</b>
<b>Fish - Banded kokapu</b>	<b><i>Galaxias fasciatus</i></b>	<b>22.4</b>	<b>15</b>	<b>8</b>
<b>Fish - Common smelt (adult)</b>	<b><i>Retropinna retropinna</i></b>	<b>22.4</b>	<b>15</b>	<b>8</b>
Oligochaete	<i>Lumbriculus variegatus</i>	25.9	26	10
Shrimp	<i>Paratya curvirostris</i>	31.1	35	11
Fish - Banded kokapu	<i>Galaxias fasciatus</i>	32.4	35	12
Fish - Common bully (juvenile)	<i>Gobiomorphus cotidianus</i>	34.8	50	13
Fish – inanga	<i>Galaxias maculatus</i>	39.0	62	14
Fish - Redfin bully	<i>Gobiomorphus huttoni</i>	41.2	62	15
Fish - Common smelt (adult)	<i>Retropinna retropinna</i>	50.1	65	16
Fish - Inanga (juvenile)	<i>Galaxias maculatus</i>	59.4	71	17
Fish - Shortfin eels (elvers)	<i>Anguilla australis</i>	95.0	82	18
Stonefly	<i>Zealandobius furcillatus</i>	>30.0	•	•
Stonefly	<i>Zephlebia dentata</i>	>30.0	•	•
Shrimp	<i>Paratya curvirostris</i>	>30.0	•	•
Fish - Common bully (adult)	<i>Gobiomorphus cotidianus</i>	>39.1	•	•
Fish - Longfin eels (elvers)	<i>Anguilla dieffenbachii</i>	>53.7	•	•

<sup>a</sup> AV = Adjusted Value. EC<sub>50</sub> value adjusted to pH 8 using the algorithm given USEPA 1998

<sup>b</sup> Percentile rank of the local species sensitivity relative to the ranked sensitivities of the 34 North American resident species data used to derive the USEPA 1998 water quality criteria.

**Table 5.** pH-dependent values of the CMC<sup>1</sup> (acute criterion) (from USEPA 1999) incorporating adjustment for New Zealand acute data.

pH	CMC, mg N/L	
	Salmonids present	Salmonids present with NZ adjustment
6.5	32.6	21.2
6.6	31.3	20.3
6.7	29.8	19.4
6.8	28.1	18.3
6.9	26.2	17.0
7	24.1	15.7
7.1	22	14.3
7.2	19.7	12.8
7.3	17.5	11.4
7.4	15.4	10.0
7.5	13.3	8.6
7.6	11.4	7.4
7.7	9.65	6.3
7.8	8.11	5.3
7.9	6.77	4.4
<b>8</b>	<b>5.62</b>	<b>3.7</b>
8.1	4.64	3.0
8.2	3.83	2.5
8.3	3.15	2.0
8.4	2.59	1.7
8.5	2.14	1.4
8.6	1.77	1.2
8.7	1.47	1.0
8.8	1.23	0.8
8.9	1.04	0.7
9	0.885	0.6

<sup>1</sup> = Criterion Maximum Concentration

**Table 6.** Summary of acute and chronic results for the mayfly *Deleatidium* spp. and fingernail clam *Sphaerium novaezelandiae* (from Hickey et al. 1999).

Species	Acute results <sup>a</sup>				Chronic results				Adjusted to pH = 8 <sup>b</sup>		
	Temp (°C)	pH	EC <sub>50</sub> <sup>c</sup>	Ref <sup>d</sup>	Temp (°C)	pH	EC <sub>20</sub> <sup>c</sup>	Ref <sup>d</sup>	EC <sub>50</sub> <sup>c</sup>	EC <sub>20</sub> <sup>c</sup>	ACR <sup>e</sup>
Mayfly, <i>Deleatidium</i> spp.	15	7.6	34.3 (23.1-85.2)	1	16	8.4	0.679 (0.42-0.95)	2	16.9	<b>1.28</b>	13.2
Fingernail clam, <i>Sphaerium novaezelandiae</i>	15	8.2	11.8 (9.9-14.4)	1	20	7.5	0.76 (0.48-1.1)	3	17.3	<b>0.42</b>	40.9

<sup>a</sup> Acute values are for 96 h exposures and were calculated from references cited. Each EC<sub>50</sub> value was converted to total ammonia nitrogen in the table above, using the speciation relationship derived by Emerson et al. (1975)

<sup>b</sup> Acute and chronic values adjusted to pH = 8 using the equations given in USEPA (1998)

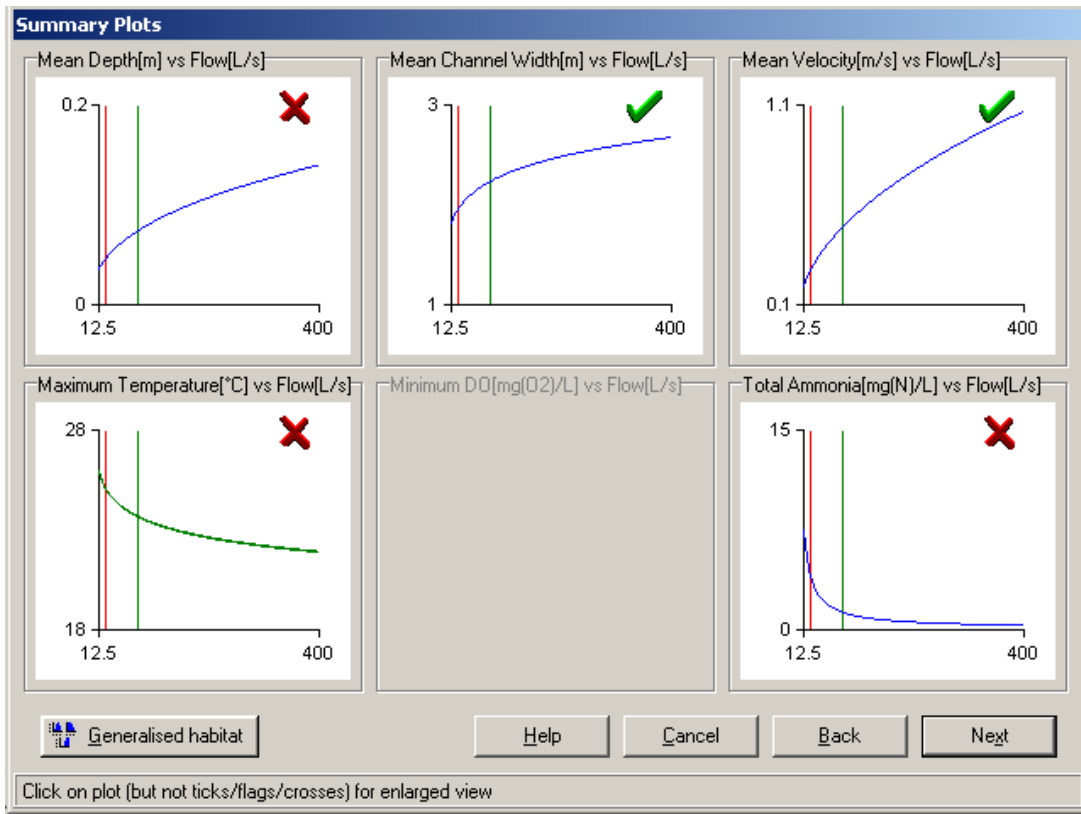
<sup>c</sup> Expressed as total ammonia (mg (N)/L)

<sup>d</sup> (1) Hickey and Vickers (1994); (2) This study based on total *Deleatidium* numbers (Table 5); (3) Hickey and Martin (1999)

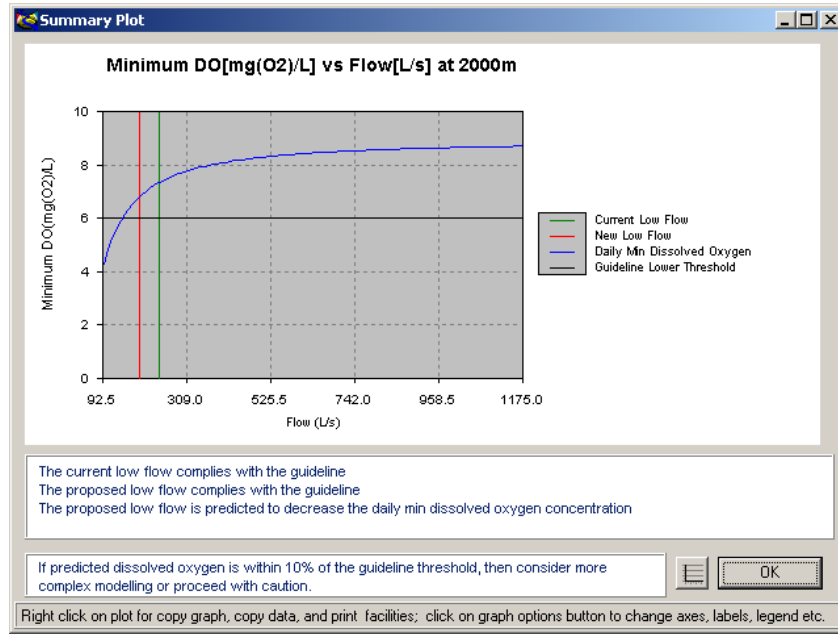
<sup>e</sup> ACR = acute chronic ratio. Calculated from adjusted acute EC<sub>50</sub> and chronic EC<sub>20</sub> values

## Summary plots

This window graphically displays the results for each of the parameters selected in the Impact Assessment window against the flow (in L/s). Results are based on the scenarios selected, the data entered in the Data window, and the specified environmental guidelines if they are used. If the results at the new flow comply with the specified environmental guidelines, and if values of the index flow comply with the guideline threshold, a green flag or tick is displayed in the upper right corner of the graph (as specified by Display Options under the Options menu). For evaluate status quo scenarios, only the index flow is taken into account.



To access an enlarged view of any of the parameters of the results the user can click within the specified graph (clicking on the tick or flag will not work). Both the summary view and the enlarged view (shown over) present the index flow as a vertical green line and the new flow (if applicable) as a vertical red line. Thus, the points where the vertical lines intercept the blue curves indicate the change in the parameter. Any threshold values are presented as maroon lines across the graphs. Again, guideline compliance or non-compliance is indicated by the colour of the flag or ticks and crosses (as specified by Display Options under the Options menu). Advice on the sensitivity of the results is offered in the text boxes below the plots.



When enlarged graphs are displayed, they can be copied either as pictures or in the form of tables of X-Y values that can be pasted into an application such as Microsoft Excel.



The user can change the graph display options by selecting the options button. The minimum and maximum values for the X- and Y-axes, number of tick marks and decimal places, axis labels, title, legend display, and grid display can be specified.

**Options**

Display | Axes

Title: Minimum DO[mg(O<sub>2</sub>)/L] vs Flow[L/s] at 2000m

X axis label: Flow (L/s)

Y axis label: Minimum DO[mg(O<sub>2</sub>)/L]

Background       Show X Ticks       Show Y Ticks

Legend               Show X Grid         Show Y Grid

OK Cancel

**Options**

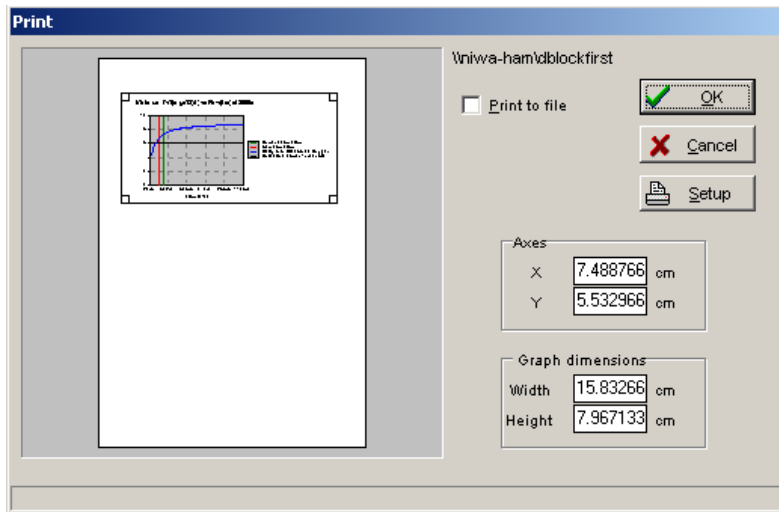
Display | Axes

	X axis	Y axis
Minimum	92.5	0.00
Maximum	1175.0	10.00
Decimals	1	0
Ticks	6	6

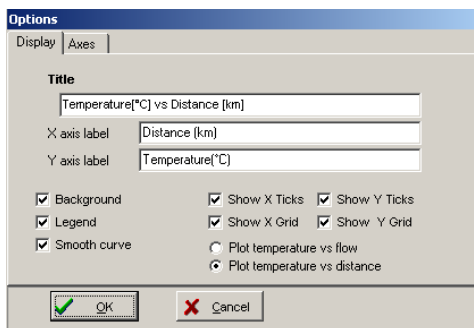
OK Cancel

Copy graph CTRL+C, print graph CTRL+P, and copy data CTRL+D facilities are also available to the user by right clicking on the enlarged plot. The graph or data can then be pasted into other applications such as Microsoft Word or Excel.

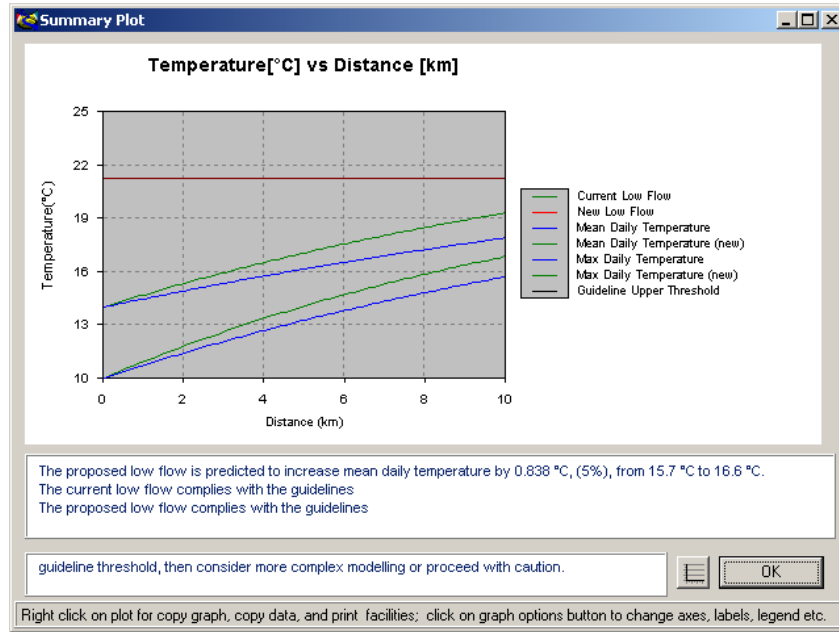
The print graph option displays a print preview where the size and location of the graph on the page can be altered by clicking and dragging on the image outline. The layout (portrait or landscape) can also be set in the print preview.



The reach length that is specified can have a significant effect on predicted water temperatures. If the reach length is short, the water temperature will be similar to that at the abstraction point. However, a long reach length may not be applicable, because the size of the stream or river increases significantly downstream and the differences in shade and geometry, as well as the addition of water, invalidate the model assumptions. The way in which water temperature changes with distance shows the rate of change of temperature with distance, and hence sensitivity to reach length.



The variation of water temperature with distance downstream of the abstraction point can be plotted by selecting the Plot temperature versus distance in graph options when the enlarged water temperature graph is displayed.



Both the mean and maximum daily temperature are shown in the same colour, with temperatures for the index flow shown in blue and those for the new flow shown in green. The mean daily temperature will always be less (above) than the maximum daily temperature.

There will be no further change in water temperature with distance when the water temperature reaches the equilibrium temperature.



## Summary Results

The Summary Results window presents a summary of results for each of the selected parameters. The user may choose to evaluate mitigation options and sensitivity, and if this is done, these results are shown here. The results of the habitat, water temperature, dissolved oxygen, and ammonia models in WAIORA apply to a single reach along which there is negligible variation in stream conditions.

The Results page shown below displays values of the selected parameters for the index flow (this is the flow that was specified in the first window – Location information) and the new flow (this is the index flow less the abstraction specified in Location information). If the impact assessment scenario is “Evaluate status quo” in the Impact assessment window, parameters will only be displayed for the index flow. Non-compliance of the specified parameters with environmental guidelines is shown by highlighting the particular table entry in red or showing the text in red.

**Results**

Catchment: Mokau  
Stream: Mokauti  
at location reference: Mokauti Power Scheme

**Scenario Evaluation: abstract water**

The index 1-day median annual low flow flow is 80 L/s, derived by guess.  
Proposed abstraction: 55 L/s.

**Scenario Evaluation**

Parameter	Index	New
Flow (L/s)	80	25
Depth [m]	0.07	0.05
Width [m]	2.23	1.96
Velocity [m/s]	0.49	0.27
Mean Daily Temperature [°C]	18.1	18.1
Max Daily Temperature [°C]	23.7	25.0
Total Ammonia [mg(N)/L]	1.3	4.0

**Environmental Guidelines:**  
The change should not:

Mitigate Clear mitigation Help Cancel Back Next

Right click for Copy (Ctrl C), Save (Ctrl S), and Print (Ctrl P) menu

The results are presented in the form of a table, followed by a list of the guidelines that were applied, then a detailed summary of results for each parameter, listing the value at each flow and the amount of change.

**Results**

Increase total ammonia to 8.408 mg(N)/L, as specified by WAIORA guideline (USEPA 1999 1-h average).  
 Increase total ammonia to 14.38 mg(N)/L, as specified by WAIORA guideline (USEPA 1999 4-d average at calculated d  
 Increase total ammonia to 5.75 mg(N)/L, as specified by WAIORA guideline (USEPA 1999 30-d average at calculated d  
 Increase total ammonia to 2.184 mg(N)/L, as specified by WAIORA guideline (ANZECC 2000 95% protection level).

**Results:**

**DEPTH**  
 The current low flow complies with the guideline  
 The proposed low flow complies with the guideline  
 The proposed low flow is predicted to decrease depth by 0.0171 m, (11%), from 0.162 m to 0.145 m.

**WIDTH**  
 The proposed low flow complies with the guideline  
 The proposed low flow is predicted to decrease width by 2.75 m, (28%), from 9.74 m to 6.99 m.

**VELOCITY**  
 The current low flow complies with the guideline  
**The proposed low flow does not comply with the guideline**  
 Decrease velocity to 0.15 m/s, as specified by WAIORA guideline.  
**The proposed low flow is predicted to decrease velocity by 0.0486 m/s, (29%), from 0.168 m/s to 0.119 m**

**MEAN DAILY TEMPERATURE**  
 The proposed low flow is predicted to increase mean daily temperature by 1.99 °C, (11%), from 17.7 °C to 19.7 °C.

Right click for Copy (Ctrl C), Save (Ctrl S), and Print (Ctrl P) menu

The results can be copied to clipboard (Ctrl P) and pasted into applications such as Microsoft Excel and Word, saved to a file as plain text or rich text form rtf (Ctrl S), or printed (Ctrl P).

### Mitigation and sensitivity

To assess possible mitigation scenarios or to examine sensitivity to selected parameters, the user may click the Mitigate... button. This displays accesses the Mitigation/Sensitivity window shown below.

The user may select the parameter(s) for which the mitigation will apply. At least one parameter must be chosen. Once the parameter(s) have been chosen the user can enter alternative values in the appropriate text boxes (white background) in the New Value column. Unavailable text boxes are greyed.

**Mitigation/Sensitivity**

Select parameters for mitigation:

Habitat  
 Water Temperature  
 Dissolved Oxygen  
 Total Ammonia

This window allows the user to consider different mitigation/sensitivity scenarios. Each parameter has limited variables which can be changed in mitigation. The results of changing these variables are shown in the summary windows. All selected parameters will be recalculated using the new data and summarised in the mitigation page of the results window. When finished press OK. This scenario will then be saved to the Audit Trail.

Data which may be changed:

	Current Value	New Value
Flow change [L/s]	55	
US canopy angle [°]		
Canopy angle [°]	60	
Num point source discharge inflows	1	
Total ammonia of each inflow [mg(N)/L]	100	
Total ammonia at top of reach [mg(N)/L]	0.1	

Help Cancel OK

To see mitigation results, press View Results or type Alt+R; To close window and save results to Audit Trail, press OK

For example, if the Water Temperature parameter is selected the user can enter alternative values in three active New Value text boxes; the abstraction rate, the US canopy angle (shade above the abstraction point) and Canopy angle (shade below the abstraction point). If the Habitat or Dissolved Oxygen parameters are

selected a new value may only be entered into the abstraction rate text box, whereas if Total Ammonia is selected, new values can be entered in all six boxes. For mitigation scenarios, new values for abstraction rate, number of point source discharge inflows, total ammonia of inflows and total ammonia at top of reach should be less than the current values, whereas the new shade values should be higher than the current value.

Once new values have been entered, the user can return to the Summary Results window (shown here) by either pressing the OK button.

Parameter	Proposed	Proposed	Mitigation	Mitigation
	Index	New	Index	New
Flow (L/s)	80	25	80	35
Depth [m]	0.07	0.05	0.07	0.05
Width [m]	2.23	1.96	2.23	2.03
Velocity [m/s]	0.49	0.27	0.49	0.32
Mean Daily Temperature [°C]	18.1	18.1	18.1	18.1
Max Daily Temperature [°C]	23.7	25.0	23.7	24.6

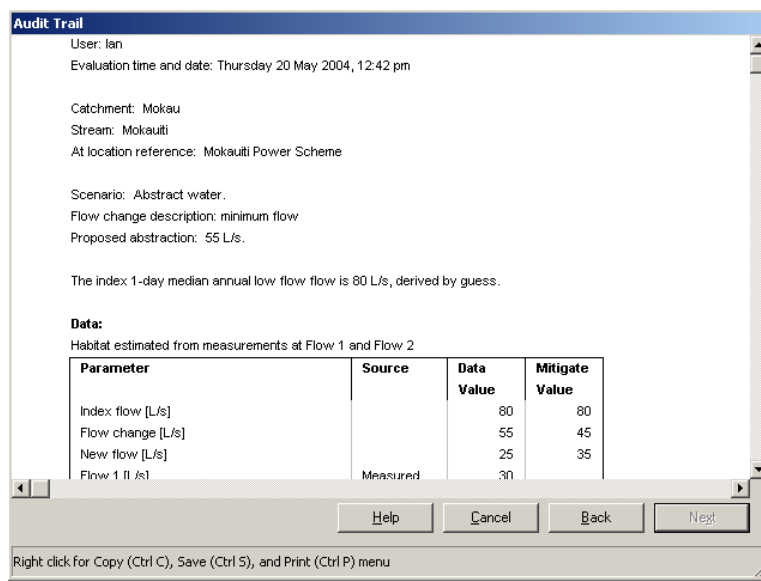
In the Results window, the mitigated parameter values (at both the index flow and the new mitigated flow), are shown along with the pre-mitigation index flow and proposed new flow.

#### Removing mitigation results

To remove mitigation results from the results and audit trail, press the mitigate button on the Summary Results window, de-select all the evaluation parameters, then press OK.

## Audit Trail

This window gives the audit trail for the current record. It reproduces the information in the Summary Results window and adds more information on the location of the site and details of the parameters used for the assessment. The user and login date and time are recorded and the location information with the catchment and stream name (with a location reference) are presented. Which scenario was chosen by the user is logged (with flow change description and abstraction rate in the abstraction scenario case). All data entries made throughout the program run are displayed. The results for each of the parameters are also presented.



The details displayed in this window can be copied (Ctrl C), saved as a text or rtf file (Ctrl S), or printed (Ctrl P). These options will also be shown in menu for with a right click and allow the user to paste the information into other applications or open the file in other applications (such as Microsoft Word, Notepad or Excel).

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## APPENDIX

### Features in WAIORA

Many of the features in WAIORA are consistent with many other windows applications. These features have been summarised. All of these actions can be performed with the mouse or with shortcut keys.

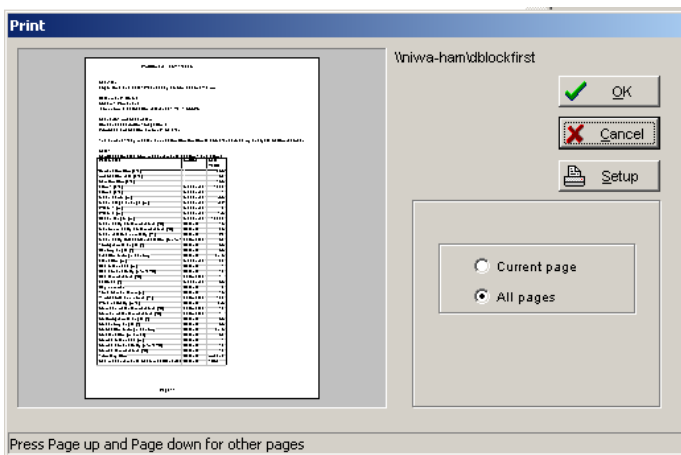
#### Copying, pasting, and saving files

##### COPYING

- 7 8
1. Right click in the zoomed summary plot, summary results or audit window and select Copy, or press CTRL+C.
  2. Paste into application such as Microsoft Word.

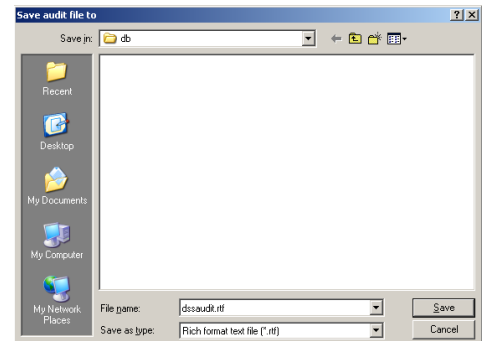
##### PRINTING

- 7 8
1. Right click in the zoomed summary plot, summary results or audit window and select Print, or press CTRL+P.
  2. A print preview will be displayed. If the table or plot does not fit on the page the page layout can be altered to landscape by pressing the Setup button. Press OK to print to the selected printer.



##### TO SAVE AS A TEXT FILE

- 7 8
1. Right click or press CTRL+S to save the audit or results window to text file.
  2. Select the directory (folder) where you want to save the file.
  3. Enter a name and file type (either rich text format (rtf) or ASCII text (txt)) for the document.
  4. Click OK.



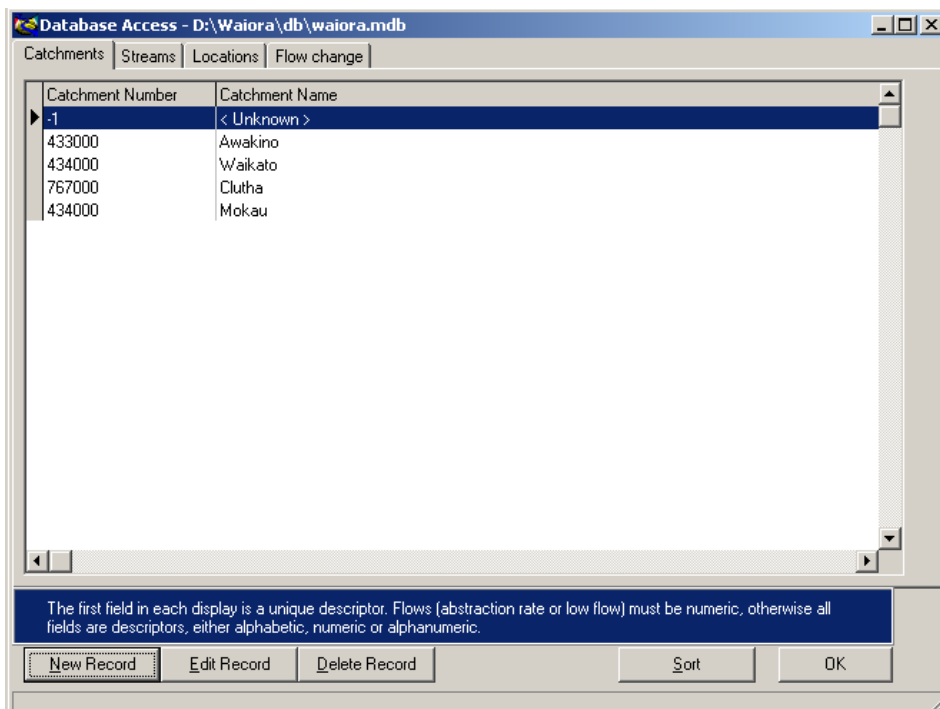
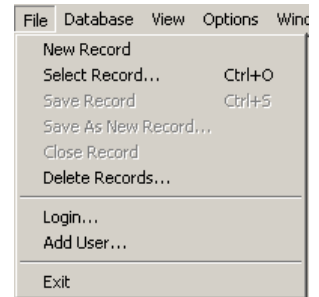


## WAIORA MENUS

The following items are in the WAIORA File menu:

### FILE MENU

<u>N</u> ew Record	Creates a new record.
<u>S</u> elect Record	Loads an existing record.
<u>S</u> ave Record	Saves the changes made to the current record to the database.
Save <u>A</u> s New Record...	Saves the current settings to a new record in the database, using the current user and login time.
<u>C</u> lose Record	Closes the current record and its associated windows. If the record has not been saved, the user is prompted to save it. New records are saved as new.
<u>D</u> elete Records...	Allows the user to delete their own records from the database.
<u>L</u> ogin...	Allows an alternative user to log in.
Add <u>U</u> ser...	Allows a new user to be added to the database.
<u>E</u> xit	Closes the open record and exits WAIORA. If changes are unsaved, a prompt will ask whether they should be saved.
<u>V</u> iew/edit database	Displays the Database with tabs for Catchments (catchment number and name), Streams (stream number, stream name and catchment name), Locations (location reference, location name, stream name and catchment name, index flow, flow statistic, flow data source), and Flow change (description, abstraction rate, location reference, stream name and catchment name). Data can be sorted, added, edited or deleted within each tab.



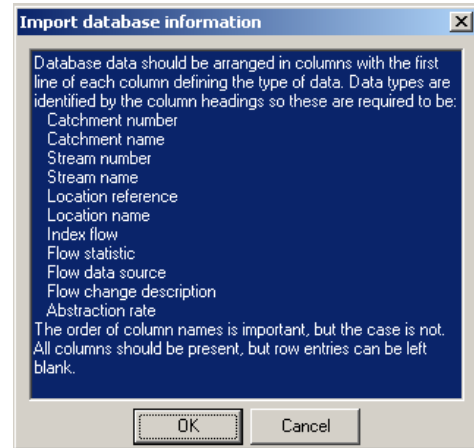
**Import database from file...**

Displays the following instruction:

To import a file press OK, Select the file type (comma delimited \*.csv, or excel spreadsheet \*.xls) and then open to add the data in the file to the existing database.

**Export database to file...**

Select the file type (comma delimited \*.csv, or excel spreadsheet \*.xls) and name, press open and all data (catchment, stream, location and flow change) will be written to the selected file.

**VIEW**

**Location Information** Displays the Location Information window.

**Impact Assessment** Displays the Impact Assessment window.

**Data** Displays the Data window.

**Environmental Guidelines** Displays the Environmental Guidelines window.

**Summary Plots** Displays the Summary Plots window.

**Summary Results** Displays the Guideline Summary window.

**Audit Trail** Displays the Audit Trail window.

**OPTIONS**

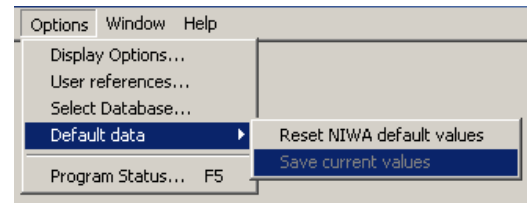
**Display Options...** Allows the user to specify if coloured flags or crosses are displayed throughout the program.

**User references** Displays a list of documents that can be edited and saved by the user.

**Select Database...** Allows you to change the WAIORA Database (WAIORA.MDB) that you are using by specifying the location of the directory that you wish to use.

**Default data** This allows you to change the default data that are used when a new record is created. You have the option of using the data that you have entered as the default set or selecting the default set, although you need to decide whether they are relevant to your stream. These default data are saved in the text file WAIORA.INI. You can also edit the values in this file to create your default data set.

**Program Status...** Displays any errors that occurred during calculation of results.

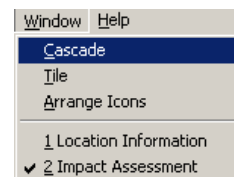
**WINDOW**

**Cascade** Cascades the open windows so all the titles are displayed, and the active window is on top.

**Tile** Tiles the open windows so that all can be viewed at the same time.

**Arrange Icons** Arranges the icons for minimized windows.

**1,2,3... command** Switches to the window and makes it active.



## HELP

<u>C</u> ontents	Opens the WAIORA Help file. The Online Help provides a comprehensive contents screen that summarises the contents of the Help system.
<u>T</u> opic Search	Displays the Search All dialog box. The Search All dialog box lets you reference Help topics on specific subjects.
A <b>o</b> ut...	Displays WAIORA's version number, programmers and contact address for program enquires.

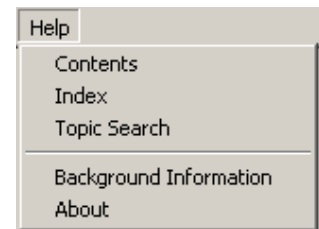
## WAIORA help

WAIORA provides an Online Help facility that provides background information about how the program should be used.

You can access this Help facility in the following ways:

7 8

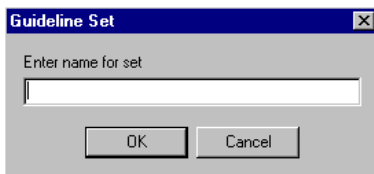
- By selecting the Contents page option (ALT+C) or the Topic Search option (ALT+T) on the Help menu (ALT+H).
- By choosing the Help command button that is available on many windows. This method gives you quick access to specific information about the current window.
- By pressing F1. Online Help facilities are linked to many edit boxes and check boxes. Specific information is displayed by pressing F1 while selecting either of these boxes. If there is no information related to a topic, the user is sent directly to the Online Help Contents Page.



## Guideline sets

### SAVING A GUIDELINE SET

To save a guideline set:

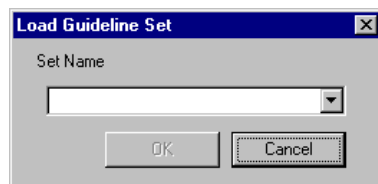


1. Select the Save Set button (ALT+S) on the Environmental Guidelines window to activate the Guideline Set dialog window.
2. Type in the name of the guideline set in the Enter name for set text box.
3. Select OK or push ENTER.

The user is unable to save a guideline set if the name specified already exists in the database or a name is not entered in the Enter name for set dialog box.

### LOADING A GUIDELINE SET

To load an existing guideline set:

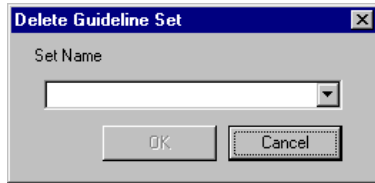


1. Select the Load Set button (ALT+L) on the Environmental Guidelines window to activate the Load Guideline Set dialog window.
2. Select the set name from the Set name drop-down box.
3. Select OK or push ENTER.

The user is unable to load a guideline set if the name specified does not exist in the database.

## DELETING A GUIDELINE SET

To delete an existing guideline set:



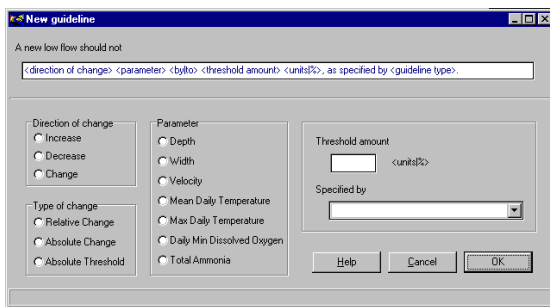
1. Select the Delute Set button (ALT+D) on the Environmental Guidelines window to activate the Delete Guideline Set dialog window.
2. Select the set name from the Set name drop-down box.
3. Select OK or push ENTER.

An anonymous user is unable to delete guideline sets.

## New guidelines

### ADDING A NEW GUIDELINE

To add a guideline:

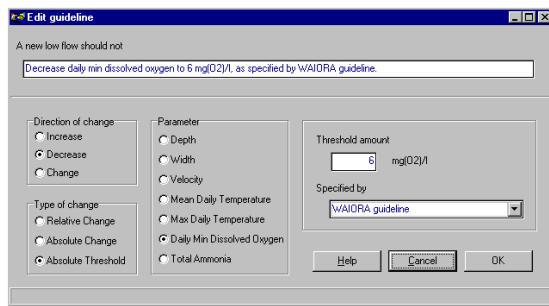


1. Select the New button (ALT+N) on the Environmental Guidelines window to activate the New Guideline dialog window.
2. Construct a new guideline using the options in the New Guideline dialog box.

Guidelines are constructed interactively using the various build components displayed on this window. As the guideline is constructed, the result is displayed in the text box at the top of the screen. This cannot be edited directly; guidelines can only be changed by using the build tools. To save this information push the OK button, to reject push Cancel.

### EDITING AN EXISTING GUIDELINE

To edit an existing guideline:



1. Select the guideline on the Environmental Guidelines window. (The text will turn maroon.)
2. Select the Edit button (ALT+E) on the Environmental Guidelines window to activate the Edit Guideline dialog window.
3. Edit the selected guideline using the options in the Edit Guideline dialog box.

Like adding a guideline, guidelines are edited interactively using the various build components displayed on this window. As the guideline is constructed, the result is displayed in the text box at the top of the screen. This cannot be edited directly, guidelines can only be changed by using the build tools. To save this information push the OK button; to reject push Cancel.

### DELETING A GUIDELINE

To delete an existing guideline, select the guideline on the Environmental Guidelines window (the text will turn maroon). Click the Delete button on the Environmental Guidelines window. The guideline will be automatically removed.

## Error messages

WAIORA errors will generally be reported to the user with a small message dialog box or will be displayed next to the relevant parameter. However, in some cases, the errors need further expansion and in this case the Program Status window is used. The example shown below displays the error message where the maximum daily temperature could not be predicted. The user can access additional information on specific errors by selecting the Program Status option under the Options menu (or by pushing F5).

```

x MAX DAILY TEMPERATURE x
Max daily temperature results were not successfully calculated.

```

## MESSAGE DIALOG WINDOWS

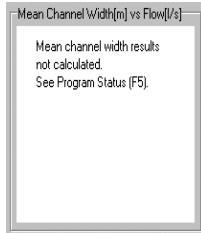
An example of a message dialog is shown here. Common reasons for these to occur are:



- the user tries to perform a restricted action (such as deleting another users record);
- missing data or information where a value is required;
- database conflicts (such as saving a guideline set with the same name as one that already exists), and
- providing incorrect information (such as an unreasonable value for a parameter).

## RECORD STATUS

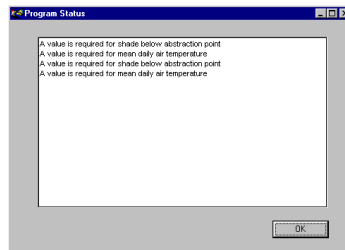
If there are problems in calculating the results for any of the parameters and/or nomograms, an error message will be displayed in the Summary Plot and/or Results window(s). This message will indicate the type of error and provide a source where more information on the error can be obtained (see examples below). These errors generally occur because of missing data, entered values are outside the valid range, or because of an internal calculation error.



Depth results not calculated. See Program Status (F5).

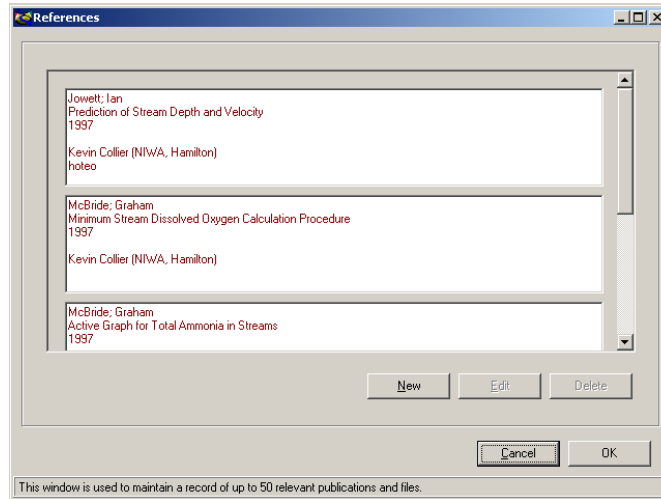
An error message can also be displayed in the Database Access window when a conflict is detected. This usually occurs when the user tries to load flow change information that already exists.

The user can access additional information on specific errors by selecting the Program Status option under the Options menu (or by pushing F5).



## User references

WAIORA contains a reference database for up to 50 relevant references and publications. New entries can be added to this database and existing references and publications can be edited or deleted. All changes made to this window are saved by pushing the OK button. By pushing the Cancel button, any changes are rejected. This window (shown below) can be accessed by selecting User references... under the Options menu (or by pushing ALT+O+R).



### ADDING A REFERENCE

To make a new reference entry, push the New button or push ALT+N. Reference and publication information can then be entered into the text boxes of the New Reference window (shown over). To save this information push the OK button. To reject push Cancel.

The 'New Reference' window contains the following input fields:

- Author
- Title
- Year
- Reference
- Where held
- Catchment
- Stream

Buttons for 'Cancel' and 'OK' are located at the bottom right of the window.

### EDITING A REFERENCE

To edit an existing reference, select the entry with a single left click (the text will turn maroon). Click the Edit button or press ALT+E. Reference and publication information can then be edited from the Edit Reference window (shown below). To save the changes push the OK button, to reject them push Cancel.

## DELETING A REFERENCE

To delete an existing reference, select the entry with a single left click (the text will turn maroon). Click the Delete button. The reference will be automatically removed.

## WAIORA options

### Background information

The background information splash screen provides the user with information about what WAIORA is designed to accomplish, the results the program produces and what is required of the user. This splash screen (shown below) can be accessed by selecting Background Info... under the Options menu (ALT+O+I).



## Display options

The user has two options available on how environmental guideline compliance or non-compliance are displayed throughout the program. The display can be either red and green flags, or a red cross and a green tick (as shown below).



The red flag or red cross indicate that the calculated results do not comply with the chosen environmental guidelines.




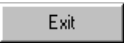
The green flag or green tick indicate that the calculated results comply with the chosen environmental guidelines.



The Display Options window (shown here) can be accessed by selecting Display Options under the Options menu (or by pressing ALT+O+O). Once the Display Options window is open, the user can click the desired guideline compliance indicator or can press F for flags and T for ticks and crosses. When WAIORA is opened for the first time, it defaults to the green and red cross option.

## Quitting WAIORA

Before quitting WAIORA the current record must be closed. The user may exit WAIORA from the main window by either:

- 7 8
- Clicking the  (Close button) at the top right corner of the screen.
  - Clicking the  (Exit button) at the bottom right.
  - Selecting File | Exit (ALT+F+X) on the menu bar.
  - Selecting ALT+F4.
  - Selecting ALT, SPACEBAR then use the UP ARROW or DOWN ARROW keys to move to Close and push ENTER, or type "C".

If a record is open, the user will be prompted to close it.

## Other windows features

### Title bar options

The title bar shows the program icon (upper-left corner), the program or active window name, and the maximise, minimise and the cancel buttons. If more than one window is open, the title bar of the active window has a different colour to the others.

### Control-menu



All windows in WAIORA have a Control menu box in the upper-left corner of each window (the program icon). This feature allows you to resize, move, maximize, minimize, and close windows.

TO OPEN THE CONTROL MENU:

- Click the Control-menu box/application icon in the upper-left corner of the window and drag to the desired option.

8

1. Press ALT, SPACEBAR to open the Control menu on the main window or ALT, HYPHEN (-) to open the Control menu on the active window.

7



2. Use UP ARROW or DOWN ARROW keys to move to the desired option and push ENTER, or type the underlined letter.

### MINIMISE, MAXIMISE AND RESTORE BUTTONS




The maximise, minimise and the cancel buttons are displayed to the upper right corner of the title bar.



- 8
- Click the minimise or maximise button  in the upper-right corner of the window. To restore the window after minimising instead of maximising it, press the restore button .

- 7
1. Press ALT, HYPHEN (-) to open the Control menu.
  2. From the Control menu, use UP ARROW or DOWN ARROW keys to move to the desired option and push ENTER, or type the underlined letter.

#### TO CLOSE A SELECTED WINDOW

- 7 8
- Click the  (close button) at the top right corner of the screen.
  - Double click the Control-menu box.
  - Click the Control-menu box/application icon in the upper-left corner of the window and drag to the Close option.
  - Double Click the Control-menu box.
  - Selecting CTRL+F4.
  - Selecting ALT, HYPHEN (-) then use the UP ARROW or DOWN ARROW keys to move to the desired option and push ENTER, or type the underlined letter.

**N.B.** To close a window without completing a command, choose the CANCEL button.

#### Menu options

Menu options allow you to select a range of commands. Firstly, select the menu and then choose the command from within that menu. Choosing a command carries out the corresponding action.

#### TO SELECT A MENU:

- 8
- Using the mouse, point to the name on the menu bar, and click the left mouse button. This opens the menu. To move directly to a menu item, you can drag the selection cursor down the menu until the menu item is highlighted, and then release the mouse button.
- 7
1. Press ALT or F10 to select the menu bar.
  2. Press LEFT ARROW or RIGHT ARROW key to select the menu you want.
  3. Press ENTER to open the selected menu.

If the name in the menu bar has an underlined letter, you can press ALT to move to the menu bar, and then type the letter that is underlined to open the menu. For example, to open the File menu, press ALT+F.

#### TO CLOSE A MENU:

- 7 8
- Click the menu with the mouse or Press ALT or F10 again, or press ESC.

#### TO CHOOSE A MENU COMMAND:

- 7 8
- Click the item.
  - Type the letter that is underlined in the item name.
  - Use the UP ARROW and DOWN ARROW keys to select the item you want and then press ENTER.

#### Command buttons



You can choose a command button to initiate an immediate action, such as carrying out or cancelling a command. The Help, Cancel, Back and Next buttons are common command buttons in WAIORA and are located to the bottom right of each window. Unavailable buttons are dimmed. The currently selected button

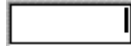
(the default) has a darker border than the other buttons. You can choose the currently selected button by pressing ENTER.

7 8

- Click the command button with the mouse
- Press TAB to move to the button you want, then press SPACEBAR or ENTER.

**N.B.** If the button has an underlined letter in its name, you can choose the command button in one step. Press and hold down the ALT button while typing the underlined letter.

### Text boxes



Information may be entered into a text box. When you move to an empty text box, an insertion point (flashing vertical bar) appears. The text you type starts at the insertion point. If the box you select already has text, this text is selected, and any text you type replaces it. You can also delete the existing text by pressing DEL or BACKSPACE.

TO SELECT A TEXT BOX:

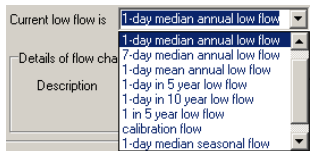
8

- Drag the pointer across the text you want to select, or double click on the word to select one word at a time.

7

1. Use TAB to select the desired text box.
2. Use arrow keys to move to the first character you want to select in the box.
3. To extend the selection, press and hold down the SHIFT while pressing the appropriate arrow key.

### Drop-down list boxes



A drop-down list box appears initially as a rectangular box with a current selection marked by the selection cursor. When you select the arrow in the square box at the right, a list of available choices appears. If there are more items than can fit in the box, scroll bars are provided.

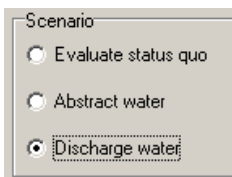
8

1. Click the arrow to the right to open the information box.
2. If there is a scroll bar present on the information box, click the up or down scroll arrow, or drag the scroll box to move to the item you want to select.
3. Click the item.

7

1. Use TAB to select the desired text box.
2. Press ALT+DOWN ARROW to open the box.
3. Use the ARROW keys to move the selection cursor to the item you want.
4. Press ALT+UP ARROW or DOWN ARROW to select the item.

### Option buttons:



Option buttons represent mutually exclusive options. You can select only one option at a time. The selected option contains a black dot. Unavailable options are dimmed.

### Check boxes

A check box next to an option means you can select or clear the option. You can select as many check-box options as needed. When a check box is selected, it contains a ü.

Select parameters for evaluation

- Habitat (Depth, Width, Velocity)
- Water Temperature
- Dissolved Oxygen
- Total Ammonia

8

- Click each blank check box to select, click a selected box to clear.

7

1. Use TAB to move to the check box you want to select or clear.
2. Press the SPACEBAR to select the box, press the SPACEBAR again to clear the selection.

NB: If the user has tabbed to a group of check boxes as display here, the ARROW keys allow the user to navigate from check box to check box.

### Scroll bars



By using scroll bars, you can move parts of the window into view when the window does not fit into the desktop. You can also use scroll bars to view unseen portions of lists and other information that cannot fit in the allotted space.

Some windows have scroll bars to allow you to view information that exists beyond the borders of the window. When you can view all the contents of a window without scrolling, scroll bars may be absent.