VALEPORT LIMITED

DataLog

Operating Manual For Use With

Model 108 MkIII & Model 308 Current Meters

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1. INTRODUCTION

This document covers the operation of the Model 108 MkIII and Model 308 Current Meters, when used with DataLog PC software. DataLog software is also compatible with other Valeport instruments, so the user may find functions that are unavailable with this instrument. These functions are for use with other Valeport instruments only, and are not covered in this manual.

1.1 DESCRIPTION

DataLog is an event driven program written in VISUAL BASIC FOR WINDOWS for use with Valeport data gathering instruments. The program allows the user to configure the sampling regime of the instruments, view data in real time using a selection of displays, and extract and view data from logging instruments.

Available displays include real time only displays for measured and calculated parameters (if applicable) tabulated scroll, and graphical output. The user can select suitable scales for the graphical displays.

Additional features of DataLog include:

- Recording of real time data to PC.
- Printing of data (tabulated scroll and graphs).
- Test Formula function to allow data checks.
- Simple statistical analysis of data.

2   INSTALLATION

2.1   INSTALLING DATALOG

It is recommended that an IBM compatible PC of 486 DX2 level or above is used, with Windows 3.1 or above. It is advisable to have at least 8Mb RAM fitted; software will operate with a standard 4Mb, but opening too many windows may cause system to "hang up".

To install DataLog follow the procedures as described below.

To install DataLog follow the procedures as described below.

- Place the installation Disk 1 in drive A.

- In Windows 95 select Run in the Startup Menu

- In the command line type A:SETUP followed by <CR>.

- Insert Disk 2 when requested.

- After a few seconds you will be asked to select the path and directory in which to install DataLog.

- Select Continue to select default DataLog directory.

The installation will now commence. When finished an OK prompt will appear with the message **INSTALLATION IS COMPLETE**. The DataLog program is now available for use under the Program Manager.

2.2   PC SETUP

In order for DataLog to operate correctly, the format of the date, time and numbers must be correctly set within the Windows Control Panel.

Function		Format	Example
Date		dd/MM/yy	23/09/96
Time		HH:mm:ss (24 hr clock)	16:37:20
Numbers:	Decimal Mark	.	1.25
	Thousands separator	,	1,321,000

Failure to set the above parameters correctly may result in the software being unable to read data from the instrument.

Flow charts on the next two pages indicate the principle steps in operating the instruments in Direct Reading and Self Recording (Model 308 only) modes. For more detailed explanations and instructions please refer to Sections 3 & 4.

FIGURE 1   OPERATION OF 308 IN LOGGING MODE

```
                 ┌─────────┐     ┌──────────────────┐     ┌──────────────────┐     ┌──────────────────┐
                 │  START  │────▶│ Check and replace│────▶│ Connect unit to PC│───▶│  Enter Windows   │
                 └─────────┘     │batteries if      │     │using 3m 'Y' lead. │     └──────────────────┘
                                 │necessary         │     │Do not apply power.│              │
                                 └──────────────────┘     └──────────────────┘              ▼
                                                                                    ◇ Is DataLog already
                          ┌──────────────────┐        No                              installed on your PC?
                          │Insert Installation│◀────────────────────────────────────◇
                          │Disk in Drive A    │                                        │ Yes
                          └──────────────────┘                                         ▼
                                  │
         ┌──────────────────────┐ │  ┌──────────────────┐     ┌──────────────┐
         │Select RUN from the   │◀┘  │Follow on-screen   │────▶│ Run DataLog  │
         │FILE menu in Program  │───▶│instructions to    │     └──────────────┘
         │Manager. In the       │    │install DataLog    │             │
         │command line type     │    └──────────────────┘             ▼
         │A:\SETUP              │
         └──────────────────────┘
```
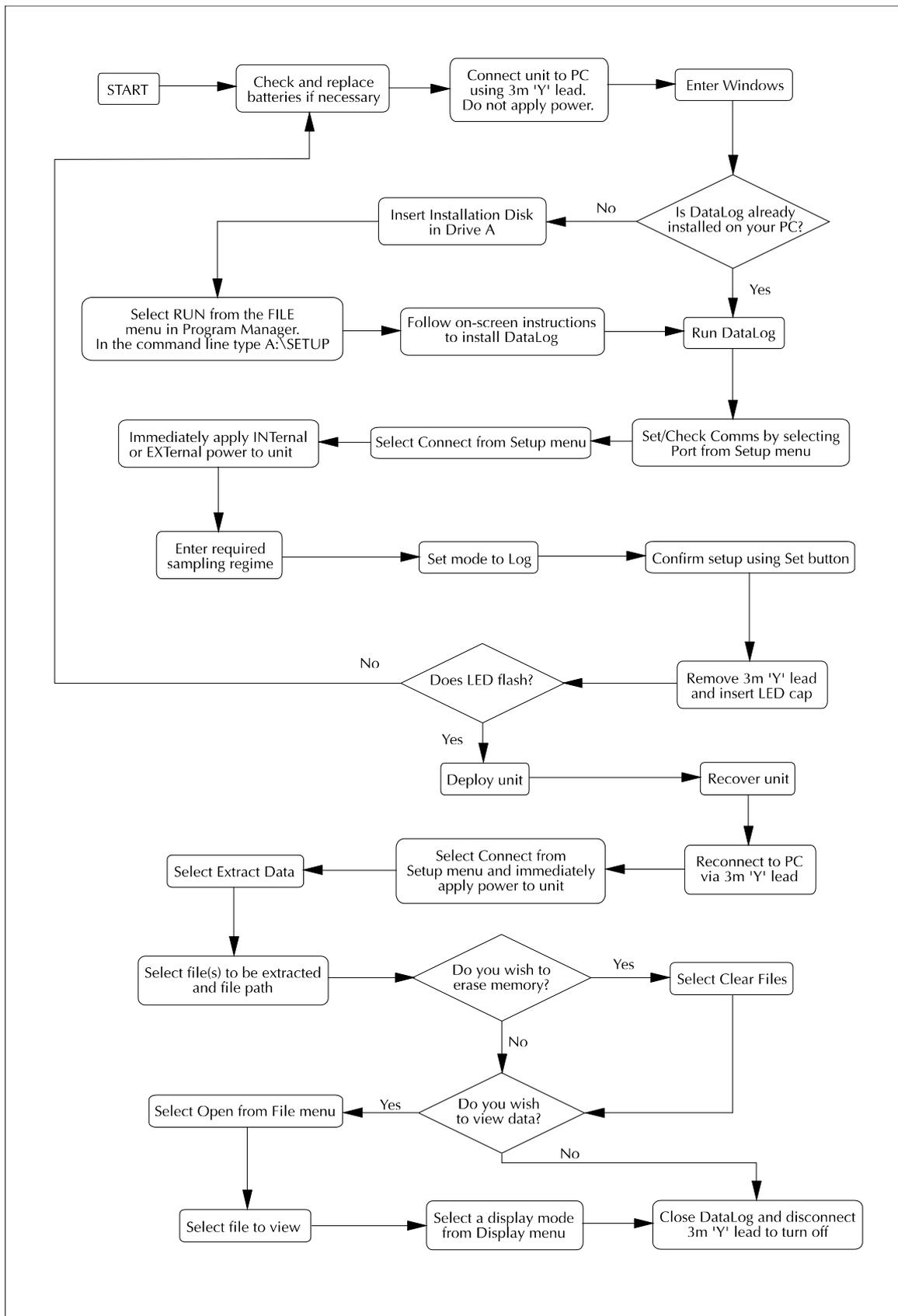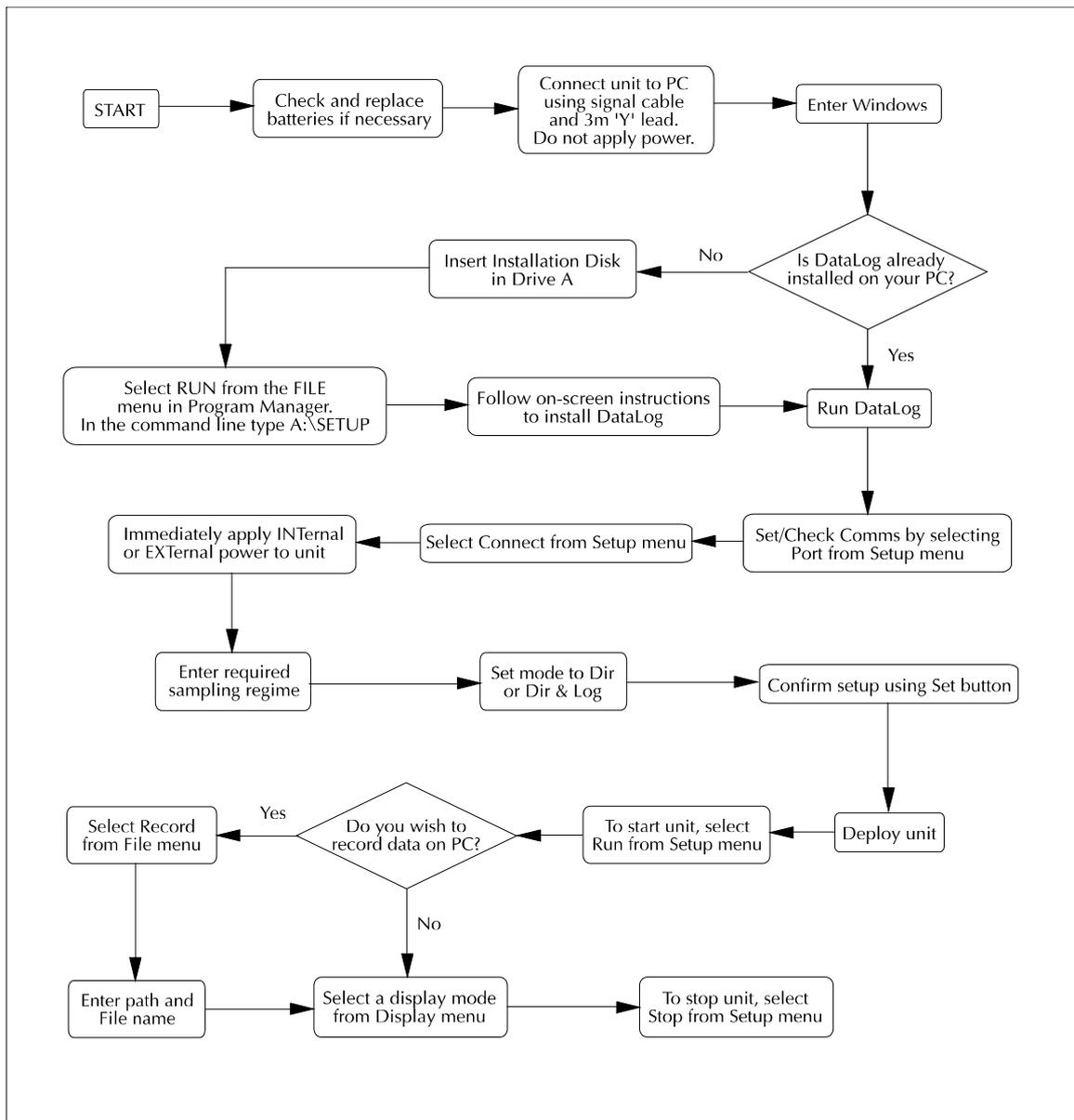
## FIGURE 2 OPERATION OF 108 MKIII & 308 IN DIRECT READING MODE

3   SETUP

In order to operate the unit, the first step is to correctly configure it using the Setup pull down menu in the opening DataLog screen.

This menu contains all controls necessary for communication with the instrument, setup of sampling regime, and data extraction.

3.1   PORT

Communications are via RS232 comms port. It is necessary to set the comms port configuration before any communications can be achieved. Do this by selecting *Port* from the *Setup* menu. The following display will be shown:
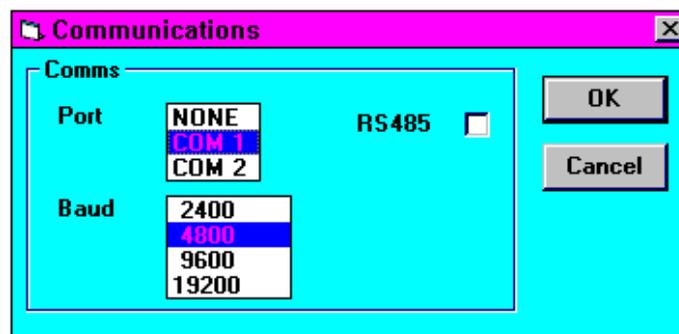
Select the correct comms port number using the mouse. Note that the default baud rate is 4800. For reference, the communications are pre-set to 8 data bits, 1 stop bit and no parity; these are not user changeable.

If the user intends to use the Current Meter in Direct Reading mode over long cable lengths, there is a factory fit option to communicate using RS485 rather than RS232. If this option is fitted to the instrument, communications must be via the RS485 adaptor supplied, and the RS485 box in the above display must be checked.

3.2   CONNECT

Having correctly configured the comms port, it is possible to communicate with the instrument. Select *Connect* from the *Setup* menu.

A Dialog box similar to that shown below will appear. Confirmed in the title block are the instrument type (in this case, Model 308) and the serial number of the unit (16509). This box allows changes to be made to the unit's setup. The different options are detailed below.

NOTE: If the *Set* command is not implemented, the changes will **not** be made in the instrument.
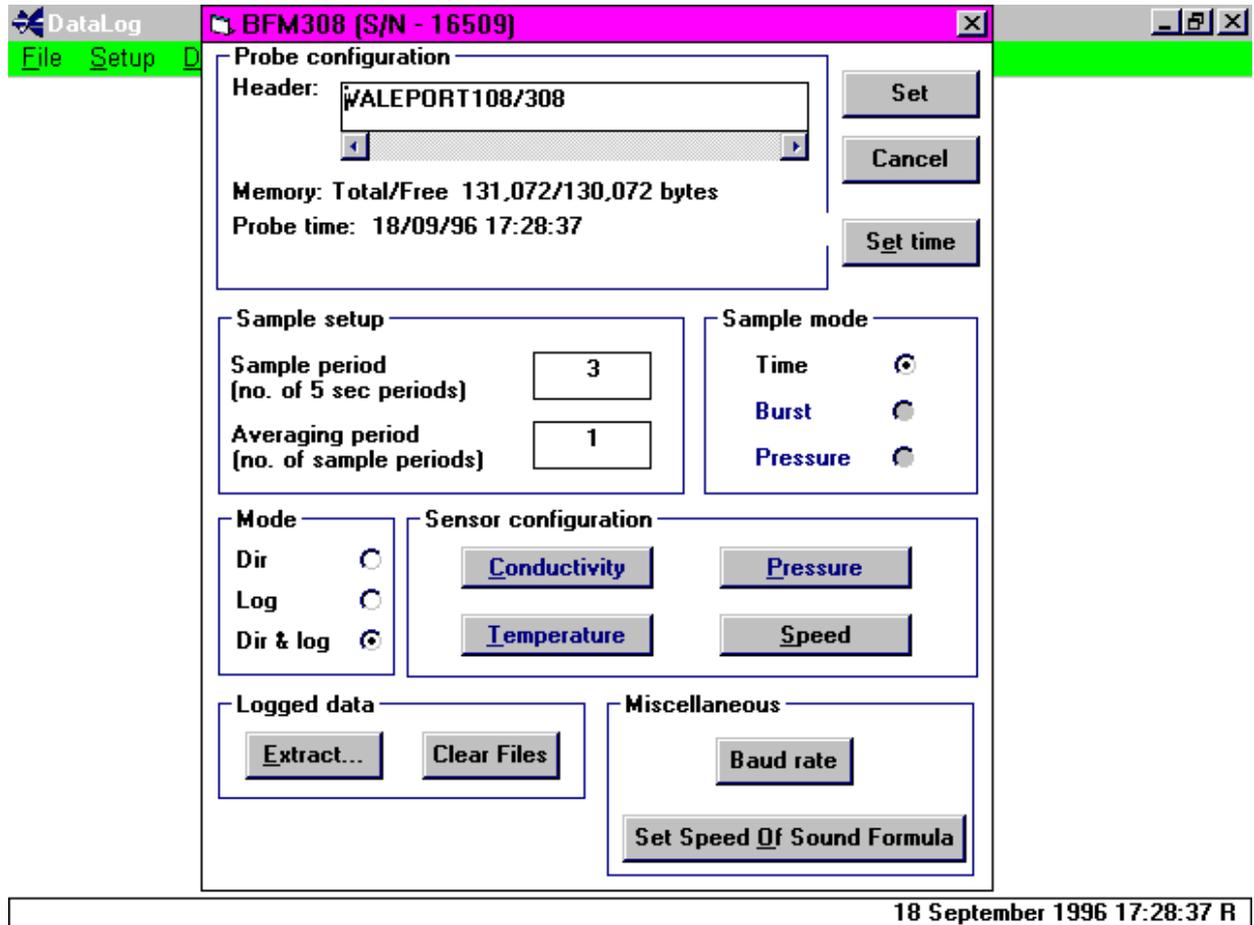
It is also possible to return to *Connect* stage from *Run* mode, if changes need to be implemented. *Run* mode must then be reselected once changes have been set.

3.3   PROBE CONFIGURATION (308 ONLY)

The amount of total memory and the amount available for recording data is shown together with the instrument date/time. In the above example, the unit has a total of 131,072 bytes of which 130,072 are unused. The user may also enter text under 'Header', to provide information about the instrument or the deployment for later reference.

3.4   SAMPLE MODE

The only sample mode available on the Model 108 MkIII and Model 308 Current Meters is TIME sampling. The instruments operate on a minimum five second cycle, during which they measure the average speed of the flow, and take a single compass reading. The length of this cycle can be set by the user to any multiple of 5 seconds, using the Sample Period box. For example, entering 12 in this box will set the sampling cycle to 12 x 5 seconds, i.e. 60 seconds. This means that the unit will measure the average flow over one minute, and then take a single compass reading to provide direction of that flow.

The user is also required to set the Average Period. This is set by the user to be the number of Sample Periods over which the data is averaged. Continuing the above example, setting an Average Period of 10 means that the data will be averaged every 10 Sample Periods, i.e. every 10 minutes.

The only data that is displayed or logged is the average value obtained at the end of the Average Period. If the user wishes to log every sample taken, Average Period must be set to 1.

3.5   MODE

The Modes available will depend upon the instrument type. If the unit is a Model 308, it will have Direct Reading, Self Recording or Both options. If the unit is a Model 108 MkIII, only Direct Reading is available. In all cases however, it is possible to record Direct Reading data to disk. See Section 4.1 for details of how to do this.

i) **Dir**   This is Direct reading where the data is transmitted in real time mode in intervals defined by the sampling setup.

ii) **Log**   This Logging mode stores averaged data in the instrument RAM in intervals defined by the sampling setup. **No data will be transmitted in this mode.**

iii) **Dir** & **Log**   This mode performs i) and ii) i.e. real time data is transmitted and stored to internal RAM.

Select the desired operating mode by clicking on the relevant option with the mouse.

3.6   PRESSURE TARE SETTING (IF FITTED)

The Model 108 MKIII and Model 308 can have a pressure sensor fitted as an option. All pressure measurements are related to absolute. Prior to deployment the tare pressure can be set. To set the current tare pressure, select Pressure in the Sensor Configuration window. The current calibration and pressure tare will be displayed. Select Set Tare; the instrument will read the current absolute pressure and then adjust all subsequent pressure readings by this amount so they are referenced to the sea level pressure at the time of deployment.
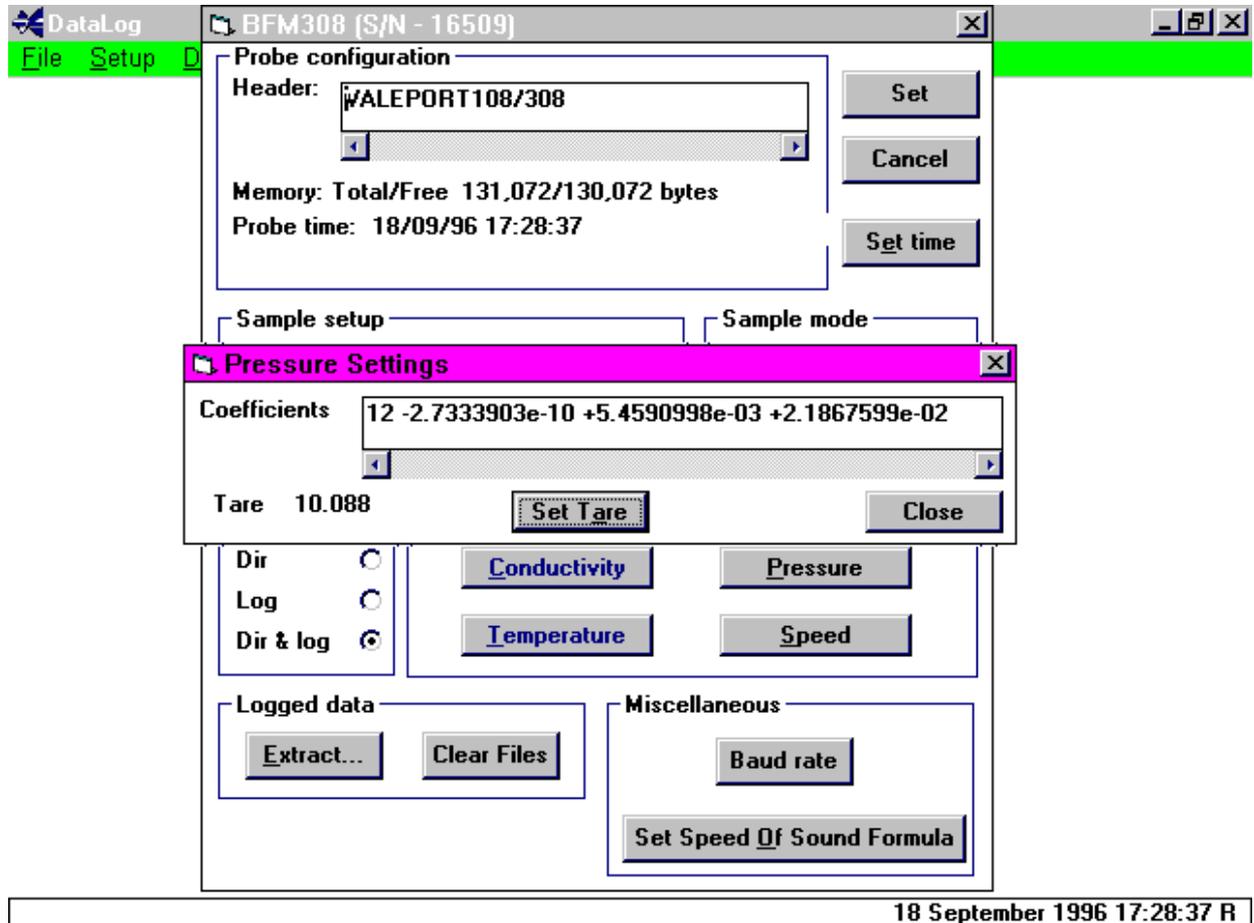
3.7   OTHER PARAMETER INFORMATION

Similar Dialog boxes will appear for the other optional sensors (Temperature and Conductivity), showing the current calibration details. These cannot be altered in DataLog. For details of how to change calibration data, refer to the main Unit Operation Manual.

3.8 MISCELLANEOUS

3.8.1 BAUD RATE

When uploading data, the baud rate limits the time taken. To speed the transfer process up, the baud may be changed to a higher rate than the standard 4800. It must be stressed that the cable lengths and the type of communications being used may restrict the maximum baud rate. If an upload error occurs, reduce the baud rate and retry.

For example, if using a short 'Y' lead to set up the instrument or extract data, 19200 should be acceptable assuming the PC in use can support this. When using very long cable lengths with current loop communications for example, the data rate may need to be slowed down to 1200 baud for successful protocol.

It should be noted, however, that the instrument will always start at 4800 baud from switch on.

3.8.2 SET SPEED OF SOUND FORMULA

If the parameters of Conductivity, Temperature and Depth are fitted, DataLog calculates the additional parameters of Density Anomaly, Salinity and Speed of Sound. Many formulae have been put forward over the years for calculating Speed of Sound, and opinion varies as to which is the best. It is generally accepted that Chen & Millero (1977) is the most accurate for depth ranges over which Valeport units operate, and for this reason, this is the formula that is used as default. However, DataLog gives the user the option to use a different formula for calculating Speed of Sound, if it is deemed necessary. To change formula, click the Set Speed of Sound button at the bottom right of the Setup screen, and the various options are displayed. If any formula other than Chen & Millero is selected, the user is asked to input the geographical latitude at which the unit is to be used. See Appendix 1.3 for an explanation of this, full details of each formula, and a short discussion on the merits of each.

3.9 LOGGED DATA

The user also has the option to Upload Logged Data from a Model 308. Full details on how to do this are given in Section 5.1.

3.9.1 CLEAR FILES

Click on this button to Erase the memory of a Model 308. A confirmation is displayed, and clicking on OK erases memory.

4   RUN MODE

4.1   RUNNING THE INSTRUMENT

After all the instrument configurations have been set as required, it is possible to begin the sampling program. If the you are using the meter in Direct Reading or Both Mode, this is achieved by selecting *Run* from the *Setup* menu. The unit enters an interrupt period for 15 seconds, during which the message *Initialising* is displayed in the bottom left hand corner of the Window. Following this, the unit enters Run mode.

If you are using a Model 308 in Logging Mode only, YOU MUST REMOVE THE 3m 'Y' LEAD USED FOR SETTING UP THE UNIT AND FIT THE LED CAP to the fish after having set the desired configuration at the *Connect* Screen. Fitting the cap automatically sets the unit into Run Mode, as above, after a 15 second period during which the LED cap flashes.

To see real time Direct Reading data, use one of the display modes detailed in Section 5, by selecting the appropriate command from the Display pull down menu.

4.2   RECORD

It is possible for Direct Reading data to be recorded on computer disk. After the desired configuration has been set in the Connect Screen, select *Record* from the *File* pull down menu. You will be asked to specify a drive, directory and file name for the record. Then proceed to run the unit as above. The data will automatically be recorded as it is produced.

In order to view direct reading data, you must select a display mode from the *Display* pull down menu. Full details on these modes are in Section 5.3.

4.3   STOP

To stop the unit Running in Direct Reading or Both modes, select *Stop* from the *Setup* pull down menu. The unit will also stop if *Connect* is selected, or if the LED cap is removed in Logging mode. The unit must be stopped in order to allow certain functions to be used in the displaying of data. See Section 5 for further details.

5 DATA HANDLING

5.1 UPLOADING LOGGED DATA (MODEL 308 ONLY)

Data are stored in internal battery backed RAM in binary format. Each time the unit is switched on or 'RUN', a new data file is created with its own header information containing averaging period, etc. following which the data is recorded. These data files can be uploaded and saved to disk by selecting *Upload* from the *Connect* screen in *Setup*. A binary file is created initially which mirrors the requested stored data files; the default name is RAW.

Calibrated files (default name CAL) are created from the binary files.

The Calibrated files can later be displayed in the various formats available with this package or imported into spreadsheets for statistical analysis.

The Display will now show the following:
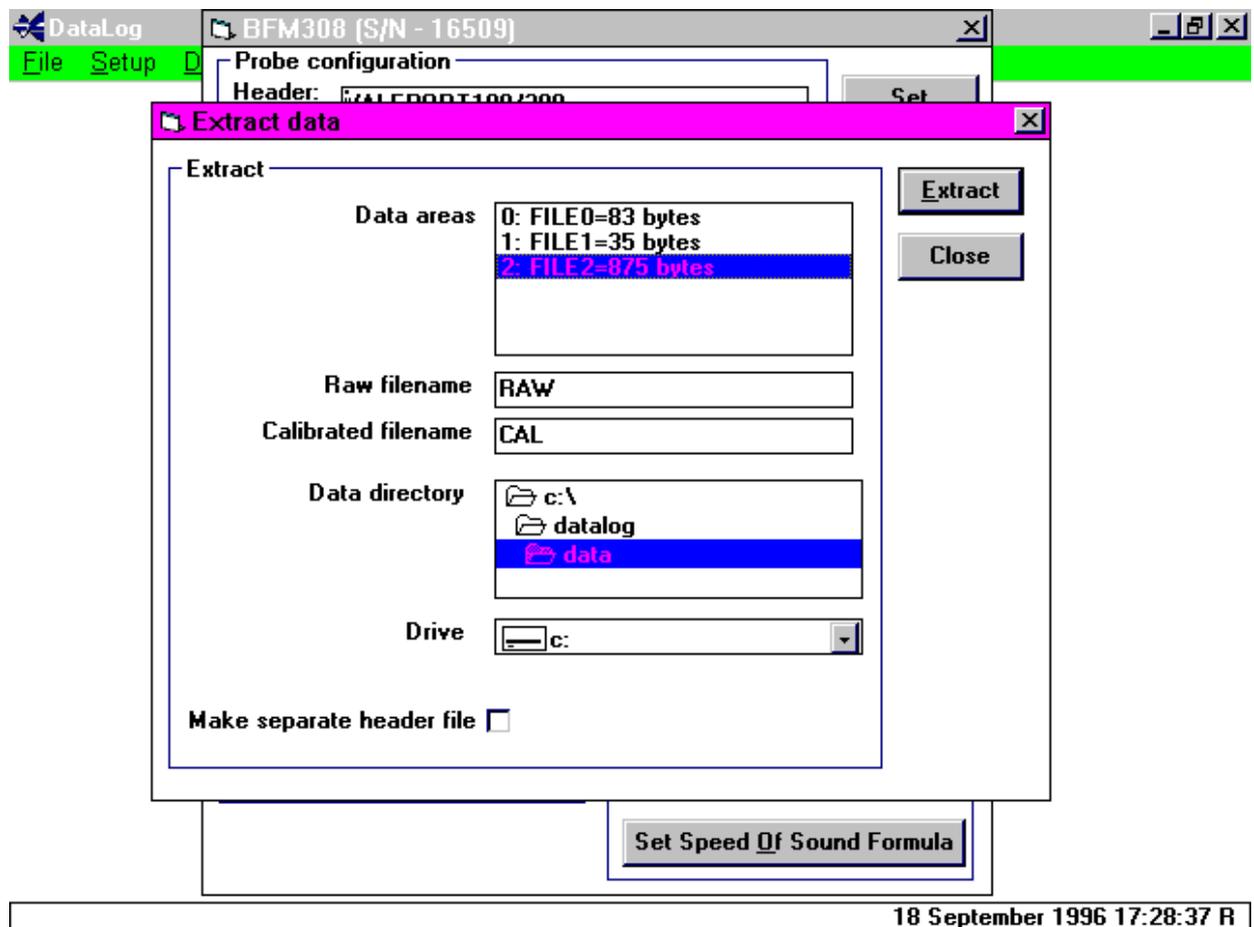
i) Data Areas: Scrollable text box containing file allocation within the instrument. If no data has been stored in the instrument, the message 'Nothing to upload' will be displayed.

ii) Raw filename: Binary format files in non engineering units. The default filename RAW may be changed; it should be restricted to 8 characters.

iii) Calibrated filename: Calibrated files generated from RAW binary files. The default filename CAL may be changed; it should be restricted to 8 characters.

iv) Data directory Standard type Dialog box to allow alternative directory paths to be set. The default path is c:\datalog.

A header file is created as default, which contains various pieces of information about the file, with the following structure. To override this, select make Separate Header File.

```
File header created by DataLog on 18/09/96 16:33:54
Device: BFM308, Serial number: 16509
Header text: VALEPORT 108/308
Mode: TIME_SAMPLE
Sample period (x5 secs): 3, Average period: 1
Impeller coefficients:   17 +1.4143845e-19 -3.5458315e-11 +2.4820728e-09 -5.5286880e-10
                          -4.8346085e-06 +1.6050182e-04 +5.6165843e-02 +1.7216420e-0
Speed of sound formula Chen & Millero
```

As many files as you want can be selected at once with the mouse by holding down Ctrl while using the mouse to click on each file. Once the desired files have been highlighted, select *Upload*. Initially the RAW binary files will be created with an extension relating to file number, e.g. RAW.005 corresponds to file number 5 in the instrument. The Calibrated data files are created using the same extension as the binary files from which they were created.

Note that the data in the instrument is not erased after uploading, further logging will occur after the last record.

5.2   SAVED DATA

If you wish to look at data already on the computer, either Uploaded from a self recording unit or recorded from Direct Reading mode, select *Open* from the *File* menu. Select the desired drive, directory and file and push Enter. The correct file will then be opened.

5.3   DISPLAYS

Data from the unit can be displayed in 5 formats. Several different displays can be shown simultaneously and iconized.

For Direct Reading Display

5.3.1   BRIEF

The _Brief_ display will show the parameters transmitted by the instrument in real time mode only. It should be noted that data will only be updated at the end of an averaging period. Data stored on disk cannot be displayed in this format.

This display is not sizeable, but can be iconized and moved outside the DataLog environment.
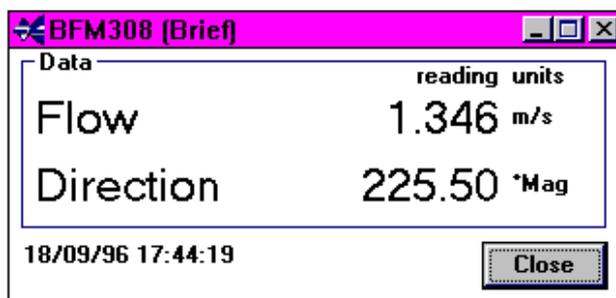
5.3.2 FULL

The *Full* display is also only available in real-time mode, and offers the parameters as shown below. The Salinity, Density Anomaly and Sound Speed are calculated by DataLog (if Conductivity, Temperature and Pressure Sensors are fitted) and not by the instrument. Parameters which are not fitted to the instrument are shown in italics and not updated. This display is not sizeable, but can be iconized and moved outside the DataLog environment.
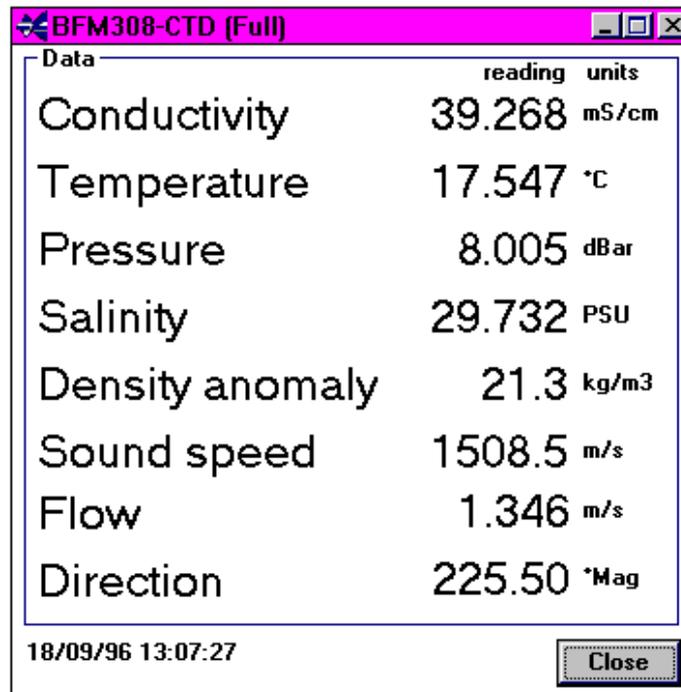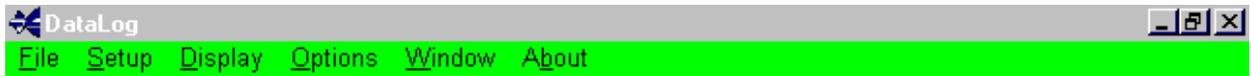
5.3.3   SCROLL

As the title suggests, a Scrolled display will be shown as below. The most recent data will be displayed at the top therefore scrolling data down. To view information outside the text box, shift the display using the arrow controls with the mouse. Unlike the *Brief* and *Full* display options, data previously stored from real time recording (see sections 4.1 & 5.2) or Uploaded from the instrument (see section 5.1) can be recalled and displayed in this format. The example below shows a typical scrolled display of recorded data.

Data displayed in this format can be printed, but not while the unit is actually running. If this screen is being used for real time display, *Stop* or *Connect* must be selected to allow data printing. To print off a table of data, select *Print* from the *Options* Menu. A standard Windows Print Options form will be displayed.

It is also possible to select the font in which the data is to be printed. Selecting *Set Print Font* before selecting the *Print* function reveals a display showing all available printer fonts. NB Some TrueType fonts will not size to the page correctly, so use of these is not recommended.

5.3.3.1 AVERAGE DATA

A display of average data values can be obtained from this screen. While the unit is stopped (or with recorded/uploaded data), the Scroll table has the property of allowing values within the table to be highlighted. This can be done either by dragging the mouse over the desired values, or by clicking on a column header to select the entire column. Then select *Data Analysis* from the *Display* menu. A table will be displayed, showing high and low values, the mean value of the data, and the Standard Deviation of the data.

NOTE: It is not possible to perform Data Analysis on more than one parameter at once.

5.3.4   GRAPH

The Graphical display function can be used for either real time or recorded data, and allows each parameter from the instrument to be displayed as a function of time or pressure. The outputs provided show the parameter type by way of engineering units; the 'Y' axes can be scaled individually but the 'X' axis can only be scaled for all parameters within each graph. To select more than one parameter for display on the same graph, use Ctrl and the mouse to click on each in the Dialog box. Several individual graphs can be displayed at once, the limitations of which would depend upon PC configuration and the number of tasks running in the WINDOWS environment, such as statistical analysis packages, word processor, etc.

Graphical representation can be made of any of the parameters from an instrument in real time mode once the connection has been established. Each graph may be iconized, but will still be refreshed as new data appears. A hard copy of the plot can be produced by selecting the pull down menu *Files* and selecting *Print* which will then show a standard type Dialog box from which print resolution, number of copies, etc. can be chosen.

A typical graph is shown below as a function of Time.

5.3.4.1 GRAPH SETTINGS

Selecting *Graph Settings* from the *Options* menu in graph mode allows the user to change certain features of the display. Shown below is the settings Dialog box, to allow changes to be made to 'X' and 'Y' axes scales, and parameter display colour. Select the parameter, in the example below this is Pressure, and enter new maximum and minimum value for the scale. The colour can be changed by selecting *Colour*, from which a set of basic and custom colours may be selected to suit.

As mentioned previously, the time axis can be changed, but this will be for all parameters displayed. Simply select *Start time* and enter required date/time, then select *End time* and enter as appropriate.
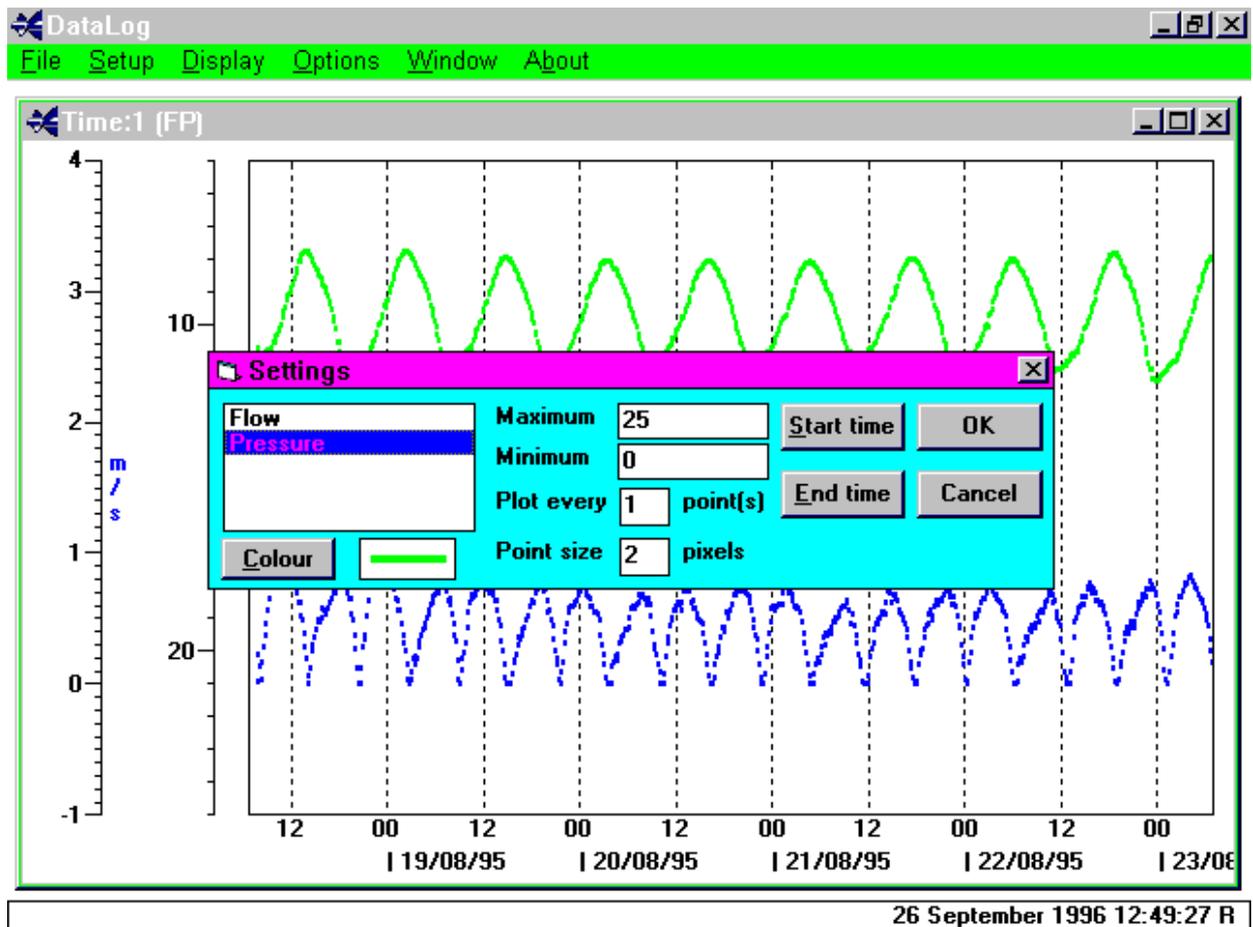
5.3.5   SCATTERPLOT

Speed and Direction data from a Model 108 MkIII or Model 308 can also be represented on a Scatterplot diagram. This function is available for viewing logged data or for real time viewing. The scroll button on the right of the display is a zoom function. This screen can also be printed by selecting *Print* from the *File* menu.
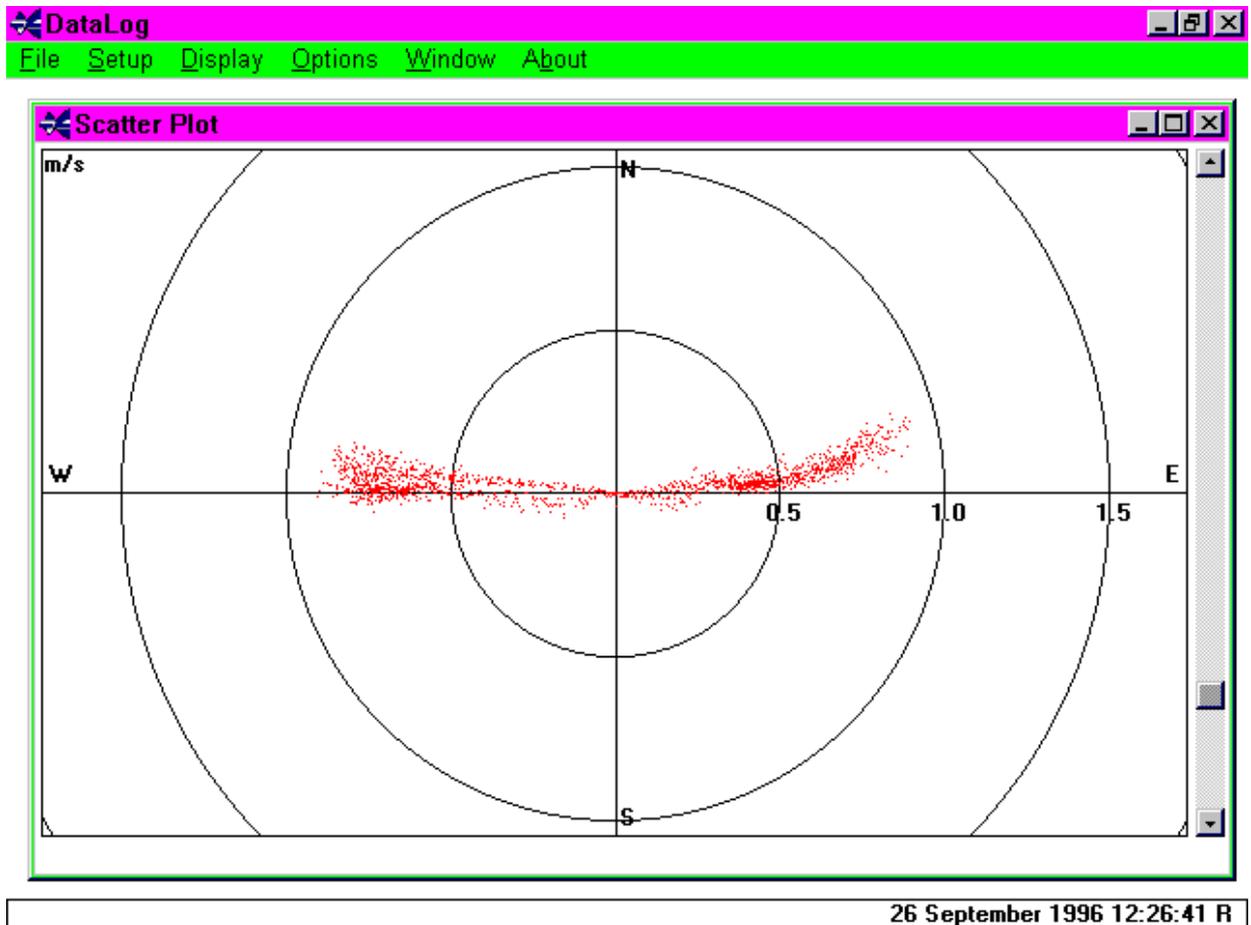
5.4 OPTIONS

This function allows the user to set various options as detailed below. Some functions are only available at specific points within the software. At all times, *Options* allows the user to select/de-select the status line at the bottom of the page

5.4.1 STATUS LINE

The Status line in situated at the bottom of the DataLog window. Real time data/filename and PC time and Date are displayed here. This can be toggled on/off by selecting *Status Line* with the mouse.

5.4.2 CONSTANTS

Select either a *UK* nautical mile (1853.18 metres) or *International* nautical mile (1852 metres) as required followed by OK to confirm.

5.4.3 UNITS

The units of speed can be selected as below (OK to confirm).
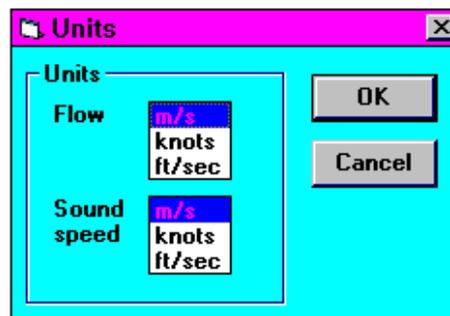
5.4.4 TEST FORMULA

A feature of DataLog is its Test Formula Option. Selecting *Test Formula* from the *Options* Menu reveals the following display, which allows the user to calculate Density Anomaly, Salinity/Conductivity, Speed of Sound using a formula of their choice, and to perform a Depth/Pressure calculation.
The following display is revealed, and an explanation of each function is given below:

5.4.4.1 USER INPUT VALUES

CONDUCTIVITY/SALINITY
The user has the option to input either Conductivity (mS/cm) or Salinity (PSU). Click on either to select (highlight), or click the check box. The program will calculate whichever is not input.

PRESSURE
Enter the required pressure in decibars.

TEMPERATURE
It is possible to use either IPTS-68 or IPTS-90 temperature values in the calculations. Simply click on the desired scale or the check box to select.

LATITUDE
This is required to correct for local gravity which is required in depth calculations for Speed of Sound [for all formulae with the exception of Chen & Millero 1977]. Enter the geographical latitude for the measurement site, using a negative number if South of the equator.

CHANGE SPEED OF SOUND FORMULA
The user can select a formula with the Change Speed of Sound Formula button. Note that for all formulae apart from Chen & Millero, geographical latitude must be input. Clicking the Calculate button then reveals the Speed of Sound as calculated using the selected formula. This has no effect on the formula used by the software for the Speed of Sound in Running Mode.

5.4.4.2 CALCULATED PARAMETERS

The formulae used for calculating Density Anomaly γ, Salinity, Depth and Speed of Sound are given in Appendix 1. Conductivity is calculated from Salinity using a Newton Raphson Iteration of the Salinity formula. Salinity and Conductivity are self explanatory functions. Speed of Sound can be calculated using various formulae, and the merits of each are discussed in Appendix 1.3. Density Anomaly γ and Depth require further explanation:

Density anomaly γ   This is Density (ρ) - 1000

Depth   This is based on the Simple UNESCO Depth formula which is based on assuming a salinity of 35 PSU and temperature of 0 °C. For simple calculations of depth for different densities, the standard depth can be corrected by multiplying it by the ratio of average density over depth of 35PSU, 0 °C water to the average density of the actual water column.

E.g.
Standard Depth [35,0] for 1000 dBar at 0 latitude = 992.117 metres

Average density [approx.] over 1000 dbar range for [35,0] seawater
$$= [\text{Density at 0 dBar} + \text{Density at 1000 dBar}]/2$$
$$= [1028.1 + 1032.8]/2$$
$$= 1030.45 \text{ kg/M}^3$$

Average density from data, using Data Analysis function [see section 5.3.3.1]
$$= 1027.6 \text{ [example number only for calculation]}$$

Density ratio $= 1030.45/1027.6$
$= 1.0028$

Revised depth estimate $= 992.117 * 1.0028$
$= 994.895 \text{ metres}$

5.4.5   SPLIT SPREADSHEET

If a saved datafile is very large, the user may find it easier to split the file into a number of smaller files for ease of analysis. If this is required, select *Split Spreadsheet* from the *Options* menu. A display similar to that shown below will appear. Select the file to be split, and choose a new name for the smaller files. By default, the new extensions to the smaller files will be of the form .000, .001, .002 etc.

The user is also invited to select the size of the new files (Number of Lines per File).
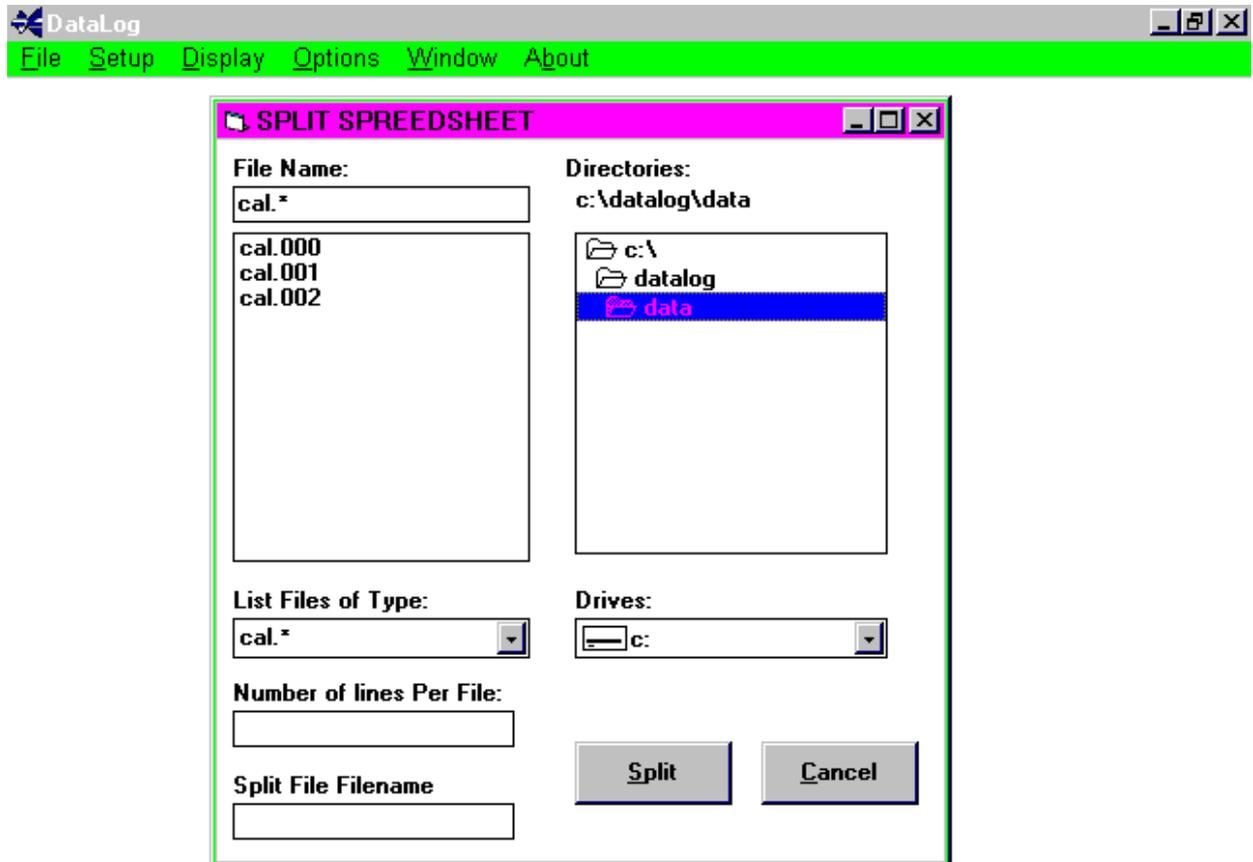
Each new file will have the same Header information as the original, but the fact that it is a Split Spreadsheet will also be indicated.

5.5 WINDOW

The *Window* pull down menu allows the user to configure the display to either *Cascade*, *Tile* or *Arrange Icons* if showing. It should be noted however that the *Brief* and *Full* displays are not affected by this command as they are created for display outside the DataLog window.

5.5.1 CASCADE

Below is an example of a cascaded display.
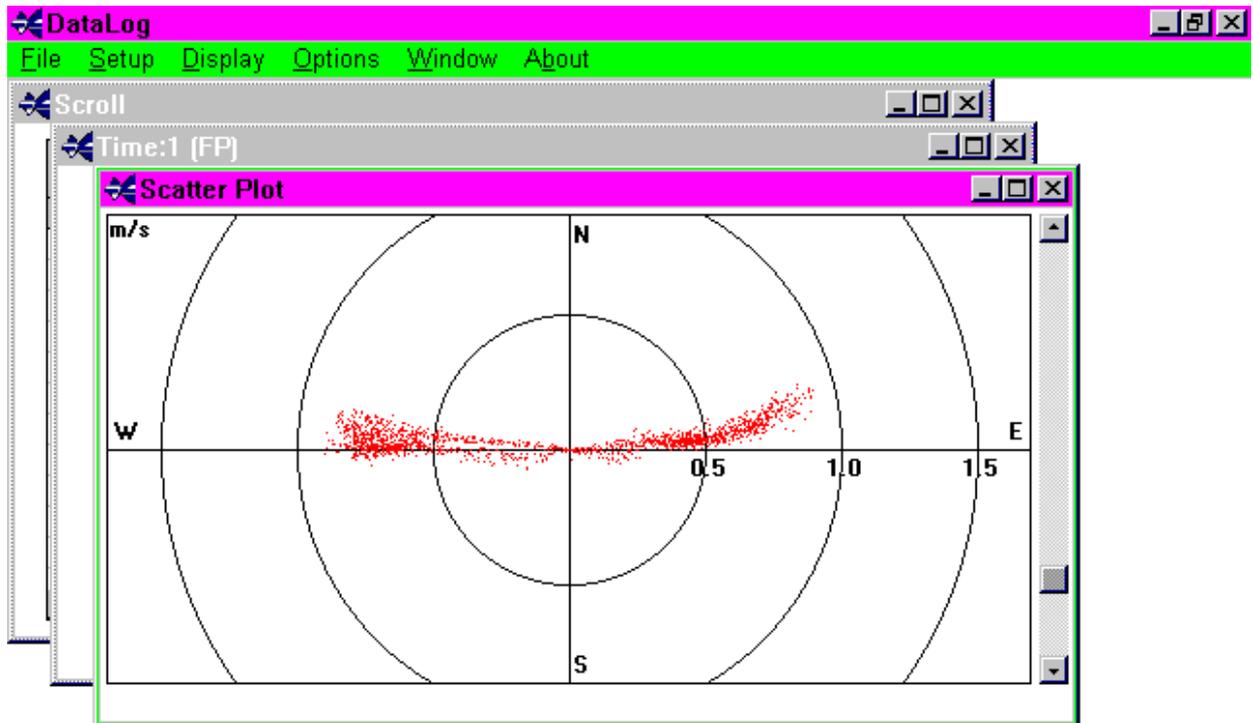
5.5.2   TILE

Below is an example of a Tiled display.
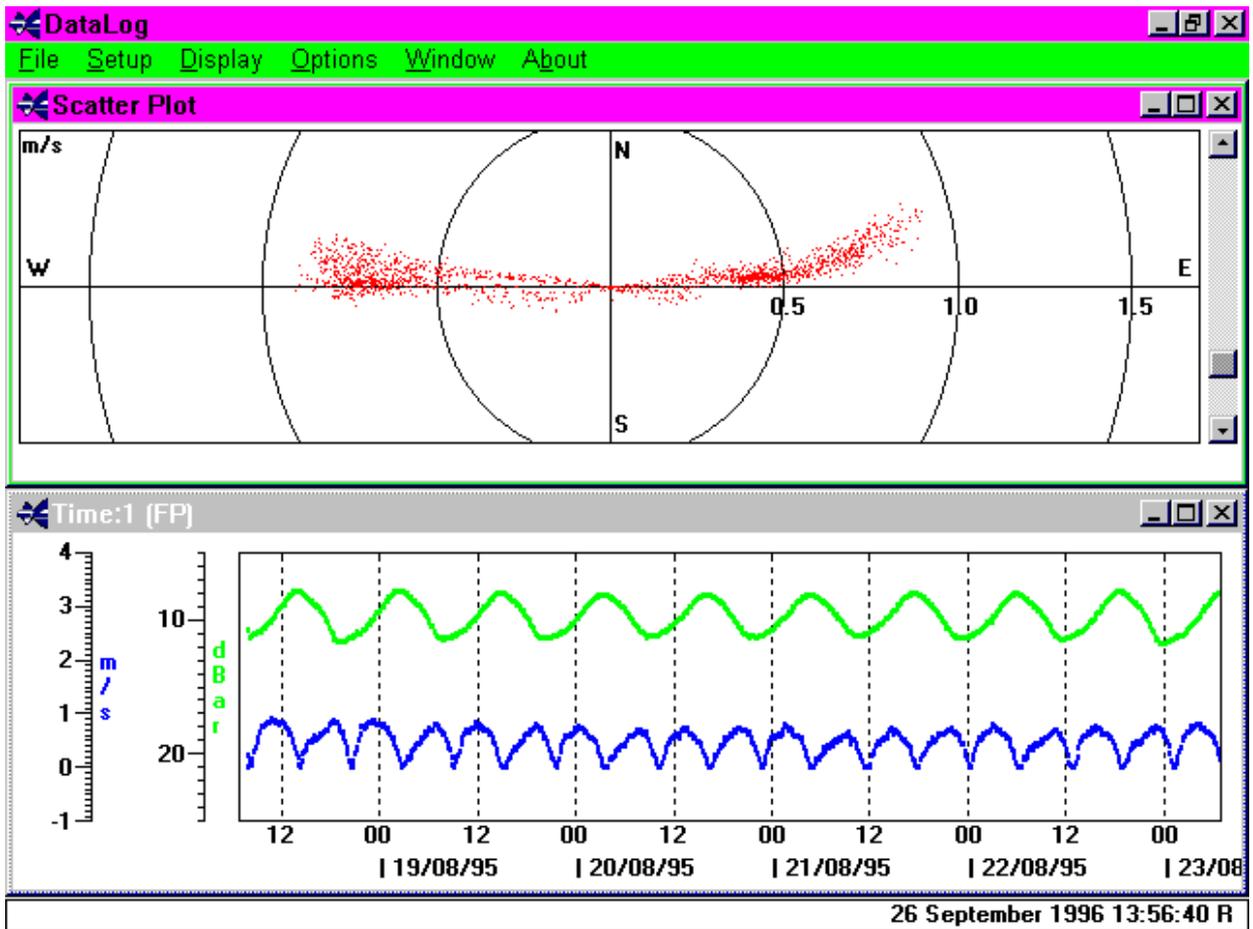
5.5.3   ARRANGE ICONS

Shown below is an example of the above function with a scatterplot display.

5.6   ABOUT

To enable the user to determine which software version is operating, select the *About* function. A display similar to below will be shown which contains information with regard to PC configuration.

APPENDIX 1   DERIVED PARAMETER FORMULAE

The following extracts are taken and adapted from "Processing of Oceanographic Station Data", published by UNESCO in 1991.

A1.1 SALINITY

The Practical Salinity Scale (PSS-78)
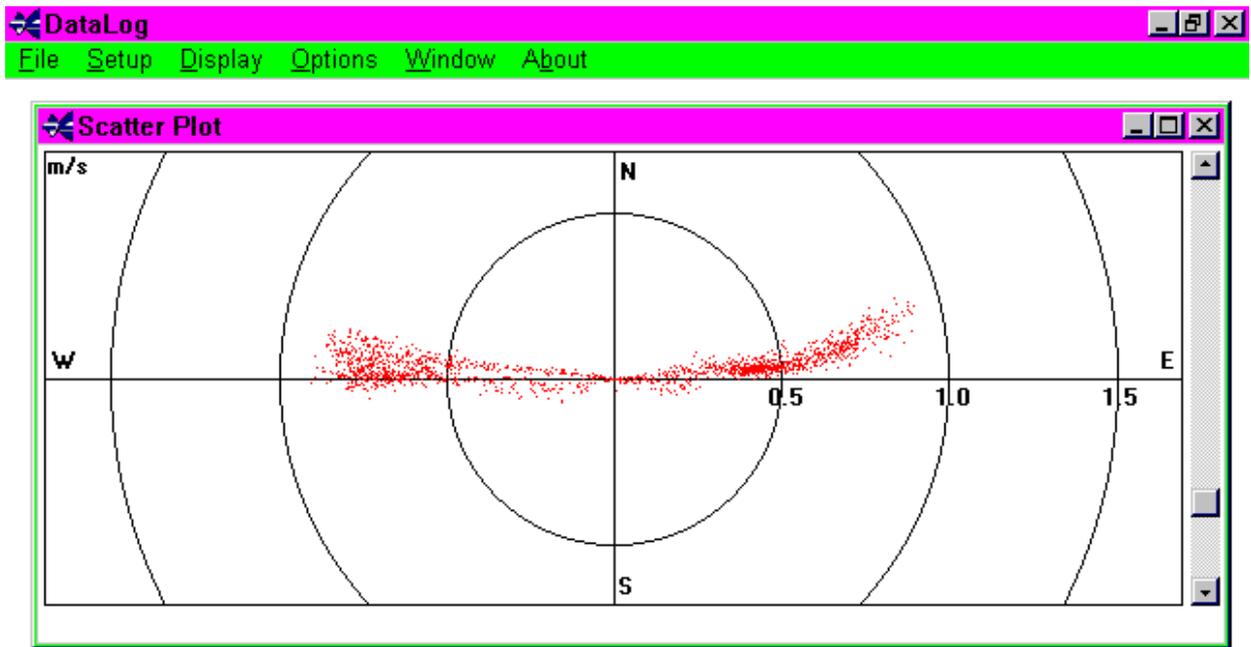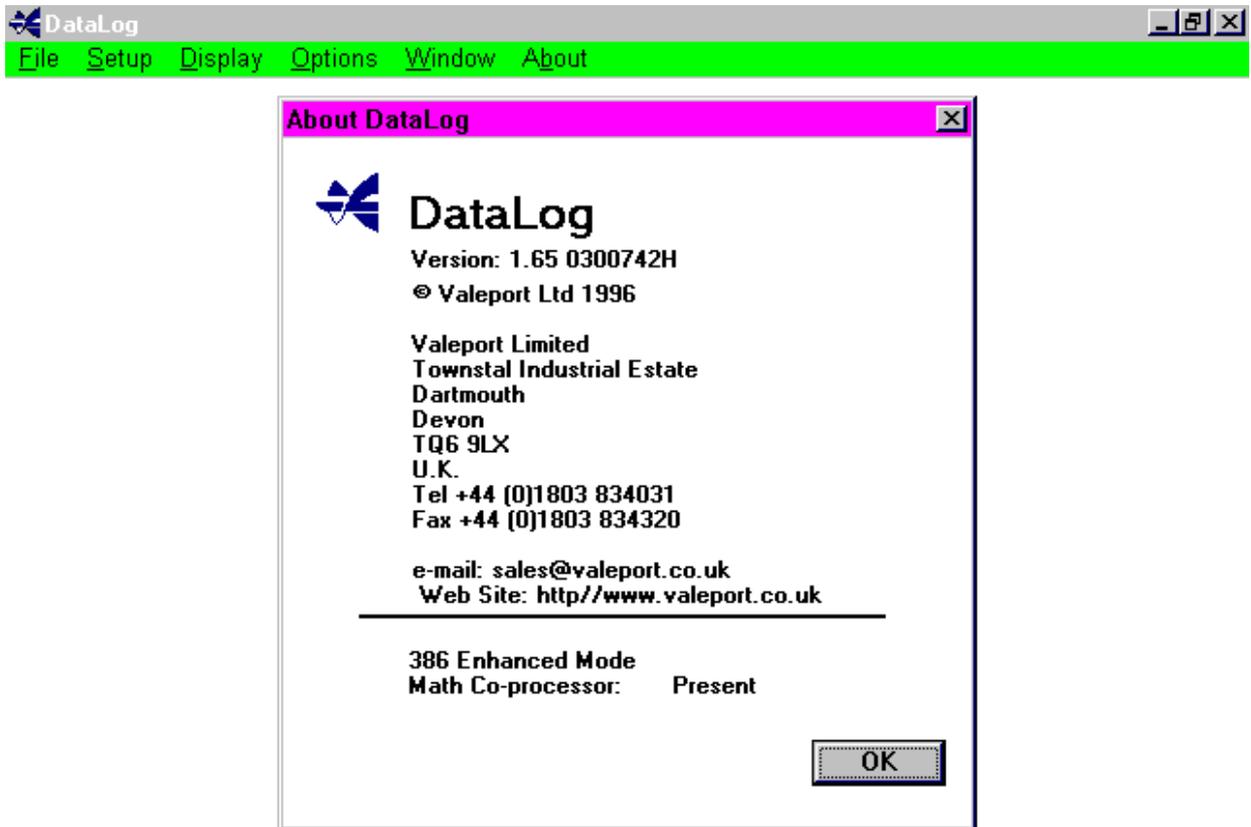
The fundamental step in constructing the practical salinity scale PSS-78 consisted of defining a single reference point (S=35) on the scale as having the same electrical conductivity as a reference potassium chloride (KCl) solution at 15°C and atmospheric pressure. The transition from the previous scale was made by selecting a single batch (P79) of Standard Seawater and equating the new scale to the old through the chlorinity relationship *S = 1.80655 Cl* for that particular batch. As the salinity on the practical scale is defined to be conservative with respect to addition and removal of water, the entire salinity range is accessible through precise weight dilution or evaporation without additional definitions. However, the practical scale is defined in terms of conductivity ratio and not by its conservative properties. Thus the second part of the definition was constructed by measuring the conductivity ratio to the KCl standard or an equivalent secondary standard over the entire range of salinities (1 to 42) of samples prepared by evaporation or dilution of batch P79 SSW and computing an empirical formula *S = S(R$_{15}$)*, where R$_{15}$ is the conductivity ratio 15°C and atmospheric pressure to the KCl standard. Thus salinities on the PSS-78 scale are defined by conductivity ratios alone. Salinities determined by any other method would not necessarily coincide with the PSS-78 scale and would have to be identified separately. Lewis and Perkin (1981) and Mamayev (1986) discuss differences between PSS-78 and previous scales and provide algorithms and tables to convert existing data to the new scale.

The algorithm for converting conductivity ratio to salinity is constructed in terms of the conductivity ratio R defined as:

$$R = C(S, t, p)/C(35, 15, 0) \qquad\qquad (1)$$

where *C(S, t, p)* is the electrical conductivity as a function of salinity *S*, temperature *t* and pressure *p*. The ratio is factored into the functions:

$$R = r_t(t) \cdot R_t(S, t) \cdot R_p(R, t, p) \qquad\qquad (2)$$

where

$$r_t(t) = C(35, t, 0)/C(35, 15, 0)$$
$$R_t(S, t) = C(S, t, 0)/C(35, t, 0)$$
$$R_p(R, t, p) = C(S, t, p)/C(S, t, 0)$$

Salinity is given by the function

$$S = \sum_{n=0}^{5} \left[a_n + \frac{\Delta t}{1+k\Delta t} b_n \right] \cdot R_t^{n/2} \qquad\qquad (3)$$

with coefficients

a$_0$ =	+0.0080	b$_0$ =	+0.0005	k =	+0.0162
a$_1$ =	-0.1692	b$_1$ =	-0.0056	Δt =	t - 15
a$_2$ =	+25.3851	b$_2$ =	-0.0066		
a$_3$ =	+14.0941	b$_3$ =	-0.0375		
a$_4$ =	-7.0261	b$_4$ =	+0.0636		
a$_5$ =	+2.7081	b$_5$ =	-0.0144		

At t = 15°C (3) reduces to the formula defining the practical salinity scale (Perkin and Lewis 1980).

The factors r_t and R_p are given by

$$r_t = \sum_0^4 C_n t^n \tag{4}$$

where

$C_0 =$	+0.6766097	$C_3 =$	-6.9698E-7
$C_1 =$	+2.00564E-2	$C_4 =$	+1.0031E-9
$C_2 =$	+1.104259E-4		

and

$$R_p = 1 + \frac{e_1 p + e_2 p^2 + e_3 p^3}{1 + d_1 t + d_2 t^2 + (d_3 + d_4 t) \cdot R} \tag{5}$$

$$= 1 + \frac{C}{B + AR}$$

with

$e_1 =$	+2.070E-5	$d_1 =$	+3.426E-2
$e_2 =$	-6.370E-10	$d_2 =$	+4.464E-4
$e_3 =$	+3.989E-15	$d_3 =$	+4.215E-1
		$d_4 =$	-3.107E-3

for temperature in °C and pressure in dBar.

Given a measurement of R, t and p, salinity is computed by solving (2) for R_t; $R_t = R/(r_t R_p)$ and evaluating S from (3). If conductivity ratio R is required given S, t and p, the ratio R_t can be found by numerical inversion of (2), and R can be found by solving the quadratic equation

$$R = r_t \cdot R_t \cdot R_p = r_t \cdot R_t \cdot \left[1 + \frac{C}{AR + B} \right]$$

or

$$R = \frac{\left[(A r_t R_t - B)^2 + 4 r_t R_t A (B + C) \right]^{1/2} + [A r_t R_t - B]}{2A} \tag{6}$$

This description of PSS-78 has been adapted from Fofonoff (1985)

A1.2 DENSITY ANOMALY GAMMA

Equation of State of Seawater (EOS-80)

The equation of state of seawater is the mathematical expression to calculate density from measurements of temperature, pressure and salinity. Virtually all the computations of density of seawater made since the beginning of the century have been based on the direct measurements of density, chlorinity and salinity made by Knudsen, Forch and Sörensen (1902), and of compression of seawater made by Ekman (1908). This equation was obtained from measurements of density of natural seawater in which the proportions of the various ions are not exactly constant. To be consistent with the new definition of the Practical Salinity, 1978, the new equation of state is based on measurements of density of standard seawater solutions obtained by weight dilution with distilled water and by evaporation. As the absolute density of pure water is not known with enough accuracy, the density of distilled water used for these measurements was determined from the equation of the SMOW (Standard Mean Ocean Water) whose isotopic composition is well defined.

The new equation of state (EOS-80) which was adopted by JPOTS in 1981 (UNESCO, 1981c) is:

$$
\left.
\begin{aligned}
v(S,\ t,\ p) &= v(S,\ t,\ 0)[1 - p/K(S,\ t,\ p)] \\
\rho(S,\ t,\ 0) &= 1/v(S,\ t,\ 0) = A + BS + CS^{3/2} + DS^2 \\
K(S,\ t,\ p) &= E + FS + GS^{3/2} + (H + IS + JS^{3/2})p + (M + NS)p^2
\end{aligned}
\right\} (7)
$$

where the coefficients A, B, ...N are polynomials in temperature t. Units: salinity, PSS-78; temperature, °C; pressure (p), bar; density (ρ), kg/m³; specific volume (v), m³/kg. These coefficients are given below.

	A	B	C	D
t^0	+999.842594	+8.24493E-1	-5.72466E-3	+4.8314E-4
t^1	+6.793952E-2	-4.0899E-3	+1.0227E-4	
t^2	-9.095290E-2	+7.6438E-5	-1.6546E-6	
t^3	+1.001685E-4	-8.2467E-7		
t^4	-1.120083E-6	+5.3875E-9		
t^5	+6.536332E-9			

	E	F	G
t^0	19652.21	+54.6746	+7.944E-2
t^1	+148.4206	-0.603459	+1.6483E-2
t^2	-2.327105	+1.09987E-2	-5.3009E-4
t^3	+1.360477E-2	-6.1670E-5	
t^4	-5.155288E-5		

	H	I	J
t^0	+3.239908	+2.2838E-3	+1.91075E-4
t^1	+1.43713E-3	-1.0981E-5	
t^2	+1.16092E-4	-1.6078E-6	
t^3	-5.77905E-7		

	M	N
t^0	+8.50935E-5	-9.9348E-7
t^1	-6.12293E-6	+2.0816E-7
t^2	+5.2787E-8	+9.1697E-10

Density Anomaly γ is defined as the Density of the water minus 1000 kg/m³.

A1.3   SPEED OF SOUND

The following information, discussion and conclusions are taken from Special Publication No.34 of the Hydrographic Society, prepared by JM Pike and FL Beiboer of METOCEAN plc. The report is entitled "A Comparison Between Algorithms for the Speed of Sound in Seawater".

The following abbreviations and units are used:

V	Computed speed of sound in seawater (m/s)
T	Temperature (°C)
S	Salinity
ϕ	Latitude in degrees
$g(\phi)$	Gravitational acceleration at the given latitude (m/s^2)
P_b	Hydrostatic pressure (bar) (1bar = 10^{5}Pa = 10/$g(\phi)$ (kg/cm^2)
P_k	Hydrostatic pressure (kg/cm^2)
D	Depth (m)

A1.3.1 STANDARD FORMULAE

A1.3.1.1   PRESSURE/DEPTH RELATIONSHIP

Several relationships are identified by Robertson(l), ranging from the approximate ("1 km of seawater generates a pressure of 101 bar"), to the precise (use of the MacKenzie or UNESCO algorithms).

The accurate relationships require computation of the gravitational field at the latitude in question using an appropriate formula for the gravitational field.

The UNESCO pressure/depth relationship has not been the subject of significant academic debate since its introduction, and is stated as follows:

$$D = \frac{(C_1 * (P_b * 10) + C_2 * (P_b * 10)^2 + C_3 * (P_b * 10)^3 C_4 * (P_b * 10)^4)}{(g(\phi) + \tfrac{1}{2} g' * P_b)} + \Delta d / 9.8$$

where:

$g(\phi)$	$= 9.780318 * (1.0 + 5.2788\text{E-}3 * \sin^2\phi + 2.36\text{E-}5 * \sin^4\phi+)$
G'	$= +2.184\text{E-}5 \text{ m.s}^{-2}. \text{ bar}^{-1}$
C_1	$= +9.72659$
C_2	$= -2.2S\,12\text{E-}5$
C_3	$= +2.279\text{E-}10$
C_4	$= -1.82\text{E-}15$, and
P_b	is the hydrostatic pressure (bar)
Δd	is the geopotential anomaly, expressed in J/kg. This term is zero for standard seawater (S = 35, T = 0°C).

The geopotential anomaly term (Δd) contains the correction for the actual density distribution within the water column, and can be evaluated for precise computation (or where there are extremes of temperature or salinity) by integrating the specific volume anomaly over the required pressure range. The procedures for this are also included in UNESCO Technical Paper #44.

The DataLog program, however, does not feature the ability to input Δd (which is therefore assumed to be 0).

This assumption is recognised as being legitimate, with the resultant pressure depth algorithm called 'Simple UNESCO Depth':

$$D = \frac{(C_1 * (P_b * 10) + C_2 * (P_b * 10)^2 + C_3 * (P_b * 10)^3 C_4 * (P_b * 10)^4)}{(g(\phi) + \tfrac{1}{2} g' * P_b)}$$

This value of D is used in all formulae within DataLog

A1.3.1.2   WOOD (1949)

$$V = 1410 + 4.21 * T - 0.037 * T^2 + 1.14 * S + 0.018 * D$$

This formula was recognised before 1960 as being inadequate, and was replaced (at least in US Navy Hydrographic Office operations) in 1962 by the Wilson formula. It is thus not used in DataLog.

A1.3.1.3   WILSON (OCTOBER 1960)

Full Version

The full version of this formula is:

$$V = 1449.14 + V_T + V_P + V_S + V_{STP} \text{ , where}$$
$$V_T = 4.5721*T - 4.4532E - 2*T^2 - 2.6045E - 4*T^3 + 7.9851E - 6*T^4$$
$$V_P = 1.60272E - 1*P_k + 1.0268E - 5*P_k^2 + 3.5216E - 9*P_k^3 - 3.3603E - 12*P_k^4$$
$$V_S = 1.39799*(S-35) + 1.69202E - 3*(S-35)^2$$
$$V_{STP} = (S-35)*(-1.1244E - 2*T + 7.7711E - 7*T^2 + 7.7016E - 5*P_k - 1.2943E - 7*P_k^2 + 3.1580E - 8*P_k*T + 1.5790E - 9*P_k*T^2)$$
$$+ P_k*(-1.8607E - 4*T + 7.4812E - 6*T^2 + 4.5283E - 8*T^3)$$
$$+ P_k^2*(-2.529E - 7*T + 1.8563E - 9*T^2)$$
$$+ P_k^3*(-1.9646E - 10*T)$$

Wilson states that the formula is valid to within ± 0.3 m/s in the ranges:

-4°C < T < 30°C; 0 < S < 37 1 kg/cm²; < P_k < 1000 kg/cm².

where $P_k = P_b \cdot \dfrac{10}{g(\phi)}$

Simplified Version

A simplified version of this formula, which is believed to have been used for a number of offshore surveys, is:

$$V = 1.449.14 + 4.5721*T - 4.4532E - 2*T^2 - 2.6045E - 4*T^3 + (1.39799 - [1.1244E - 2*T])*(S-35) + 1.643E - 2*D$$

The range of validity is likely to be comparable to the full version, with simplification (and inaccuracy) introduced by replacing the pressure terms with a depth term (of unknown provenance), and ignoring 4th order temperature terms (*inter alia*).

A1.3.1.4   MEDWIN (1975)

This simple formula was based on the Del Grosso equation and is:

$$V = 1449.2 + 4.6*T - 0.055*T^2 + 0.00029*T^3 + (1.34 - 0.010*T)*(S - 35) + 0.016*D$$

Medwin states the formula is valid *"for realistic combinations of T, S, P"* in the ranges 0 < T < 3S°C, 0 < S < 45, 0 < D < 1000 m. The fact that the equation was based on the Del Grosso equation, however, leads to the conclusion that the range of validity cannot be superior to the Del Grosso formula itself, which is deemed to be valid only in a limited temperature and salinity range.

The more likely validity of the Medwin formula is indicated in the matrix below, in which the maximum valid pressure (in bar) is indicated for each temperature and salinity:

	T (°C)			
S	*0*	*5*	*10*	*15*
33	100	100	100	69
34	100	100	100	100
35	100	100	100	100
36	100	100	100	69
38	69	69	100	100

A1.3.1.5 CHEN AND MILLERO (1977)

This formula was adopted by UNESCO in 1983 and is as follows:

$$V = C_w(t,p) + A(t,p).S + B(t,p).S^{3/2} + D(t,p).S^2$$

where,

$$C_w(t,p) = C_{00} + C_{01}.T + C_{02}.T^2 + C_{03}.T^3 + C_{04}.T^4 + C_{05}.T^5 +$$
$$(C_{10} + C_{11}.T + C_{12}.T^2 + C_{13}.T^3 + C_{14}.T^4).P_b +$$
$$(C_{20} + C_{21}.T + C_{22}.T^2 + C_{23}.T^3 + C_{24}.T^4).P_b^2 +$$
$$(C_{30} + C_{31}.T + C_{32}.T^2).P_b^3$$

$$A(t,p) = A_{00} + A_{01}.T + A_{02}.T^2 + A_{03}.T^3 + A_{04}.T^4 +$$
$$(A_{10} + A_{11}.T + A_{12}.T^2 + A_{13}.T^3 + A_{14}.T^4).P_b +$$
$$(A_{20} + A_{21}.T + A_{22}.T^2 + A_{23}.T^3).P_b^2 +$$
$$(A_{30} + A_{31}.T + A_{32}.T^2).P_b^3$$

$$B(t,p) = B_{00} + B_{01}.T + (B_{10} + B_{11}.T).P_b$$

$$D(t,p) = D_{00} + D_{10}.P_b$$

with the coefficients defined in the following matrix:

Subscript	A	B	C	D
00	+1.389	-1.922E-2	+1402.388	+1.727E-3
01	-1.262E-2	-4.42E-5	+5.03711	
02	+7.164E-5		-5.80852E-2	
03	+2.006E-6		+3.3420E-4	
04	-3.21E-8		-1.47800E-6	
05			+3.1464E-9	
10	+9.4742E-5	+7.3637E-5	+0.153563	-7.9836E-6
11	-1.2580E-5	+1.7945E-7	+6.8982E-4	
12	-6.4885E-8		-8.1788E-6	
13	+1.0507E-8		+1.3621E-7	
14	-2.0122E-10		-6.1185E-10	
20	-3.9064E-7		+3.1260E-5	
21	+9.1041E-9		-1.7107E-6	
22	-1.6002E-10		+2.5974E-8	
23	+7.988E-12		-2.5335E-10	
24			+1.0405E-12	
30	+1.100E-10		-9.7729E-9	
31	+6.649E-12		+3.8504E-10	
32	-3.389E-13		-2.3643E-12	

The Chen & Millero expression is based upon comprehensive observations on seawaters in the ranges $0<T<40°$, $0<S<40$, $0<P_b<1000$. Some concern has been expressed, however, at the accuracy of the formula at pressures exceeding 100 bar.

A1.3.1.6 DEL GROSSO (1974)

$V = C_{000} + DC_T + DC_S + DC_P + DC_{STP}$, where

$C_{000} \quad = 1402.392$

$DC_T \quad = 0.501109398873E+1*T - 0.550946843172E-1*T^2 + 0.221535969240E-3T^3$

$DC_S \quad = 0.132952290781E+1*S + 0.128955756844E-3*S^2$

$DC_P \quad = 0.156059257041*P_k + 0.244998688441E-4P_k^2 - 0.883392332513E-8*P_k^3$

$DC_{STP} \quad = -0.127562783426E-1*T*S + 0.635191613389E-2*T*P_k$

$\qquad + 0.265484716608E-7*T^2*P_k^2 - 0.159349479045E-5*T*P_k^2$

$\qquad + 0.522116437235E-9*T*P_k^3 - 0.438031096213E-6*T^3*P_k$

$\qquad - 0.161674495909E-8*S^2*P_k^2 + 0.968403156410E-4*T^2*S$

$\qquad + 0.485639620015E-5*T*S^2*P_k - 0.340597039004E-3*T*S*P_k$

The formula is deemed to be valid only in the temperature and salinity ranges, and up to the pressures (bar), indicated in the matrix below:

S	T (°C)			
	0	5	10	15
33	1034	1034	275	69
34	1034	1034	207	207
35	1034	1034	414	207
36	1034	1034	275	69
38	69	69	414	414

A1.3.1.7 MACKENZIE (1981)

Based upon widespread oceanographic measurements, the MacKenzie formula is:

$$V = 1448.96 + 4.591*T - 5.304E - 2*T^2 + 2.374E - 4*T^3$$
$$+ 1.340*(S-35) + 1.630E - 2*D + 1.675E - 7*D^2$$
$$- 1.025E - 2*T*(S-35) - 7.139E - 13*T*D^3$$

and is stated to be valid for naturally occurring seawaters in the intervals indicated in the matrix below:

P_k	$T\ (°C)$	S
0	0-30	30-40
50	0-20	32-40
100	0-14	32-34
	0-16	35-38
	10-16	39-40
200	0-12	32-36
	0-16	37
	8-16	38-39
500	0-5	33-36
	12-14	38-39
800	0-5	34-35

A1.3.2 DISCUSSION

A1.3.2.1   DEVELOPMENT OF FORMULAE

A useful overview of the history of seawater speed of sound measurements and formulae is provided by Dulshaw *et al.*

All formulae given above (and the majority of others referred to in the course of this study) were empirically derived from measurements of acoustic velocity of seawater samples whose temperature, salinity and pressure were measured in the oceans and/or varied in the laboratory. The Robertson equation is one of the few attempts to base the equations for the speed of sound on theoretical considerations alone.

The Wood formula, while in use even now, wass considered as early as 1960 to be unreliable for the advancing technology and requirements of that era, and was superseded by the Wilson formula in 1961.

The recognition of defects in the experimental methods of Wilson, together with the adoption of the practical salinity scale and the international equation of state for seawater (EOS-80) resulted in the Wilson formula being superseded for oceanographic purposes by the Chen & Millero formula, which still represents the formal standard for oceanographic purposes.

The limitations of the Chen & Millero formula in turn were revealed by precise in situ observations of acoustic velocity with depth, and by the advent of tomographic methods to determine seawater physical properties along very large path-lengths (across oceans) and to great depths.

These observations have led in recent years to the realisation that the Chen & Millero formula has distinct limitations at high pressures, and that the Del Grosso equation may be more realistic for such specialist purposes. The wide validity range for salinity and temperature of the Chen & Millero formula is of value for measurements on the continental shelf, however. The quality of fit of the Del Grosso equation to the modern high-pressure data sets (and the corrections that should consequently be applied to the Del Grosso equation) is currently the subject of some debate.

A1.3.2.2   COMPARISON OF FORMULAE

The Wood and Wilson formulae do not fit modem experimental and observational data well, and should no longer be used for precise computations. This probably is the result of improvements in observational and analytical techniques over the years, together with changes in computational methods of salinity and depth.

The remaining algorithms show fairly close agreement with one another, diverging as pressure increases.

The Chen & Millero formula is commonly accepted for oceanographic use, and was derived from measurements over a wide salinity, temperature and pressure range.

At high pressures (>100 bar), however, recent research suggests that the Del Grosso equation is more accurate, although this formula is valid only for a limited range of oceanic waters.

The Del Grosso formula has been used as a benchmark to appraise the accuracy of the other algorithms.

The following order of preference is suggested:

i)   Chen & Millero (only for water depths less than 1000m)
ii) Del Grosso (only for water depths greater than 1000m)
iii) MacKenzie (for rapid computations in oceanic waters to 8000m water depth)
iv) Medwin (for rapid computations in oceanic waters to 1000m water depth)

The Medwin and Wilson (simplified) formulae diverge considerably from the remaining algorithms at temperatures greater than 20°C. This is expected from two simple formulae lacking higher order temperature terms.

There may be some advantages in using the MacKenzie and Medwin formulae where depth is known, and where the computation of pressure for inclusion in the Chen & Millero or Del Grosso formulae would become unnecessarily onerous. The user should be made aware, however, of the limited range of conditions of temperature, salinity and pressure over which these formulae are valid.

A1.3.2.3 THE PRESSURE/DEPTH ALGORITHM

An accurate expression for computing pressure from depth (and *vice versa)* may be desirable:

a)   for its own sake, to enable precise pressure and depth computations to be made for a variety of purposes; and

b)   to enable precise speed of sound computations to be made.

When using speed of sound algorithms with a pressure term (Chen & Millero, Del Grosso), the water pressure can be measured directly, estimated from a known depth and inversion of the UNESCO pressure/depth algorithm (possibly based on a carefully calibrated conductivity/temperature/depth cast), or calculated from standard tables. According to Saunders and Fofonoff, who were the originators of the basic method adopted in the UNESCO formula, these estimates should be carried out at 5 bar pressure intervals near the surface and at 200 bar intervals for greater depths.

When using speed of sound formulae with a depth term (MacKenzie or Medwin), the depth may be estimated or measured by some independent means; or computed from a pressure measurement and a conductivity/temperature depth cast. It is more likely, however, that these methods would not be used for precise purposes; they are in any case valid only for oceanic waters in which the errors in the estimation of depth, introduced through ignoring the geopotential anomaly, would not be excessive.

A1.3.3 CONCLUSIONS

1. It is recommended that use of the Wood and Wilson formulae be discontinued for precise purposes, as they do not provide good agreement with modern data sets and computational methods of salinity and depth.

2. It is of crucial importance to ensure that the formulae (of whatever origin) are used only for observations made within the ranges of temperature, salinity and pressure for which each expression is deemed valid.

3. It is recommended that the Chen and Millero formula be used for seawaters on the continental shelf. This incorporates a pressure term which should be measured directly; evaluated from a known depth using the full UNESCO formula and data obtained either from oceanographic tables or from a conductivity/temperature/depth cast; or the error in using the simplified UNESCO formula deliberately accepted.

4. In deep ocean waters, the Del Grosso formula is currently favoured, especially for long path-lengths. This also uses a pressure term.

5. Where rapid computations are necessary, or where the depth is known (but not pressure), the simple MacKenzie (9 terms) and Medwin (5 terms) formulations may prove of value. These expressions are strictly valid only for normal oceanic waters. Where depth is computed from pressure, the simplified UNESCO equation for the pressure/depth relationship could be used without introducing significant error.

6. Incorporation of the full UNESCO pressure/depth algorithm (incorporating the geopotential anomaly) would be a useful addition to any software package, although there may be little discernible benefit to the accuracy of the speed of sound computations. The complete formula would, however, enable a full suite of precise applications to be available for use worldwide.