

National Evaluation Centre

**EVALUATION OF A  
YSI-6000 SUBMERSIBLE  
WATER QUALITY MONITOR**

National Rivers Authority



**NRA**

*National Centre  
for  
Instrumentation  
and  
Marine Surveillance*

© National Rivers Authority (1994)

The contents of this report are the copyright of the NRA and all rights are reserved. No part of this publication may be reproduced, stored in a retrieval system or transmitted, in any form or by any means electronic, mechanical, photocopying, recording or otherwise, without the prior written consent of the NRA.

This report has been prepared by NRA as an objective and impartial assessment. None of the information contained in this report shall be construed as an endorsement of the product by the NRA and no liability is accepted by the NRA for any decisions made or actions taken as a result.

THE EVALUATION OF A YSI-6000 SUBMERSIBLE WATER  
QUALITY MONITOR

Authors : A.J.Chappell (BSc), C.J.Wright (BEng)

Issue date : February 1995

Report number : NRA eval 04 - 1

ENVIRONMENT AGENCY



042394

N.R.A.  
Instrument Evaluation Centre  
Fobney Mead : Rose Kiln Lane  
Reading : RG2 0SF



NRA  
Evaluation  
Centre

THE EVALUATION OF A YSI-6000 SUBMERSIBLE WATER QUALITY MONITOR

A.J.Chappell BSc  
C.J.Wright BEng

Contents

Executive Summary

1. Introduction
2. Major findings
  - 2.1 Implications for use
  - 2.2 Instrument performance
  - 2.3 Comments on use, construction, and documentation
  - 2.4 Comments from field use
  - 2.5 Manufacturer's comments
3. Details of instrument evaluated
4. Test Results
5. Test procedures
6. Definitions, abbreviations and references

Acknowledgements

Appendix : Calculations and reference measurements.

## EXECUTIVE SUMMARY

This report describes the evaluation of a YSI6000 water quality logger. It is designed for field use in fresh or saline water to measure dissolved oxygen, temperature, ph, conductivity, and depth. It also has locations available for other sensors which may be developed.

The instrument failed during the tests and needed to be repaired due to a failure of components on the main circuit board.

There was no flow effect found for the D/O, temperature, and conductivity sensors. A minor flow effect was found on the pH sensor of 0.2 units.

Temperature changes affected the D/O sensor by 0.35% per °C. The depth sensor was also affected by temperature.

The instrument was susceptible to ground loop interference which caused large errors when connected to an earthed computer. YSI are developing an optical isolation system however this was not tested.

As with all field instruments careful maintenance and calibration is required before deployment in order to obtain accurate readings.

## 1. INTRODUCTION

There are currently a number of submersible water quality meters in use by the NRA and there is now a need to understand how environmental factors affect the reliability and accuracy of data obtained. In order to gain some information about the precision and operational limits of a YSI6000 in natural waters a series of tests were carried out on a standard operational meter obtained from the manufacturer's UK agent.

The instrument is a multi-parameter meter which directly measures temperature, dissolved Oxygen, pH, depth, and conductivity. Conductivity is corrected for temperature and displayed as specific conductivity at (25°C), and is used to derive values for salinity, resistivity, and total dissolved solids. The dissolved oxygen (%sat) is used to calculate the oxygen concentration as mg/l, this is automatically corrected for temperature and salinity.

The instrument was tested over 6 months at the NRA evaluation centre at Fobney Mead and its facilities at Lea Marston and Crossness. The test program was agreed to by the NRA regions and by YSI ltd.

The test findings are presented in sections 2 and 4. In section 2 the results are summarised along with comments about operation and construction, and the implications for use are given. Section 4 contains detailed test results after some initial data analysis. The test methods are outlined in section 5. If more information is required then the authors can be contacted at :

NRA Evaluation Centre  
Fobney Mead  
Rose Kiln Lane  
Reading  
RG2 0SF  
Tel : 0734 314015  
Fax : 0734 311438

Copies of this report are available to NRA staff from the above address.

## 2. MAJOR FINDINGS

### 2.1 Implications for use

The results of these tests can be used to estimate the accuracy and uncertainty which can be expected from this instrument in normal use.

pH	$\pm 0.2$
Conductivity	$\pm 130 \mu\text{S}/\text{cm}$ (typically $1000 \mu\text{S}/\text{cm}$ )
D/O (% saturation)	$\pm 5\%$ to $\pm 10\%$
Temperature	$\pm 0.3 \text{ }^\circ\text{C}$

The pH uncertainty is estimated from the variations between the laboratory and the YSI6000 in the drift tests, and the flow effect of 0.2pH. The temperature uncertainty is estimated from the overall accuracy and the fresh water drift test.

The conductivity uncertainty is estimated from the drift test differences, and has been corrected for the calibration offset which occurred. It will also include uncertainties arising from differing temperature coefficients.

A potential source of conductivity error is the presence of air bubbles in the sensor during calibration which can create an offset in the readings. Since conductivity probes are normally stable the chance of this occurring can be reduced by checking the probe reading in a known solution, only re-calibrating when errors are found.

The D/O uncertainty is estimated from the fresh water drift test and the temperature effect. Water temperature is a significant consideration when deploying the instrument since it can cause errors of up to 7% if it instrument is calibrated at 23°C and used in water at 3°C. The most direct solution is calibration in a temperature bath, or on site using a lap-top computer with an RS232 link.

As there is only a minor flow effect on the pH probe the instrument can be safely deployed in still water, eg a lake or close to a river bank with no ill effect on the sensors.

It would not be possible to deploy the instrument tested as an on-line sensor without some form of electrical isolation since any electrical connection to an instrument with an independent earth would create large errors from common mode (ground loop) interference.

## 2.2 Instrument performance

### Water Flow Rate

The results show that there is no significant effect on the temperature, conductivity or depth sensors. The D/O sensor was slightly affected although the effect was less than 2% saturation at 100%. The pH sensor was also slightly affected, changing by -0.2 as the flow increased from zero to 0.35 m/s.

### Battery Voltage

The results show no significant effect on the temperature, conductivity, or depth sensors.

The pH readings increased from 8.5 to 8.9 as the voltage dropped from 4.5V to 3.5V, and the D/O readings increased from 105% to 148% when the voltage fell from 5.0V to 3.5V. These effects occur well below the normal operating voltage and the batteries would normally have been changed before any errors occurred.

The instrument shut down at 3.4V.

### Water Temperature

The temperature sensor performance was not affected throughout the range of the temperature test.

The difference between the pH reading and the laboratory analysis changed from 0 in water below 19.4°C to -0.2 at 40.1°C and -0.5 at 45.0°C. During the test the pH of the water was typically 8.5.

The depth reading changed by +2.6 ft as the temperature changed from 9.1°C to 45.0°C. The instrument was immersed to approximately 1.2 ft during the test.

The difference in conductivity reading between the instrument and the laboratory changed from -65µS/cm at 4.0°C to +47µS/cm at 45.0°C. These variations are probably due to the difference between the conductivity coefficient of the river water and the coefficient used by the instrument. The conductivity was typically 500µS/cm during the test.

The D/O reading varied from -18.4% (ie a reading of 81.6%) at 4.0°C to -4.7% (ie a reading of 95.3%) at 45.0°C. The variation is approximately linear at a rate of +0.35% per °C which would cause an error of 7% if the instrument was calibrated in a laboratory at 23°C and used in a river at 3°C. (There is an apparent calibration error which caused an offset in these readings; however we do not believe that this has any effect on the temperature variations.)

### Response time

The response time was measured before and after the drifts test at Lea Marston and Crossness.

The maximum response time of the Dissolved Oxygen probe changed from 1 minute 36 seconds before the fresh water drift test at Lea Marston to 2 minutes 42 seconds after. The membrane was then changed and the response time varied between 58 seconds before and 56 seconds after the test at Crossness.

The longest response of the conductivity sensor was 12 sec after the drift test at Lea Marston, all other measurements were less than 10 seconds.

The response time of the pH electrode varied from 10 seconds initially to 3 minutes 35 seconds after the test at Lea Marston, then reduced to less than 7 seconds after the test at Crossness.

#### Accuracy

The accuracy of the dissolved oxygen, conductivity, and depth probes were tested directly. The accuracy of the temperature probe has been inferred from the temperature test and the accuracy of the pH can be inferred from the drift test results.

**Dissolved Oxygen :** The maximum variation between the instrument reading and the reference solution was 4.1% at 152.3% saturation. Above 70% the differences are not significant since they are smaller than the uncertainty of the reference solutions. The difference at 41.5% is 3.6% which is slightly larger than the reference uncertainty.

**Conductivity :** The conductivity difference varied from +8 $\mu$ S/cm at 5 $\mu$ S/cm (de-ionised water) to -188 $\mu$ S/cm at 58640 $\mu$ S/cm (0.3% reading).

**Depth :** The depth error varied from +0.82m (+2.7ft) at 10.0m (8.2% reading) to +7.2m (23.5ft) at 120.0m (+6.0% reading).

**Temperature :** The temperature difference varied from +0.3°C to -0.1°C. The fluctuations seem to be caused by random noise.

**pH :** From all the tests carried out the pH accuracy appears to be  $\pm 0.2$  units

#### Effect of conductivity on pH

The pH reading in 0.0001 molar HCl (pH 4.0) varied slightly from 4.03 at 37 $\mu$ S/cm (pure solution) to 3.97 at 395 $\mu$ S/cm.

#### Fresh water Fouling and Drift

The instrument was deployed for three weeks in a tank of flowing river water at the Severn Trent region monitoring station at Lea Marston. Comparisons with the results of analysis of water samples show that the short term trends in the instrument results follow the laboratory results for most of the test. They are also consistent with the permanent monitoring station and other instruments deployed at Lea Marston at the same time.

After approximately 10 days the dissolved oxygen values drifted down compared to the laboratory analysis. This is probably due to the build up of silt etc. on the probe surface during the test. The response of the probe was slower after the test.

The conductivity readings during the test were approximately 50% high compared to the laboratory analysis. This was a constant offset throughout the test and could be caused by air bubbles becoming trapped within the sensor during the pre-test calibration.

The tank had a constant depth and the values given by the depth sensor varied from 0 to 0.8 m, with an average and sample standard deviation of  $0.52 \pm 0.15$  m. The variations in the depth readings follow changes in atmospheric pressure, which would be expected since the depth is measured using a pressure transducer.

## Estuarine Fouling and Drift

The instrument was deployed for three weeks at the in the tidal Thames on the Thames region floating monitor at Crossness. Comparison with laboratory analysis of samples taken from a nearby pier shows good correlation with the instrument for pH and conductivity. The instrument dissolved oxygen and temperature results are consistent with the known water quality of that part of the Thames, and with the monitoring station and other instruments deployed on the monitor at the same time.

The values given by the depth sensor varied from 0.0 to 0.8 m, with an average and sample standard deviation of  $0.52 \pm 0.15$  m. This variation represents changes in atmospheric pressure since the instrument was mounted at a constant depth.

The response time of the pH sensor was faster after the test than before. The response time of the other sensors did not change significantly.

### 2.3 Comments on use, construction, and documentation

The instrument is approximately 495 mm long, 89 mm diameter and weighs 2.9 kg. The connector for the communication cable is protected by a screw on cap during a logging run, and the sensors are protected by a plastic cage.

The dissolved oxygen, conductivity, and temperature sensors are built into a single compact unit. This is an elegant design which leaves three locations for other sensors; however, if any one sensor fails then it will be necessary to replace all three which could be more expensive than separate sensors.

The batteries are easily changed by removing a cover in the top of the instrument and sliding them into (and out of) place. The communication cable includes two wires for an external DC power supply.

The calibration procedure is reasonably straight forward. The temperature and ORP (when fitted) sensors are factory set and do not require calibration. The pH probe is calibrated using two or three buffer solutions, the conductivity with one solution and the D/O at 100% in moist air. Tight fitting calibration cups are provided which were difficult to remove from the sonde after use. Frequent calibration of the conductivity probe would not normally be necessary, so care needs be taken since it is easy to trap air bubbles inside the probe, especially if it has become slightly dirty.

For the dissolved oxygen calibration it is necessary to allow the probe to settle for approximately 20 minutes. This is because the probe may change slowly by up to 5% in that time. The software also requires the local atmospheric pressure to allow for it in the calibration. (This is usually available in the telephone weather forecast)

Communication with the instrument was carried out using software supplied for the purpose. The software is menu driven and easy to learn and use. However there were a number of problems encountered during the tests and it was often difficult to establish the connection between the YSI6000 and the computer. Contact cannot be established when the batteries are low and while this is reasonable there is no indication that this is the cause of the problem. On a number of occasions contact was not made even with new batteries or an external power supply, this was found to be due to moisture on the terminals, even when they looked dry.

The instrument was very susceptible to ground loop (common mode) interference which caused the readings to be unreliable. A number of tests needed to be repeated with the computer isolated from mains earth. This will make the instrument unsuitable for on-line monitoring attached to a computer or a grounded telemetry system. YSI have stated that an optical isolation system is being developed, but it was not available for testing.

The instrument was returned to YSI-UK for repair during the tests. A failure occurred on the main circuit board caused by the common mode interference experienced during the tests.

Even with the water electrically isolated in a plastic bucket or the computer isolated from mains earth the on-line results from the conductivity and D/O probes fluctuated by  $\pm 50 \mu\text{S}/\text{cm}$  and  $\pm 2\%$  respectively. This can be seen in some of the test results, but the cause is unknown.

The manual is clear and readable and seems to contain all the necessary information about operation of the instrument and the software. It also has sections about the operating principles of the sensors, trouble shooting and diagnostic software.

#### 2.4 Comments from field use

A number of YSI6000 instruments have been used by NRA north west region in the lakes of the lake district and they have made the following general comments.

Rapid build up of slime was noticed at one site which caused the sensors to drift during a four week un-attended deployment. For reliable results it was necessary to calibrate and service the instrument every two weeks.

It was not possible to calibrate the pH probe after deployment in a lake with low conductivity water (60 to 100  $\mu\text{S}/\text{cm}$ ). During the measuring run the pH readings were believable, but it was not possible to get sensible readings in commercial buffer solutions after the test, hence the probe could not be re-calibrated.

The software provided by YSI is not able to communicate with the colour printers available which caused problems when reporting data from a number of instruments.

They also occasionally had difficulty establishing communication between the instrument and a computer.

## 2.5 Manufacturer's comments

YSI incorporated provided the following comments on this report :-

Overall, this report is very positive and should be a selling point for the instrument with various NRA branches. There are a few anomalies with regard to the report which I don't understand and which I have discussed below. There are also several issues with regard to performance which either have already been corrected or will be corrected in the UPG 2 package and I have also pointed out these areas. It would have helped if we knew the version of EMS6000 software in the sonde which was tested and whether or not the sonde was equipped with sensor isolation via capacitor harness.

### ANOMALIES:

[1] The instrument should be disabled in an "Unattended Sample" mode at 6.0 V and therefore I am not sure why the report said that the instrument shut down at 3.4 V.

However, the the study was done with a power supply input in "Discrete Sample" Mode and we have little data on this situation. Perhaps we could confirm how this study was done and note that adverse effects on the sensors should not occur in the "Unattended Mode" if the instrument is functioning properly.

[2] There would seem to be more error than anticipated with regard to the temperature effect on DO accuracy. Sometimes it is difficult to keep from under- or over-saturating water during temperature variation. We would prefer that this test was done in water-saturated air which is vented to atmospheric pressure to make sure that the error really is due to the sensor. However, it is possible that the unit contains the wrong temperature compensation coefficient. We should determine the tempco factor by typing "dotempco" at the command line - it should be 1.1%/degree C for most probes. However, we should point out to the NRA that, because of the flexibility of our software, the user can enter a different tempco if it fits better to the existing probe.

[3] If I understand the test correctly, the conductivity accuracy value given in "Major Findings" on page 7 is somewhat misleading. As stated, the specification could lead the user to suspect that an error of +/- 130  $\mu\text{s/cm}$  could occur at any conductivity, or, in other words, the instrument could not differentiate between 130 and 260  $\mu\text{s/cm}$ . This does not seem to fit with the data on page 18. I suggest that the spec on page 7 be changed to something like "1 percent of reading or 10  $\mu\text{s/cm}$ , whichever is greater".

Even with this qualifier, it doesn't seem to me that the accuracy is as good as it should be. We would prefer that the test be run as an A/B test against another conductivity meter of known performance so that any errors in the composition of the solutions are eliminated.

[4] The test sonde was apparently not equipped with an ORP probe, and the authors seem unaware that this parameter can also be measured with the 6000. We should point this out since ORP might be useful to some of the potential users of the instrument.

### Corrections in Later Instruments:

[1] The groundloop problem has been fixed in all UPG instruments and could be fixed in earlier instruments with the addition of an optional isolator board.

[2] The rather large effect of temperature on depth/level has been corrected in UPG instruments by additional factory characterization/calibration-of-each sensor.

[3] As pointed out by the authors, many of the problems with inability to communicate with the sonde occurred at low battery voltage. This should not happen under normal operating conditions with the voltage above 6 volts. The additional occasional problems should have been corrected in later software versions of the standard instrument and will be dealt with further in the UPG 2 units.

[4] The inability of the deployment group in the northwest region to calibrate the pH probe after deployment in low conductivity water is surprising. It would help to know if the probe was manufactured by Ingold or ASI. However, we will try to confirm this effect in our laboratory with the currently-supplied 6031 probe from ASI. In any case, we should tell the NRA that we are working with our supplier to develop a special sensor for use under these low ionic strength conditions.

[5] The 20-minute stabilization time for the DO sensor noted on page 10 seems reasonable after a membrane change, but too long on a probe which is [or has been] in use. Probably this determination was made in the "Discrete Sample" mode. Perhaps the probe electrodes were in need of resurfacing, an easy task for a user with our new sanding kit and instructions. In any case, we would think that, in the "Discrete Sampling" mode, the DO readings should stabilize within at least 2 percent of the final reading in 2 minutes if the probe has an optimal surface condition.

3. DETAILS OF INSTRUMENT EVALUATED

The instrument tested was a standard production model normally used for exhibitions and demonstrations, and was lent to the NRA by the manufacturer. It was fitted with sensors for Dissolved Oxygen, Temperature, and Conductivity in a single module, and with separate pH and Depth sensors.

Instrument	Model 6000 Depth
Serial Number	93 H 08691
Sensors fitted	D/O; Temperature; pH; Conductivity; Depth
Length (approximate)	495 mm
Diameter (approximate)	89 mm
Mass (approximate)	2.9 kg
Manufacturer	YSI Inc. Box 279, Yellow Springs Ohio 45387 USA
UK Distribution	YSI Ltd Lynchford House Lynchford Lane Farnborough Hants. GU14 6LT
	Tel: 0252 514711
	Fax: 0252 511855

4. TEST RESULTS

Water Flow Rate

The instrument was rigidly mounted in the flow tank at Fobney Mead and subjected to different water flow speeds. Samples were taken throughout the test for analysis of pH and conductivity. The tank was continuously aerated to maintain 100% saturation, and the temperature was measured with a hand held thermometer.

The results shown in table 1 are quoted as differences between the sample values and the instrument readings to remove any bulk changes and highlight the effect of flow on the instrument. The results show that there is no significant flow effect on temperature, pH, conductivity, or depth. The D/O sensor seems to be slightly affected - less than 2% - in still water.

The noise in the conductivity differences is present in the YSI6000 raw data. The cause is unknown, but may be due to electronic interference. Salinity is not shown since it is derived from the conductivity values.

Table 1 : Effect of water flow rate

Water Flow speed m/s	Reading Difference (YSI6000 - reference)				
	Temp °C	pH	D/O %sat	Conductivity @ 25°C µS/cm	Depth ft
off	-0.2	-0.0	-2.4	6	0.0
0.04	0.1	-0.1	-0.7	21	0.0
0.09	0.1	-0.2	-0.8	11	0.0
0.13	0.2	-0.1	-0.6	-17	0.0
0.20	0.1	-0.1	-1.8	2	0.1
0.27	0.1	-0.1	-1.2	- 6	0.1
0.32	0.2	-0.2	-0.8	1	0.1
0.35	0.2	-0.2	-1.6	28	0.1
0.33	0.2	-0.2	-1.5	0	0.1
0.28	0.0	-0.2	-1.5	- 8	0.1
0.20	0.2	-0.2	-1.7	-95	0.1
0.15	0.1	+0.0	-1.0	-29	0.1
0.05	0.1	+0.1	-1.5	4	0.1
off	0.2	0.0	-2.1	4	0.1
0.34	0.2	-0.1	-1.5	0	0.1
off	0.2	+0.0	-2.7	21	0.1

### Effect of low battery

The external battery pack was replaced with a variable stabilised power supply. The instrument was then placed in a tank of stirred aerated river water and the supply voltage was varied as shown below.

The instrument values are given in table 2. We assume that the water conditions did not change significantly during the test however the temperature changes indicated are probably real. The results show no significant effect on temperature, conductivity, or depth. The D/O and pH readings increase when the supply voltage drops below 4.5V. The instrument shut down when the voltage dropped below 3.4V.

Table 2 : Effect of battery voltage

Supply Volts. V	YSI6000 reading				
	Temp °C	pH	Sp. Cond µS/cm	D/O %sat.	Depth m
12.5	19.9	8.45	794	104.3	0.4
12.0	19.9	8.46	774	104.7	0.4
11.5	19.9	8.46	659	104.6	0.4
11.0	20.0	8.44	820	104.8	0.5
10.5	20.1	8.45	800	104.7	0.5
10.0	20.1	8.45	799	104.5	0.5
9.5	20.1	8.41	775	104.8	0.2
9.0	20.2	8.45	769	104.6	0.5
8.5	20.3	8.45	816	104.4	0.5
8.0	20.3	8.44	768	104.7	0.5
7.5	20.3	8.45	815	105.2	0.5
7.0	20.3	8.45	824	104.5	0.5
6.5	20.4	8.45	814	104.4	0.5
6.0	20.4	8.45	795	104.4	0.5
5.5	20.4	8.46	823	104.4	0.5
5.0	20.4	8.45	822	104.5	0.5
4.5	20.5	8.46	793	112.6	0.4
4.0	20.4	8.61	784	123.7	0.4
3.5	20.4	8.87	783	147.6	0.5

### Water temperature

The instrument was placed in a tank of recirculated water and the temperature was increased through the steps shown. A sample was taken at each temperature for laboratory analysis to provide reference information.

The results shown in table 3 are quoted as differences between the sample values and the instrument readings to remove any bulk changes and highlight the effect of temperature on the instrument.

The results show that the D/O, pH, specific conductivity, and depth sensors are affected, but there is no significant effect on the temperature sensor.

The D/O variations are approximately linear with a change of +0.35% per °C. The specific conductivity variation is probably due to the difference between the temperature coefficient of the river and the instrument value.

Table 3 : Effect of temperature

Water Temp. °C	Reading Difference (YSI6000 - Reference)				
	Temp °C	pH	D/O %sat	Conductivity μS/cm	Depth ft
4.0	+0.2	0.0	-18.4	- 65	0.0
9.1	+0.3	0.0	-17.0	+ 1	0.0
19.4	-0.1	0.0	-13.1	+ 15	+0.3
30.6	+0.1	-0.2	- 9.3	+ 30	+0.8
40.1	0.0	-0.2	- 6.6	+ 47	+1.9
45.0	-0.1	-0.5	- 4.7	+ 47	+2.6
19.4	0.0	0.0	-17.1	+ 20	0.0

### Response time

The instrument was transferred quickly between solutions with different measurand concentrations. The response time values represent the time taken for the instrument to complete 90% of the step change.

Table 4 : Response times (2/2/94)

Sensor (step change)	Response time	
	rising	falling
Conductivity (50 to 9900 μS/cm)	5 sec	<3 sec
pH (4.5 to 9.95)	10 sec	8 sec
Dissolved Oxygen (2 to 100%)	1 min 27 sec	1 min 36 sec

Table 5 : Response times (10/3/94 : After fresh water drift test)

Sensor (step change)	Response time	
	rising	falling
Conductivity (70 to 10500 $\mu$ S/cm)	12 sec	<5 sec
pH (4.2 to 9.7)	3 min 35 sec	3 min 28 sec
D\O (old membrane) (2 to 100%)	1 min 50 sec	2 min 42 sec
D\O (New membrane) (2 to 100%)	54 sec	58 sec

Table 6 : Response times (15/4/94 : After estuarine drift test)

Sensor (step change)	Response time	
	rising	falling
Conductivity (2 to 10300 $\mu$ S/cm)	<5 sec	<3 sec
pH (4.0 to 10.0)	<6 sec	<7 sec
Dissolved Oxygen (2 to 100%)	56 sec	55 sec

Accuracy : Dissolved Oxygen

The instrument was placed in different solutions with known % saturation of dissolved oxygen. The uncertainty of the reference values is  $\pm 2\%$  sat or  $\pm 5\%$  of reading, whichever is greater. (ie  $41 \pm 2\%$  sat, see section 5 for details).

Table 7 : Dissolved Oxygen Accuracy

Reference value % saturation	Instrument reading %sat.	
	increasing	decreasing
2	-	4.2
41.5	45.0	45.1
70.7	73.2	73.3
100	101.6	102.2
152.3	148.2	-

Accuracy : Conductivity

The sonde was placed in sodium chloride or potassium chloride solutions with known conductivity.

Table 8 : Conductivity Accuracy

Solution Conductivity $\mu\text{S}/\text{cm}$	Instrument reading $\mu\text{S}/\text{cm}$	
	increasing	decreasing
5	11	13
210	222	223
415	402	411
12900	12756	12811
58640	58452	-

Accuracy : Depth

The instrument was lowered to known depths down a borehole.

Table 9 : Depth Accuracy

Depth (ft)\(m)	Reading (ft)\(m)
32.8 \ 10	35.5 \ 10.82
65.6 \ 20	70.4 \ 21.45
98.4 \ 30	106.4 \ 32.43
164.0 \ 50	175.1 \ 53.37
262.5 \ 80	278.1 \ 84.76
393.7 \ 120	417.2 \ 127.16

### Effect of conductivity on pH

The instrument was placed in 0.0001M HCl with different quantities of sodium chloride added to adjust the conductivity as shown in table 8.

Table 10 : pH value in 0.0001M HCl

Conductivity $\mu\text{S/cm}$	pH Reading pH
37	4.03
59	3.96
94	3.96
153	3.96
248	3.97
395	3.97

### Fresh water Fouling and Drift test

The following graphs show the data recorded by the instrument when it was deployed in a tank fed with a continuous supply of water pumped from the river Tame at Lea Marston.

Laboratory data has also been plotted where it is available and the instrument trends mostly follow the laboratory results (the laboratory DO %saturation values plotted are calculated from the average of three winkler analysis - shown on the DO mg/l graph).

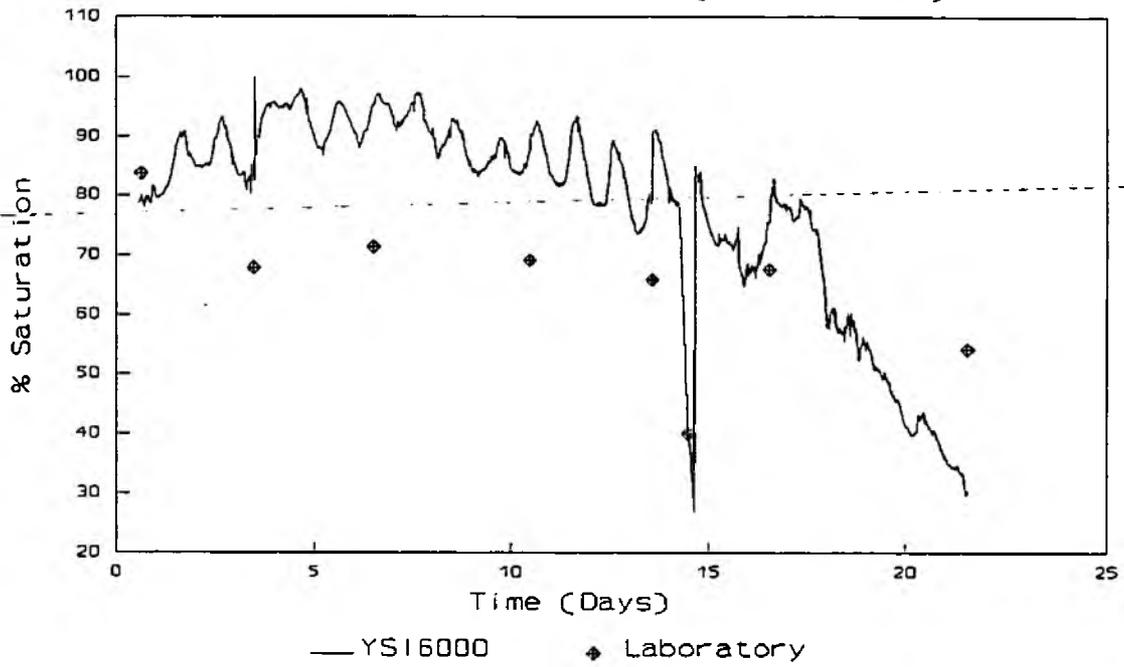
The tank remained at a constant depth. The values given by the depth sensor varied from 0.0 to 0.8 m, with an average and sample standard deviation of  $0.52 \pm 0.15$  m.

The response times before and after the test are shown in tables 4 and 5.

The spike in D/O and temperature values at 14 days was caused when the water supply to the tank was interrupted.

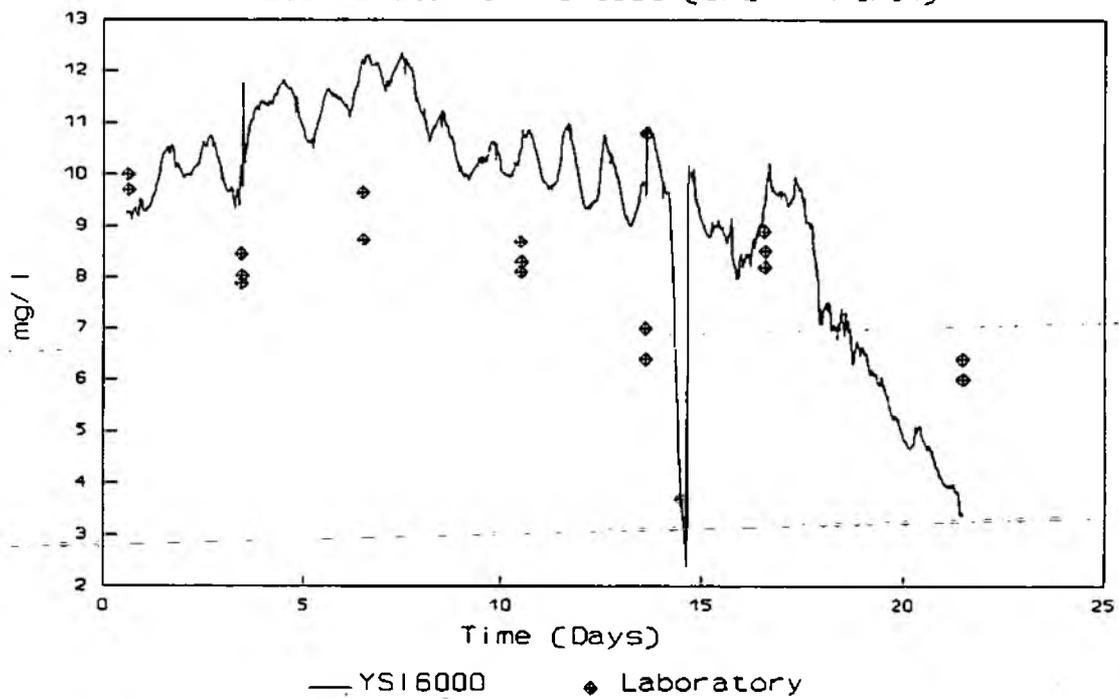
# D/O %sat

Lea Marston drift test (8/2 - 1/3/94)



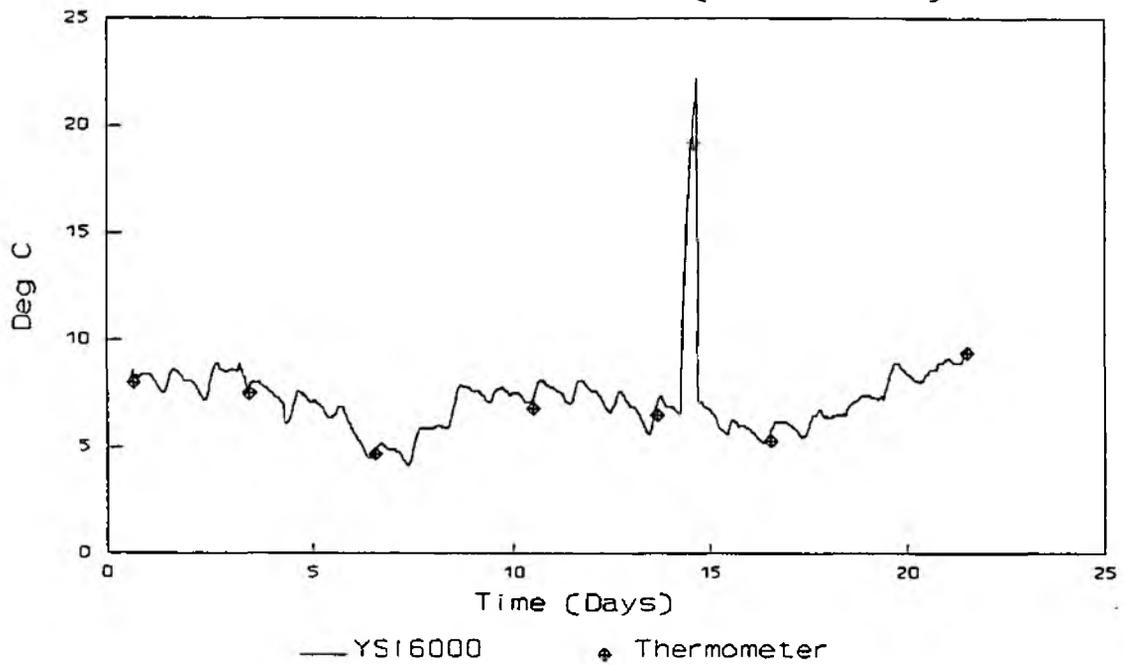
# Dissolved Oxygen mg/l

Lea Marston drift test (8/2 - 1/3/94)



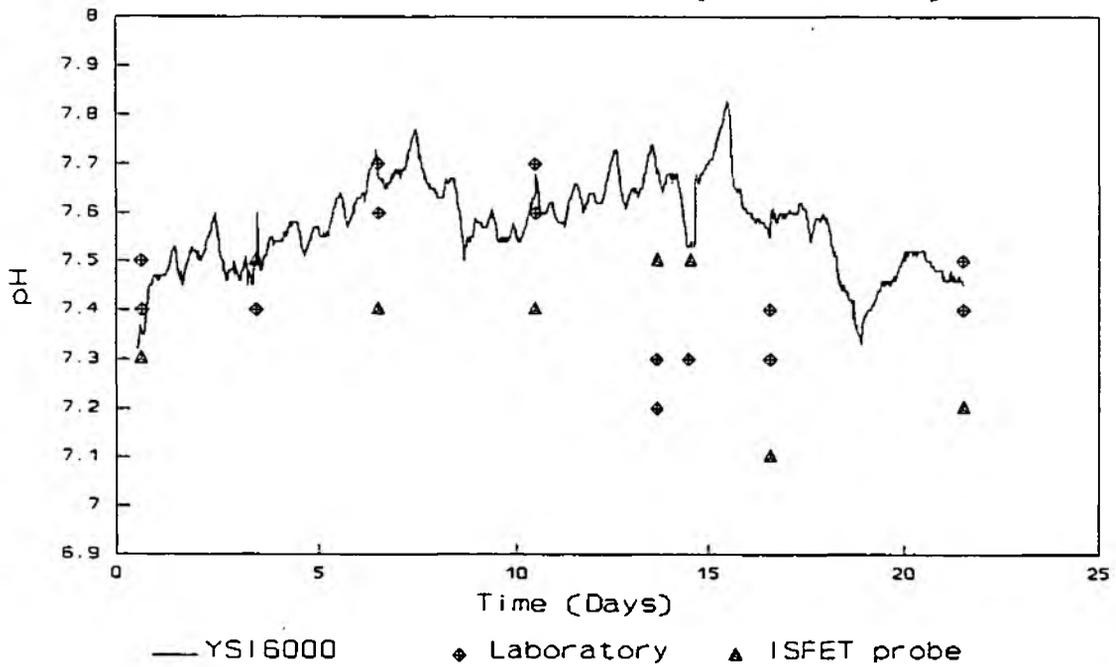
# Temperature

Lea Marston drift test (8/2 - 1/3/94)



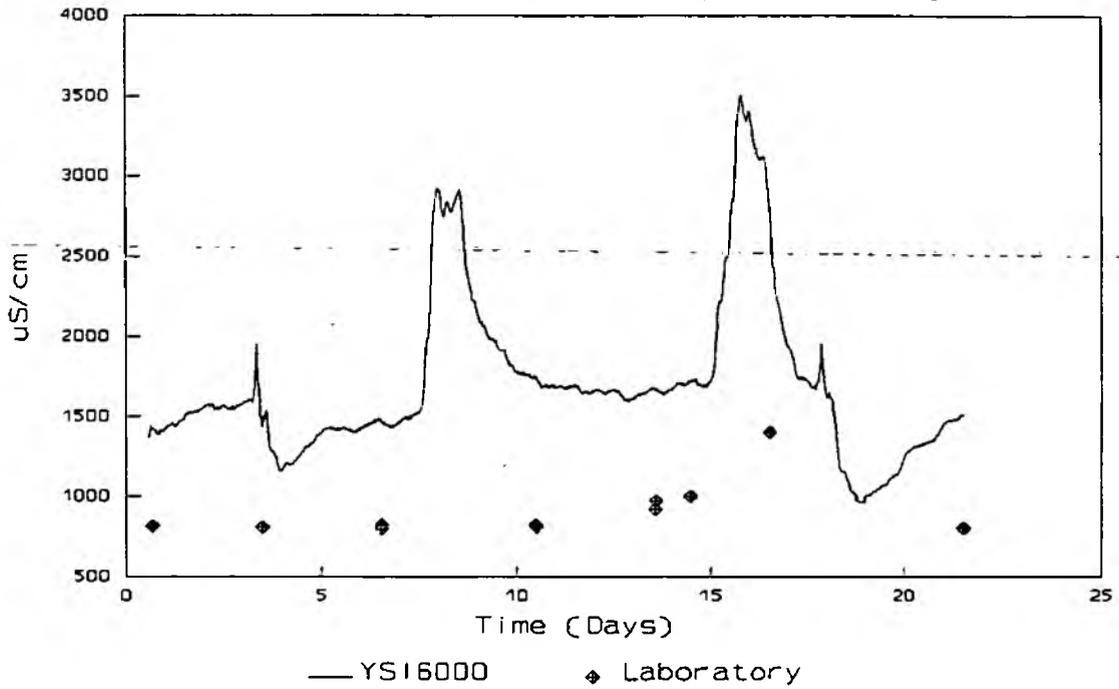
# pH

Lea Marston drift test (8/2 - 1/3/94)



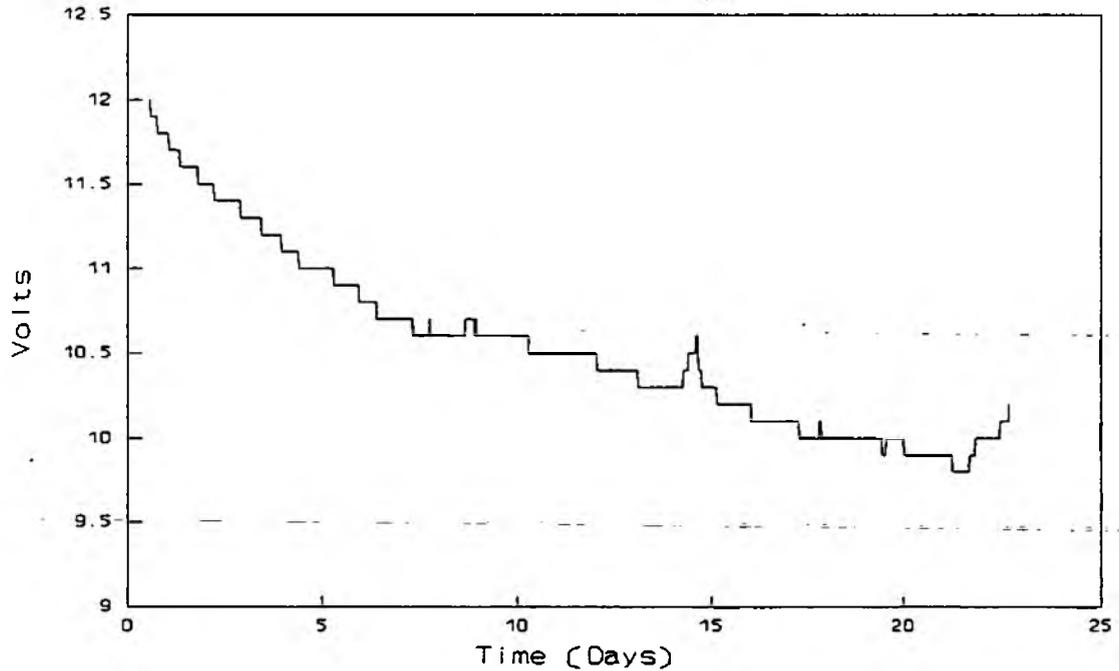
# Conductivity at 20 deg C

Lea Marston drift test (8/2 - 1/3/94)

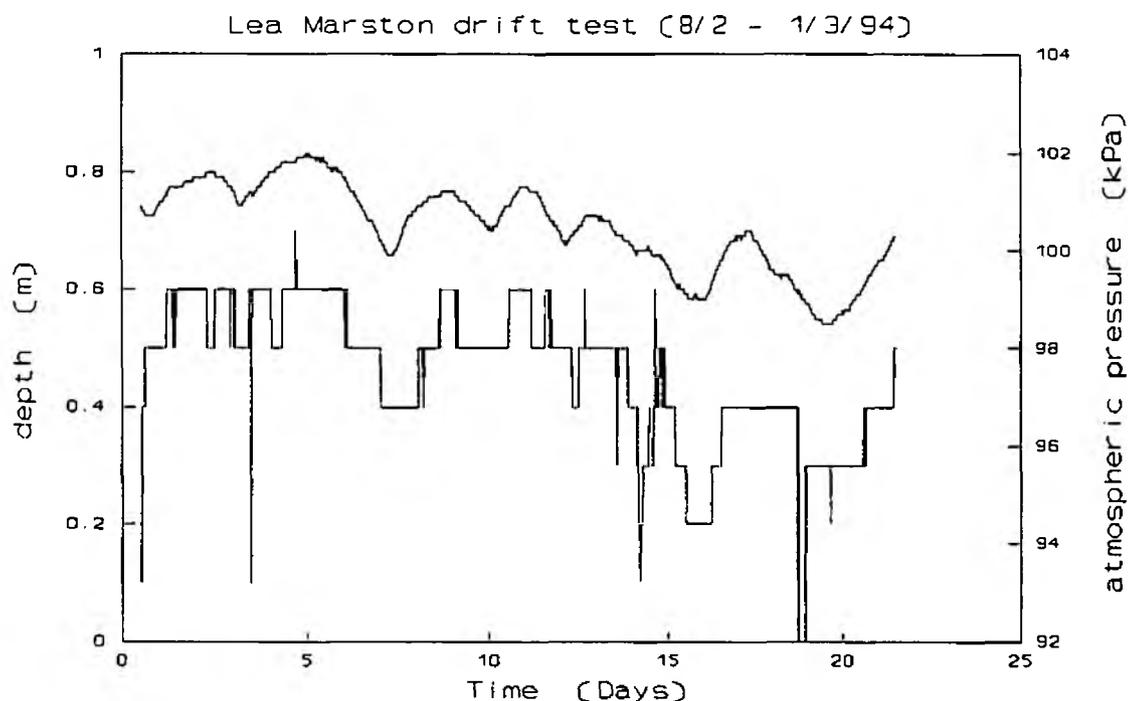


# Battery

Lea Marston drift test (8/2 - 1/3/94)



# Depth



## Estuarine water Fouling and Drift test

The following graphs show the data recorded by the instrument when it was deployed at the floating water quality monitor moored in the tidal Thames at Crossness.

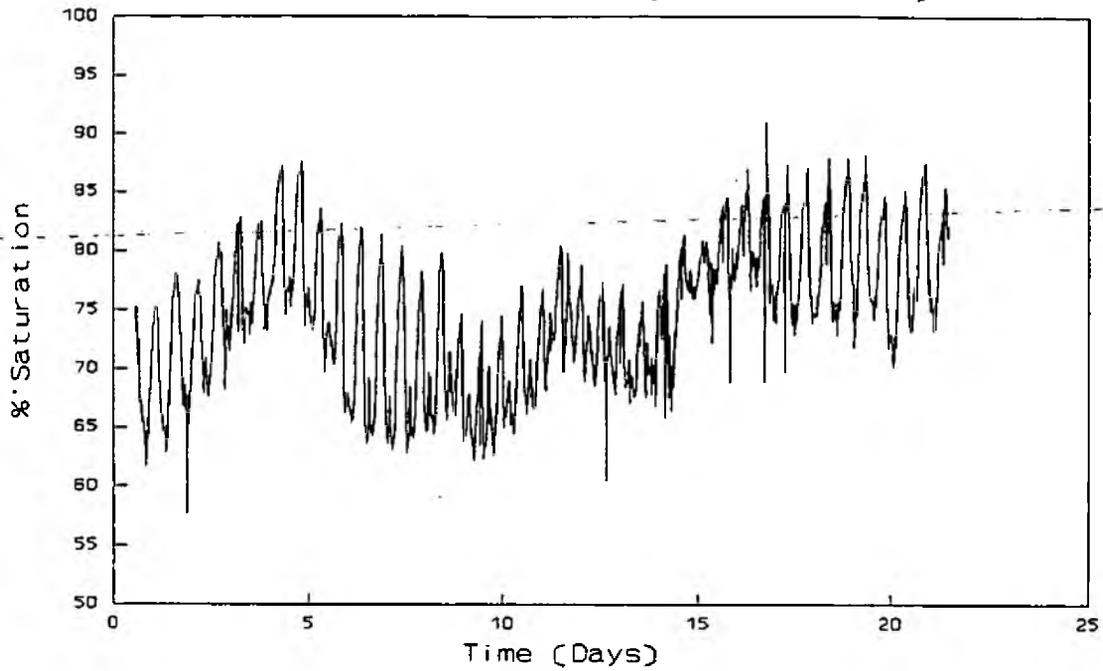
Laboratory data has also been plotted where it is available and it shows good correlation with the instrument. Where lab data is not available the instrument results are consistent with the known water quality of that part of the Thames, and with other instruments deployed on the monitor at the same time.

The depth results are not shown graphically because the logger was fixed to a floating platform, so there were no real variations of depth. The values given by the depth sensor varied from 0.0 to 0.8 m, with an average and sample standard deviation of  $0.52 \pm 0.15$  m.

The response times before and after the test are shown in tables 5 and 6.

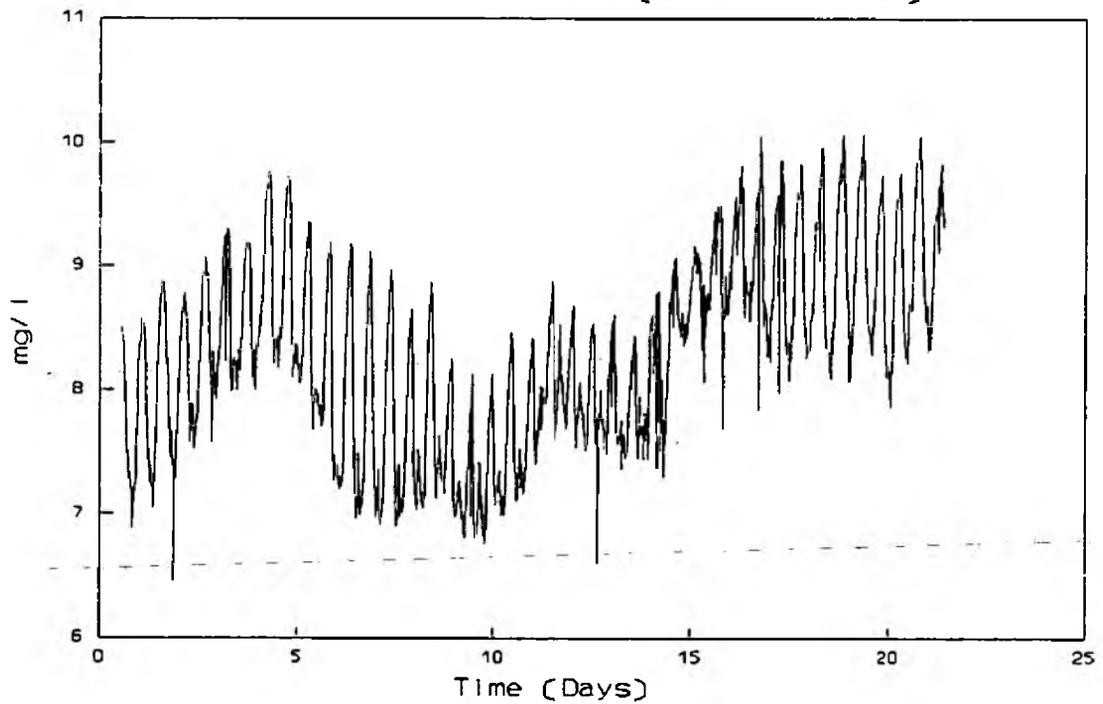
# D/O % sat

Crossness drift test (21/3 - 11/4/94)



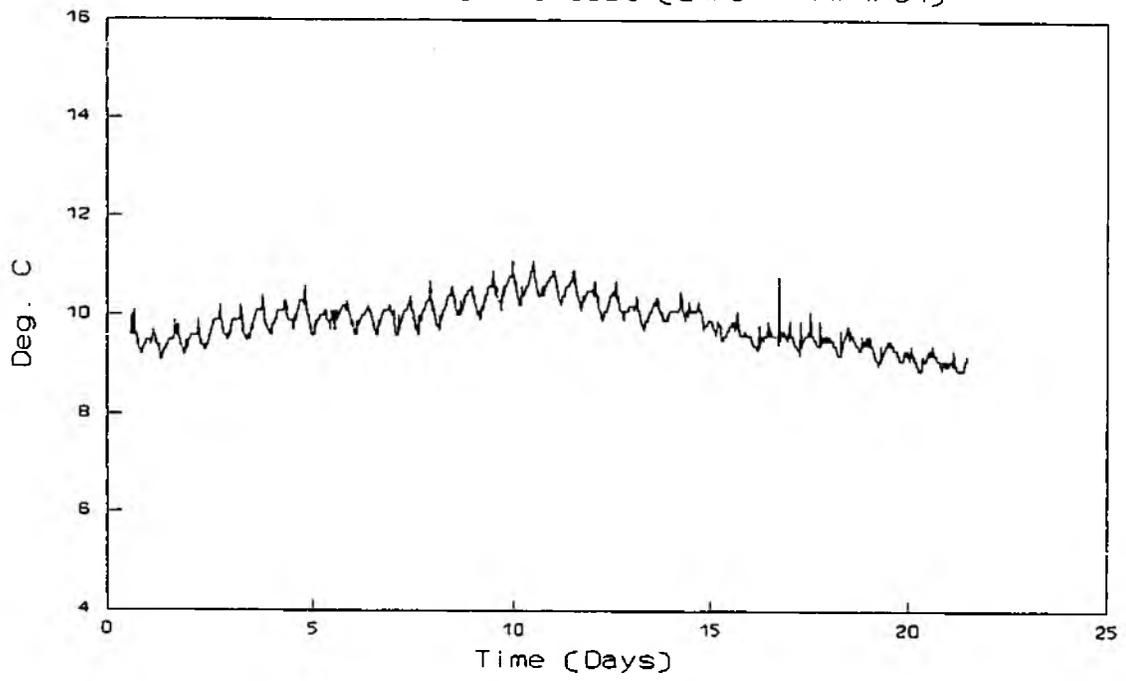
# Dissolved Oxygen mg/l

Crossness Drift test (21/3 - 11/4/94)



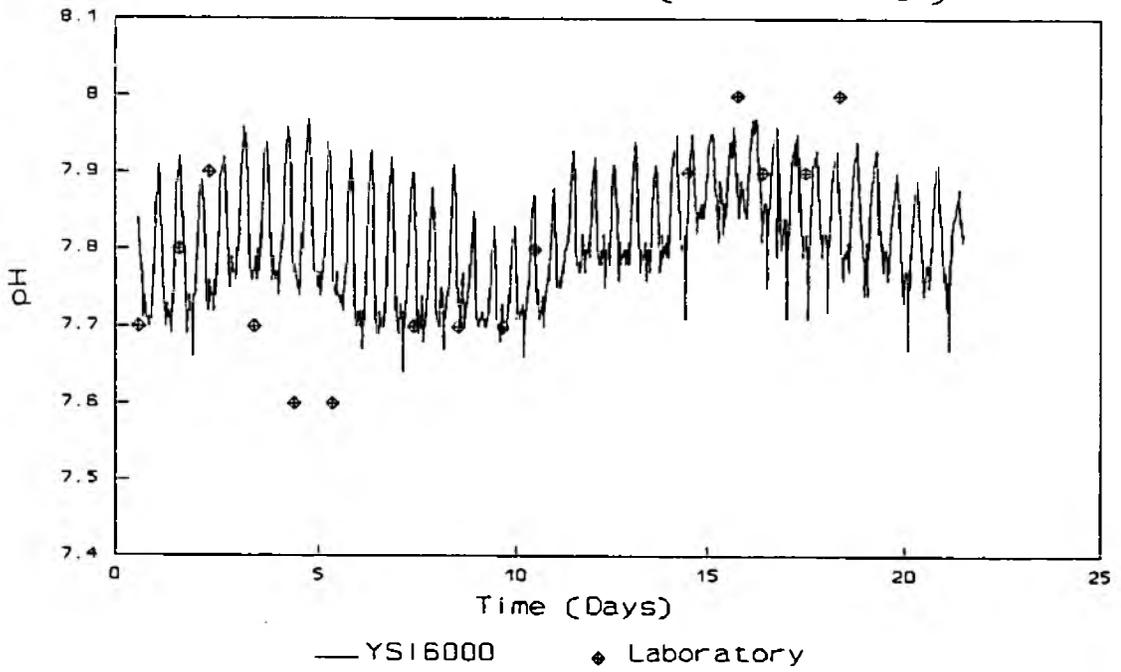
# Temperature

Crossness Drift test (21/3 - 11/4/94)



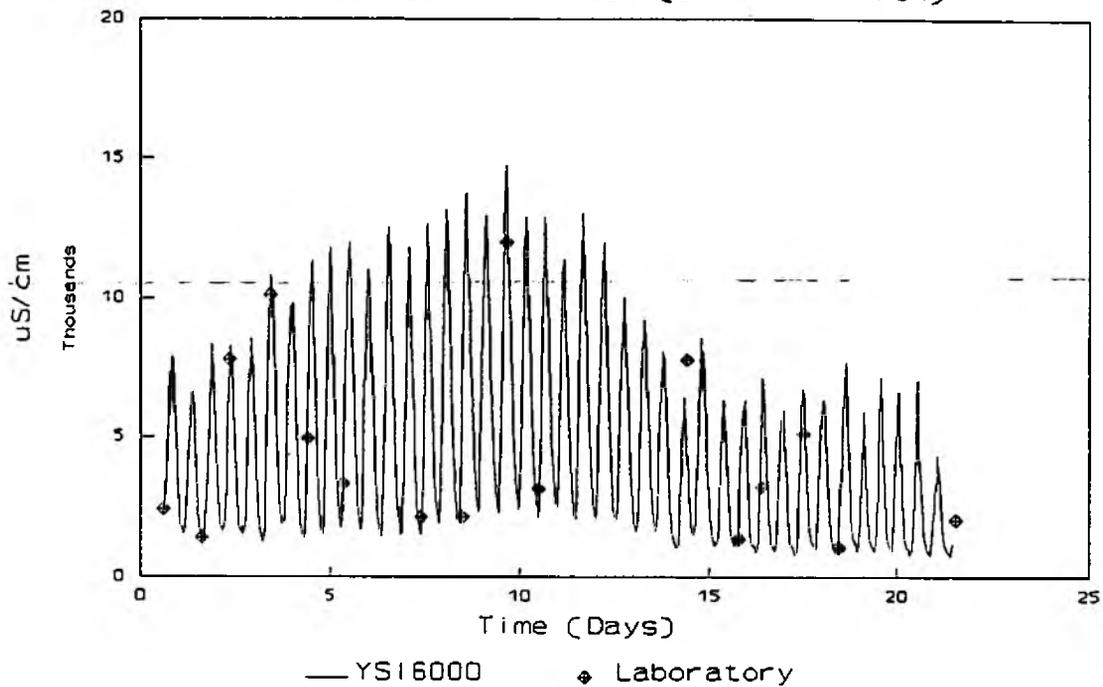
# pH

Crossness Drift test (21/3 - 11/4/94)



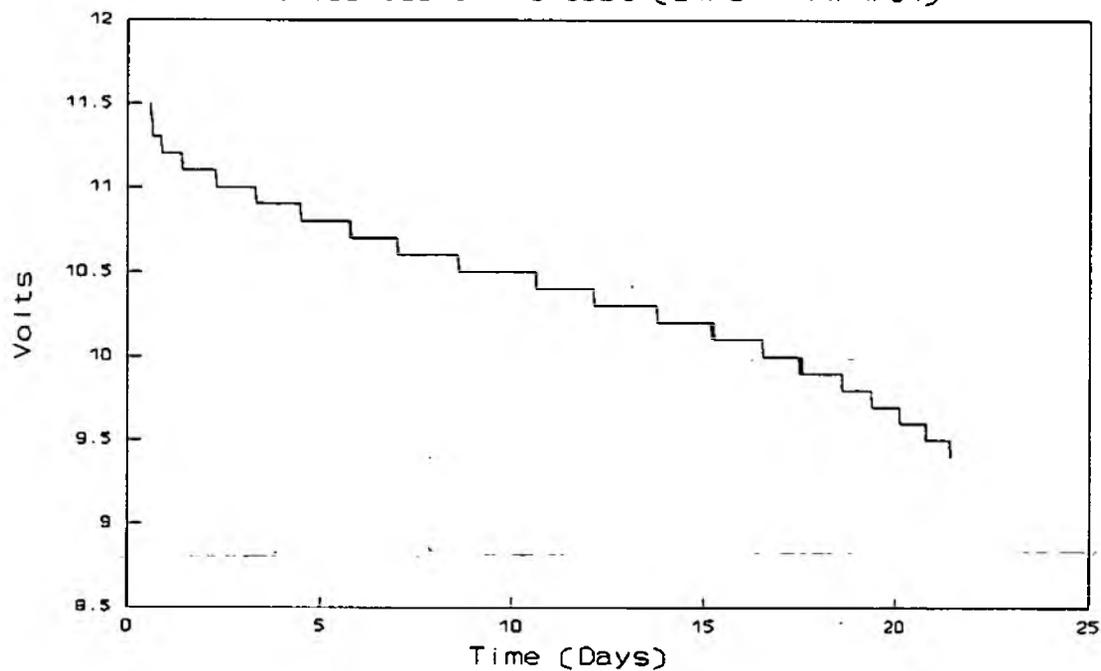
# Conductivity at 20 degC

Crossness drift test (21/3 - 11/4/94)



# Battery

Crossness drift test (21/3 - 11/4/94)



## 5. TEST PROCEDURES

### Flow rate

The instrument was calibrated according to manufacturer's instructions then clamped rigidly in a large flow tank filled with river water. It was positioned vertically with the sensors and the lower half immersed, and was connected to a computer for continuous operation. The computer was isolated from mains earth during the test to reduce the effects of common mode interference.

The water in the tank was continuously aerated to maintain the oxygen level at 100% saturation and samples were taken regularly during the test for analysis of the pH and conductivity. The depth was constant and the temperature was checked using a thermometer. The flow speed was increased in steps to 0.37 m/s (as measured by an electromagnetic flow meter) then decreased stepwise to 0.0 m/s. The instrument parameters were allowed to stabilise at each speed before being recorded.

### Water temperature

The instrument was calibrated according to manufacturer's instructions. It was then placed in a tank of recirculated river water and connected to a computer for continuous operation. The computer was isolated from mains earth during the test to reduce the effects of common mode interference.

The water temperature was increased stepwise from 3.7 to 45.1°C and allowed to stabilise for 30 minutes each time before the instrument readings were noted and a sample was taken for analysis. The level of Dissolved oxygen was fixed by continuous aeration, the depth was constant, and pH and conductivity were measured in samples sent to the Fobney analytical Lab.

### Battery voltage.

A stabilised DC power supply was connected to the instrument using the socket provided on the communication cable. The voltage was reduced from 12.5V in 0.5V steps with the instrument sensors placed in stirred aerated river water. At each voltage the output was recorded and the minimum operating voltage was recorded.

### Response times

The response times of the instrument sensors were tested by transferring the instrument from water near the minimum of the measuring range to water near the maximum of the range. Instrument readings were recorded at regular intervals after the step change and a graph of reading against time was used to calculate the response time (time to complete 90% of the step change). This test was carried out before and after the fouling and drift tests.

### Accuracy

The accuracy of each sensor was checked separately in the following way.

The Oxygen was checked by placing the instrument in five vessels bubbled with five different oxygen/nitrogen mixtures to give known %saturation levels at  $2 \pm 2$ ,  $41.5 \pm 2$ ,  $70.7 \pm 4$ ,  $100$ ,  $152.3 \pm 8$ ,  $194.3 \pm 10$ , from calibrated cylinders.

The Conductivity accuracy was tested by placing the instrument in the following solutions with known conductivities : De-ionised water , 100 ppm NaCl (210  $\mu$ S/cm), 200 ppm NaCl (415  $\mu$ S/cm), 0.1 M KCl (12900  $\mu$ S/cm), and 0.5 M KCl (58640  $\mu$ S/cm).

The accuracy of the depth probe was checked by submersing the instrument to it's maximum working depth in a deep borehole attached to a hydrology probe. The instrument was held at known depths for 5 to 10 minutes to allow it to record at least one logged value. The log file was later analyzed and the relevant depth readings were retrieved.

#### Effect of conductivity on pH

The instrument was placed in 0.0001M HCl (pH 4.0, 37  $\mu$ S/cm). It was then placed in other solutions of 0.0001M HCl with different amounts of sodium chloride added to change the conductivity. The pH reading in each solution was recorded and each solution was checked with a low conductivity pH probe and a conductivity meter.

#### Fresh water Fouling and Drift

The instrument was calibrated according to manufacturer's instructions. It was then immersed in water from the river Tame for 3 weeks at Lea Marston. The trend in levels of D/O, temperature, pH, conductivity, NH<sub>3</sub> and turbidity of the water were monitored using standard Severn-Trent region monitoring station. The instrument was checked at least three times each week and a number of samples were taken for laboratory analysis at each visit. The level of fouling was assessed after the test.

#### Estuarine Fouling and Drift

The instrument was calibrated according to manufacturer's instructions. It was then subjected to estuarine conditions on the Thames region monitoring platform moored in the Thames at Crossness for three weeks. The trend in levels of D/O, temperature and conductivity were monitored using standard water quality instruments, and samples were regularly taken for analysis from a nearby pier.

## 6. REFERENCES

YSI : YSI model 6000 Environmental Monitoring System  
Operating and Service manual

A Chappell : Test protocol for Submersible water quality meters

BSI : BS6068:section 2.15 (1986) Determination of dissolved oxygen -  
electrochemical probe method.

NRA : Report on Water Quality Monitoring at Ambergate

Standard Methods for the Examination of Water and Wastewater (1989)

## ACKNOWLEDGEMENTS

Thanks must be given to the pollution staff at Crossness, the Laboratory staff at Fobney Mead, and to YSI ltd for loan of the instrument. Also thanks to field staff at NRA in Warrington for their comments.

## APPENDIX : CALCULATIONS AND REFERENCE MEASUREMENTS

### Dissolved Oxygen

For mg/l values the reference measurements are made by Winkler titration. The uncertainty is assumed to be  $\pm 0.5$ mg/l from observation.

For %sat values the water is aerated to 100%, or to other values, by bubbling air or Oxygen\Nitrogen certified mixtures through water. The uncertainty is approximately  $\pm 5\%$  of reading.

### Temperature

The reference measurements were made using mercury in glass thermometer calibrated traceable to national standards. The total uncertainty is taken as  $\pm 0.1^\circ\text{C}$ .

### pH

The pH is compared against laboratory measurements made using an automated CSP pH meter. During the drift test the readings were confirmed by comparison with the monitoring station and a portable ISFET pH meter calibrated before each use. The traceable uncertainty is  $\pm 20\%$  of reading.

### Conductivity

The conductivity is compared against laboratory measurements made using an automated CSP conductivity meter. The laboratory readings were given as conductivity at  $20^\circ\text{C}$ , this adjusted to  $25^\circ\text{C}$  for comparison with the instrument values using a temperature coefficient for the water of 1.91% per  $^\circ\text{C}$ . The traceable uncertainty of the laboratory values is  $\pm 20\%$  of reading.

### Salinity

The salinity values of sea and estuarine water were calculated from laboratory measurements of chloride in samples submitted for analysis by the following relationship:

$$\text{SALINITY} = \text{CHLORIDE} \times 1.80655$$