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National Evaluation Centre

**EVALUATION OF AN
HYDROLAB DS3 SUBMERSIBLE
WATER QUALITY MONITOR**

National Rivers Authority

National Evaluation Centre Manager
National Rivers Authority
February 1995



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THE EVALUATION OF A HYDROLAB DS3 SUBMERSIBLE WATER QUALITY MONITOR

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Evaluation
Centre

THE EVALUATION OF A HYDROLAB DS3 SUBMERSIBLE WATER QUALITY MONITOR

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EXECUTIVE SUMMARY

This report describes the evaluation of a Hydrolab DS3 water quality logger. It is designed for field use in fresh or saline water to measure dissolved oxygen, temperature, conductivity, pH, and redox.

The instrument functioned well during the tests.

The accuracy of the measurements were found to be within the measurement uncertainty of the reference systems.

No significant flow effects were found.

The only sensor slightly affected by temperature was D/O which changed by approximately 0.23% per °C.

As with all field instruments careful maintenance and calibration is required before deployment in order to obtain readings within the accuracy found in these tests. Deployment of over 1 month is not recommended because of the limitations of the batteries and because the D/O membrane seems to become prone to drift.

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 Hydrolab Datasonde 3 in natural waters a series of tests were carried out on a standard operational meter fitted with a low flow D/O membrane obtained from the manufacturer's UK agent - Omnidata ltd.

The instrument is a multi-parameter meter which directly measures temperature, dissolved Oxygen, pH, depth, conductivity and redox potential. Conductivity is corrected for temperature and displayed as specific conductivity at (25°C), and is used to derive a value for salinity. 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 Omnidata ltd (for Hydrolab).

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 :

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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. Comparison with samples taken during the drift test at Lea Marston show that the instrument reading is well within the NAMAS uncertainty of the Laboratory analysis. The following variations were found

pH	< ± 0.25	(typically pH 7.4)
Conductivity	< ± 70µS/cm	(typically 1000µS/cm)
D/O (at Fobney Mead)	< ± 5%sat	(typically 100%)
Temperature	< ± 0.3°C	(typically 17°C)

When deploying the instrument it is important to fit the correct batteries, and to fit the warm-up batteries for the D/O probe. For deployments longer than 4 weeks the external battery pack will be necessary. If however the batteries are allowed to go flat the readings remain accurate for all probes except the D/O which becomes erroneous when the voltage drops below 9V. The instrument will provide an estimated deployment time based on the battery life and the remaining memory.

It is still advisable to empty the memory before use. It is also important to renew the D/O membrane as it seems to start to drift after approximately 1 month.

As there was no significant flow effect found with the low flow membrane (the normal\high flow membrane was not tested) the instrument can be safely deployed in still waters.

The calibration method is reasonably good, but care should be taken (as always) to avoid allowing air bubbles to be trapped in the conductivity probe. The temperature difference between calibration and the field may be important for the D/O probe in winter. If the river is at 3°C and the calibration carried out at 23°C then an offset of 4.5% could occur.

The good communications software make it possible to deploy the DS3 attached to a processor and/or sampler, however the response time of the low flow D/O membrane (approximately 8 min) is not fast enough for single measurements, either in a hand-held mode (!!), or in an intermittent pumped system.

2.2 Instrument performance

Flow Rate

No significant variations were observed in the instrument readings when the water speed was varied from 0 to 0.37 m/s. (The D/O sensor was fitted with a low flow membrane.)

Battery Voltage

The battery voltage level had no significant effect on the measurement of temperature, pH, conductivity, depth, or redox. The D/O reading increased from 100% to 120% as the battery voltage dropped below 9V. The instrument switched itself off when the voltage dropped below 8.35V. The D/O warm-up batteries were not fitted during the test.

Water Temperature

The temperature, pH, and depth sensors were not significantly affected by temperature changes.

The DO readings changed from +1.7% at 3.7°C to -8.5% at 45.1°C when compared to the reference values (the water was aerated giving a reference of 100% throughout). The effect was approximately linear with a slope of -0.23% per °C (correlation coefficient of 0.97). This would generate a maximum error of 4.6% if the instrument was calibrated in a laboratory at 23°C then used in a river at 3°C.

The specific conductivity readings changed from -24µS/cm at 3.7°C to -52µS/cm at 40.2°C when compared to the reference values (laboratory analysis). The effect was approximately linear with a slope of -0.65µS/cm per °C (correlation coefficient of 0.97). This is a minor effect and is probably due to the difference between the assumed temperature coefficient of 1.91 %/°C and the temperature coefficient of the river water used for the test of approximately 2.2 %/°C.

Response time

The response time was measured before and after the first drift test at Lea Marston, and after the drift test at Crossness.

The response time of the D/O sensor fitted with a low flow membrane for a rising step change (from 2 to 100%) increased from 7 min 12 sec to 8 min 14 sec at Lea Marston. The membrane was then replaced for the test at Crossness and the rising response time again increased from 4 min 15 sec to 6 min 24 sec. The falling response (from 100 to 2%) also increased at Lea Marston from 9 min 48 sec to 10 min 36 sec, but decreased at Crossness from 8 min 45 sec to 7 min 24 sec.

The response time of the conductivity cell was <7 sec initially, 13 sec after Lea Marston, and <5 sec after Crossness.

The response time of the pH electrode was more variable. With a rising step of pH 3.8 to 9.9 it changed from 63 sec initially, to 78 sec after Lea Marston, then to 10 sec after Crossness. With the falling step it changed from 40 sec initially, to 57 sec after Lea Marston, then to 8 sec after Crossness.

Fresh water fouling and drift

Comparisons with the results of analysis of water samples show a good correlation with the instrument except for the D/O and are also consistent with the permanent monitoring station and other instruments deployed at Lea Marston at the same time.

The dissolved oxygen values recorded by the instrument quickly dropped to 0 to 20%. This is probably due to a layer of anaerobic silt which built up in the tank and may have covered the sensor. The D/O probe was tested for 1 week on return to Fobney and functioned correctly.

The tank had a constant depth and the values given by the depth sensor varied from 0.3 to 0.7 m, with an average and sample standard deviation of 0.55 ± 0.09 m.

Estuarine fouling and drift

The instrument was deployed on a floating water quality monitor moored in the tidal Thames at Crossness. It did not complete the full three week test because the memory was occupied by a number of other large files which should have been deleted before deployment. We are confident that the instrument would have performed well under normal circumstances.

Where available the laboratory data 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 are consistent with other instruments deployed on the monitor at the same time.

The depth readings of the instrument varied from 0.0 to 0.5 m, with an average and sample standard deviation of 0.40 ± 0.11 m. This variation is probably due to changes in atmospheric pressure since the logger was mounted at a fixed depth on a floating platform.

Accuracy

The accuracy of the dissolved oxygen, conductivity, and depth probes were tested directly. The accuracy of the temperature probe was inferred from the temperature test. The accuracy of the pH can be inferred from the drift test results. The Redox sensor was not assessed.

Dissolved Oxygen : The maximum variation between the instrument reading and the reference solution was 1.3% at 194.3% saturation. This is not significant since it is smaller than the uncertainty of the reference solutions.

Conductivity : The conductivity difference varied from $+30\mu\text{S}/\text{cm}$ at $210\mu\text{S}/\text{cm}$ (14.2% reading) to $+612\mu\text{S}/\text{cm}$ at $58640\mu\text{S}/\text{cm}$ (1.04% reading).

Depth : The depth error varied from $+0.1\text{m}$ at 2.0m (5% reading) to $+0.5\text{m}$ at 100.0m ($+0.5\%$ reading)

Temperature : The temperature difference was no greater than $\pm 0.1^\circ\text{C}$, which is within the uncertainty of the reference system.

Effect of conductivity on pH

The pH reading in 0.0001 molar HCl (pH 4.0) varied from 4.12 at $39\mu\text{S}/\text{cm}$ (pure solution) to 3.83 at $254\mu\text{S}/\text{cm}$ and $404\mu\text{S}/\text{cm}$. At low conductivities the pH reading became more unstable when the solution was stirred, with variations of up to ± 0.3 units.

2.3 Comments on use, construction, and documentation

The instrument is approximately 690 mm long, 90 mm diameter and weighs 4.2 kg with a waterproof connector for the communication cable. It is strongly made and seems robust. The sensors are normally protected by an open cage formed by the four supports of the sinker weight.

The polarisation of the D/O sensor is maintained by two dedicated batteries which are mounted directly onto the PCB.

To calibrate the sensors the logger needs to be supported vertically with the sensors uppermost. Calibration solutions are then poured into a calibration cup which is fitted around the sensors. It is necessary to enter the atmospheric pressure when calibrating the Dissolved Oxygen. Initially this is an awkward operation, but quickly becomes straight forward.

The batteries are housed in a separate compartment at the top of the instrument and some manual dexterity is required when changing them. It is necessary to fit long life alkaline batteries when deploying the instrument for more than three weeks although a rechargeable external battery pack is available which will give a much longer deployment.

On-line operation of the instrument is possible using the RS232 link and any standard communications package. The instrument commands are presented in a set of menus which are easily learnt. It is also possible to download data using standard comms software, but Hydrolab provide software which makes the process much easier.

The manual is clear and readable, and contains much additional information about measurement techniques. The only main criticism is the absence of a page (or section) detailing the full instrument and sensor specifications.

2.4 Manufacturer's comments

Omnidata systems Ltd (for Hydrolab) provided the following comments on this report :-

Hydrolab has taken the opinion that to force a system such as a conductivity or pH probe to work effectively throughout the entire range of environmental conditions will cause increased error.

Hydrolab uses two separate cell blocks for it's conductivity probe. The first is the freshwater block which is accurate from 0 to 10 ms/cm. The second, and the block tested in this report, is the saltwater block which is used for water with specific conductance up to 100 ms/cm. The two blocks are easy to exchange and come with the Hydrolab units. There is a large amount of overlap so if you think you will be in an area with conductivity readings above 5 ms/cm use the saltwater block. If you are working in water with conductance of 200 μ s/cm use the freshwater block to increase the accuracy of the readings.

The problems associated with measuring pH in low ionic strength water have also been dealt with by Hydrolab. The LISREF [Low Ionic Strength Reference] probe should be used in water with a conductance of less than 200 μ s/cm. With the LISREF Hydrolab has been able to keep the same specifications of ± 0.2 units over the entire range of 0-100 ms/cm. In this report the Datasonde 3 was fitted with a standard pH reference.

Hydrolab also gives the end user the choice of Dissolved Oxygen measurement membranes. The membrane which was tested in this report was the Lowflow membrane. The Lowflow membrane was designed for long term deployment. It does not have a fast response time but in most long term deployments a fast response time is not needed. Where a fast response time is needed we use the standard membrane and a stirrer to get flow insensitive, fast response, accurate readings.

I would like to thank the NRA for the time and effort they have put into testing the Hydrolab Datasonde 3.

3. **DETAILS OF INSTRUMENT EVALUATED**

The instrument tested was a standard production model loaned to the NRA by Omnidata Systems Ltd.

Instrument	Data-Sonde 3
Sensors fitted	D/O; pH; Temperature; Conductivity; Redox; Depth
Serial Number	19413
Length (approximate)	686 mm
Diameter (approximate)	87 mm
Mass (approximate)	4.2 kg
Manufacturer	Hydrolab Corporation Austin Texas USA
UK Agent	Omnidata Systems Ltd Herts Business Centre Alexander Road London Colney Herts. AL2 1JG Tel : 0727 827837 Fax : 0727 827838

4. TEST RESULTS

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 effect on temperature, pH, conductivity, or depth. There is a drift apparent in the D/O readings but this does not correlate with the flow speed. Salinity is not shown since it is derived from the conductivity values. Redox is not shown because there was no reliable reference data, however the raw results did not seem affected.

Table 1 : Effect of water flow rate

Water Flow speed m/s	Reading Difference (Hydrolab - reference)				
	Temp °C	pH	D/O %sat	Conductivity @ 20°C µS/cm	Depth m
off	0.0	-0.1	+5.0	-	-0.1
0.04	0.0	-0.1	+4.9	-	-0.1
0.11	0.0	-0.1	+4.8	-15	-0.1
0.16	0.0	-0.1	+4.5	-16	-0.1
0.21	0.0	-0.1	+4.1	-17	-0.1
0.33	0.0	-0.1	+4.0	-15	-0.1
0.37	0.0	-0.2	+3.5	-13	-0.1
0.31	0.0	-0.2	+4.4	-14	-0.1
0.22	0.0	-0.2	+3.8	-16	-0.1
0.16	0.0	-0.2	+3.5	-16	-0.1
0.09	0.0	-0.2	+3.1	-15	-0.1
0.04	0.0	-0.1	+2.9	-20	-0.1
off	0.0	-0.1	+2.1	-24	-0.1
0.35	+0.1	-0.1	+2.1	-26	-0.1
off	0.0	-0.1	+2.7	-28	-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 0.4°C temperature change indicated is probably a real change. The results show no significant effect on temperature, pH, conductivity, depth, or redox. The D/O readings increase when the supply voltage drops below 9.0V. The instrument shut down when the voltage dropped below 8.35V.

Table 2 : Effect of battery voltage

Supply Volts. V	Hydrolab reading					
	Temp °C	pH	Sp. Cond µS/cm	D/O %sat.	Redox mV	Depth m
16.0	19.04	8.34	503	103.3	288	0.0
15.5	19.08	8.34	503	103.2	289	0.0
15.0	19.11	8.34	503	102.9	289	0.0
14.5	19.13	8.34	503	102.9	289	0.0
14.0	19.16	8.34	502	102.8	289	0.0
13.5	19.17	8.34	502	102.7	290	0.0
13.0	19.20	8.34	502	101.6	290	0.0
12.5	19.21	8.34	502	102.5	290	0.0
12.0	19.24	8.35	503	102.7	290	0.0
11.5	19.25	8.35	502	102.6	290	0.0
11.0	19.27	8.35	502	102.8	290	0.0
10.5	19.29	8.35	502	102.5	290	0.0
10.0	19.3	8.35	502	102.7	290	0.0
9.5	19.32	8.35	502	102.6	290	0.0
9.0	19.34	8.35	502	102.1	290	0.0
8.5	19.38	8.35	502	104.2	290	0.0
8.4	19.42	8.35	502	119.7	291	0.0
16.0	20.11	8.36	503	103.8	279	0.0

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 there is no significant effect on temperature, pH, or depth.

The D/O difference showed a real change from +1.7% at 3.7°C to -8.5% at 45.1°C. The specific conductivity difference also changed with temperature from -24µS/cm at 3.7°C to -50µS/cm at 45.1°C. Salinity is not shown since it is derived from the conductivity values. Redox is not shown because there was no reliable reference data, however the raw results did not seem affected.

Table 3 : Effect of temperature

Water Temp. °C	Reading Difference (Hydrolab - Reference)				
	Temp °C	pH	D/O %sat	Conductivity µS/cm	Depth m
3.7	0.0	-0.2	+1.7	-24	0.0
9.5	-0.1	-0.2	-0.4	-28	0.0
19.0	0.0	-0.2	-3.0	-37	0.0
30.8	0.0	-0.1	-3.5	-39	0.0
40.2	-0.1	-0.0	-7.0	-52	+0.1
45.1	0.0	-0.2	-8.5	-50	+0.1

Response time

The instrument was transferred quickly from between solutions with different measurand concentrations. The response time values represent the time taken for the instrument to complete 90% of the step change. The dissolved oxygen response was measured only with a low flow membrane, a normal membrane should react more quickly.

The test was carried out before and after the initial drift tests.

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

Sensor (step change)	Response time	
	rising	falling
Conductivity (33 to 10900 µS/cm)	<7 sec	<7 sec
pH (3.8 to 9.9)	63 sec	40 sec
DO (2 to 100%)	7 min 12 sec	9 min 48 sec

(Response time continued)

Table 5 : Response times (10/3/94 : After first visit to Lea Marston)

Sensor (step change)	Response time	
	rising	falling
Conductivity (40 to 10500 μ S/cm)	12 sec	13 sec
pH (3.8 to 9.9)	78 sec	57 sec
DO (old Lf membrane) (2 to 100%)	8 min 14 sec	10 min 36 sec
DO (new Lf membrane) (2 to 100%)	4 min 15 sec	8 min 45 sec

Table 6 : Response times (15/4/94 : After visit to Crossness)

Sensor (step change)	Response time	
	rising	falling
Conductivity (40 to 10500 μ S/cm)	<5 sec	<5 sec
pH (3.8 to 9.9)	10 sec	8 sec
DO (old Lf membrane) (2 to 100%)	6 min 24 sec	7 min 24.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 (ie 41 ± 2 %sat, see section 5 for a full list). At each concentration the difference between the instrument reading and the reference concentration is less than the reference uncertainty.

Table 7 : Dissolved Oxygen Accuracy

Reference value % saturation	Instrument reading %sat.	
	increasing	decreasing
0		1.1
41.5	40.9	42.0
70.7	70.4	71.9
100	99.0	100.9
194.3	193.0	

Accuracy : Conductivity

The sonde was placed in 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	17	17
210	238	240
415	450	453
12900	13341	13368
58640	59252	

Accuracy : Depth

The instrument was lowered to known depths down a borehole attached to a hydrology probe.

Table 9 : Depth Accuracy

Depth (m)	Reading (m)
2.0	2.1
10.0	10.2
20.0	20.3
30.0	30.3
50.0	50.4
75.0	75.5
100.0	100.5

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 10.

In low conductivity solutions the reading became unstable when the solution was stirred, variations of up to ± 0.3 pH units were observed.

Table 10 : pH value in 0.0001M HCl

Conductivity μS/cm	pH Reading pH
39	4.12
62	3.91
98	3.88
158	3.86
254	3.85
404	3.85

Fresh water Fouling and drift

The following six graphs show the data recorded by the instrument when it was deployed at Lea Marston for the second time from 10/6 to 1/7/94. The logger was calibrated and placed in a tank supplied with water pumped from the river Tame. Data from the first drift test is not given because the instrument batteries failed (due to incorrect deployment).

Laboratory data from analysis of water samples has been plotted where available and it shows good correlation with the instrument except for the D/O. Where lab data is not available the instrument results are consistent with the known water quality and are consistent with the permanent monitoring station and other instruments deployed at the same time.

The errors caused in the instrument D/O readings are probably due to a layer of anaerobic silt which built up in the tank and may have covered the sensor. Data from the D/O probe is also presented when it was tested for 1 week on return to Fobney, the sensor functioned correctly.

The D/O sensor was calibrated at the start of each test. After the Lea Marston drift test the value given in aerated tap water was 97% and after the 1 week test at Fobney it was 91%.

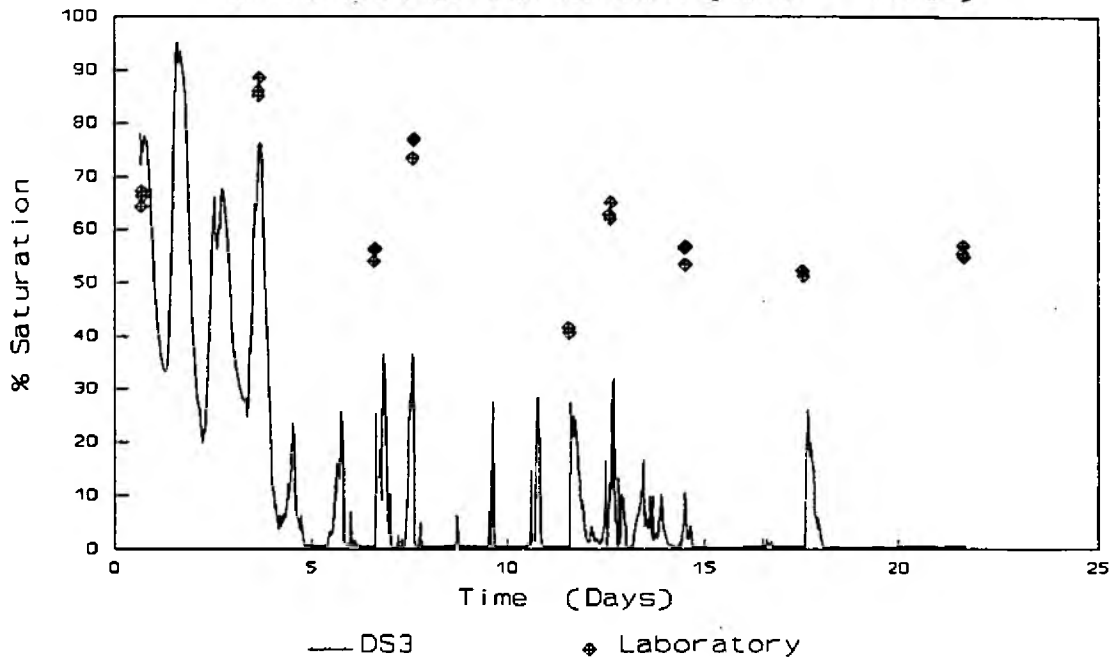
Comparison of the temperature measurements against a thermocouple placed in the tank at the same time show differences varying from -0.3 to 0.3°C. The average and standard deviation was $-0.004 \pm 0.086^\circ\text{C}$.

The depth results are not shown graphically as the tank was maintained at a constant depth throughout. The values given by the depth sensor varied from 0.3 to 0.7 m, with an average and sample standard deviation of 0.55 ± 0.09 m.

During the first drift test at Lea Marston the response of the conductivity and pH sensors increased and the change in D/O response is not significant. See tables 4 and 5 above.

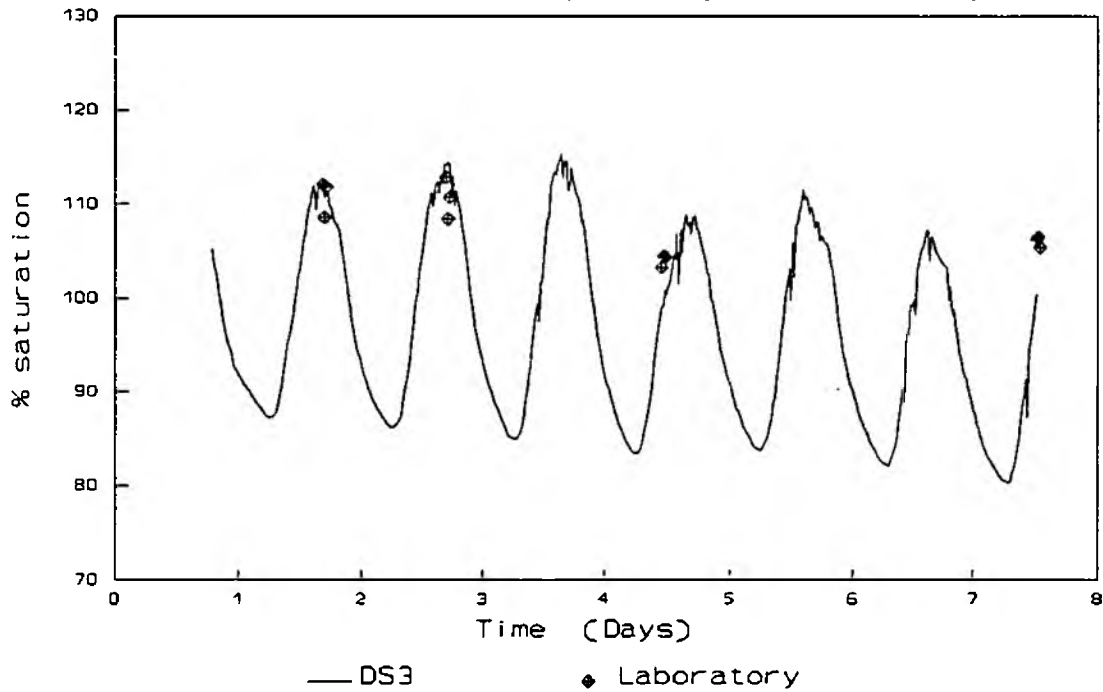
O/O %sat

Drift test at Lea Marston (10/6 - 1/7/94)



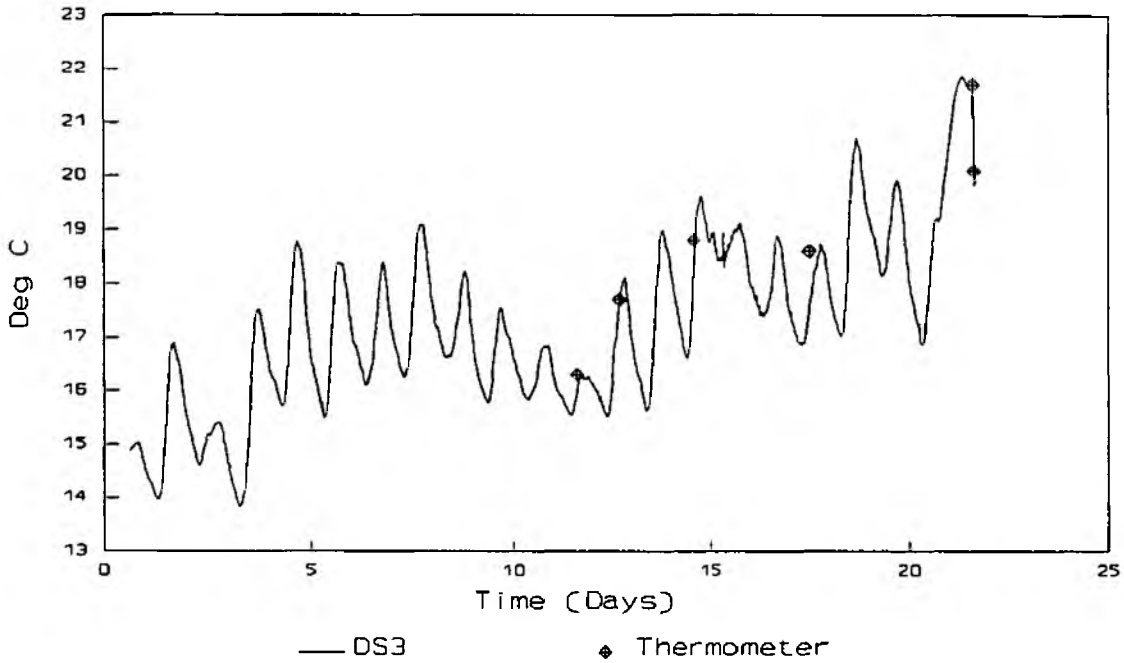
Dissolved Oxygen % sat

Drift test at Fobney Mead (18/7 - 25/7/94)



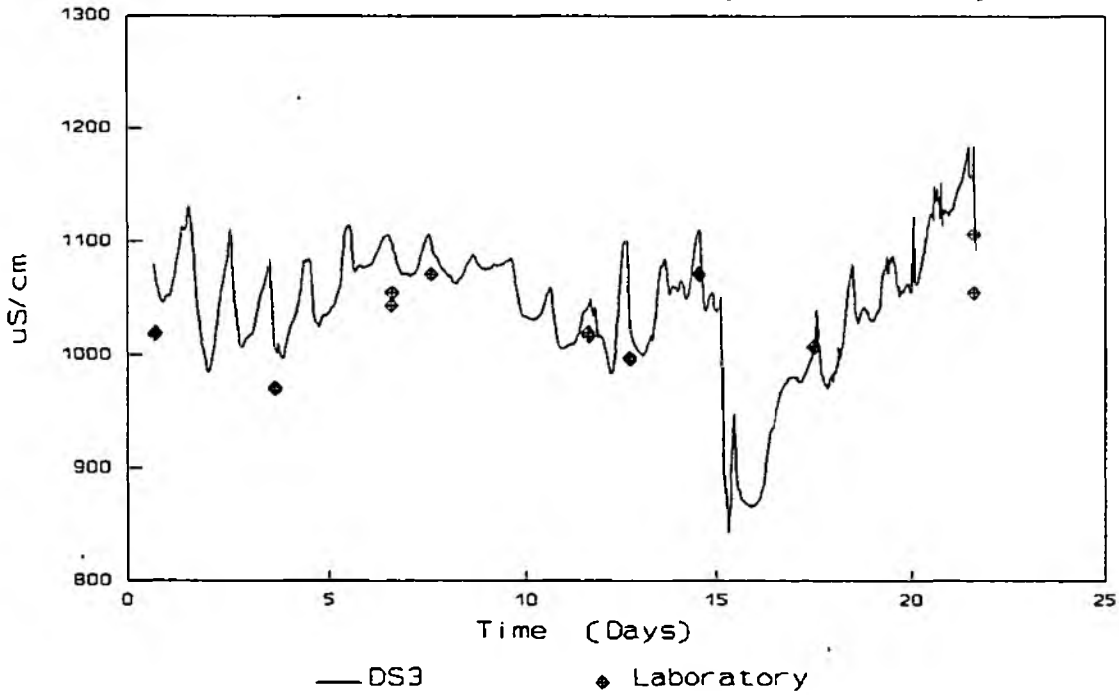
Temperature

Drift test at Lea Marston (10/6 - 1/7/94)



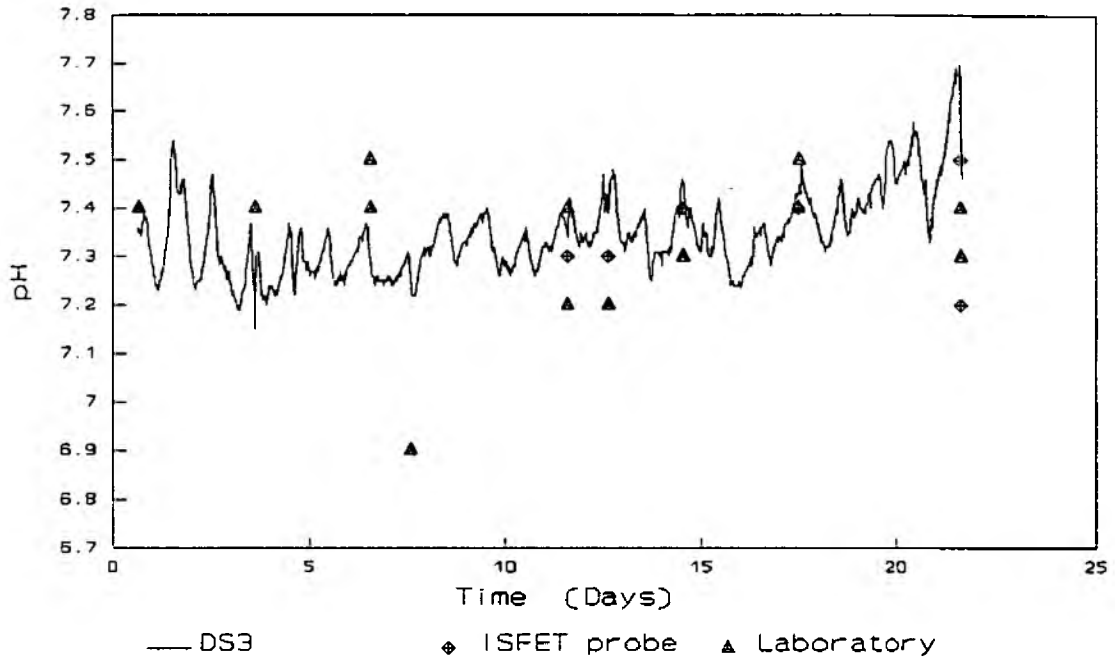
Conductivity @25 Deg C

Drift test at Lea Marston (10/6 - 1/7/94)



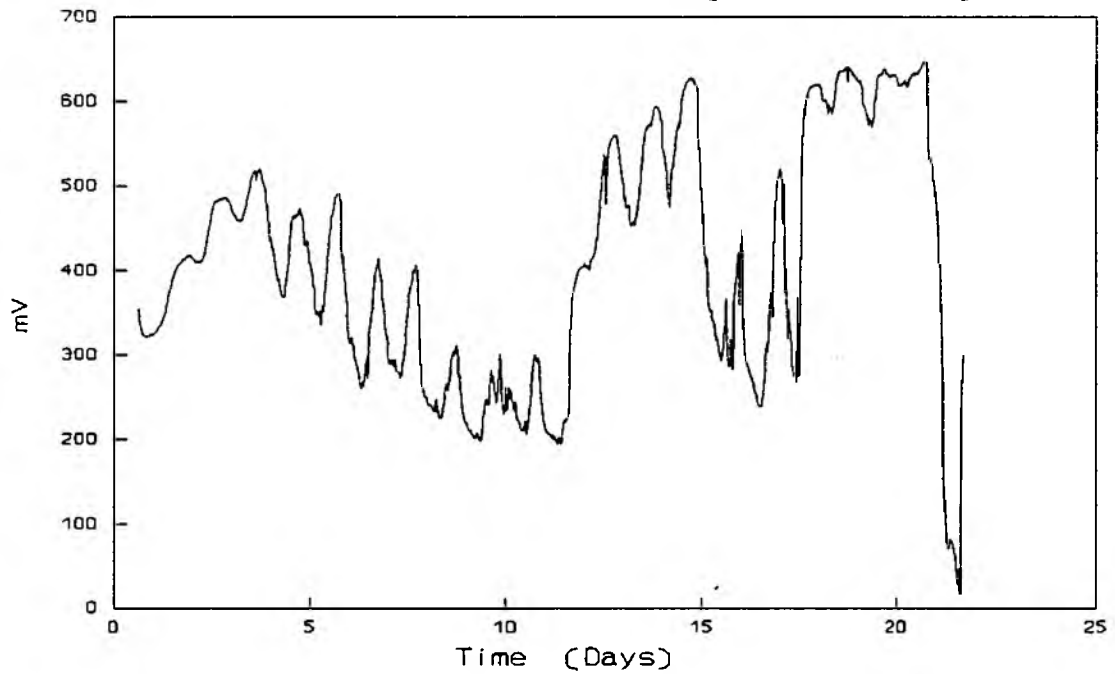
pH

Drift test at Lea Marston (10/6 - 1/7/94)



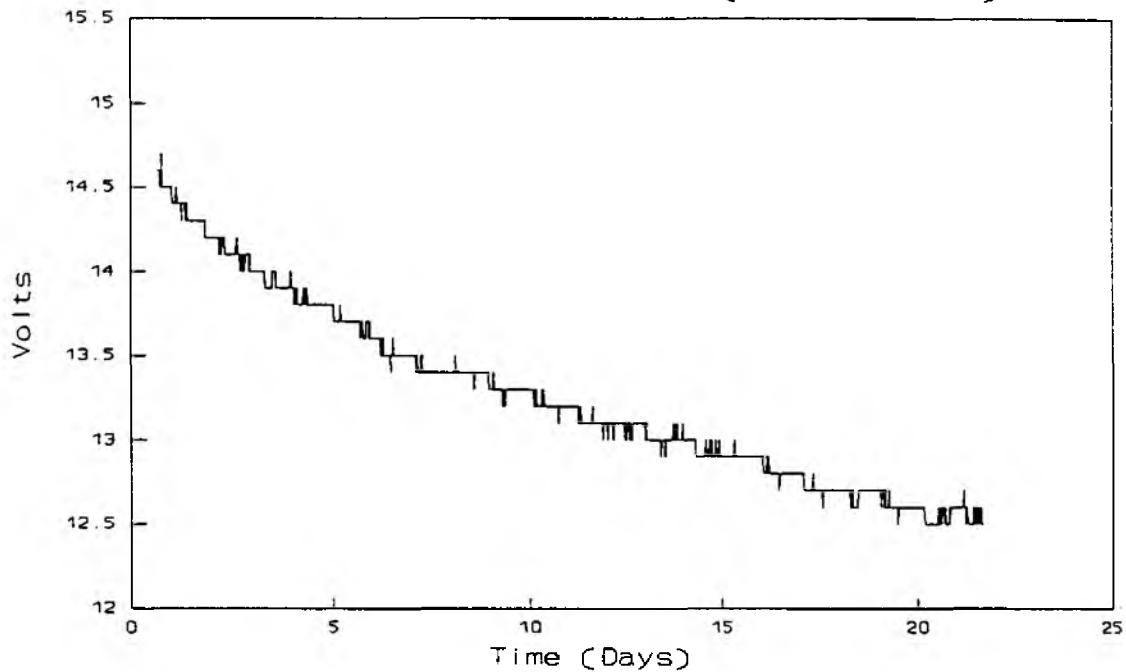
Redox

Drift test at Lea Marston (10/6 - 1/7/94)



Battery

Drift test at Lea Marston (10/6 - 1/7/94)



Estuarine Fouling and Drift

The following six 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 from 22/3 to 3/4/94. Unfortunately the instrument did not complete the full three week test because it's memory was occupied by a number of other large files which should have been deleted before deployment. We are confident that the instrument would have performed well under normal circumstances.

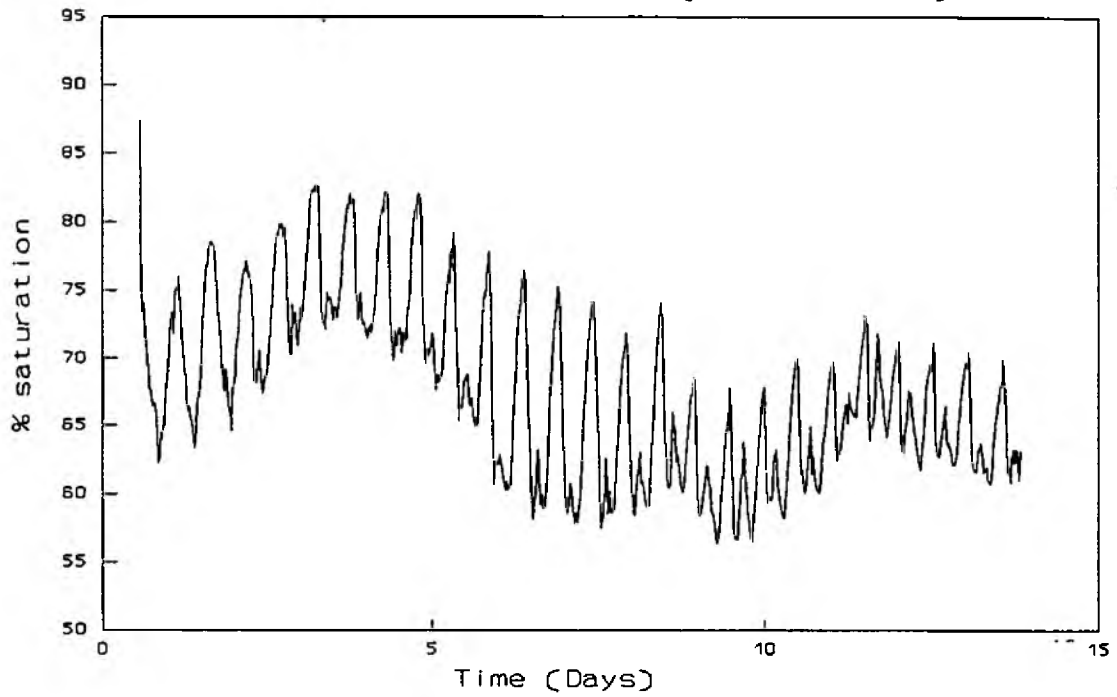
Laboratory data has also been plotted where it is available and it shows good correlation with the instrument. Where lab data is not available the instrument results are consistent with the known water quality of that part of the Thames, and are consistent with other instruments deployed on the monitor 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 0.5 m, with an average and sample standard deviation of 0.40 ± 0.11 m.

The response time of the conductivity and pH sensors decreased during the test. The change in D/O response is not significant. See tables 5 and 6 above.

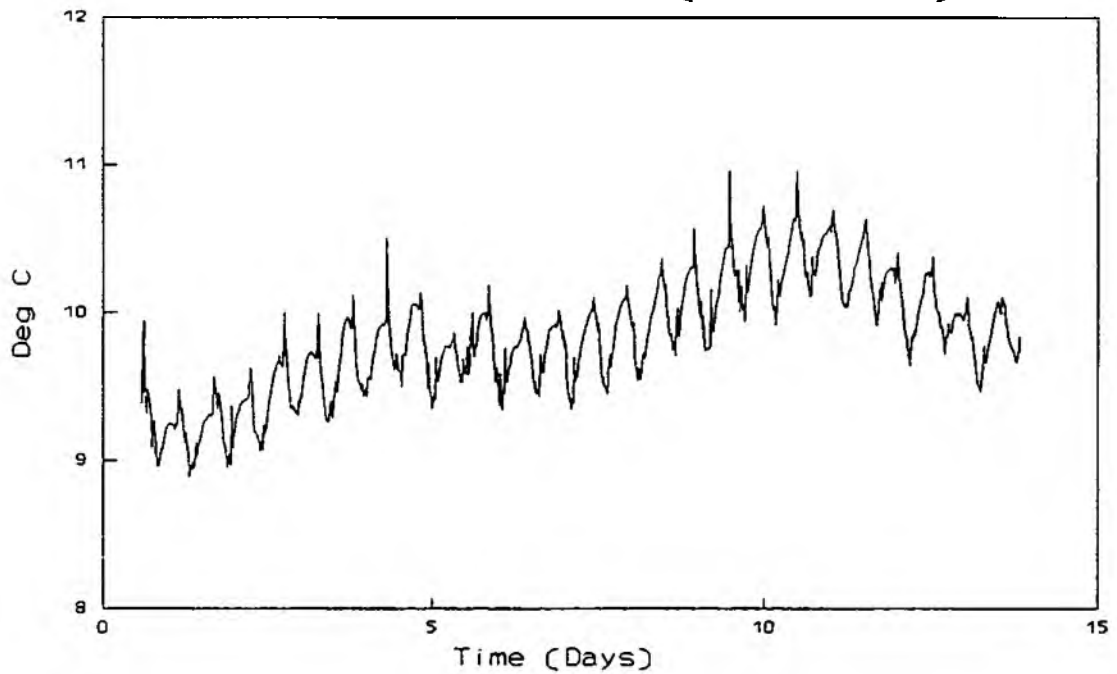
Dissolved Oxygen %sat

Drift test at Crossness (22/3 - 3/4/94)



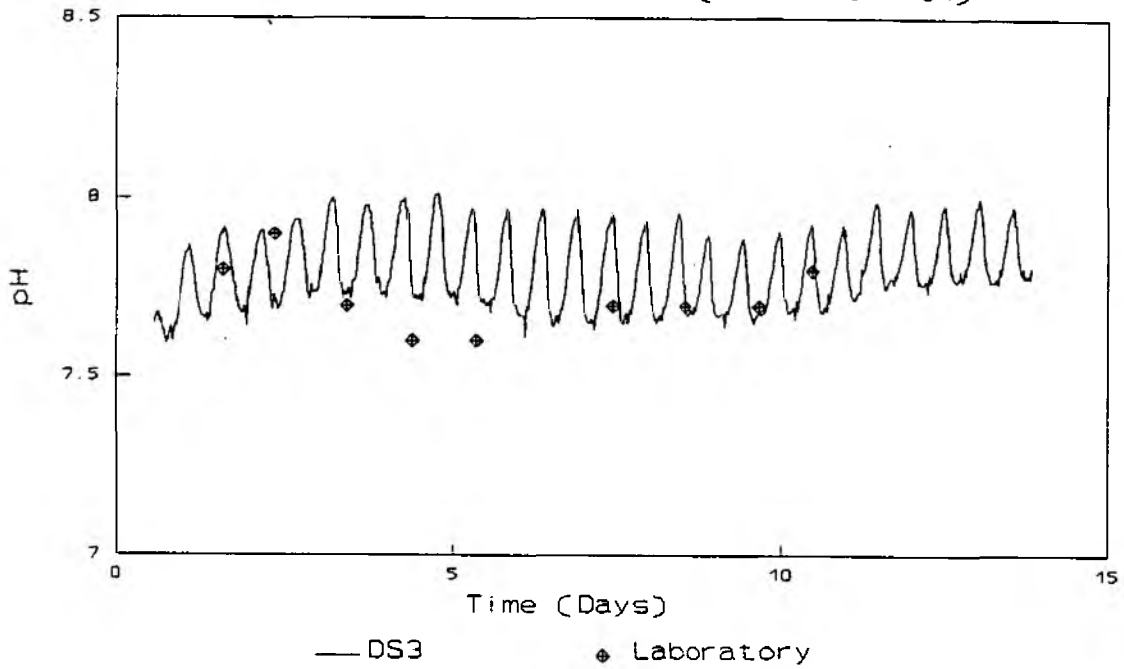
Temperature

Drift test at Crossness (22/3 - 3/4/94)



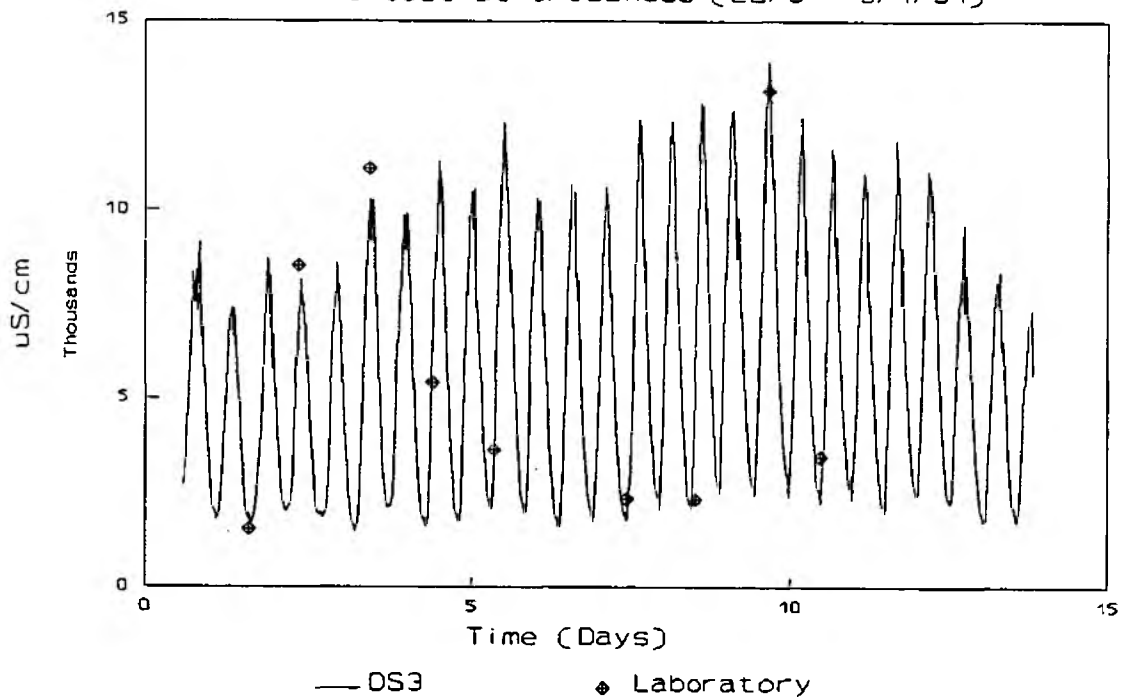
pH

Drift test at Crossness (22/3 - 3/4/94)



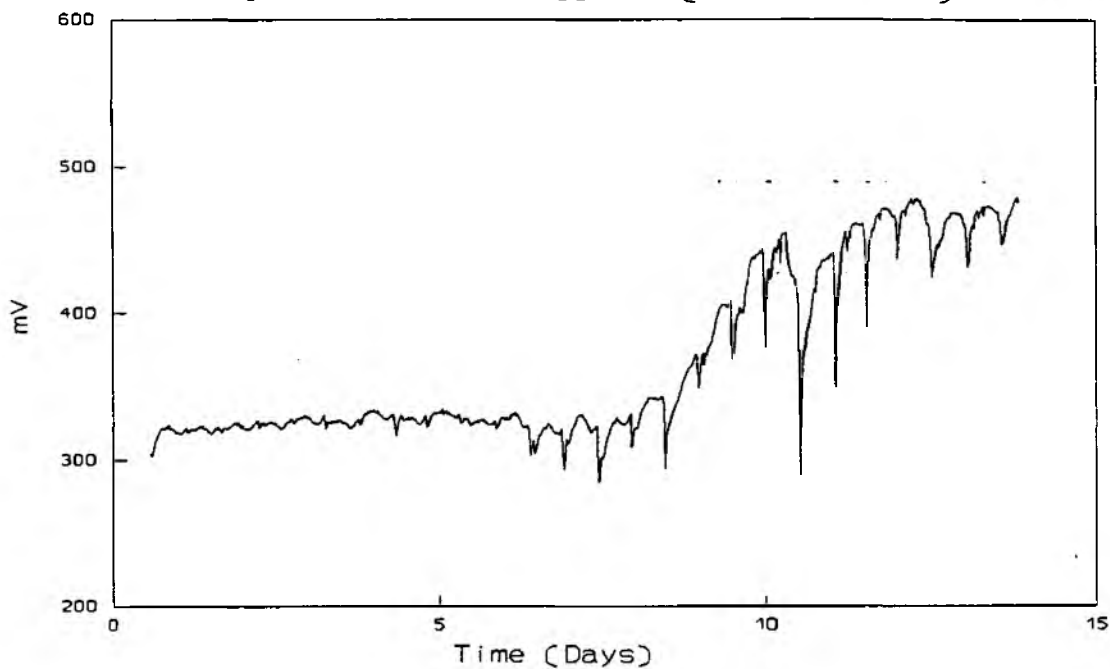
Conductivity @25 Deg C

Drift test at Crossness (22/3 - 3/4/94)



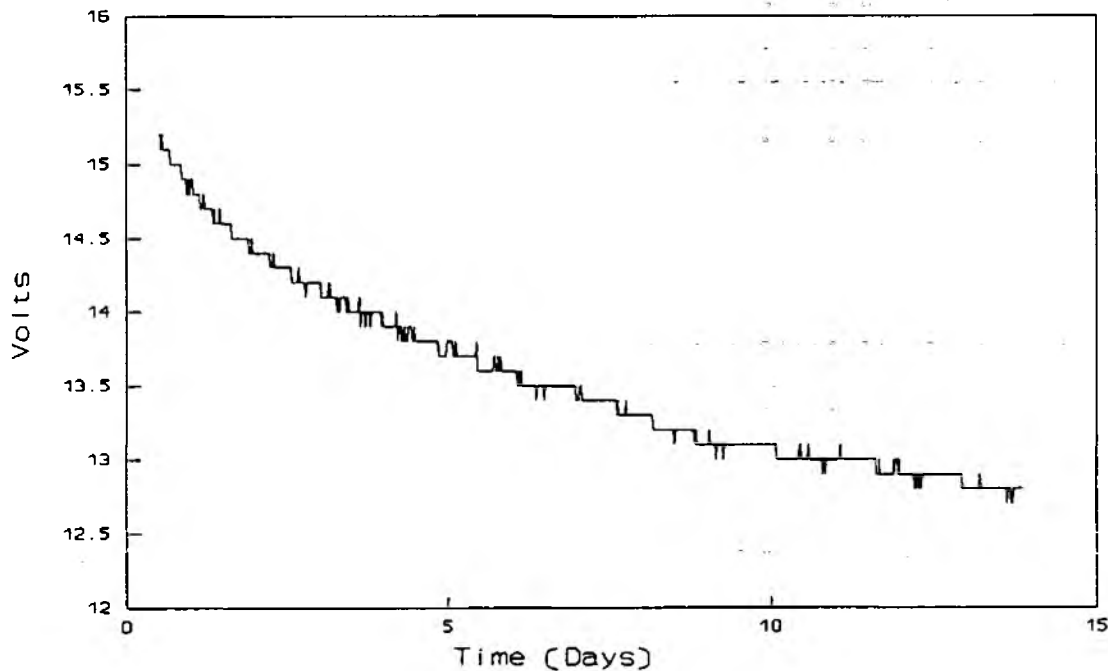
Redox

Drift test at Crossness (22/3 - 3/4/94)



Battery Voltage

Drift test at Crossness (22/3 - 3/4/94)



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 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 water temperature was increased stepwise from 3.7 to 45.1°C and allowed to stabilise for 30 minutes at each temperature before the instrument readings were noted. The level of dissolved oxygen was fixed by continuous aeration, the depth was constant, and pH and conductivity were measured in samples taken at each temperature.

Effect of low battery.

A stabilised DC power supply was connected in place of the external battery pack, with the internal batteries removed. The voltage was reduced from 15.5V 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.

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 ± 2 , 41.5 ± 2 , 70.7 ± 4 , 100, 152.3 ± 8 , 194.3 ± 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 μ S/cm), 200 ppm NaCl (415 μ S/cm), 0.1 M KCl (12900 μ S/cm), and 0.5 M KCl (58640 μ 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 probe 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 μ S/cm). It was then placed in other solutions of 0.0001M HCl with different amounts of sodium chloride 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.

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 and a graph of reading against time was plotted 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.

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_3 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.

The results showed a large drop in D/O which was attributed to the development of a layer of anaerobic silt which covered the sensors, therefore a further 1 week test was carried out in the river Kennet at Fobney Mead.

Estuarine Fouling and Drift

The instrument was calibrated according to manufacturer's instructions. It was then subjected to estuarine conditions for three weeks at the Thames monitoring station moored at Crossness. 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

Hydrolab : Datasonde 3 Operating 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 Omnidata for loan of the instrument.

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 ± 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 river 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 monitor panel 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°C , this adjusted to 25°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:

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