EA-Water Resources Box 10

ENVIRONMENT
AGENCY

Pressure Sensor Evaluation

EA North West Region
1997-2000 Contract

Contents

Introduction

Following the formation of the National Rivers Authority and subsequently the Environment Agency, it has always been recognised that there is a variety of differing standards for instrument procurement, installation and operation. In the majority of cases a certain amount of harmonisation would be possible between the different types of system in use, and others not being compliant, encouraged to meet the common standard.

This has been the case for pressure sensors, and in 1996, a project was agreed to take into account the requirements of all users nationally, and agree a National Specification with a view to appoint a National Supplier.

The objectives of this particular project are:-

- To identify pressure sensor manufacturers compliant with the Nationally agreed specification.
- Allow us to take full advantage of cost savings by avoiding the current, fragmented procurement approach.
- Have confidence in measurements.
- Encourage a move towards National standardisation.
- Meet the National Environment Agency needs for water level measurement.

The objectives of this particular report are:-

- Present all the results gathered from performance testing
- Show compliance with the Nationally agreed specification

In order that a reasonable appreciation of product performance is achieved, it is necessary to test each sensor under typical operating conditions, to ascertain performance and therefore compliance with the National Specification (Appendix A).

Therefore each sensor evaluated is treated to the same conditions, in a purpose built testing facility located in Warrington (EA North West).

Companies tendered

As the National purchasing requirement will exceed £149k over the 2 - 3 year contract, EEC procurement rules have been followed. From the initial OJEC advertisement, a response of approximately 12 companies was received. From these 12 companies, only six companies replied expressing interest following the submission to each of them an indication of the main points within our National specification.

The six companies were then invited to tender, of which one company withdrew their submission during the formal tender period.

The companies tendered were:- Transinstruments (Gems), Dynamic Logic (Shape), Status Instruments (represented by Checkmate Products), Penny & Giles, Druck and Trolex - the company that declined to submit a tender.

Because of all the varying pricing strategies on offer, it is difficult to make an assessment accounting for all potential requirements. Therefore, the best approach is to select a typical sensor for use at the majority of higher accuracy installations. Therefore the performance evaluation is based upon the following:-

A two wire (4-20mA) pressure transmitter, 0.2% accuracy, ranged for 4mWG, and 10m of cable attached.

The 4mWG refers to a sensor that is vented to atmospheric pressure (no account of atmospheric pressure needs to be made) and in this particular case, 4 metres range, Water Gauge. Also, in some instances, a manufacturer will supply a certain amount of connecting cable free-of-charge, and at the time of ordering, the purchaser needs to specify how much cable is required to be attached.

Test Overview

There are three main areas for testing each sensor supplied for evaluation purposes:-

- Depth/level measurement accuracy.
- Temperature stability.
- Electrical characteristics and mechanical construction.

From each company invited to tender, three sensors were requested to be made available for testing. Therefore, each test consisting of one sensor from each company tested as a group, will require three group tests to be carried out.

Measurement system description

The measuring system (Appendix D) has been selected to reflect the majority of applications employed by the Agency, and to identify the "worst case" scenario of any typical application. The measurement system comprises of a DT50 datalogger manufactured by Data Electronics, programmed and configured for the following:-

- Potentially 8 analogue input channels, each individually calibrated; and one channel to accept a PT100 temperature sensor. Each channel is configured to directly convert the 4-20mA input signal to millimetres of water. IE:- 4-20mA = 0 - 4000mm.
- Have high resolution so that the millimetre can be observed. The resolution of this particular logger is in the region of 1 part 65,000, therefore less than 1mm can actually be displayed, though is ignored for our evaluation purpose.
- Variable logging rates, selectable depending upon the required application. Typically 30 second logging for level tests, 5 minute logging for temperature tests and 1 minute logging for rapid temperature tests.
- Power up the sensors only at the time a reading is required, allowing one second to stabilise before taking a reading.
- Output the readings as a serial data signal to a PC to enable readings to be monitored and data retrieved.

Level Testing

The level tests comprise of; commencing at a minimum level (approximately 200mm) and increasing in 200mm steps to the maximum level (4000mm). Readings are recorded on the data logger, and by hand to include the reference water level measurement. The test is then repeated for dropping the water level by 200mm steps, from the maximum level, to the minimum level.

Please note that these results are based upon the fact that physically, all sensors are installed to the same height (the rig base) and that an arbitrary reference point of 4.4 metres above this base point has been selected. Zero offset readings will vary depending upon actual zero (4mA) error and the actual height of the sensor measuring face (see diagram 1). These offset errors are applied to the results for each sensor tested, therefore the readings are the actual measured water level.

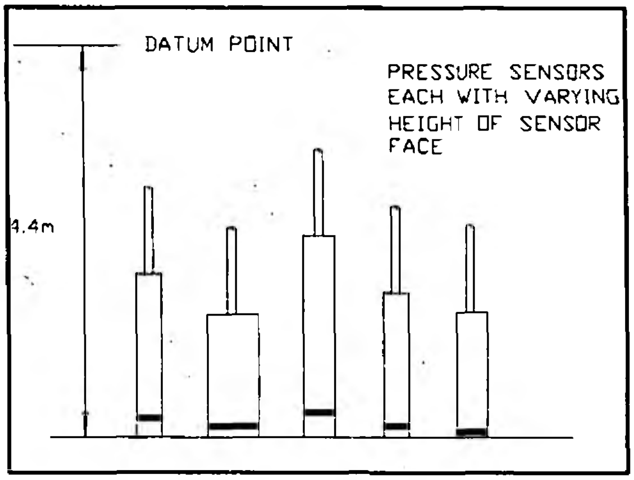


Figure 1

For completeness, the actual "in air" readings - the level measured by each sensor with zero water depth (it should be 4mA or 0mm) are shown below:-

Company	Test 1 zero error	Test 2 zero error	Test 3 zero error
Transinstrument	+35mm (4.140mA)	+30mm (4.120mA)	+18mm (4.072mA)
Dynamic Logic	+37mm (4.148mA)	+43mm (4.172mA)	+24mm (4.096mA)
Status Instruments	-2mm (3.992mA)	0mm (4.000mA)	+8mm (4.032mA)
Penny & Giles	-15mm (3.940mA)	-18mm (3.928mA)	-9mm (3.964mA)
Druck	-18mm (3.928mA)	+9mm (4.036mA)	+10mm (4.040mA)

The results are presented taking into account this offset.

The main points to look for in these results for a good sensor are:-

- Line as straight as possible (range is linear, and stable).
- Line as horizontal as possible (range is correct).

Temperature tests

Bearing in mind the previously mentioned datum errors encountered in conducting the first test (Test 1- Temperature test), it can be seen that even though problems were experienced for the first test, there is an obvious trend being followed by three of the sensors (Transinstruments, Status, and Druck), but the remaining two (Dynamic Logic and Penny & Giles) are not following this. It can therefore be assumed that three sensors are correct as they each respond in the same fashion, where as the remaining two - Dynamic Logic and Penny & Giles, show a different response.

The main points to look for in these results for a good sensor is:-

- Line is horizontal and as straight as possible (readings are unaffected by temperature).

Rapid temperature tests

This involves installing the sensors in a water bath and altering the temperature in steps. Each shift in temperature is expected to take 15 minutes, compared with an hour for the water rig tests. Also, the water depth is minimal as compared with the test rig readings, which are acquired under maximum instrument range conditions.

The data logger is used to record measurements once each minute. Also, the readings are noted by hand at each 15 minute interval. If there is a design flaw with the sensor breather pipe (pipe bore too small), errors will manifest as the level reading dropping for a short period, recovering as the sensor body (and the expanding air inside) obtaining equilibrium.

The results presented are that of the readings recorded by the data logger. The main points to look for in these results are:-

- Plotted lines are horizontal and straight (readings unaffected by temperature).
- No dip in readings at time of temperature change (thermal shock effects).
- Any other effects - such as noisy or unstable readings.

None of the sensors indicated any additional errors during these tests that were not already observed during the temperature testing in the large test rig. The results from the rapid temperature test are presented in Appendix B.

From these results it can be seen that manufacturers have addressed the problems observed in the tests conducted in 1993. That is the output of some sensors dipped by an equivalent of several millimetres each time the temperature was increased. This problem was traced to the venting system for the sensor body. As the temperature increased, the gas (air) inside the sensor expanded, but vented off up the capillary very slowly. This had the effect of pushing against the back of the pressure sensing element, making it indicate as though water depth was reducing.

Electrical and further testing

These tests are undertaken to highlight the stability of readings output as a 4-20mA signal. Poor stability sensors have readings that fluctuate to a greater extent as to those with good stability. The process involves the recording of the 4-20mA output for a given pressure, with a recording oscilloscope. The results for a perfect sensor should show a straight line (no noise); poor sensors will show a noisy or varying output. The bigger the variance, the poorer the output stability will be.

To the user, a poor stability sensor will give a different water level for repetitively recorded readings at a location where the water level is known to be static. A good sensor will indicate stable readings; a true reflection of the unchanging water level (depth).

No major problems were indicated by any of the sensors; the results are indicated as figures only as the recording oscilloscope is unable to output the data gathered into any form of plot.

Compliance summary

The following table summarises which companies had a performance compliant sensor, in accordance with our specification for a 0.2% and 0.5% accuracy sensor:-

Company	Result	0.2%	0.5%	Comments
Transinstrument (Gems)	0.124%	Pass	Pass	Exhibits "warm up" effects
Dynamic Logic	0.484%	Fail	Pass	Poor calibration
Status Instruments	0.315%	Fail	Pass	
Penny & Giles	1.161%	Fail	Fail	Temperature errors observed
Druck	0.151%	Pass	Pass	

Recommendation

After examining the results, the tender response, and compliance with the specification, I recommend Druck to be appointed on the basis of the following:-

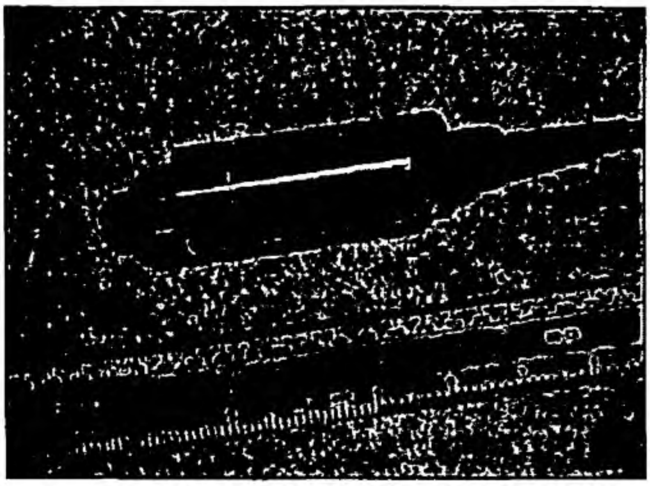
- Most compliant with the National specification.
- The best overall results from the evaluation.
- Manufacture a wide range of sensors, able to meet all our needs.
- Has a good previous history with the Agency; used in the majority of regions.
- The best "value for money" offered for a typical pressure sensor.

Chris Addis
EA North West Region.

These recommendations were accepted by the National Hydrometric Group, after which Druck were appointed to supply the Environment Agency for all pressure sensing needs.

Transinstruments (GEMS)

Model 4600B



Instruments were supplied without "depth-cones" the plastic protective covering on the pressure port, though this does not cause any problems. The instrument is well constructed, and of an adjustable type by removing the cable entry cover. Pressure connection for calibration purposes is via 0.25 BSP female fitting. The breather tube is of very small bore. During electrical tests, the sensor exhibited a "warm up" time of approximately 20 seconds before a reading was stable.

Serial Numbers:- L451653, L451672, L452182.

Description	Sensor 1 L451653	Sensor 2 L452182	Sensor 3 L451672	Average
Linearity error (+/- % of range)	0.05%	0.064%	0.05%	0.055%
Temperature error (+/- % of range)	*0.225%**	0.1%	0.038%	0.069%
Combined linearity and temperature error	*0.275%**	0.164%	0.088%	0.124%
Span error (accounting for offset errors)	-1mm	-4mm	-10mm	-5mm
Offset error ("zero" reading)	+35mm	+30mm	+18mm	+27.7mm
Electrical noise/stability	<2mV @ 19.97mA, 1 kOhm load, 30v supply			
Power supply range	9v@50 Ohm - 30v@1.1 kOhm			

* Errors introduced by test rig, these values not used in any final calculation of averages.

<u>Construction</u>

The sensor is well constructed, and is of the type that can be user calibrated to any specific range (within instrument limitations) by removing the cable entry cover and adjusting the calibration controls. All though this may be of benefit to some users, it means that users will have to consider the following:-

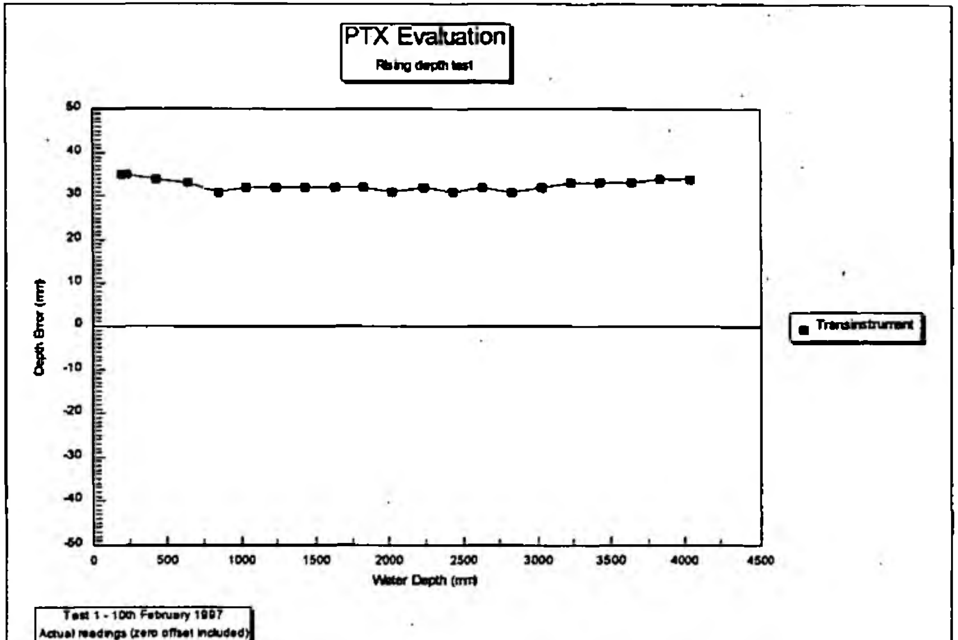
- The need for a pressure calibration system.
- Risk of nullifying warranty due to failure to reseal the access cover properly.

The atmospheric vent tube also gives some concern. The very small bore of the tube will mean some restriction of airflow during conditions when atmospheric pressure rapidly changes (such as wind or localised warming).

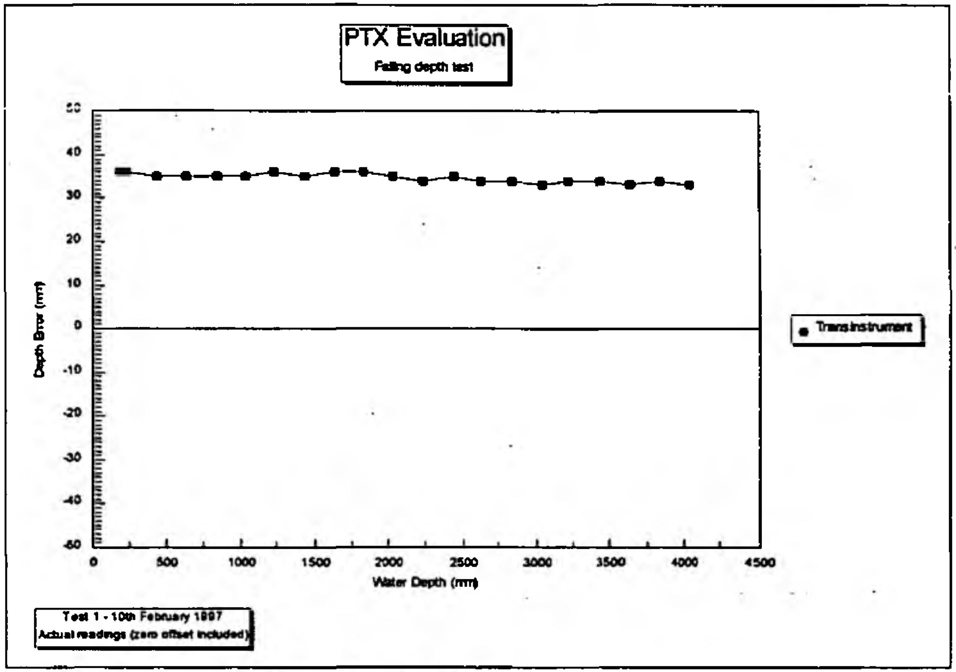
Overall

Overall, the sensor performed reasonably well, but performance was affected by offset errors which had to be accounted for. Potentially, the errors are introduced by the 20 second warm up time to allow the sensor reach offset stability. As the recording system operates under a pulse powering regime (typical of any "in-field" installation) the offset was observed. This is not a major problem as long as a consideration of the ratio of on-time to off-time is undertaken, as well as the actual offset by the recording system used.

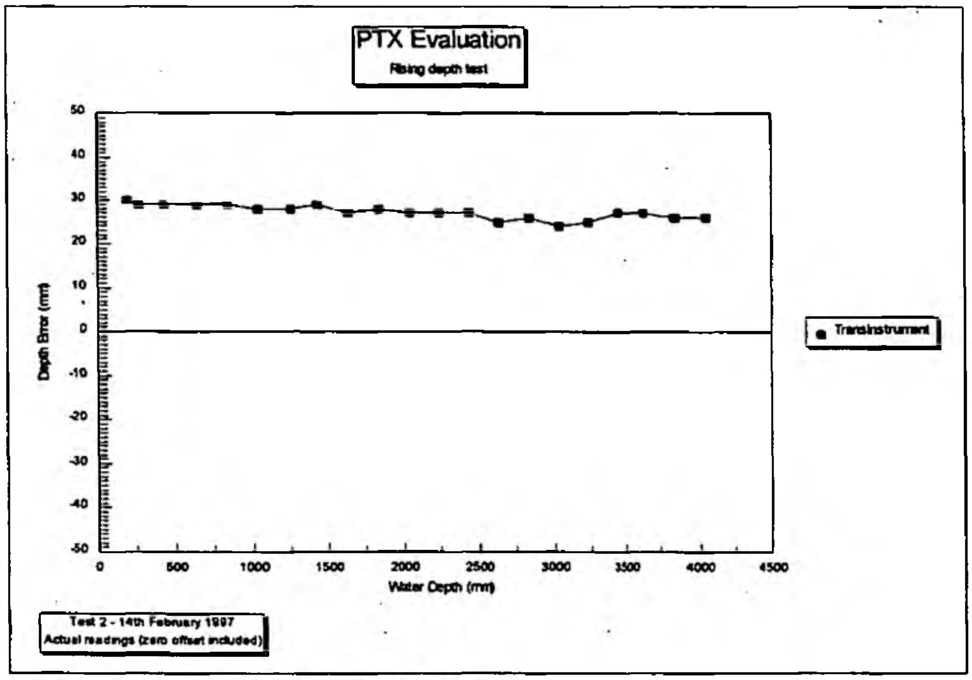
Manufacturer guidelines suggest that a ratio of 20:1 for off:on times should be followed, this was well within the guidelines for the recording system used during the evaluation.


PTX Evaluation
Rising depth test
Depth Error (mm)
50
40
30
20
10
0
-10
-20
-30
-40
-50
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Water Depth (mm)
Transinstrument
Test 1 - 10th February 1997
Actual readings (zero offset included)

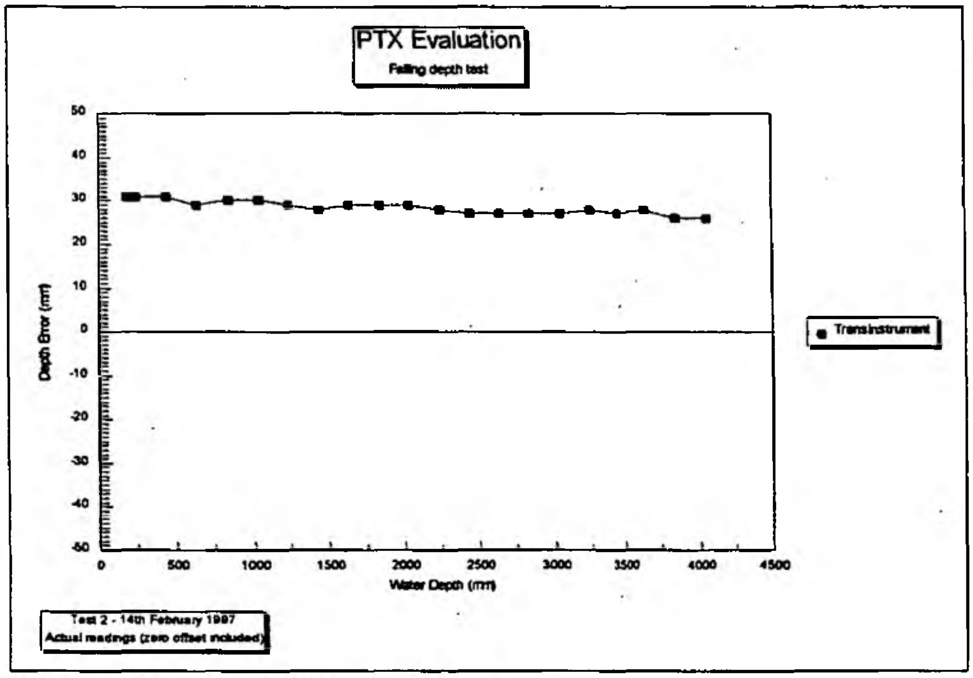
Plot 1 - Sensor 1 rising depth test



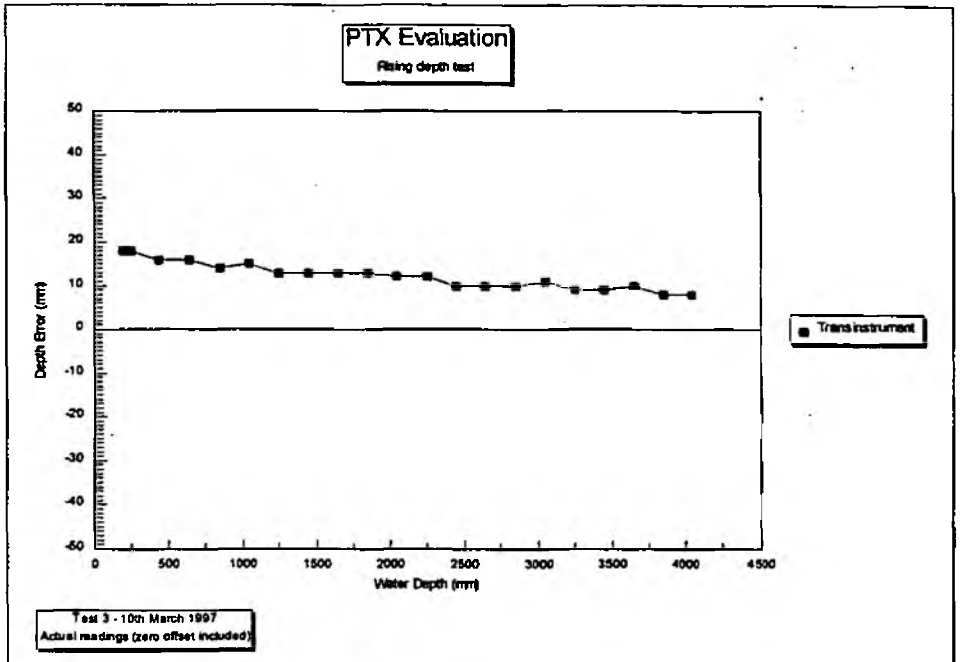
Plot 2 - Sensor 1 falling depth test



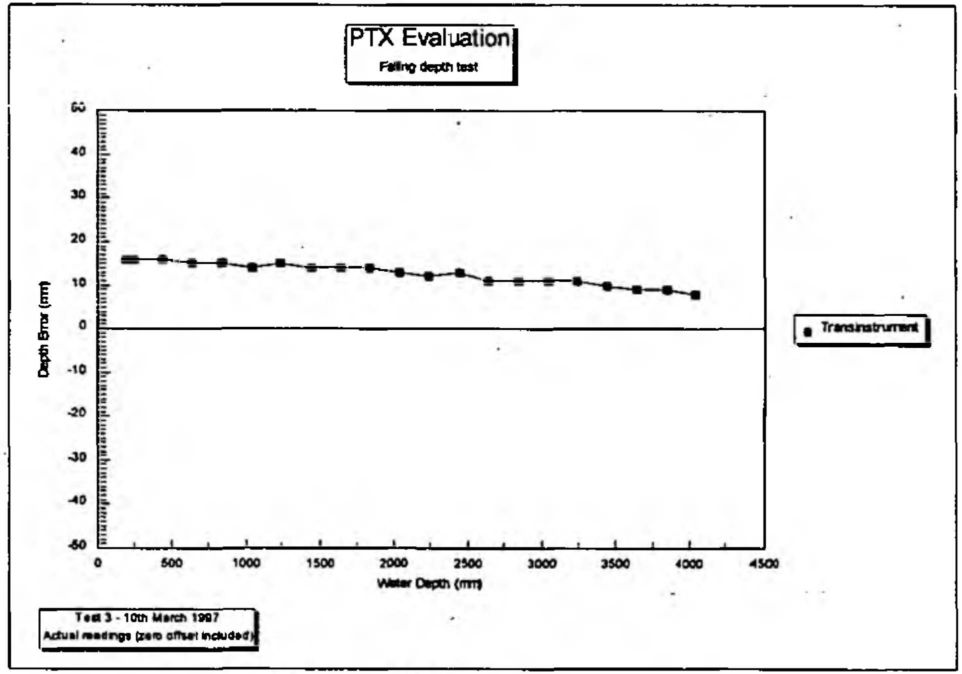
Plot 3 - Sensor 2 rising depth test



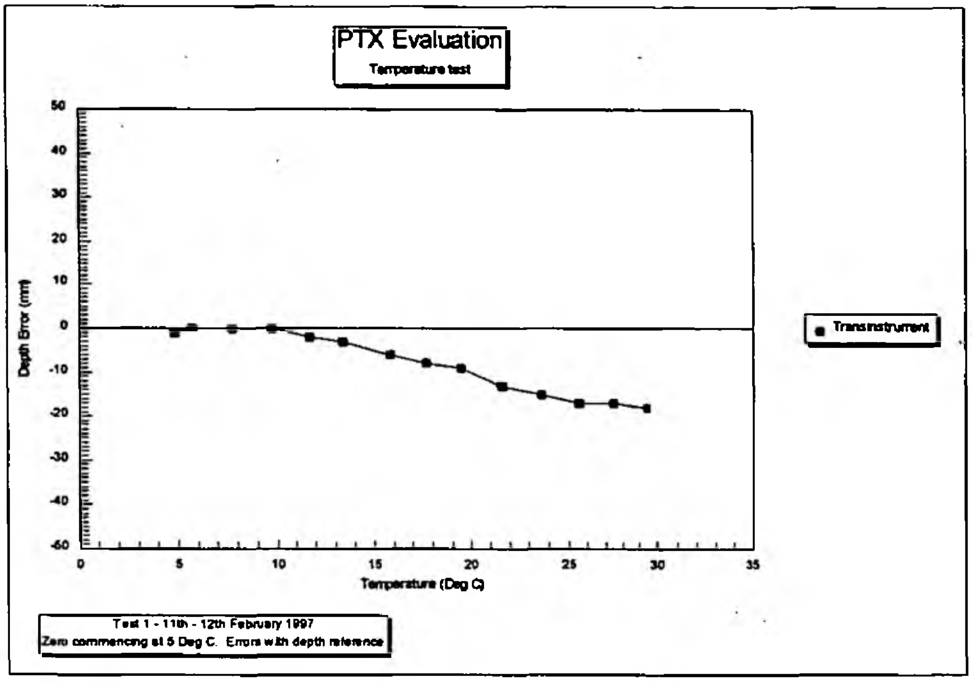
Plot 4 - Sensor 2 falling depth test



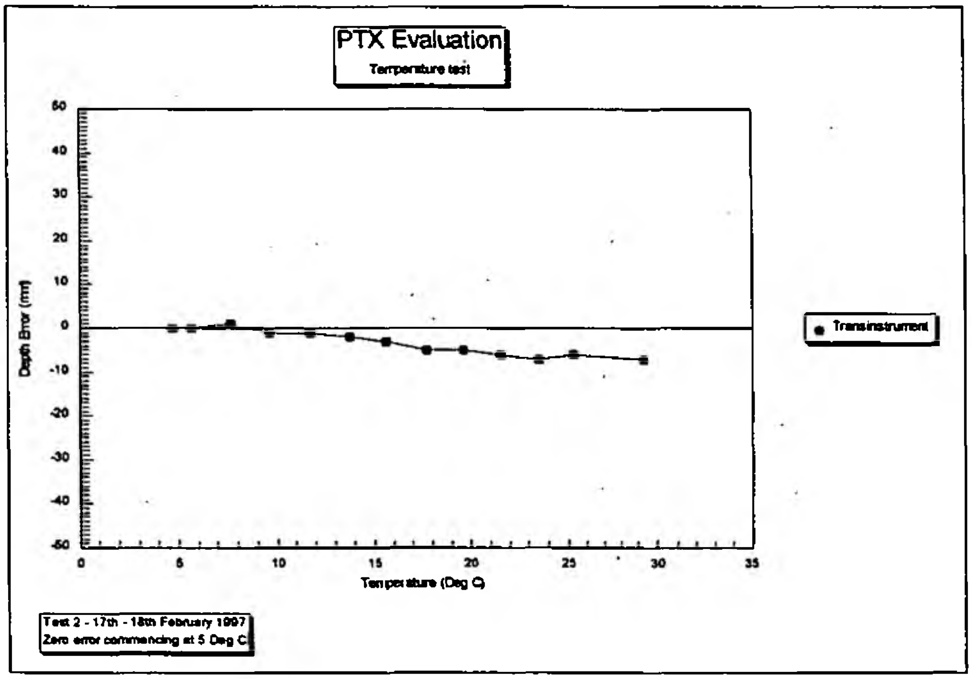
Plot 5 - Sensor 3 rising depth test



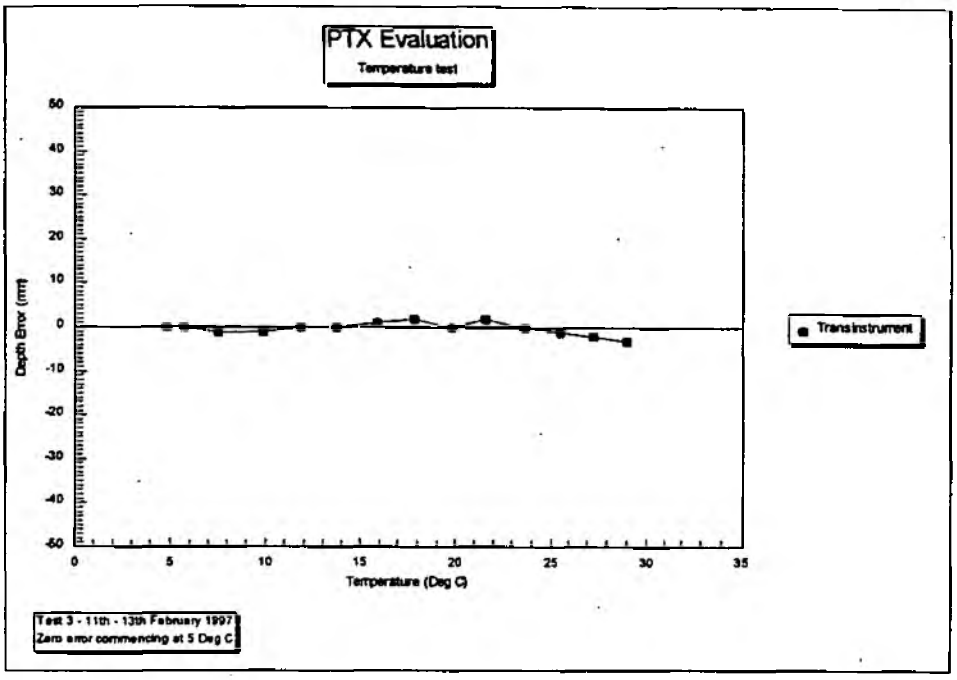
Plot 6 - Sensor 3 falling depth test



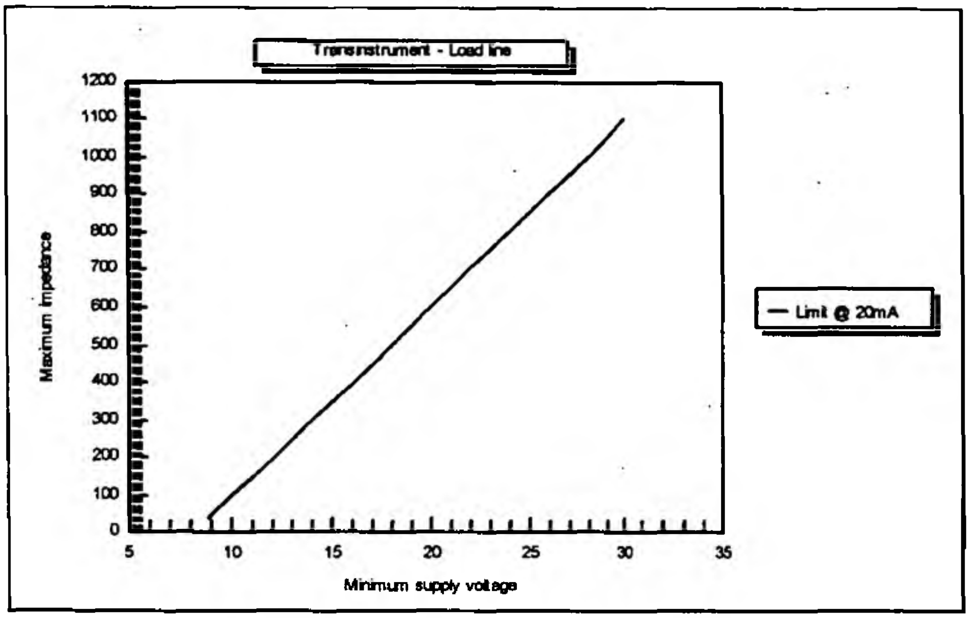
Plot 7 - Sensor 1 temperature test



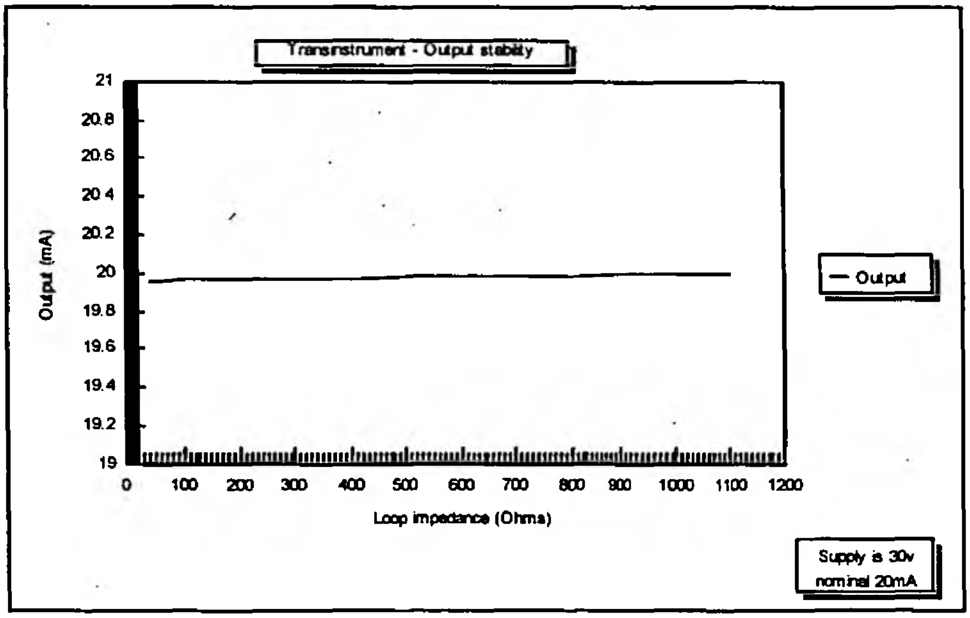
Plot 8 - Sensor 2 temperature test



Plot 9 - Sensor 3 temperature test



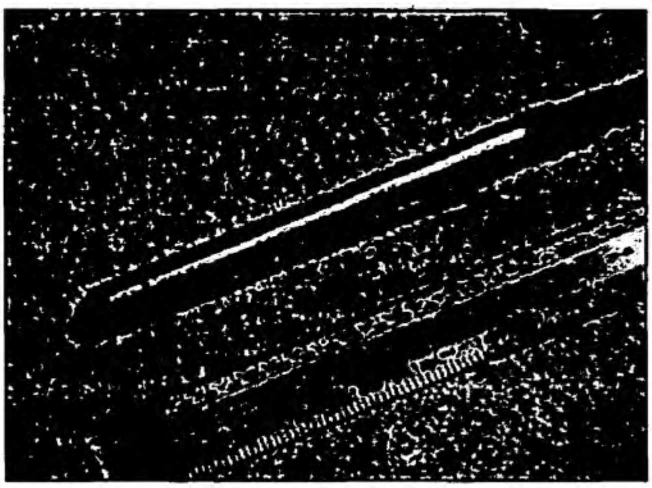
Plot 10 - Typical output load characteristic



Plot 11 - Output stability

Dynamic Logic (Shape)

Model SH3502



Instruments only supplied in stainless steel, which the company describes as suitable for "occasional saline exposure". This will limit the application at tidal sites. The cable is little inflexible which means weights will need to be added to sites were cable relaxation is a problem. The breather tube is of small bore. Pressure port is 0.125 BSP female fitting for calibration purposes.

Serial numbers:- SH3502-1464, SH3502-1465, SH3502-1466.

Description	Sensor 1 1465	Sensor 2 1466	Sensor 3 1464	Average
Linearity error (+/- % of range)	0.113%	0.088%	0.088%	0.096%
Temperature error (+/- % of range)	*0.238%**	0.225%	0.55%	0.388%
Combined linearity and temperature error	*0.351%**	0.313%	0.638%	0.484%
Span error (accounting for offset errors)	-60mm	-26mm	-26mm	37.3mm
Offset error ("zero" reading)	+37mm	+43mm	+24mm	34.7mm
Electrical noise/stability	<3mV @ 20mA 1k Ohm load 30v Supply			
Power supply range	9.1v@50 Ohm - 30v@1.1 kOhm			

* Errors introduced by test rig, these values not used in any final calculation of averages.

<u>Construction</u>

The instrument is reasonably constructed, though it is limited to stainless steel. This means that the sensor could not be used in saline (sea water) applications because of the corrosive qualities of the water. In addition, the cable used in relation to the sensor weight means that it will not hang straight and will require additional weights adding to it.

Overall

The sensor exhibited some areas of concern, namely, the temperature and calibration.

Temperature

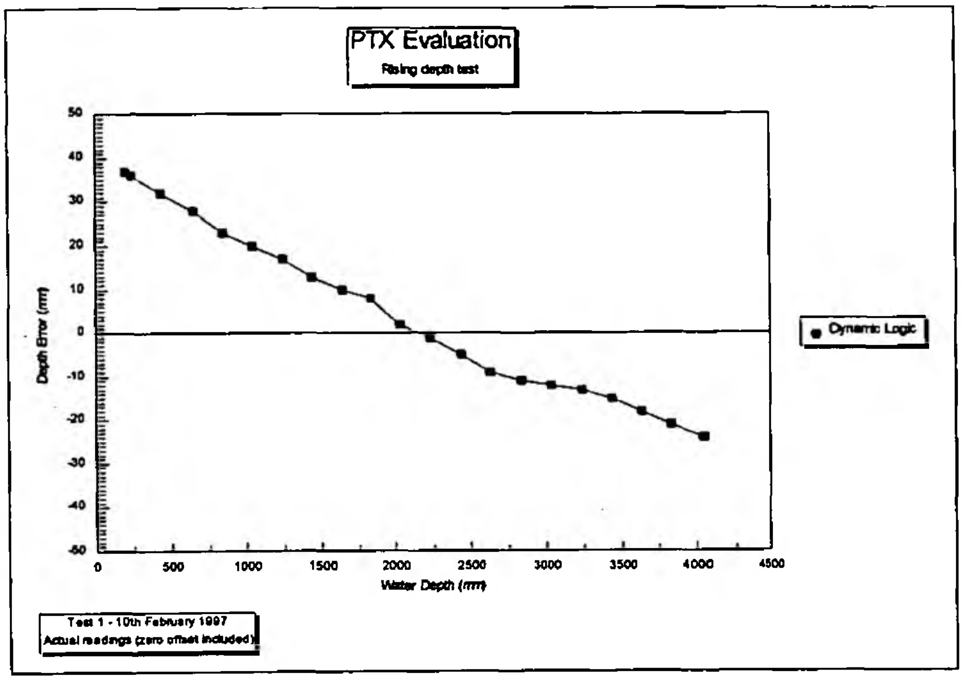
All three sensors tested, indicated errors caused by temperature effects. These errors themselves alone make the sensor fail to meet our 0.2% specification. The overall errors enable the sensor to only just meet the 0.5% specification.

Calibration.

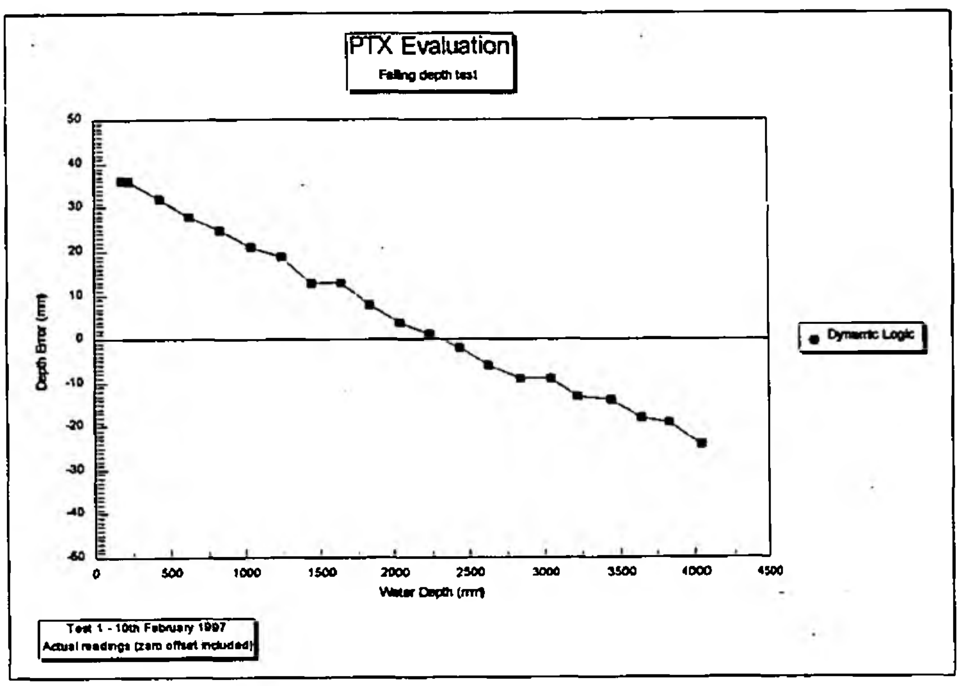
The calibration of the sensors could have been better. The results could imply that they have actually been calibrated for different ranges, such is the amount of error indicated by the slope of the plots for each of the depth tests. Each have range errors in the same direction (under reading) which indicates that the manufacturers calibration system is likely to be at fault.

Although in most applications the span can be accounted for in the calibration of the measuring system as a whole at time of installation, and indeed the results presented here do not account for additional calibration errors, the sensor should still be calibrated to the range indicated on it (4.000m instead of 3.940m as one appears to be set).

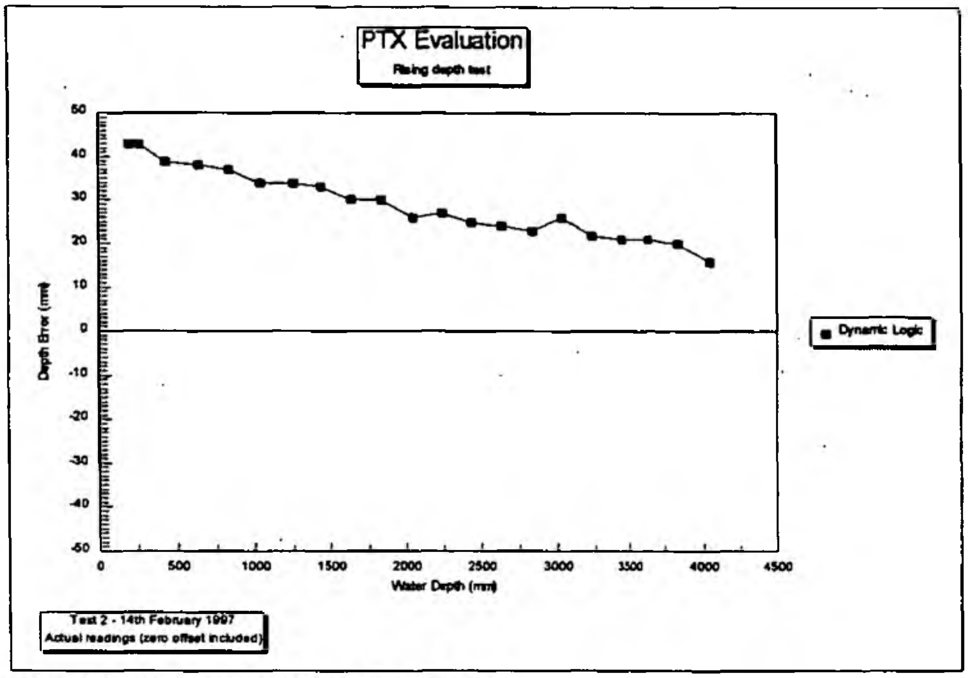
As the sensors stand, they only just meet the 0.5% specification, but including the range errors in the results would push the errors beyond the 0.5% specification, making the sensor totally unacceptable.



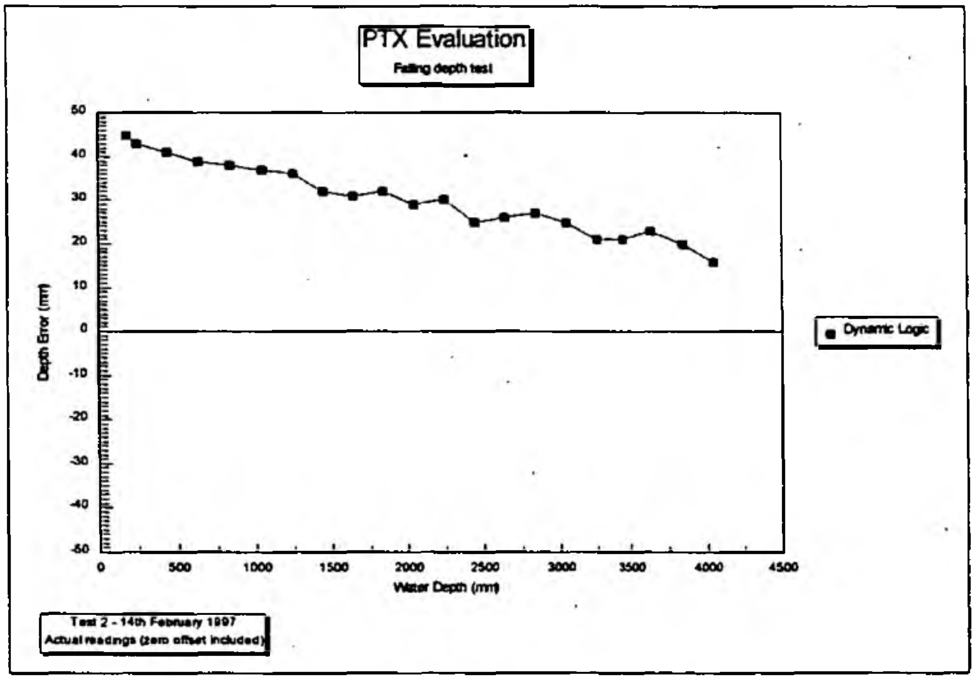
Plot 12 - Sensor 1 rising depth test



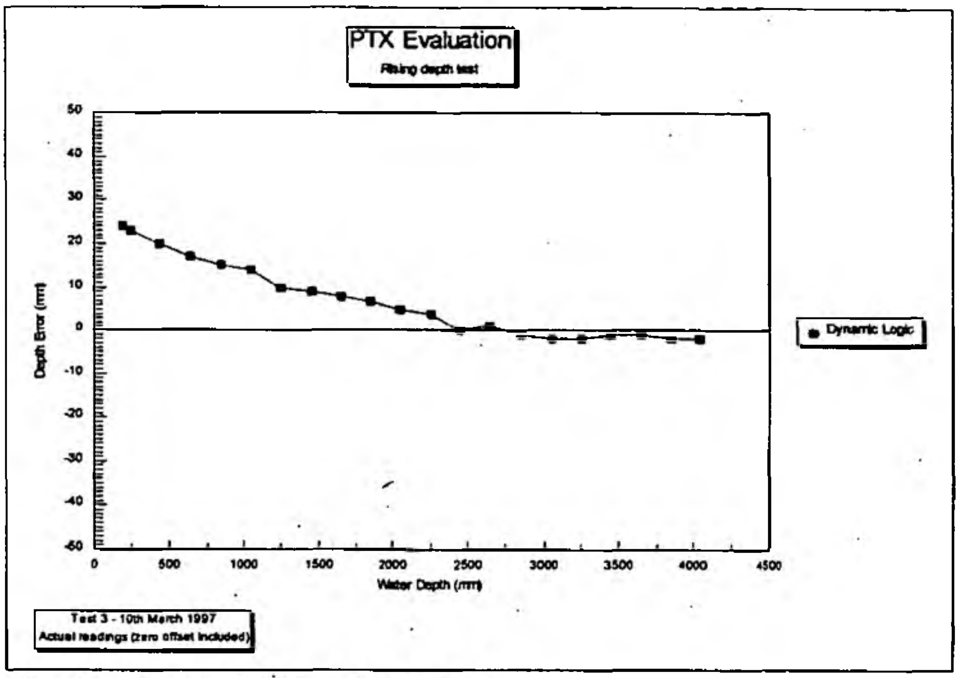
Plot 13 - Sensor 1 falling depth test



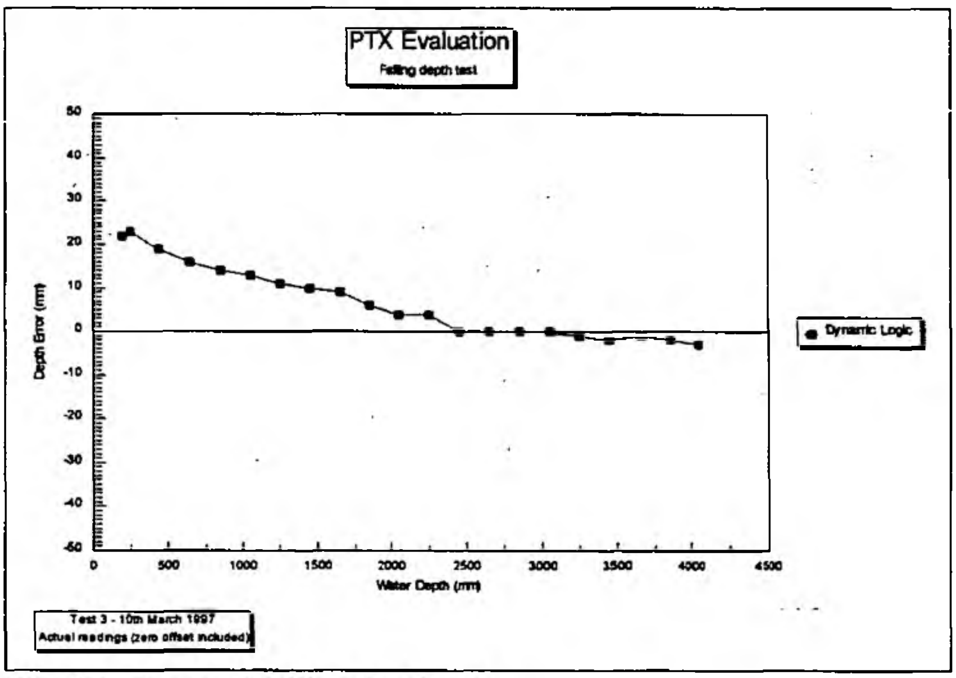
Plot 14 - Sensor 2 rising depth test



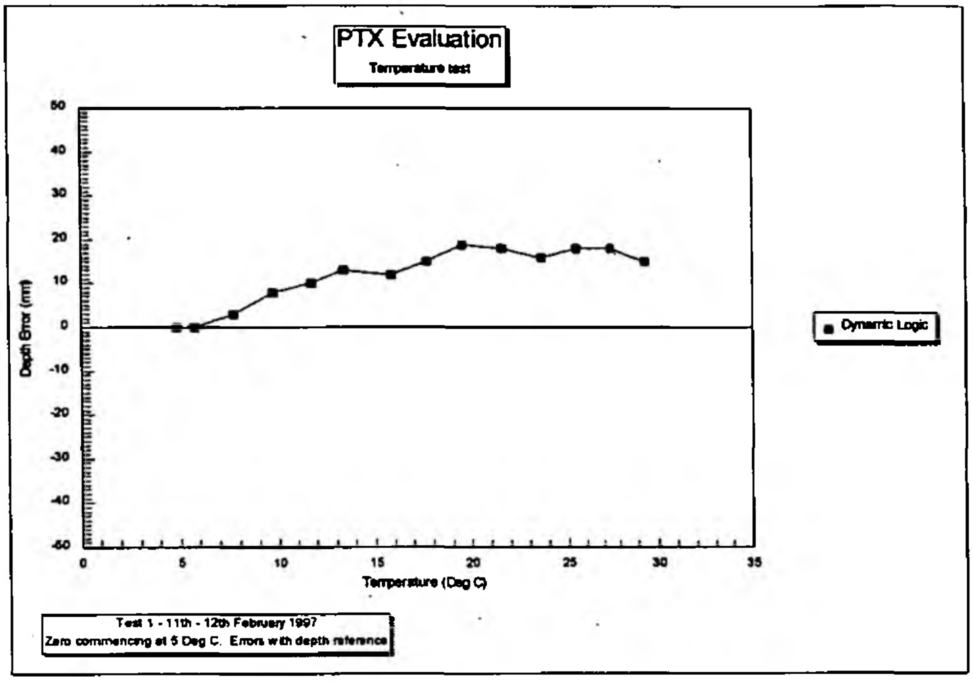
Plot 15 - Sensor 2 falling depth test



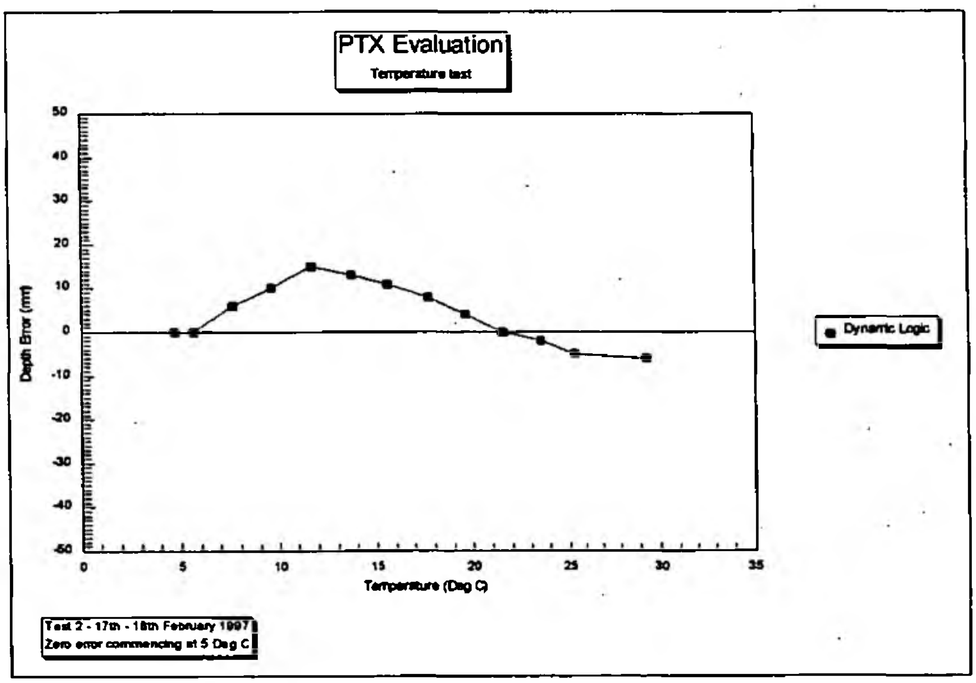
Plot 16 - Sensor 3 rising depth test



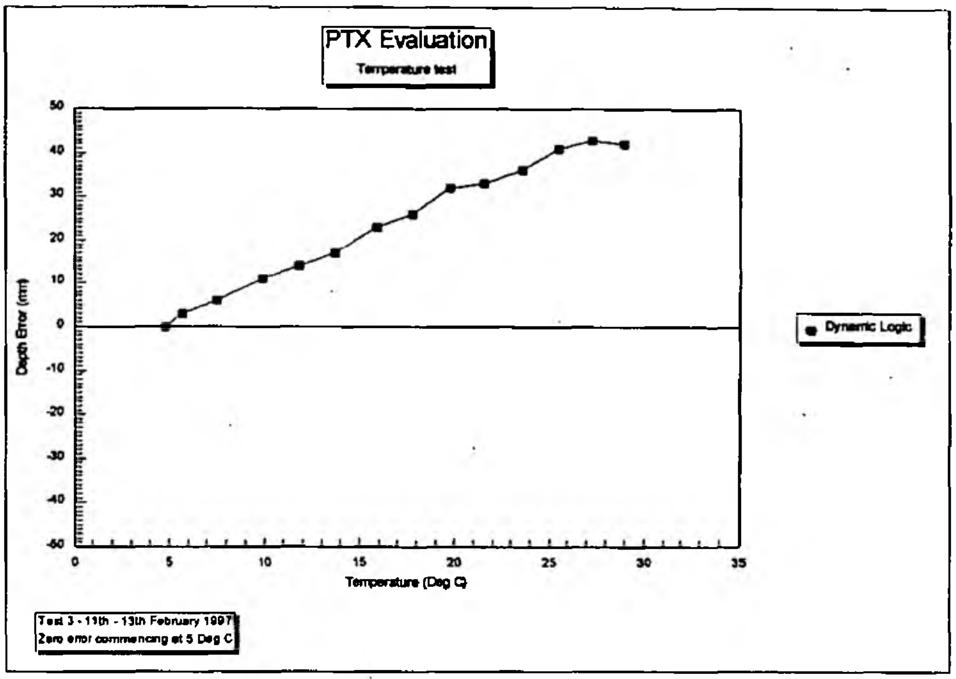
Plot 17 - Sensor 3 falling depth test



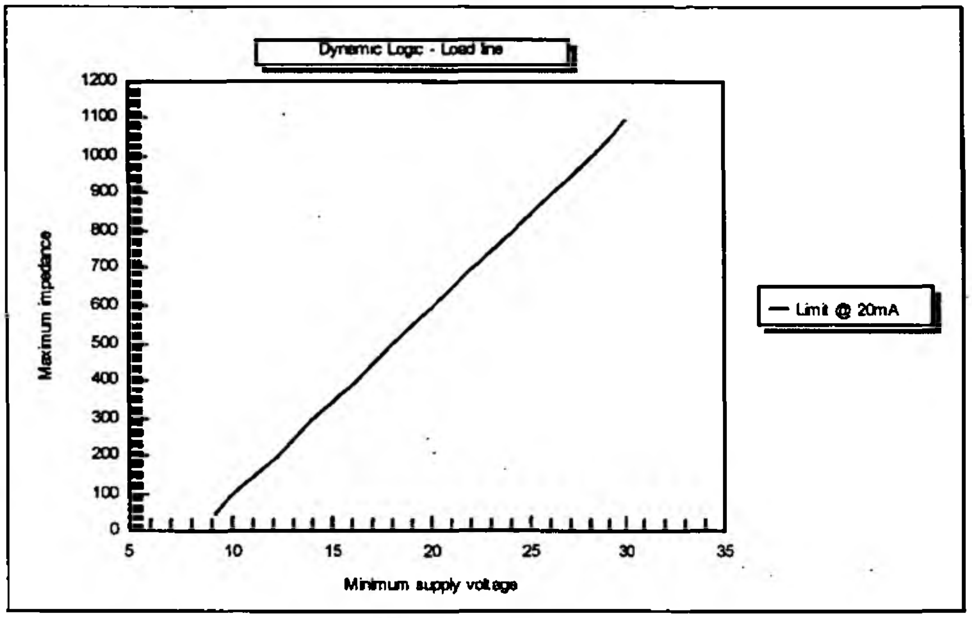
Plot 18 - Sensor 1 temperature test



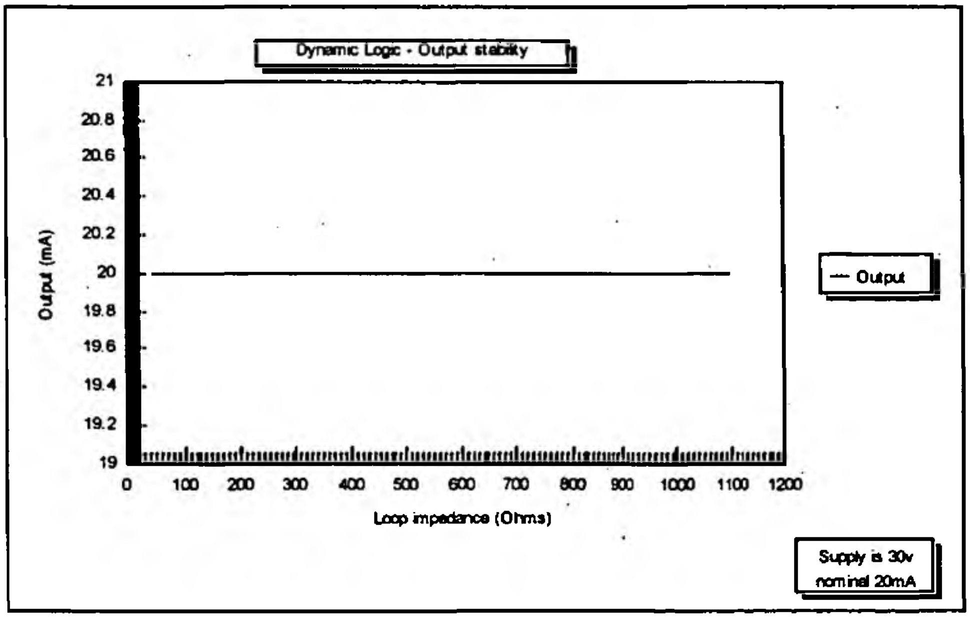
Plot 19 - Sensor 2 temperature test



Plot 20 - Sensor 3 temperature test



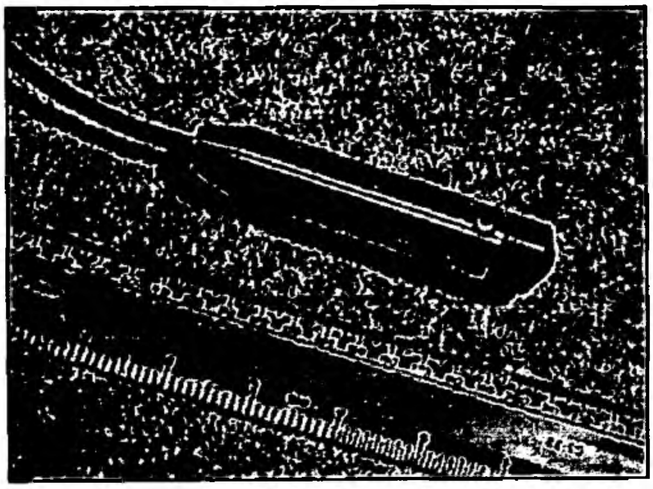
Plot 21 - Typical output load characteristics



Plot 22 - Output stability

Status Instruments

Model PTX22G



This company was represented by a third party - Checkmate Products. Cable entry has no strain relief which could lead to chaffing on the cable entry port with the sensor body. No indication if alternative materials to the stainless steel construction is available for saline applications. The breather tube is of very small bore. Pressure port; not stated but appears to be 0.25 BSP male fitting for calibration purposes.

Serial numbers:- 038477-1, 038477-2, 038477-3.

Description	Sensor 1 038477-2	Sensor 2 038477-1	Sensor 3 038477-3	Average
Linearity error (+/- % of range)	0.125%	0.088%	0.075%	0.096%
Temperature error (+/- % of range)	*0.238%**	0.125%	0.313%	0.219%
Combined linearity and temperature error	*0.363%**	0.213%	0.388%	0.315%
Span error (accounting for offset errors)	+1mm	-5mm	-4mm	-2.7mm
Offset error ("zero" reading)	-2mm	0mm	+8mm	2mm
Electrical noise/stability	<3mV @ 20.00mA, 1 kOhm load, 30v supply			
Power supply range	8.7v@50 Ohm - 30v@1.12 kOhm			

* Errors introduced by test rig, these values not used in any final calculation of averages.

<u>Construction</u>

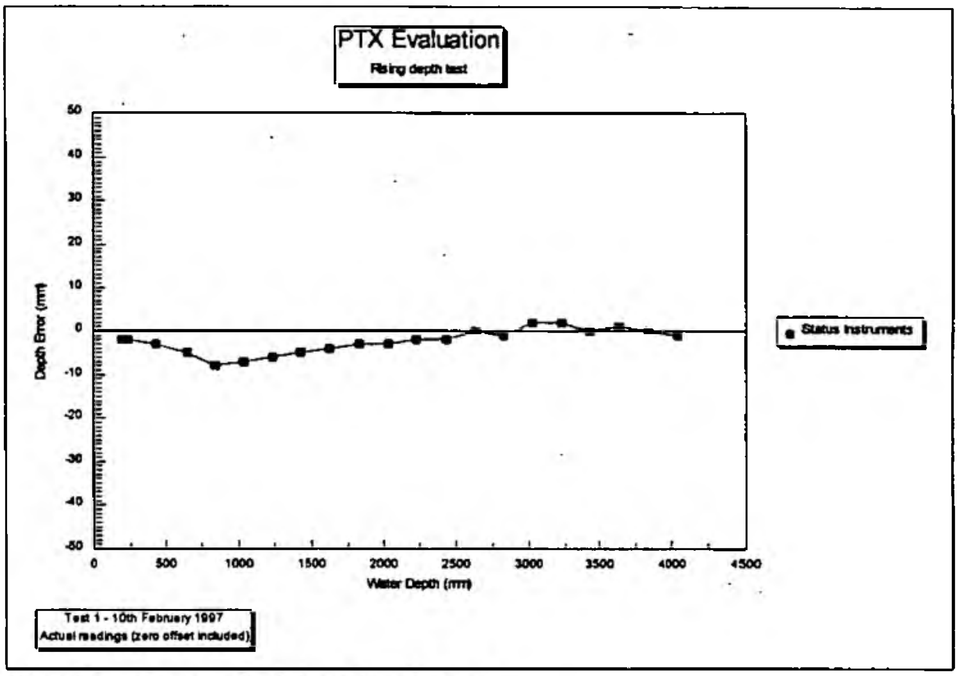
The sensor is only available in stainless steel which would limit it to fresh water applications only. Although reasonably constructed, the sensor cable entry has no strain relief included which could lead to chaffing of the cable on the sensor body.

Overall

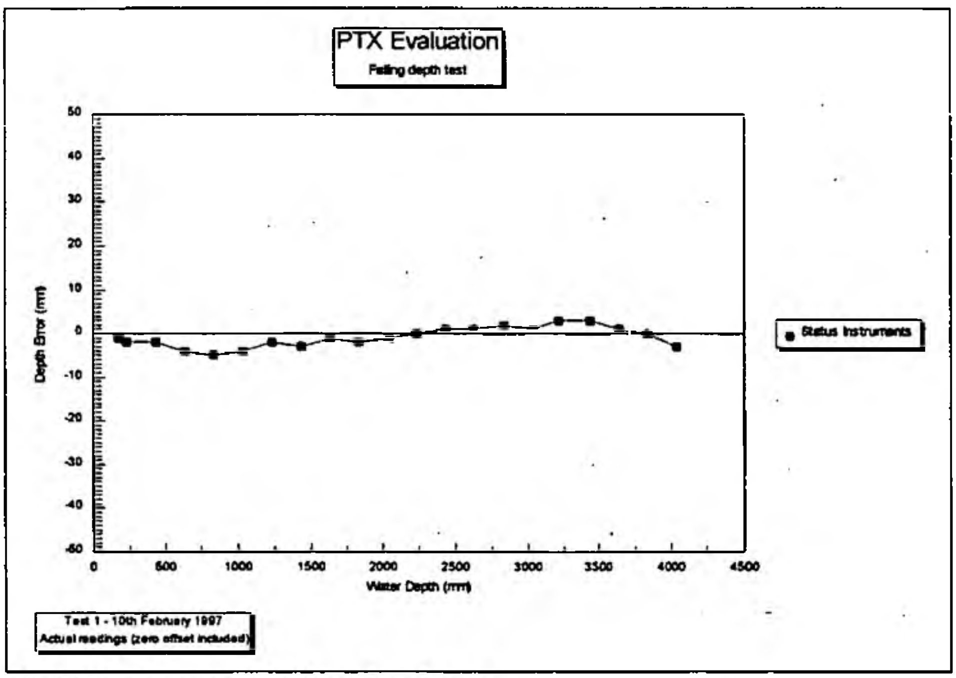
The sensor exhibited fairly reasonable results, but mostly let down on some non-linearities detected during the depth tests, but mostly on errors detected during temperature tests.

The average combined error of all sensors was a little above our 0.2% specification. At an average error of 0.315% it puts it as being compliant with the 0.5% specification only. There were no major range or offset errors detected.

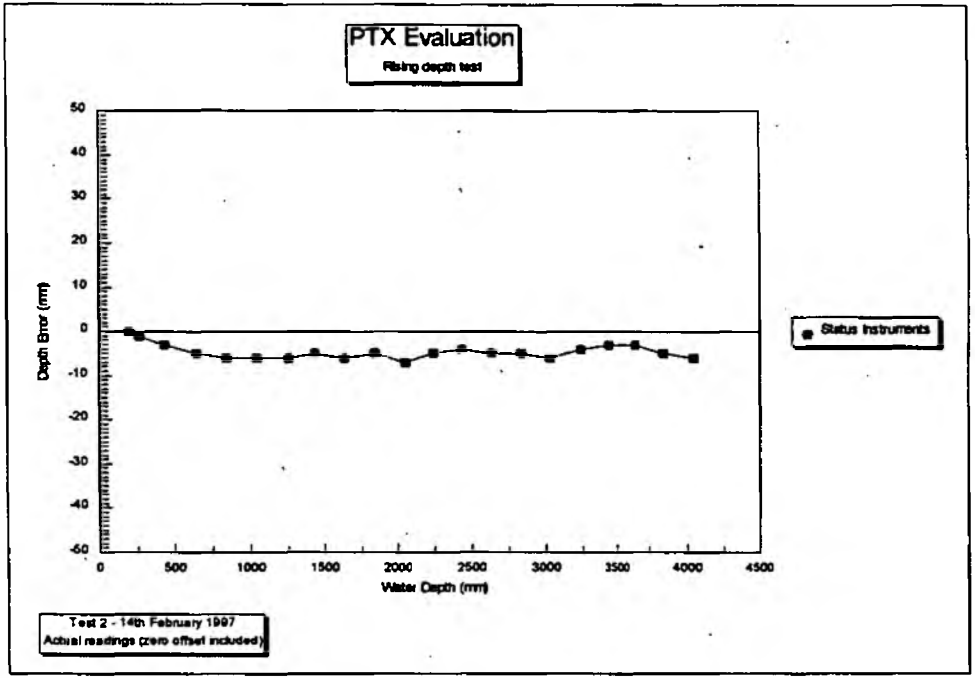
Of all the sensors tested, this one was the best for power supply requirements. At 8.7v for a 50 ohm load (with maximum output current of 20mA), it has the lowest supply voltage requirement, and at 30v supply, it was able to drive 1120 ohms; the highest of all sensors tested.



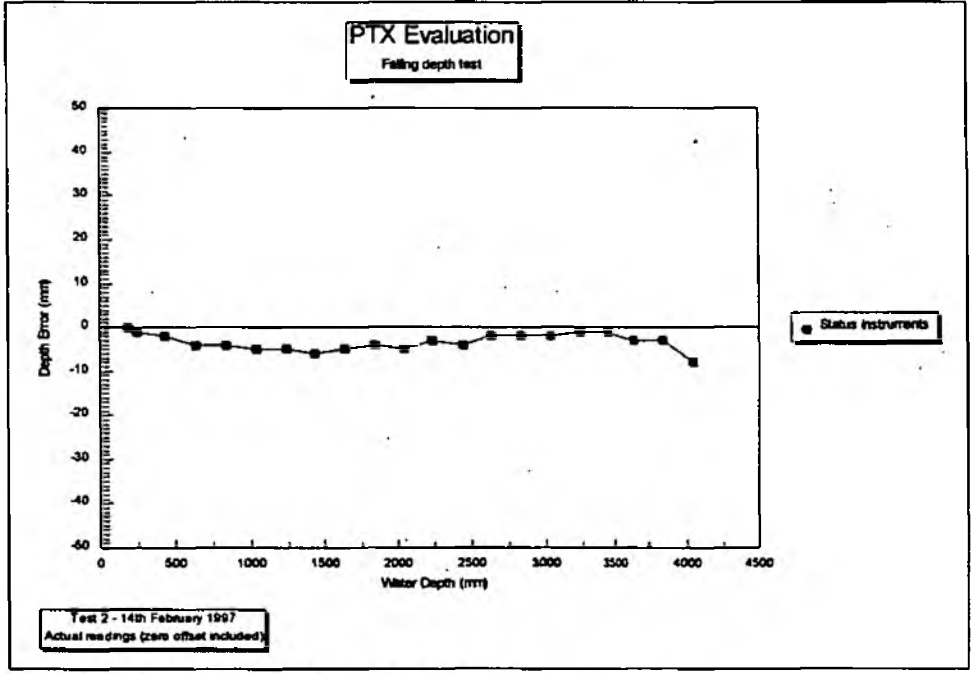
Plot 23 - Sensor 1 rising depth test



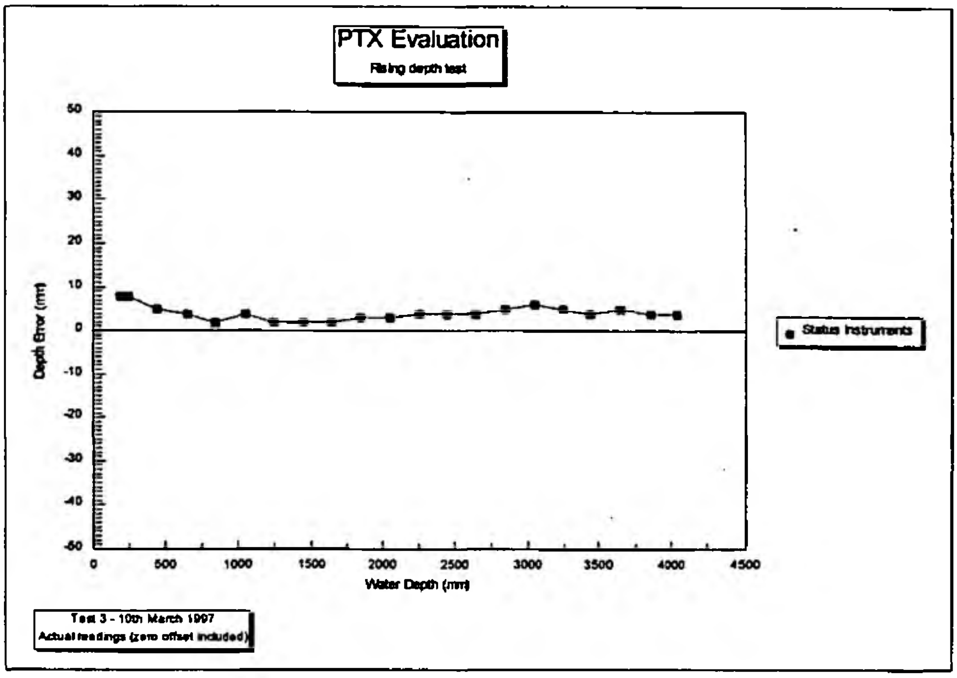
Plot 24 - Sensor 1 falling depth test



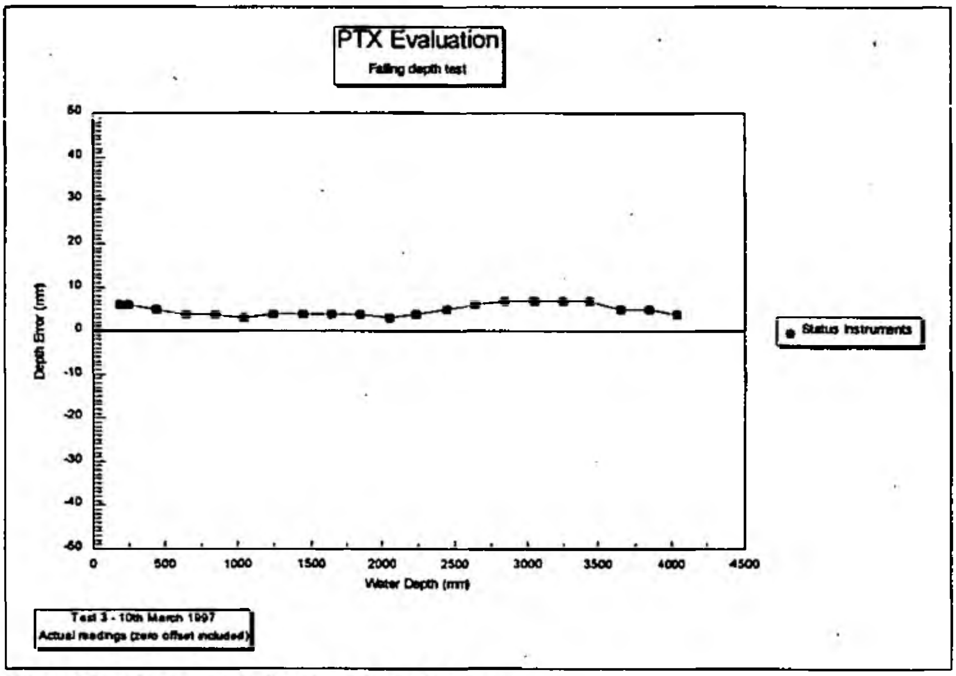
Plot 25 - Sensor 2 rising depth test



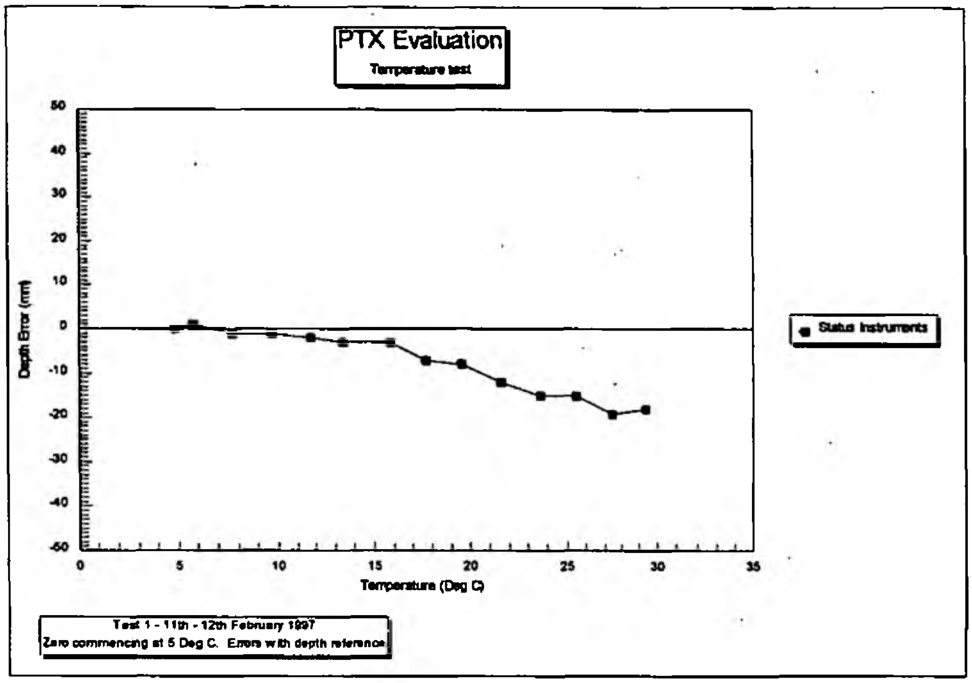
Plot 26 - Sensor 2 falling depth test



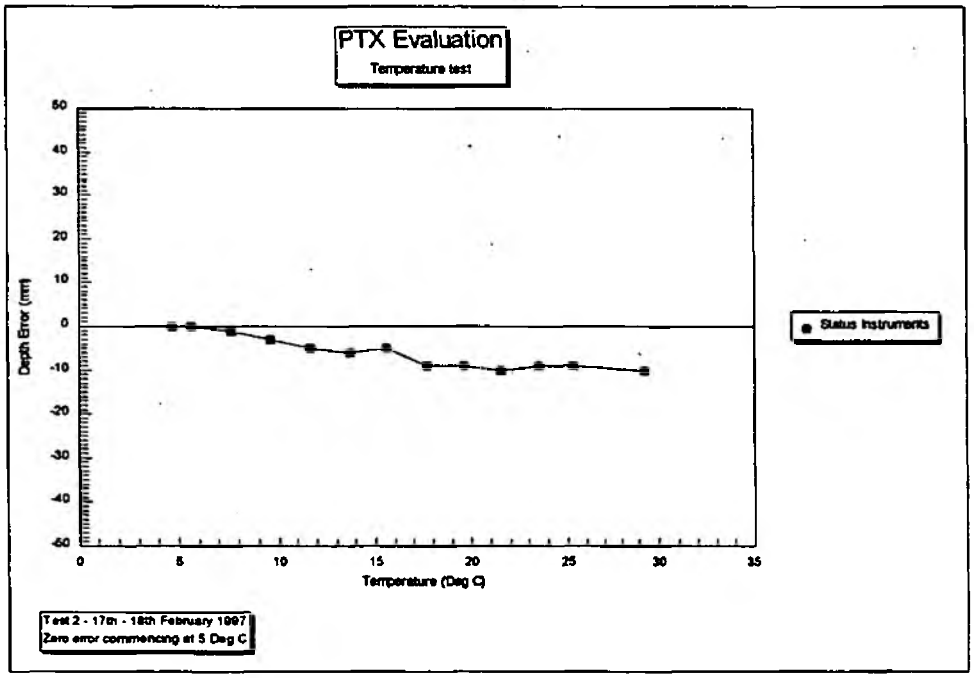
Plot 27 - Sensor 3 rising depth test



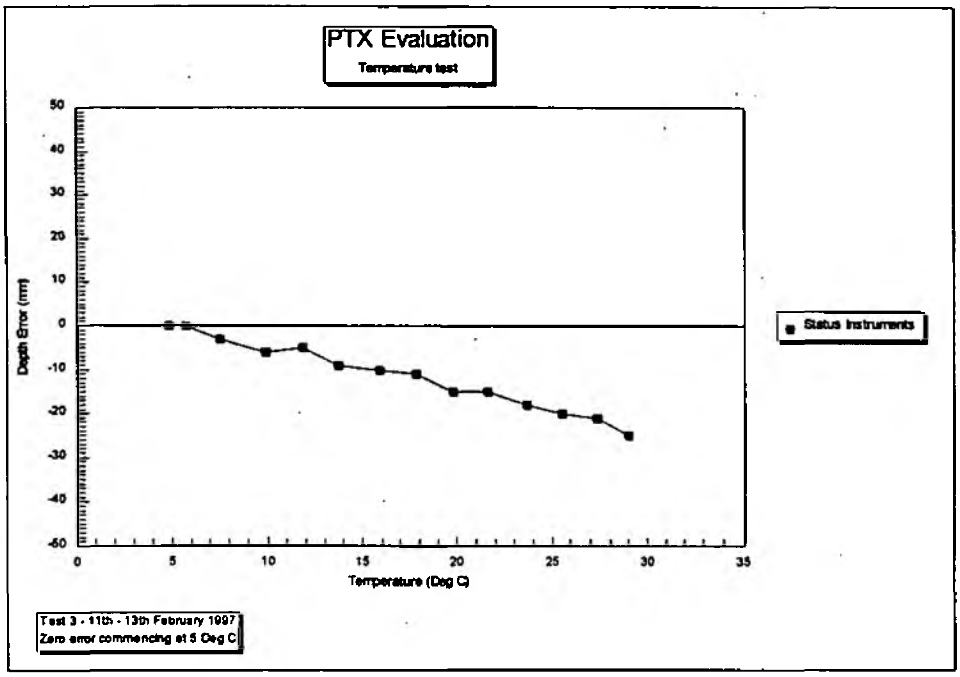
Plot 28 - Sensor 3 falling depth test



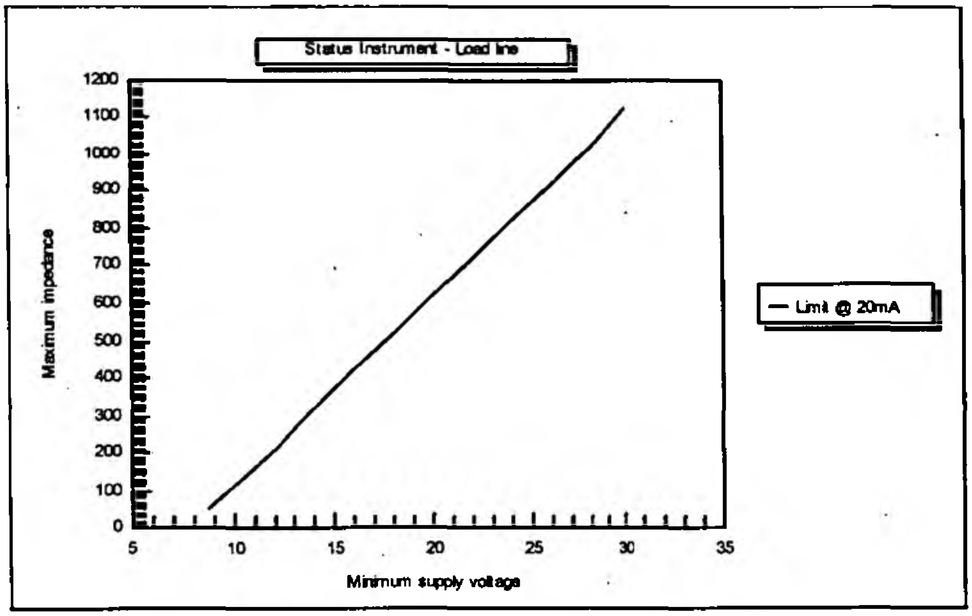
Plot 29 - Sensor 1 temperature test



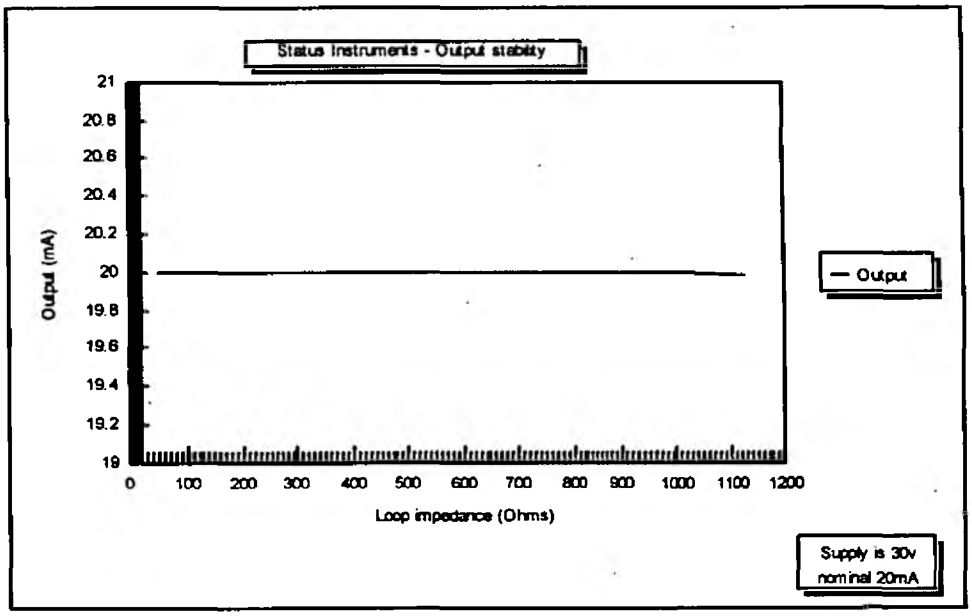
Plot 30 - Sensor 2 temperature test



Plot 31 - Sensor 3 temperature test

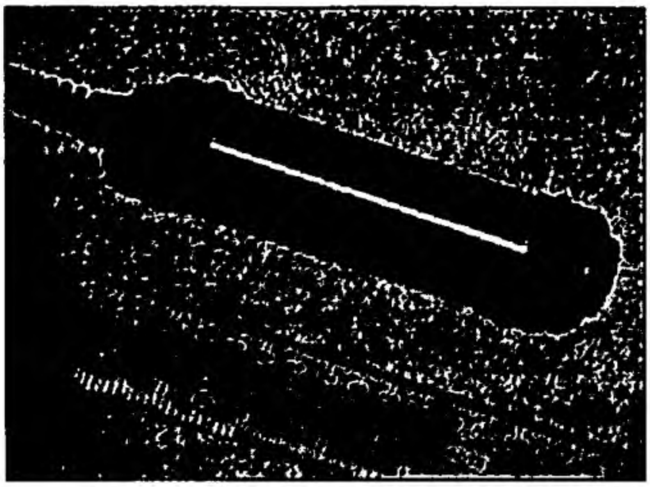


Plot 32 - Typical output load characteristic



Plot 33 - Output stability

Penny & Giles
Model D68096Mk6



A well constructed sensor which has reasonable weight to allow it to hang without cable relaxation being a problem. Sensor supplied is of the adjustable type. The indication that only 316L stainless steel is available for the material of construction. The breather tube is of very small bore. For calibration purposes the pressure port is 0.25 BSP female fitting.

Serial numbers:- 432093, 432094, 432095.

Description	Sensor 1 432095	Sensor 2 432094	Sensor 3 432093	Average
Linearity error (+/- % of range)	0.238%	0.188%	0.225%	0.217%
Temperature error (+/- % of range)	*0.463%**	1.15%	0.738%	0.944%
Combined linearity and temperature error	*0.701%**	1.338%	0.963%	1.161%
Span error (accounting for offset errors)	-14mm	-19mm	-16mm	-16.3mm
Offset error ("zero" reading)	-15mm	-18mm	-9mm	-14mm
Electrical noise/stability	<5mV@20mA, 1 kOhm load, 30v supply			
Power supply range	9.3v@50 Ohm - 30v@1.09k Ohm			

* Errors introduced by test rig, these values not used in any final calculation of averages.

<u>Construction</u>

This sensor was well constructed from 316L stainless steel. However there is no availability of sensors in alternative materials for tidal/saline applications. The sensor is quite heavy and is the only one tested that would not cause concern for the cable fitted to it reacting like a spring. The weight of the sensor is heavy enough to allow to hang straight with out any cable relaxation.

It is of the type that can be calibrated by the user, access to the controls is by removing the rubber boot and cover around the cable entry. All though this may be of benefit to some users, it means that users will have to consider the following:-

- The need for a pressure calibration system
- Risk of nullifying warranty due to failure to reseal the access cover properly.

The atmospheric vent tube also gives some concern. The very small bore of the tube will mean some restriction of airflow during conditions when atmospheric pressure rapidly changes (such as wind or localised warming).

Overall

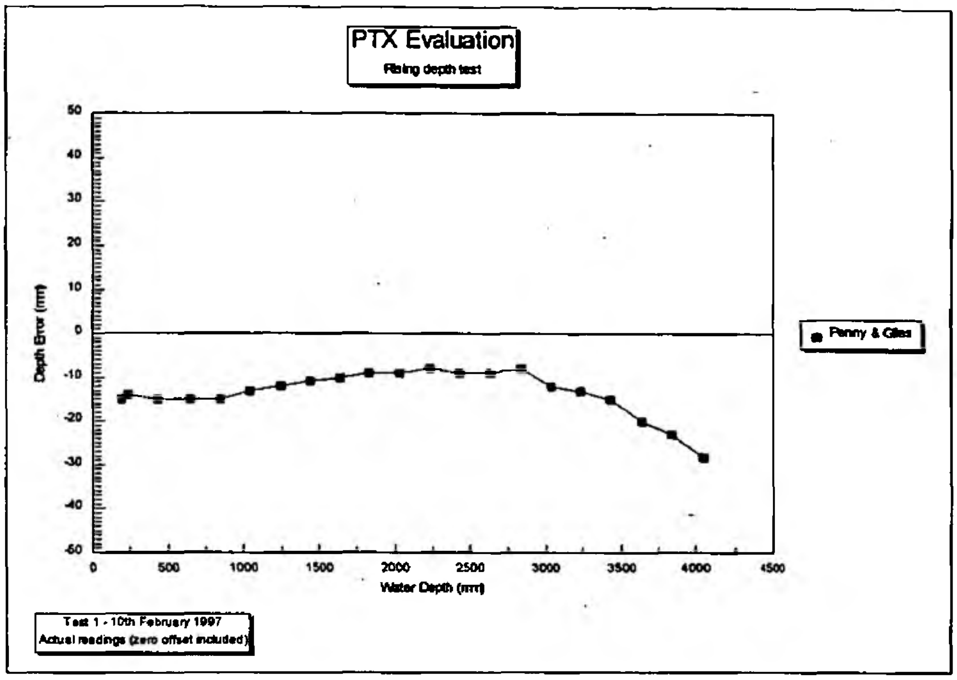
The sensor tests indicated some areas of concern, namely temperature and linearity.

Temperature

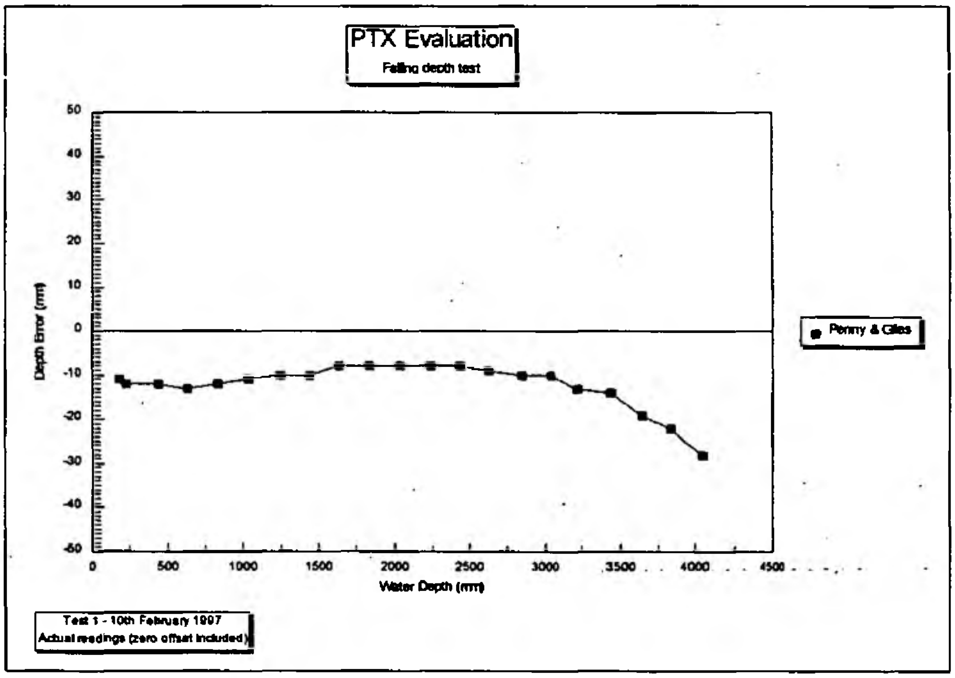
Of all the errors observed, the temperature errors were the most contributory to allowing the sensor to fail to meet any of our specifications. Temperature compensation was so poor that it made the sensor the worst out of all the manufacturers tested. The temperature errors for each sensor were all in the area of +/- 1%. This was brought to the companies attention and they have since made attempts to rectifying the problem. The results of retesting are presented in Appendix C.

Linearity

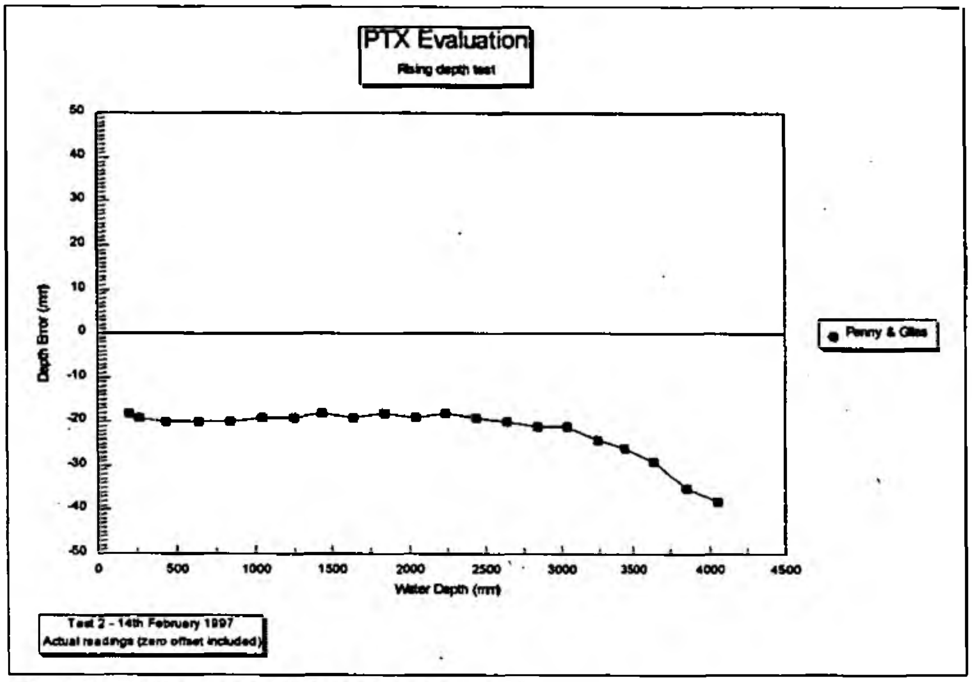
The linearity errors alone make the sensor unable to meet our 0.2% specification. At overall average linearity errors of 0.217%, and assuming the temperature errors are corrected, the sensor should be able to meet our 0.5% specification. At this present time, the sensor fails to meet any of our specifications.



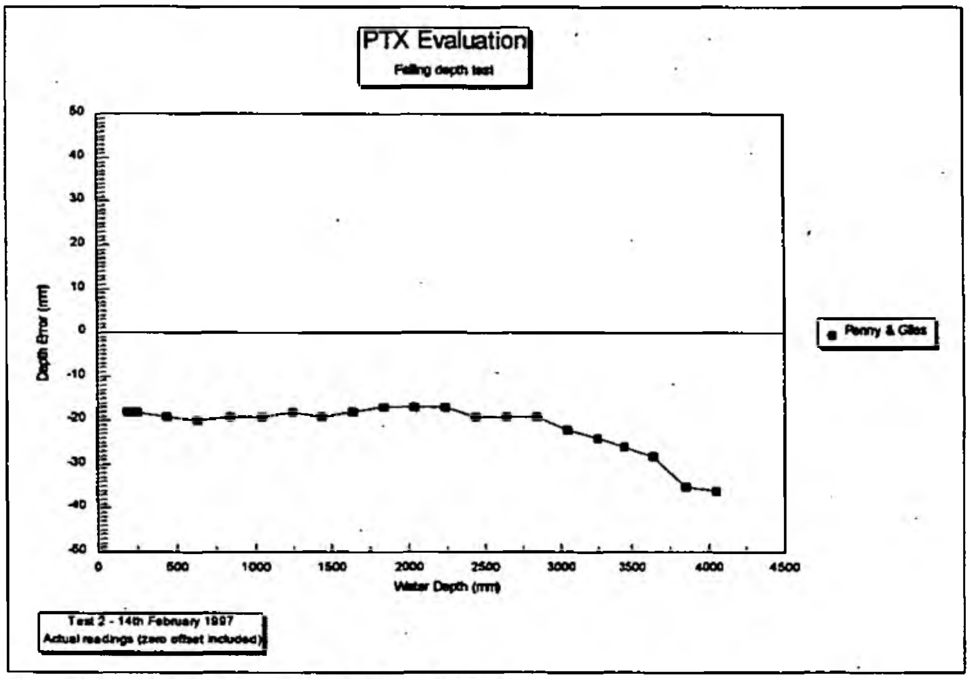
Plot 34 - Sensor 1 rising depth test



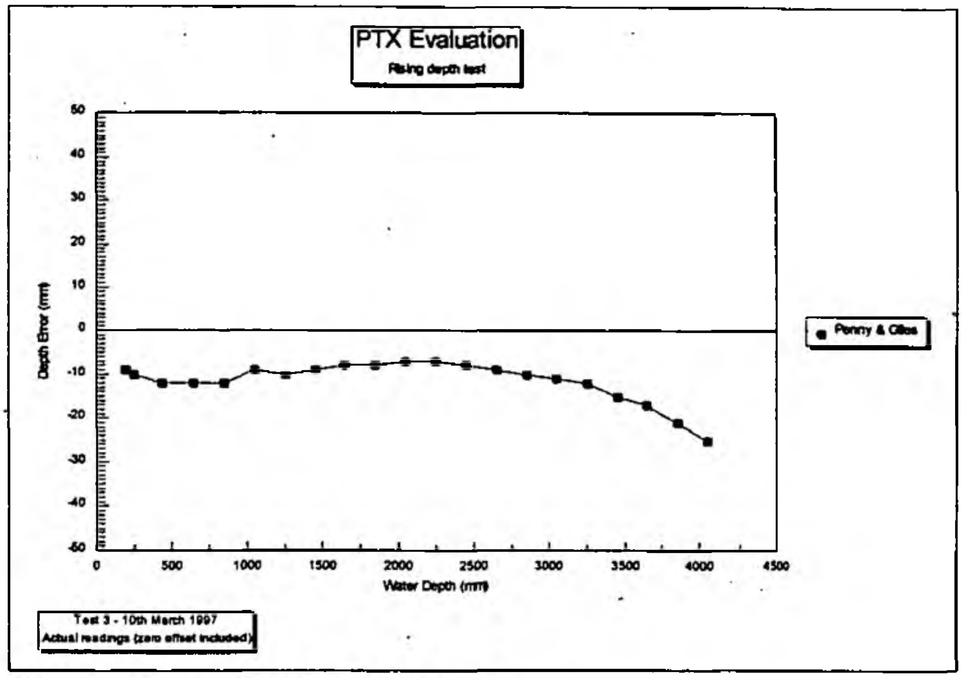
Plot 35 - Sensor 1 falling depth test



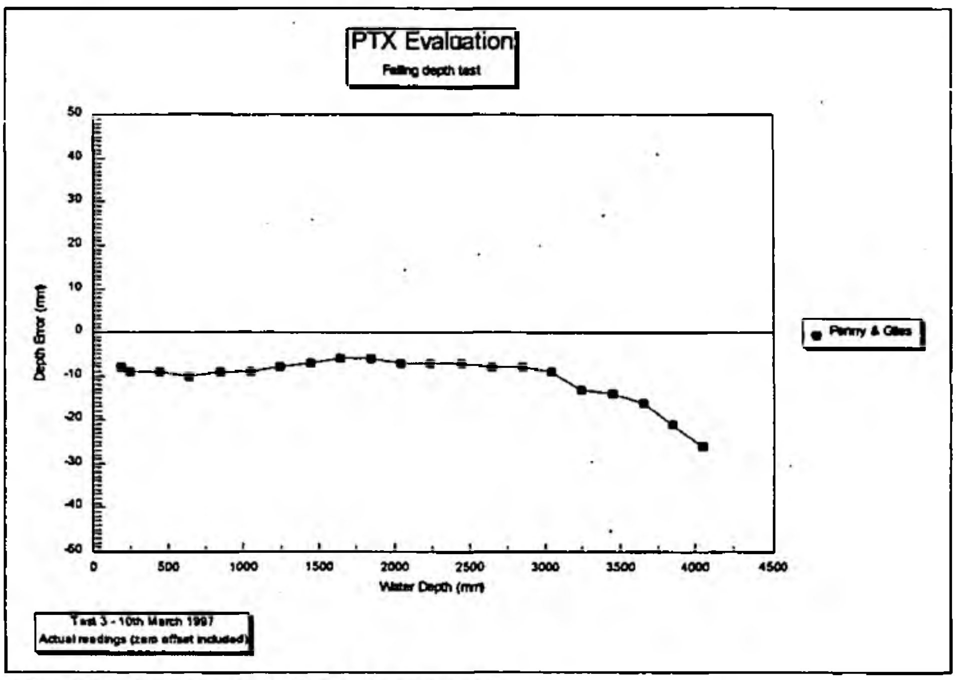
Plot 36 - Sensor 2 rising depth test



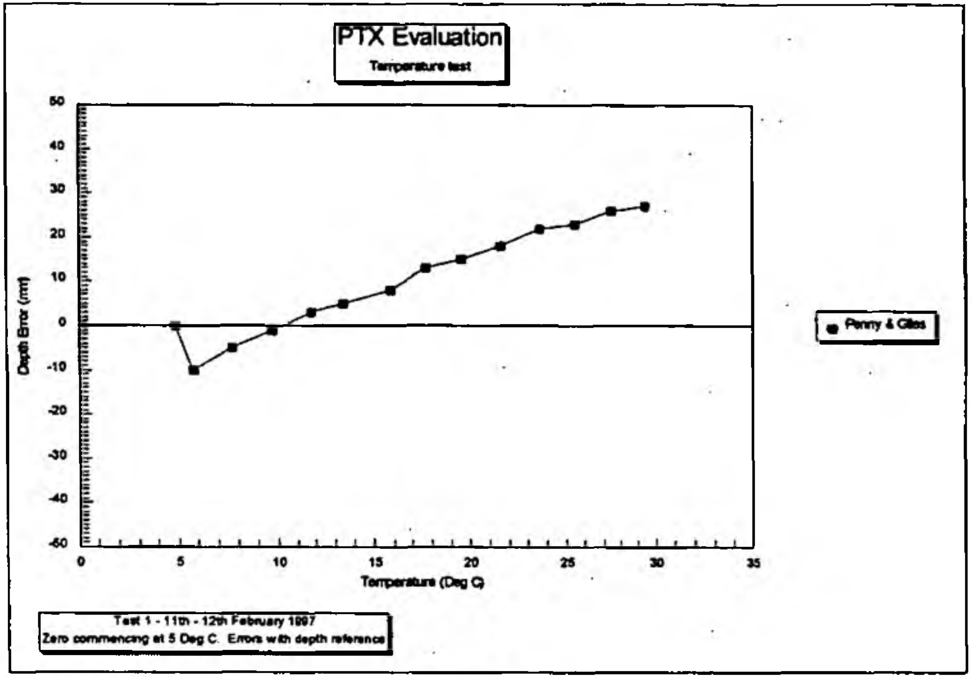
Plot 37 - Sensor 2 falling depth test



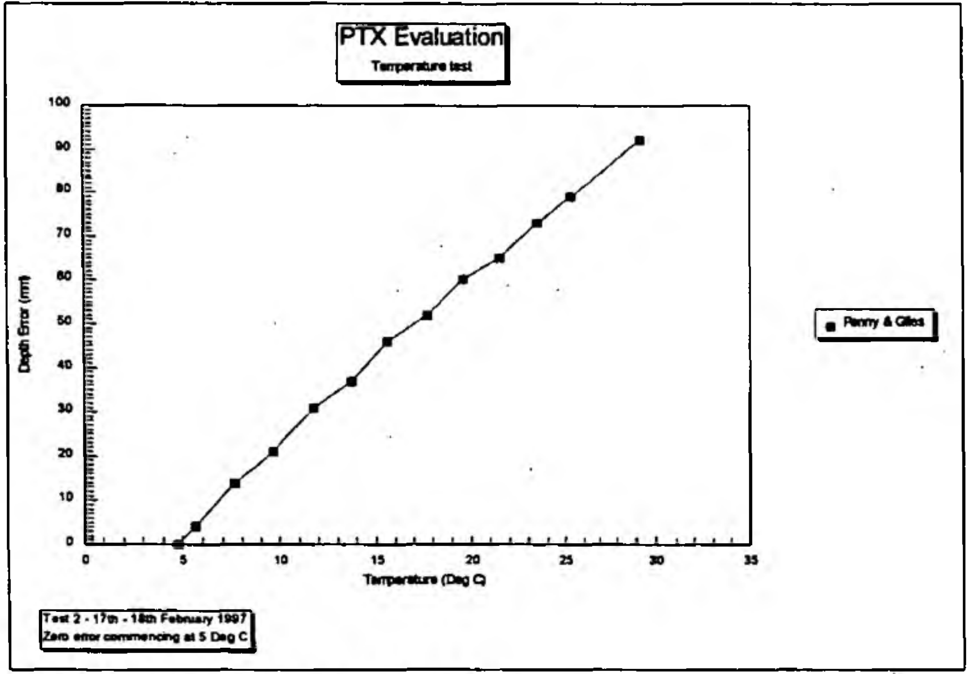
Plot 38 - Sensor 3 rising depth test



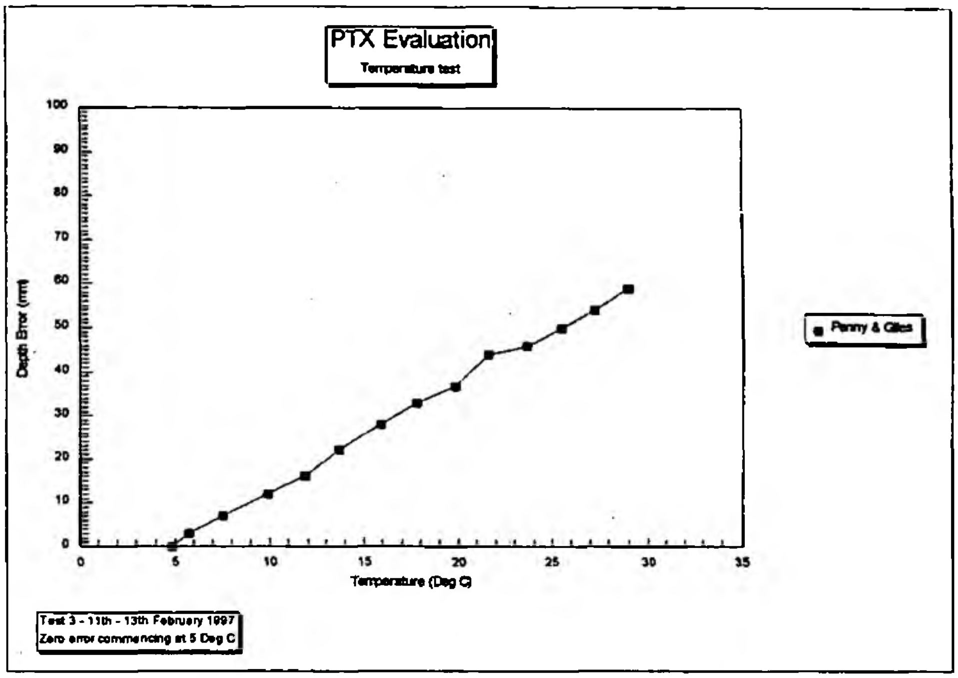
Plot 39 - Sensor 3 falling depth test



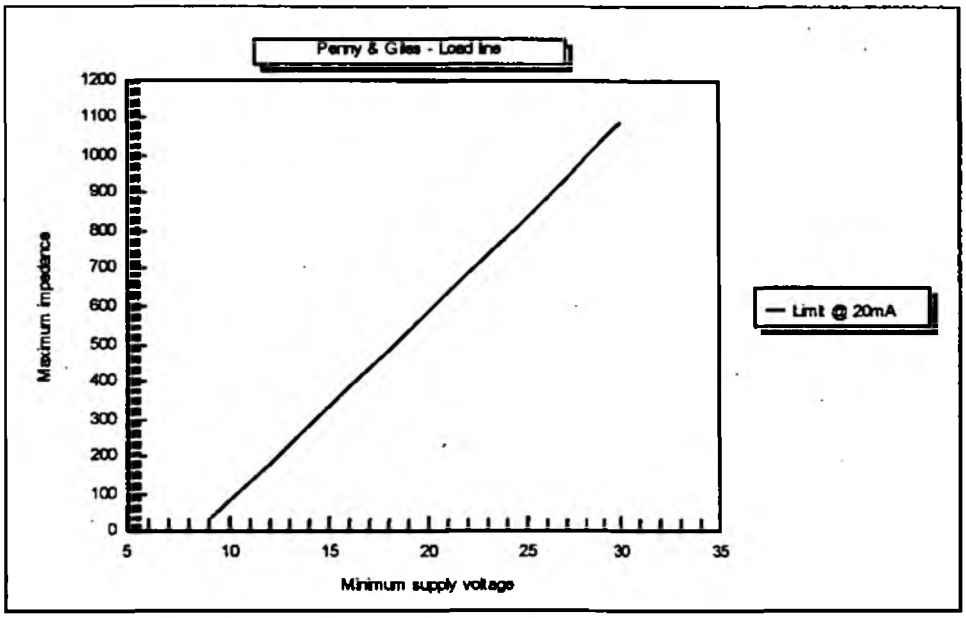
Plot 40 - Sensor 1 temperature test



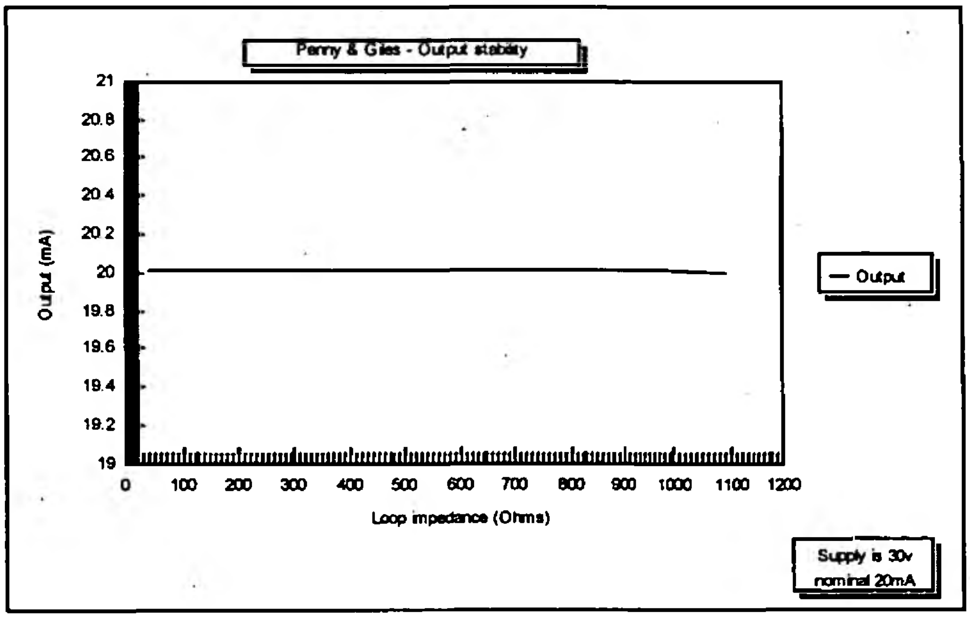
Plot 41 - Sensor 2 temperature test



Plot 42 - Sensor 3 temperature test



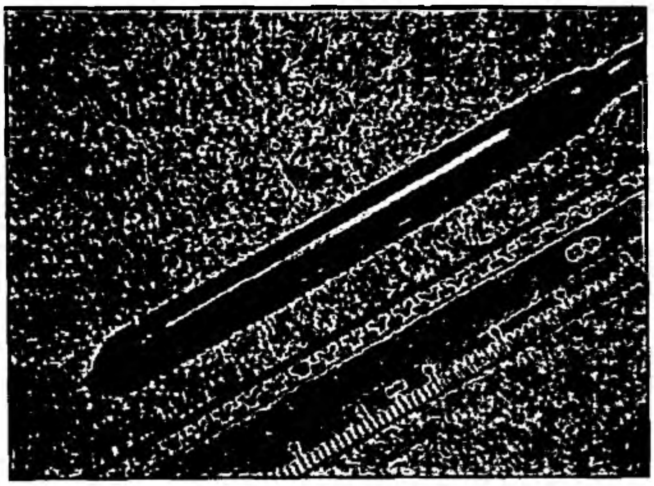
Plot 43 - Typical output load characteristic



Plot 44 - Output stability

Druck

Model PTX1830



The sensor on offer is a new development by Druck, to be known as the 1830 series. It is constructed from titanium which has the benefit of being able to be installed in saline applications without the need to specifically order alternative materials. The cable is a little inflexible, meaning cable relaxation may be a problem in some applications. The breather tube is of the largest bore (2mm dia approx) of all the sensors evaluated. For calibration purposes the pressure port is M14 x 1.5mm male fitting.

Serial numbers:- 890701, 893742, 895012.

Description	Sensor 1 890701	Sensor 2 895012	Sensor 3 893742	Average
Linearity error (+/- % of range)	0.05%	0.05%	0.05%	0.05%
Temperature error (+/- % of range)	*0.1%**	0.113%	0.088%	0.101%
Combined linearity and temperature error	*0.15%**	0.163%	0.138%	0.151%
Span error (accounting for offset errors)	-5mm	-8mm	-11mm	-8mm
Offset error ("zero" reading)	-18mm	9mm	10mm	0.3mm
Electrical noise/stability	<3mV@20mA, 1 kOhm load, 30v supply			
Power supply range	9.3v@50 Ohm - 30v@1.06 kOhm			

* Errors introduced by test rig, these values not used in any final calculation of averages.

<u>Construction</u>

The sensor is well constructed, from titanium which will enable it to be installed in most applications including saline (tidal) depth measurement.

The sensor is of a new design that Druck has introduced to replace a variety of sensors that previously users purchased. The advantages of all the sensors have been drawn together into one sensor - the 1830 series, which are on a normal manufacturing basis. Previously, high accuracy sensors such as the Druck PTX161/D were considered as "specials" and were on a 15 week delivery.

The pressure connection has holes around the circumference which may cause problems where users connect these into pressurised systems. If this is the case then it will be necessary for users to make the supplier aware that these holes are either not required, or the pressure fitting the sensor is to be connected to is able to accommodate them.

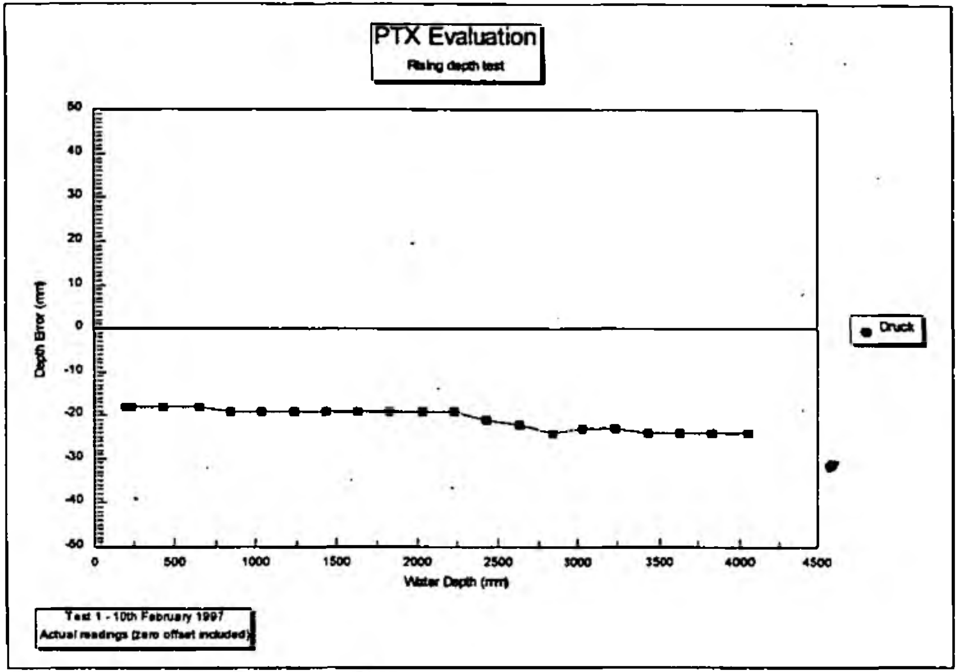
The cable fitted to the sensor was a little inflexible. This will cause newly installed sensors that are hung from a reference point to relax over time. Therefore, some applications will require additional weights adding to the sensor to enable it to hang straight with out the need to make allowance for cable relaxation.

Overall

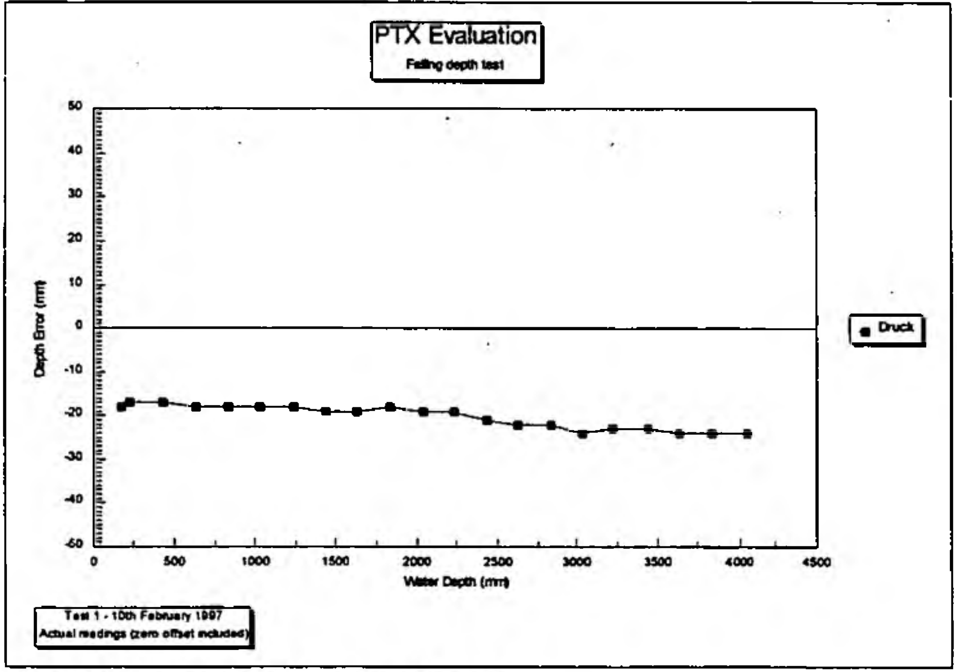
The sensor performed well, though did indicate some offset errors, varying between sensors. The linearity and temperature errors were minimal, allowing the sensor to meet our 0.2% specification.

No problems were detected with the power supply limitations or the output stability; at a minimum supply voltage of 9.3v at 50 ohm load (with 20mA output) the sensor is quite able to operate with battery powered data loggers utilising a pulse powering regime.

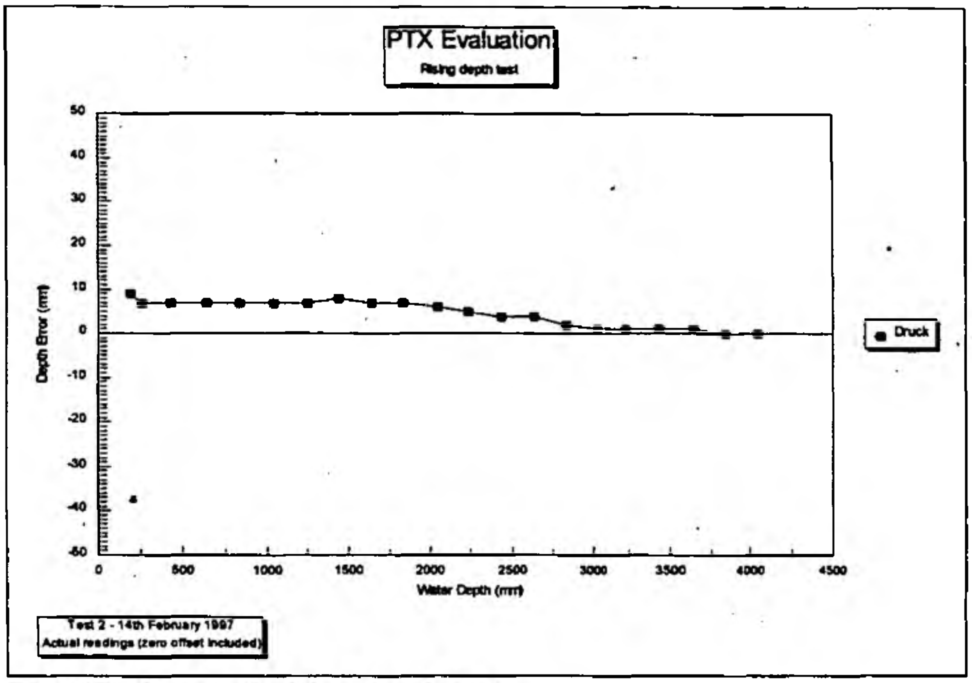
Overall, this was the best sensor tested out of all those supplied by other manufacturers.



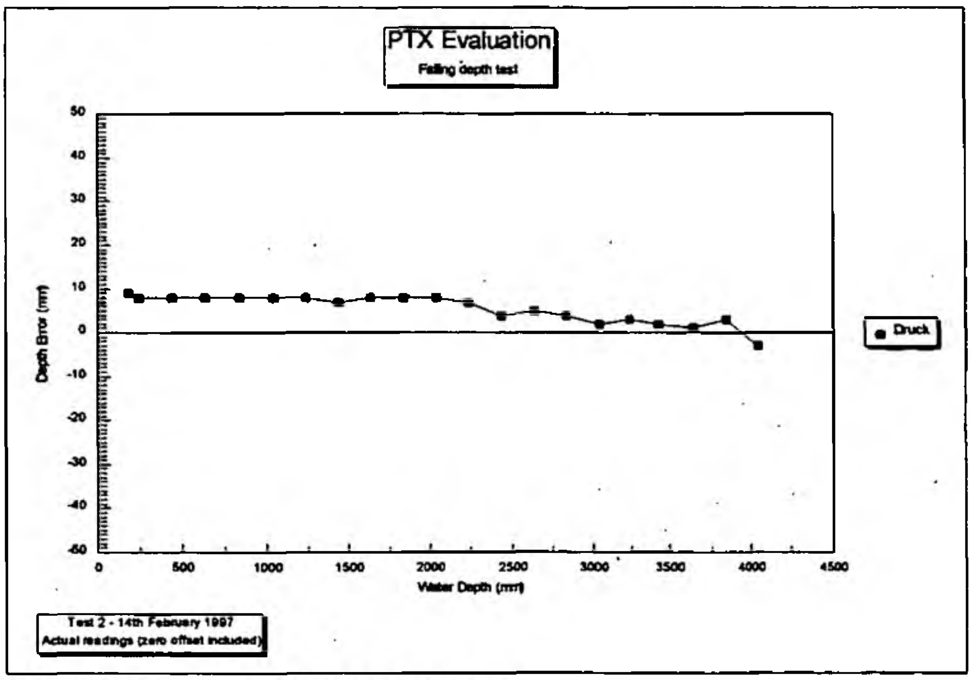
Plot 45 - Sensor 1 rising depth test



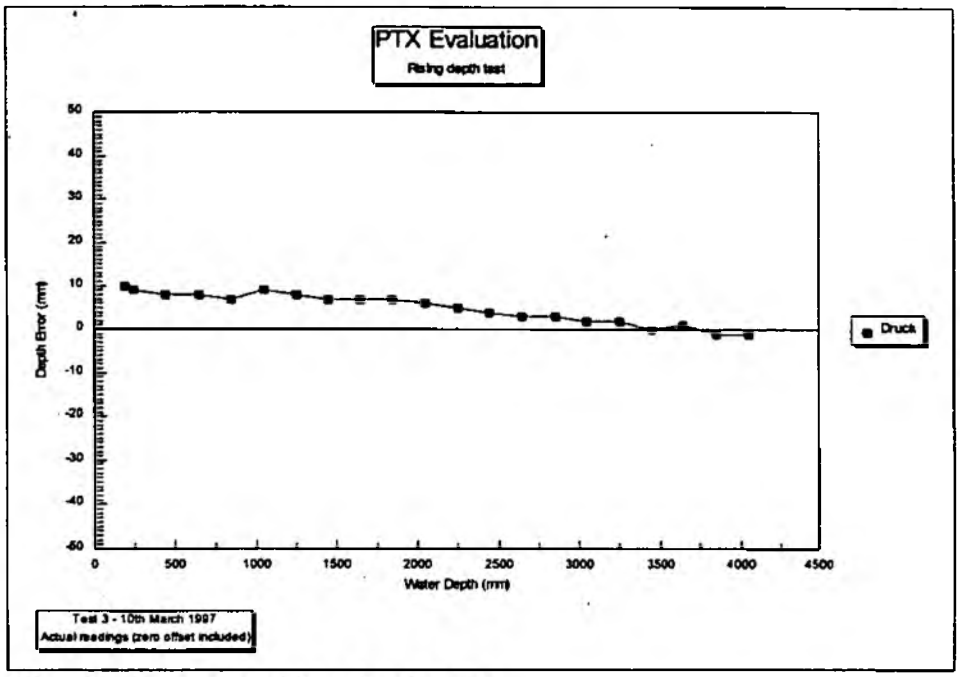
Plot 46 - Sensor 1 falling depth test



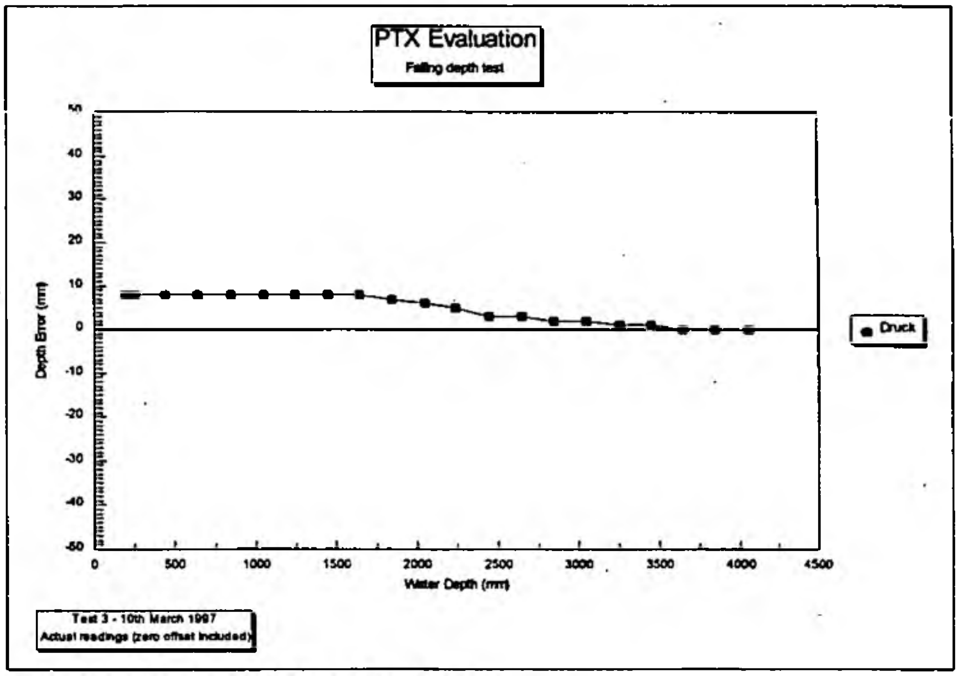
Plot 47 - Sensor 2 rising depth test



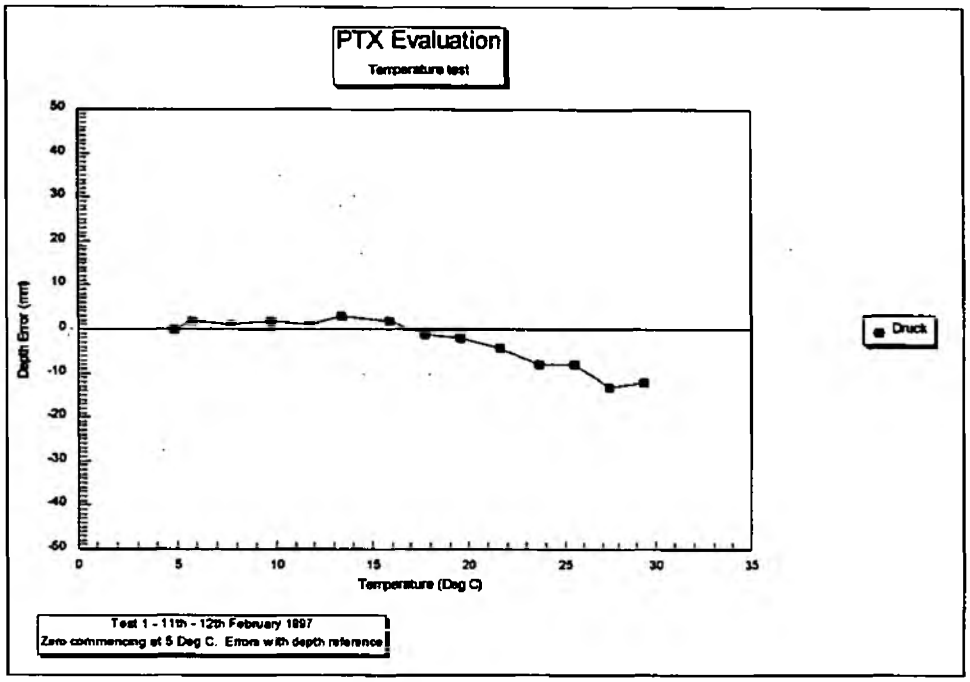
Plot 48 - Sensor 2 falling depth test



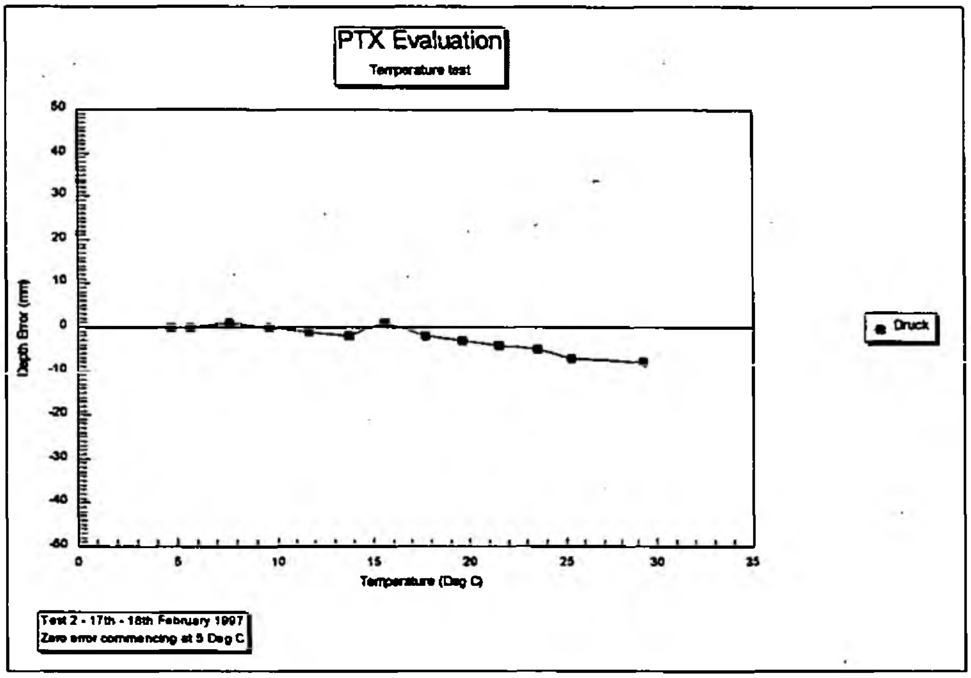
Plot 49 - Sensor 3 rising depth test



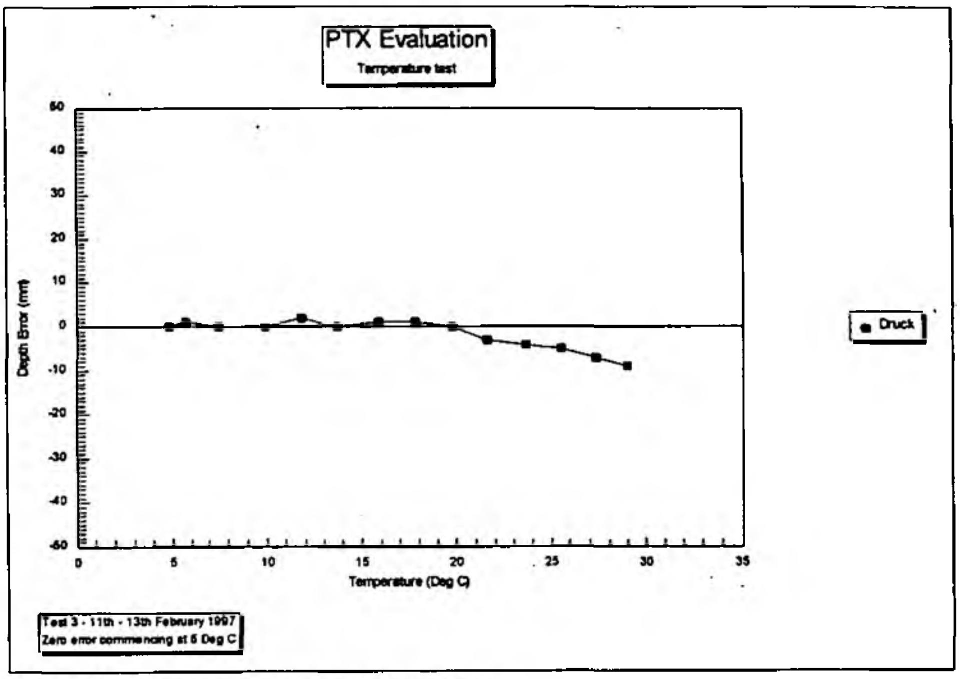
Plot 50 - Sensor 3 falling depth test



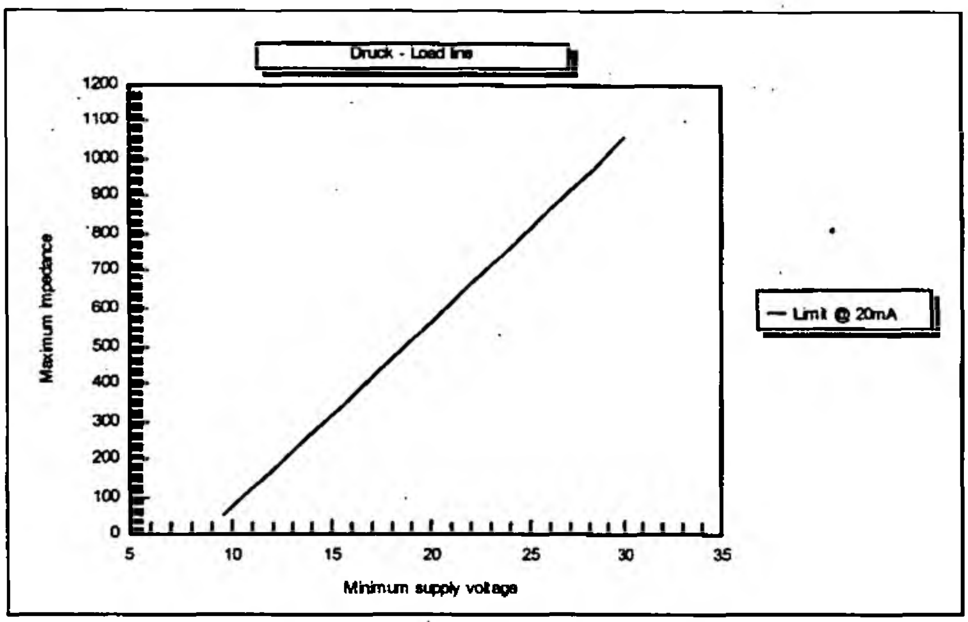
Plot 51 - Sensor 1 temperature test



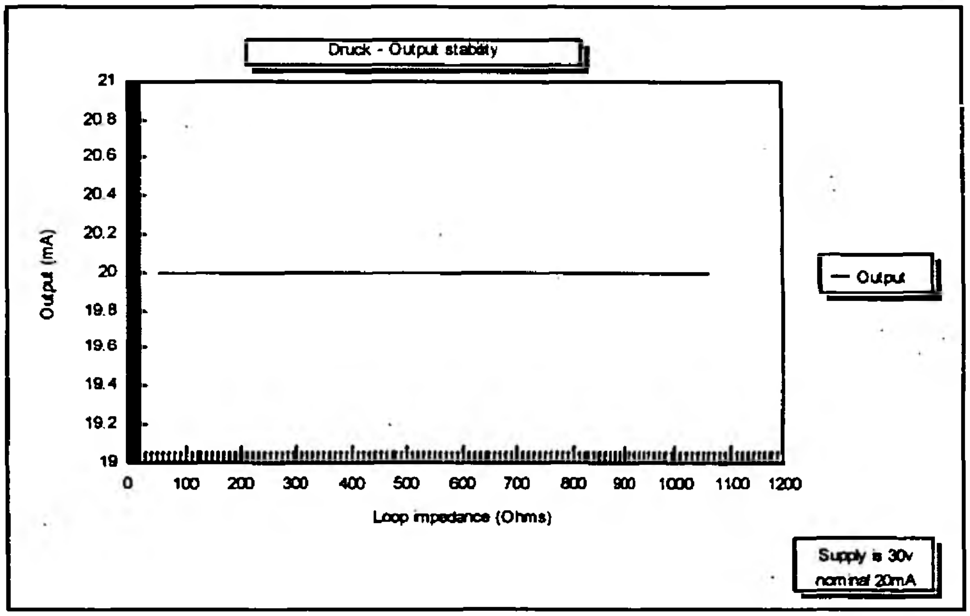
Plot 52 - Sensor 2 temperature test



Plot 53 - Sensor 3 temperature test



Plot 54 - Typical output load characteristic



Plot 55 - Output stability

Appendix A

Specification for the supply of
Submersible Pressure Sensor

Specification IDD/11
7th August 1996

Introduction

The Environment Agency operate a number of level monitoring stations, many of which are used for flood warning as well as collection of water level data at locations where it is not possible to install a full monitoring station. Utilising the effect of pressure increasing linearly with water depth, pressure sensors are one of the most straight forward methods of measuring water depth.

Our current stock of fixed, standard ranges are dependent on application type.
For example, in North West Region:-

Hydrometry and Flood Monitoring (surface waters), have standard ranges of 4 metres, 7 metres, and 12 metres water gauge; and other non-standard ranges varying between 1 metre and 3 metres. Groundwater prefer 1 Bar and 5 Bar ranges.

However, this is not necessarily the case in other regions and therefore a large variety of differing ranges, signal output types, physical size and mechanical construction will be required.

One method of having a minimum stock of sensors would be to have a single sensor that can be user calibrated to the required range, with this point, adjustable as well as fixed range sensors will be considered.

Specification

1 **Construction**

(a) The housing for the sensor should be constructed from a non-corroding material such as stainless steel, hastalloy or titanium. Sensors are occasionally used in saline installations ie: tidal monitoring, and therefore sensors purchased for this type of installation should be constructed from suitable materials able to withstand this type of environment.

In some installations, the external dimensions of the sensor are a critical factor for selection. In some borehole applications, pressure transducers (4 wire types) of external diameter of approximately 10mm are required. In other applications, sensors of approximately 15mm and 30mm maximum are employed.

(b) Sensors are generally preferred to be fixed range without user access to any calibration controls. However, where relevant, access to any calibration controls should be via a user unseal/reseal port, preferably the cable entry point by removing hexagon screws or similar. Any fasteners should be of non-corroding material as described in 1(a).

(c) The cable connecting the sensor to the recording equipment should be of a suitable type for being submerged in water, contain the ventilation tube (Gauge referenced types), and be flexible/strong enough to allow the transmitter to be hung from the cable without any stretching or relaxation of the cable.

The cable should employ an integral material to allow the sensor to hang without stretching, typically this should be Kevlar or similar non-rotting material.

(d) The cable should enter the casing of the sensor using a suitable seal; and the requirement to undertake this is requested to take several options.

For the majority of order requests, permanent potting material is acceptable (fixed range sensors). Additional options are also requested to be made available, these being :-

(i) Stainless steel (or similar non-corroding material) cable gland rated to IP68, to enable the purchaser to attach their own cable during the time of installation or replacement.

(ii) Suitable plug and socket connector rated to IP68; the cable mounting socket incorporating the necessary ventilation tube allowing through connection from the plug fitted to the casing of the sensor. This is also to enable the purchaser to attach their own cable at time of installation and also assist with the replacement of sensor should it become faulty.

2 Accuracy and Environmental

(a) The accuracy is to be +/- 0.2% of calibrated range or better; under all conditions of repeatability, temperature, humidity, electrical supply, and water depth. This figure has been selected from the most stringent operation required of the sensor, that being in applications for hydrometry, where accuracies requiring +/- 0.1% for other types of sensor are not uncommon.

For applications requiring a lesser overall accuracy, a second sensor is required which is to have an overall accuracy of +/- 0.5% of calibrated range or better; under all conditions of repeatability, temperature, humidity, electrical supply, and water depth. This selection of sensor accuracy is made on the basis of cost savings over the +/- 0.2% sensor, but if cost savings are minimal, then only the +/- 0.2% sensor will be required.

(b) The temperature range that the sensor is expected to operate under is 0 - 25 degrees Celsius, although conditions in winter may cause the water surrounding the sensor to become frozen. Therefore under freezing conditions, the sensor should be capable of enduring this without any detrimental effect. Extreme water temperatures are anticipated to be within the range of 0 to -10 degrees Celsius.

(c) The over-range pressure that the pressure sensor should be capable of withstanding without detrimental effect is twice full range pressure. Full range pressure is the maximum range the sensor can be calibrated to, ie:- a nominal 1 bar unit is commonly employed, therefore 2 bar would be the maximum over range pressure expected without any detriment to the sensor.

(d) The pressure connection should be of a standard type, protected by a plastic cap or cover allowing pressure to be measured via small holes etc. Calibration of the sensor is then possible by unscrewing the cap and attaching the sensor to the appropriate calibration system. Therefore standard pressure connections currently in use are M14 x 1.5mm male thread, and 1/4 BSP female thread.

In some previous cases, it has been necessary to add stainless steel weights to the sensor to allow it to hang correctly on the supplied cable (see 1(c)). The pressure connection fitting is used to attach the weight and transfer pressure measurement to the sensor face.

(e) The specific gravity of water is taken as 1.000. Therefore any pressure ranges referred to in metres of watergauge (mWG) use this specific gravity. Should sensors be required to operate in circumstances of different specific gravity such as salt or sea water, the specific gravity will be selected and advised at time of ordering. Adjustable sensors do not apply to this point other than the points raised previously in 1(a) and 1(b).

3 Electrical

The following section refers to 2 wire transmitter systems, the largest requirement for pressure sensor systems to be used for measuring water depth. Other output signal types are discussed in section 4. However, any relevant point made here applies to other output types unless specifically indicated in section 4.

(a) The transmitter is required to be of the two wire type and have a signal range of 4-20mA representing the calibrated range.

(b) Current limiting is required to be employed should over-pressure conditions arise. The limited value should prevent milliampere signals from rising above 25 - 30mA.

(c) The supply to the transmitter is unregulated, and expected to be in the range of 9-30 volts DC. In applications using batteries, the supply is expected to drop to 10 volts before signals are expected to fail. This being because the recording system will generate a volt drop of 1 volt at 20mA signal (50 ohms), hence the minimum operating voltage of 9 volts. Similarly, the sensor should be capable of driving 20mA into a load of 1000 ohms (20 volts drop) at a supply of 30 volts.

(d) The power supply at some installations maybe turned on for a short period before taking a reading, this is expected to be around 3 seconds maximum for each reading to be taken, and at a typical logging period of every 15 minutes. Therefore the sensor should be able to reach stable reading within 1 second or better, following power up.

(e) Calibration (where applicable) is to be via multi-turn potentiometers and where necessary, switches to alter the span (range) and zero (offset) of the instrument. Other methods using remote handsets or standard portable computers (PC's) will be considered, full details must be given for consideration.

(f) The period between recommended calibrations should be 6 months or better.

(g) Protection from lightning damage being induced within the signal/supply cable is not an absolute necessity as protection is installed at the monitoring/recording system for prevention of harmful energy reaching the monitoring/recording system. However, should protection be employed, it is then a preferred option and details should be given.

(h) To meet with recent EEC regulations, the sensor should have Electromagnetic Compatibility (EMC) approval. Details of the approval should be given.

(i) To indicate the wide variety of required instrument ranges, listed here are ranges indicated by all regions of the Agency:- 1mWG, 1.75mWG, 2mWG, 3mWG, 3.5mWG, 4mWG, 7mWG, 10mWG, 12mWG, 16mWG, 20mWG, 30mWG, 40mWG, 75mWG, 90mWG, 350mBar, 1 Bar, 2Bar, 5Bar,

4 Other output signal types

There will also be a need for sensors requiring a different output type, and are generally of the "standard" pressure transducer type, requiring a separate supply. The following gives details:-

(a) **4 Wire sensors**
These are of the type requiring a regulated supply, typically 10 vdc, and a signal output in the order of millivolts representing the measured value. Where applicable, the aforementioned relevant points apply with addition of the following:-

Input impedance (supply)	2k ohms (10v @ 5mA)
Output impedance (load)	50k ohms or better.
Typical ranges	0.3 Bar, 1 Bar, 2 Bar, 2.5 Bar, 5 Bar
External diameter	Some applications requiring as small as 10mm diameter.
Applications	Borehole water level monitoring.
Overall accuracy	+/- 0.2% of calibrated range

Note: In one region, it has been indicated that they use a 3 (4) wire sensor with an output signal of 1 - 5v indicating calibrated range. the general specification for this sensor is:-

Output signal	1 - 5v DC
Supply voltage	9 - 24v DC
Response time	1 second maximum
Input current	3.5mA maximum
Operational temperature	-10 to +20 degC
Accuracy	+/- 0.2% FSD

(b) **Intelligent systems**
Although this is at present an area in its infancy, it is recognised that some manufacturers are starting to produce sensors that output data by means of serial data information, enabling large networks to be constructed using minimal cabling requirements.

Although at present, we are unable to take advantage of such developments, there is a recognised need to keep informed of new developments and to look at ways of being able to interface these developments with our existing and future data collection systems. Therefore if alternative signalling methods are available or under development, we request that the manufacturer provides details.

5 Formal evaluation and the contract

(a) Formal evaluation

During the Tender period, there will be a formal evaluation of manufacturers sensors, from which the main basis of company selection will be placed. The required criteria for the evaluation is that each company must supply at their own cost the following:-

Three, 2 wire transmitters with 4 - 20mA output representing a calibrated range of 0 - 4mWG, and to the higher accuracy quoted in the specification (+/- 0.2%). The cable length is required to be at least 6 metres and of typical construction normally supplied to purchasers.

Each sensor will be tested for accuracy, linearity, repeatability, temperature and electrical stability; and compliance with the specification using testing facilities located in Warrington. The time allowed for the evaluation will be over the last two weeks of the formal tender period, at the end of which all sensors on loan will be returned to the manufacturer.

(b) The contract

These points are to assist the tenderer in producing his response.

(i) As the Agency requires a variety of differing types of pressure sensor, it is expected that the tendering company should offer some sort of broad discount to be applied to what ever product the company supplies in connection with this specification and tender.

(ii) The delivery time from receipt of order is requested to be as quick and as financially reasonable as possible. The Agency considers that a typical delivery time of 4 - 6 weeks is not unreasonable, but should this be not possible to meet, or if some financial variation be available for differing delivery times then the Tenderer should also give details of these as well as his best time to deliver.

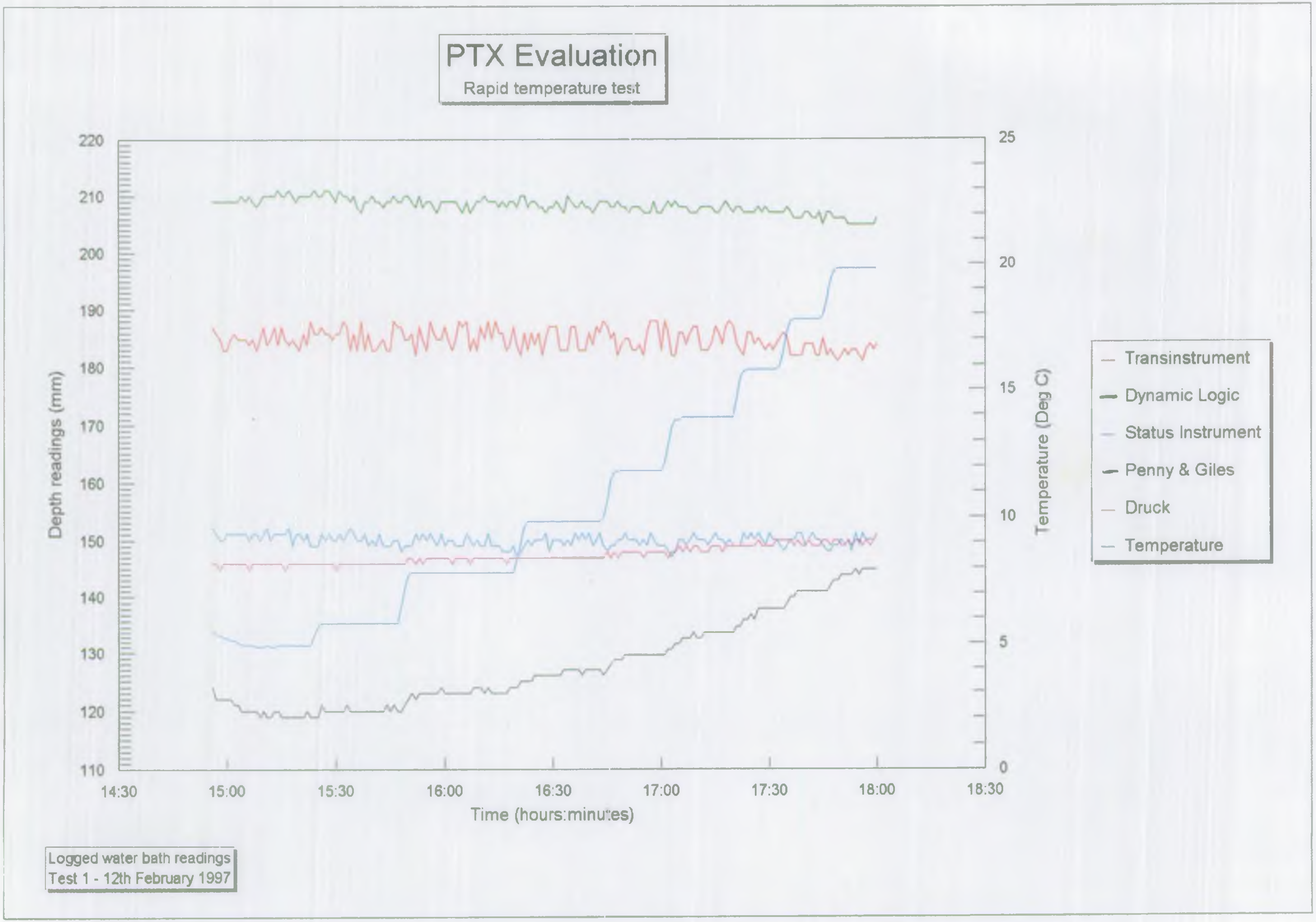
(iii) The cost of delivery should be included within the unit price of any sensor supplied, as detailed in the "Conditions of contract". Therefore delivery will be to any Agency office or contractor premises working on behalf of the Agency, within England and Wales.

(iv) Each region will order as they require sensors, on the basis that they will use a point of reference, identifying the agreed contract with the successful company. Typically, national annual numbers are estimated at 280 units of varying type, though actual numbers are dependent on specific projects and the requirement for replacements.

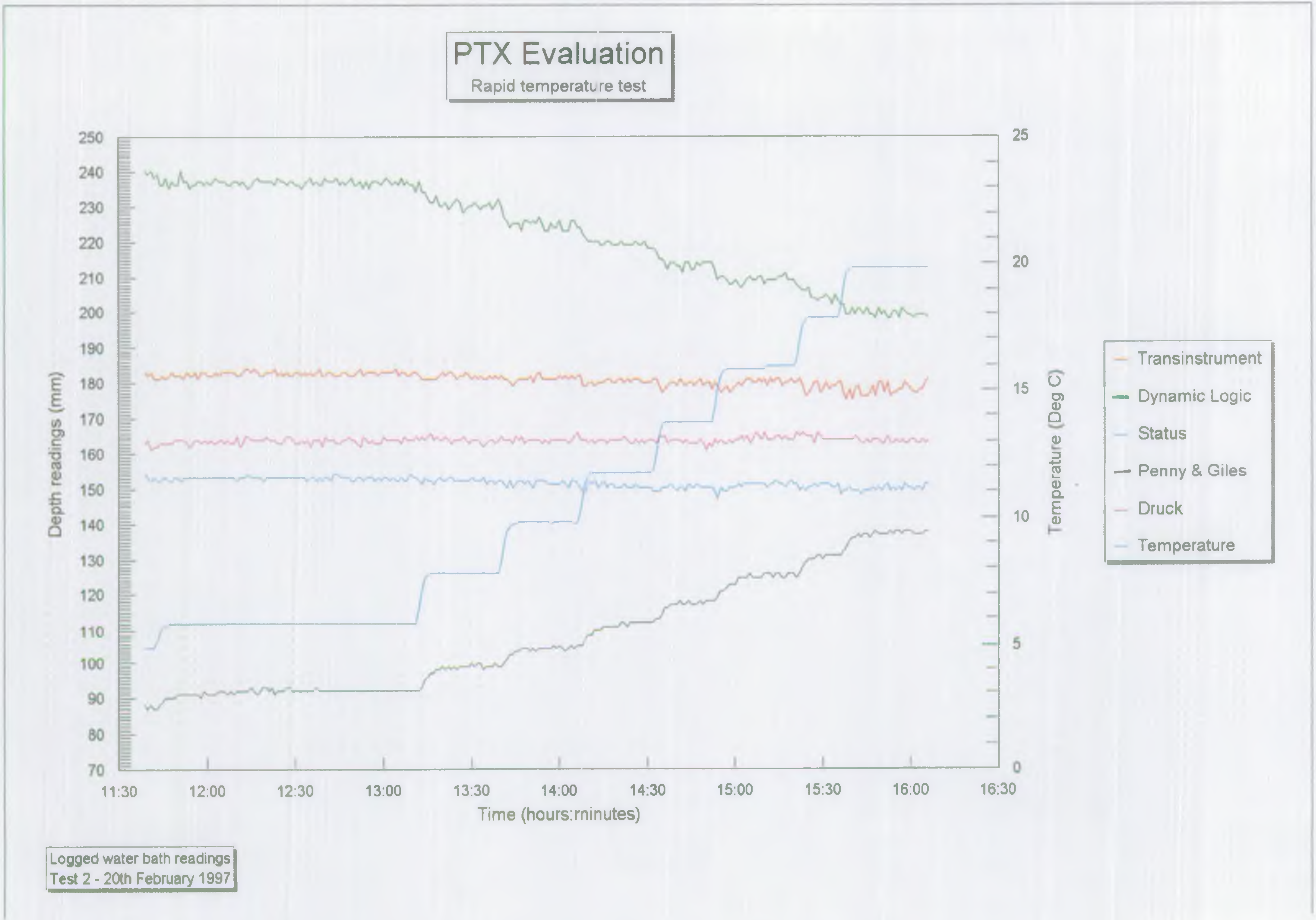
At the time of ordering, the customer will specify the sensor type, pressure connection type, calibrated range, cable length (if they require cable), and the cable connection (permanent potted, cable gland, or removable connector).

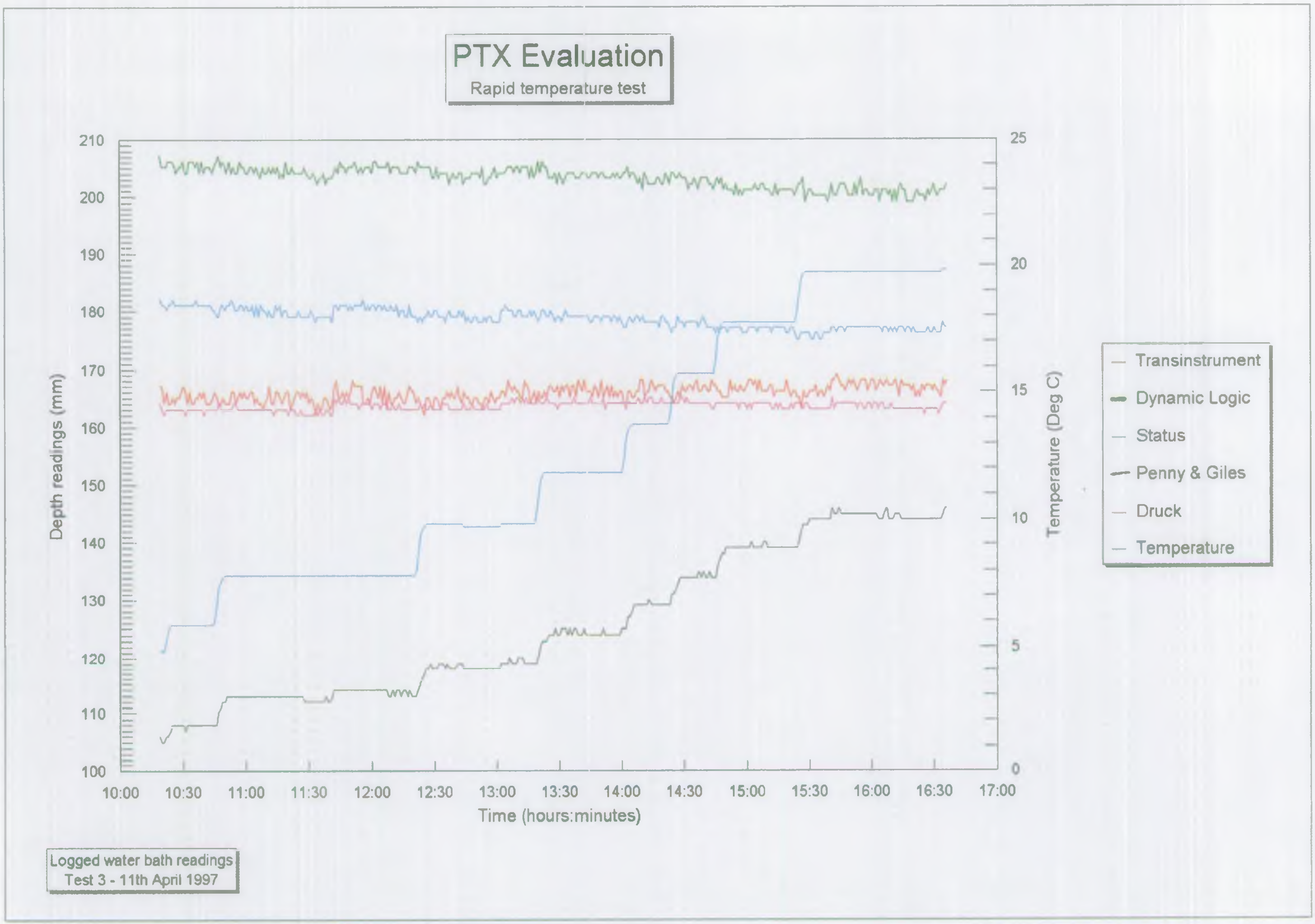
(v) It is requested that the tenderer responds to the specification by stating whether he is fully compliant or not with each point or statement. In circumstance of where the tenderer is not fully compliant, further detail will be required as to his reasons of detraction or variation from the specification. Alternative specification may be considered from the tenderer, but this must be submitted separately, in addition to the standard response.

Appendix B



PTX Evaluation
Rapid temperature test
Depth readings (mm)
Temperature (Deg C)
Time (hours:minutes)
220
210
200
190
180
170
160
150
140
130
120
110
25
20
15
10
5
0
14:30
15:00
15:30
16:00
16:30
17:00
17:30
18:00
18:30
Transinstrument
Dynamic Logic
Status Instrument
Penny & Giles
Druck
Temperature
Logged water bath readings
Test 1 - 12th February 1997


PTX Evaluation
Rapid temperature test
Depth readings (mm)
Temperature (Deg C)
Time (hours:minutes)
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
25
20
15
10
5
0
11:30
12:00
12:30
13:00
13:30
14:00
14:30
15:00
15:30
16:00
16:30
Transinstrument
Dynamic Logic
Status
Penny & Giles
Druck
Temperature
Logged water bath readings
Test 2 - 20th February 1997


PTX Evaluation
Rapid temperature test
Depth readings (mm)
Temperature (Deg C)
Time (hours:minutes)
210
200
190
180
170
160
150
140
130
120
110
100
25
20
15
10
5
0
10:00
10:30
11:00
11:30
12:00
12:30
13:00
13:30
14:00
14:30
15:00
15:30
16:00
16:30
17:00
Transinstrument
Dynamic Logic
Status
Penny & Giles
Druck
Temperature
Logged water bath readings
Test 3 - 11th April 1997

Appendix C

Level Instrument Testing Facility

Environment Agency - Warrington

1 Introduction

The EA hydrometric service currently uses a wide variety of instrumentation at fixed and temporary sites, and for spot measurements. There is a variation in applicability, performance, reliability and cost - it is important that these aspects should be critically assessed to maximise usefulness and value for money for the EA.

Some equipment is made to comply with either British Standards or Meteorological Office Standards. The majority does not comply with any standard and performance can only be judged against the accuracy of measured output and/or the manufacturers specification.

Equipment is generally purchased and installed on a trial basis. Historically, this has been carried out often on an area, or some cases a regional basis. There has been little or no standardisation of evaluation techniques, objective analysis of results, and more importantly communication of recommended outcomes. The result of this approach benefits only the supplier. The salesman will benefit from a number of sales to different officers of a system that may already have been discounted by one region/area due to its inadequacies.

Conversely, it can also be a hindrance to the development of a promising system if several differing demands are made from different sources, which may overstretch the resources of the supplier. It should be recognised that there are many small suppliers who have limited R&D funding available for new instruments.

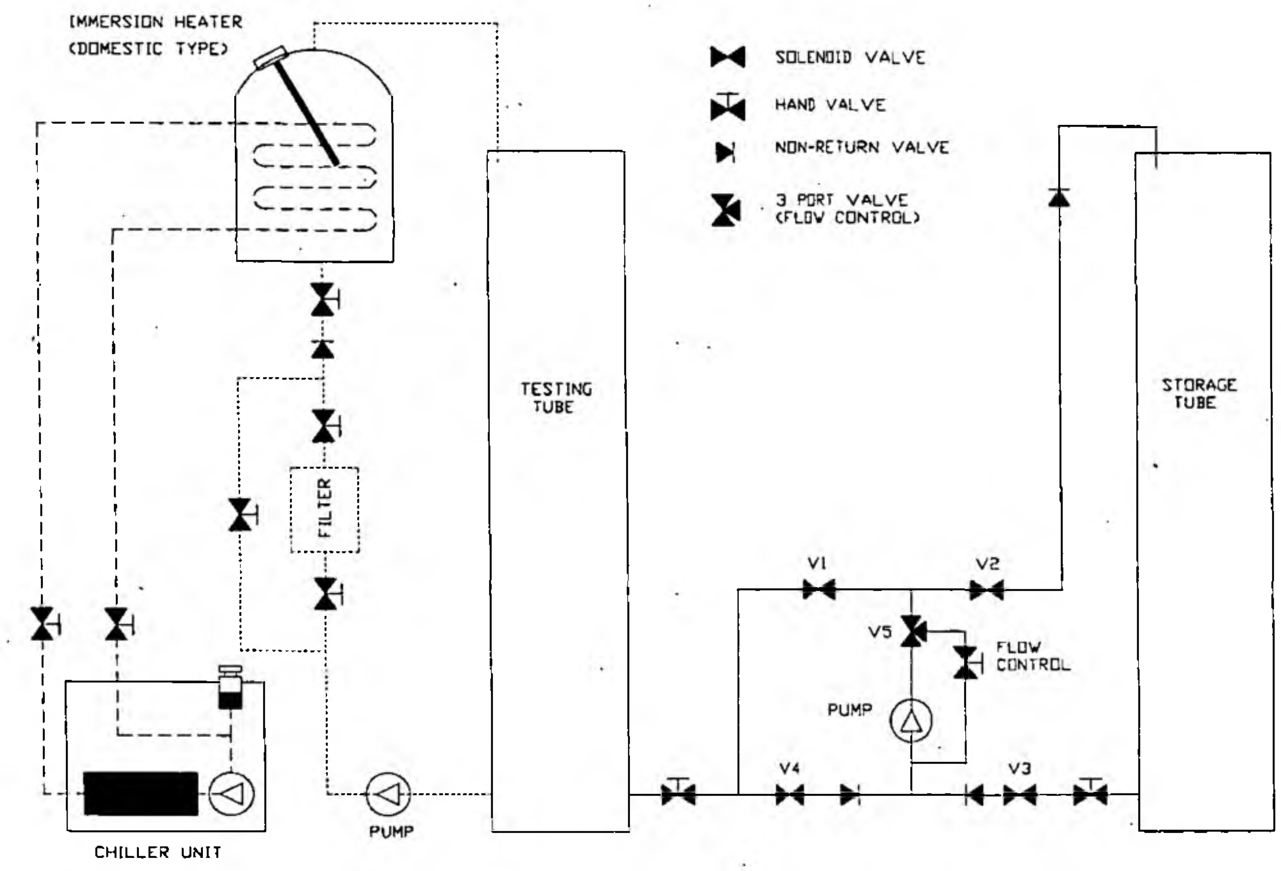
Another problem is the recommendation of equipment suitability based on it being used in other regions. Often new equipment is limited in its applicability and although may be performing well at one type of installation, the suitability may not transpose to another site. Salesmen are generally not experts in uses, application and installation limitations of their equipment.

2.1 Evaluation

The North West Region of the Agency has recognised the need to test instrumentation against the manufacturers own specification using a facility specifically built to enable the simulation of water levels typically found in rivers.

The test rig is basically a column of water, 300mm in diameter, that can be raised or lowered at the push of a button. The maximum level that can be acheived is a little over 4 metres, which can also be temperature controlled between 5 - 30 degrees Celsius. Limit switches and over temperature protection has been included in the design, to shut the system off should inadvertent operation occur.

The water is re-used during each test, and is stored in a similar vertical tube, located adjacent to the testing column. Water is pumped either in or out of the testing column, depending whether the water level is required to be raised or lowered.



2.2 The Test Rig

The diagram above represents the main components of the water level testing facility. Three areas can be seen, the valve and pump arrangement for filling and emptying the rig (solid line), the temperature circulation loop (dotted line) and the cooling loop (dashed line).

Level control
The water is either pumped in or out of the test tube at the same point. This maintains where required, a stable, non-turbulent water level. Included with the flow direction valves, is a three port valve to control the flow rate, and hence the rate of rise or fall of the water level. A future enhancement to the rig could enable a specific hydrograph to be followed by controlling the flow rate valve.

Temperature control
Water is taken out of the rig and passed through a domestic water heating cylinder. An electric heater is used to warm the water as it passes through it, before returning it to the top of the rig. Built into the domestic heater tank is a separate pipe loop normally used to heat the water from a domestic heating system. In our case, this is used to cool the water.

Cooling circuit
This loop is totally separate from the rig water, especially as it contains anti-freeze to enable it to operate efficiently. The water is pumped through the domestic heating cylinder, through the sealed pipe loop and back down to the chiller unit. Typically, the loop operates at 5 - 7 degrees Celsius below the required operating temperature. Therefore, if an efficient control of 5 degrees

Celcius is required, the cooling loop will be operating at approximately -1 to 0 degrees Celsius, depending upon the actual ambient temperature. Ambient temperature is typically 16 - 20 degrees Celsius.

3 Testing method

3.1 Level test

The level test mainly consists of comparing the instrument under observation with a known standard. The standard in our case is a contact probe, with a measuring tape attached. The probe itself will measure water level far more accurately than any other instrument in use - though it does relie on the skill of the operator.

Water is pumped into the rig in stages, and readings taken once the water level is stable. The instrument reading and the reference level are noted down together.

Once the the limit of the instrument or test rig is reached, the direction of water travel is reversed, and readings taken in a similar manner as before. The readings taken on rising cycle can be compared with readings on the falling cycle to observe any hysteresis that may be present in the instrument.

3.2 Temperature test

In order for this test to proceed the rig has to be filled to the instrument range or the limit of the rig. This is so the instrument under test is put under the conditions most likely to indicate any errors. The water is then circulated through the temperature control system, until temperature control is acheived. Typically, preparation for temperature testing is made several hours before it is required. It is easier to warm up the water in the rig than cooling it down, as cooling from 20 deg C to 5 deg C can take several hours depending upon ambient temperature; so normally, the temperature tests are conducted from cool to warm.

The proceedure is to run the circulation pump during temperature control, and stop it when the temperature is stable and readings are required to be taken. As in the level test, the instrument level reading and the reference level reading are taken together, along with a reference temperature reading taken from a temperature probe in the vacinity of the sensor under test. Typically, 2 deg C steps are taken between readings, and the time allowed to stabilise can be around 1 hour.

Appendix D

Reference	Ch.1	Ch.2	Ch.3	Ch.4	Ch.5	Ch.6	Ch.7	Ch.8
0	0	0	0	0	1	1	1	0
1000	1001	1001	1001	1001	1002	1002	1002	1001
2000	2002	2002	2002	2002	2003	2003	2004	2003
3000	3003	3003	3003	3003	3004	3004	3005	3004
4000	4003	4003	4004	4003	4005	4005	4005	4005

Calibration results for DT50 logger, used for evaluation.

Reference is Druck/Unomat II, Serial No. 14091

Program listing for DT50 logger, used for the evaluation.

```
'Program 8ch S/E ip ptx and pt100 logger
'-----------------------------------------------
/c/n/u/m/o/P
P22=44
P15=1

S1=-2,3990,400,2000   'Set ptx1 cal
S2=-3,3988,400,2000   'Set ptx2 cal
S3=2,4010,400,2000   'Set ptx3 cal
S4=-1,3996,400,2000   'Set ptx4 cal
S5=1,4005,400,2000   'Set ptx5 cal
S6=0,3999,400,2000   'Set ptx6 cal
S7=-3,3984,400,2000   'Set ptx7 cal
S8=0,4004,400,2000   'Set ptx8 cal
S9=0,1000,0,1000   'Set pt100 cal

10..20CV(W)=0

BEGIN
'------------------------------------
'Schedule to take readings and output on serial port

RA10S
1DSO(1000,W)=1     'Turn output on for time
1+V(X,T,S1,=1CV,W)   'Read and scale ptx1
1-V(X,T,S2,=2CV,W)   'Read and scale ptx2
2+V(X,T,S3,=3CV,W)   'Read and scale ptx3
2-V(X,T,S4,=4CV,W)   'Read and scale ptx4
3+V(X,T,S5,=5CV,W)   'Read and scale ptx5
3-V(X,T,S6,=6CV,W)   'Read and scale ptx6
4+V(X,T,S7,=7CV,W)   'Read and scale ptx6
4-V(X,T,S8,=8CV,W)   'Read and scale ptx7
5PT385(4W,S9,=9CV,W) 'Read and scale pt100
1DSO(W)=0
'Log readings
'-----------

D
T
1CV(FF0)
2CV(FF0)
3CV(FF0)
4CV(FF0)
5CV(FF0)
6CV(FF0)
7CV(FF0)
8CV(FF0)
9CV(FF1)

END

LOGON
G
```