

**FIELD TESTS OF THE AANDERAA PRESSURE
LOGGER WITH PNEUMATIC TIDE GAUGES,
AND THE DESIGN OF ASSOCIATED PNEUMATIC
CONTROL CIRCUITS**

by

A. Browell and D. T. Pugh

Report No 37

1977

**INSTITUTE OF
OCEANOGRAPHIC
SCIENCES**

NATURAL ENVIRONMENT
RESEARCH COUNCIL

INSTITUTE OF OCEANOGRAPHIC SCIENCES

**Wormley, Godalming,
Surrey, GU8 5UB.
(0428 - 79 - 4141)**

(Director: Professor H. Charnock)

**Bidston Observatory,
Birkenhead,
Merseyside, L43 7RA.
(051-653-8633)**

(Assistant Director: Dr. D. E. Cartwright)

**Crossway,
Taunton,
Somerset, TA1 2DW.
(0823-86211)**

(Assistant Director: M.J. Tucker)

**Marine Scientific Equipment Service
Research Vessel Base,
No. 1 Dock,
Barry,
South Glamorgan, CF6 6UZ.
(04462-77451)
(Officer-in-Charge: Dr. L.M. Skinner)**

*On citing this report in a bibliography the reference should be followed by
the words UNPUBLISHED MANUSCRIPT.*

FIELD TESTS OF THE AANDERAA PRESSURE
LOGGER WITH PNEUMATIC TIDE GAUGES,
AND THE DESIGN OF ASSOCIATED PNEUMATIC
CONTROL CIRCUITS.

A. Browell and D.T. Pugh

REPORT NO 37

1977

Institute of Oceanographic Sciences
Bidston Observatory
Birkenhead, Merseyside L43 7RA

Abstract	1
Introduction	2
Description of instrument	4
One month comparison with Neyrpic gauge	4
Van de Castelee tests at Gladstone Dock	5
Datum stability	7
Pneumatic circuitry design	7
Conclusions	10
Acknowledgements	10
References	11
Appendix 1. Commissioning procedure and testing of pneumatic equipment	
Appendix 2. Pneumatic circuitry component details	

Abstract

Aanderaa Instruments Ltd., Victoria, British Columbia, market a 'water level gauge' which monitors pressure at selected intervals and stores the values on magnetic tape. The pressure is sensed by a quartz crystal transducer, manufactured by Paroscientific, whose claimed characteristics of zero stability and insensitivity to temperature are superior to anything else commercially available.

This report summarises the results of two field tests of the gauge, when used as the recording part of pneumatic tide gauge systems. A Van de Castele test showed a standard deviation of 2.7 mm in the difference between measured and actual water levels over a tidal cycle. Because the transducer is very expensive, the pneumatic control circuitry has been redesigned to protect it against overload, and to simplify operating procedures. For use with pneumatic systems a differential pressure transducer is found to be most suitable.

However, the absolute pressure version of the instrument has an application as an open-sea tide gauge, and extensive tests have been made by the Research Technology Group at Bidston, for both applications. Details of these laboratory tests and of open-sea deployments are not included here, but will be published in a later report.

1. Introduction

Since 1970 the Institute of Oceanographic Sciences', Bidston Laboratory, has used pneumatic tide gauges extensively for measurements of water level at temporary coastal stations and from off-shore rigs. Pneumatic systems, normally used in the bubbling mode, are very versatile and much more easily installed than conventional stilling-well gauges. They have been used with up to 460m of connecting pressure tube between the underwater outlet and the recorder. The standard recorder for these measurements has been the Neyrpic 'Telimnip' which, because it balances a column of mercury against a column of seawater, has good datum stability and absolute accuracy (better than 0.02m with careful handling, Pugh (1971)). However, friction in the mechanically operated float-pen mechanism and the friction of the float in the manometer tube require careful control if significant back-lash errors are to be avoided. Furthermore, the limitations of chart recording apply: finite chart length, the need for humidity control for dimensional stability, occasional erratic transport, and the time required to extract data by eye, prior to treatment by computer.

The requirements for a coastal gauge to be used with pneumatic systems may be summarised :-

- a) a sensitivity better than 0.01m of water head equivalent (1.0 mb or 100 nm^{-2})
- b) a datum stability of the order of 0.01m of water head equivalent over a period of months
- c) automatic logging in a form which is easily converted for computer processing, without attention for at least 4 months
- d) pressure averaging over a selected period to eliminate errors due to waves

Requirement b) is the most difficult to satisfy. However, requirement a) has an implicit condition that the 'secondary sensitivity' of the transducer to temperature shall be less than 0.01m over an operating temperature range of at least 10°C . Requirement c) arises because gauges are often installed

at remote sites, but it is thought that intervals of longer than 4 months between visits are unlikely because the underwater tubing would also need to be checked.

The laboratory of Aanderaa Instruments at Victoria, British Columbia now market an instrument whose specifications meet the above requirements. The most important component, the pressure transducer, is a quartz crystal, manufactured originally for aeronautical applications, by Paroscientific, Redmond, Washington State. Signals from this are integrated and logged at selected intervals on the conventional Aanderaa magnetic tape logger which has proved reliable in the Aanderaa (Bergen) current meter. Translation and processing facilities for this logger were already established at Bidston, which was an additional advantage.

Laboratory and field tests have been made on a number of these gauges at Bidston since March 1974, both with pneumatic systems and for deployment as bottom-mounted open sea gauges. Initially, laboratory calibration of pressure and temperature sensitivity were made on an absolute pressure gauge (TG1A, No 11). Sensitivity to tilt was also monitored. This instrument was connected into the pneumatic tide gauge on the Inner Dowsing light tower in January 1975 for a one month run in parallel with a Neyrpic gauge. This instrument was later returned to Aanderaa because its temperature response exceeded the specifications. A differential version (TG2D, No 69) was fitted to a pneumatic system on the Conoco platform A-R ($53^{\circ}32'N$, $2^{\circ}15'E$) in May 1975 but this was later found to have been damaged in shipment. A replacement gauge (TG2D, No 94) operated on the Conoco rig from February 1976 to September 1976. The Committee on Tide Gauges planned to instal another gauge (TG2D, No 105) on a Shell-Esso gas rig ($53^{\circ}05'N$, $2^{\circ}08'E$) and before deployment a full Van de Castele test was made in Gladstone Dock stilling well. New pneumatic control circuitry developed for this rig was also tested. The purpose of the new circuitry was to ease operations in the field, and to provide protection to the expensive (ca £1000) quartz crystal transducer against accidental pressure overload.

This report contains details of the field tests relevant to the use of the instrument in conjunction with pneumatic bubbler

systems for coastal water level measurements, and of the pneumatic circuitry designed to operate these systems.

2. Brief instrument description

Two basic models are now available, Series 2, which records pressure, and Series 3 which records pressure, temperature and elapsed time.

Series 2 has standard sampling intervals of 15 and 30 minutes, with wave-averaging integration times of 2s, 18s, 100s or 14 minutes. 30,000 samples may be stored, which means a recording limit of 312 days. Sampling may be initiated at any time by external triggering.

Series 3 has standard sampling intervals of $3\frac{3}{4}$, $7\frac{1}{2}$, 15, 30, 60 and 120 minutes and a constant integration period of 28s. An acoustic transducer is fitted. The recording limit is 156 days.

Both series may be supplied with absolute pressure crystals for the ranges 10m, 30m, 150m and 300m, or with a differential crystal for the 20m range. For pneumatic systems the differential version is normally best as atmospheric pressure variations are automatically eliminated, and only water head pressure is recorded. The guaranteed recording accuracy is 0.01% of range, with a recording resolution of 0.001% of range. For the 30m range this is 0.3mm and 0.03mm. These accuracies are for temperature variations -5°C to $+35^{\circ}\text{C}$.

The equipment is housed in a cylindrical pressure container of 0.125m diameter and the overall length is 0.50m. The weight in air is 15kgm. Figure 1 shows the gauge and the associated pneumatic control circuitry.

3. One month comparison with a Neyrpic recorder

A pneumatic tide gauge system with a Neyrpic recorder has been in operation on the Inner Dowsing light tower since 1971. An absolute Aanderaa gauge (TG1D No 11), having a 150m range, was fitted in parallel with the Neyrpic recorder from 22nd January 1975 to 19th February 1975, and set to sample and record system pressure at 10 minute intervals.

The magnetic tape was translated at Bidston and readings converted to pressure using the manufacturer's calibration of February 1974. These were then converted to hourly pressures and harmonically analysed for tidal constituents. Atmospheric pressures were not removed before analysis. Simultaneous data from the Neyrpic gauge was analysed in the same way, except that atmospheric pressure is automatically eliminated. The results for four principal constituents are shown in Table 1.

The gauge was known to have a slight temperature sensitivity but no correction was made for this, which probably explains why the phase of K_1 and the amplitude of S_2 show the largest divergence. Nevertheless the agreement is very good.

After this test the gauge was returned to the manufacturer for exchange with a TG2D model. One puzzling feature of both the analyses which is not relevant to this report, is the large discrepancy between the value obtained for the amplitude of K_1 , and that obtained from the analysis of a year of data (0.151m).

4. Van de Castelee tests at Gladstone Dock

The Committee on Tide Gauges purchased a TG2D (No 105), 30m range, for installation on the Shell-Esso gas production rig ($53^{\circ}05'N$, $2^{\circ}08'E$) in the North Sea. Before installing the gauge on the rig a full Van de Castelee test was made in the stilling well at Gladstone Dock, Liverpool, on 9th December 1976. The purposes of this test were :-

- a) to establish the Aanderaa system in a way which enabled comparison with gauges which had been tested previously,
- b) to test the pneumatic control circuitry which had been designed and built for the Shell-Esso installation, prior to adopting it for other Aanderaa installations.

The recorder was connected into a standard pneumatic bubbler system, with a pressure point outlet approximately 0.6m below well datum, and a gas flow rate of 10 ml per minute at atmospheric pressure. Well levels were measured using an electrical contact probe with a resolution of 1 mm. Over a period of a spring tide a set of readings of the well level were taken to coincide with

the 15 minute automatic recording cycle of the Aanderaa gauge. The Aanderaa was set to integrate the frequency output from the Paroscientific transducer over a 100s period. Each set of 15 minute readings consisted of five readings of well level at 30s intervals, the central reading being timed to coincide with the middle of the 100s integrating period. The means of these five values were then calculated. At high water a temperature/salinity profile in the well was made using a previously calibrated bridge (Figure 2).

Aanderaa frequency counts were converted to pressure using a parabolic least-squares fit to calibration data at 1, 0.1, 0.5 and 1.0 bars, determined by P.R. Foden in May 1976, at 4°C. The temperature during the Van de Castele test was 6°C. The pressures were then corrected for a) pressure drop due to the static gas pressure head in the tube (a maximum of +25 mm at high water) and b) the dynamic effects of gas flow along the tube (virtually constant at -1 mm throughout the test). These corrected pressures at the pressure point outlet were then divided by the mean water density (Figure 3) which changed with the level being recorded, and by the appropriate value of gravitational acceleration (9.8136 ms^{-2}), to give the level of water above the outlet. Atmospheric pressure variations were automatically eliminated because of the differential transducer.

An interesting systematic error showed when the Aanderaa readings were converted to pressure using a curve fitted at 1.5 bars and 2.0 bars in addition to the points in the range 0 to 1.0 bar. Pressures were systematically too high, showing the it is important to have several calibrations in the range to be measured.

The normal plot of the differences between computed and measured well levels, after correcting for the level of the pressure point below well datum, is shown in Figure 4. Five values which gave large errors have been omitted because they were associated with timing uncertainties in the readings. The least squares line through the plot is :-

$$\begin{aligned} (\text{TG2D} - \text{Well Level}) &= (3.9 \pm 1.0) + (0.54 \pm 0.16) \text{ Well Level} \\ &\text{in mm} && \text{(m)} \end{aligned}$$

with a standard deviation of 2.73 mm. There is a small systematic difference between readings on the rising tide (mean = -0.7 ± 0.6 mm) and on the falling tide (mean = 2.6 ± 0.6 mm), consistent with a hysteresis in the Aanderaa gauge. This same effect was noticed during the laboratory calibrations.

The gradient on the mean line may be due to a calibration error in the Aanderaa (it is apparent that the differences are symmetrical about the 4.4 m well level, which corresponds to the calibration point at 0.5 bars). However, the error is only 5mm in 10 m, equivalent to a difference of 0.0005 ms^{-2} in gravitational acceleration, which in turn is equivalent to 5° of latitude. Alternatively an overestimate of well density of 0.5 kg m^{-3} would produce the same effect. The standard deviation from this straight line is extremely small, and may be due in part to errors in measuring the well level with the electrical probe. At mid-tide the level was changing by 1 mm every 1.8 seconds, which emphasises the importance of the correct timing of readings.

5. Datum stability

Datum stability may be expressed in terms of the zero pressure output count for a TG2D or TG3D gauge when open to atmospheric pressure at both ports. Model TG2D, No 94, was deployed on a Conoco gas rig during 1976 and visited at intervals by D.L. Leighton. The zero pressure output counts are summarised in Table 2. For this gauge a count change of 100 is approximately 0.01 m of water head, so that for this particular case the zero varies by 2 mm from the mean count for this particular transducer. The specified zero stability is 0.008% of full scale in 6 months.

This gauge performed without fault during the period from February to October 1976, although useful records ended in September when the underwater pressure point was damaged.

6. Pneumatic circuitry design

This section deals with the design of the auxilliary pneumatic equipment necessary for the operation of an Aanderaa gauge in a pneumatic tide gauge system.

In the design particular consideration has been given to the delicate nature of the quartz transducer, and the need to protect it against over-pressurisation and to provide additional protection against external mechanical shock. The control equipment is required to supply gas (air) at a controlled flow rate to a submerged pressure point, with the object of presenting a pressure, related to the head of sea water above the pressure point, to the pressure transducer and recorder. This equipment is required to operate for long periods in a saline environment, in some cases for several years, with a design period of four months between services. A facility to enable the underwater pipeline to be purged is also necessary. The system is illustrated in Figures 1 and 5.

The air supply should last for at least 200 days as this is the approximate lifetime of the gauge batteries in normal operation, and well in excess of the design interval between services of 4 months. As for Neyrpic deployments, compressed air is supplied from standard diving cylinders which supply dry air and have the advantage of being easily recharged at any diving shop. Cylinders are normally charged to 200 bars and in this case two standard 1.5 m^3 (55 cu.ft.) cylinders connected in tandem are capable of maintaining an air supply to atmosphere of 10 ml per minute for approximately 200 days.

To obtain a controlled flow pressure to the control equipment (normally 3 to 5 bars), an adjustable pressure reducing valve is fitted directly to the air cylinder manifold. The reduction valve normally used has a maximum outlet pressure of 10 bars and a maximum flow rate well in excess of that required. The dual pressure gauge indicates both the reduced pressure and the air cylinder pressure content.

Two pressure gauges are used, both having 0.10 m (4") diameter dials, one gauge having a range of 0 - 2 bars and the other a range of 0 - 6 bars. Both gauges are flush mounted on the panel and have $\frac{3}{8}$ " B.S.P. connections. The 0 - 6 bar gauge monitors the input pressure and the 0 - 2 bars gauge shows the measured water head pressure in the output system. Both gauges are of normal commercial quality.

The flow meter used in the equipment is adjustable up to 20 ml. per minute for air at 15°C and atmospheric pressure. This controls the flow rate from the high pressure side to the operational pressure side of the system. Details of how to calculate the appropriate flow rate for a particular installation are given by Pugh (1976).

Two pressure relief valves of the "popoff to atmosphere" type are employed. One valve is used on the input side to protect the - 6 bar pressure gauge and the flow meter, and has an adjustable cracking pressure range from 3.5 to 10 bars. The second valve is used to protect the output circuit system and has the vital function of guarding against overloading the Paroscientific quartz crystal pressure transducer in the Aanderaa recorder. The cracking pressure of this valve is 0.7 to 3.5 bars. Both valves have $\frac{1}{4}$ " male NPT connections.

The valves for function selection are high quality ball valves having top loaded TFE packing seals to ensure freedom from leakage at high or low temperatures. The valves have an orifice diameter of 3.5 mm and a maximum pressure rating of 200 bars at 20°C. All connections are $\frac{1}{4}$ " Swagelock.

All connections to the control panel are of the "snap on" type being self sealing when broken. This type of connector was chosen both for ease of operation in the field and to provide a test facility for the pressure relief valves and also for leak testing of the internal pipework. Except for the inlet gas supply, all connections were so arranged that terminations were made in the female (self sealing) element of the coupling, thus eliminating the need for further isolating valves.

Two manifolds are used in the circuit, manufactured from 37 x 25 mm ($1\frac{1}{2}$ " x 1") brass bar and machined to suit the various connections required. The piping is $\frac{1}{4}$ " O.D. annealed copper with terminations into $\frac{1}{4}$ " Swagelock compression fittings except for the manifolds where joints are self soldered.

The completed control panel and the Aanderaa recorder are housed in a standard 0.53 x 0.53 x 0.22 m (21" x 21" x 9") pressed steel cabinet, the only external equipment being the air storage cylinders and the pressure reducing valve. To minimise mechanical

shock the Aanderaa is arranged to be freestanding on a spring loaded base plate and held near the top in a neoprene lined split clamp arranged so that, when tightened, the clamp permits the recorder to move vertically and thus allow the spring to dissipate energy from vibration.

Details of the field use of the equipment are given in Appendix 1, and a list of components is given in Appendix 2.

Conclusions

1. The Aanderaa gauge with the Paroscientific pressure transducer has a standard deviation of less than 3 mm from a least squares line fitted to the difference between the gauge and the well level, on a Van de Castele test. Harmonic analyses of simultaneous Aanderaa and Neyrpic observations give good agreement.
2. For use with pneumatic tide gauge systems the TG2D is better than the TF3D because it has a longer operating life, may be externally triggered, and the integration times are selectable.
3. The gauge meets the requirements for coastal water level measurement. It is proposed to use a number of Aanderaa gauges, as standard loggers at temporary coastal water level stations. These systems will incorporate the pneumatic circuitry described in this report.

Acknowledgements

This work has been done in cooperation with several members of the Bidston laboratory staff; particular mention is made of the work done by D.L. Leighton on gauge deployment, by A.J. Harrison and his section on instrument evaluation, and by W. Ainsow and I. McDermott during the Van de Castele test.

The work described in this report was funded by a Consortium consisting of the Natural Environment Research Council, the Ministry of Agriculture Fisheries and Food, and the Departments of Energy, the Environment and Industry.

References

- PUGH, D.T. 1971 Sea level measurements using the Neyrpic bubbler pressure gauge. Institute of Coastal Oceanography and Tides Internal Report No 22.
- PUGH, D.T. 1976 The design of coastal tide gauges. Hydrographic Society Proceedings, Special publication No 4. 51-73.

Appendix 1

Commissioning procedure and testing of pneumatic equipment

This section is to be read in conjunction with Figure 5.

Commissioning

1. Assuming the Aanderaa recorder to be connected to the control panel and all the necessary external connections made, proceed as follows. Ensure that the control wheel on the reducing valve (3) is screwed back (anti-clockwise) as far as it will turn, and that valves (7) and (8) are in the CLOSED position. Slowly open the isolating valve(s) (2) on the compressed air cylinder(s) (1) to their full extent. The pressure in the storage cylinders can now be read on the inner scale of the dual pressure gauge on valve (3). This pressure should be about 200 bars on newly charged cylinders. Screw the control wheel on the reducing valve (3) in slowly until the required supply pressure is shown on the gauge (9) having the 0 - 6 bar range. The required pressure would normally be 3 bars, and is common to the manifold (4) together with the pipework up to the input of the 3-way ball valve (7). The pressure relief valve (6) is common to the manifold (4) and is provided to protect the pressure gauge (9) and the flowmeter (11) against excess pressure; the 'blow off' pressure of the relief valve (6) should normally be set to 5 bars.
2. The flow rate is set and measured as the volume flow to atmospheric pressure. To open manifold (5) to the atmosphere, connect an open-ended male half of a 'snap-on' coupling to the connection marked WATER HEAD MONITOR. Turn valve (7) to OPERATING to allow air to flow to the input of the flow meter. Adjustment of the serrated control knob will vary the rate of flow, which can be read directly from the graduations on the glass tube of the flow meter. Having set the desired flow rate (Pugh (1976)), return valve (7) to CLOSED and remove the open-ended male section of the 'snap-on' connector from the WATER HEAD MONITOR CONNECTION. From Figure 1 it can be seen that on turning valve (7) to OPERATING the metered air flows into the manifold (5) and is common to the recording instrument via connector (13), the pressure gauge (10), the relief valve (12), the pipe work up

to the valve (8) and the line to the WATER HEAD MONITOR connector. The selecting of OPERATING on valve (8) will permit the metered air to flow via connector (14) to the submerged pressure point. Note that valve (8) should be operated at the same time as valve (7). Failure to turn valve (8) to operating will cause the pressure to rise slowly within the circuit until it reaches the preset limit of relief valve (12) - approximately 1.9 bars.

With valves (7) and (8) set to OPERATING the metered air escapes to atmosphere via the submerged pressure point. The pressure gauge (10) will be indicating a pressure due to the head of water above the pressure point, this being also transmitted to the recording instrument via connector (13). The equipment is now operating. During a tidal cycle, changes in pressure due to the varying head of water above the pressure point can be observed on gauge (10).

3. Purging of the system is desirable when first putting the equipment into operation and thereafter, periodically during servicing. Do this by first setting valve (8) to PURGE and then setting valve (7) to PURGE. The system is designed so that the sequence of operating (8) and (7) is not too critical. From Figure 1 it can be seen that the flow of purging air is completely isolated from the remainder of the circuit. This air pressure is indicated on gauge (9). After purging, return valves (7) and (8) to the CLOSED position. To conserve air purging should normally not exceed 30 seconds.

4. The equipment is provided with an additional monitoring facility (16) marked WATER HEAD MONITOR. This connector is of the self-sealing 'snap-on' type, the line being common to the recorder and pressure gauge (10). Any suitable pressure calibrator may be connected without the need to interrupt the operation of the equipment.

Test procedures

1. Relief valves, when subjected to long periods of service in an adverse environment may become "sticky". It is therefore advisable to carry out periodic functional checks. To test

relief valve (6) proceed as follows. Turn valve (7) to CLOSED. Open isolating valve (2) on storage cylinder(s) (1), and screw in the control wheel on reducing valve (3), thus increasing the gas input pressure to exceed 5 bars. At a pressure of 5 bars the relief valve (6) should open and the escaping air will be audible. DO NOT FORGET to reset the gas input pressure to normal (3 bars) on reducing valve (3) after this test.

2. Test relief valve (12) as follows. Remove all external connections except GAS SUPPLY INPUT. Input gas pressure should be 3 bars. Turn valves (7) and (8) to OPERATING. The pressure gauge (10) should indicate a steady increase in pressure until 1.9 bars is reached, when the relief valve should open and no further increase of pressure should occur. Due to the low volume of air flowing through the flow control valve, the escape of air is not audible in this case so close attention to the pressure gauge is necessary. Reconnect the submerged pressure point line to relieve the excess pressure in the system. It is always advisable to disconnect the recorder from the control panel when testing the relief valve (12).

3. Should either relief valve require attention, access is gained by removing the control panel from the cabinet. Should it become necessary to remove any permanent connection for maintenance purposes, a leak test using soapy water is recommended after re-connection. The conditions required for leak testing are obtained by following the same procedure as for testing relief valve (12). In the interests of air economy it is advisable to leak test all unions external to the control panel, e.g. at the storage cylinders, connections to the reducing valve (3) and in the vicinity of the isolating valves (2).

Table 1. Comparison of tidal constituents at the Inner Dowsing, from analysis of simultaneous Aanderaa and Neyrpic data, January/February 1975.

Constituent	<u>Aanderaa</u>		<u>Neyrpic</u>			
	H(m)	g(^o)	H(m)	g(^o)	H(m)	g(^o)
O ₁	0.165	128.1	0.167	129.1	0.002	1.0
K ₁	0.073	327.9	0.076	322.5	0.003	-5.4
M ₂	1.932	162.8	1.938	161.7	0.006	-0.9
S ₂	0.667	210.8	0.655	210.0	-0.012	-0.8

Table 2. Zero pressure count stability for Aanderaa model TG2D, number 94.

<u>Date</u>	<u>Zero pressure count</u>
26. 1.76	174515
6. 2.76	174507
24. 2.76	174505
28. 4.76	174520
23. 7.76	174494
15.12.76	174533

Appendix 2.

LIST OF COMPONENTS

COMPONENT	MANUFACTURER/SUPPLIER	No. REQD	TYPE/ITEM NO	MATERIAL	REMARKS
"Whitey" 3 way ball valve	Techmation Ltd 5 Edgeware Way Edgeware, Middlesex HA8 3JP	2	B-43XS4	Brass (plated)	Type No. indicates size, material & type of connection
Nupro "R" series relief valve	as above	1	B-6R4M-10	"	"
Nupro "R" series relief valve	as above	1	B-6R4M-50	"	"
Quick connects coupling	as above	3	B-QC4-B1-400	"	"
Quick connects coupling	as above	3	B-QC4-S-400	"	"
Quick connects coupling	as above	1	B-QC4-S1-400	"	"
Quick connects coupling	as above	1	B-QC4-B-400	"	"
Flow rate meter	G.E.C. Elliot Automation Ltd Rotameter Works 330 Purley Way Croydon, Surrey	1	Rotameter Type 1300/VAA Brass 1.663 RA 17082530 2-20 cc/min air.		Generally long delivery
Pressure gauge	Budenburg Gauge Co.Ltd Box 5, Broadheath Altrincham, Cheshire	1	1A/11/18 100mm (4") 0-2 bar panel mounting		

Appendix 2 (cont'd)

COMPONENT	MANUFACTURER/SUPPLIER	No. REQD	TYPE/ITEM NO	MATERIAL	REMARKS
Pressure gauge	Budenburg Gauge Co. Ltd Box 5, Broadheath Altrincham, Cheshire	1	1A/11/18 100mm (4") 0-6 bar panel mounting		
Copper tubing	Optional	12	ft. $\frac{1}{4}$ " O.D.	Copper	Annealed Inst. Tubing
Manifolds		2		Brass	Shop fabricated to suit
Press reducing valve	Underwater Instrumentation Ltd Argyroneta House Goosepool, Chertsey Surrey	1	Manobloc		Imported from France
Air storage cylinders	Optional	1	Standard 60 cu.ft.		Standard Diving cylinders (300 bars)
Instrument case	Modine Ltd Greengate Works Dawson Street Salford, Lancs, M3 7WP	1	21" x 21" x 9 No. M.C. 14 "Enots" control cabinet	Mild Steel, lockable	

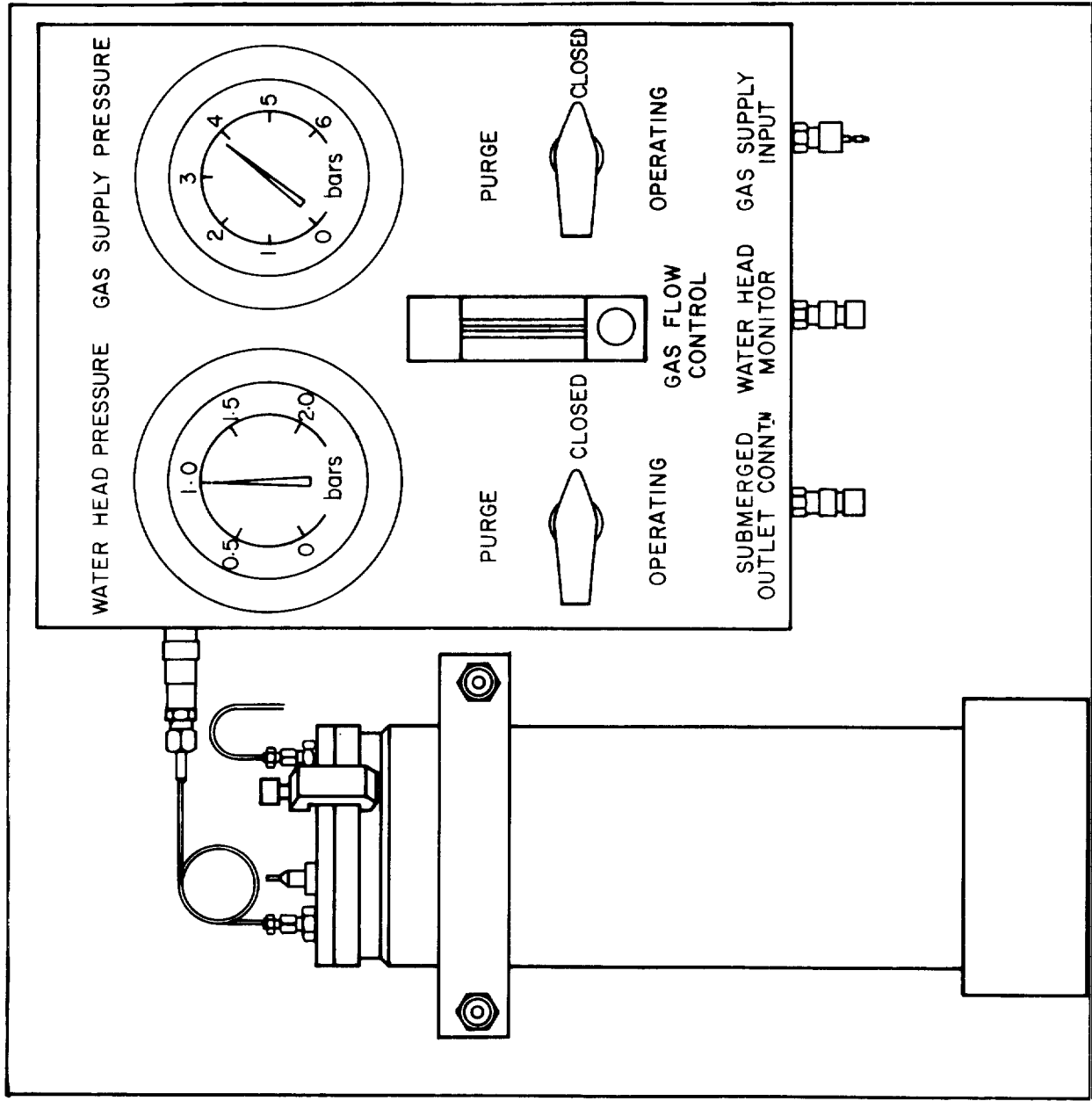


FIG. 1 SCHEMATIC DIAGRAM OF AANDERAA PRESSURE GAUGE AND THE ASSOCIATED PNEUMATIC CONTROL CIRCUITRY

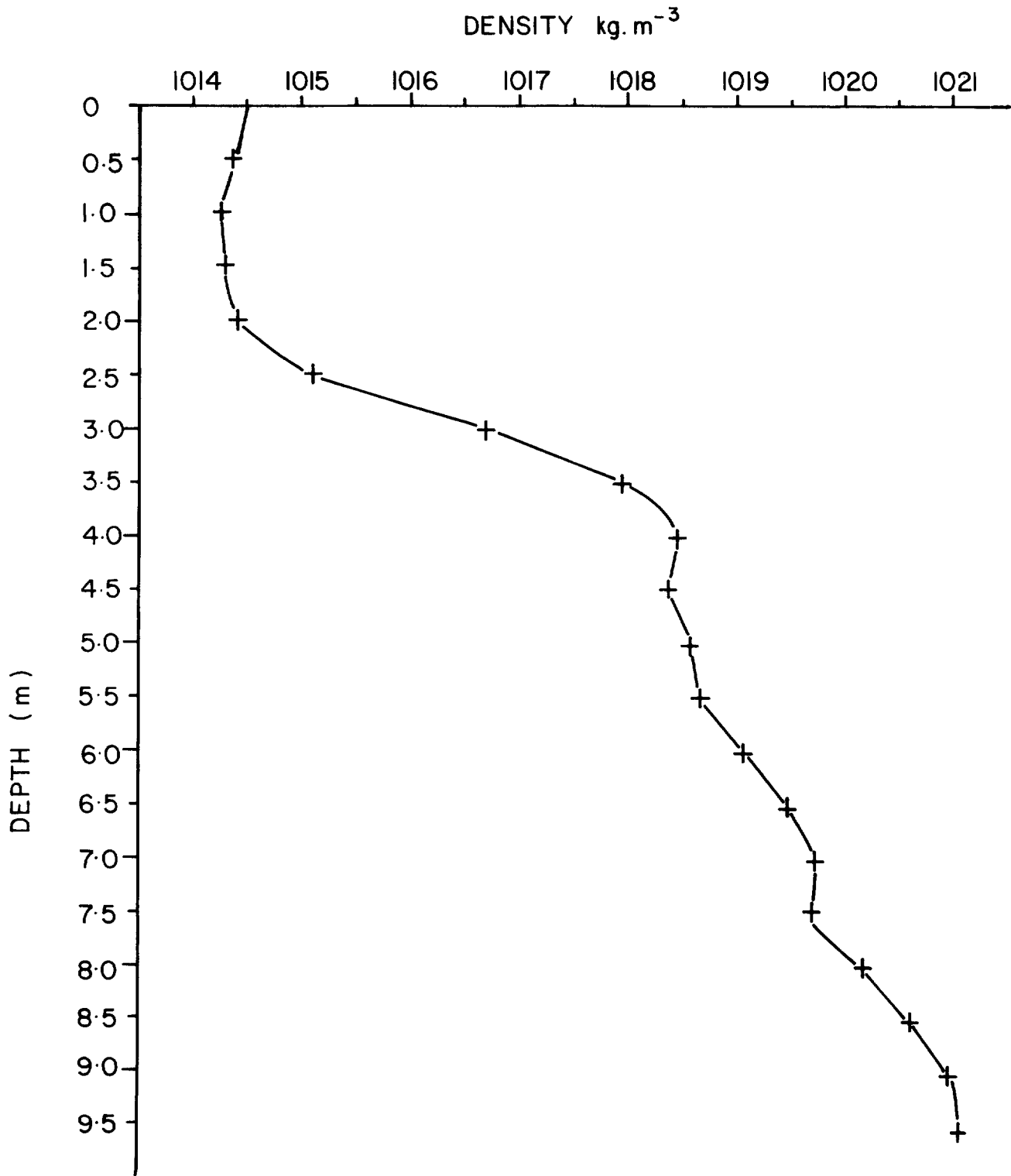


FIG. 2. WATER DENSITY PROFILE IN GLADSTONE STILLING WELL, 1230 G.M.T., 9-12-76 HIGH WATER AT 9.0 m ACD.

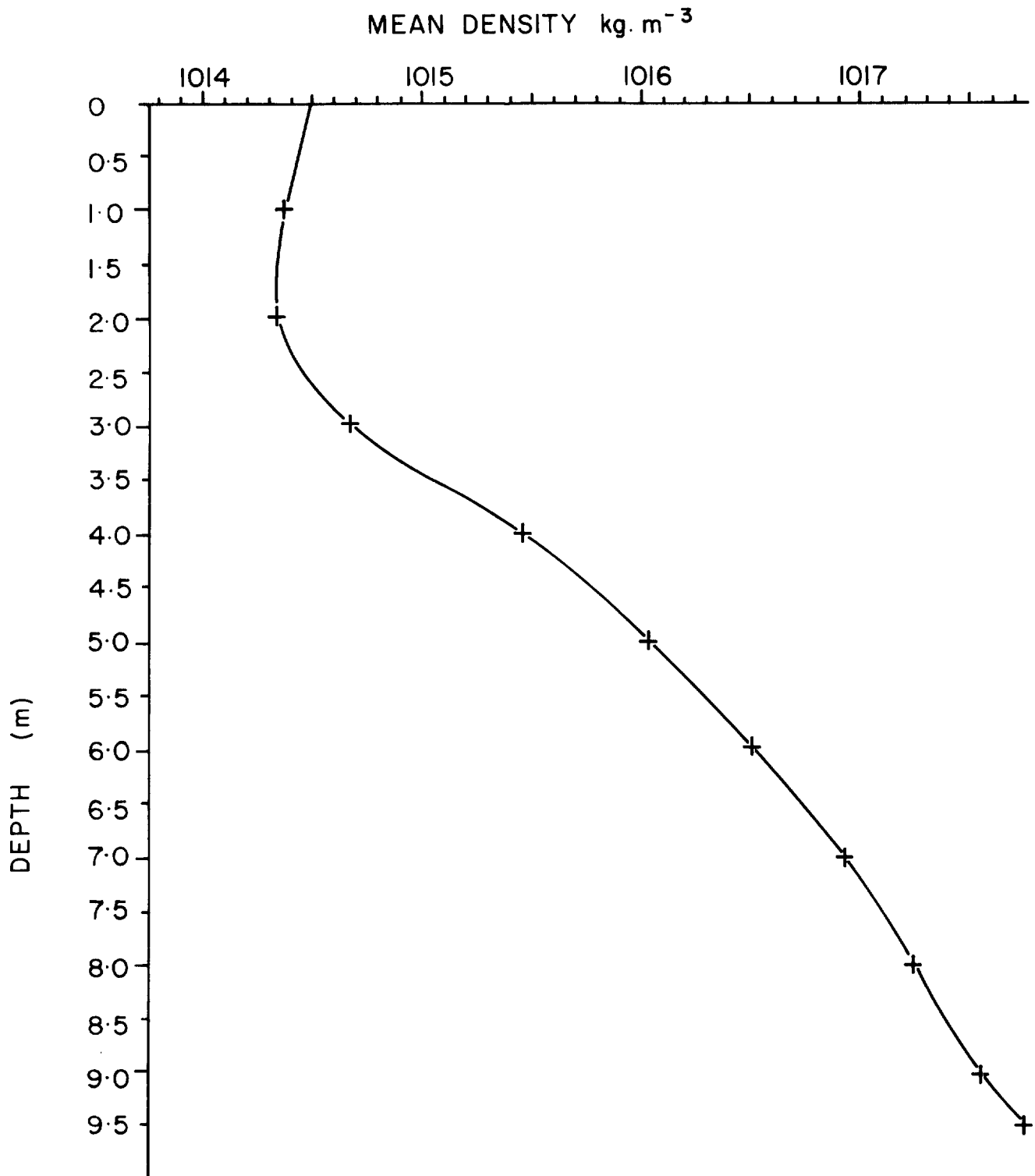
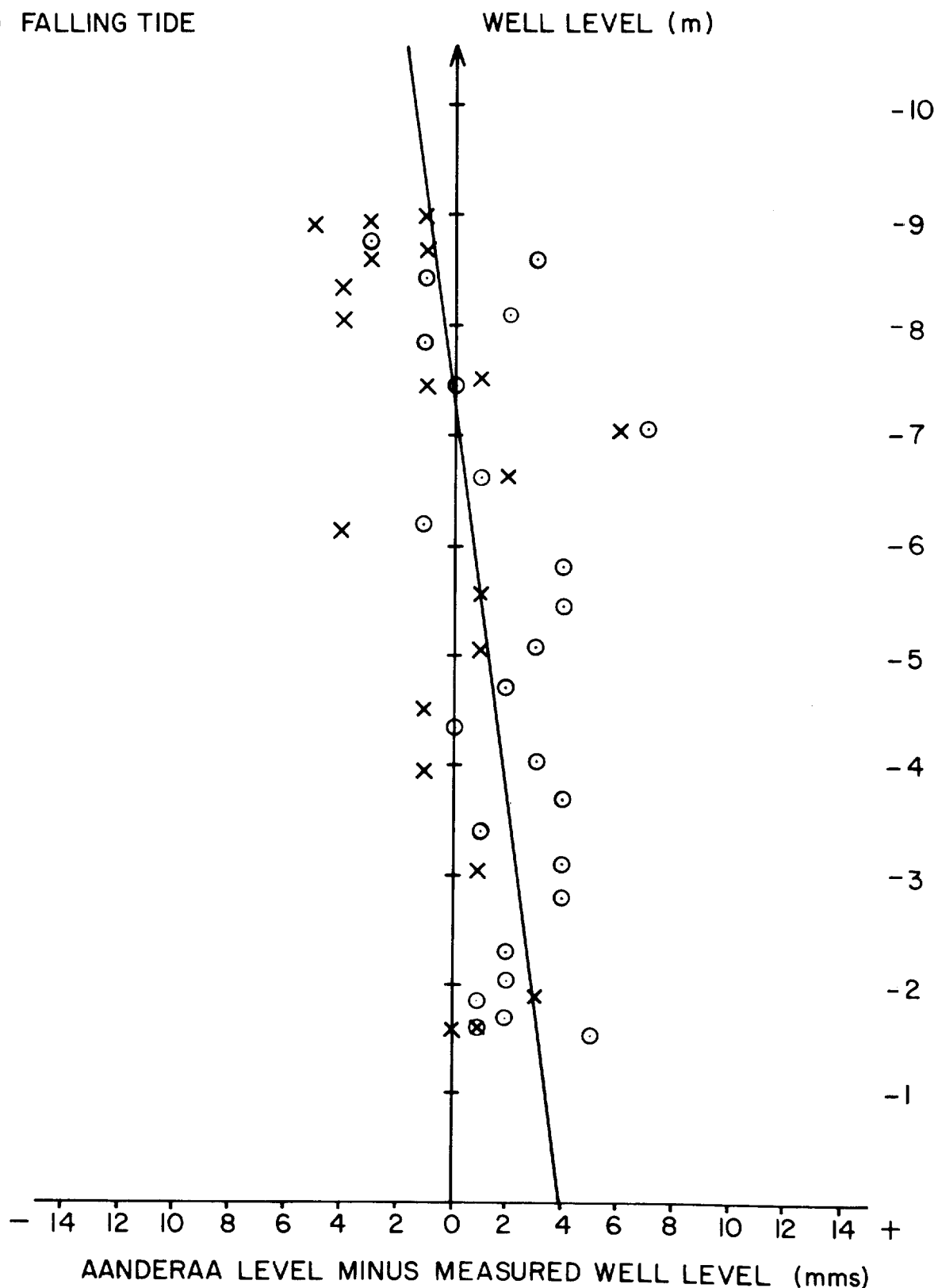


FIG. 3. MEAN WATER DENSITY FROM FIG. 2. AS A FUNCTION OF DEPTH BELOW THE SURFACE

FIG. 4. DIFFERENCES BETWEEN AANDERAA AND WELL LEVEL AS A FUNCTION OF WELL LEVEL

× RISING TIDE
 ⊙ FALLING TIDE



**FIG. 5 SCHEMATIC DIAGRAM
OF CONTROL EQUIPMENT**

