Properties of Dredged Material

Minipod deployments at the Tees disposal site

N G Feates

Report TR 61
June 1998

HR Wallingford

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Contract

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Summary

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HR Wallingford was commissioned by MAFF CEFAS to carry out a study aimed at investigating the physical properties of dredged material. During the winters of 1995/1996 and 1996/1997 a minipod was deployed adjacent to the Tees disposal site. The duration of each of the two deployments was about six weeks. The purpose of the deployments was primarily measure the hydrodynamic conditions that exist at the site as an aid to predicting the likely level of dispersion of the dredged material being placed at the disposal site.

This report is one of a series of Technical Reports produced under this contract and provides supporting information to the main study report (Reference 1). This report presents the data collected by the minipods deployed around the periphery of the Tees disposal site.

A minipod is a bottom lander developed by CEFAS (Centre for Environment, Fisheries and Aquaculture Science), an agency of MAFF (Ministry of Agriculture, Fisheries and Foods). The minipod was designed to enable an estimate of the sediment concentration near to the seabed to be made.

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1. INTRODUCTION

1.1 Background

HR Wallingford was commissioned by MAFF CEFAS to carry out a study aimed at investigating the physical properties of dredged material. Minipods have been used to measure the hydrodynamic conditions at various locations around the periphery of the Tees disposal site. As part of this study a specifically designed instruments, ISIS (Instrument for Shear Stress In-Situ) and SedErode (Sediment Erosion Device) have been used to measure the critical erosion thresholds of samples of in-situ, dredged and placed material i.e. during the three phases of the dredging cycle. The results of the erosion studies are reported in Reference 2.

This technical report contains the results of the minipod deployments at the Tees and provides supporting information to the main study report (Reference 1).

1.2 Objectives

One of the locations studied under this project was the Inner disposal site offshore of the River Tees (Figure 1). Maintenance dredging operations in the River Tees is carried out more or less on a daily basis, with regular placements of small amounts of material at the disposal site. In contrast, another site studied was the Roughs Tower disposal site offshore of Harwich Harbour (References 3 and 4). Maintenance dredging operations in Harwich Harbour are typically carried out in the form of 5-6 intensive campaigns per year. For this reason large amounts of material tend to be placed at the disposal site in relatively short periods of time.

MAFF CEFAS minipods were deployed from the MAFF research vessel RV Cirolana at two locations in the vicinity of the dredged material disposal site in order to establish the hydrodynamic regime that exists at the site. The minipod positions were carefully selected in order to detect the passage of dredged material placed at the site. The deployments were left on the seabed for a duration of about six weeks and were programmed to record measurements for an 8½ minute period every hour. The recorded data was then post processed to take into account instrument calibrations. The resulting data provides a time series of the hydrodynamic conditions that exist at each of the sites.

1.3 Report structure

The remainder of this report is in five chapters. In Chapter 2 the minipod and associated instrumentation is described. In Chapter 3 the siting of the minipods and the method of deployment is given. In Chapters 4 and 5 the data collected from each of the deployments is given. Conclusions arising from the minipod deployments at the Tees are given in Chapter 6.

2. MINIPOD INSTRUMENTATION

A minipod is a bottom lander developed by CEFAS (Centre for Environment, Fisheries and Aquaculture Science, an agency of MAFF (Ministry of Agriculture, Fisheries and Foods). The minipod was designed to enable an estimate of the sediment concentration near to the seabed to be made. Plate 1 shows a minipod on board the MAFF research vessel RV Corystes prior to deployment.

Each minipod was fitted with a set of sensors to provide information relating to the hydrodynamic conditions that exist at the site. Both of the Tees deployments were fitted with the same set of instruments. All of the sensors are controlled by an intelligent logging system. Different logging regimes may be triggered by changes in significant wave height. The instruments are described below.

2.1 Current meter

A single Marsh McBirney electromagnetic current meter was used to measure current speeds in the X and Y horizontal planes. From this information, and knowing the orientation of the minipod, current velocities and directions can be derived. The current meter was fixed at a height of about 0.42 m above the bed. The current meter is shown fitted to a minipod in Plate 2.

2.2 Suspended sediment sensor

Point measurements of the suspended sediment concentration was obtained by the use of a Miniature Optical Backscatter Sensor (MOBS). For both of the Tees deployments two MOBS were fitted to the minipod to measure the suspended sediment concentration at two heights above the bed. The MOBS were fixed at heights of about 0.54 m and 0.72 m above the bed. The MOBS are shown fitted to a minipod in Plate 2.

2.3 Acoustic backscatter sensor

A two-frequency (1 MHz and 6 MHz) Acoustic Backscatter Sensor (ABS) was used to measure the vertical profile of suspended sediment concentration between the sensor and the bed. The data provided by the ABS, which is in terms of nominal backpressure, may also be used to make an estimate of the sediment size distribution. The ABS was fixed at a height of 0.80 m and 0.87 m above the bed for deployments 122 and 139 respectively. The ABS is shown fitted to a minipod in Plate 2.

2.4 Pressure sensor

Tidal elevation and wave statistics (significant wave height, wave period and bed orbital velocity) were derived from a Digiquartz pressure sensor installed at a height of 1.76 m above the bed.

2.5 Syringe water sampler

To provide water samples with which to aid the calibration of the optical sensors four syringe water samplers were fitted to each of the two minipods. The samplers, which have a capacity of 1.8 litres, operate by moving a piston within a cylinder to draw water from an intake nozzle fixed to one of the minipod legs at the same height above the bed as the MOBS are fitted. The control system allows each syringe to be programmed independently, firing when a certain criteria is met. Plate 3 shows syringe water samples mounted on a minipod.

2.6 Sediment trap

To provide a sample with which to calibrate the acoustic backscatter sensors sediment traps have been used. The sediment traps (mini booner tubes) are fixed to one of the minipod legs at a height of 0.3 m above the bed. The tubes are designed to trap any suspended sediment passing through the tube. Once the minipod has been recovered from the seabed the sediment may be removed. Plate 2 shows a timed booner tube sediment trap fitted to a minipod.

2.7 Auxiliary sensors

Each minipod also incorporated a standard set of auxiliary sensors for measuring the orientation of the minipod on the seabed i.e. pitch, roll, and compass orientation. Water temperature is also recorded. The pitch and roll sensors can be used in conjunction with the compass to determine if the minipod has moved on the seabed during a deployment. The true current direction is determined from the current meter u and v components of velocity corrected based on the measured compass reading i.e. corrected for the minipod orientation.

3. MINIPOD SITES

The positions of the two minipod deployments are given in the table below and shown in Figure 2.

Deployment	Duration	Name	Latitude	Longitude	Bed level
Dep122	30/01/96 – 14/03/96	Tees Disposal Site	54 41.844 N	01 03.268 W	32.0m CD
Dep139	06/12/96 – 20/01/97	Tees Disposal Site	54 41.913 N	01 02.478 W	33.0m CD

Prior to each of the deployments the seabed was inspected using side-scan sonar to ensure that the proposed location was sufficiently flat and free of obstructions.

The Tees disposal site locations were selected so as to be close enough to the disposal site to be representative of the hydrodynamic conditions that exist at the site. Ideally a minipod should be located such that it is aligned with either the flood or ebb tide relative to the disposal site (i.e. to the south-east or north-west respectively) so that any dispersing dredged material should pass the minipod. In the case of the Tees deployments, safety of navigation issues meant that the minipod locations were more to the north of the disposal site.

The minipods were deployed from the MAFF research vessel RV Cirolana. In each case one or two surface guard buoys marked the presence of the minipod. Also a Notice to Mariners was issued prior to each deployment.

4. DEPLOYMENT 122

4.1 Description of deployment

The first minipod was deployed at the Tees disposal site on 30 January 1996. The minipod was recovered on 14 March 1996. The minipod location is given below and shown in Figure 2.

Tees Disposal Site (Deployment 122) 54° 41.844′N 01° 03.268′W

The minipod recorded a good data set. The pitch and roll sensors showed that the minipod had not moved on the seabed during the deployment period.

4.2 Sidescan sonar survey

Prior to the deployment of the minipod a sidescan sonar survey of the northern half of the designated disposal site was conducted. Bed features identified included an area of small sand ripples to the north-west of the general placement area. The ripples were generally perpendicular to the direction of the tidal flow. Also identified on the seabed, particularly along the northern edged of the dsignated area, were scour marks running normal to the tide. These were assumed to be anchor tracks. There was also evidence of numerous individual material placements, particularly to the north of the designated disposal area.

4.3 Recorded data

The recorded data from the minipod is shown graphically as a time series plot and is discussed below.

4.3.1 Pitch and roll sensor

The data from the pitch and roll sensor is shown in Figures 3. The figure clearly shows that the minipod remained reasonably stable for the duration of the deployment apart from a small movement at 2200 on 18 February.

4.3.2 Current meter

Figure 4 shows the current speed data measured by the electromagnetic current meter. The effect on the measured current speed of the spring-neap tidal cycle can be clearly seen. The maximum current speed measured was about 30 cm/s.

4.3.3 Suspended sediment sensors

The data recorded by the Miniature Optical Backscatter Sensors (MOBS) is shown in Figure 5. The data shown is in terms of the voltage output from the sensors rather than actual suspended solids concentrations. Since the calibration of the MOBS sensor is a linear relationship comparing relative changes in the magnitude of the voltage output is justifiable though not quantifiable. As expected the data shows a small shift in the voltage output between the upper and lower sensors. Close to the bed the level of turbidity is normally greater than higher up in the water column. In this case the sensors were fixed at heights of 550 mm and 740 mm above the seabed. The figures show that on occasions over-scale readings were measured. Readings over-scale for long periods such as those around 20 February, can be associated with periods of large wave activity.

4.3.4 Acoustic backscatter sensor

The minipod was fitted with a two-frequency Acoustic Backscatter Sensor (ABS) at a height of 0.80 m above the bed.

Generally the ABS detected only very small variations in backpressure between the sensor and the bed. The strongest signals were measured late on 18 February, a time of rapidly increasing wave activity. Figure 6 shows the ABS record for the 2000h burst. The associated wave height at this time is between 1 m and 2 m. Figure 7 shows the ABS data from the 2200h burst. At this time the wave heights are varying between about 1 m and 5 m. Note that it was at this time that the pitch and roll sensor showed a small movement of the minipod on the seabed.

4.3.5 Significant wave height

In Figure 8 the significant wave height is shown for the deployment. The wave statistics are derived from the data recorded by the pressure sensor. The figure shows that the average significant wave height (H_s) measured was about 0.75 m. During periods of significant wave activity the derived H_s was typically between 1 m and 2 m. The maximum significant wave height was about 4.8 m measured in the early hours of 19 February.

4.3.6 Summary of data

In Figures 9 to 14 the data is shown on a weekly basis showing the effect of wave activity on the suspended solids concentrations at the Tees disposal site. The water depth and wave data are derived from the pressure sensor, which operates on the depth below surface principle. The suspended solids data is derived from an optical sensor fitted to the minipod at a height of 0.55 m above the bed.

4.4 Dredging activity

During the period of the deployment maintenance material dredged from the river was placed at the disposal site more or less on a continual daily basis. The Tees and Hartlepool Port Authority operate a fleet of three dredgers. Two of the vessels are of the trailing suction hopper type and the third is a grab dredger. The larger of the two trailers, Heortnesse, has a hopper capacity of 1,500 m^3 and normally works six days a week for 12 hours a day. The smaller trailer, Cleveland County, works a similar regime but on a 'week on week off' basis. Both vessels typically make three or four trips to the disposal site each day. The grab dredger Seal Sands works only as and when required and makes a very small contribution to the total amount of maintenance material placed at the site.

During the period of the minipod deployment a total volume of about 190,000 m^3 of dredged material was placed at the site, 80% of which was sand.

Figure 15 shows a record of dredger activity at the Tees disposal site for the duration of the minipod deployment. Also shown is the suspended sediment concentration and significant wave height as measured by the minipod for the same period. In order to determine whether the effects of material placements at the disposal site were in fact detected my the minipod sensors it was first necessary to identify periods of relatively high suspended sediment concentration when wave effects were minimal. Figures 16 to 19 show four such occasions.

The figures show the PVD (progressive vector diagram) of a plume released at the disposal site based on current speeds and directions measured by the minipod. In three of the four cases the centreline of the plume is shown to pass the minipod 4 to 5 hours after release some 1,000 m to the south. In the fourth case (Figure 19) the plume is shown to pass much closer to the minipod 5 to 6 hours after release. This was the only occasion identified where the minipod sensors may have detected the passage of a plume of dredged material. Figure 19 shows an increase in the level of suspended solids over a period of about 4 hours (2100 to 0100) with no substantial increase in the associated significant wave height. The peak of the concentration rise occurs at about 2300 which is some 5¼ hours after the time of release. This agrees very well with the time at which the plume is calculated to have passed close to the minipod as shown in the PVD in Figure 19.

It should be noted that during the period of the minipod deployment 80% of the 190000 m^3 of material placed at the disposal site was sand, the remainder being silt and clay. Each of the four dredger loads discussed above was largely sand with very little fine cohesive material. Each of the plumes discussed above had been subject to dispersion by waves and currents for between 4 and 7 hours prior to passing the minipod site which was located some 2 km from the disposal site. If a constant current speed of 0.1 m/s and a water depth of 33 m is assumed, for a settling velocity of 5 mm/s, fine sand (d_{50}=0.1 mm) would take about 2 hours to reach the bed and would be dispersed over a distance of 660 m. This is probably an overestimate as samples taken from the Tees disposal site suggest that the median particle size of the bed material is significantly larger that that assumed above.

It is therefore considered unlikely that any of the placed dredged material would have reached the site of the minipod before either reaching the seabed or having fully dispersed in suspension. For future deployments at the Tees it is clear that either the minipod should be located closer to, and up or down tide of, the disposal site. Alternatively the dredged material should be released closer to the minipod.

5. DEPLOYMENT 139

5.1 Description of deployment

During the winter of 1996-1997 a second minipod was deployed at the Tees disposal site from the vessel RV Cirolana. The minipod was deployed on 6 December 1996 and recovered on 20 January 1997. The minipod location, which is some 870 m to the east of the winter 1995-1996 deployment, is given below and shown in Figure 2.

Tees Disposal Site (Deployment 139) 54° 41.913′ N 01° 02.478′ W

The minipod recorded a good data set. The pitch and roll sensors showed that the minipod had not moved on the seabed during the deployment period.

5.2 Sidescan sonar survey

A sidescan sonar survey was carried out of the seabed at the proposed minipod sites to ensure that the selected locations were suitable.

5.3 Recorded data

The recorded data from each minipod is shown graphically as a time series plot and is discussed below.

5.3.1 Pitch and roll sensor

The data from the pitch and roll sensor for deployment 139 is shown in Figure 20. The figure shows very little movement of the minipod during the period of deployment. The high frequency variations in the compass reading are considered to be due to interference.

5.3.2 Current meter

Figure 21 shows the current speed data measured by the electromagnetic current meter at a height of 420 mm above the bed. The variation in current speed due to the spring-neap cycle can be clearly seen. The maximum current speed measured was about 35 cm/s.

5.3.3 Suspended sediment sensors

The data recorded by the two Miniature Optical Backscatter Sensors (MOBS) is shown in Figure 22. The sensors were fitted at heights of 530 mm and 710 mm above the seabed. As expected the data shows a shift in the voltage output between the upper and lower sensors indicating higher levels of suspended solids closer to the bed. As observed during the winter 1995-1996 minipod deployments over-scale readings were measured on a few occasions during periods of large wave activity.

5.3.4 Acoustic backscatter sensors

The minipod deployed during this period was equipped with an Acoustic Backscatter Sensor (ABS) installed at a height of 0.80 m above the bed. The recorded data shows that the bed level was in fact about 12 cm higher than this.

Figures 23 to 25 show examples of the ABS burst data recorded during periods of variable wave activity. The burst mean significant wave height (H_s) for the data shown in the three figures is 279 cm, 548 cm and 558 cm respectively. The ABS response from one wave condition to another is quite marked. Despite the measured H_s for the data shown in Figures 24 and 25 being similar, the ABS response through the water column is quite different. The reason for this variability is probably the difference in the mean water level between the two cases (38 m and 37 m respectively).

5.3.5 Significant wave height

In Figure 26 the significant wave height is shown for the deployment. The wave statistics are derived from the data recorded by the pressure sensor. The figure shows that the period of the largest waves occurred around 20 December when the maximum significant wave height (H_s) was about 5.6 m. A comparison of Figure 26 and Figure 22 clearly illustrates the positive correlation between significant wave height and suspended solids concentration.

5.3.6 Summary of data

In Figures 27 to 32 the data is shown on a weekly basis showing the effect of wave activity on the suspended solids concentrations at the Tees disposal site during the deployment.

5.4 Dredging activity

During the period of the deployment maintenance material dredged from the river was placed at the disposal site more or less on a continual daily basis as described in Chapter 4. During the period of the minipod deployment a total volume of about 92,500 m^3 of dredged material was placed at the site, 60% of which was sand, the remainder being silt.

Figure 33 shows a record of dredger activity at the Tees disposal site for the duration of the minipod deployment. Also shown is the suspended sediment concentration and significant wave height as measured by the minipod for the same period. The figure shows that no dredging took place over the Christmas period or during periods of large wave activity (such as on 20 December).

From the analysis of the dispersion of placed material from the previous Tees minipod deployment described in Section 4.4 above it was clear that dredged material placed in the centre of the disposal site would not be carried past the minipod site. For this reason a special request was made to the Tees and Hartlepool Port Authority to place a limited number of loads of dredged material in the northern corner of the disposal site. Based on progressive vector diagrams calculated from the winter 1995-1996 deployment it was considered that dredged material placed here should pass nearby the minipod.

Figures 34 to 38 show the PVD (progressive vector diagram) for each of six loads of dredged material placed in the northern corner of the disposal site based on current speeds and directions measured by the minipod. Also shown in each of the figures is the associated suspended solids data measured by the minipod sensors. In order to be able to isolate increases in suspended solids concentration due to the passage of a plume of dredged material from increases due to wave activity the determined significant wave height is also shown. The first five loads placed at the site were silt and the last was sand. In most cases the measured current speeds and directions indicate that the placed material should have dispersed in such a way as to pass the minipod site. From Figures 34 to 38 it can be seen that the turbidity data recorded by the Miniature Optical Backscatter Sensors does not positively detect the passage of a plume of material. Figures 35 and 36 show two occasions when the passage of the dispersing silt plume was expected to have been detected by the minipod. In both cases the centre of the plume would have passed very close to the minipod within two hours of placement. The associated record of suspended solids concentrations at the site shows no evidence of a temporary increase during this period.

It should be noted that for this minipod deployment the burst length was only 8½ minutes with an interval between bursts of 1 hour. It therefore follows that it is quite possible that in some cases the passage of the plume of dredged material was simply missed by the instrumentation. Advances in computer technology meant that minipod deployments at Harwich in November 1997 were able to utilise larger storage disks that allowed the burst length to be increased to 10 minutes with a reduced interval of 30 minutes.

6. CONCLUSIONS

1. Since January 1996 two minipod deployments have been made to the north of the Tees disposal site. The minipods were deployed from the MAFF research vessel RV Cirolana.

2. The deployments were left on the seabed for a period of between four to six weeks and were usually programmed to record measurements for an 8½ minute period every hour. The resulting data provided a time series of the hydrodynamic conditions that exist at each of the sites.

3. At each of the sites there was a regular variation in the level of turbidity during the tidal cycle. During periods of spring tides suspended solids concentrations were higher than during neap tide periods.

4. The major influencing factor on the level of near-bed suspended solids concentration is the associated wave conditions.

5. During each of the periods of minipod deployment maintenance dredging material was placed at the disposal site. The only occasion when the effect of material placement may have been detected at the minipod site was during the winter 1996/97 deployment. In this case the minipod detected an increase in the level of suspended solids over a period of about 4 hours with no substantial increase in the associated significant wave height. This increase coincided with the passage of a plume of paced material based on current speeds and directions measured by the minipod.

6. During the period of the winter 1996/97 deployment it was found that the majority of the plumes tracked from the disposal site were passing well south of the minipod location. Therefore, prior to the winter 1997/98 deployment a special request was made to the Tees and Hartlepool Port Authority to place a limited number of loads in the northern corner of the disposal site, some 1 km to the north of the usual placement area. During the 10 days after deployment six loads of dredged material were placed at the requested location. Analysis of the recorded suspended solids data showed no evidence of passing plumes of dredged material being detected.

7. A possible reason for the passing plumes not being seen by the minipod instrumentation may be the relatively short burst length in relation to the burst interval. For the Tees minipod deployments the burst length was only 8½ minutes with an interval between bursts of 1 hour. It therefore follows that it is quite possible that in some cases the passage of the plume of dredged material was simply missed by the instrumentation. Advances in computer technology meant that minipod deployments at Harwich in November 1997 were able to utilise larger storage disks that allowed the burst length to be increased to 10 minutes with a reduced interval of 30 minutes.

7. ACKNOWLEDGEMENTS

HR would like to thank the many staff at the CEFAS Lowestoft Laboratory for their assistance in collection and guidance in the analysis of the minipod data. Special thanks go to the crews of the MAFF research vessel Cirolana for their help during the deployment and retrieval of the equipment.

Thanks are also due to the Tees and Hartlepool Port Authority for providing information relating to the dredging activity during the period of the deployments.

8. REFERENCES

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2. Properties of dredged material. Measurement of sediment properties of dredged material from the Tees estuary. HR Wallingford. Report TR 54.

3. Properties of dredged material. Measurement of sediment properties of dredged material from Harwich Harbour. HR Wallingford. Report TR 46.

4. Properties of dredged material. Minipod deployments at the Roughs Tower disposal site. HR Wallingford. Report TR 47.

Figures

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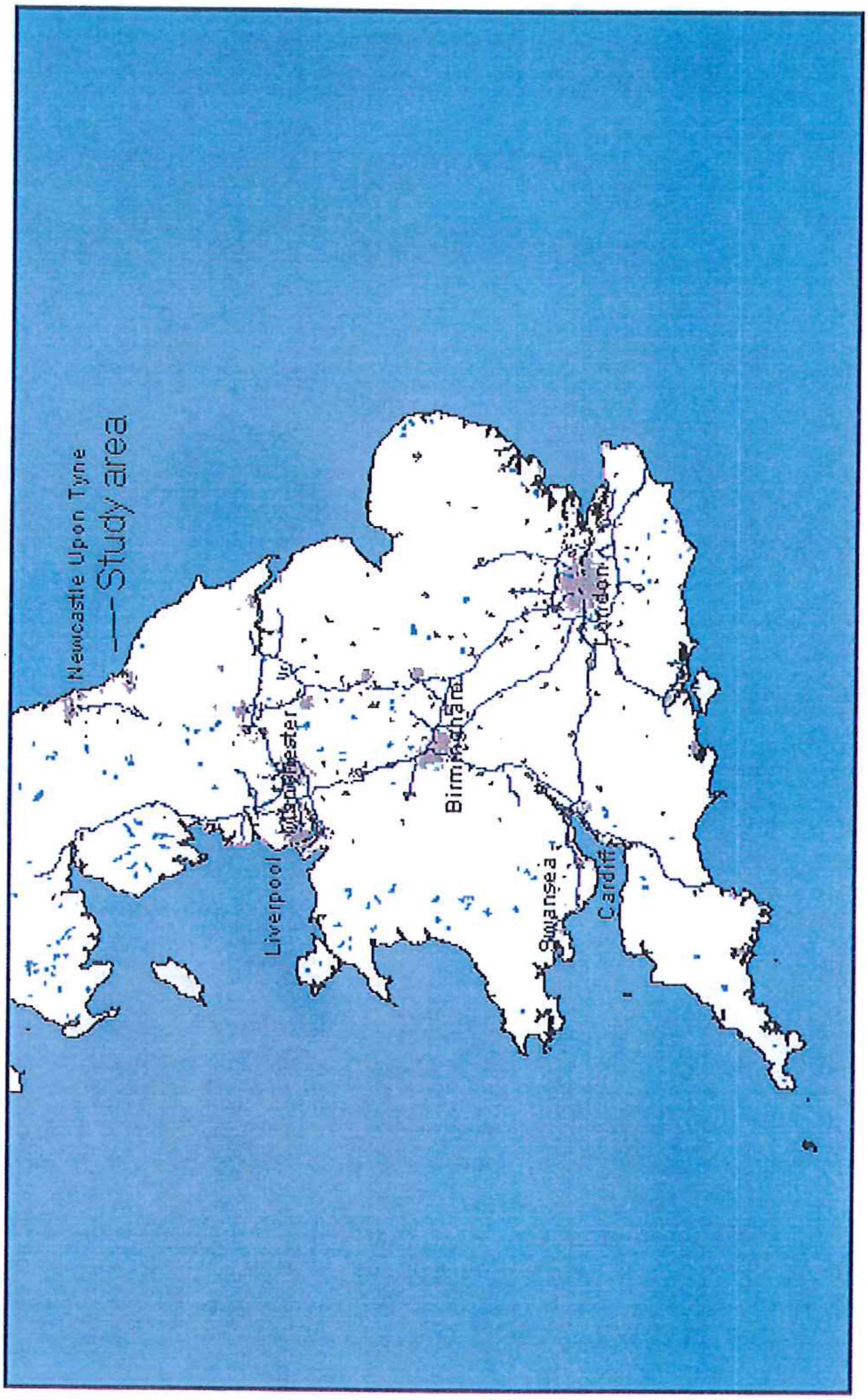

Figure 1 Study area

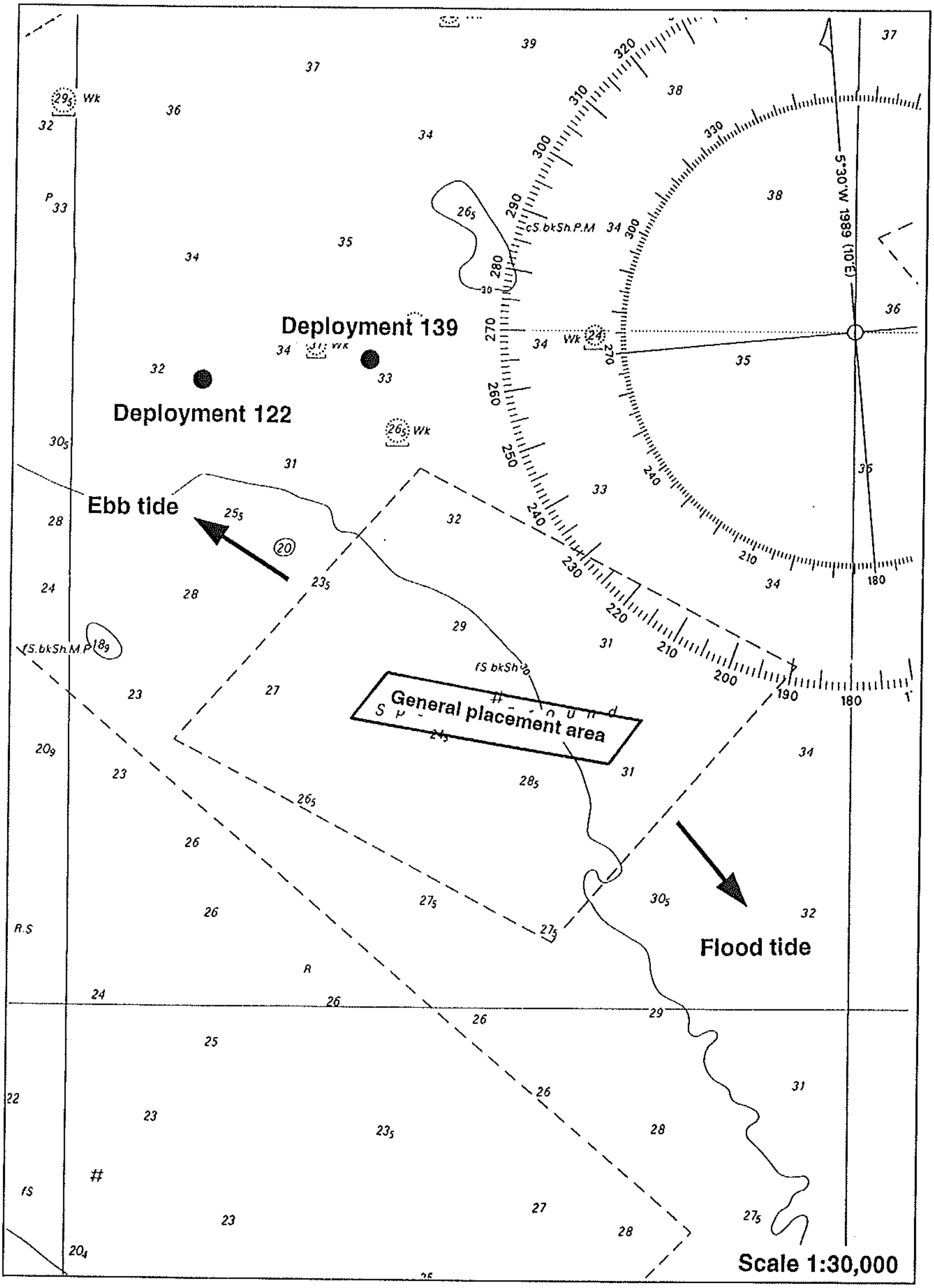

Figure 2 Minipod locations

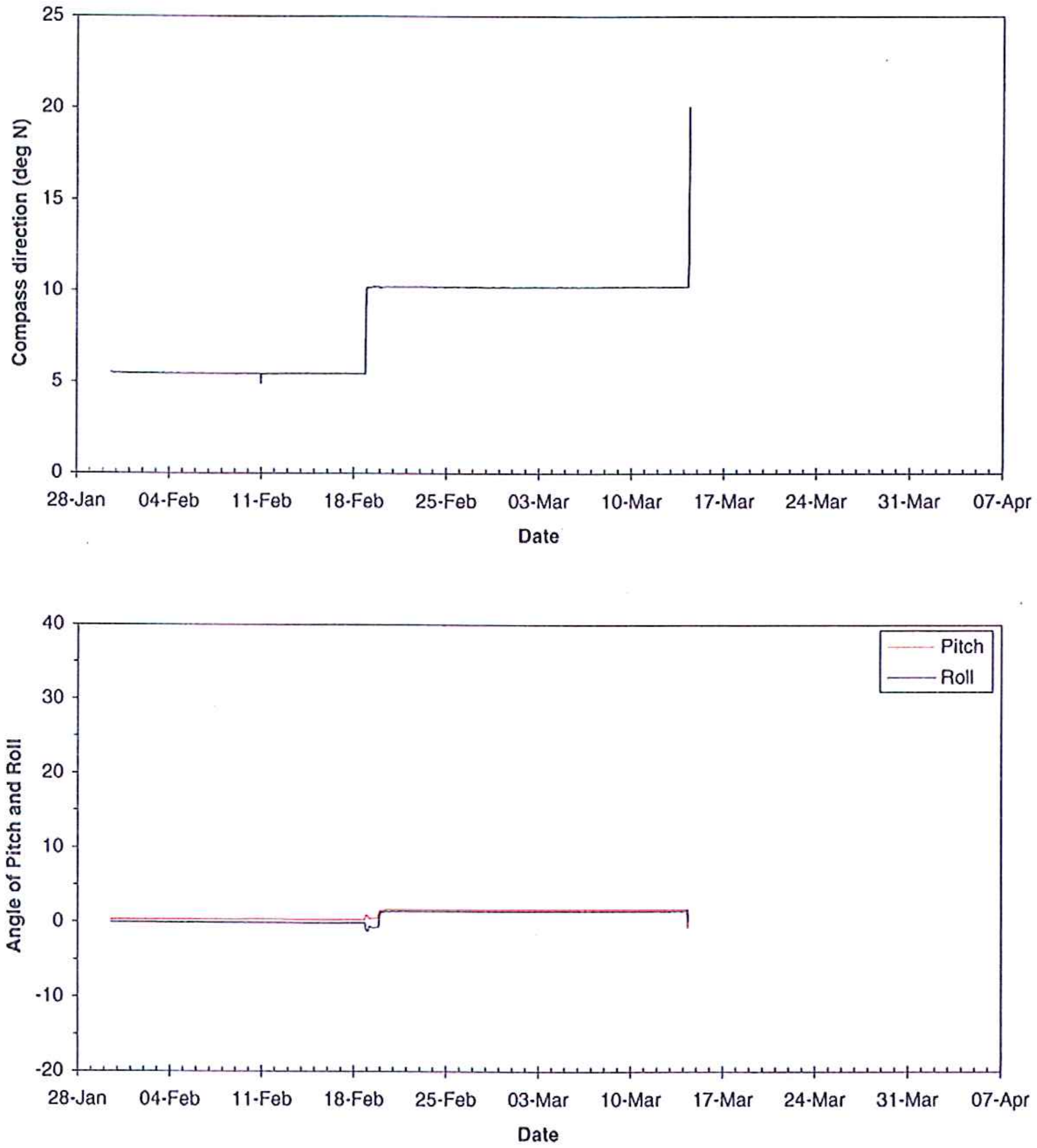

Figure 3 Pitch and roll sensor – Deployment 122

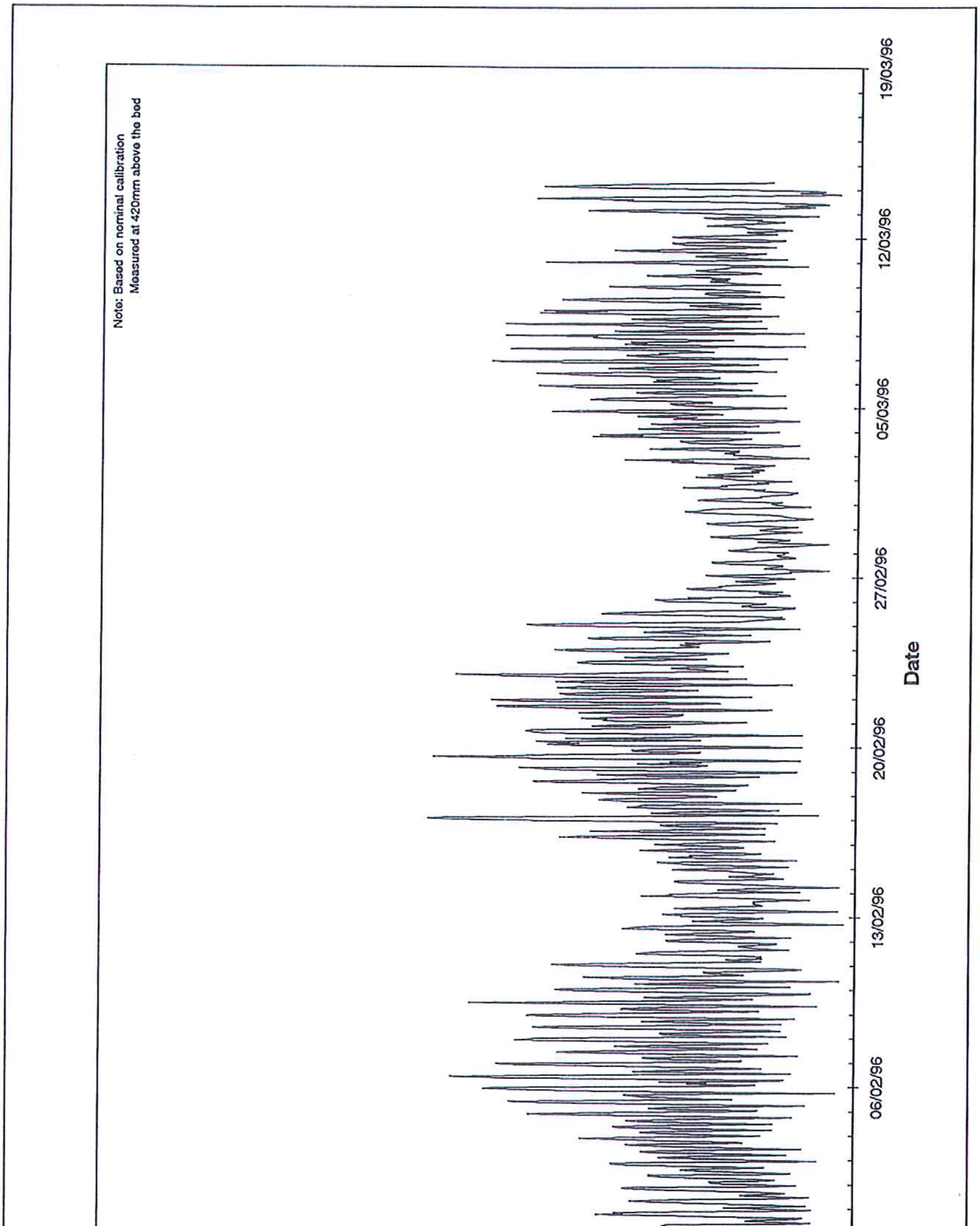

Figure 4 Current meter data – Deployment 122

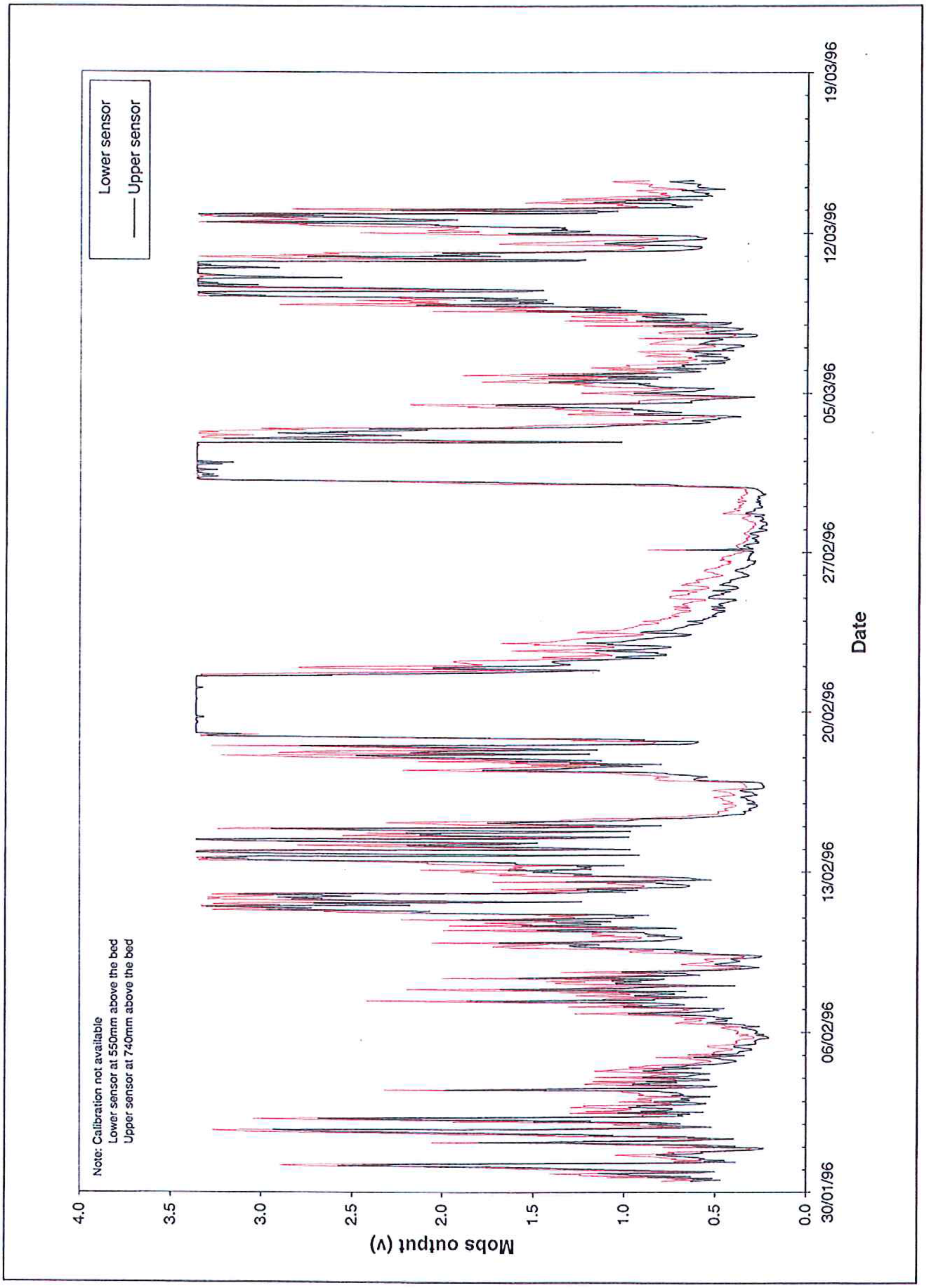

Figure 5 MOBS data – Deployment 122

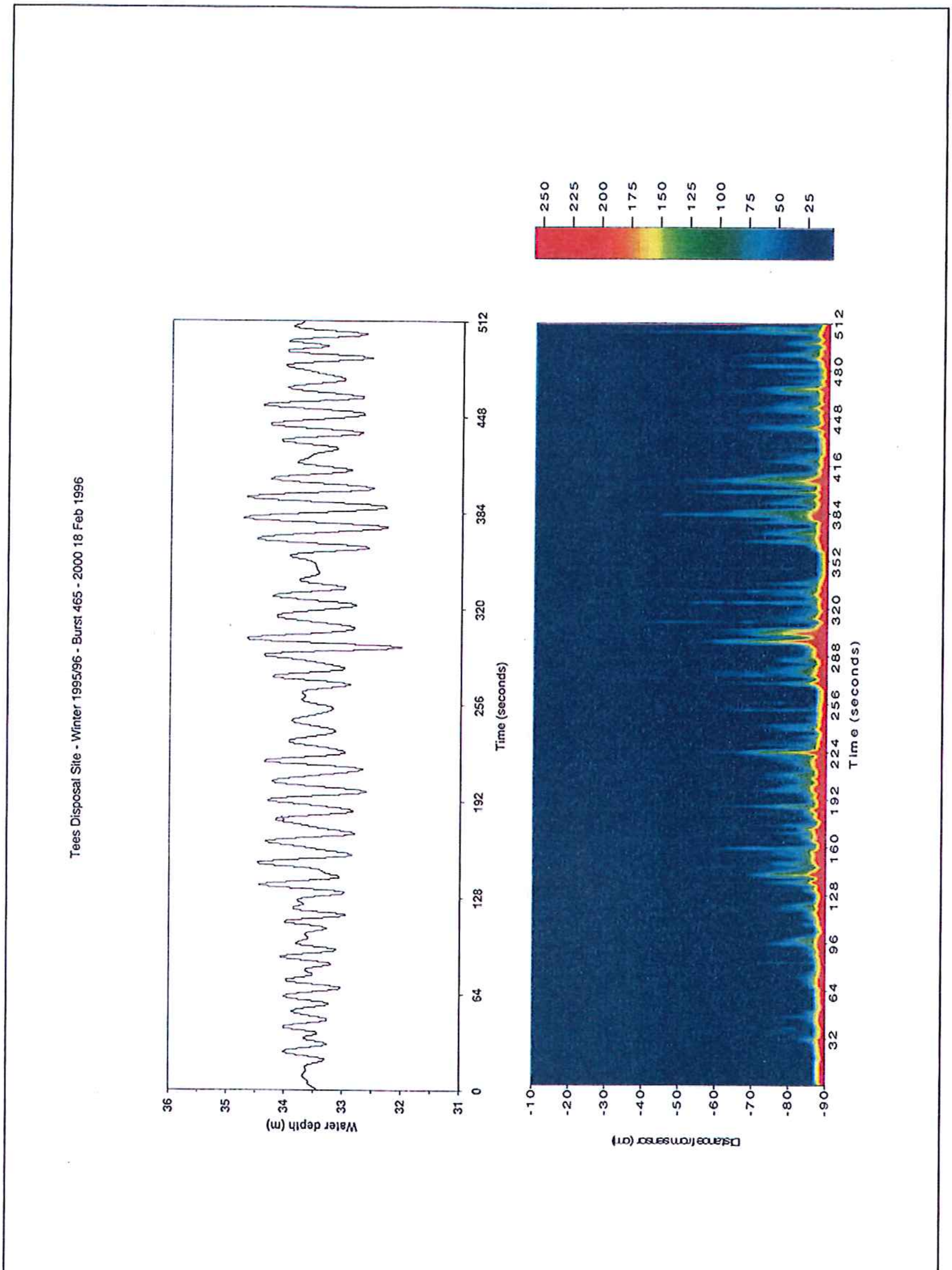

Figure 6 ABS data – Burst 465 – Deployment 122

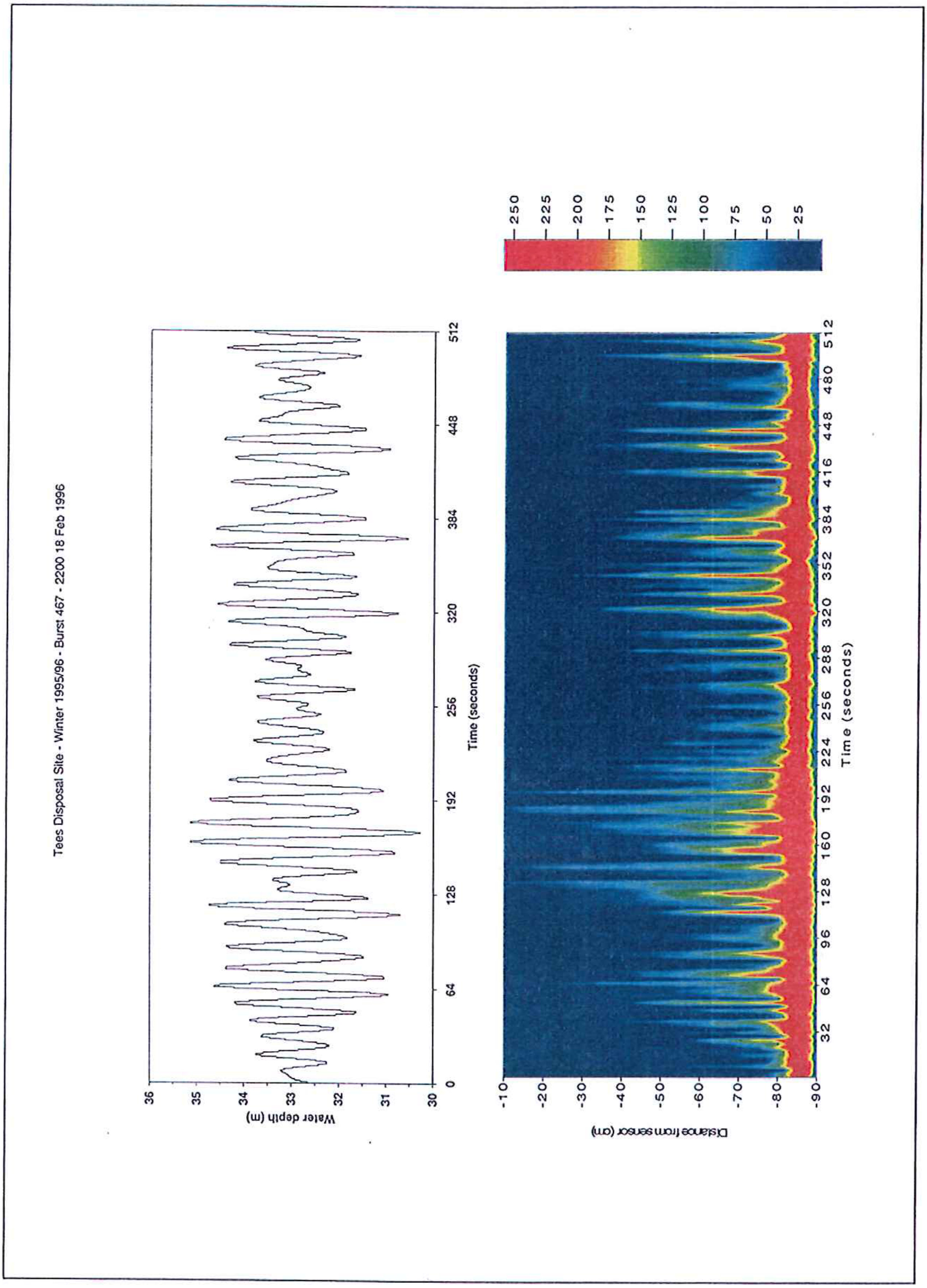

Figure 7 ABS data – Burst 467 – Deployment 122

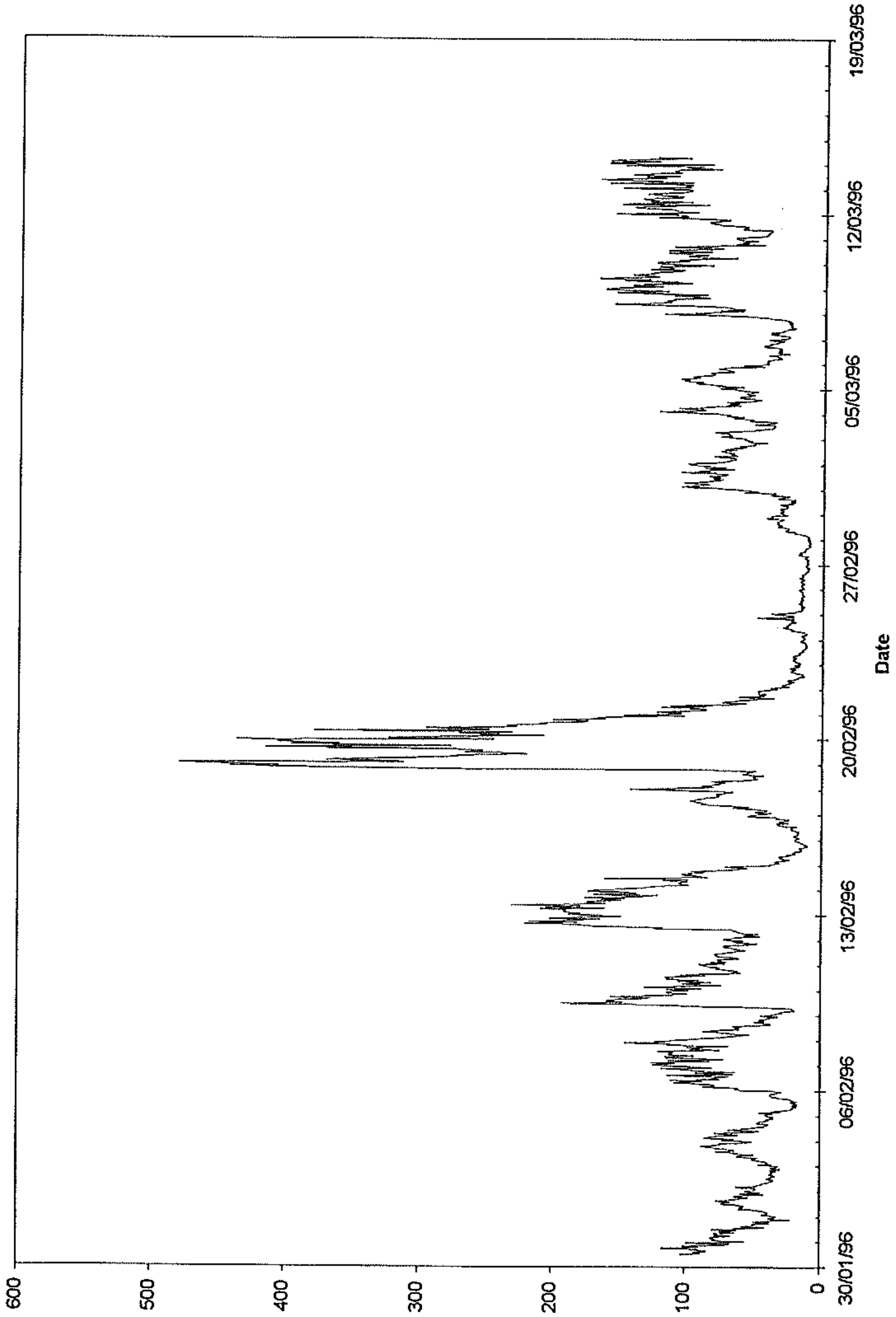

Figure 8 Significant wave height – Deployment 122

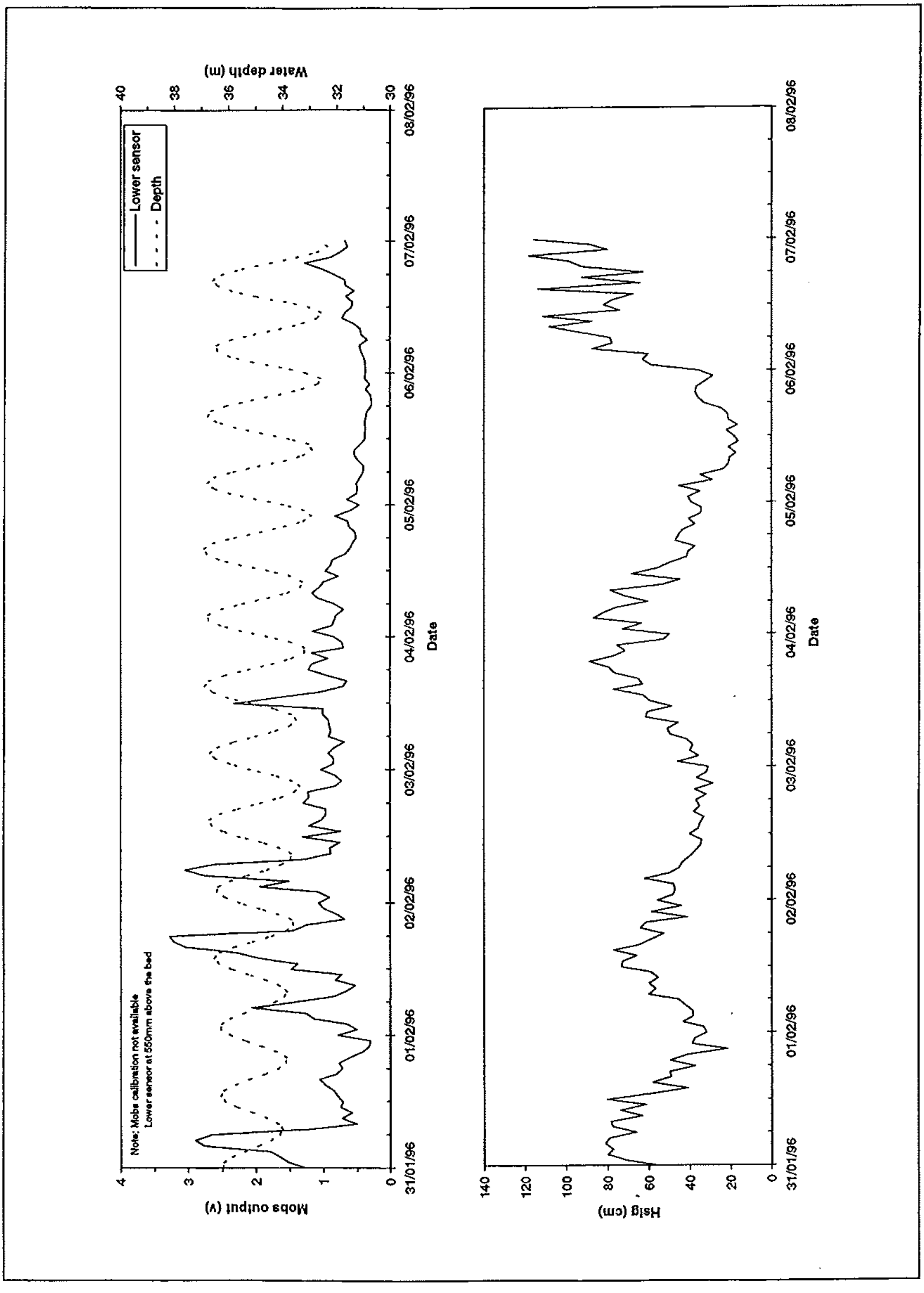

Figure 9 Summary of data – Week 1 - Deployment 122

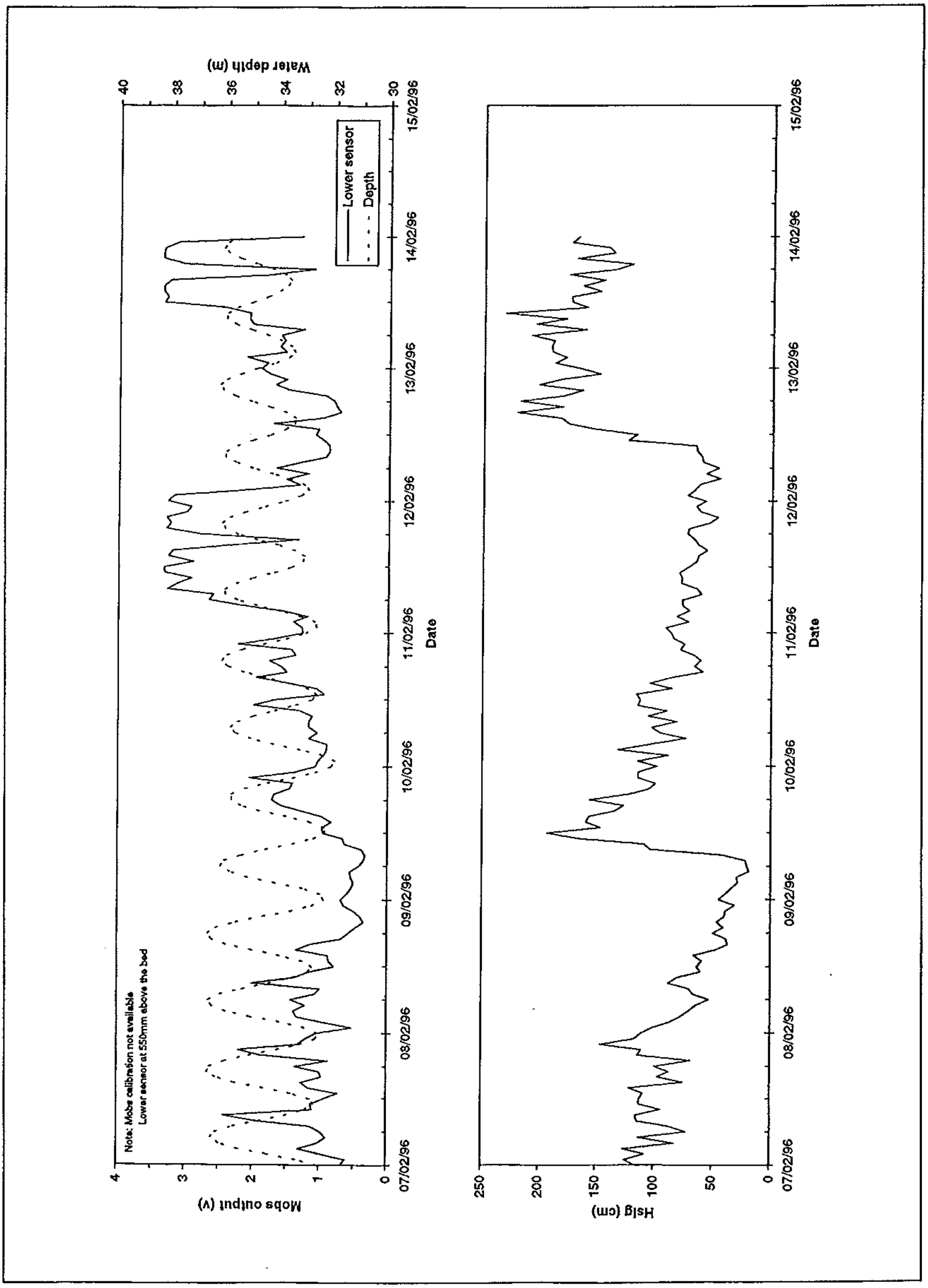

Figure 10 Summary of data – Week 2 - Deployment 122

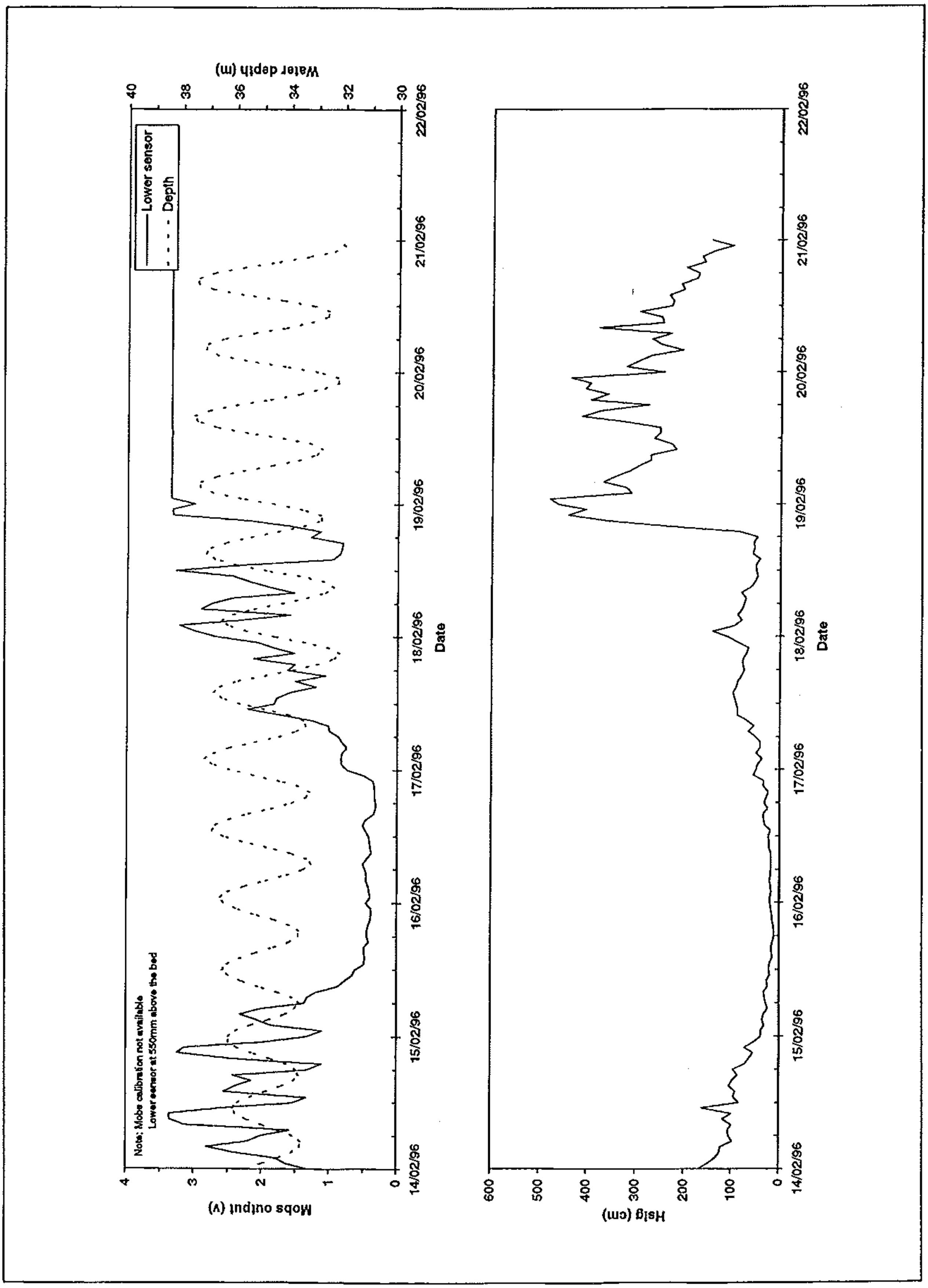

Figure 11 Summary of data – Week 3 - Deployment 122

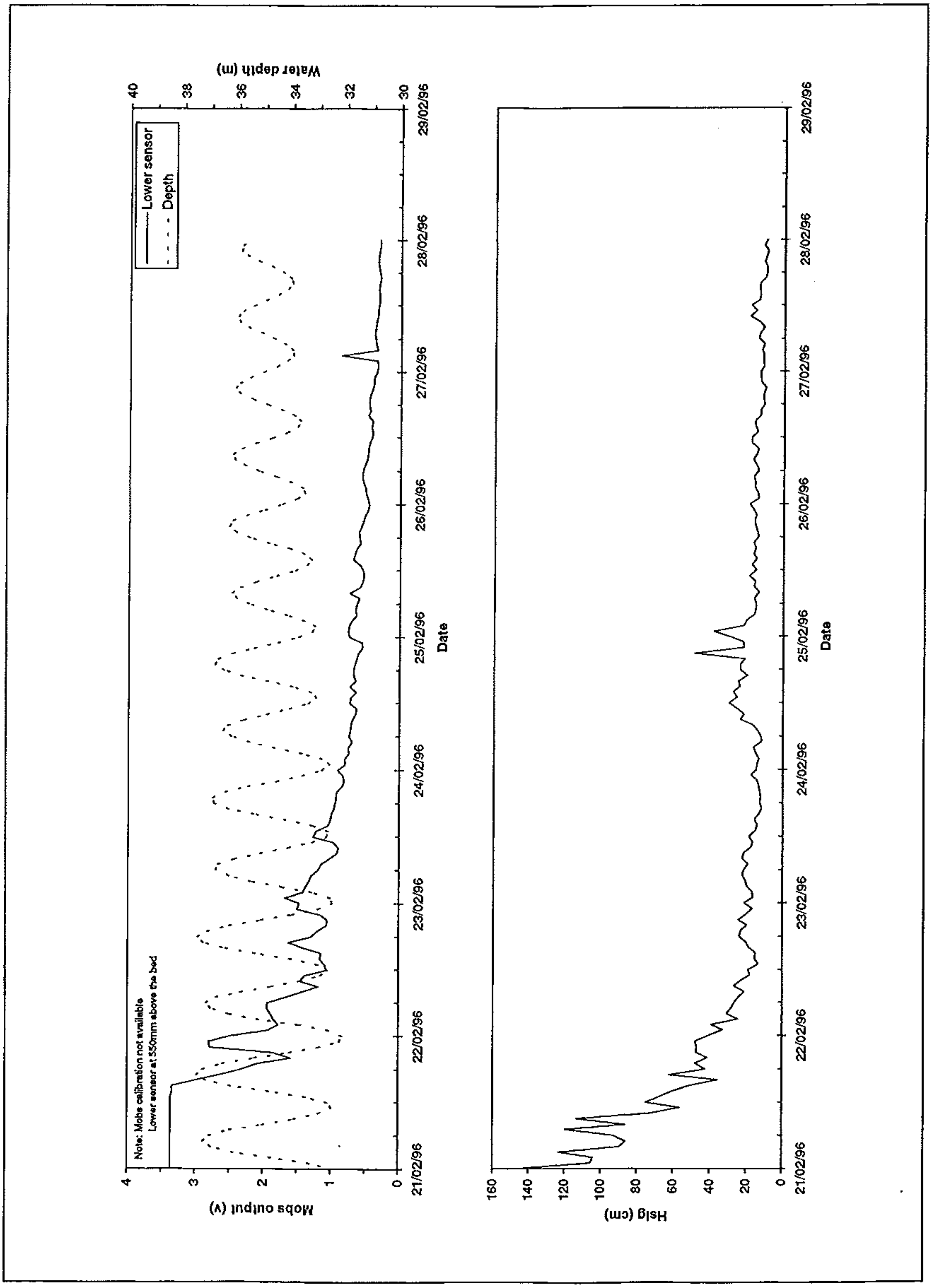

Figure 12 Summary of data – Week 4 - Deployment 122

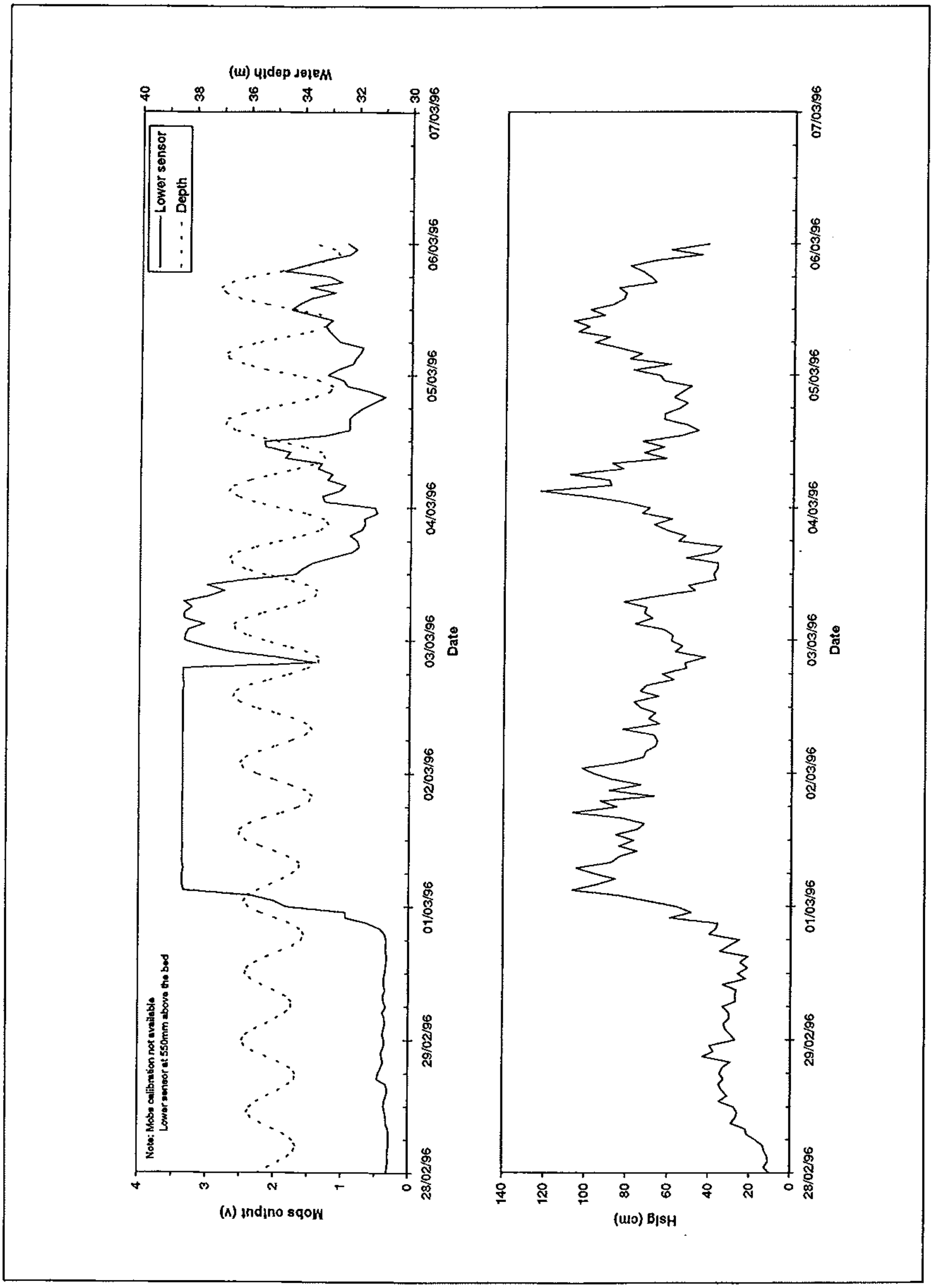

Figure 13 Summary of data – Week 5 - Deployment 122

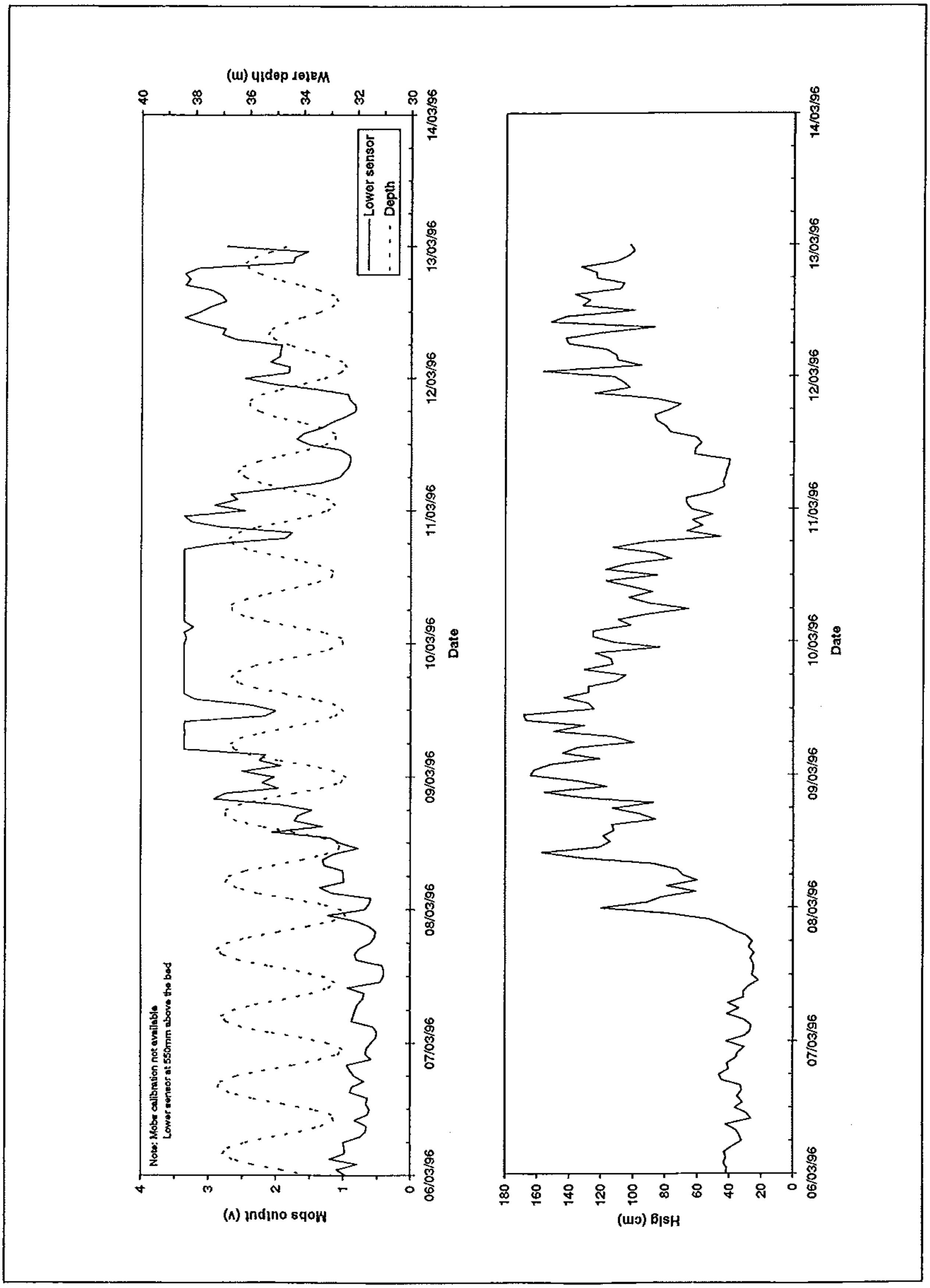

Figure 14 Summary of data – Week 6 - Deployment 122

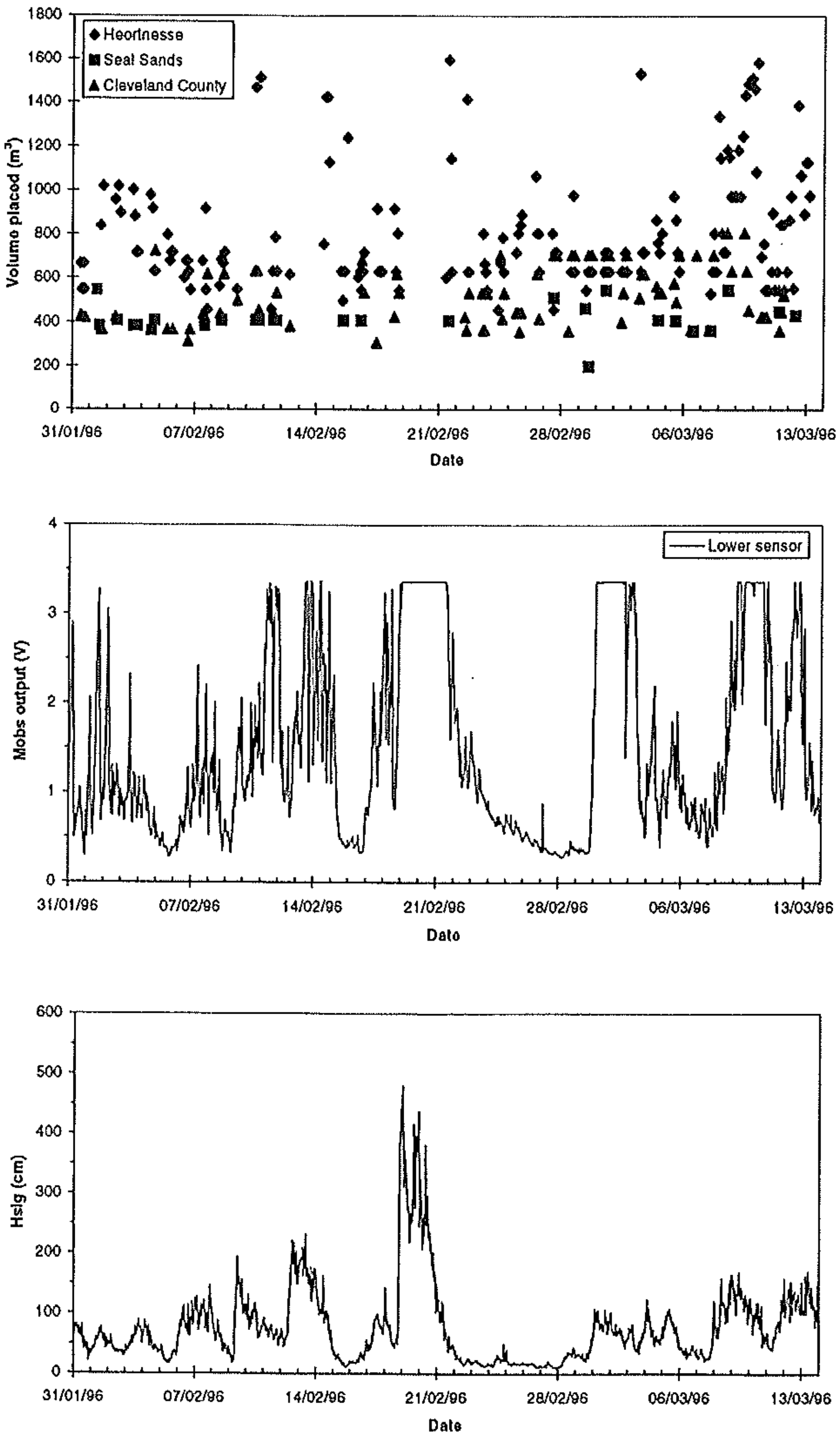

Figure 15 Dredging activity – Deployment 122

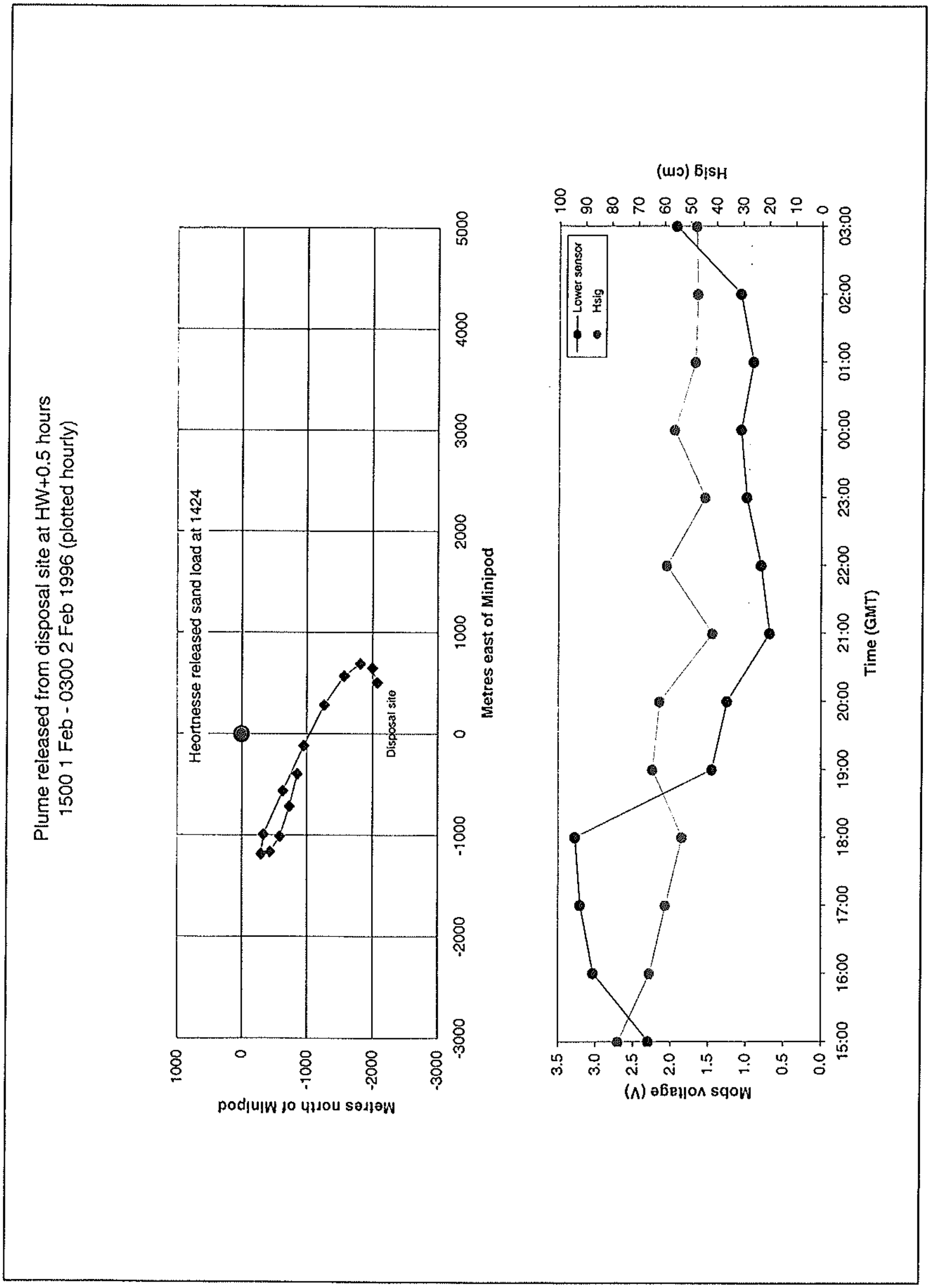

Figure 16 Placement 1 – Deployment 122

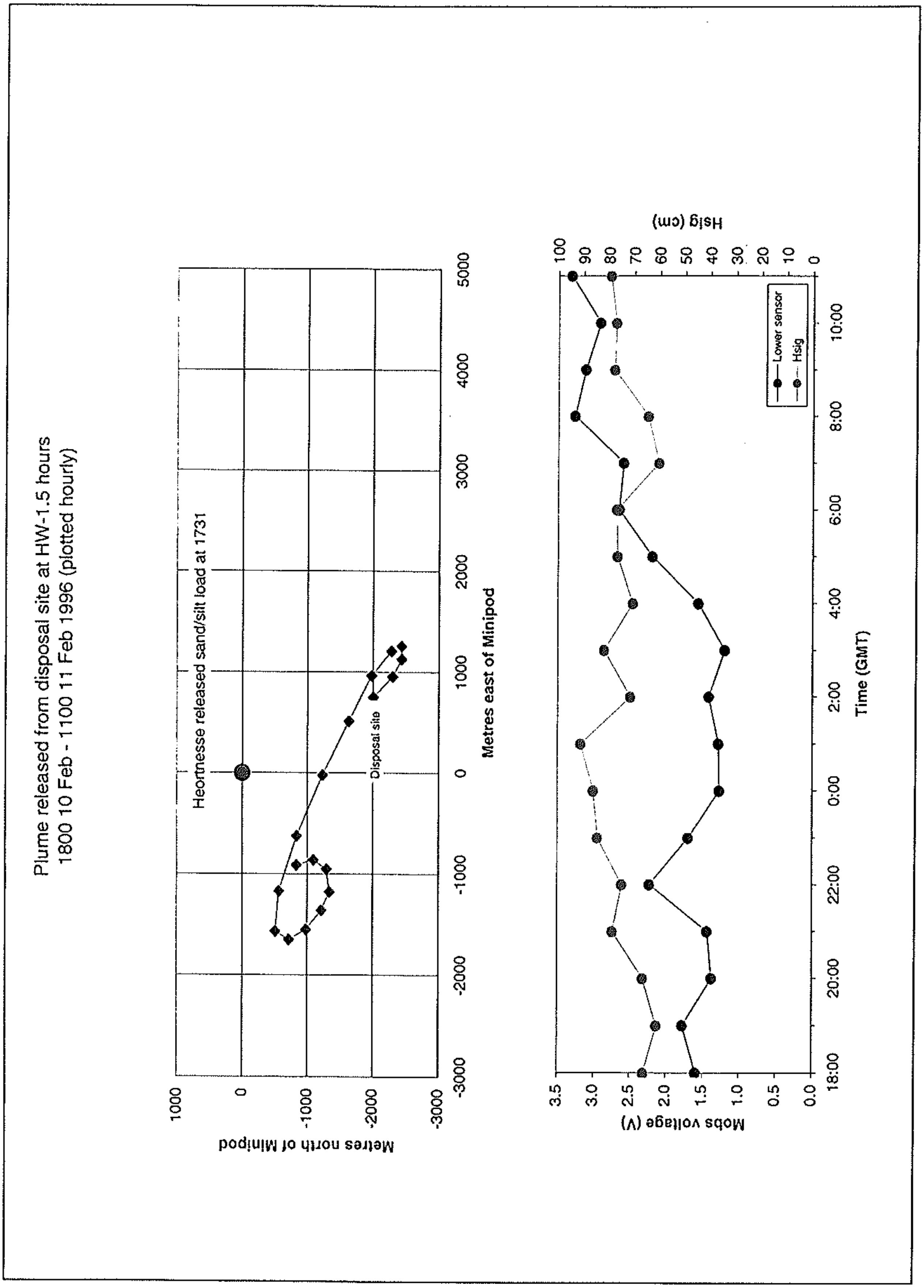

Figure 17 Placement 2 – Deployment 122

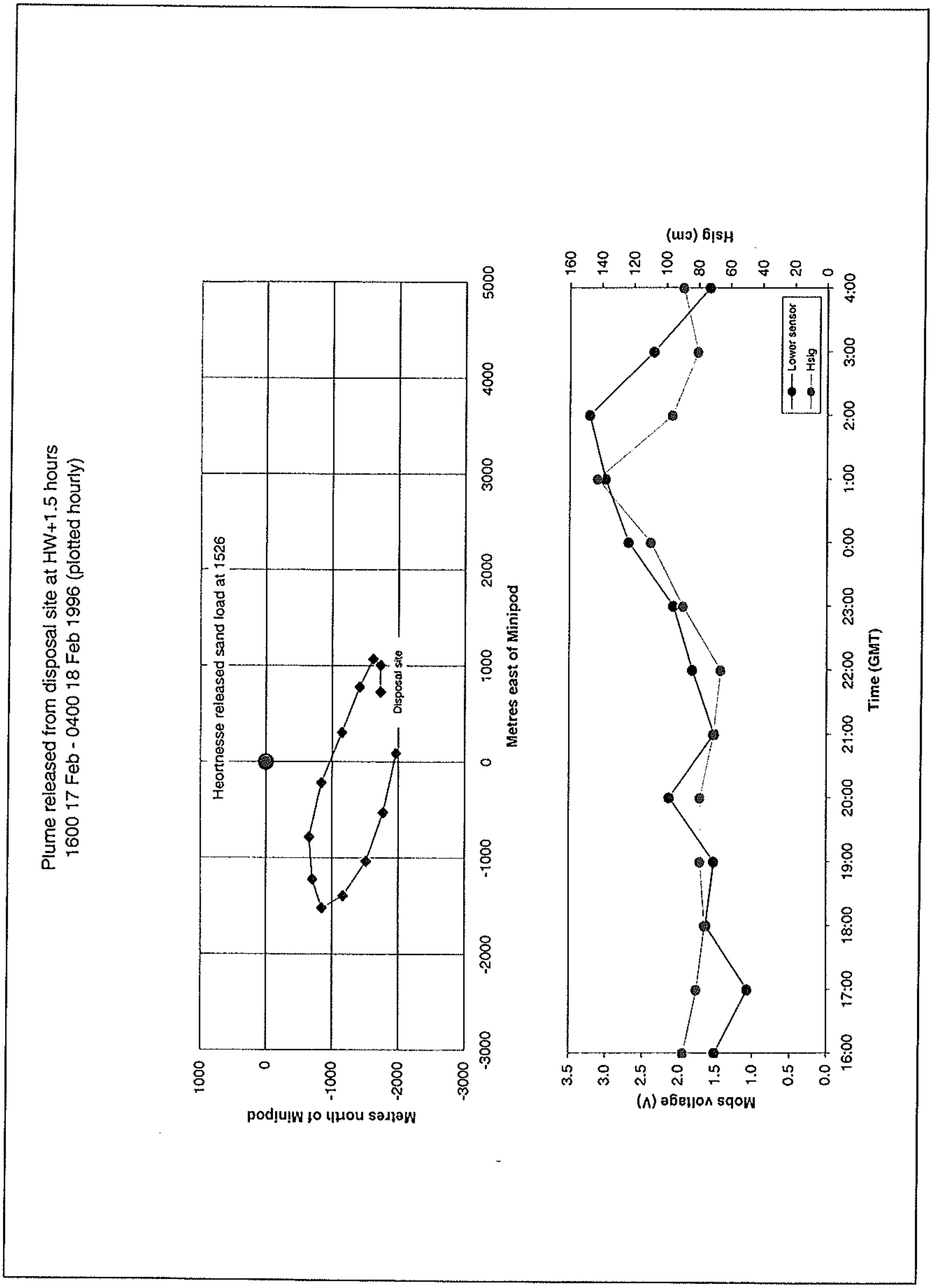

Figure 18 Placement 3 – Deployment 122

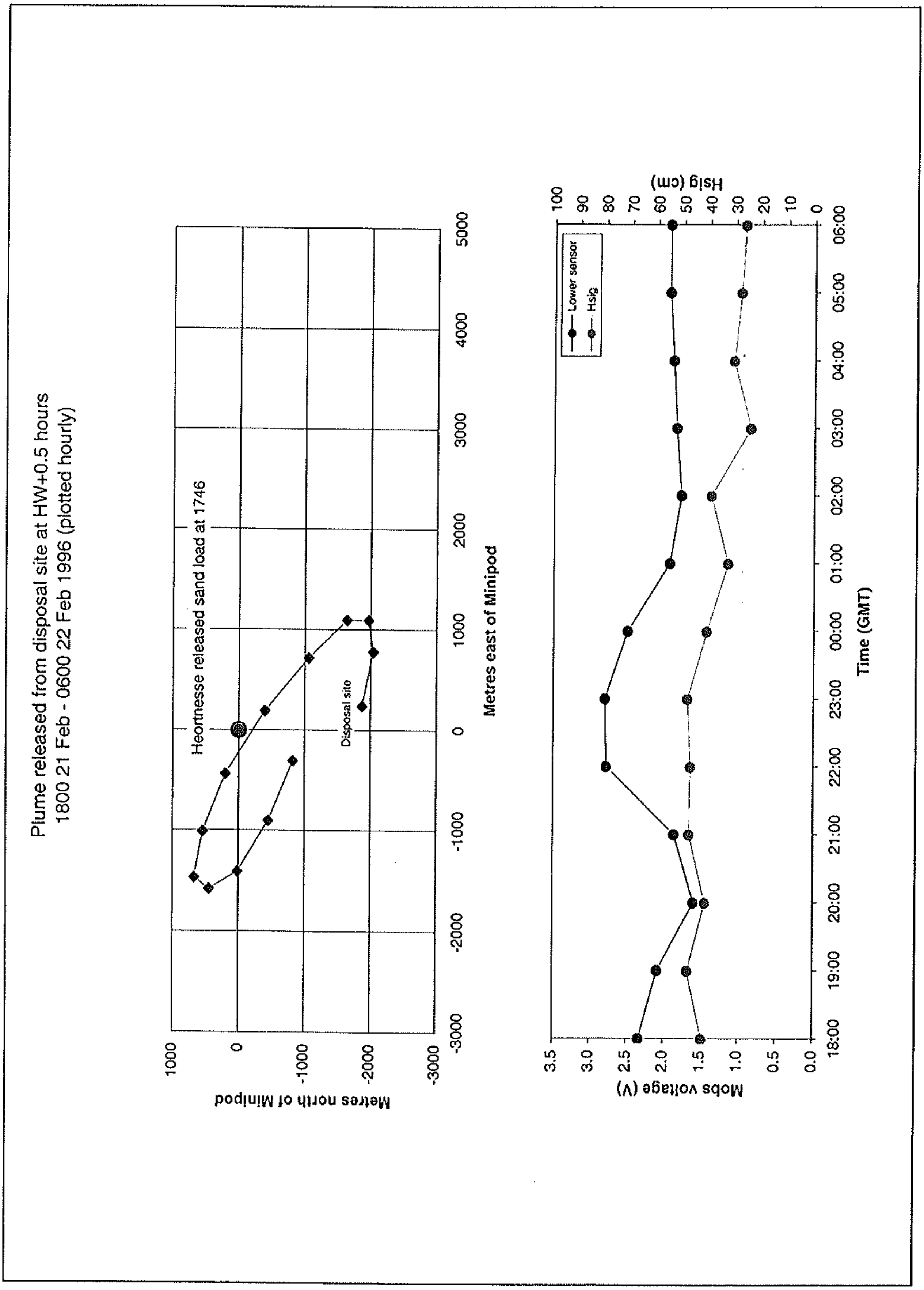

Figure 19 Placement 4 – Deployment 122

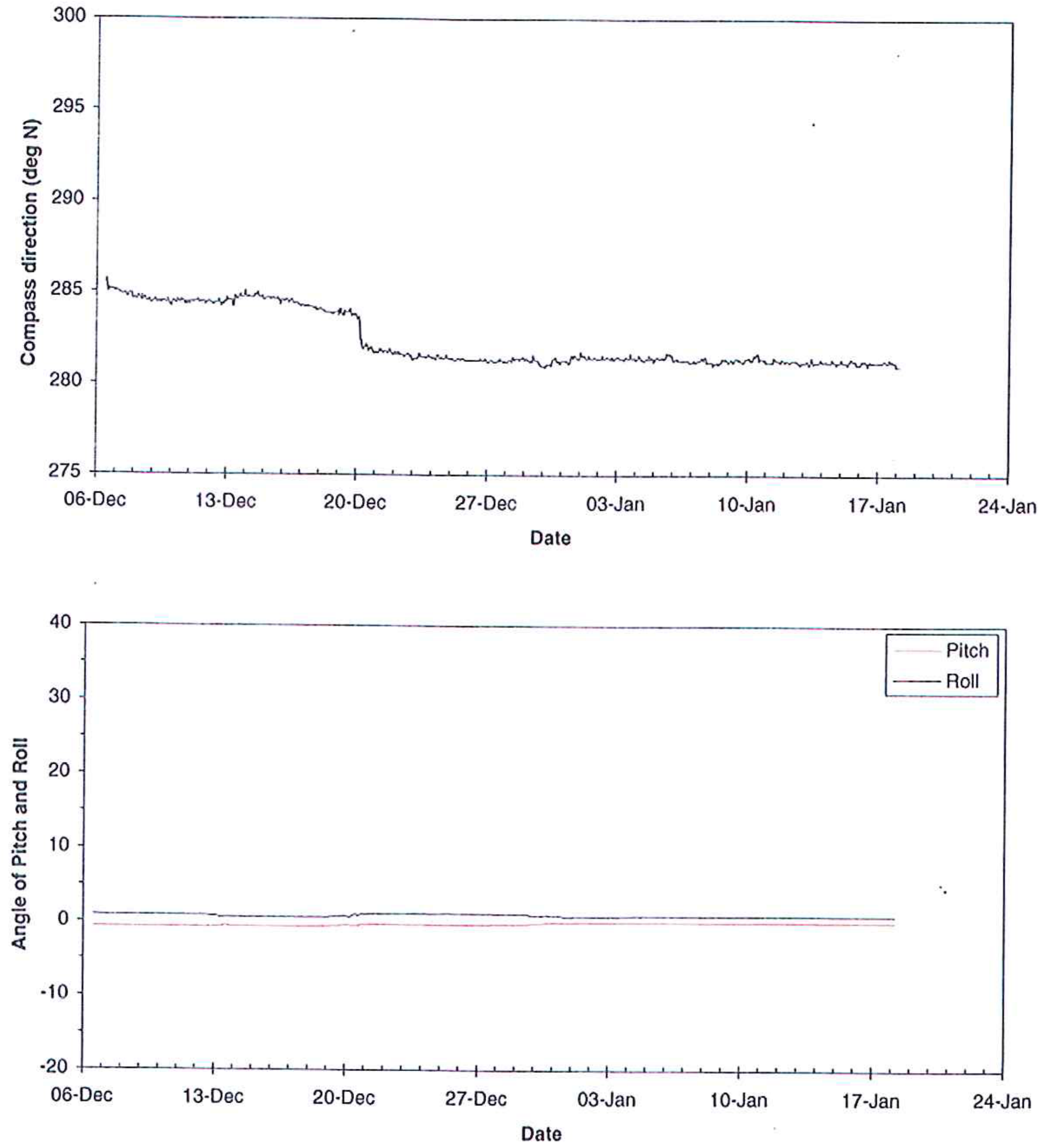

Figure 20 Pitch and roll sensor – Deployment 139

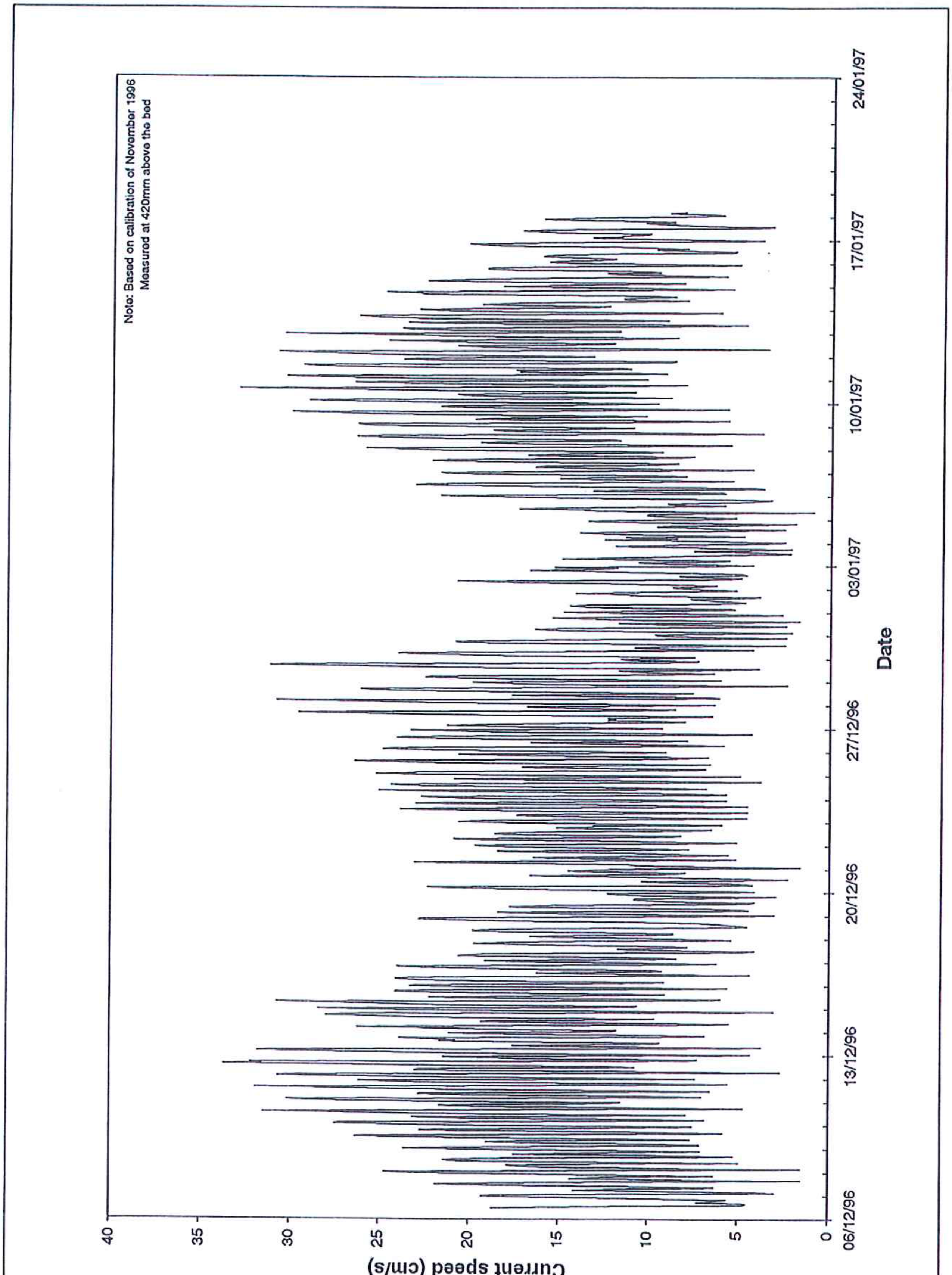

Figure 21 Current meter data – Deployment 139

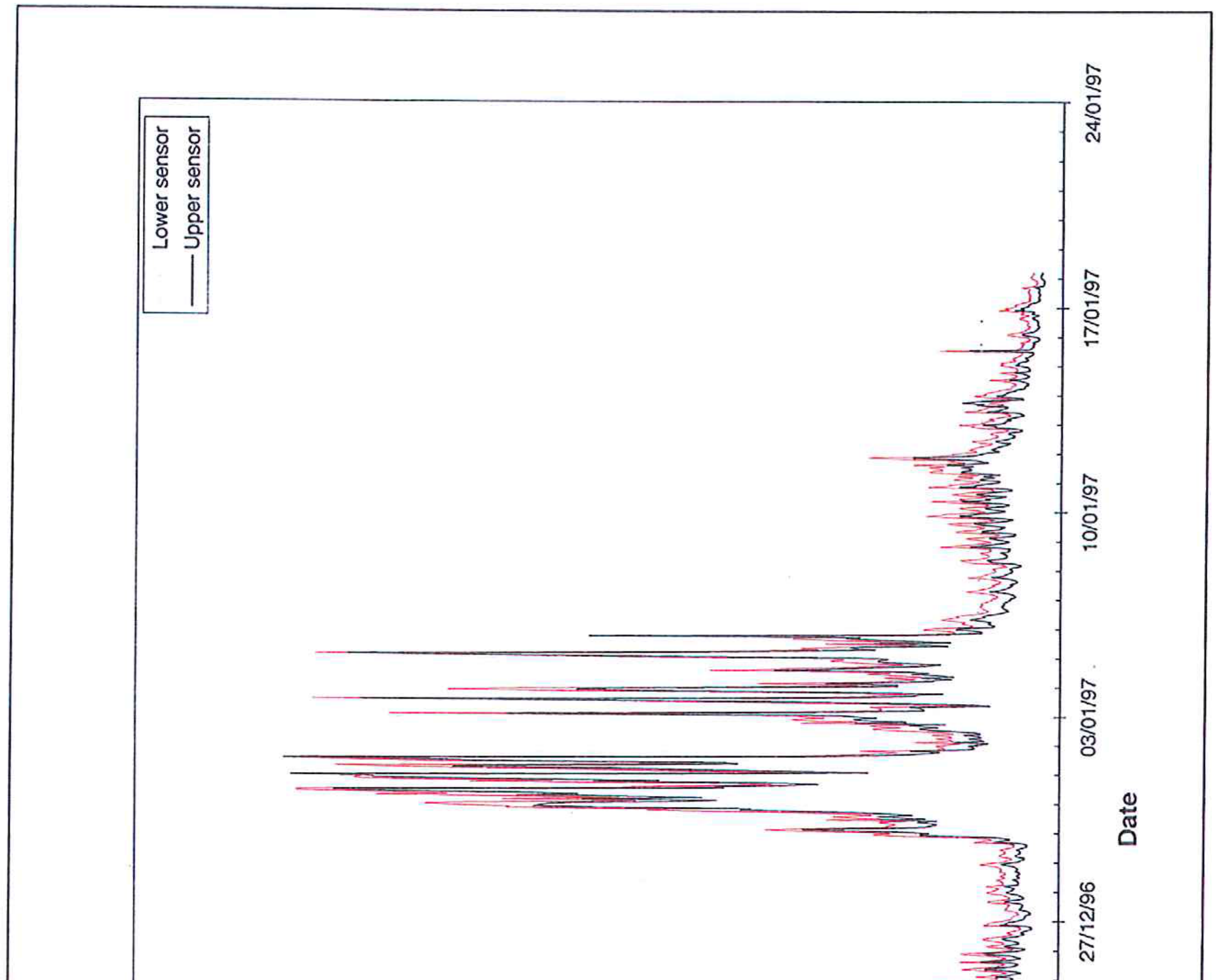

Figure 22 MOBS data – Deployment 139

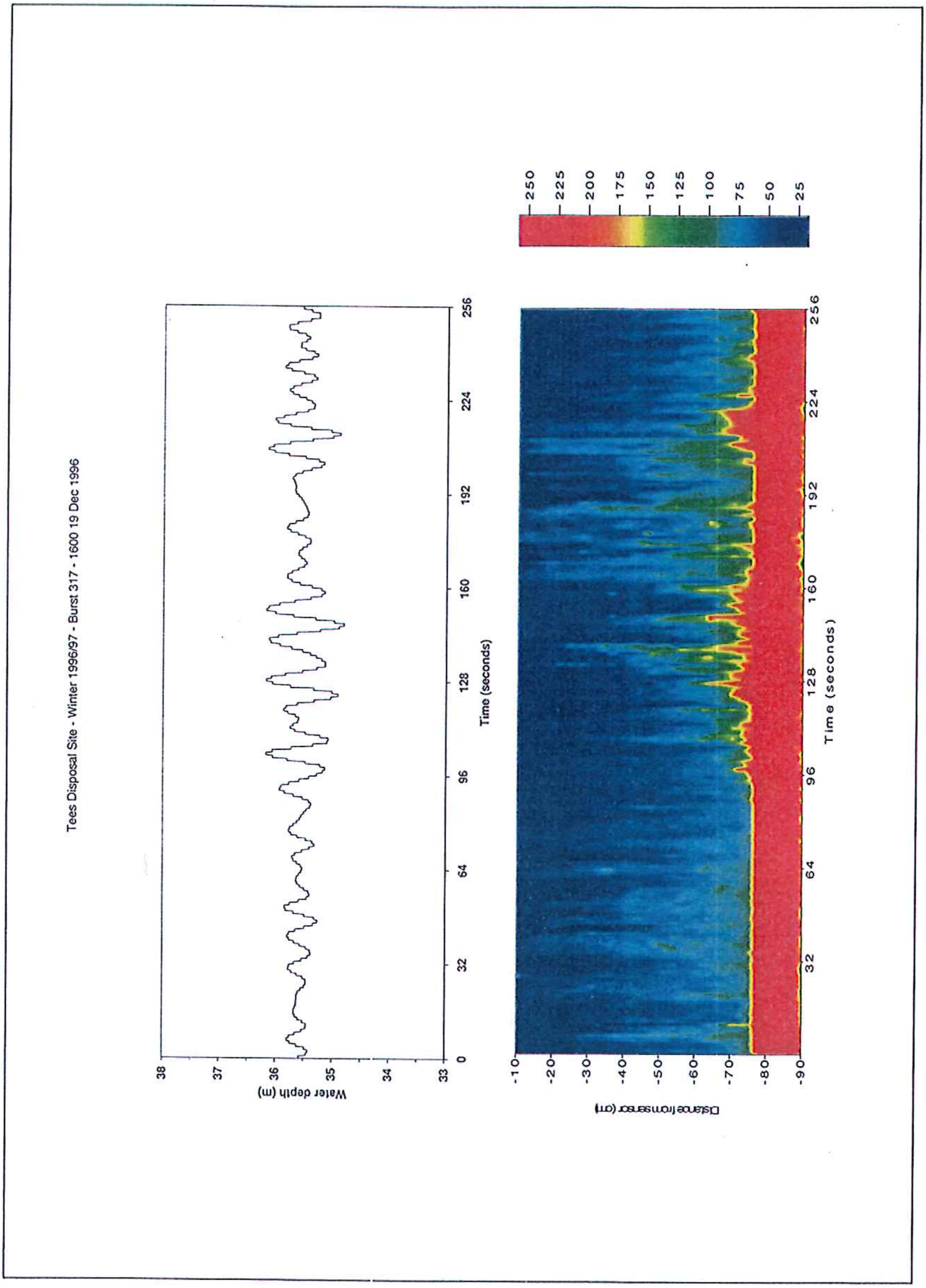

Figure 23 ABS data – Burst 317 – Deployment 139

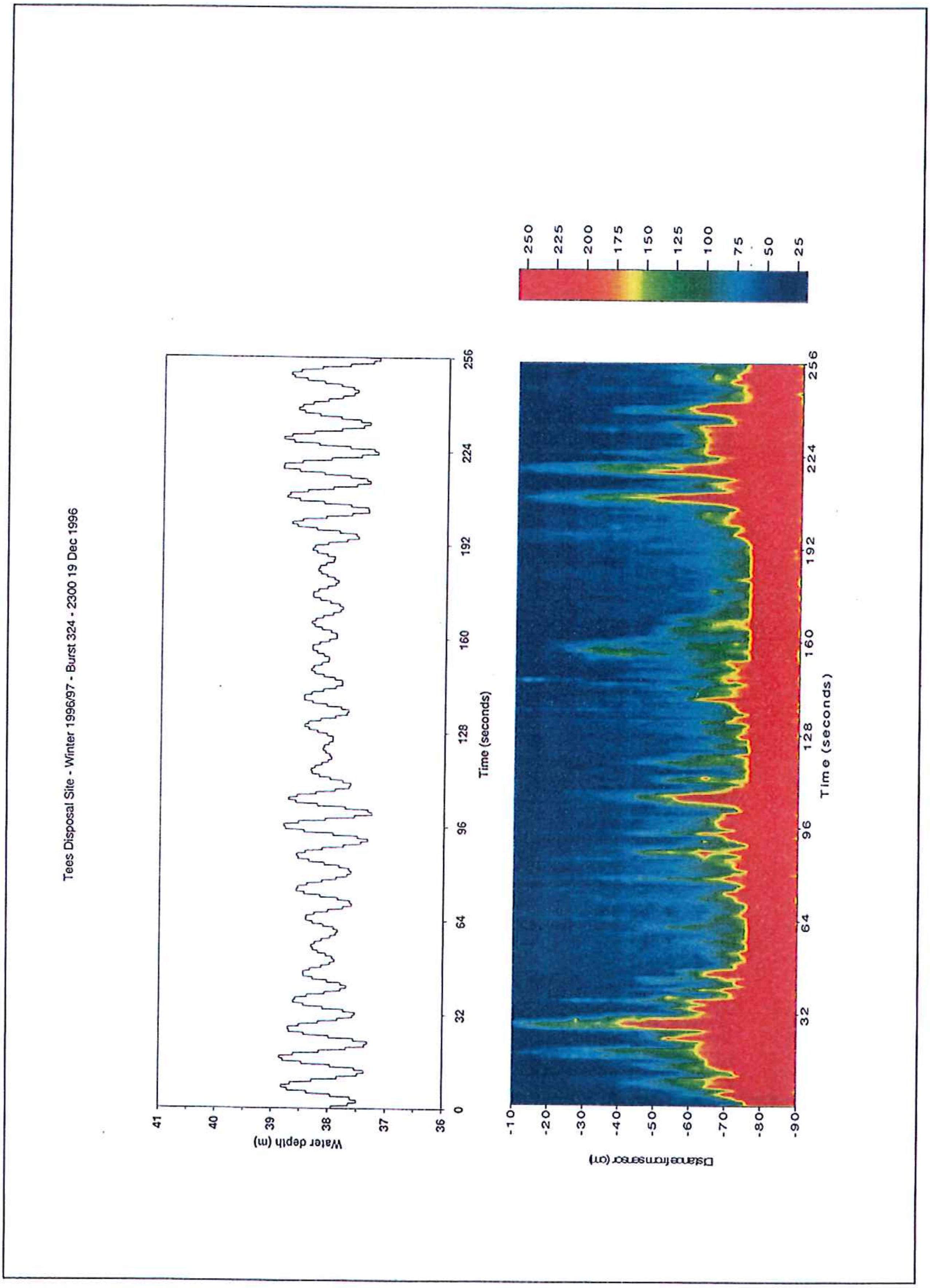

Figure 24 ABS data – Burst 324 – Deployment 139

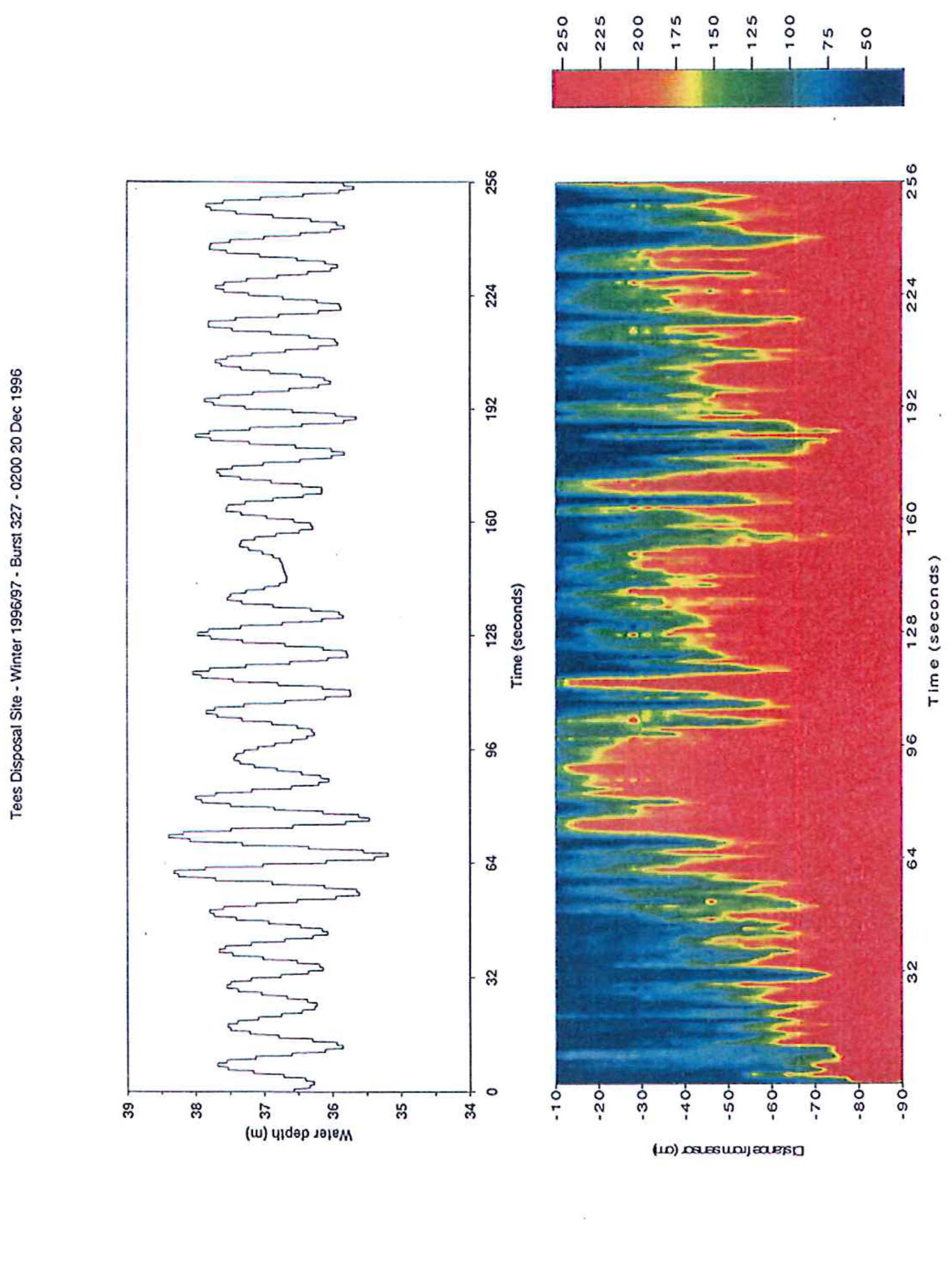

Figure 25 ABS data – Burst 327 – Deployment 139

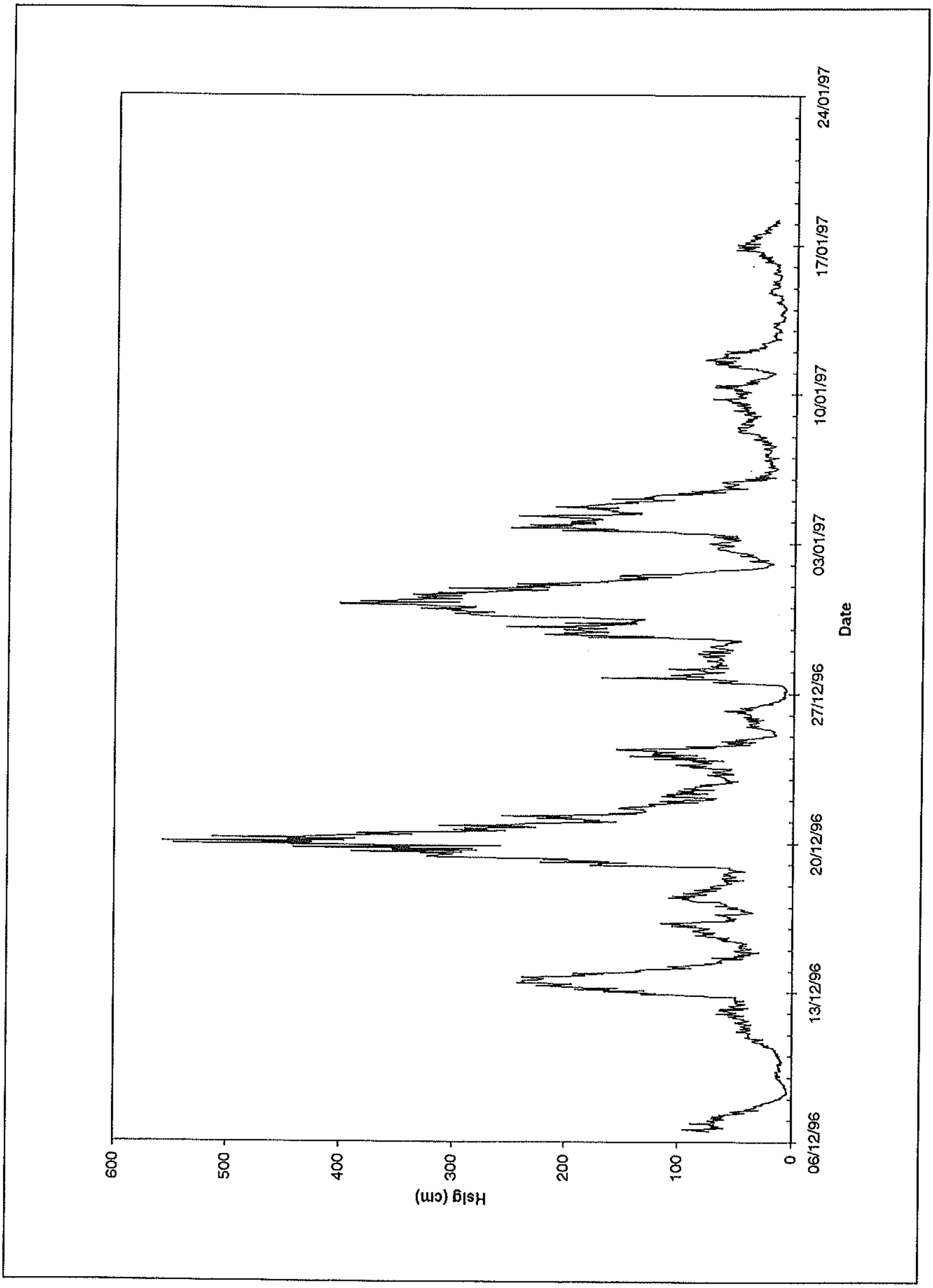

Figure 26 Significant wave height – Deployment 139

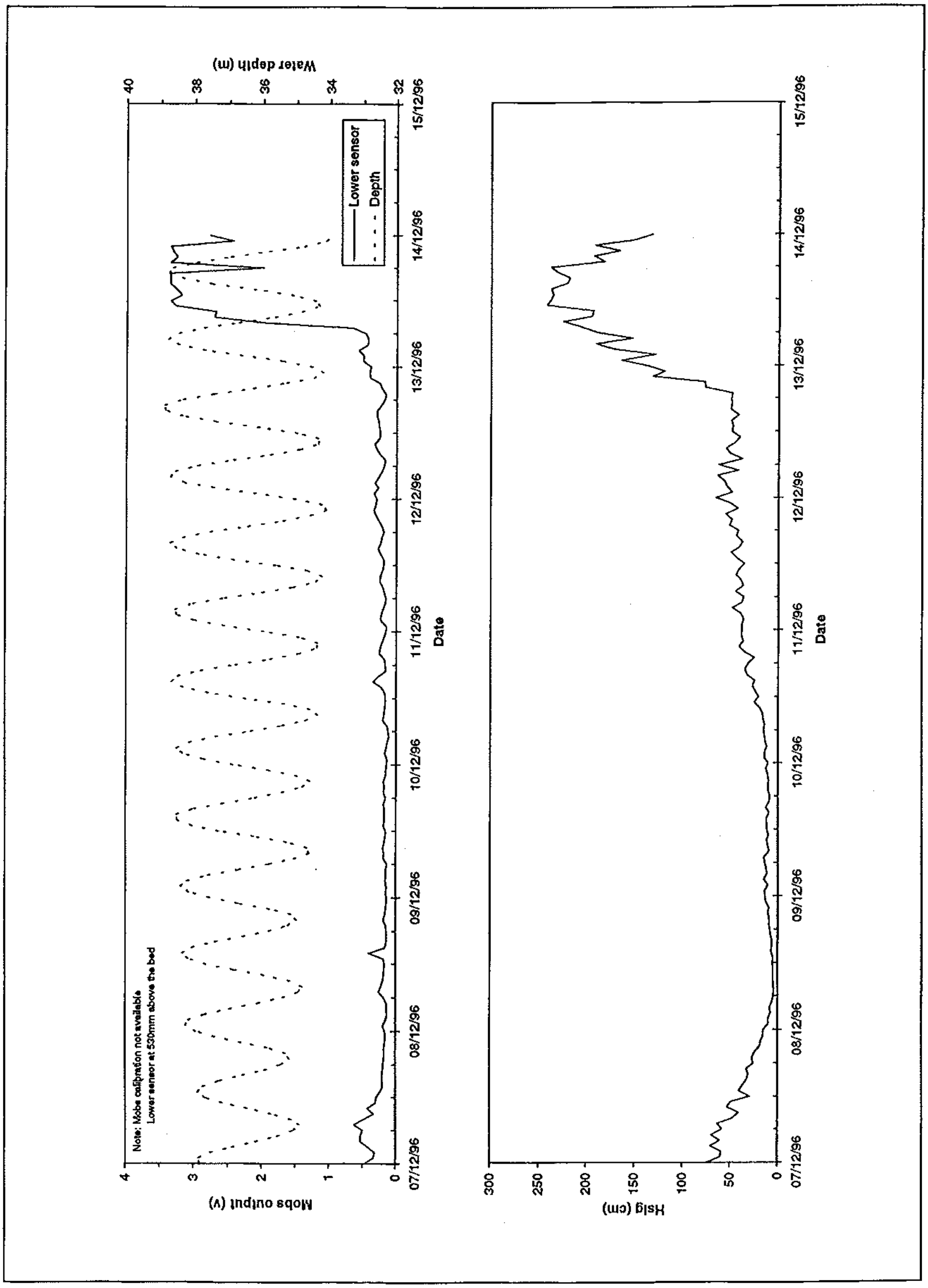

Figure 27 Summary of data – Week 1 - Deployment 139

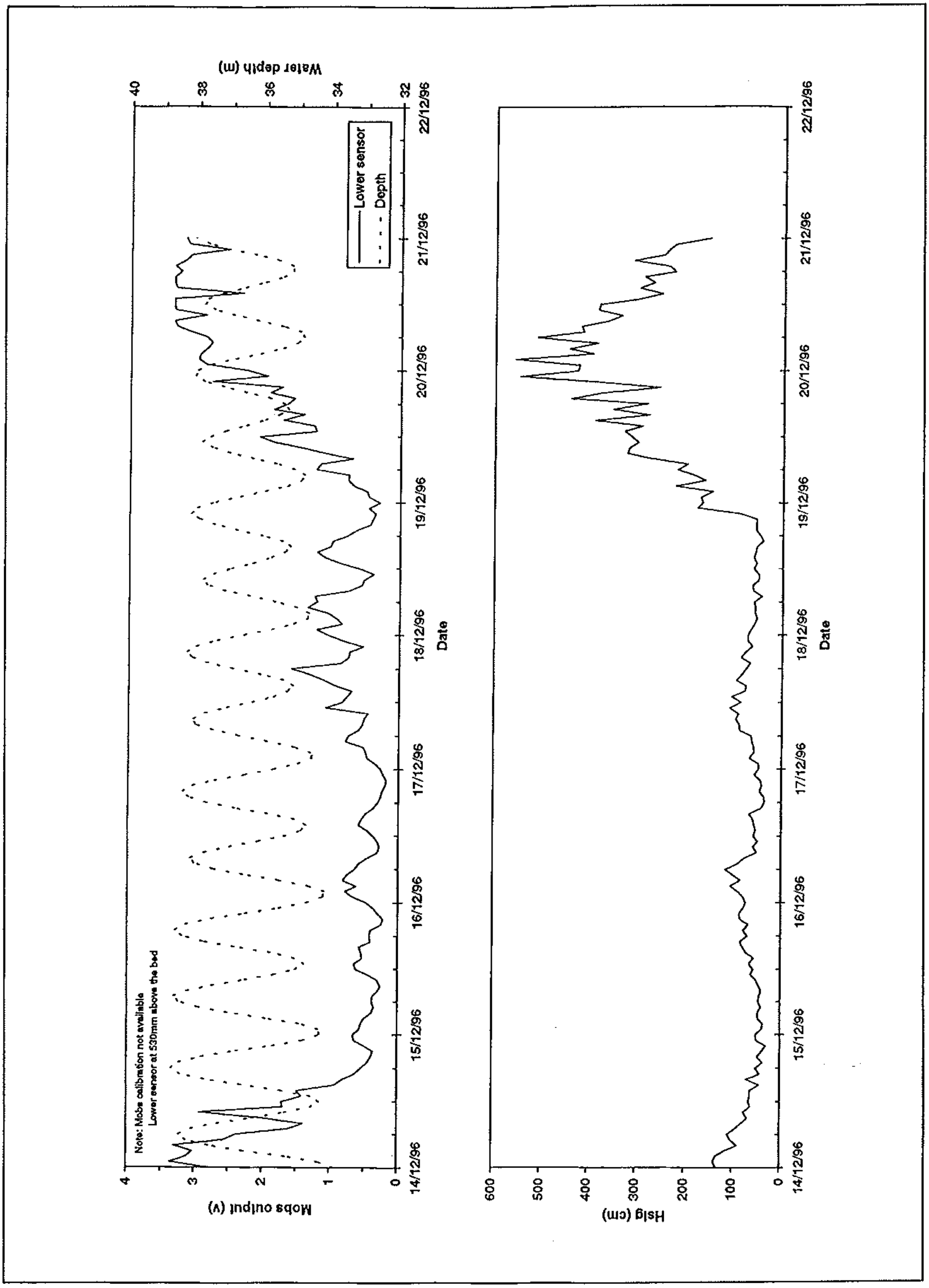

Figure 28 Summary of data – Week 2 - Deployment 139

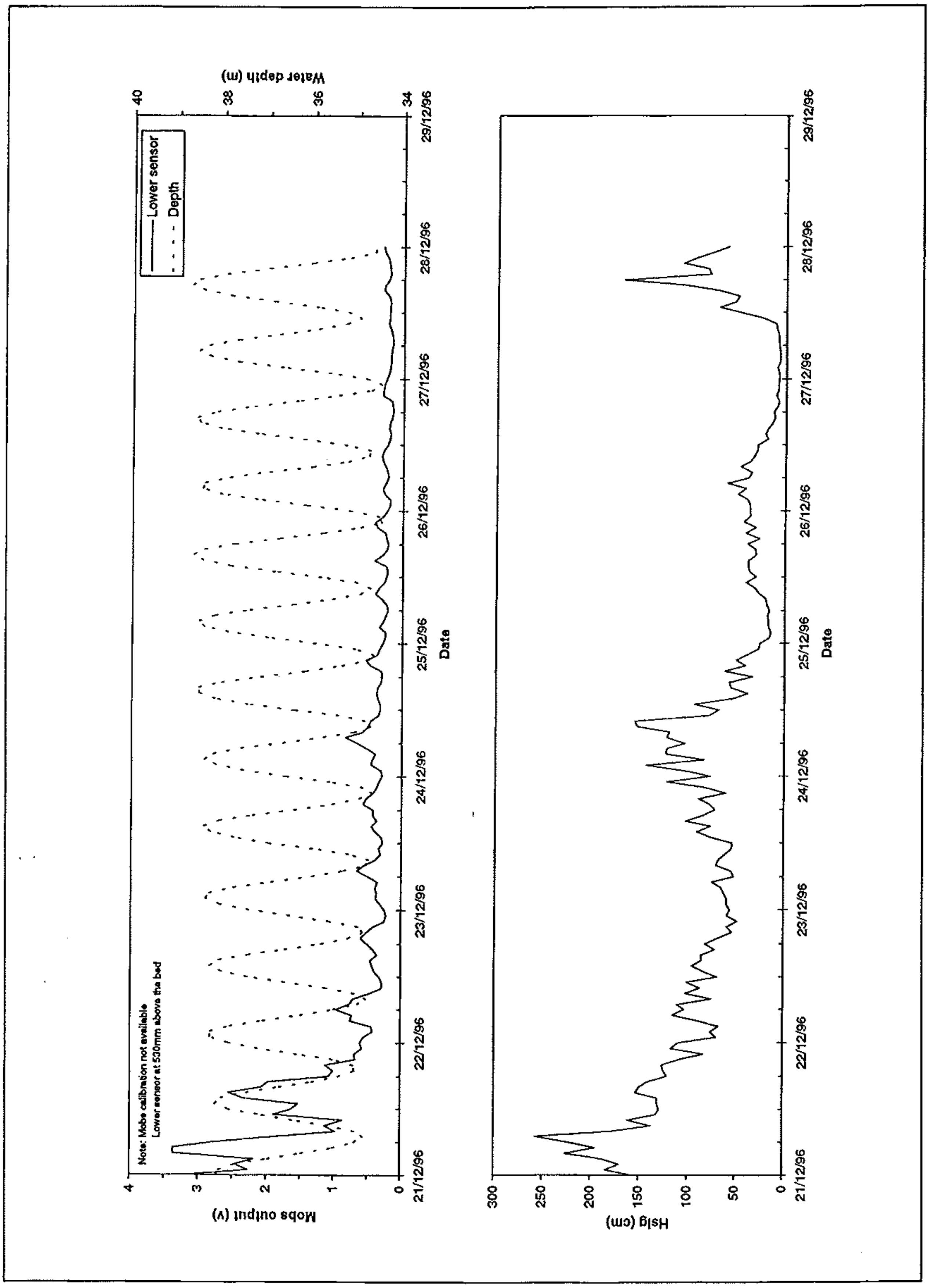

Figure 29 Summary of data – Week 3 - Deployment 139

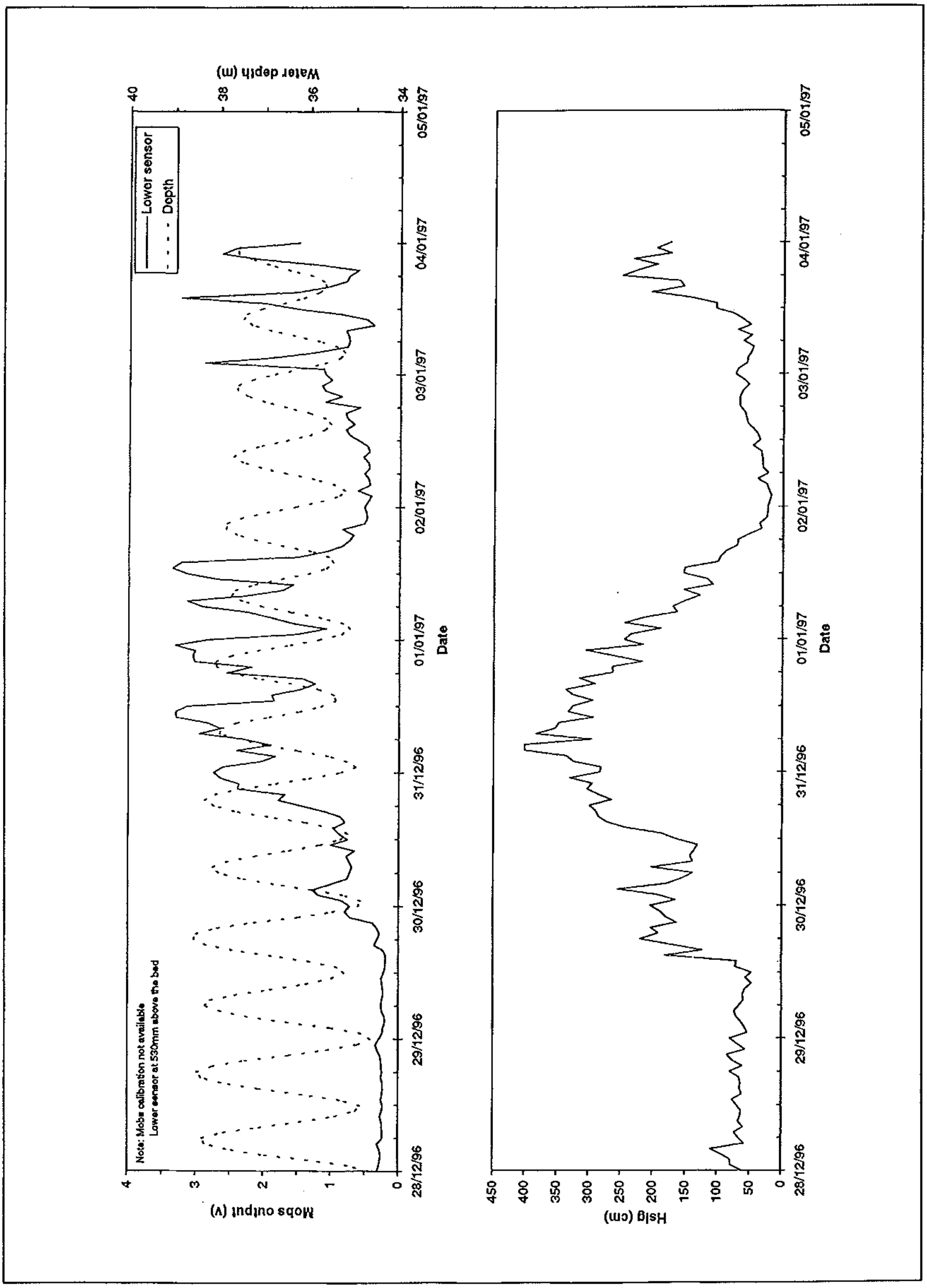

Figure 30 Summary of data – Week 4 - Deployment 139

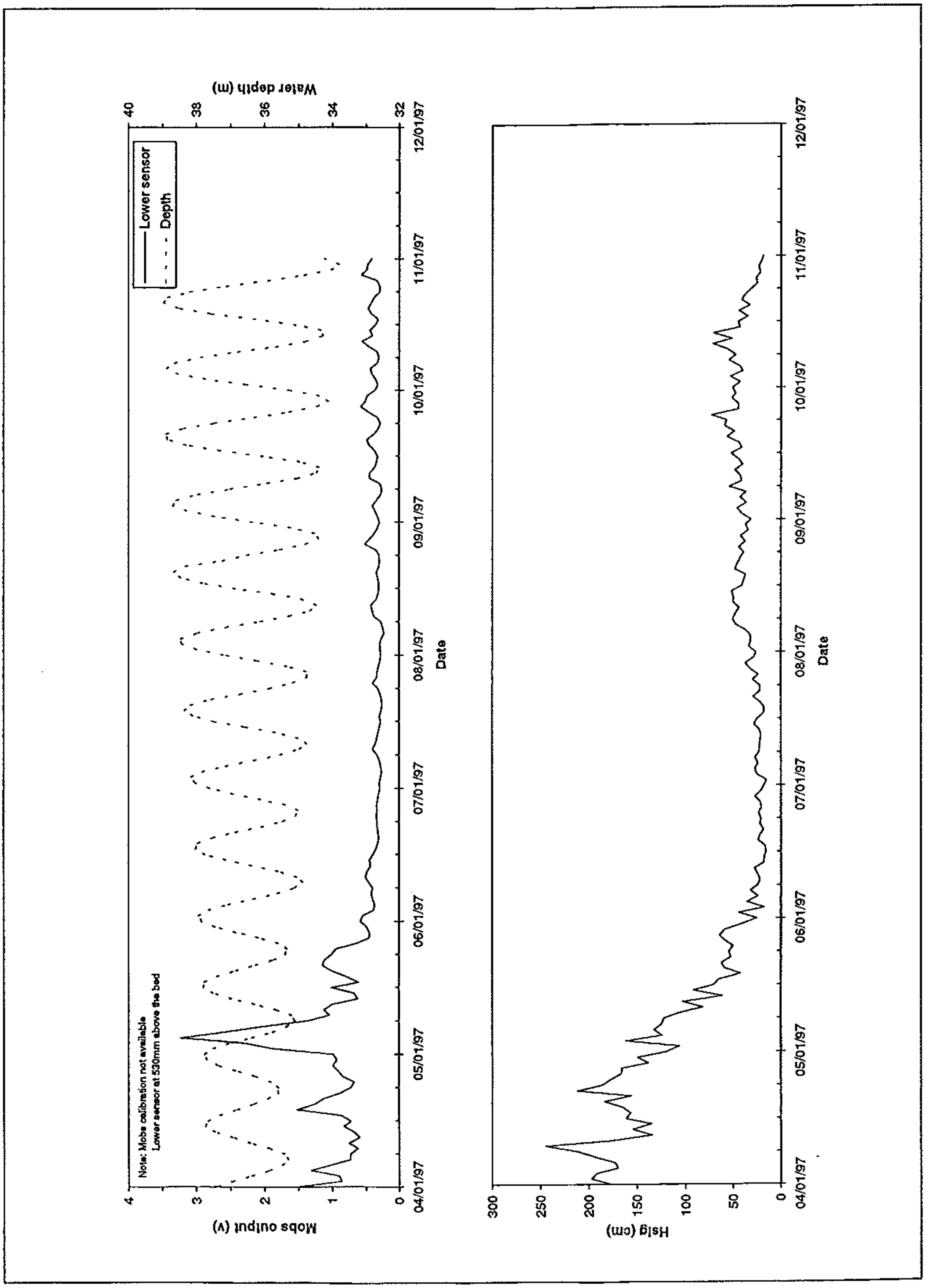

Figure 31 Summary of data – Week 5 - Deployment 139

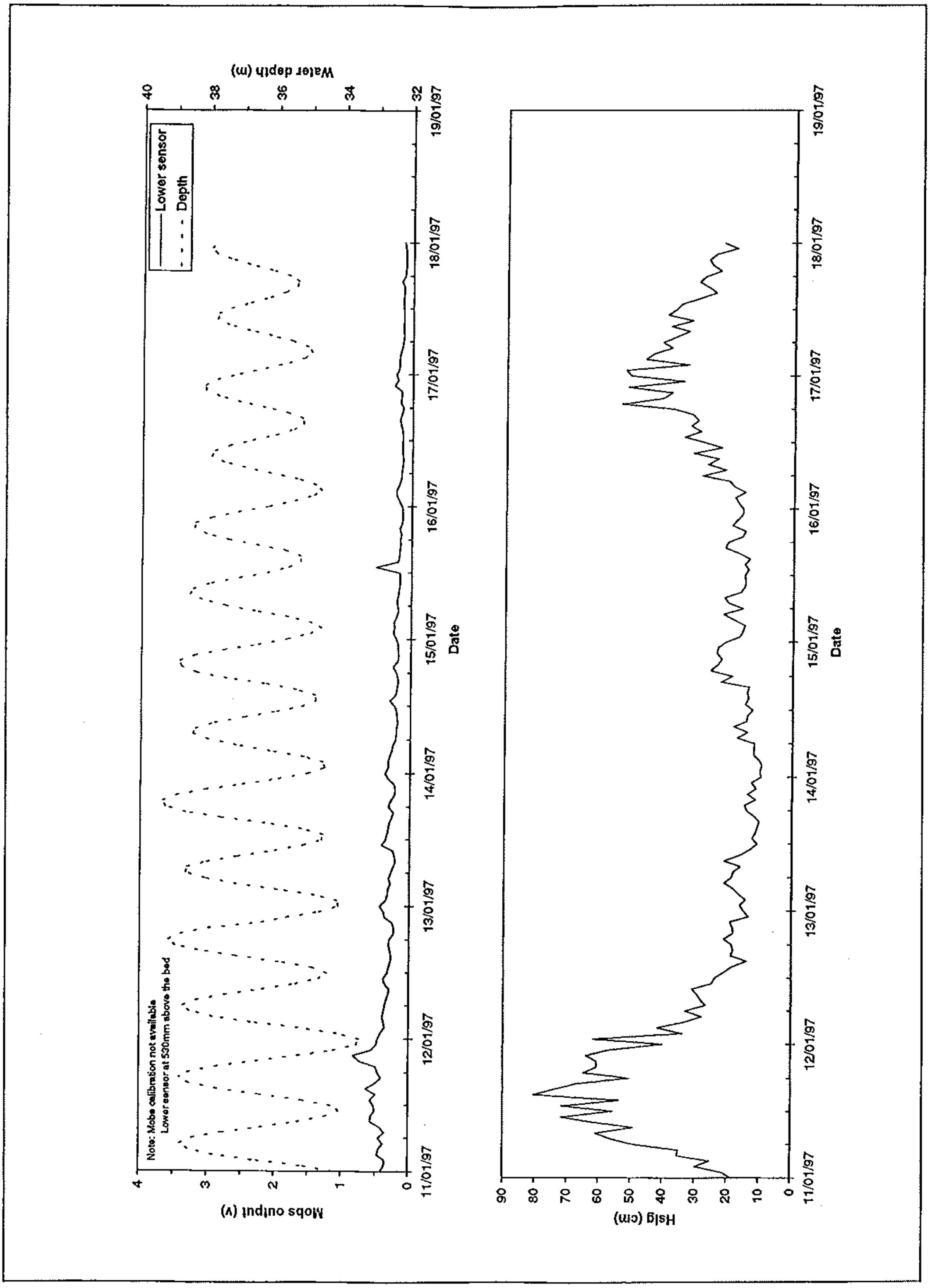

Figure 32 Summary of data – Week 6 - Deployment 139

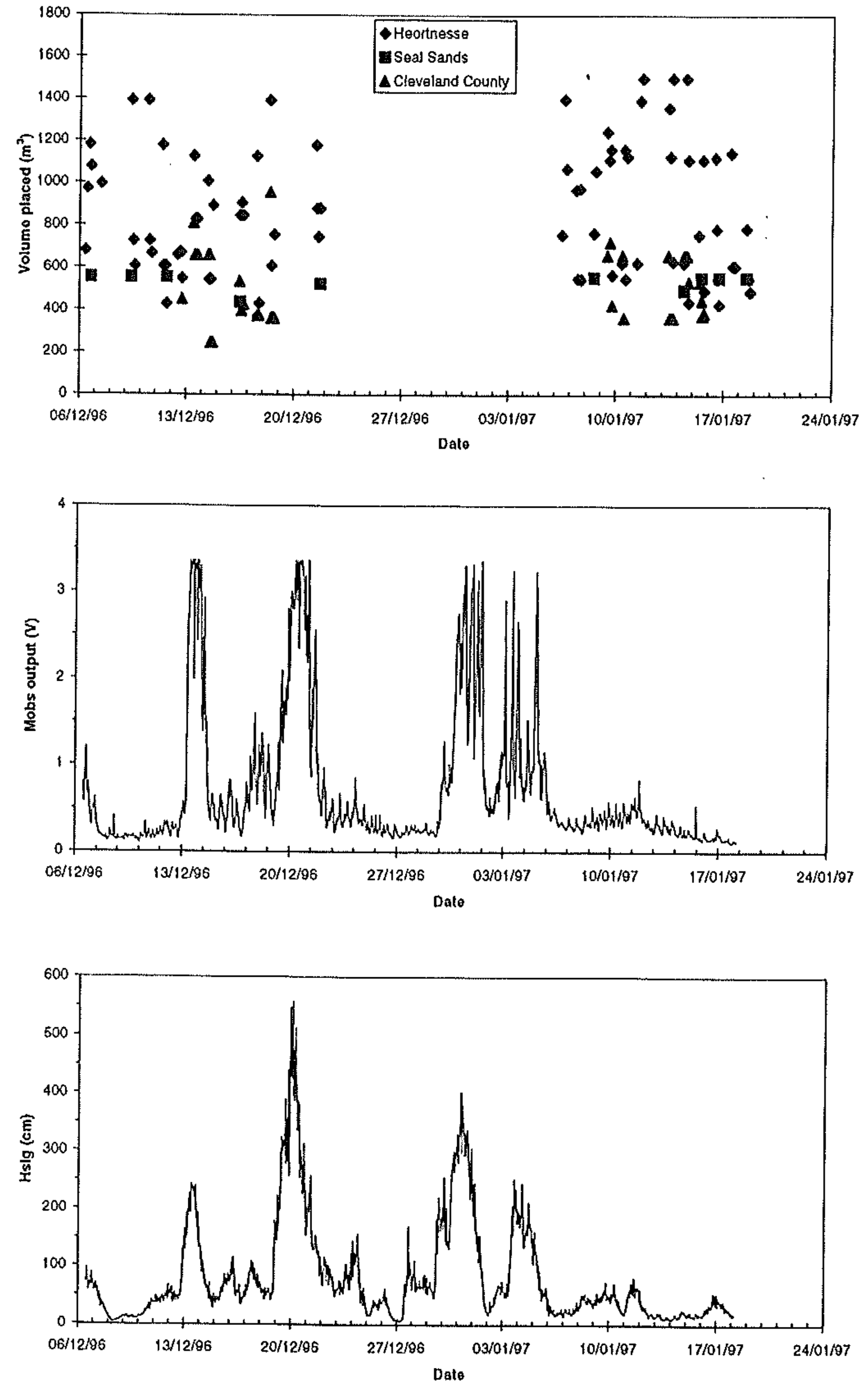

Figure 33 Dredging activity – Deployment 139

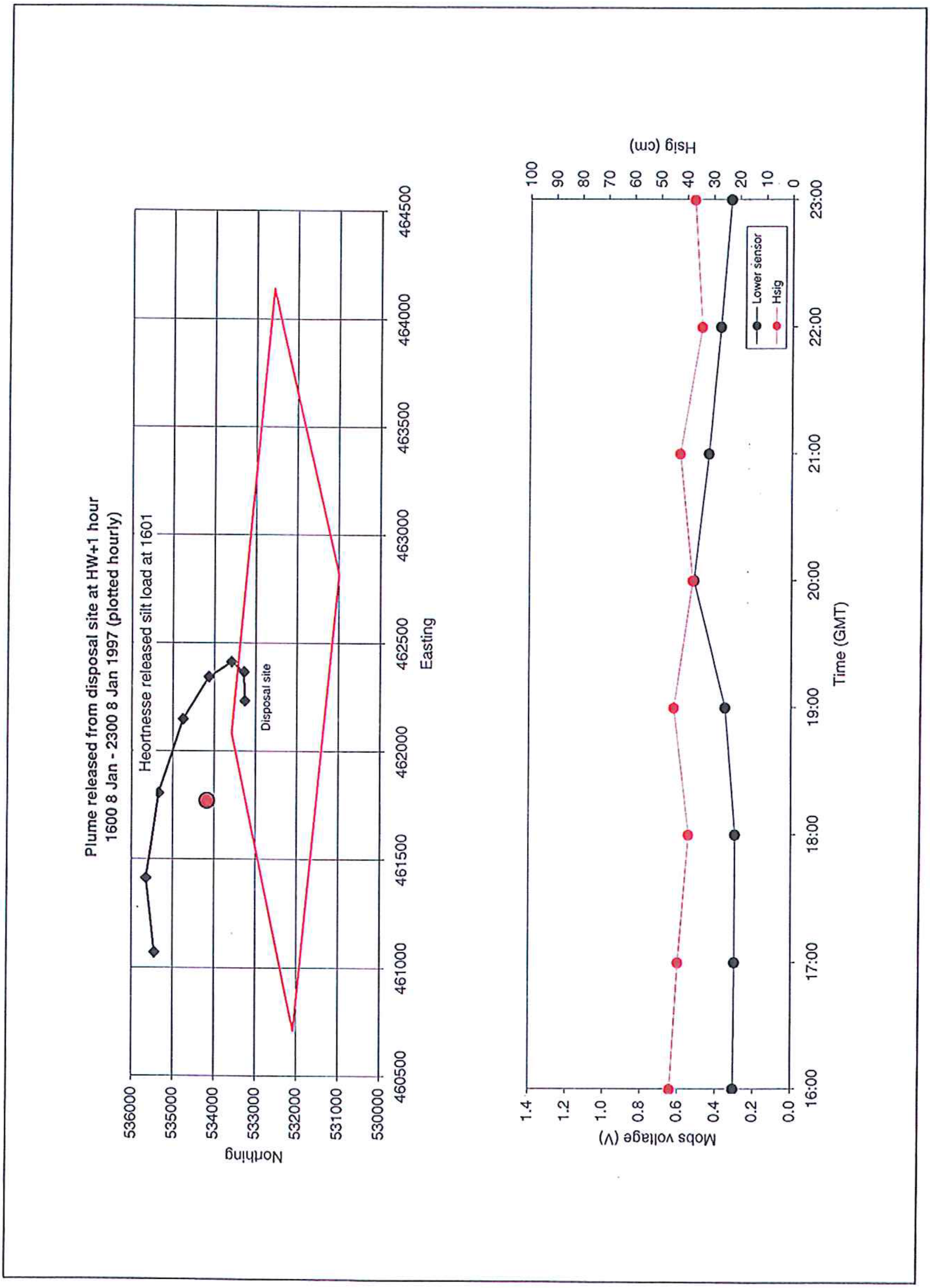

Figure 34 Placement 1 – Deployment 139

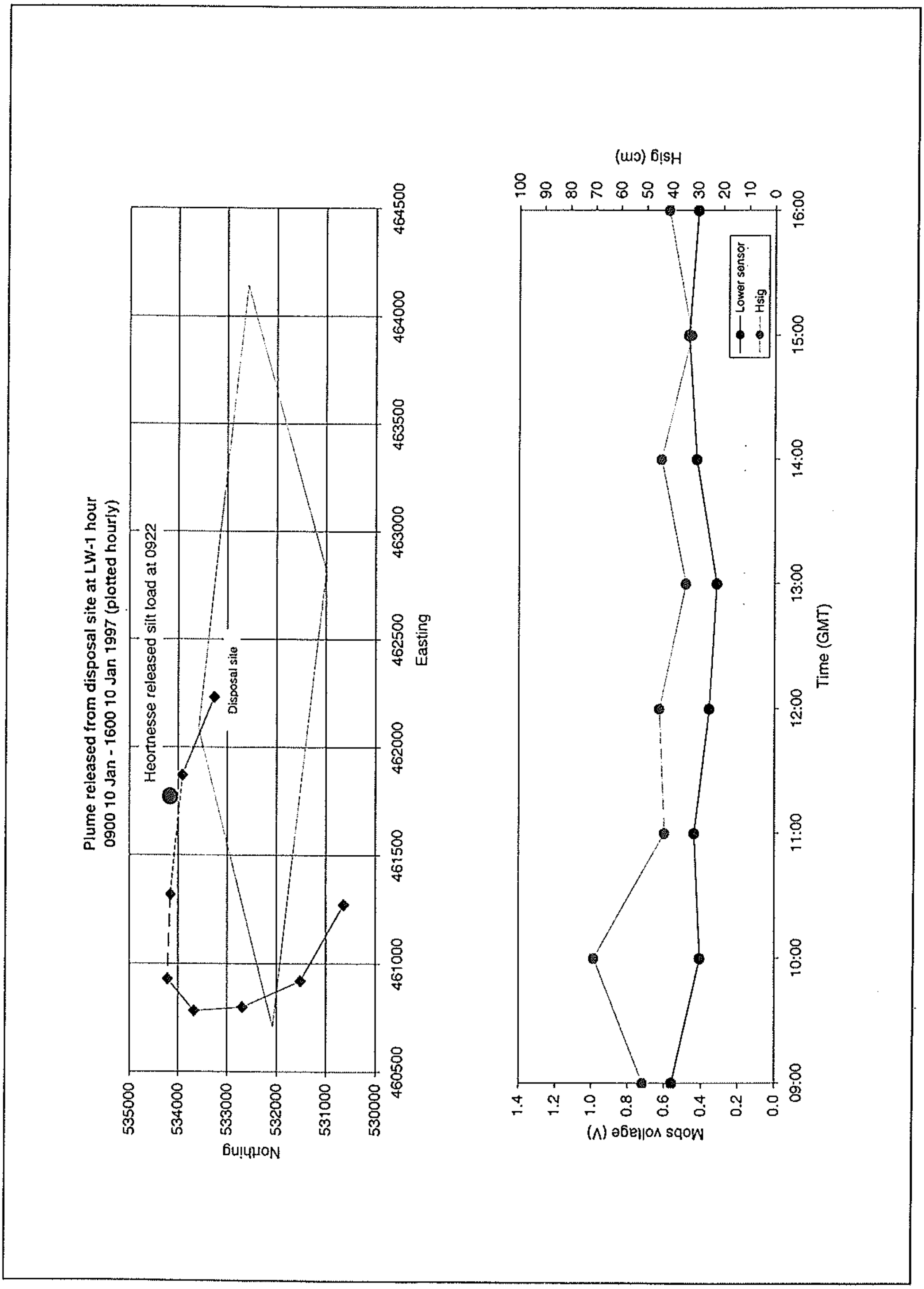

Figure 35 Placement 2 – Deployment 139

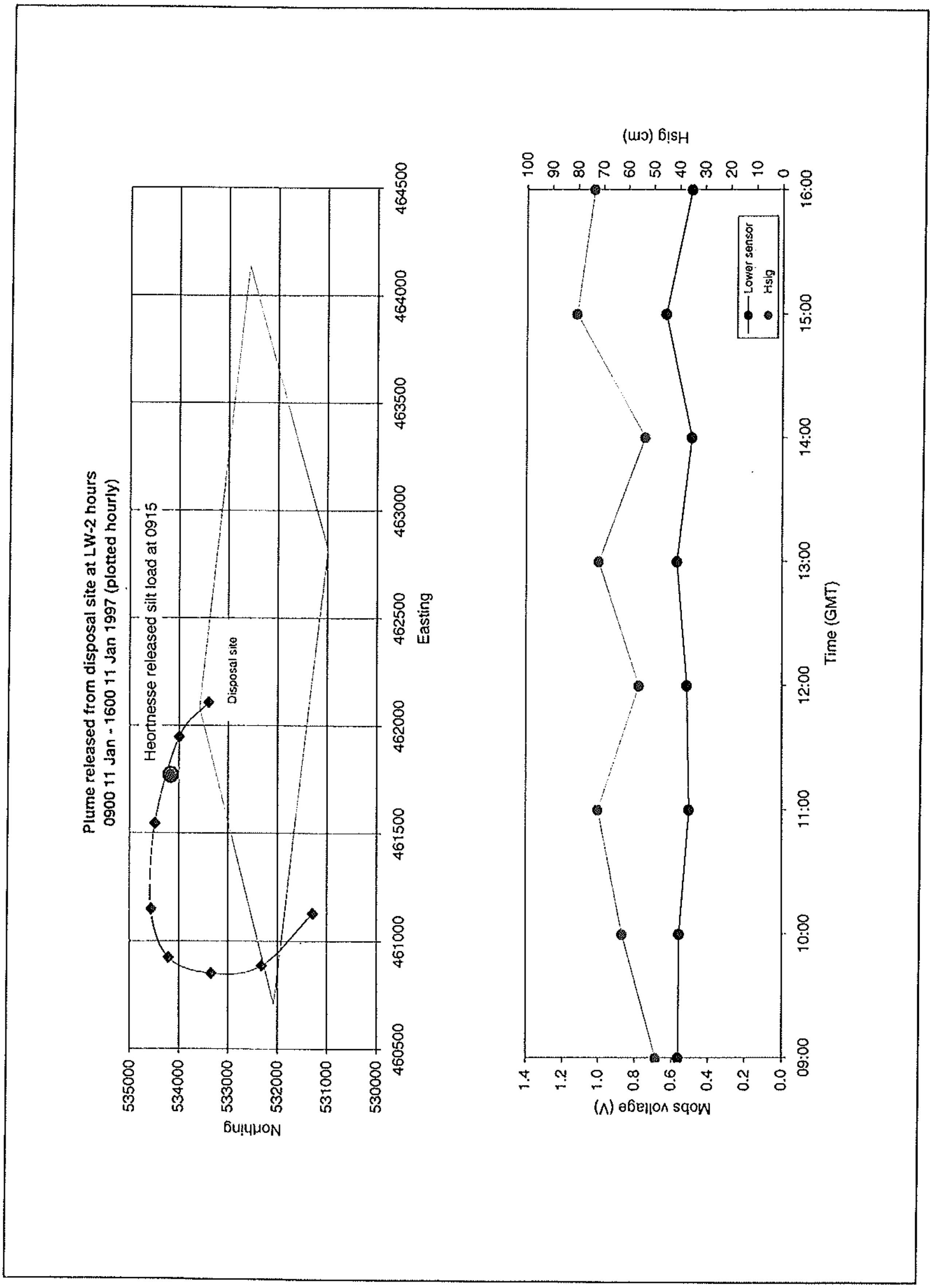

Figure 36 Placement 3 – Deployment 139

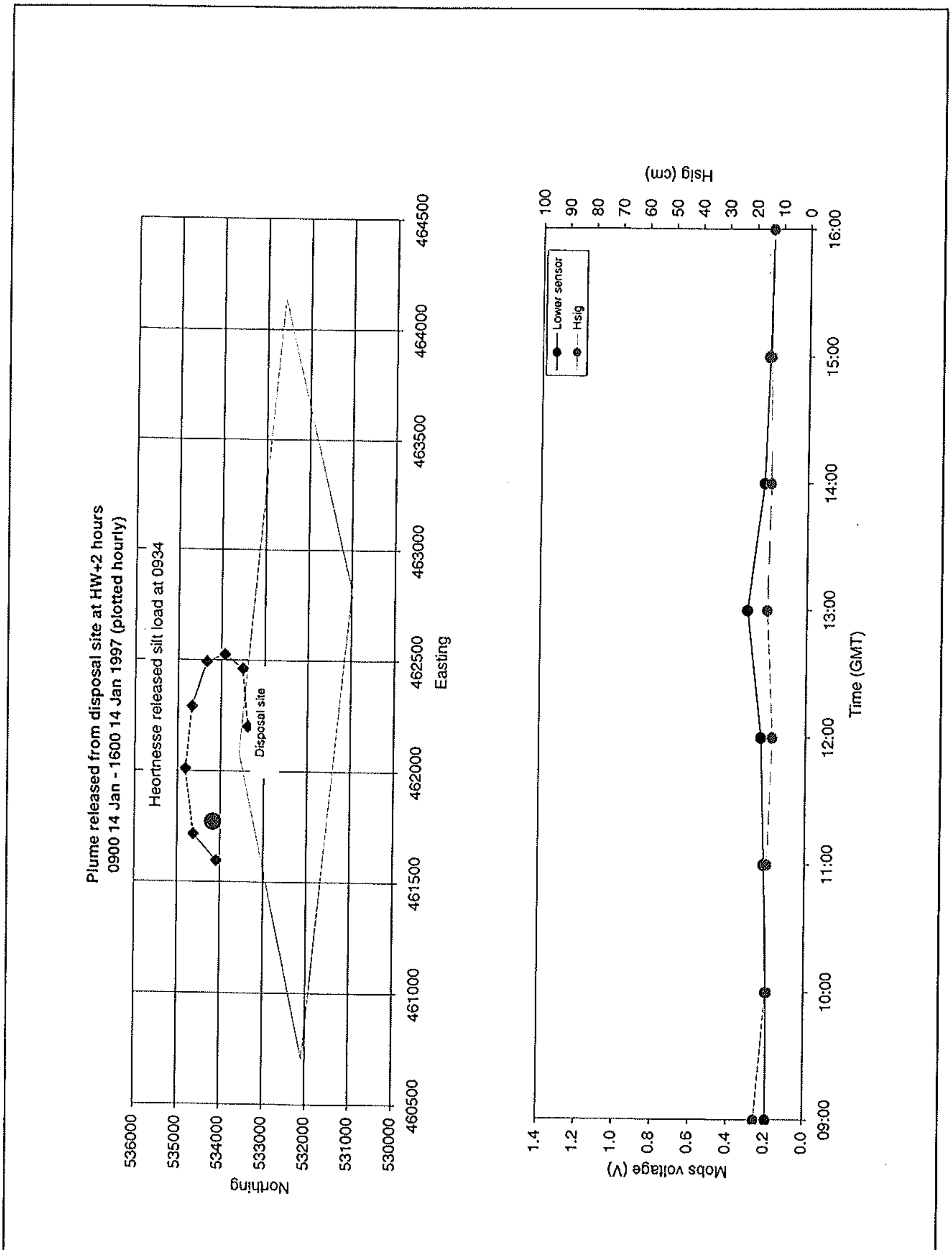

Figure 37 Placement 4 – Deployment 139

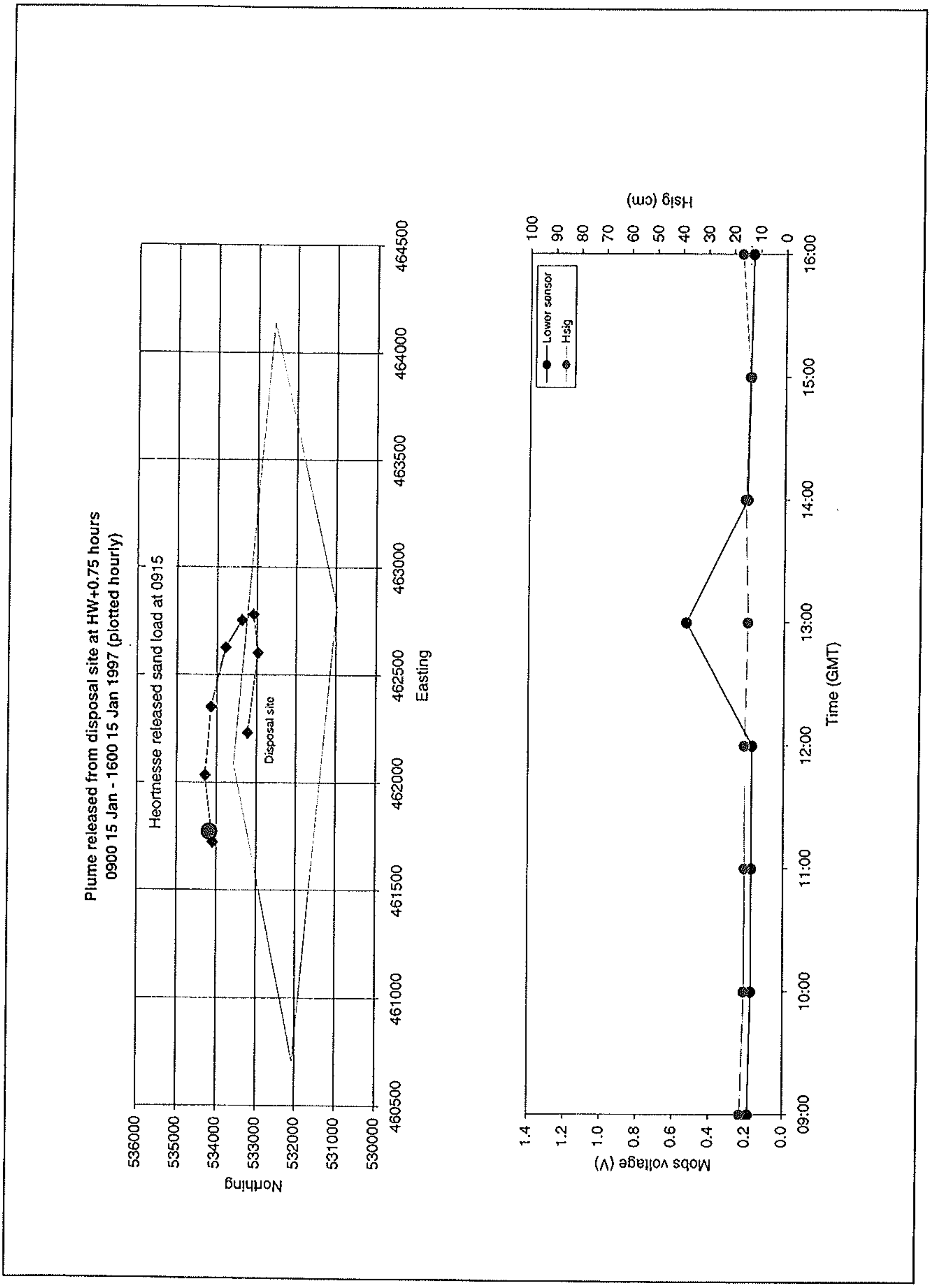

Figure 38 Placement 5 – Deployment 139

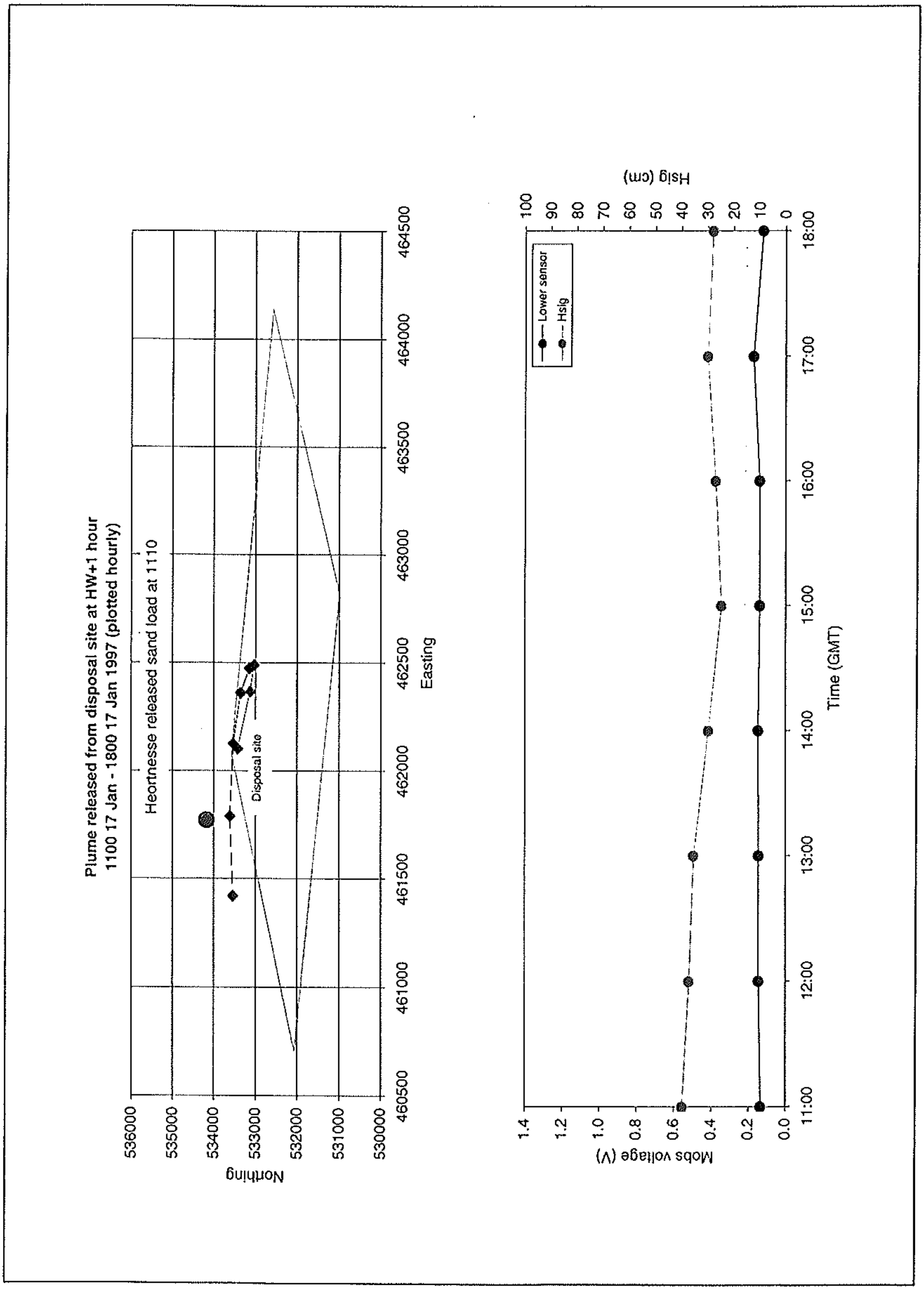

Figure 39 Placement 6 – Deployment 139

Plates

Plate 1 Typical minipod arrangement

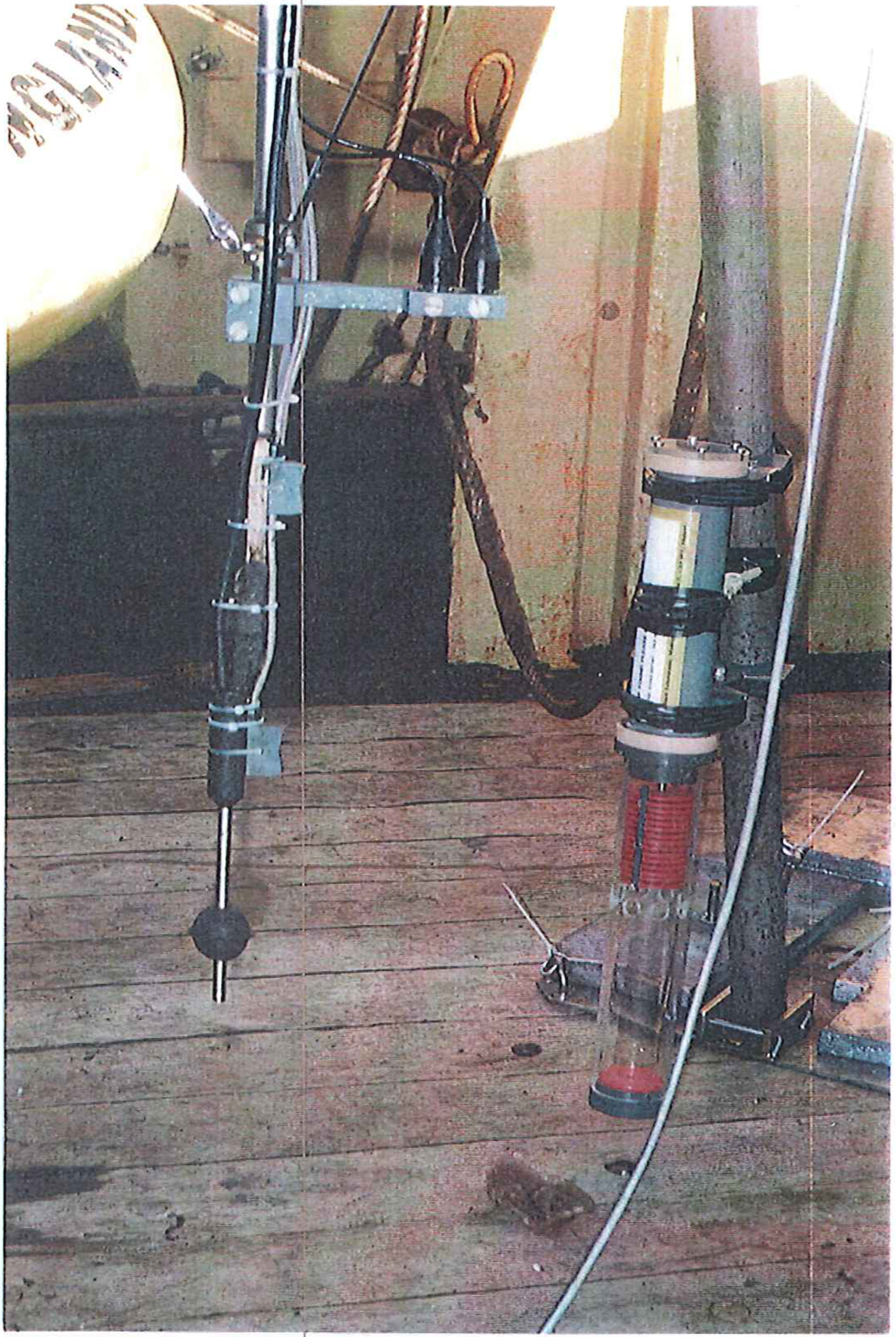

Plate 2 Minipod instrumentation

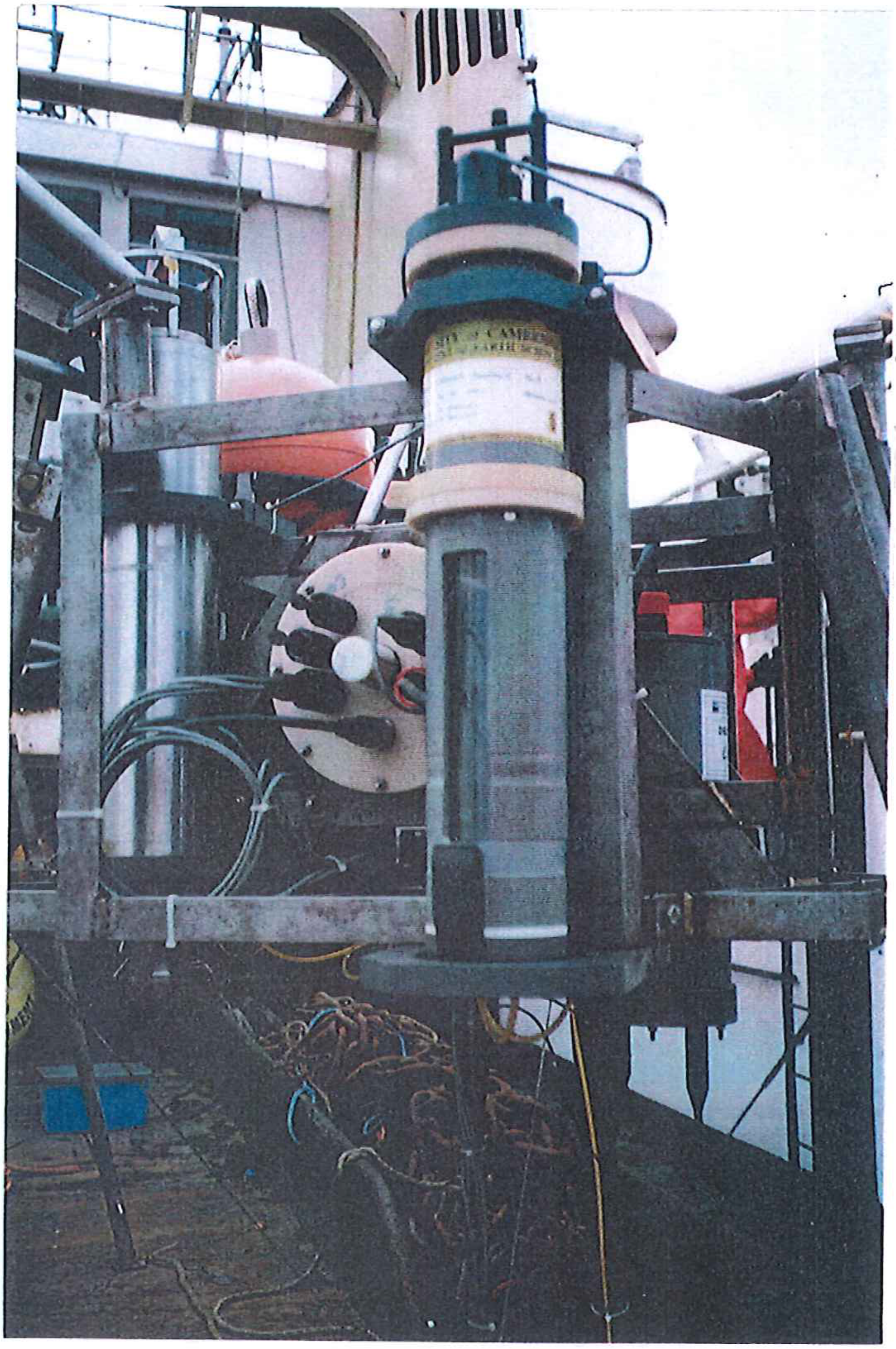

Plate 3 Syringe water sampler