Field measurements of erosional behaviour and settling velocities of intertidal sediments at the Dollard, Netherlands 21-23 May 1996

H J Mitchener and N G Feates

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HR Wallingford

Address and Registered Office: **HR Wallingford Ltd.** Howbery Park, Wallingford, Oxon OX10 8BA
Tel: + 44 (0)1491 835381 Fax: + 44 (0)1491 832233

Contract

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Prepared by Helen Mitchener (name) Scientist (job title)

Approved by Richard Whitehouse Project Manager

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Summary

Field measurements of erosional behaviour and settling velocities of intertidal sediments at the Dollard, Netherlands 21-23 May 1996

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Two staff from HR Wallingford Ltd. participated in the INTRMUD Joint Field Experiment in the Dollard Estuary, The Netherlands. SedErode and the HR Floc camera were used to make detailed in-situ measurements of the erodibility of the surface sediments, and of the settling velocity and suspended sediment load over spring tides on 21, 22 and 23 May 1996.

SedErode was deployed during low water periods at a total of 16 stations around the bridge structure installed, as part of the Dutch BOA project, in the middle of the Heringsplaat area of the Dollard intertidal mudflat. Surface samples were taken for laboratory determination of bulk density, sand content and organic carbon content. Shear vane strength measurements, detailed observations and photographs were also taken at each SedErode station.

A Valeport (Owen) sampling tube was deployed 21 times from the centre of the bridge structure over high water periods and the settling properties of suspended particulate matter were determined with the HR floc camera. 18 bottle samples of sampling tube water were also collected and analysed for suspended sediment concentration and organic carbon content. Nine video sequences were analysed in detail to provide the settling velocity and particle size distribution of the Dollard estuarine water.

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1 Introduction

SedErode (ISIS Mark II, Mitchener et al 1996) and the HR Floc Camera (Dearnaley, 1994) were deployed as part of the INTRMUD Joint Field Experiment in the Dollard Estuary, Netherlands during week 21 of 1996 (21 to 23 May inclusive). Measurements were made of surface erosion shear stress using SedErode, surface sediment properties, and the settling velocities and characteristics of the suspended particulate matter using the HR Floc camera.

This report describes the collection, analysis and interpretation of the data which was obtained by HR Wallingford Ltd. during this survey.

2 Objectives

The purpose of deploying both SedErode and the Floc Camera at the Dollard was to provide HR Wallingford and INTRMUD participants with complimentary data from both instruments over spring tide conditions. This data will then be compared with other data from the Dollard to try and quantify the processes occurring at this intertidal mudflat. The data can also be used as a basis for the intercomparison of erosion and floc measurement devices, but this was not the main aim of the measurements. The HR Wallingford sampling programme was driven by the scientific aims of INTRMUD and it is anticipated that this data report will be used by all INTRMUD participants to parameterise intertidal mudflat processes.

3 Site Details

3.1 Overview of Dollard mudflat site

The Dollard Heringsplaat mudflat in Northern Holland is a very wide expanse of mudflat, which can be reached by boat during high water conditions, or by a long trek across exposed mud at certain low water periods. The overall topography of the mudflat is very flat (overall gradient about 1:1000), and the tide covers and uncovers the mudflat very quickly (estimated by observations at about 1m plan distance inundated every 10s). Figure 1 shows the general Dollard location map, and Plate 1 shows the experimental site at high water and low water respectively. The Dutch BOA project uses the Heringsplaat as an experimental site and has constructed an instrument bridge.

On the days 21-23 May 1996, the sediment surface around the BOA bridge in the Dollard (co-ordinates 53° 18' 01" 20 N and 7° 09' 35" 77 E) was largely homogeneous mud and sand. There were a number of topographic features on medium (1 to 10m) and micro (less than 1m) length scales. The mudflat was described as walkable cohesive mud with sporadic runnels and was surrounded by a major channel to the ENE and WNW, which was the main tidal channels in the Heringsplaat. Within a radius of 50m from the centre of the BOA bridge the sediment was muddy in character, but outside this area patches of harder sediment, soft cohesive mud and sandy patches were observed.

There appeared to be substantial organic matter and flora and fauna within the fabric and surface of the mudflat. A consistent topographic feature observed on 21 and 22 May was the occurrence of round, green-brown domed patches of jelly-like mud of diameter 5 to 10cm which was covered with what appeared to be unicellular algae. These features had occurrences of about 5 to 25 every 1m^2. Another common feature in the upper sediment was a matting of filamentous algae, which formed a discontinuous sub-surface layer around the BOA bridge site, with some sporadic patches on the surface. Erosion tests with SedErode resulted in a ragged surface, with algal strands exposed where the surface had been disturbed. The domed patches and matting features are shown in Plate 2. The lower figure shows the imprint of a footprint (approximately 0.25m length) and the surrounding domed features. Worms, shells and other motile fauna (such as Corophium volutator - small amphipod crustacean) were common and birds followed the tide in and out in search of worms etc.

The medium scale surface topography (less than 10m) was largely flat with a few runnels (no ridges) on 21 and 22 May. After some windy weather (with associated higher wave activity) on 22 May late afternoon and evening, ripple features with length (crest - crest) about 40 to 45 cm and trough to crest height about 3 to 4cm were observed on 23 May. The ripple features contained muddy ripple bedforms with sand patches visible within the ripple troughs. Plate 3 shows the runnel and ripple features (scales - pen in upper plate is 15cm long, and rule in lower plate is 20cm long). The increased wave activity also removed the surface worm casts which were a regular feature on 21 and 22 May, but had disappeared on 23 May. By afternoon on 23 May raindrop impact on the mudflat also created small micro-craters on the surface, of the order 0.5 to 2cm diameter.

The BOA bridge structure comprised a personnel shelter and a storage/materials container, with a walkway between and a central pole for continuous monitoring of hydrodynamic quantities (see Section 6). The BOA bridge was used for storage and as a base of reference for the measurements for the HR Wallingford Dollard mudflat survey.

Access to the site was by boat provided by the University of Utrecht, which included a catamaran 'Geos', cruiser 'Calypso' and later in the week Rijkswaterstaat vessels Amadeus, Timeran and inflatables.

INTRMUD personnel at the Dollard site during 21 - 23 May 1996 were:

Helen Mitchener	SedErode - erosion measurements	HR Wallingford
Nigel Feates	HR Floc camera - settling velocity	HR Wallingford
Bart Kornman	coordinator/boat assistance	Univ. Utrecht
Wilhem v.d.Lee	and ISEF	Univ. Utrecht
Henk Markies	engineer/repair	Univ. Utrecht
Sarah Lee	Vibrocoring for history and	Univ. Cardiff
Stephen Shayler	fabric analysis	Univ. Cardiff
Olivier Cazaillet	ECOVUS density meter	SOGREAH
Ben de Winder	biological sampling	Rijkwaterstaat
assistant	biological sampling	

Measurements made outside the INTRMUD project:

John Corneliese	pore pressures, core sampling wave measurements	Rijkswaterstaat

3.2 HR sampling programme

To make good use of the tidal conditions at the site and to make best use of the available daylight hours SedErode was deployed during those periods when the mudflat surrounding the BOA bridge was exposed during daylight. The Floc camera was utilised during all other available periods when there was sufficient water at the sampling position beneath the bridge. Figure 2 shows the sampling strategy for the HR Wallingford measurements during 21 - 23 May in the Dollard.

On 21 May, 4 posts were set up around the BOA bridge for the basis for the SedErode measurements. The square transect with sides 50m long was set up aligned to the BOA bridge orientation (orthogonal to the main tidal flow), as shown in Figure 3. A total of 16 SedErode sampling stations were set up around the edge of the box, with a nominal separation of 12.5m.

3.3 SedErode Sampling Strategy

The aim of the SedErode measurements was to obtain a data set of erodibility measurements and sediment properties which could be investigated for spatial and temporal variation. The sequence of SedErode measurements was:

Day 1 21.5.96 Tuesday	Transect set up and sites D1 - D3
Day 2 22.5.96 Wednesday	sites D4 - D10
Day 3 23.5.96 Thursday	sites D11 - D16

Figure 3 shows the locations of each site with respect to the BOA bridge and the receding/flooding tide. The following measurements were made at each SedErode Site:

- critical shear stress for erosion τ_b and turbidity time series
- shear vane strength x 5
- photos before, general, and after erosion
- surface sample of top 5mm for
    - bulk density
    - Carbon content
    - mud: sand split
- SedErode site description/log

4 Measurement of Erosion Properties

4.1 Instrumentation

SedErode has been developed to measure the erosion shear stress of cohesive sediments in-situ. The need for such an instrument was identified because of the difficulty of simulating natural conditions in the laboratory, and the effects of collection, transport and storage on field sediment samples. SedErode is the successor to ISIS (Instrument for shear Stress In-Situ) and is a portable, fully contained instrument for use on intertidal mudflats and natural sites of cohesive sediment (Mitchener et al, 1996)

The basic principle of SedErode is that known shear stresses can be applied to a mud surface and the bed response (turbidity) can be monitored. A full technical description of ISIS is given by Williamson and Ockenden (1996), and a summary of this information in Appendix 1 of this report.

The instrument consists of 2 units: a bell head unit and a pump and control unit. The instrument is fully portable, with internal rechargeable batteries and has been designed for use on intertidal mudflats.

The shear stresses applied with SedErode are generated by water flow through the circular, bell-shaped head which fits inside a cylindrical perspex column with an annular clearance of 3mm. The bell head is positioned about 6mm above the sediment surface and water is drawn radially across the test surface, up through the centre of the bell, and recirculated to be replaced under the bell head via a diffuser.

A mixing chamber within the recirculating system allows the eroded sediment to be thoroughly mixed into the system volume and a nephelometer measures the turbidity of the recirculating water. The volume of the SedErode recirculating system is approximately 1 litre. During each SedErode test a solid state logger records both the reservoir turbidity and the recirculating flow discharge. These are also noted at regular intervals by the operator during a measurement run.

During an erosion test the flow discharge is progressively increased in small steps until a turbidity jump is observed, which corresponds to material being removed from the bed surface and mixing into the recirculating volume. At this point the critical shear stress for the initiation of erosion is exceeded and the test can be considered to be completed.

Plate 4 shows the SedErode instrument during deployment on the Dollard mudflat.

4.2 SedErode sampling and analysis

The SedErode head unit was positioned onto the mud surface, and the system was filled with ambient seawater, which had been collected at HW and allowed to settle out before decanting the clearer water. The head unit was then positioned close to the bed and the system was carefully filled with water. The nephelometer turbidity sensor was zeroed, and logging of discharge and turbidity commenced. The discharge was increased in controlled steps to apply increasing shear stress steps to the mud surface. The lowest discharge setting (ie. the lowest applied shear stress) was applied for at least 2 minutes to allow the water within the recirculating system to become fully mixed, and a baseline turbidity to be established prior to increasing the applied shear stresses and monitoring the erosion response.

Each SedErode measurement run took about 10-15 minutes to complete, with additional time on the auxiliary measurements. Appendix 2 shows the SedErode time series plots of applied shear stress and turbidity. The incipient point of critical surface erosion was taken as the average of the 2 applied shear stress steps between which material was removed from the mud bed and mixed into the recirculating system. Higher applied shear stresses then resulted in increasing turbidities within the SedErode system due to additional material being removed from the surface, and confirmed that surface bulk erosion had occurred.

4.3 Auxiliary measurements and observations

Prior to SedErode being planted at each site a photographic record was taken of the test surface and a scrape of the top 2mm of the sediment was taken from around the surface. The sediment samples were double-bagged in polythene, stored in a cool box, frozen and taken back to HR Wallingford for subsequent laboratory analysis for bulk density, mud and sand content and organic carbon content by loss on ignition at 550°C. Finally, a series of five shear vane measurements were taken from around the perimeter of the test surface using a Pilcon hand shear vane of diameter 33mm, and operational depth 20mm to 70mm below the mud surface. Details of the site details, measurements and sample analyses are given in Appendix 2 for each SedErode site.

The mean local salinity during the deployment was 18.1ppt and the local water temperature under the BOA bridge was typically 12°C. These measurements indicate a water density of $1013kgm^{-3}$ and a viscosity of $1.269 \times 10^{-6}\ m^2s^{-1}$.

4.4 Results

A total of 16 locations were investigated using SedErode. Table 1 shows the summary of the SedErode critical erosion shear stress measurements and the surface sediment properties. The manual turbidity recordings are presented for sites D1 and D3 because of a poor logging connection. The critical erosion shear stress values were taken from analysis of the time series plots of applied shear stress and turbidity in Appendix 2. The critical shear stress for erosion was taken as the shear stress at which material started to be removed from the bed, and subsequent higher shear stress steps resulted in more erosion, thus confirming the incipient point of erosion.

The critical erosion shear stresses measured using SedErode ranged from $0.55Nm^{-2}$ to $1.02Nm^{-2}$. Ten of the 16 measurements fall within a small range from 0.55 to $0.60Nm^{-2}$, and there did not appear to be any significant variation in the erodibility over the sampling area over the 3 days deployment time, nor spatially within the 50m grid.

The grain size of the surface sediment samples comprised mainly of sand (less than 63µm), with the sand content of the samples ranging between 73.4% and 90.3% by weight. The samples predominantly consisted of fine to medium sand, with a uniform texture and a substantial amount of organic material.

The carbon content by loss on ignition at 550°C ranged between 1.84% to 4.75% by weight. The organic content is estimated at between about 5 and 10% by weight (equal to approximately 2.5 x the % weight loss on ignition at 550°C). This is a high value and indicates a significant amount of biomass within the surface sediment which was also indicated in the observations.

Figures 4 and 5 show the relationships between the bulk density and sediment properties and the critical erosion shear stress and sediment properties respectively (see section 7.1 for the discussion of these results).

5 Measurement of Settling Velocity

5.1 Instrumentation

The HR Floc Camera operates on the basic technique of taking video footage of settling particles in a water sampling tube at high resolution, which can then be analysed for settling velocity and particle size. Appendix 3 describes the HR floc camera instrumentation, sampling and analysis in detail. The HR Floc camera and PC system was set up in the wet laboratory (above the East BOA bridge leg), for the Dollard deployments. Plate 5 shows the HR Floc camera apparatus as it was set up in the wet laboratory container during the Dollard fieldwork.

5.2 Floc camera sampling and analysis

The water samples were obtained using the Valeport derivative of the Owen sampling Tube. The tube used for Dollard water sampling had an internal diameter of 50mm and is about 1m in length. The tube was lowered into the water from the mid-span position of the BOA bridge and held at the required depth until the tube had aligned with the local current direction. A messenger weight was then dropped down the lowering line which triggered the closing mechanism and trapped a sample of the Dollard water. The water depth and height of water sample above the bed surface was estimated via 10cm markings on the line. Plate 6 shows the Valeport tube being deployed from the BOA bridge.

The Valeport tube was retrieved into the BOA bridge wet laboratory in a horizontal position until it was placed in vertical and held in a stand which was set up in the wet laboratory. Video filming of the settling process was monitored from the start time of uprighting the tube and any fine adjustments of the camera bellows to ensure a clear image were quickly made. Filming typically lasted for 20 minutes. The video tape data was processed back at HR Wallingford Ltd. to obtain the settling velocity and size distribution.

On completion of filming the contents of the tube were drained into 2 litre sample bottles which were taken back to HR Wallingford for subsequent laboratory analysis for suspended sediment concentration and organic content by loss on ignition at 550°C. The temperature of the water sample was also recorded.

The process of capturing a water sample in a tube, raising it to the surface and then transporting it to, and righting it in the frame, was likely to induce significant turbulence and circulations within the column. As a result, in order to satisfactorily determine the gravitational settling velocity of the flocs it was necessary to make assumptions about the fluid motions through the section of the column that was in focus. The first assumption was to consider that the fluid motion was uniform across the image area. This was not always the case and resulted in certain parts of recordings being unusable for settling velocity analysis. The second assumption was to assume that the fastest upward travelling floc, or slowest downward travelling floc, depending on the natural fluid motion in a pair of images, was actually moving at the same speed as the local flow.

The processing technique involved correcting against the speeds of the slowest downward floc (or fastest upward floc). This process is described in Appendix 3. The results of the correcting process are shown in Figure 6. The upper plot shows the raw data from twelve pairs of images with both upward (-ve) and downward (+ve) motion. The lower plot shows the same data corrected for the assumed fluid speed.

Typically ten to twelve pairs of images were analysed from the first 1-2 minute period of the tape recording and the results of this analysis were used to determine a settling velocity distribution for the suspension at that time. The settling velocity distribution was processed using Stoke's Law to determine an effective floc density and by assuming spherical particles of constant density, with a volume $4/3\pi r^3$, where r is the mean radius (height + width from video analysis)/4. For this assessment the density of water was assumed to be 1016kgm^{-3} (based on temperatures on the range 12-13°C and salinities in the range 18-21ppt). The kinematic viscosity of the water was taken to be 1.2×10^{-6}m^{2}s^{-1}.

5.3 Results

During the three days of measurements a total of 21 tubes (see sampling schedule in Figure 2) were taken for processing of which 18 were considered to be suitable for laboratory analysis of suspended solids concentration and organic content by loss on ignition. Table 2 summarises the laboratory determinations together with the associated field notes such as time of sampling, water depth and sample temperature.

It can be seen that there was a large variation in the sample concentration, ranging from 10 mg/l to 11,310 mg/l. Those at high concentrations, say above 120 mg/l were considered to be artificially high due the surface bed sediment having been disturbed by the lowering of the sampling tube into position. The water temperature of the samples varied between 12.0 and 14.6°C with higher temperatures generally being measured during the afternoon sampling periods.

Based on the results shown in Table 2 and an assessment of the quality of recorded images 9 of the tubes were selected for detailed analysis by image processing. The results are presented in detail in Appendix 4 with selected examples being reproduced in this section of the report.

The analysis procedure of each of the selected tubes resulted in graphs of settling velocity versus particle size being generated for both the x and y particle dimensions (width and height respectively). An example is shown in Figure 7 (Tube 1) with the complete set of results being presented in Figures A4.1 to A4.18 in Appendix 4. These figures show a wide range of scatter which is due to the variability in the properties of the flocs selected for analysis, such as material type (sand, silt, organics) and effective density.

From Figures A4.1 to A4.9 in Appendix 4 it can be seen that the largest particle size measured was about 2.5mm (Tube 14) and the smallest was about 0.015mm (Tube 11). For consistency all figures have common axes in some cases a number of particles fell outside of the range of the graph.

Figure 8 shows the particle size distribution resulting from the analysis of Tube 1. It shows that the peak in the particle size distribution falls into the 0.1 to 0.2mm size band. It should be noted that the distribution of the size of particles selected by the computer operator may be skewed towards a preferential band of sizes. It should also be noted that this method of image analysis cannot resolve the smallest flocs as they are barely visible even at this level of magnification. Despite these two factors it is considered that for typical estuarine suspensions the technique is probably able to resolve about 80-90% of the settling mass (Dearnaley, 1994). The particle size distributions for all of the tubes processed are shown in Figures A4.10 to A4.18 in Appendix 4.

Further analysis of the measured data can be carried out by first making an assumption about the relationship between particle volume, settling velocity and effective density. In this analysis the radius of an individual particle is assumed to be 25% of the sum of the measured width and height. Figure 9 shows the variation of specific gravity (using Stokes Law) with particle size for Tube 1. The larger particles have a lower specific gravity as these are composed of several flocs stuck together with water trapped between them, the larger the flocculated particles are the closer the specific gravity will be to that of water. Smaller particles with a higher specific gravity are probably sand grain or organic matter. The majority of the particles measured have a specific gravity of about 1.1. Figure 9 also shows the settling velocity characteristics of the measured particles for Tube 1. The lower figure shows the median settling velocity to be about 1.6mm/s and the maximum about 3.0mm/s. Figures A4.19 to A4.23 in Appendix 4 show the derived settling velocity distributions for each of the nine tubes processed. Figure 10 shows a summary plot of the cumulative mass versus the settling velocity for all of the analysed tubes. The numerical results are summarised in Table 3.

In order to assess the sensitivity of the image processing procedure in terms of the derived settling velocity distribution sensitivity tests were carried out on the measured data from Tube 8 which had a distribution which fell in the middle of the distribution envelope shown in Figure 10. Three sensitivity tests were carried out as described below:-

1. An error band of ± 2 pixels (16μm) was applied to the measurement of vertical displacement used in the calculation of settling velocity.

2. An error band of ± 2 pixels was applied to the x and y measurement of the particle size.

3. As mentioned above it is considered that for typical estuarine suspensions the technique is probably able to resolve about 80-90% of the settling mass. The calculation was therefore revised to enable an additional 10% and 20% of the total measured mass to be allowed for. It was assumed that the particle size of this additional mass was equal to the size of the smallest particle originally measured.

Figure 11 shows the results of the sensitivity tests described above and illustrates that the level of accuracy applied in determining the particle size has no significant effect on the results. Increasing the total mass shifts and compresses the settling velocity distribution as would be expected although the median settling velocity (W50) remains largely unaffected because of the form of the distribution.

6 Additional Data

In addition to the HR Wallingford sampling programme, measurements of hydrodynamics and meterological data were continuously logged from the BOA bridge. The data refer to Dutch datum (N.A.P. which is Amsterdam new level, below mean sea level). The local bed level was 0.222m above N.A.P. The time of the data refer to C.E.T. (Common European Time), which is equivalent to British Summer Time, or Greenwich Mean Time + 1 hour. These data have kindly been supplied by the University of Utrecht and provide a framework for future analysis of the data collected by HR Wallingford and other INTRMUD participants.

6.1 Hydrodynamics

The hydrodynamic data taken from the BOA bridge comprised of the following instruments which were taken from the central pole:

- 3 ellipse type EMF current velocity sensors
  - EMF 1 (0.247m above N.A.P, 0.025m wrt. bed)
  - EMF 2 (0.637m above N.A.P, 0.415m wrt. bed)
  - EMF 3 (0.989m above N.A.P, 0.767 wrt. bed)

- 3 sphere type EMF current velocity sensors
  - EMF 4 (0.301m above N.A.P, 0.079m wrt. bed)
  - EMF 5 (0.806m above N.A.P, 0.584 wrt. bed)
  - EMF 6 (1.207m above N.A.P, 0.985 wrt. bed)

- 3 turbidity sensors
  - MEX 1 (0.253m above N.A.P, 0.031m wrt. bed)
  - MEX 2 (0.302m above N.A.P, 0.080m wrt. bed)
  - MEX 3 (0.714m above N.A.P, 0.492m wrt. bed)

The following measurements were also taken from the bridge poles:

- 2 capacitance wires for water height
  - CAP 1 (0.036m above N.A.P, -0.186m wrt. bed)
    - West leg under personnel shelter
  - CAP 2 (0.059m above N.A.P, -0.163m wrt. bed)
    - East leg under wet lab.

- 1 conductivity/temperature probe
- 1 fluorometer

During the INTRMUD field experiments data was obtained with EMF sensors 4, 5 and 6. Data from the turbidity sensors is only available between 30 May 1996 and 1 June 1996 and unfortunately, there was no turbidity data from the BOA bridge which spans the INTRMUD fieldwork during the first week (20 - 24 May 1996). Figure 12 shows the tide levels at CAP1 and CAP2 between the dates 21 and 24 May 1996.

The conditions on Tuesday 21 May were expected to be that of peak Spring tides, with the tidal range decreasing throughout the rest of the week. Figure 12 shows however, that the tidal heights measured at the BOA bridge are rather erratic and do not appear to follow a typical Spring-Neap tidal envelope. This may be due to the flat, exposed nature of the Heringsplaat and hence the influence of shallow water depths and meteorological conditions such as wind stress and barometric pressure may effect local water levels.

For most of the time the velocity sensors were out of water, because of the shallow water depths experienced at Heringsplaat site. EMF 4, which was the lowest sensor at 0.079m above the local bed produced the longest records of velocity data as it was underwater for the longest time. The velocity data indicates that the tidal currents are ebb dominated with velocities reaching a maximum of $0.1ms^{-1}$ on the flood for EMF 4, and $0.2ms^{-1}$ maximum on the ebb. This feature of ebb-dominated tidal asymmetry was also found on the other EMF records, and a possible reason for this asymmetry may be that the ebb currents are wind assisted in the shallow water depths, as the wind direction was predominantly from the westerly sector which was approximately parallel to the direction of the tide covering and uncovering the mudflat.

6.2 Meteorological data

Meteorological data was collected throughout the Dollard fieldwork period from a weather station set up on the roof of the wet laboratory (East BOA bridge leg). Figure 13 shows the wind speed and direction over the period 20 to 25 May 1996. During the HR deployment period the wind speed was increasing from Beaufort force 2 to 3 between 2 to $6ms^{-1}$ on Tuesday 21 May 1996 to force 5 at around $10ms^{-1}$ on Thursday 23 May 1996. The wind direction was predominantly from the W and SW sector. Figures 14 and 15 show the rainfall, humidity, air temperature and solar radiation respectively for the period 20 to 25 May 1996. During the time of the HR deployments the weather deteriorated from a gentle breeze and sunny on 21 May to overcast with a fresh breeze and rain on 23 May.

7 Discussion

7.1 SedErode results

Comparative plots (Figures 4 and 5) were analysed to investigate if there were any relationships between the sediment properties and the erodibility. Figure 4 shows the sand content and organic carbon content plotted against bulk density. The upper plot shows that there is an increased density with sand content, with a maximum density of 1820kgm^{-3} occurring at a sand content of 90.33% (site D8). The lower plot shows that there is a decrease in the bulk density with increasing carbon content, which is also as might be expected as the density of organic material is less than typical estuarine sediment.

Figure 5 shows the bulk density, sand content and organic carbon content plotted against the critical erosion shear stress. There does not appear to be a clear relationship between the critical erosion shear stress and surface sediment properties at this sites. However, the data indicates that the erosion shear stress values appear to exhibit more variability than the sand content and density values. There is approximately the same order of variability in the erosion shear stress and organic carbon content.

These results reflect the complexity of the parameters governing the erosion shear stress of cohesive sediments, and highlight the need for detailed research in this area.

7.2 Floc camera results

During the three days of measurements it was observed that there was an unusually high level of organic content in the majority of the water samples obtained and this was confirmed by subsequent laboratory analysis. The organic content was typically 25% of the total mass with a minimum and maximum of about 4% and 35% by weight respectively. The level of suspended solids concentration was between 10mg/l and 11,310mg/l with an arithmetic mean of about 30mg/l. It was observed that on some occasions the surface bed sediment was disturbed whilst positioning the sampling tube in the water column. On these occasions very high levels of suspended solids were measured in association with low levels of organic content. It is considered that any sample with a concentration above about 120 mg/l had been artificially increased through disturbance of the surface bed sediments, and the organic content was significantly reduced.

Early indications from conversations with other INTRMUD Dollard fieldwork participants are that the measurements and observations made during this study are comparable with results made available by the Institute of Marine Studies at the University of Plymouth. This group made similar measurements of floc characteristics during the following week (30 and 31 May 1996) using INSSEV (Fennessey et al, 1994). Plymouth suggested that their initial results showed that the settling flocs consisted mostly of organic material and generally were less than 500 microns in diameter. Plymouth found that the suspended solids concentrations during the second Dollard fieldwork week were typically less than 100 mg/l. Many of the flocs appeared to have stringers attached, one was in excess of 5mm long. These initial results are in general agreement with the results from the HR floc camera in the preceding week and it appeared that the sediment characteristics in the water column did not change significantly between the first and second fieldwork weeks.

The median settling velocities (w_{50}) of the samples was between 0.6mm/s and 3.1mm/s. Of those samples which had concentrations of less than 120mg/l the median settling velocity was typically about 1.2mm/s. The maximum particle settling velocity measured was 5.7mm/s for a corresponding sample concentration 680mg/l. These values are slightly higher than the settling velocities previously obtained for estuarine mud (HR 1988), which typically show a w_{50} less than 0.5mm/s for concentrations at around 120mg/l. It is not clear whether the slight variation in the settling velocity for the Dollard suspended sediment is due to the site specific characteristics of the Dollard sediments (ie mineralogy, grain size, shape etc.) or the high organic content of the Dollard sediments and the presence of interconnected organic particle or 'stringers' observed during the fieldwork. It should also be noted that the period of field measurements was in May, which is likely to have coincided with a local seasonal phytoplankton bloom, and this may have attributed significantly to the nature of the suspended matter in the water column, which may not have been so evident in the months preceding the bloom period. It will be interesting to hear about the INTRMUD biologist's observations and information regarding local blooms in light of the high organic matter observed during the two fieldwork weeks.

Sensitivity tests carried out on the analysis procedure showed that small inaccuracies (± 16µm) in the determination of the particle size or settling velocity had no significant effect on the overall results. Artificially increasing the total mass in the sample, assuming that smaller, slowly settling particles are present, had the effect of shifting and compressing the settling velocity distribution curve, however the median settling velocity remained largely unaffected due to the form of the distribution.

Prior to this field experiment the floc camera had not been deployed in such a remote location as the BOA bridge or in such shallow water. HR Wallingford are not aware of any previous measurements of settling velocities of natural suspended material in shallow water depths of less than 1m.

8 Conclusions

1. SedErode and the HR Floc camera were successfully deployed at the Dollard Estuary, Netherlands over the period 21 to 23 May 1996 to measure:

   - critical erosion shear stress and sediment properties over the LW period at 16 sites in a 50m square transect around the BOA bridge location

   - settling characteristics of suspended matter over the HW period via the collection of 21 tubes of water samples

2. The practicalities of performing the fieldwork at such a remote site were greatly assisted by the presence of the bridge although some sampling time was lost in having to transfer personnel to the site by boat and then transferring all of the necessary equipment from the boat, across 50m of mudflat, to the bridge making use of a mud sledge and a crane. The wet lab

on the bridge, allocated for setting up the floc camera system, proved to be quite adequate although there were, at times, problems with vibration affecting the high magnification video recording particularly when the crane mounted on the roof of the wet lab was being used.

3. The surface sediment was characterised as a homogeneous muddy sand with a significant biomass content. The sediment samples had the following properties:

   - bulk density ranging from 1460kgm^{-3} to 1820kgm^{-3}.
   - sand content ranging from 73.4% to 90.3% by weight.
   - carbon content (loss on ignition at 550°C) between 1.84% and 4.75% by weight.
   - the pore water had a mean temperature of 12°C and salinity of 18.1ppt.

   The bulk density of the sediment was found to decrease with increasing carbon content, and increase with increasing sand content.

4. The critical erosion shear stress measurements were mostly in the range 0.55Nm^{-2} to 0.60Nm^{-2}, with a maximum shear stress of 1.02Nm^{-2}. There did not appear to be any clear systematic relationships between the critical erosion shear stress and the sediment properties at this site. No variations in the erodibility or sediment properties were found over the 50m transect area or the 3 days' deployment.

5. The floc camera samples were taken from water depths ranging from 0.2m to 1.3m. The suspended sediment was found to have the following properties:

   - the concentrations ranged from 10mg/l to 119mg/l for undisturbed water samples, but significantly higher for samples in which the bed was disturbed.
   - the carbon content was high, ranging from 18.83% to 35.05% by weight of the undisturbed suspended matter samples, but significantly lower for samples in which the bed was disturbed.
   - the particle size for undisturbed samples, ranged between 0.02mm and 2.27mm. For samples in which the bed was disturbed the particle size ranged from 0.04 to 0.39mm.
   - the median particle settling velocities for undisturbed samples (w_{50}) ranged from 0.6 to 2.0mms^{-1}, with the maximum settling velocity recorded at 4.6mms^{-1} for a sample concentration of 19mg/l. For disturbed samples the maximum settling velocity recorded was 5.7mms^{-1} for a sample concentration of 680mg/l.
   - the temperature of the samples ranged from 12.0°C to 14.6°C

6. Observations and carbon content analyses indicated that here was significant biomass in the suspended sediment and the surface sediment layer at the Dollard site.

9 Acknowledgements

HR Wallingford would like to thank the following people for their help and assistance during the Dollard fieldwork: Mr Bart Kornman, Mr Wilhem van der Lee and Mr Wilfried Ten Brinke from the University of Utrecht for their assistance with the planning and provision BOA bridge results. Thanks are due to Mrs Liz Stevenson and Mr Rob Adams for their help in producing the report.

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(* Please note that H.J. Mitchener was H.J. Williamson prior to 6.8.96.)

Tables

Table 1 Summary of SedErode measurements and sediment sample properties

Sample number	Critical erosion shear stress (Nm^{-2})	Bulk density (kgm^{-3})	Organic carbon content (% wt. loss at 550°C)	Sand content (>63μm) (%)	Mud content (<63μm) (%)
D1	1.02	1600	3.69	77.59	22.41
D2	0.71	1720	3.98	84.15	15.85
D3	0.92	1680	2.55	84.04	15.96
D4	0.58	1700	3.91	84.84	15.16
D5	0.72	1660	4.29	81.89	18.11
D6	0.71	1770	3.06	88.46	11.54
D7	0.55	1780	3.23	87.95	12.05
D8	0.67	1820	1.84	90.33	9.67
D9	0.56	1780	3.98	83.24	16.76
D10	0.60	1800	3.79	83.66	16.34
D11	0.57	1820	3.14	85.28	14.72
D12	0.73	1780	2.76	84.05	15.95
D13	0.56	1770	3.69	87.00	13.00
D14	0.57	1460	4.75	75.39	24.61
D15	0.56	1650	3.59	77.10	22.90
D16	0.56	1610	4.29	73.43	26.57

Table 2 Summary of Floc camera water sample data

Tube No	Date	Local Time	Time relative to High Water	Water depth (m)	Depth below surface (m)	Salinity (ppt)	Sample temp (°C)	Conc (mg/l)	% Weight loss at 550 °C	Comments
1*	21-05-96	1300	HW-3.0	0.4	0.2	21.1	12.3	95	35.05	
2*	21-05-96	1320	HW-2.7	0.4	0.2	21.2	12.6	14	22.26	
3	21-05-96	1337	HW-2.4	0.8	0.1	21.2	12.6	28	22.71	
4	21-05-96	1408	HW-1.9	0.9	0.5	21.3	12.6	18	21.82	
5	21-05-96	1434	HW-1.4	1.2	0.7	21.7	13.5	10	28.9	
6	21-05-96	1503	HW-1.0	1.1	0.6	22.9	13.6	12	18.85	
7*	21-05-96	1531	HW-0.5	1.3	0.8	22.0	13.6	10	29.3	
8*	22-05-96	0623	HW+2.0	0.2	0.1	N/A	12.0	68	20.98	
9*	22-05-96	0632	HW+2.2	0.2	0.1	N/A	12.1	680	6.32	Disturbed bed
10	22-05-96	0642	HW+2.4	0.2	0.1	N/A	12.2	3,315	3.88	Disturbed bed
11*	22-05-96	1438	HW-2.0	0.8	0.3	21.4	12.6	41	20.02	
14*	22-05-96	1624	HW-0.6	N/A	0.3	21.3	13.2	19	24.08	
15	23-25-96	0628	HW+1.5	0.5	0.3	N/A	12.3	11,310	2.77	Disturbed bed
16	23-25-96	0647	HW+1.8	0.3	0.2	N/A	12.6	3,587	2.48	Disturbed bed
18*	23-25-96	1419	HW-2.8	0.6	0.3	21.4	14.6	774	4.58	Disturbed bed
19*	23-25-96	1436	HW-2.5	0.6	0.3	21.4	14.4	119	19.52	
20	23-25-96	1453	HW-2.3	N/A	N/A	21.5	14.5	52	21.92	
21	23-25-96	1516	HW-1.9	0.6	0.3	21.6	14.5	67	18.83	

Note: * alongside tube number indicates tube selected for image processing

Table 3 Summary of Floc camera image processing data

Tube No	Conc (mg/l)	Measured particle size (mm)		Measured particle settling velocities (mm/s)	
		Minimum	Maximum	Median	Maximum
1	95	0.05	0.80	1.6	3.0
2	14	0.05	0.65	1.0	4.3
7	10	0.05	0.97	1.1	1.9
8	68	0.04	0.69	1.3	2.2
9*	680	0.04	0.39	3.1	5.7
11	41	0.02	0.68	0.6	1.3
14	19	0.10	2.27	2.0	4.6
18*	774	0.09	0.37	1.3	2.4
19	119	0.05	0.52	0.8	1.6

Note: * alongside tube number indicates 'disturbed' bed sample

Figures

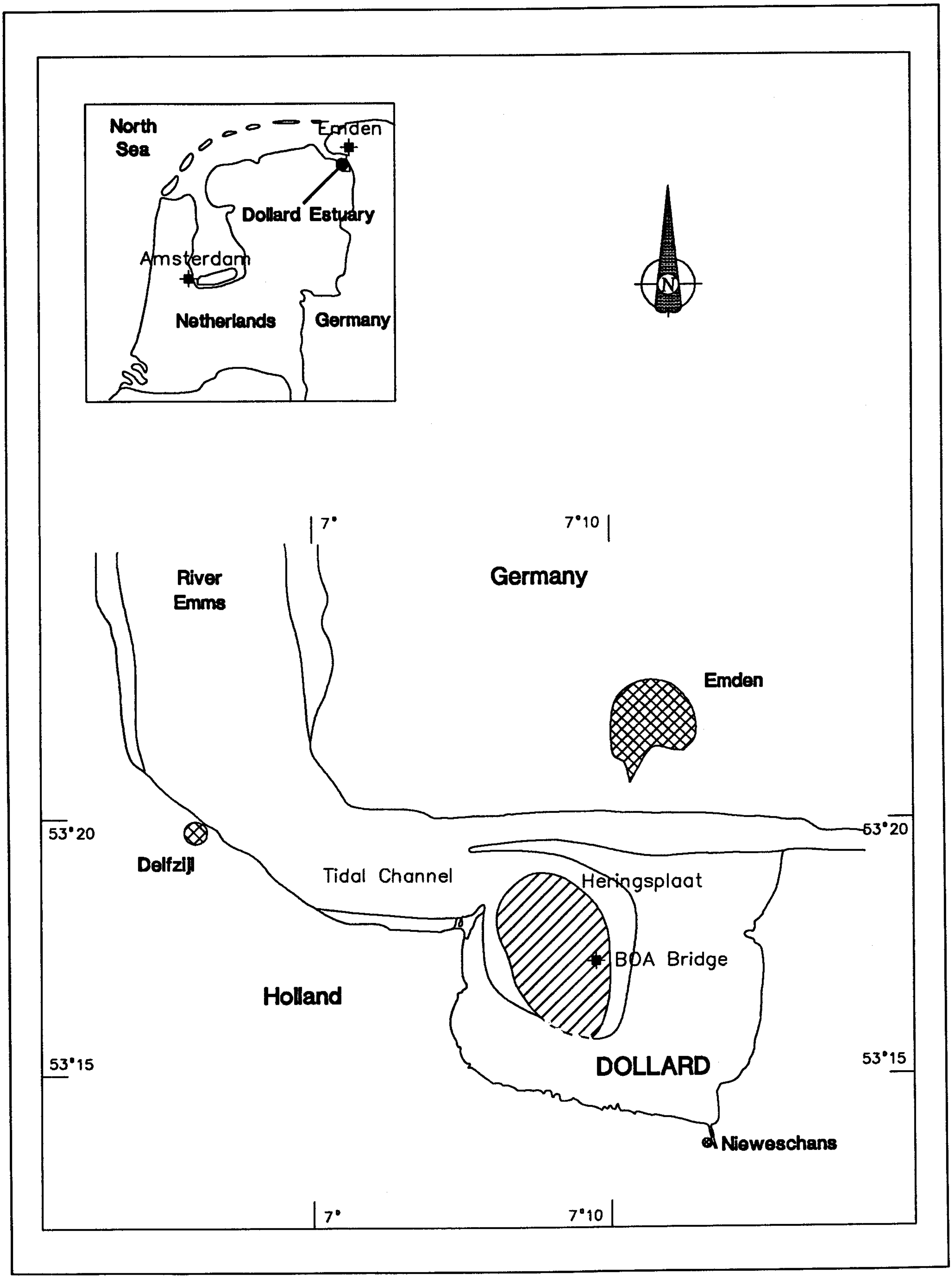


Figure 1 Dollard location map

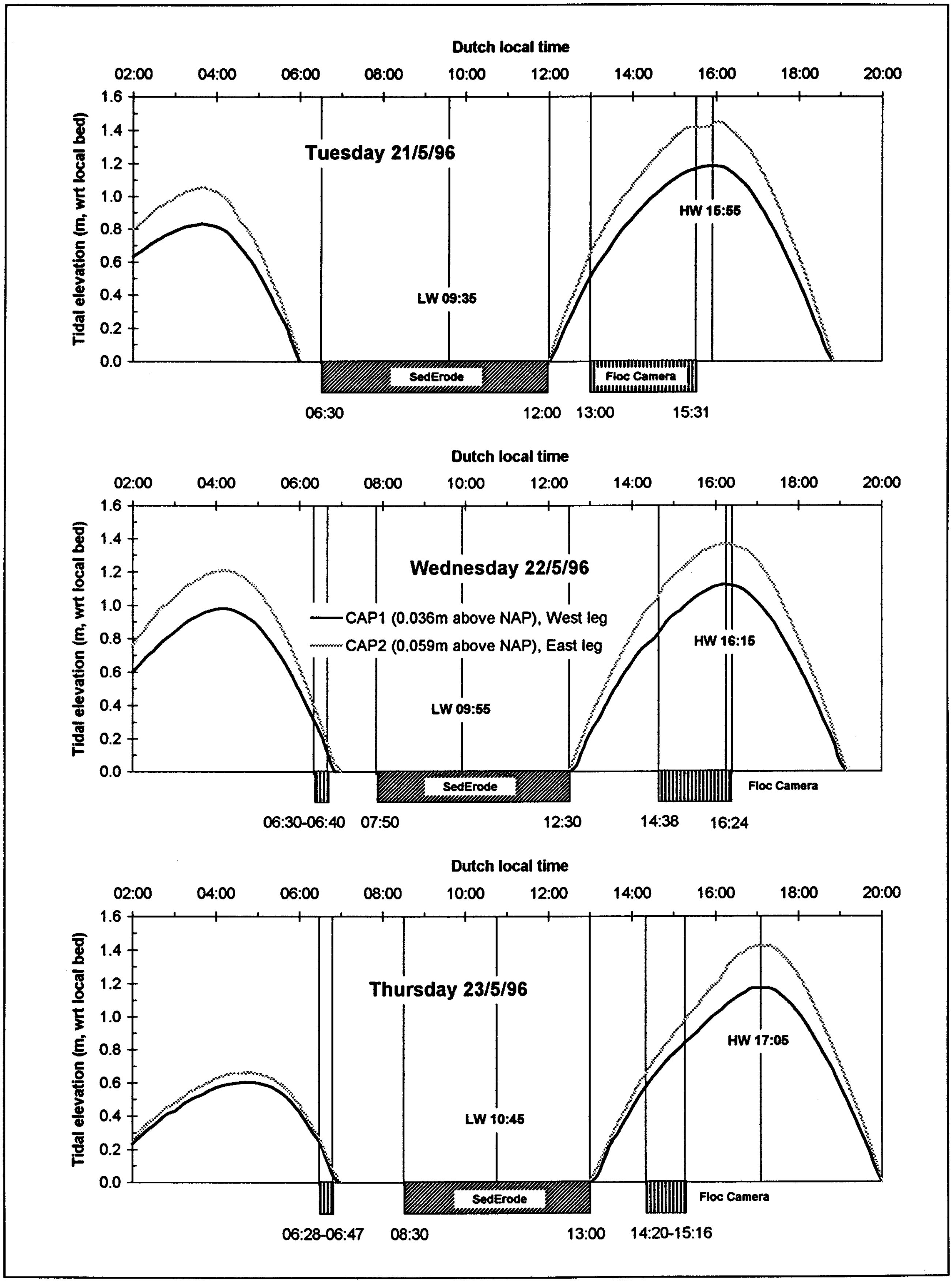


Figure 2 Dollard fieldwork schedule

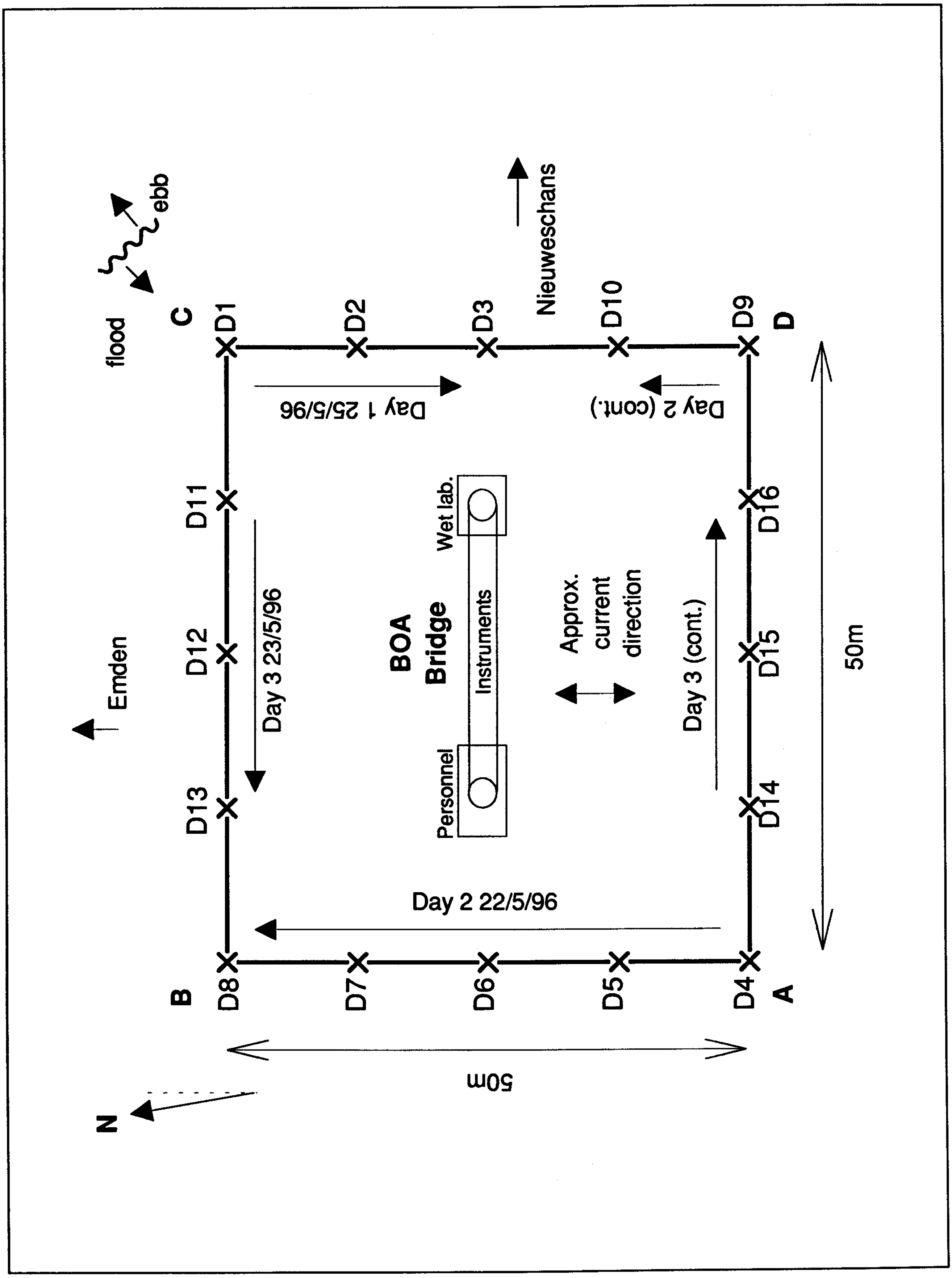


Figure 3 SedErode sampling locations

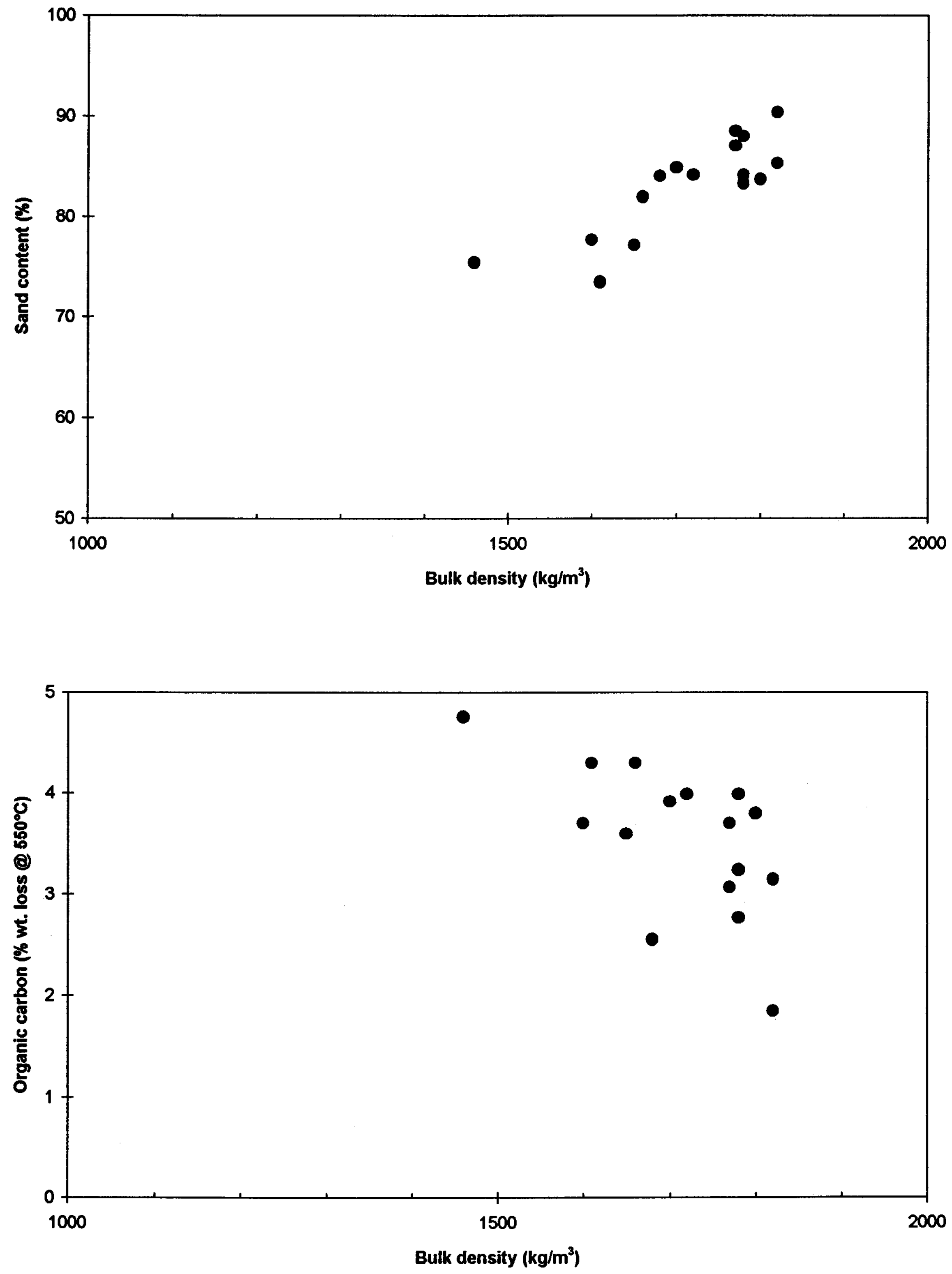


Figure 4 Sand content and organic carbon content vs bulk density for the Dollard sites

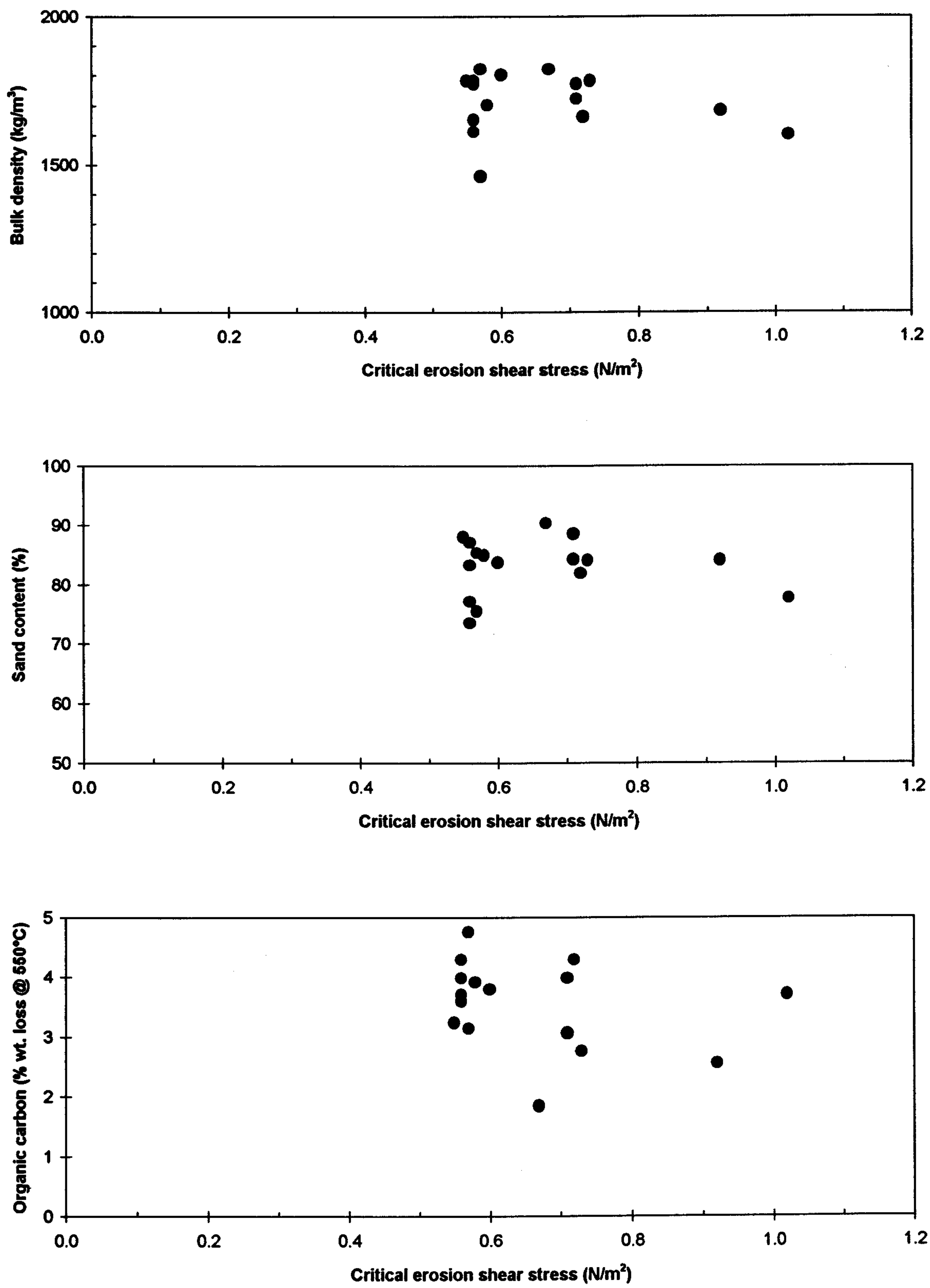


Figure 5 Bulk density, sand content and organic carbon content vs critical erosion shear stress for the Dollard site

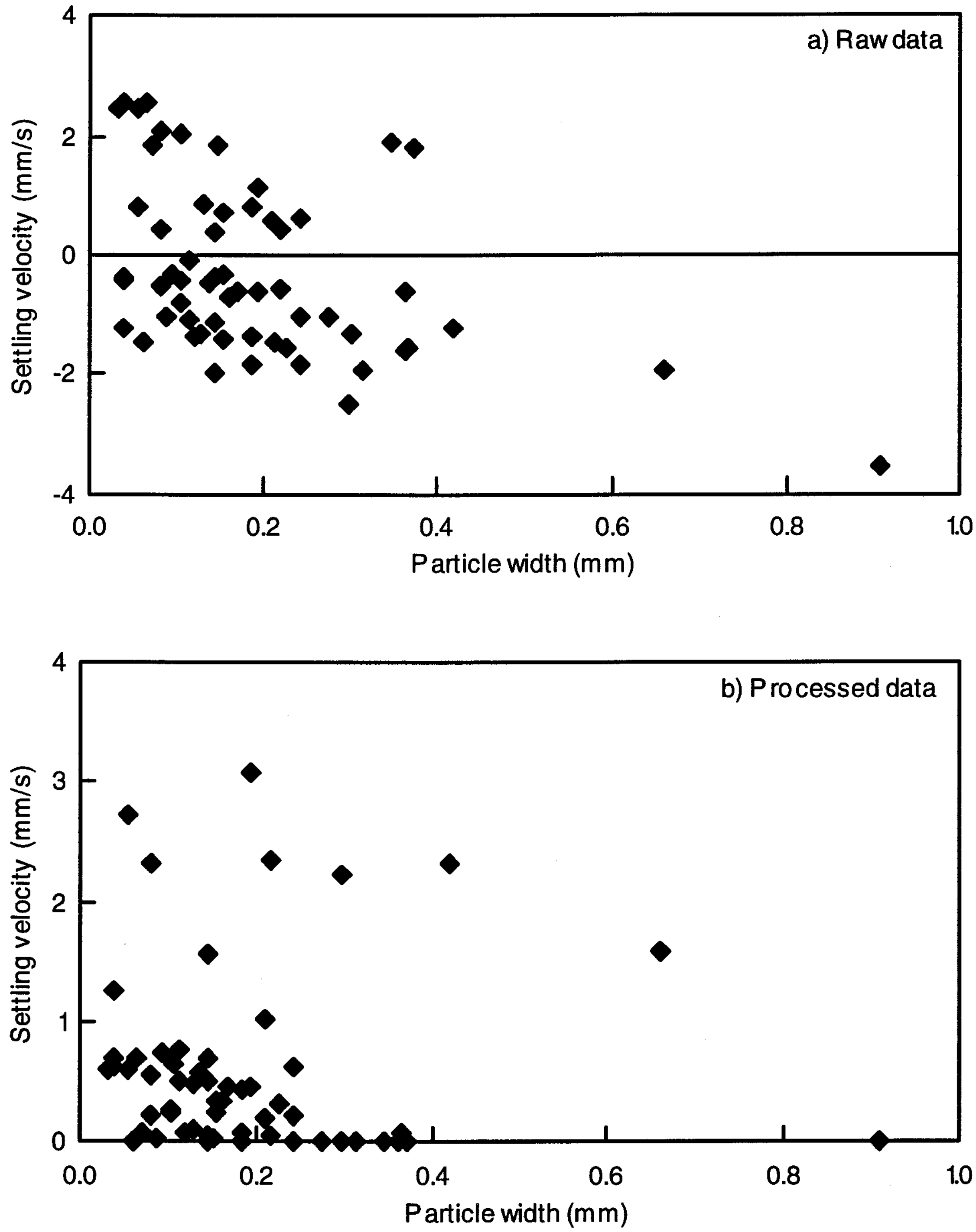


Figure 6 Comparison of raw and processed data - Tube 1

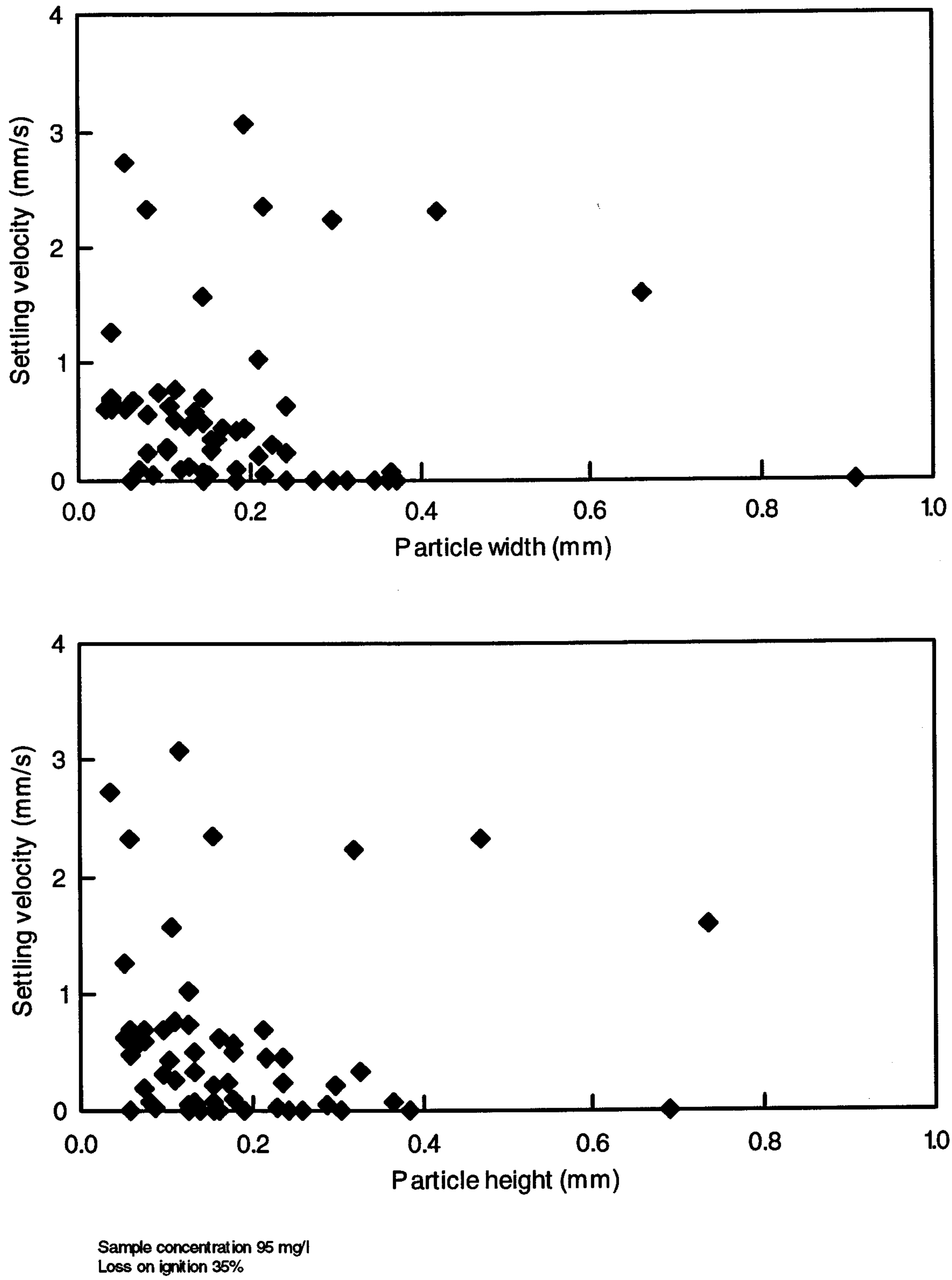


Figure 7 Variation of settling velocity with particle size - Tube 1

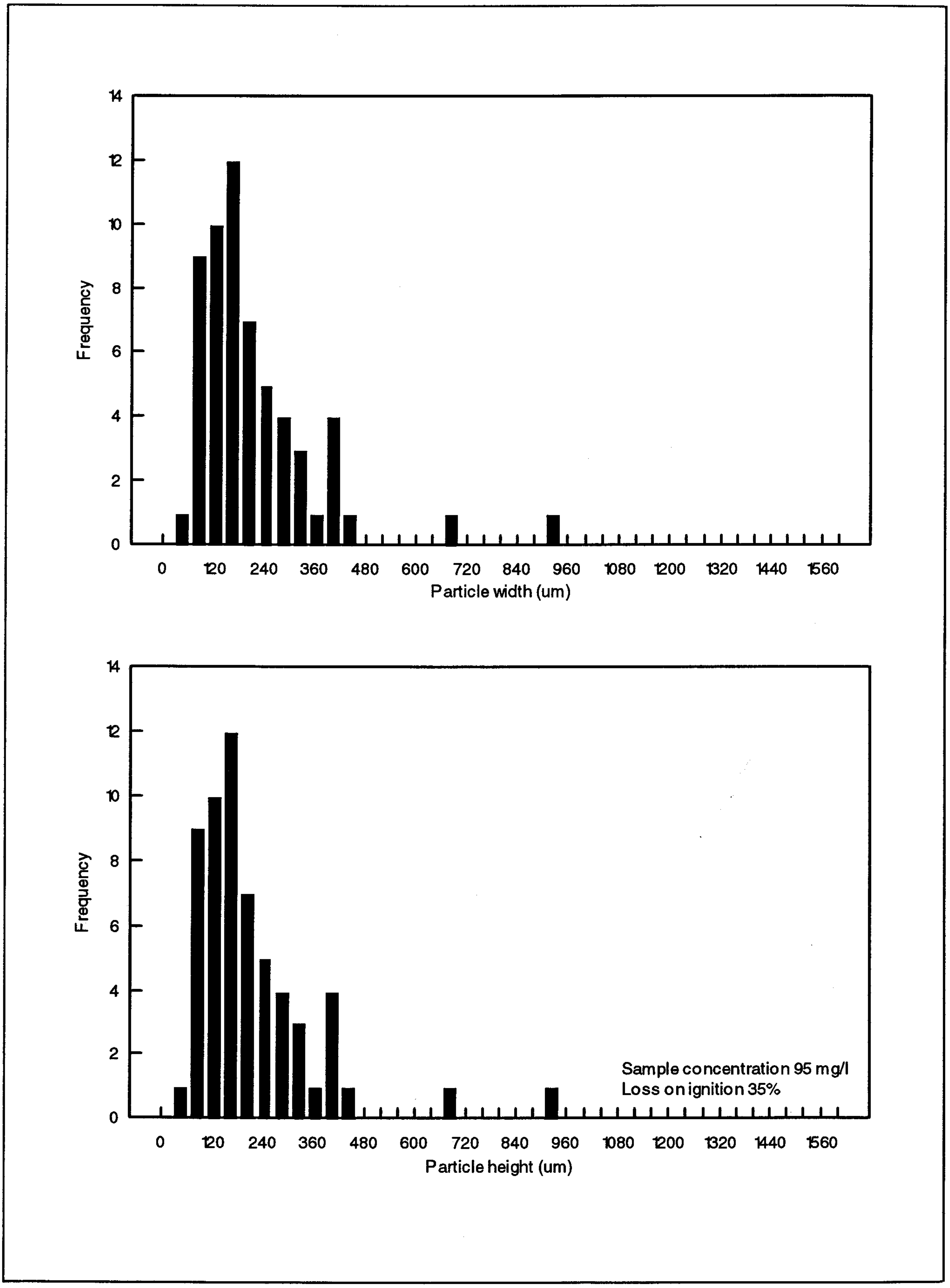


Figure 8 Particle size distribution - Tube 1

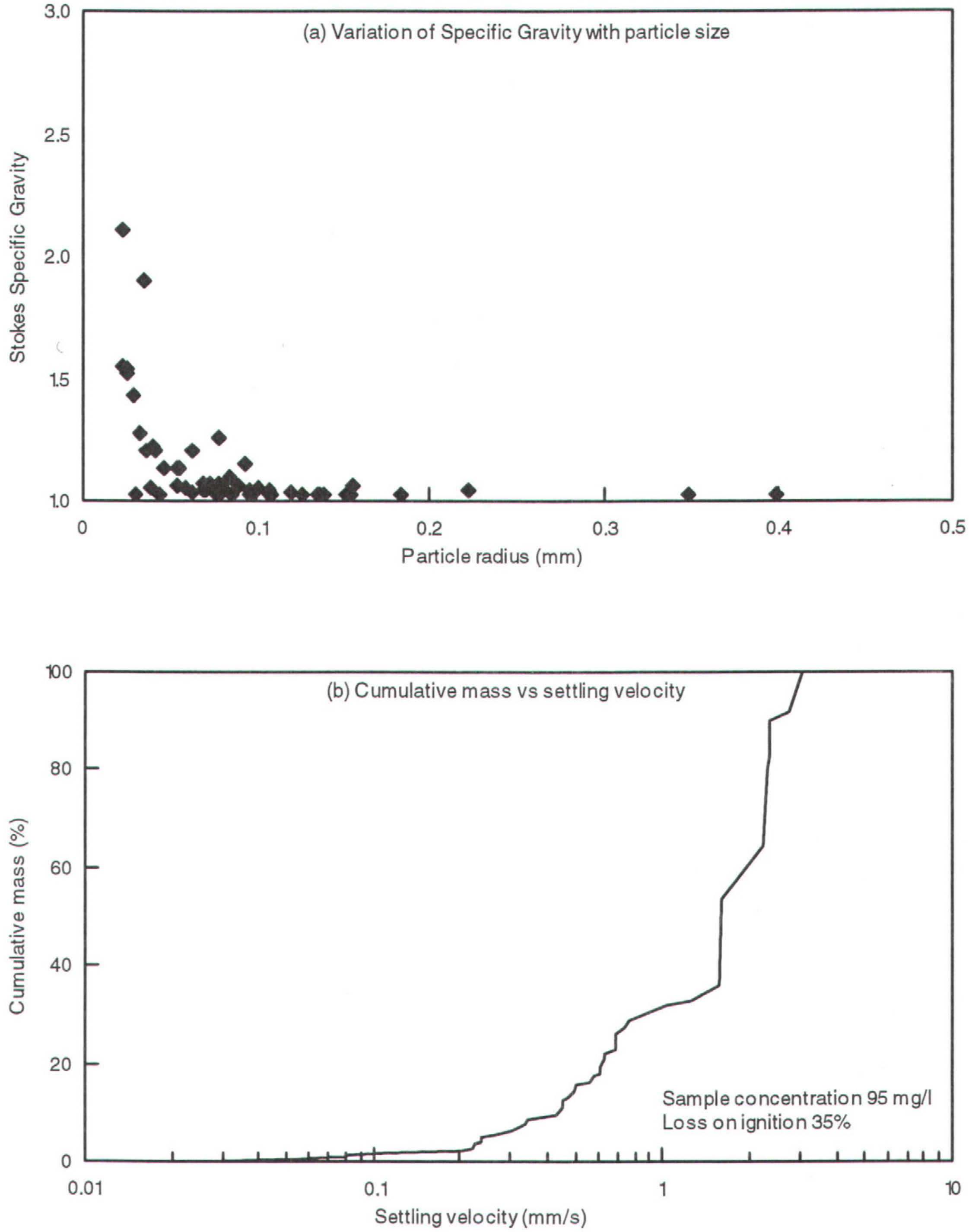


Figure 9 Derived relationships for Tube 1

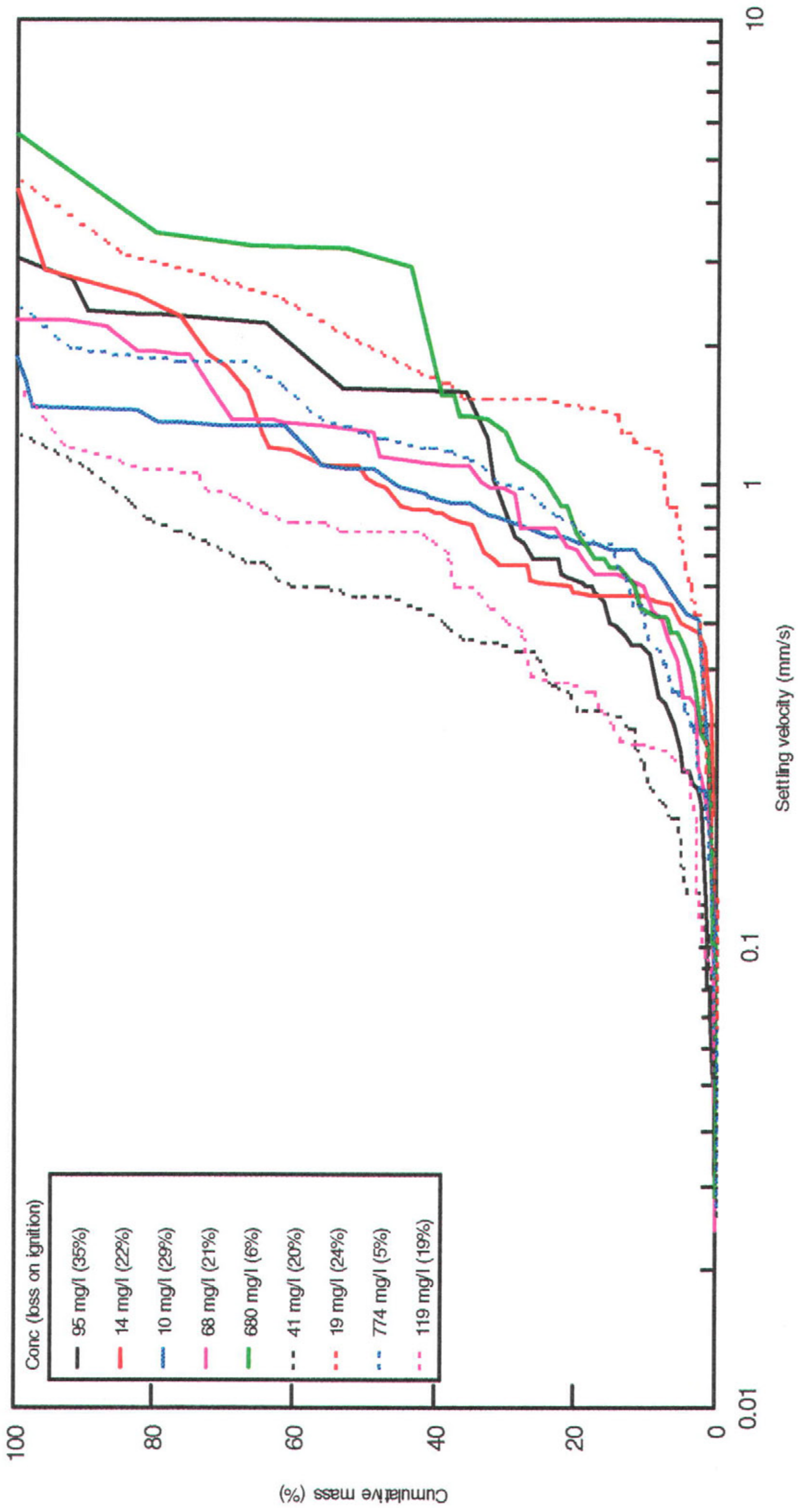


Figure 10 **Summary of cumulative mass versus settling velocity determinations**

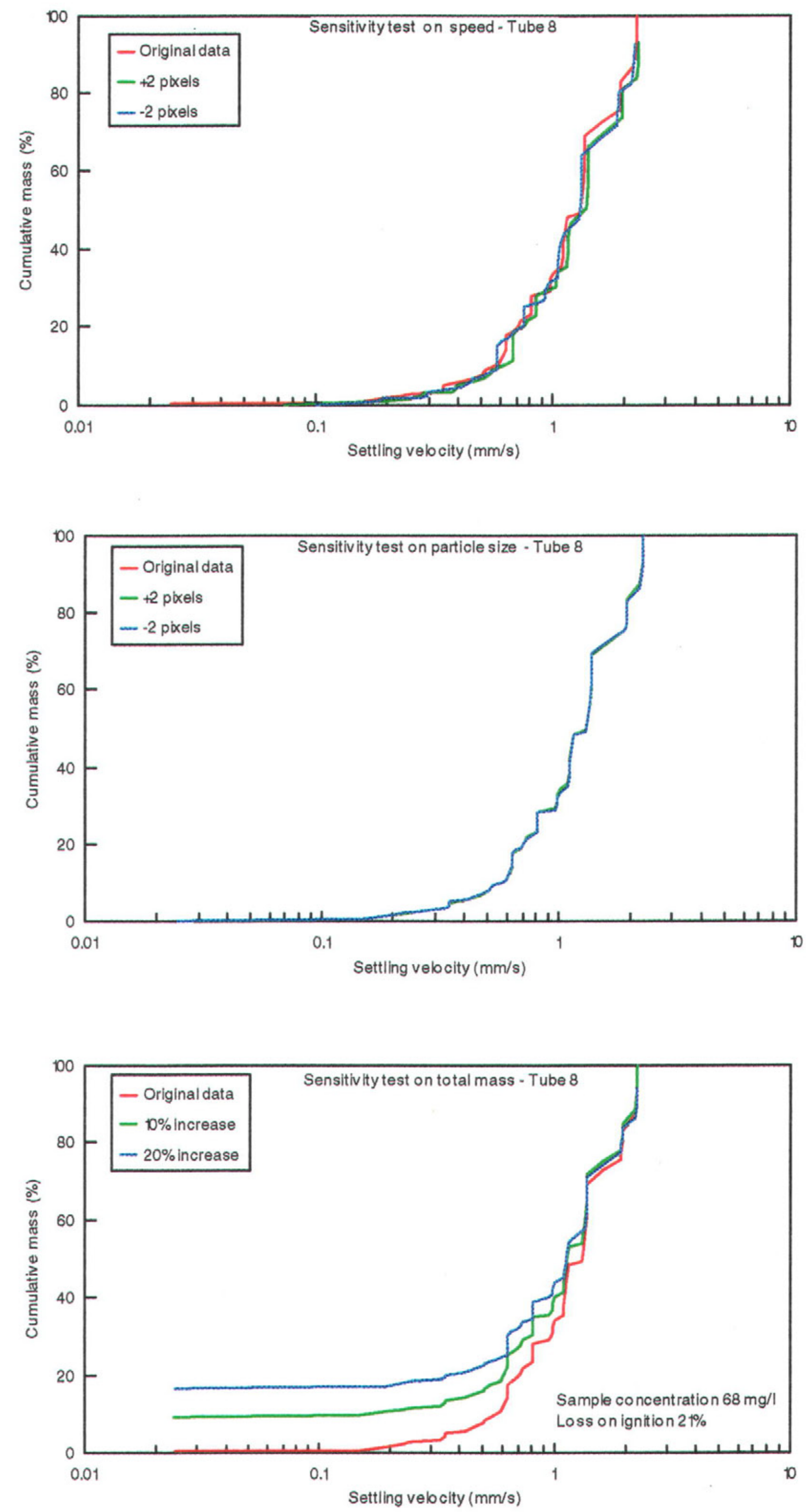


Figure 11 Results of sensitivity tests

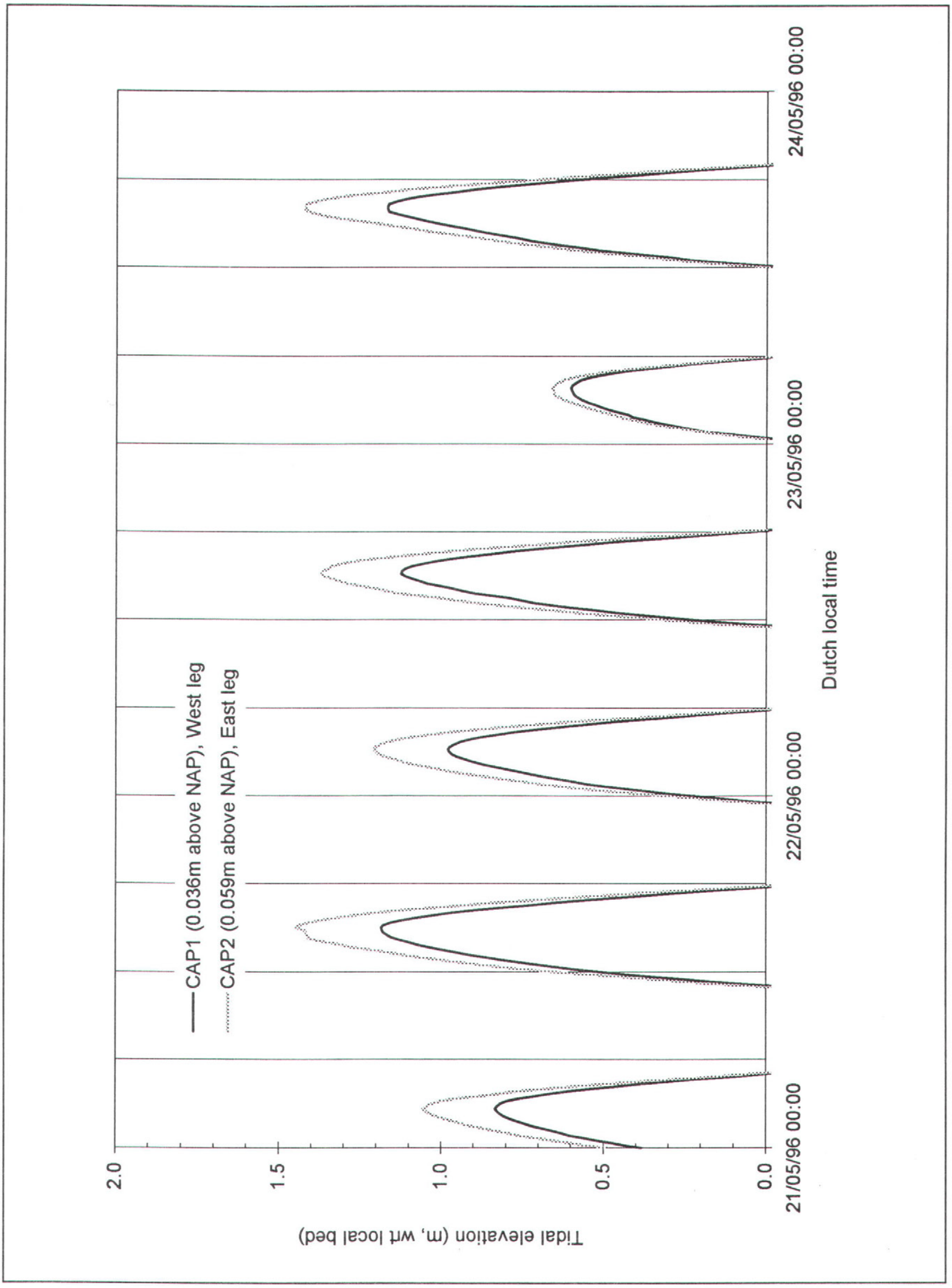


Figure 12 Tide levels at the BOA bridge 21 - 24 May 1996

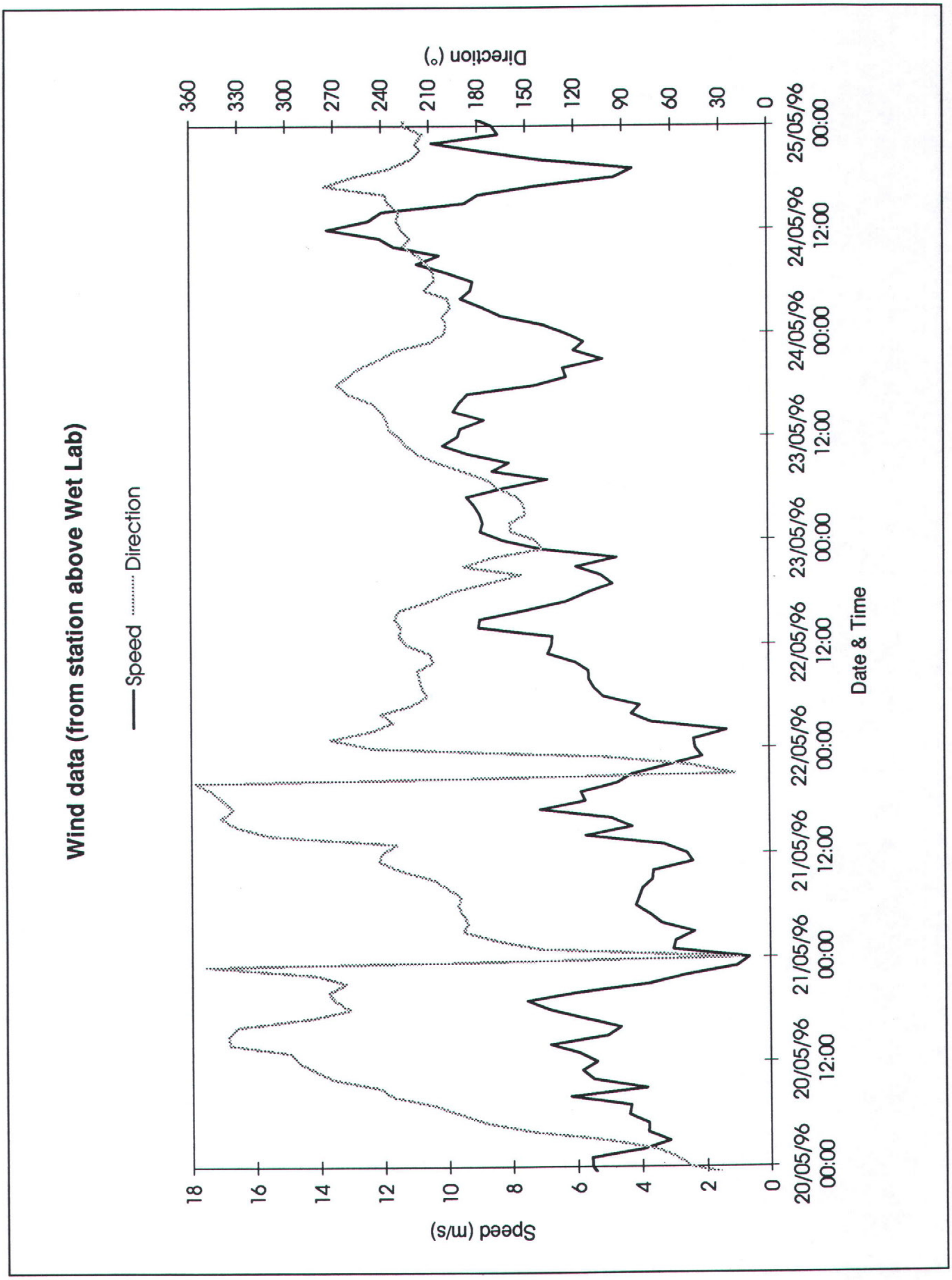


Figure 13 Wind speed and direction at the BOA bridge 20 - 25 May 1996

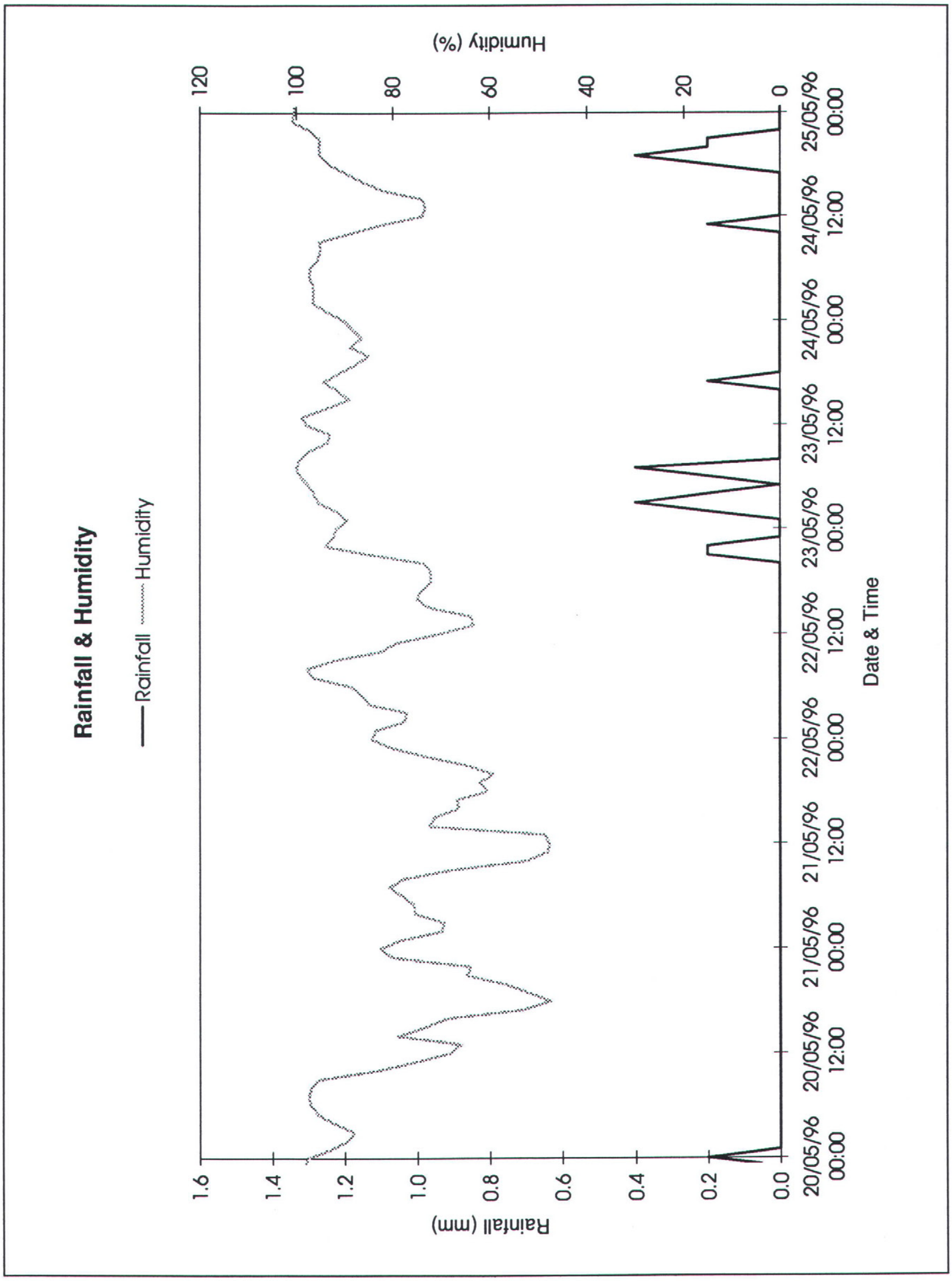


Figure 14 Rainfall and humidity at the BOA bridge 20 - 25 May 1996

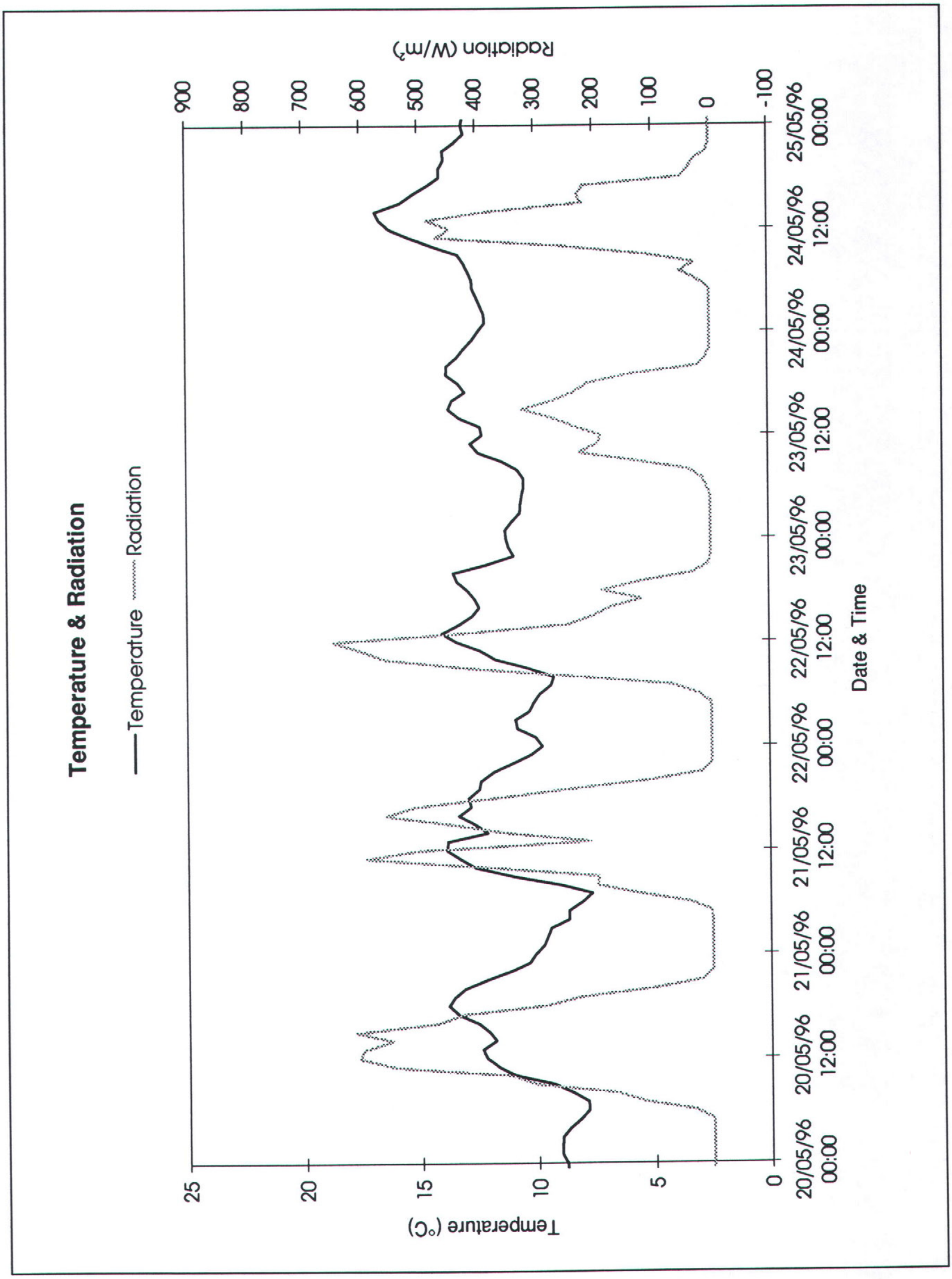


Figure 15 Temperature and radiation at the BOA bridge 20 - 25 May 1996

Plates

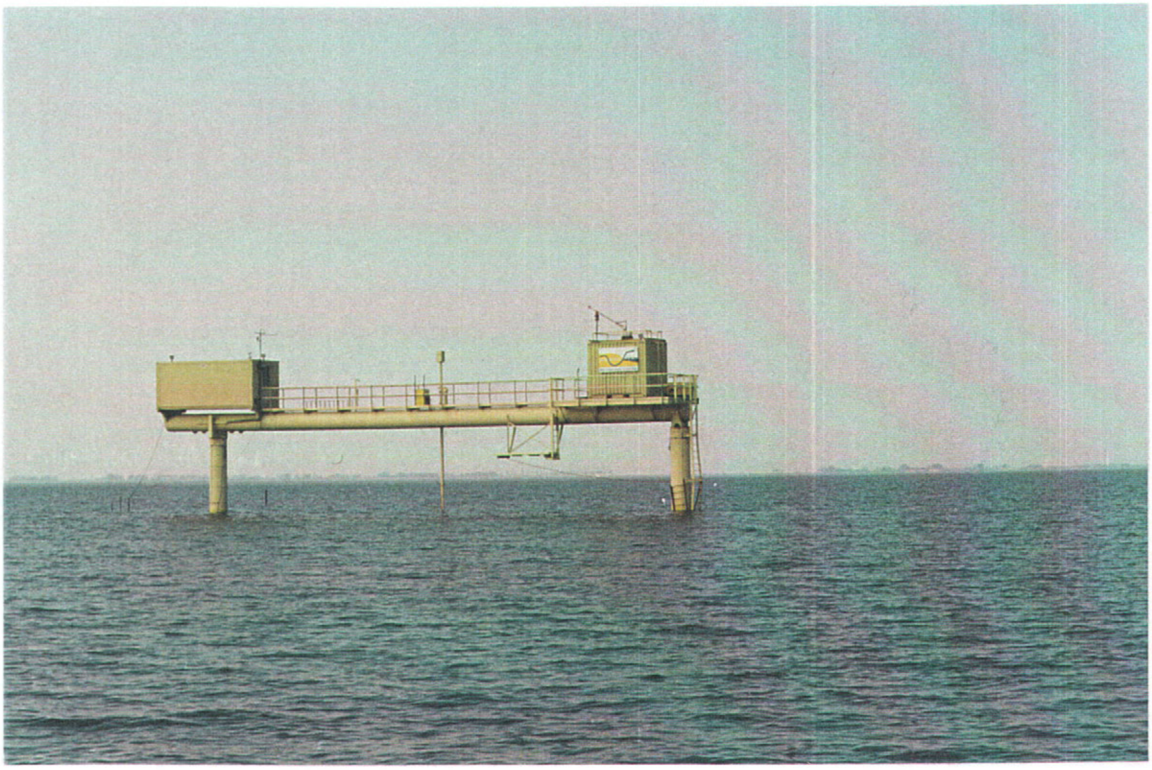
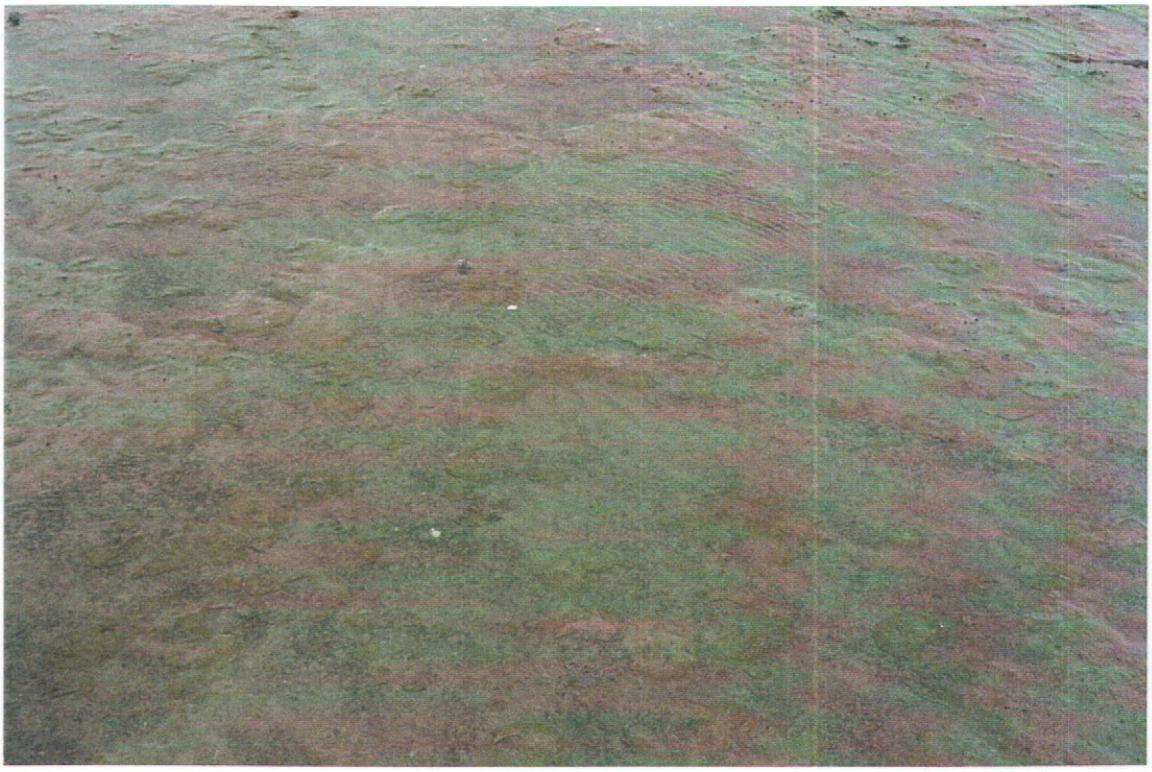


Plate 1 General Dollard mudflat site



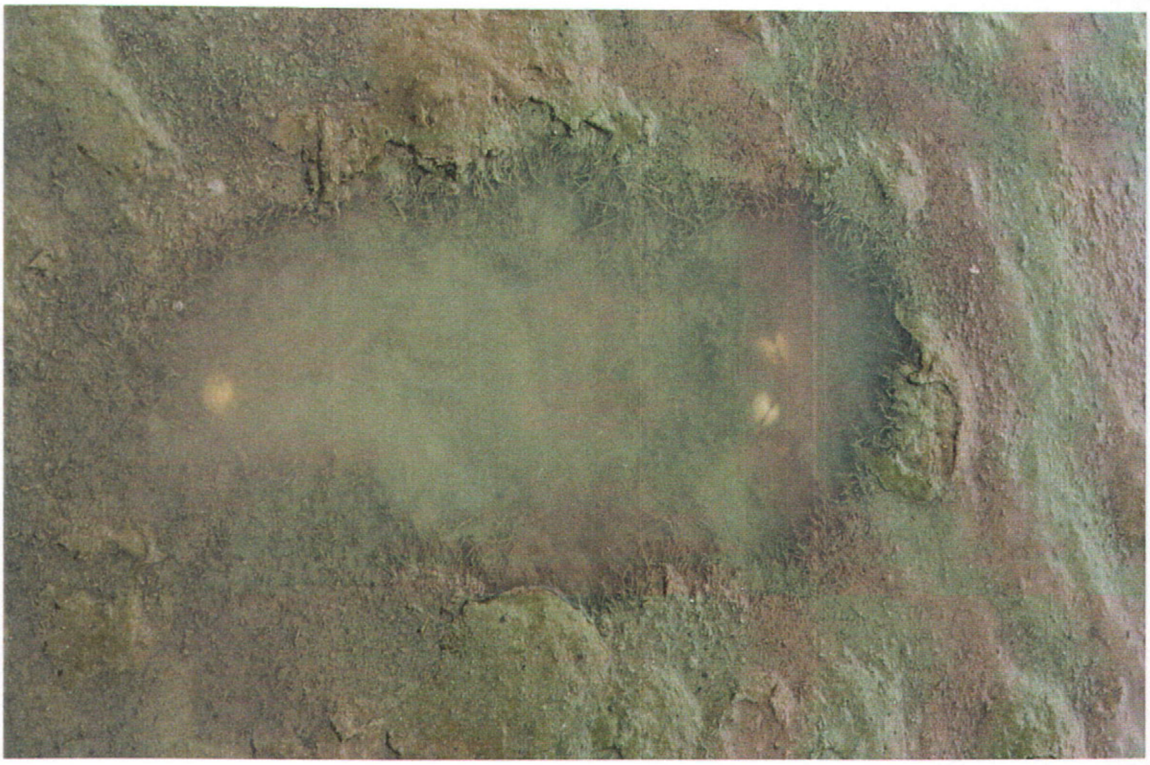
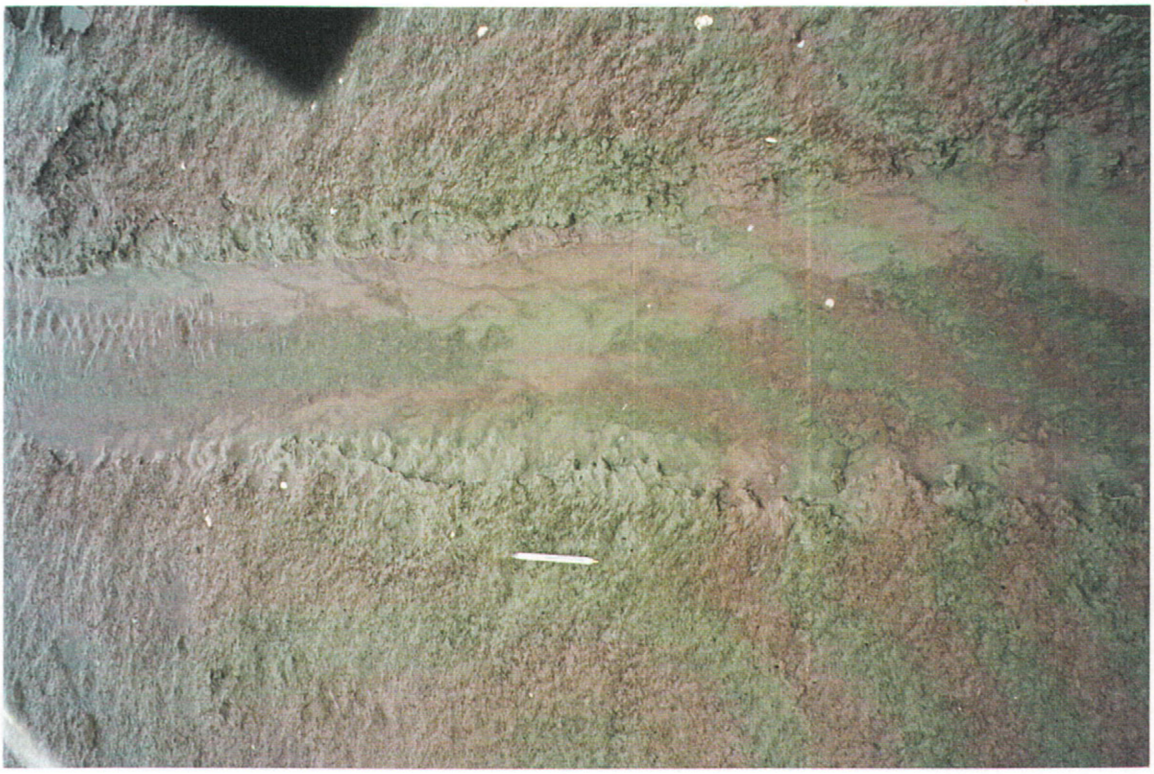


Plate 2 Dome and matting features around the BOA bridge



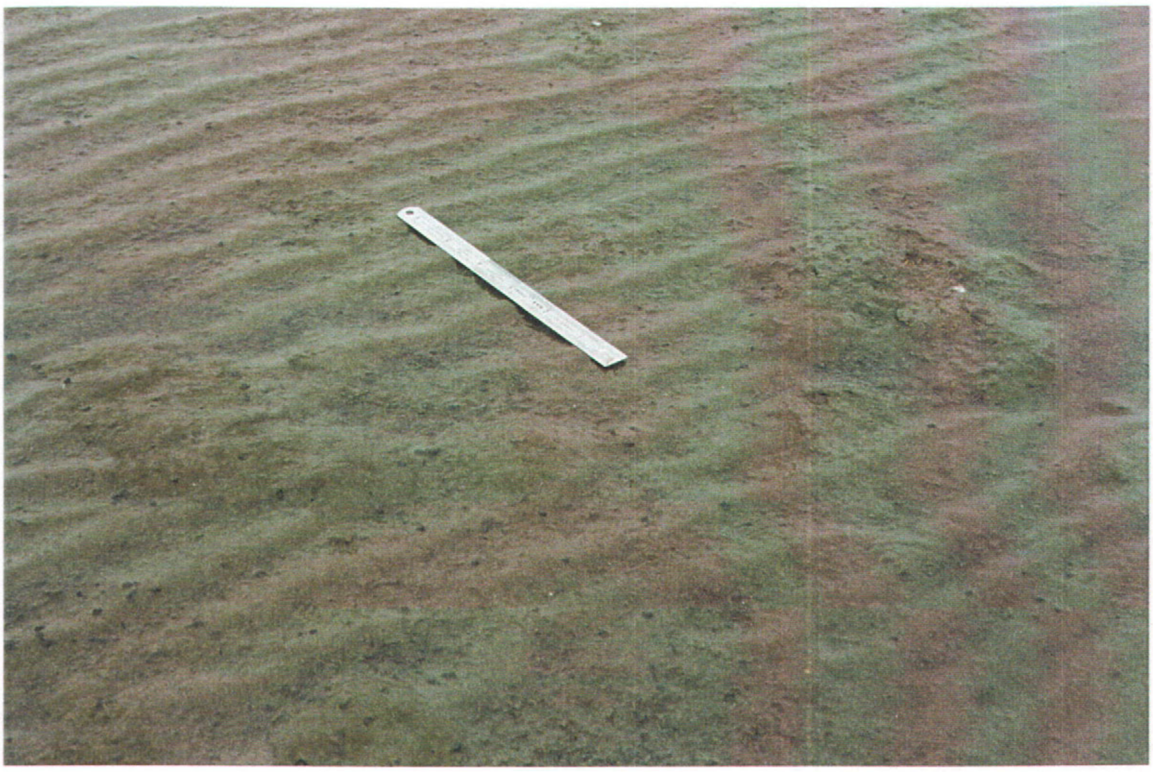
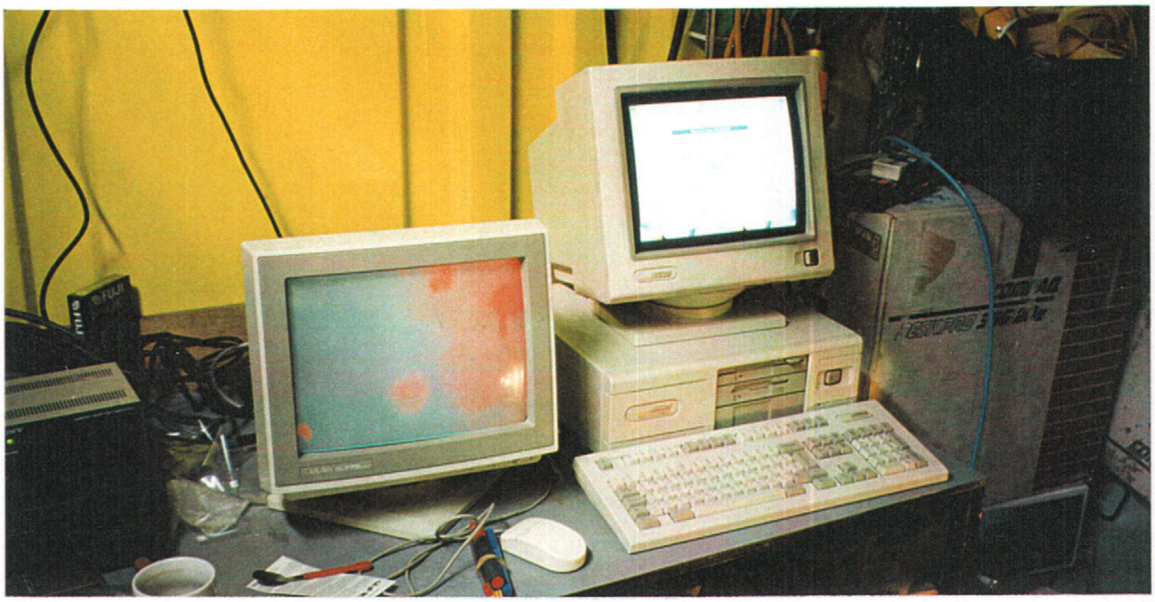


Plate 3 Runnel and ripple features on 23 May 1996

Plate 4 SedErode deployment at the Dollard site



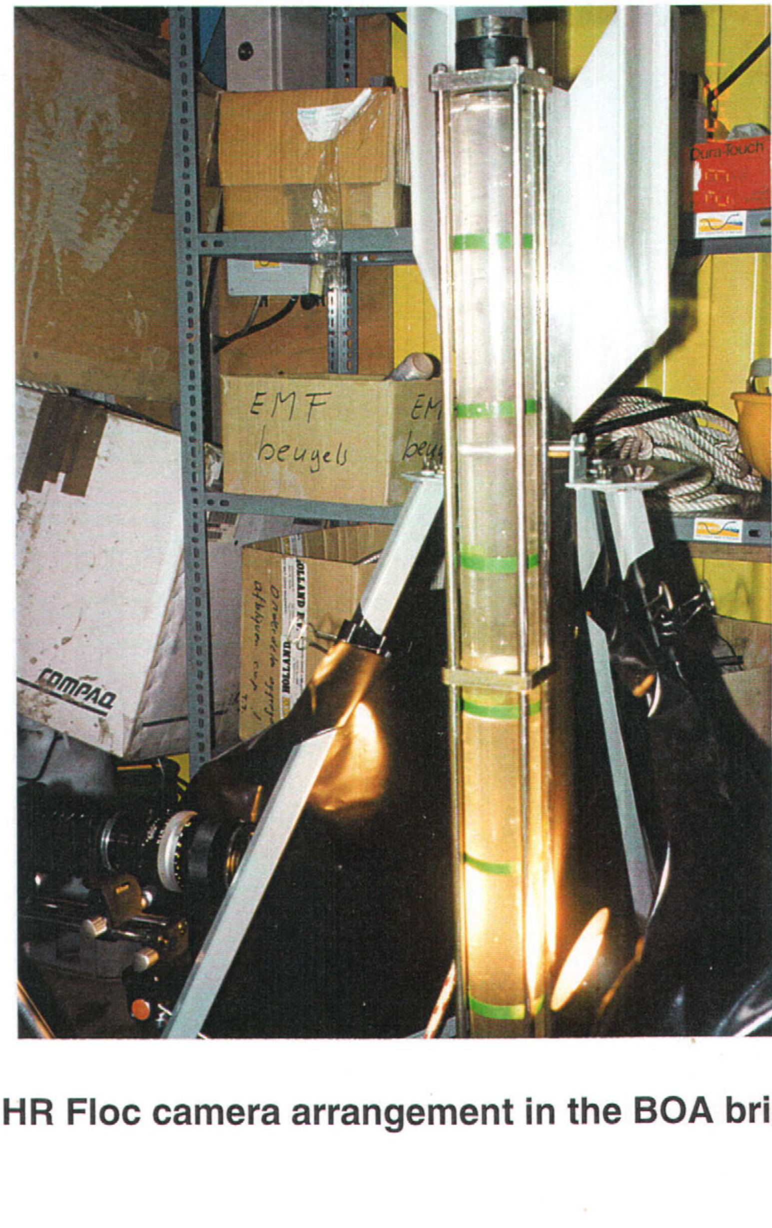
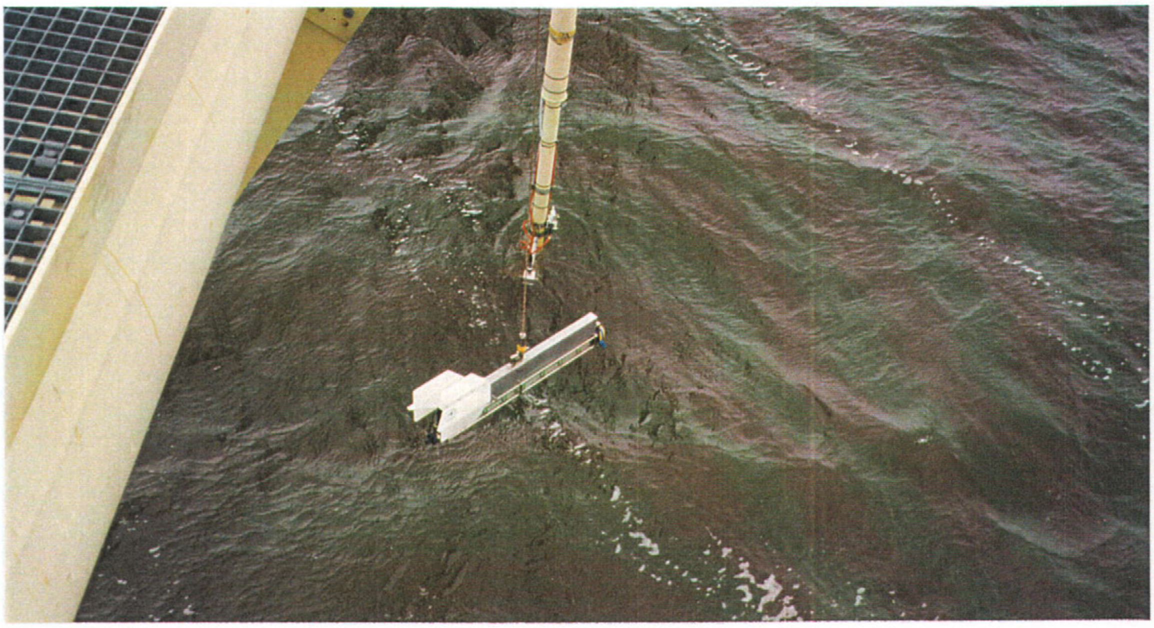


Plate 5 HR Floc camera arrangement in the BOA bridge container



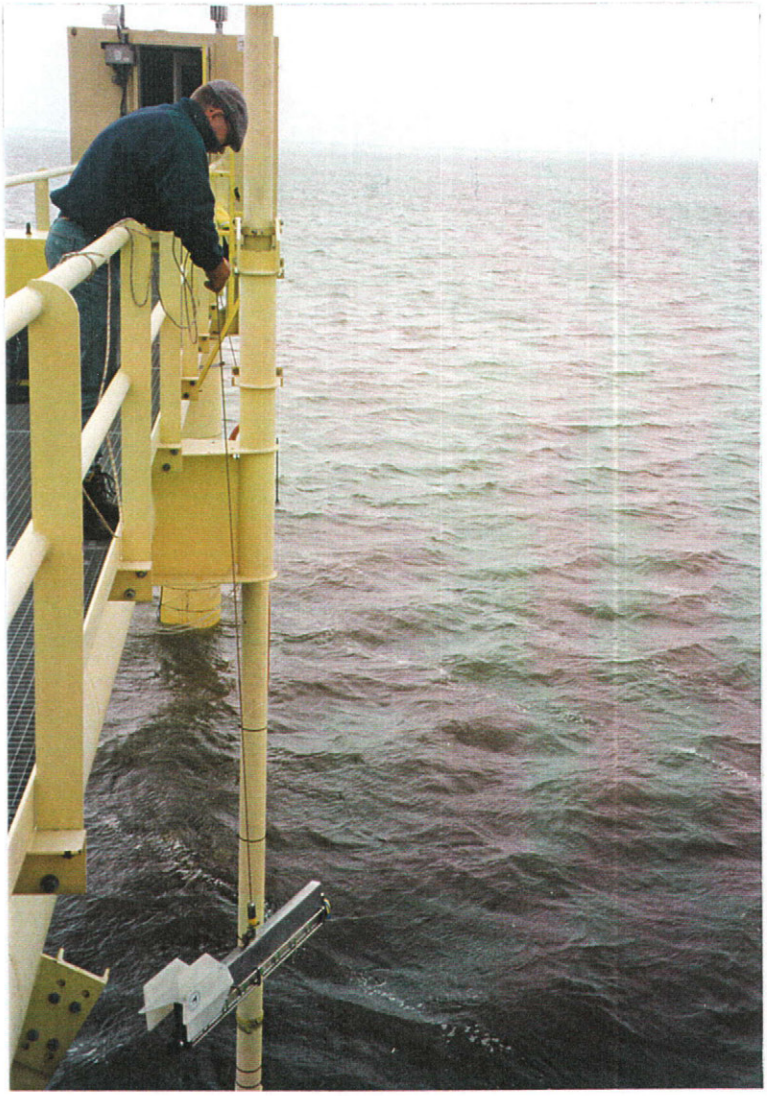


Plate 6 Valeport settling tube deployment

Appendices

Appendix 1

SedErode - Sediment Erosion Device

Appendix 1 SedErode - Sediment Erosion Device

1. SedErode Instrument

SedErode comprises a head unit and a control box. The instrument is used to apply a known applied shear stress to a planar surface of cohesive sediment and detect the onset of surface erosion.

The head section comprises a recirculating system which generates radial flow with a known shear stress, across a 0.09m diameter area of sediment surface, via the specially designed bell head. The recirculating system is mounted on a 0.4m diameter baseplate, with a short thin-walled tube which is pushed into the sediment to position the bell head above the mud surface. A nephelometer is used to continuously monitor the recirculating water turbidity.

The control box contains a rechargeable battery supply, discharge (ie applied shear stress) control, and logging ports for applied shear stress and turbidity monitoring. Figure A1.1 shows the SedErode instrument being deployed on a typical mudflat.

The applied shear stresses generated by SedErode under different operating conditions have been measured using hot film shear stress probes (Graham et al, 1992) at the University of Plymouth. This data has been used to generate a calibration equation relating the discharge though the system and the gap to the applied shear stress.

2. Operation

The head unit is carefully positioned over a typical planar area of sediment under investigation. The unit is filled with clear local water and the recirculating system is bled of any air. The nephelometer is zeroed, and shear stress and turbidity logging is commenced. The water is recirculated over the test site first at a very low shear stress to allow even mixing of the recirculating water and establish a turbidity baseline prior to erosion testing. A series of controlled increasing shear stress steps are then applied, typically 1-2 minutes duration whilst monitoring of the turbidity. The onset of erosion occurs when there is a sharp increase in the turbidity, which corresponds to the removal of surface material into the recirculating water. The measurement time typically takes about 15 minutes.

3. Results and Interpretation

The output from the SedErode measurements is a time series of applied shear stress and turbidity in the system. Figure A1.2 shows a typical example of the results obtained using SedErode. The turbidity can be directly calibrated against the concentration of the mud under test, and this record gives the sediment response to the applied shear stress steps. Analysis of the time series data then yields the onset of surface erosion, and the erosion rate as material is removed from the surface. The interpretation as to the definition of erosion depends on the application of the results, but for most engineering purposes it is practical to consider that erosion occurs when there is "bulk surface rupture", which continues when a higher shear stress is applied. Another definition of cohesive sediment erosion is "benign erosion", when loose surface deposits are removed and this type of erosion results in small discontinuous turbidity increases. The use and interpretation of the SedErode instrument and results can be chosen by the user and varied to investigate specific erosion characteristics of cohesive sediments.

4. Applications

SedErode can be used on any cohesive-based sediment to measure the surface erosion shear stress. Measurements have enabled the relationship between erosion shear stress and simpler measures of sediment properties, such as density and sand content, to be investigated. The critical surface erosion shear stress is a fundamental parameter for input into predictive models of coastal and estuarine cohesive sediments. Example of sites are:

- intertidal mudflats
- river banks
- coastal areas
- sewer and drainage systems
- saltmarshes
- reservoirs

To date SedErode (and its predecessor ISIS) have been used to measure in excess of 130 measurements of surface critical erosion shear stress at sites covering the Dollard Estuary (Netherlands), 3 sites in Severn Estuary (UK), Humber Estuary (UK), Tollesbury Creek, Essex (UK), and Mersea Island, Essex (UK).

6. References

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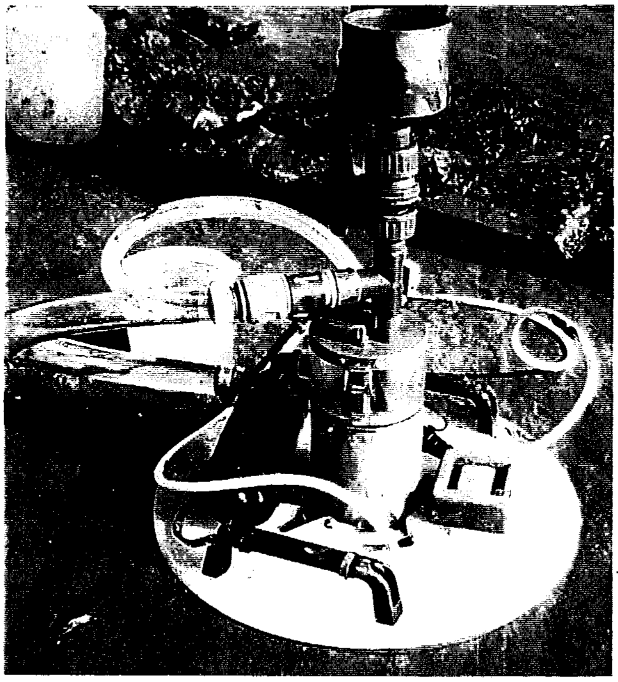


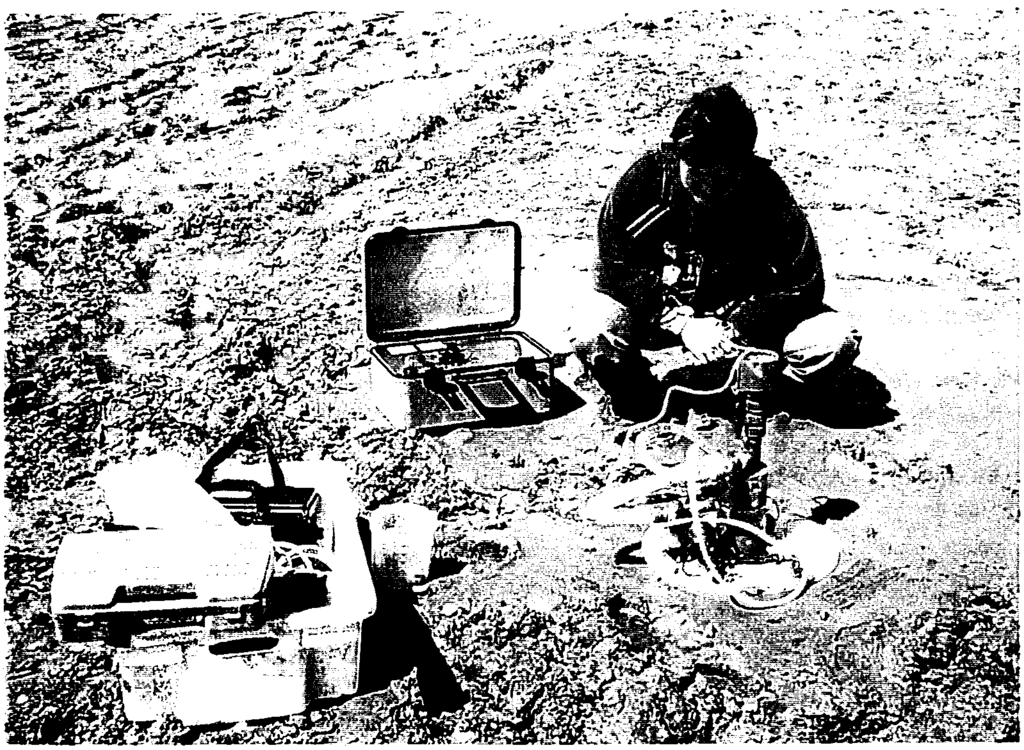
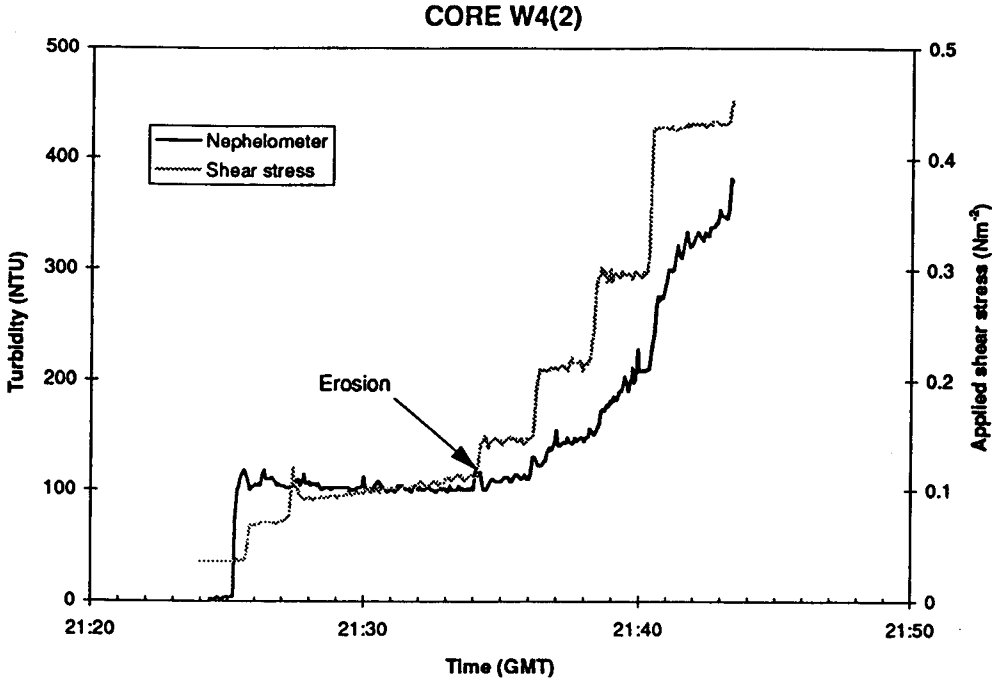


Figure A1.1 SedErode deployment



Site:	**Cirolana RV NIOZ core W4(2)**	**Data file:**	(downloaded from Squirrel data logger)
Isis planted:	21:16	Path:	sediments/helen/dredge/sellfd/selw002.I01
Date:	26/05/96		
Operator:	H.J.Mitchener		

Site description:

texture:	medium
colour:	pale / medium
covering:	surface water
topography:	smooth
biologically activity:	active
composition:	mud / fine sand
other features:	no algae

Surface sample: (from top 10mm) - W4(2)

Bulk density (kgm^{-3}):	1870
Sand content (% by wt):	83.30
Mud content (% by wt):	16.70
Organic carbon (% loss by wt on ignition):	4.21

Shear vane: 33mm vane

Time: 20:10
Observer: N.Feates

Measurements (kPa): 1.0
1.7
1.7
1.8
1.2 Average = 1.48

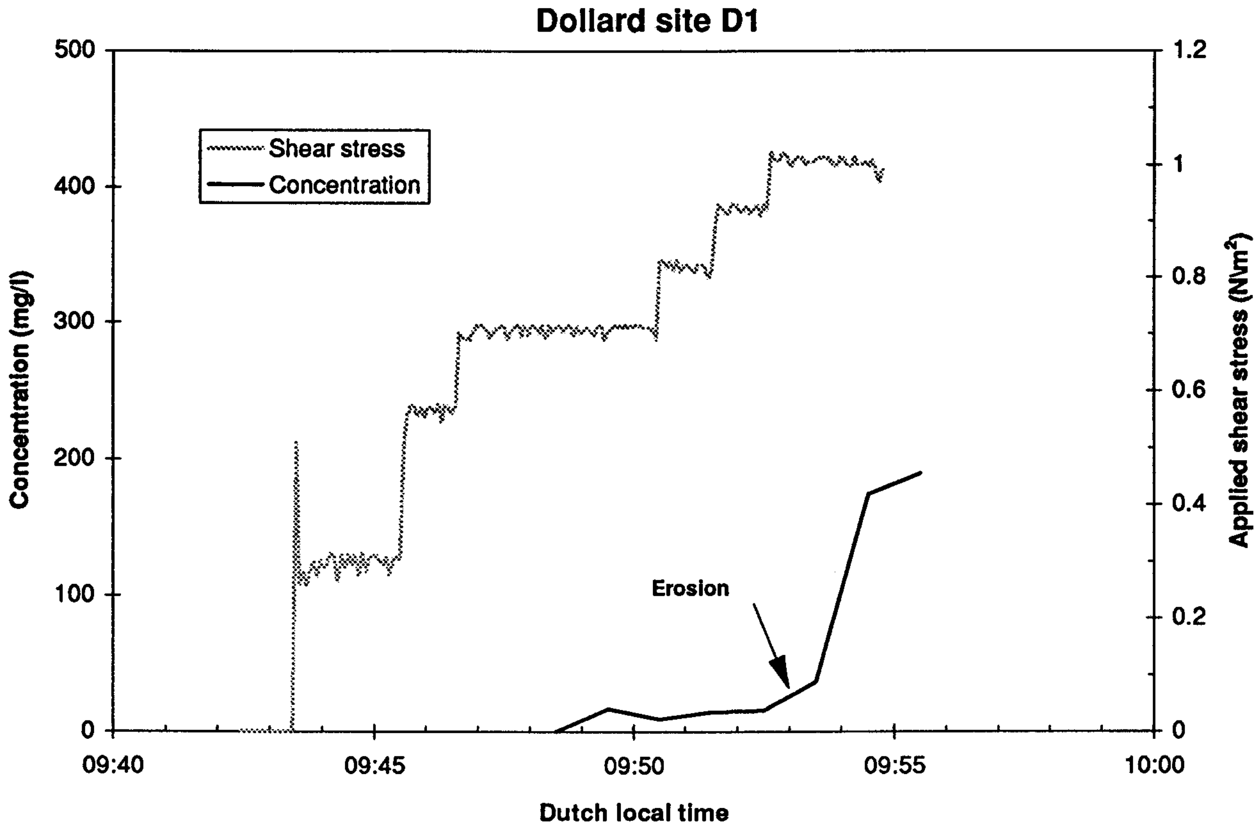
Photographs: Film 2

Time:	~	Number:	5
Time:	~	Number:	~
Time:	~	Number:	~

Figure A1.2 Example of typical results obtained using SedErode

Appendix 2

SedErode time series plots



Site: Dollard Estuary, Netherlands
Time: 09:05
Date: 21/05/96
Operator: H.J.Mitchener

Data file: (downloaded from Squirrel data logger)
Path: ..\sediments\helen\intrmud\dollard\d1.l01

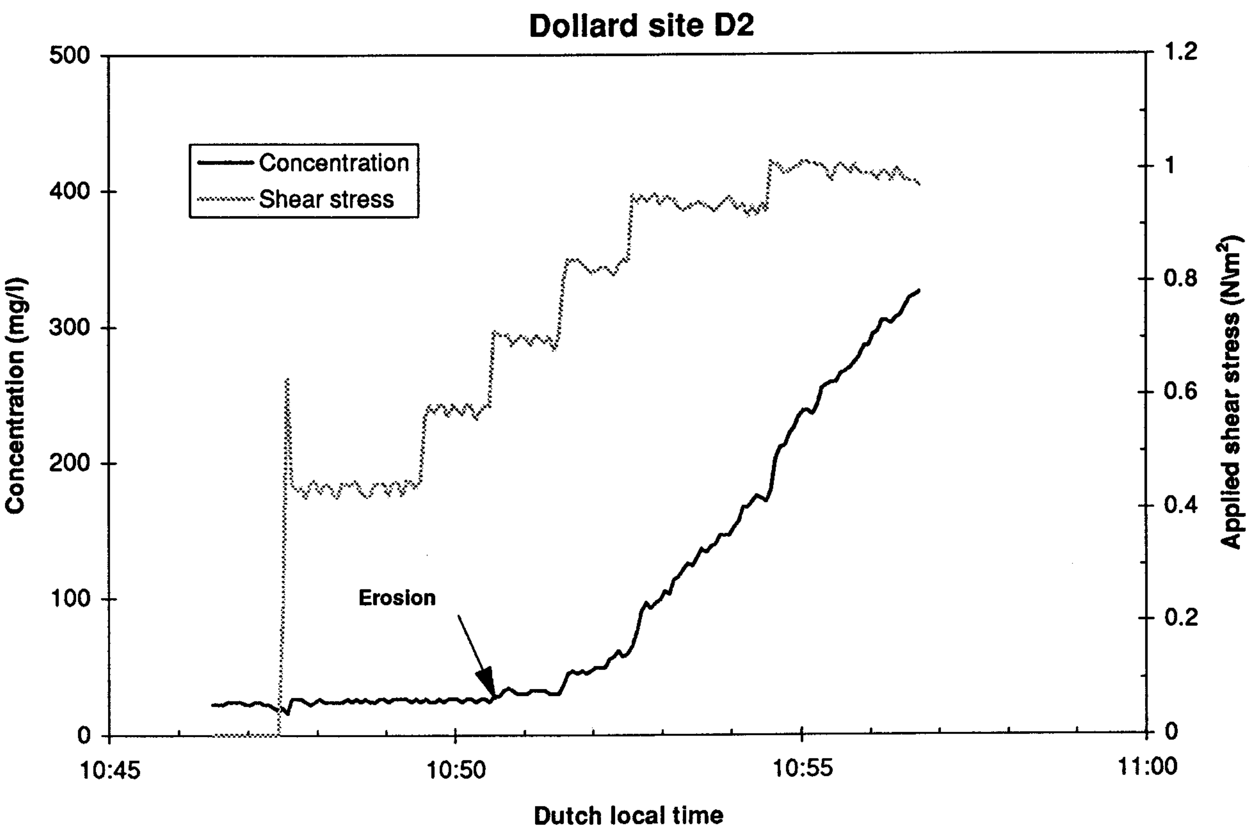
Site description:
texture: soft / medium
colour: medium / dark
covering: algal film / water
topography: worm holes
biologically activity: active
composition: mud / sand / homogeneous
other features: phytoplankton bloom in water

Surface sample: (from top 5mm) - D1
Bulk density: 1600kg/m^3
Sand content: 77.59%
Mud content: 22.41%
Organic carbon (by ignition): 3.69%

Shear vane: 33mm vane
Observer: N.Feates
Measurements (kPa): 2.0
2.4
2.7
3.3
2.4
Average: 2.6

Photographs: Film 1
Time: 08:55 Number: 15
Time: 08:55 Number: 16
Time: 10:10 Number: 17

Critical erosion shear stress: **1.02N/m^2**



Site: **Dollard Estuary, Netherlands**
Time: 10:15
Date: 21/05/96
Operator: H.J.Mitchener

Data file: (downloaded from Squirrel data logger)
Path: ..\sediments\helen\intrmud\dollard\d2.l01

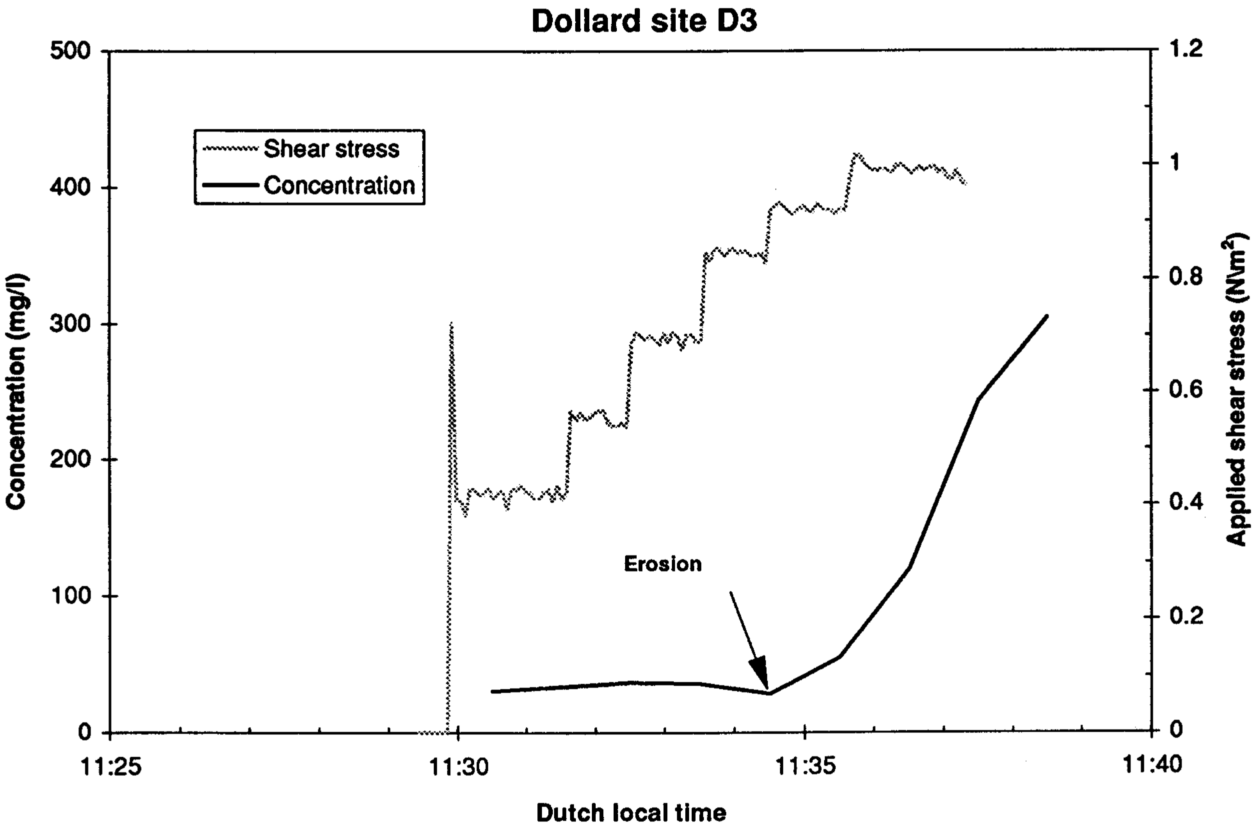
Site description:
texture: medium
colour: medium
covering: algal film / water
topography: worm holes
biologically activity: active
composition: mud / sand / homogeneous
other features: diatoms on surface

Surface sample: (from top 5mm) - D2
Bulk density: 1720kg/m³
Sand content: 84.15%
Mud content: 15.85%
Organic carbon (by ignition): 3.98%

Shear vane: 33mm vane
Observer: N.Feates
Measurements (kPa): 3.5
3.2
3.6
4.3
4.0
Average: 3.7

Photographs: Film 1
Time: 10:10 Number: 18
Time: 10:10 Number: 19
Time: 11:07 Number: 21

Critical erosion shear stress: 0.71N/m²



Site: **Dollard Estuary, Netherlands**
Time: 11:15
Date: 21/05/96
Operator: H.J.Mitchener

Data file: (downloaded from Squirrel data logger)
Path: ..\sediments\helen\intrmud\dollard\d3.l01

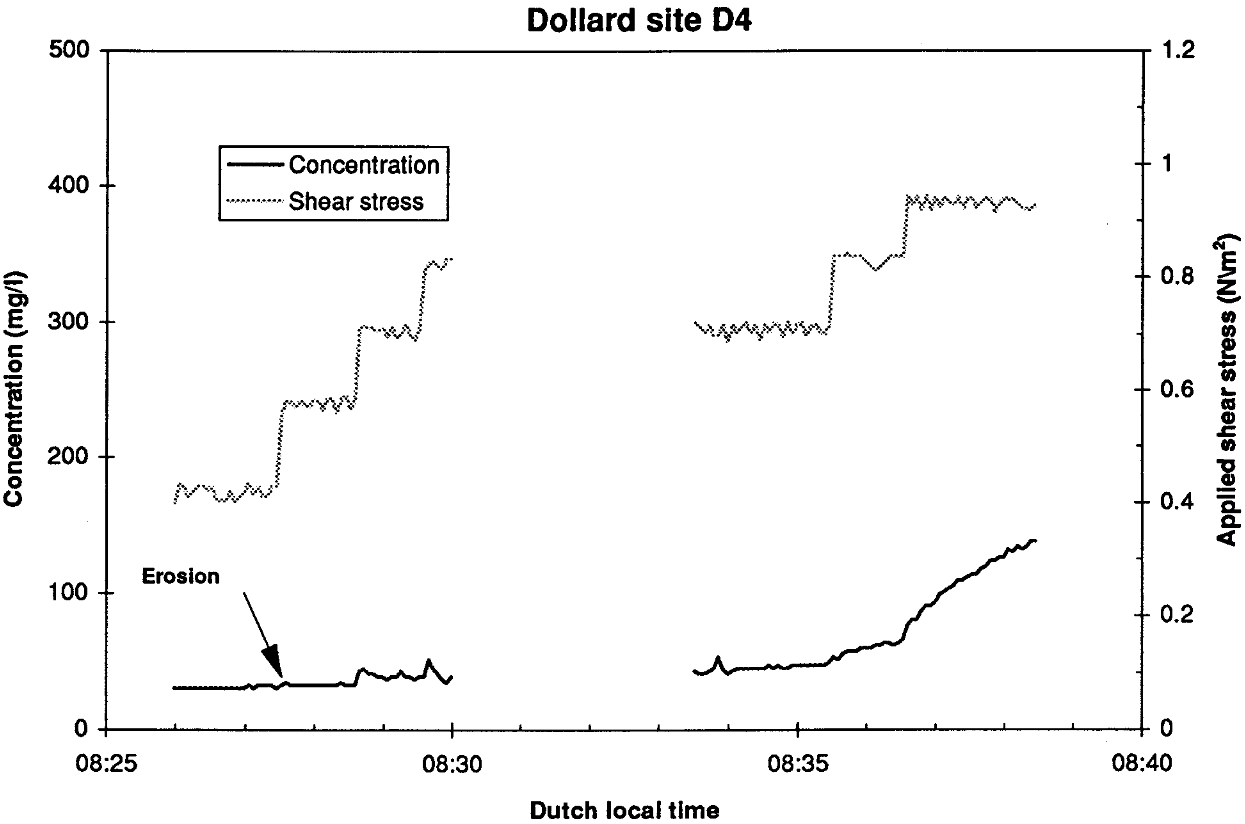
Site description:
texture: soft / medium
colour: medium
covering: algal film
topography: worm holes / on flat
biologically activity: active
composition: mud / sand / homogeneous
other features: ~

Surface sample: (from top 5mm) - D3
Bulk density: 1680kg/m^3
Sand content: 84.04%
Mud content: 15.96%
Organic carbon (by ignition): 2.55%

Shear vane: 33mm vane
Observer: N.Feates
Measurements (kPa): 3.8
3.4
3.9
3.8
3.8
Average: 3.7

Photographs: Film 1
Time: 11:07 Number: 22
Time: 11:07 Number: 23
Time: 11:40 Number: 24

Critical erosion shear stress: **0.92N/m^2**



Site: **Dollard Estuary, Netherlands**
Time: 08:02
Date: 22/05/96
Operator: H.J.Mitchener

Data file: (downloaded from Squirrel data logger)
Path: ..\sediments\helen\intrmud\dollard\d4.l01

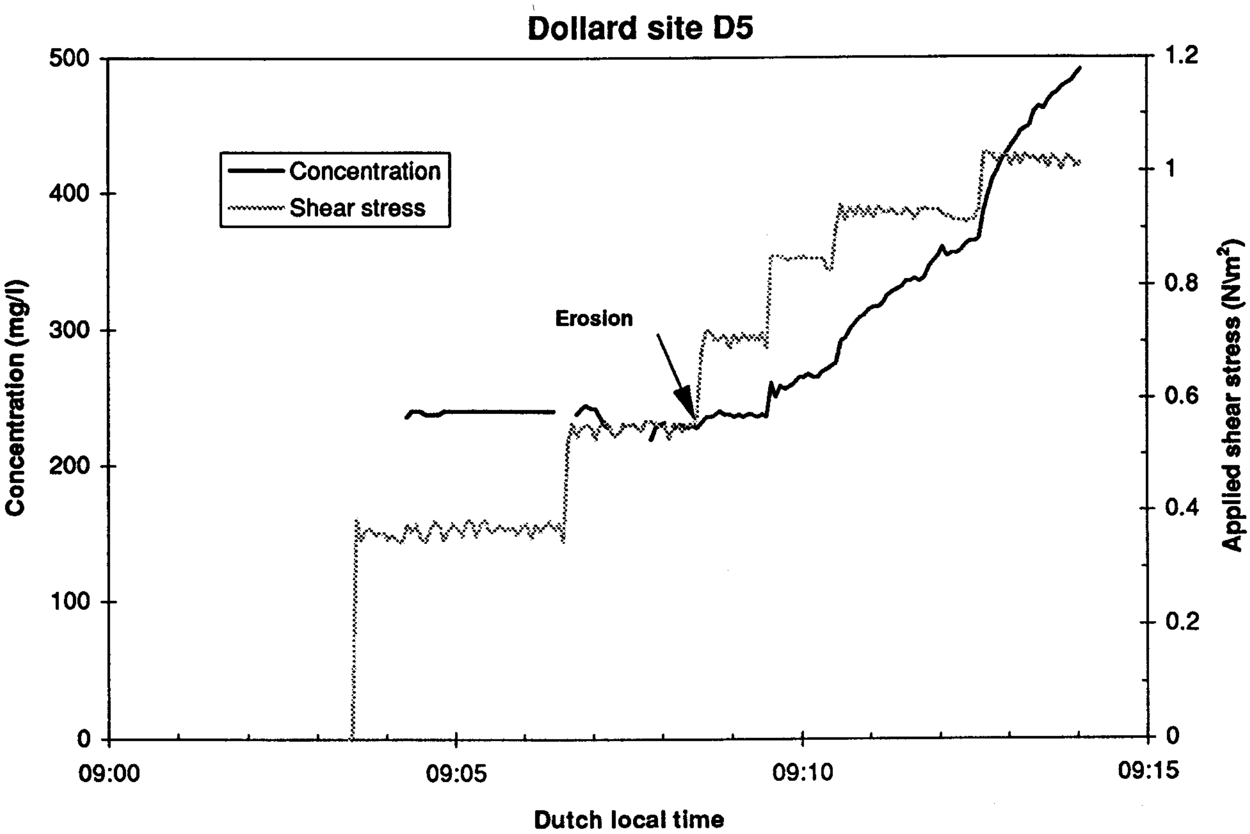
Site description:
texture: medium
colour: medium
covering: algal film
topography: pitted / worm holes / on flat
biologically activity: active
composition: mud / sand / homogeneous
other features: worms / algae / chloridium

Surface sample: (from top 5mm) - D4
Bulk density: $1700 kg/m^3$
Sand content: 84.84%
Mud content: 15.16%
Organic carbon (by ignition): 3.91%

Shear vane: 33mm vane
Observer: N.Feates
Measurements (kPa): 3.2
2.8
2.8
3.7
3.6
Average: 3.2

Photographs: Film 2
Time: 07:57 Number: 2
Time: 07:57 Number: 3
Time: ~ Number: ~

Critical erosion shear stress: **$0.58 N/m^2$**



Site:	**Dollard Estuary, Netherlands**	**Data file:**	(downloaded from Squirrel data logger)
Time:	09:03	Path:	..\sediments\helen\intrmud\dollard\d5.l01
Date:	22/05/96		
Operator:	H.J.Mitchener		

Site description:

- texture: soft / medium
- colour: pale / medium
- covering: algal film / algal strands
- topography: pitted / on flat
- biologically activity: active
- composition: mud / sand / homogeneous
- other features: ~

Surface sample: (from top 5mm) - D5

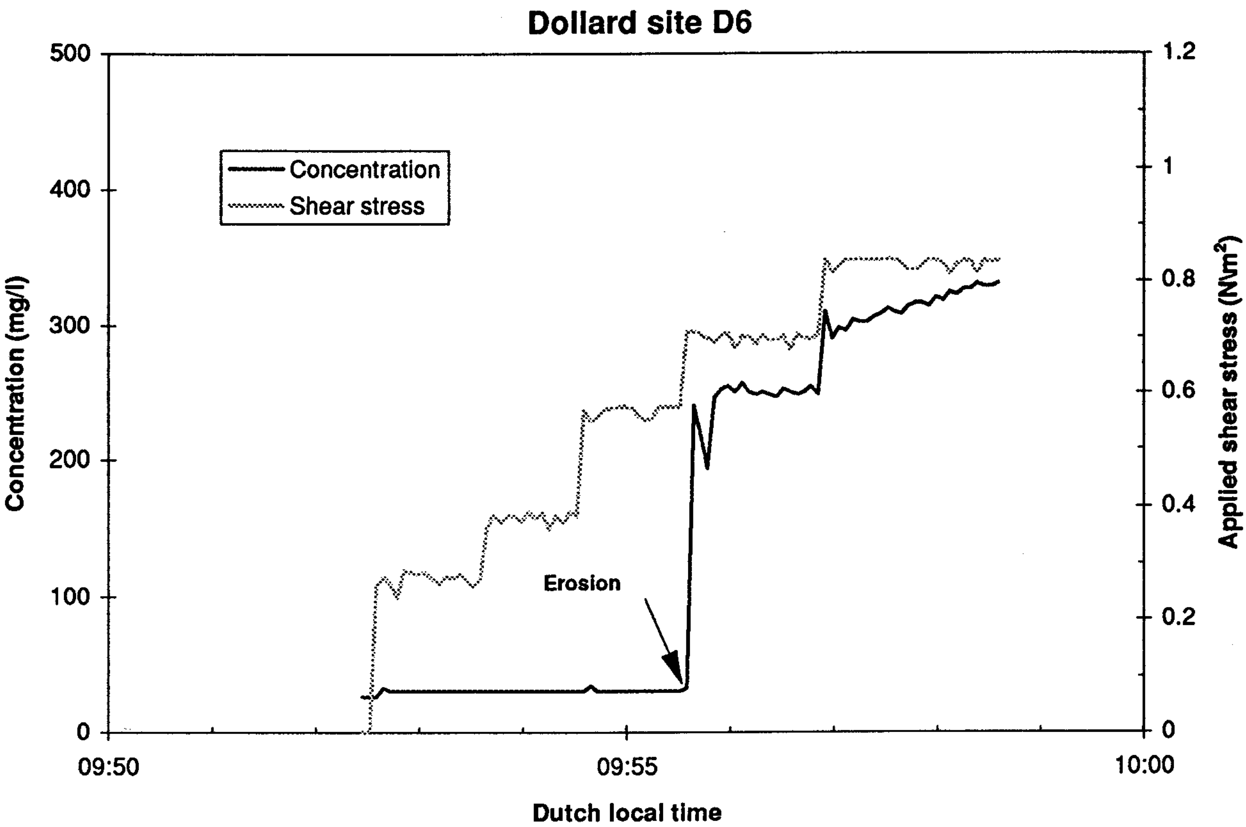
- Bulk density: 1660kg/m^3
- Sand content: 81.89%
- Mud content: 18.11%
- Organic carbon (by ignition): 4.29%

Shear vane:	33mm vane
Observer:	N.Feates
Measurements (kPa):	3.0
	2.2
	3.0
	2.6
	2.7
Average:	2.7

Photographs: Film 2

Time: 08:50	Number: 12
Time: 08:50	Number: 13
Time: 09:20	Number: 14

Critical erosion shear stress: **0.72N/m^2**



Site: **Dollard Estuary, Netherlands**
Time: 09:45
Date: 22/05/96
Operator: H.J.Mitchener

Data file: (downloaded from Squirrel data logger)
Path: ..\sediments\helen\intrmud\dollard\d6.l01

Site description:

texture: soft / medium
colour: medium
covering: algal film / algal strands
topography: pitted / worm holes / on flat
biologically activity: active
composition: mud / sand / homogeneous
other features: biology

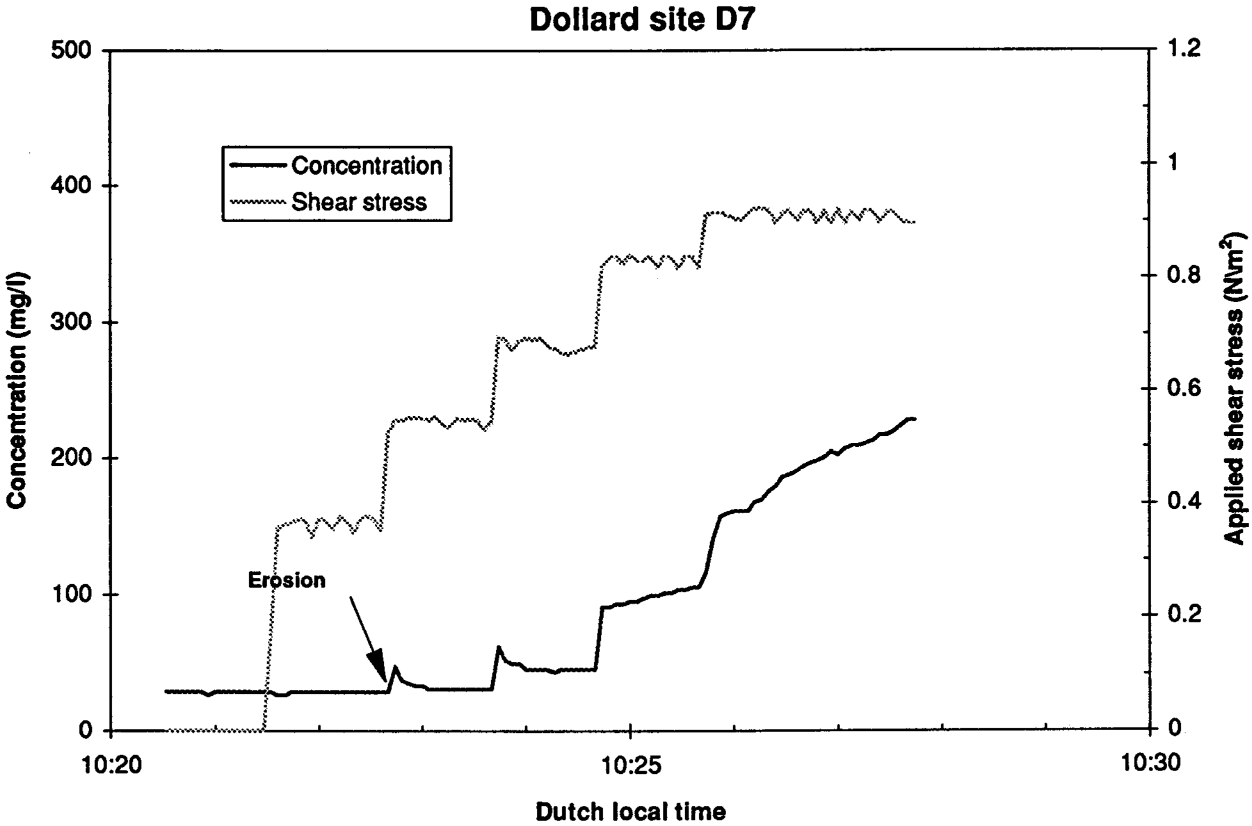
Surface sample: (from top 5mm) - D6

Bulk density: 1770kg/m³
Sand content: 88.46%
Mud content: 11.54%
Organic carbon (by ignition): 3.06%

Shear vane: 33mm vane
Observer: N.Feates
Measurements (kPa): 2.0
2.0
2.0
2.4
2.8
Average: 2.2

Photographs: Film 2
Time: 09:39 Number: 16
Time: 09:39 Number: 17
Time: ~ Number: 18

Critical erosion shear stress: **0.71N/m²**



Site:	**Dollard Estuary, Netherlands**	**Data file:**	(downloaded from Squirrel data logger)
Time:	10:09	Path:	..\sediments\helen\intrmud\dollard\d7.l01
Date:	22/05/96		
Operator:	H.J.Mitchener		

Site description:

- texture: soft
- colour: pale / medium
- covering: algal film / water
- topography: pitted / worm holes / on flat
- biologically activity: active
- composition: mud / sand / homogeneous
- other features: ~

Surface sample: (from top 5mm) - D7

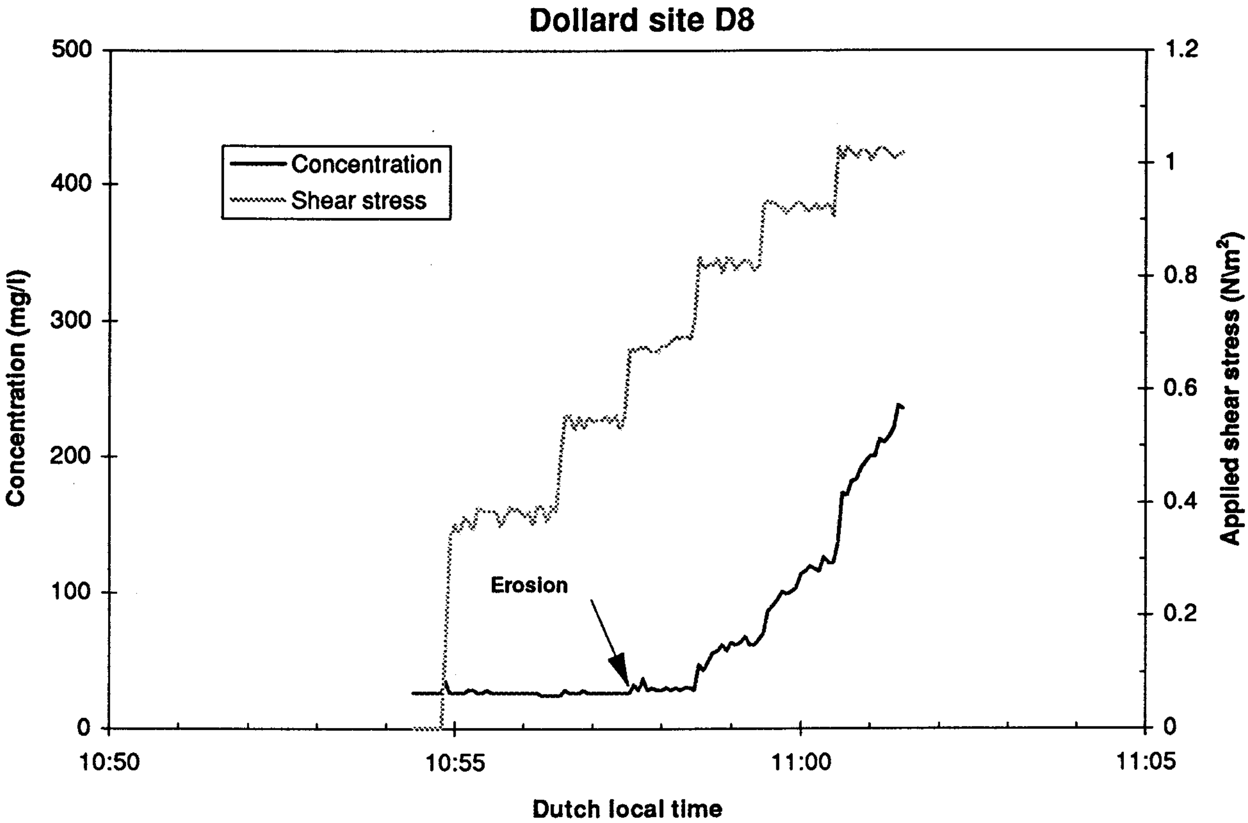
- Bulk density: 1780kg/m^3
- Sand content: 87.95%
- Mud content: 12.05%
- Organic carbon (by ignition): 3.23%

Shear vane:	33mm vane
Observer:	N.Feates
Measurements (kPa):	1.9
	2.3
	2.1
	2.0
	2.2
Average:	2.1

Photographs: Film 2

Time: 10:06	Number: 20
Time: 10:06	Number: 21
Time: 10:34	Number: 22

Critical erosion shear stress: **0.55N/m^2**



Site:	**Dollard Estuary, Netherlands**	**Data file:**	(downloaded from Squirrel data logger)
Time:	10:45	Path:	..\sediments\helen\intrmud\dollard\d8.l01
Date:	22/05/96		
Operator:	H.J.Mitchener		

Site description:

texture: medium / hard
colour: medium
covering: algal film / algal strands
topography: pitted / worm holes / on flat
biologically activity: active
composition: mud / sand / homogeneous
other features: ~

Surface sample: (from top 5mm) - D8

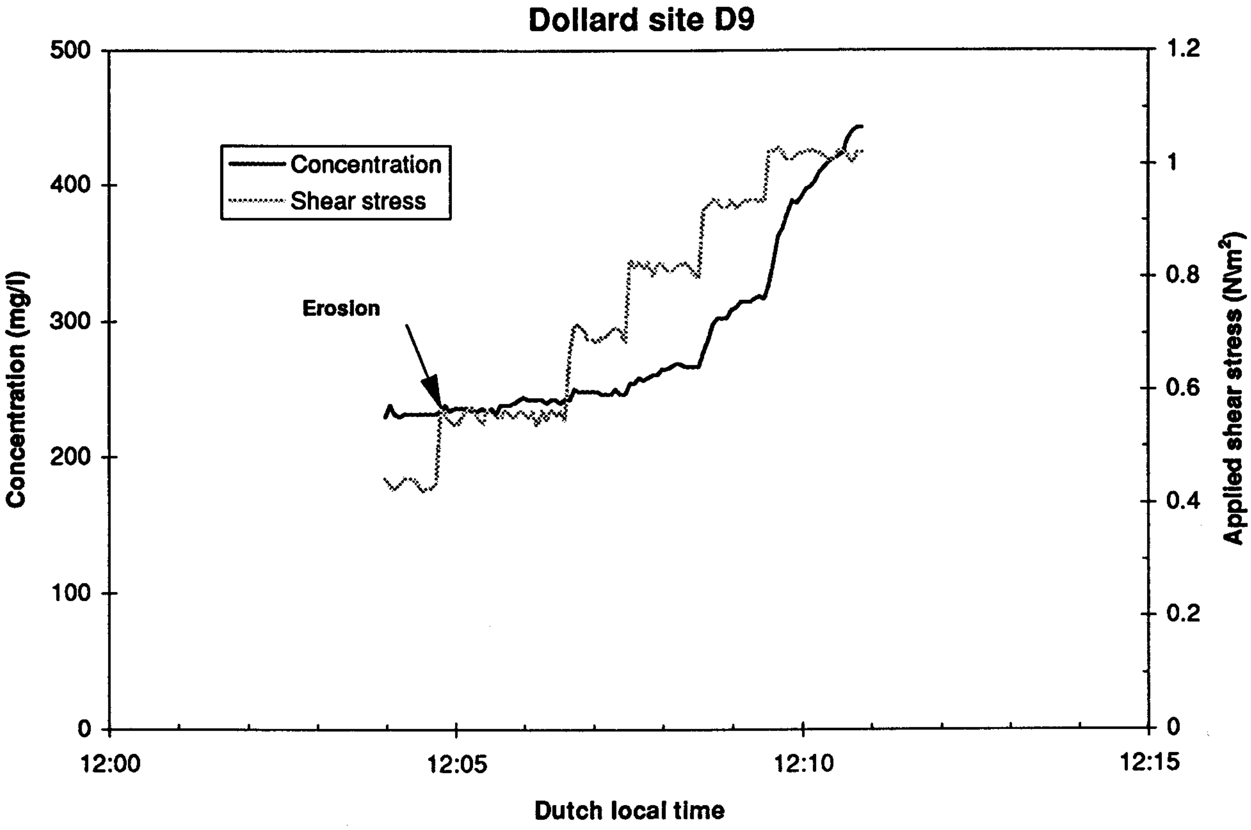
Bulk density: $1820 kg/m^3$
Sand content: 90.33%
Mud content: 9.67%
Organic carbon (by ignition): 1.84%

Shear vane:	33mm vane
Observer:	N.Feates
Measurements (kPa):	2.5
	4.0
	3.2
	3.2
	3.0
Average:	3.2

Photographs: Film 2

Time: 10:39	Number: 23
Time: 10:39	Number: 24
Time: ~	Number: 25

Critical erosion shear stress: **$0.67 N/m^2$**



Site: **Dollard Estuary, Netherlands**
Time: 11:50
Date: 22/05/96
Operator: H.J.Mitchener

Data file: (downloaded from Squirrel data logger)
Path: ..\sediments\helen\intrmud\dollard\d9.l01

Site description:
texture: medium / hard
colour: medium
covering: algal film
topography: pitted / worm holes / on flat
biologically activity: active
composition: mud / sand / homogeneous
other features: ~

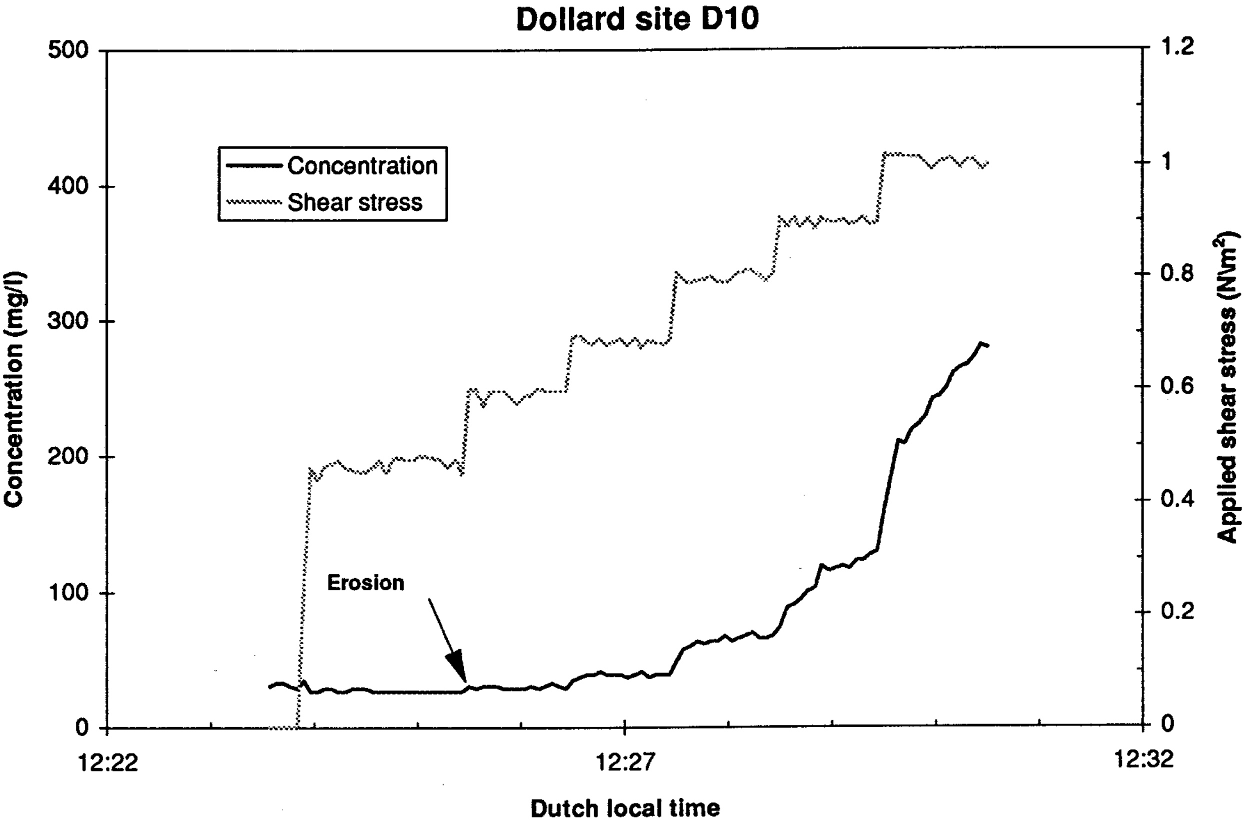
Surface sample: (from top 5mm) - D9
Bulk density: 1780g/cm^3
Sand content: 83.24%
Mud content: 16.76%
Organic carbon (by ignition): 3.98%

Shear vane: 33mm vane
Observer: N.Feates
Measurements (kPa): 4.3
4.0
3.7
4.0
4.0
Average: 4.0

Photographs: Film 2
Time: 11:45 Number: 26
Time: 11:45 Number: 27
Time: 12:13 Number: 28

Critical erosion shear stress: **0.56N/m^2**

Dollard site D10



Site: **Dollard Estuary, Netherlands**
Time: 12:18
Date: 22/05/96
Operator: H.J.Mitchener

Data file: (downloaded from Squirrel data logger)
Path: ..\sediments\helen\intrmud\dollard\d10.l01

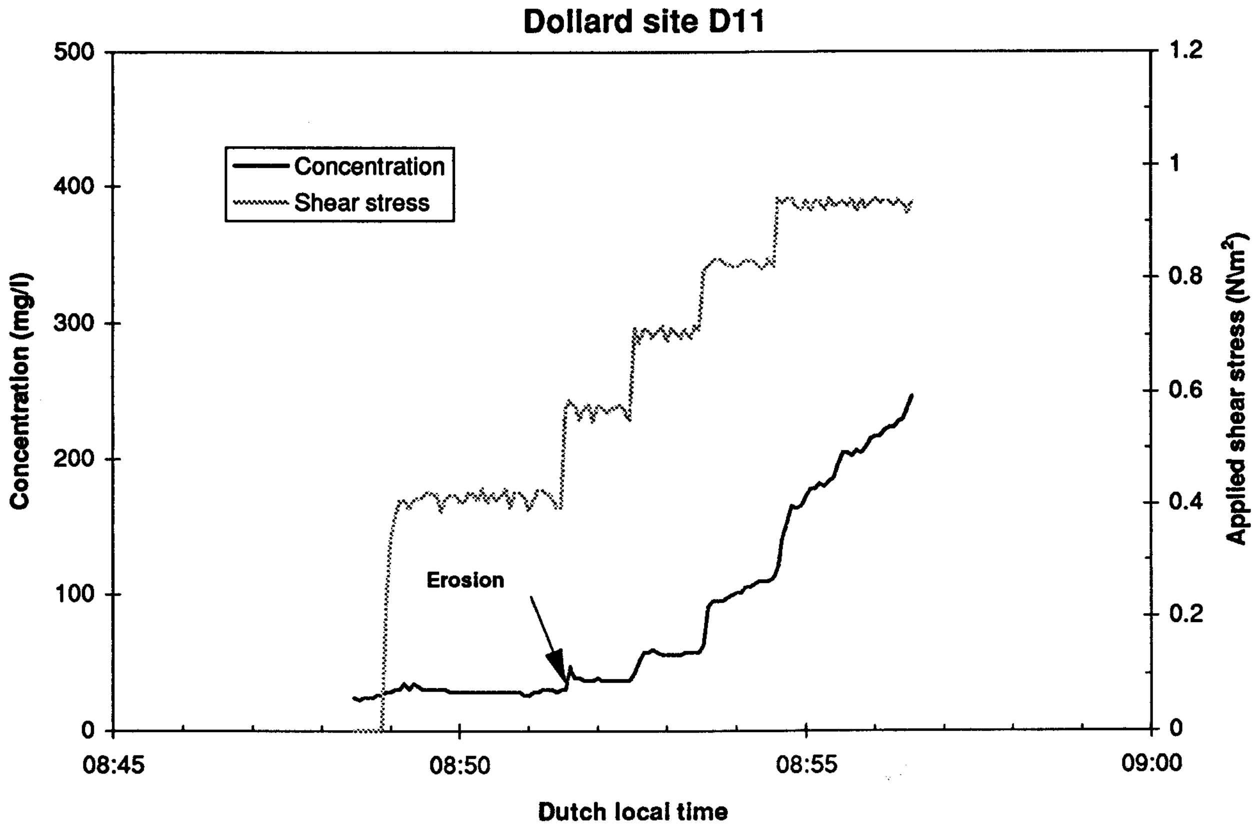
Site description:
texture: medium / hard
colour: medium
covering: algal film
topography: pitted / smooth
biologically activity: ~
composition: mud / sand
other features: ~

Surface sample: (from top 5mm) - D10
Bulk density: 1800kg/m^3
Sand content: 83.66%
Mud content: 16.34%
Organic carbon (by ignition): 3.79%

Shear vane: 33mm vane
Observer: N.Feates
Measurements (kPa): 3.3
3.6
3.9
3.3
4.0
Average: 3.6

Photographs: Film 2
Time: 12:18 Number: 29
Time: 12:18 Number: 30
Time: ~ Number: 31

Critical erosion shear stress: **0.60N/m^2**



Site:	**Dollard Estuary, Netherlands**	**Data file:**	(downloaded from Squirrel data logger)
Time:	08:37	Path:	..\sediments\helen\intrmud\dollard\d11.l01
Date:	23/05/96		
Operator:	H.J.Mitchener		

Site description:

texture: medium
colour: medium
covering: algal film
topography: ~
biologically activity: active
composition: mud / sand / homogeneous
other features: ~

Surface sample: (from top 5mm) - D11

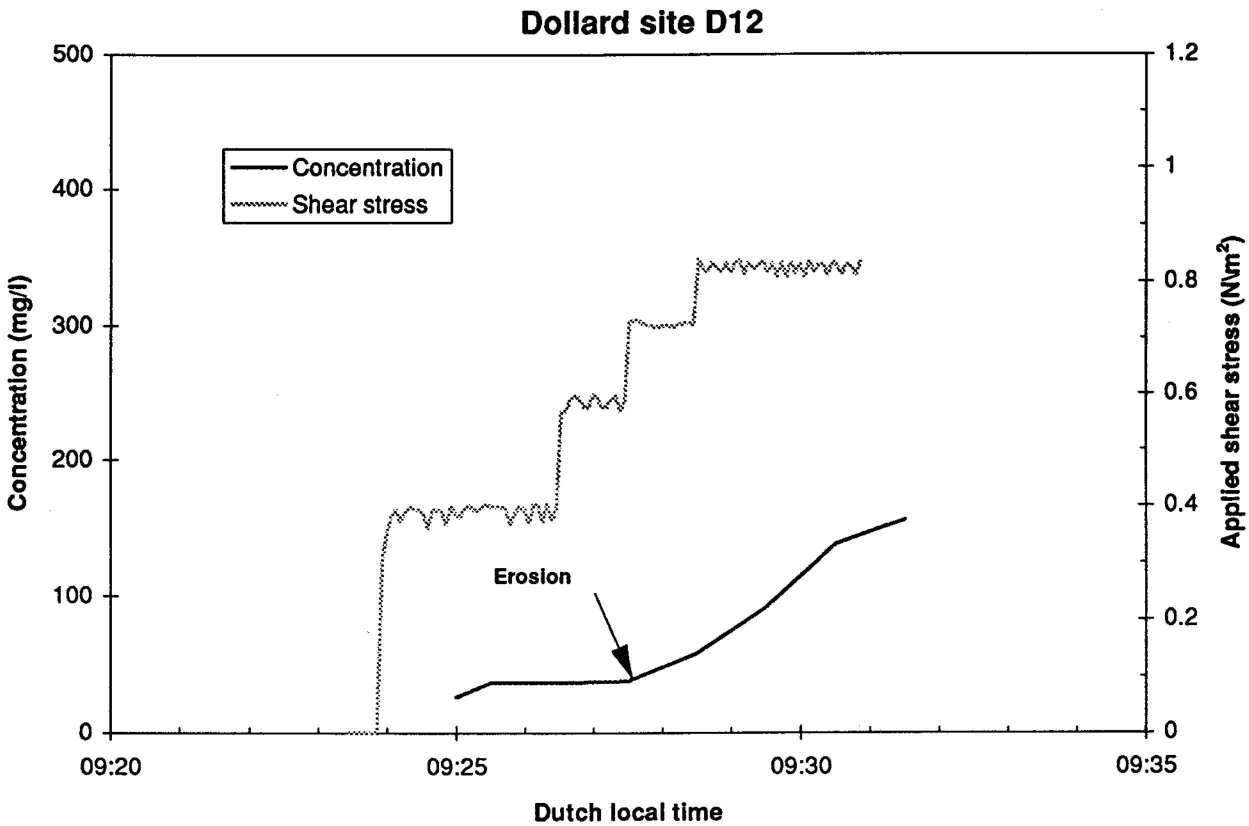
Bulk density: $1820kg/m^3$
Sand content: 85.28%
Mud content: 14.72%
Organic carbon (by ignition): 3.14%

Shear vane:	33mm vane
Observer:	N.Feates
Measurements (kPa):	2.8
	3.2
	3.3
	2.8
	2.5
Average:	2.9

Photographs: Film 3

Time: 08:34	Number: 1
Time: 08:34	Number: 2
Time: ~	Number: 10

Critical erosion shear stress: $0.57N/m^2$



Site:	**Dollard Estuary, Netherlands**	**Data file:**	(downloaded from Squirrel data logger)
Time:	09:09	Path:	..\sediments\helen\intrmud\dollard\d12.l01
Date:	23/05/96		
Operator:	H.J.Mitchener		

Site description:

- texture: soft / medium
- colour: medium
- covering: algal film
- topography: smooth / on flat
- biologically activity: active
- composition: mud / sand / homogeneous
- other features: ~

Surface sample: (from top 5mm) - D12

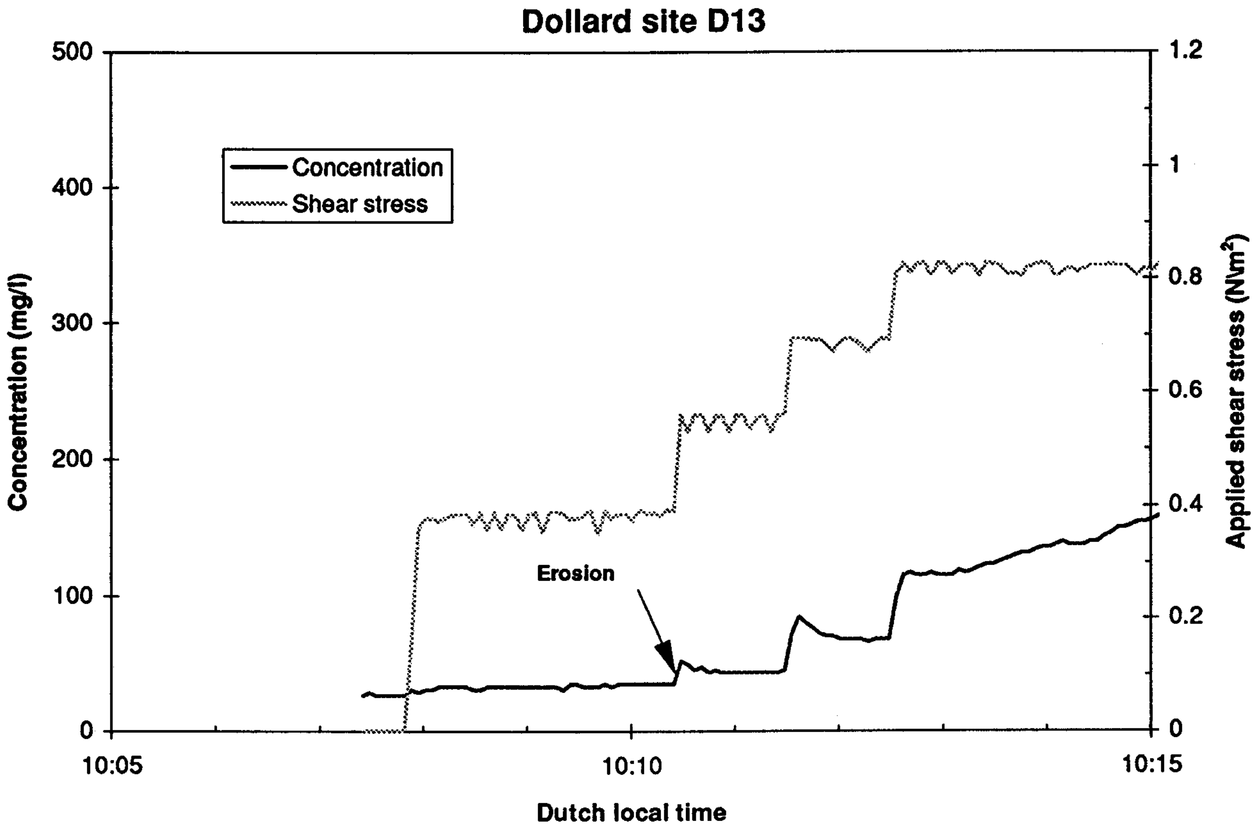
- Bulk density: 2670kg/m^3
- Sand content: 84.05%
- Mud content: 15.95%
- Organic carbon (by ignition): 2.76%

Shear vane: 33mm vane
Observer: N.Feates
Measurements (kPa): 2.9
2.0
2.5
2.9
2.4
Average: 2.5

Photographs: Film 3

Time	Number
09:08	11
09:08	12
09:30	17

Critical erosion shear stress: 0.73N/m^2



Site: Dollard Estuary, Netherlands
Time: 10:04
Date: 23/05/96
Operator: H.J.Mitchener

Data file: (downloaded from Squirrel data logger)
Path: ..\sediments\helen\intrmud\dollard\d13.l01

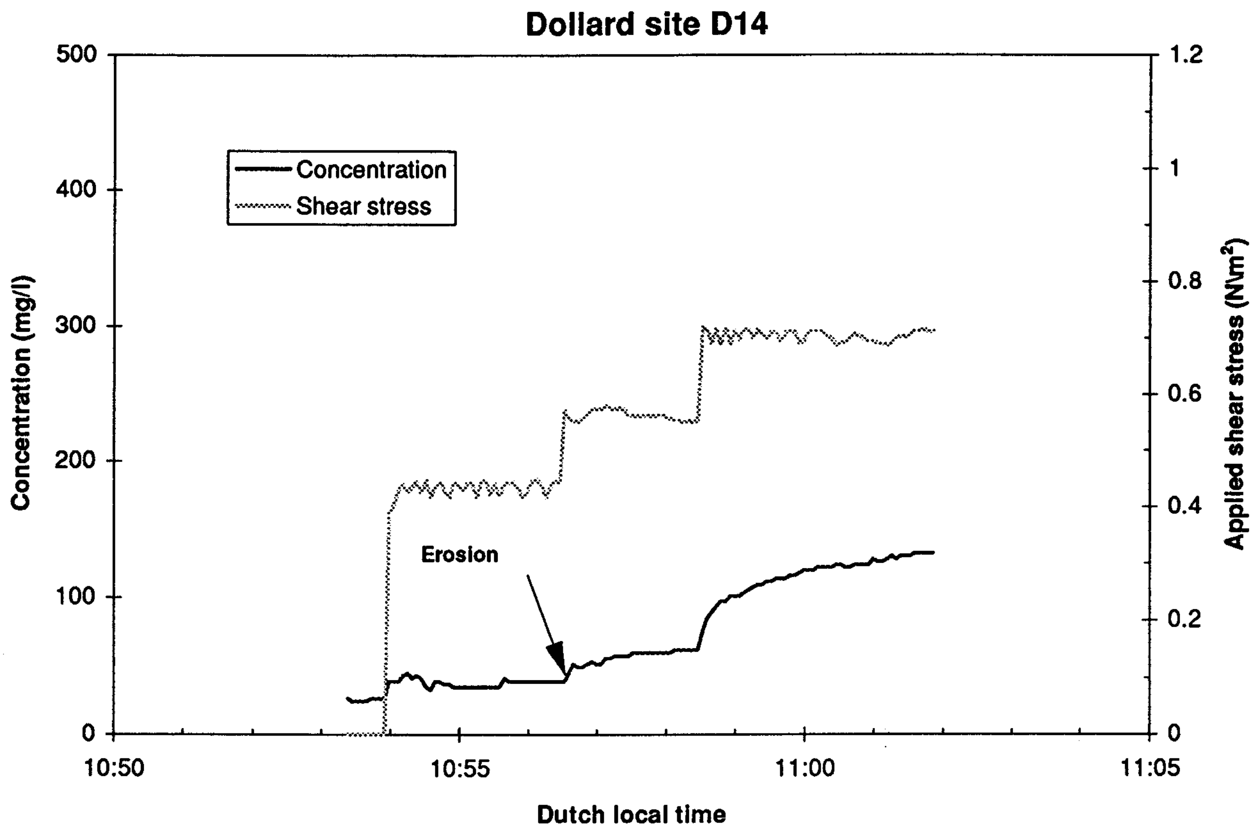
Site description:
texture: soft / medium
colour: medium
covering: algal film / water
topography: pitted / on flat
biologically activity: active
composition: mud / sand / homogeneous
other features: high sand content

Surface sample: (from top 5mm) - D13
Bulk density: 1770kg/m^3
Sand content: 87.00%
Mud content: 13.00%
Organic carbon (by ignition): 3.69%

Shear vane: 33mm vane
Observer: N.Feates
Measurements (kPa): 2.5
2.6
2.7
3.0
2.8
Average: 2.7

Photographs: Film 3
Time: 09:46 Number: 18
Time: 09:46 Number: 19
Time: ~ Number: 30

Critical erosion shear stress: 0.56N/m^2



Site: **Dollard Estuary, Netherlands**
Time: 10:45
Date: 23/05/96
Operator: H.J.Mitchener

Data file: (downloaded from Squirrel data logger)
Path: ..\sediments\helen\intrmud\dollard\d14.I01

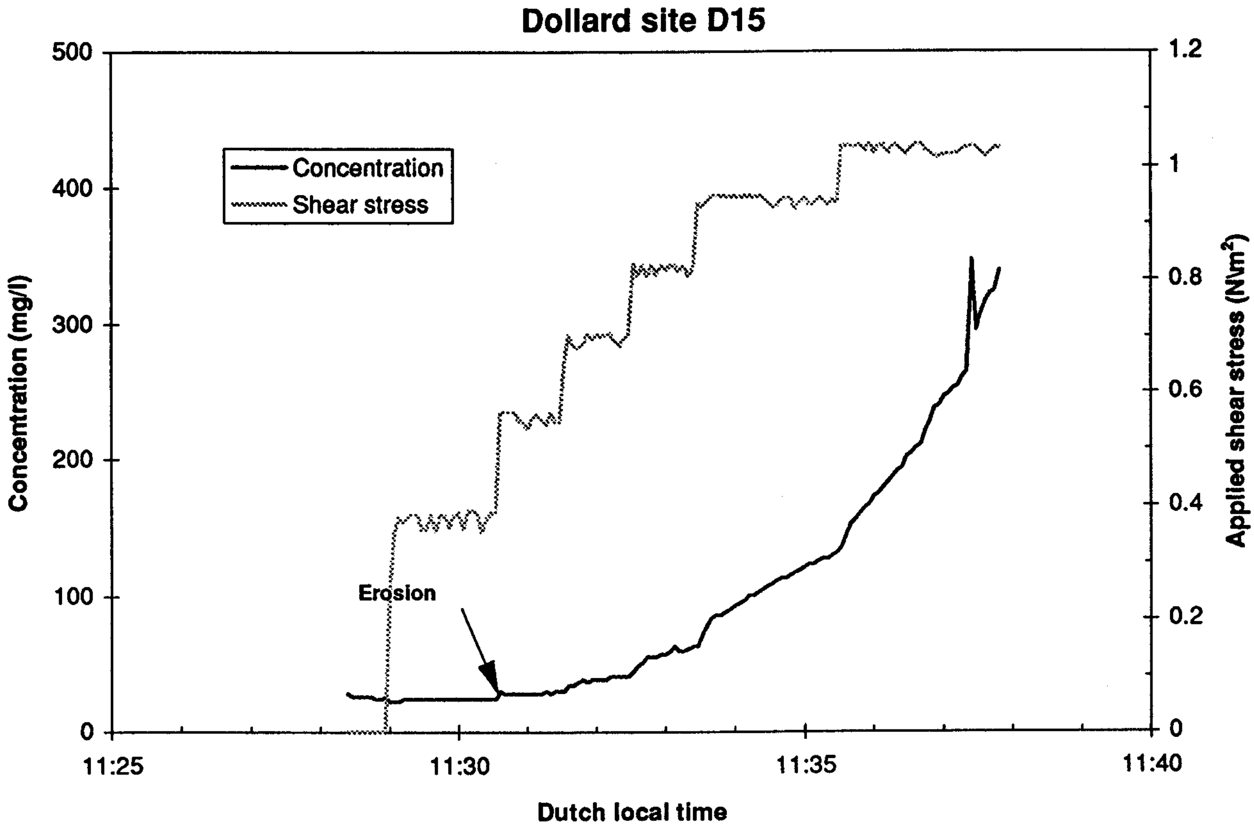
Site description:
texture: soft / medium
colour: medium
covering: algal film / water
topography: smooth
biologically activity: algal mat
composition: mud / sand / homogeneous
other features: high sand content

Surface sample: (from top 5mm) - D14
Bulk density: 1460kg/m^3
Sand content: 75.39%
Mud content: 24.61%
Organic carbon (by ignition): 4.75%

Shear vane: 33mm vane
Observer: N.Feates
Measurements (kPa): 2.1
2.2
2.9
2.7
2.8
Average: 2.5

Photographs: Film 3
Time: 10:24 Number: 25
Time: 10:24 Number: 26
Time: ~ Number: 27

Critical erosion shear stress: **0.57N/m^2**



Site:	**Dollard Estuary, Netherlands**	**Data file:**	(downloaded from Squirrel data logger)
Time:	11:25	Path:	..\sediments\helen\intrmud\dollard\d15.l01
Date:	23/05/96		
Operator:	H.J.Mitchener		

Site description:

texture: soft / medium
colour: medium
covering: algal film
topography: pitted / on flat
biologically activity: active
composition: mud / sand / homogeneous
other features: ~

Surface sample: (from top 5mm) - D15

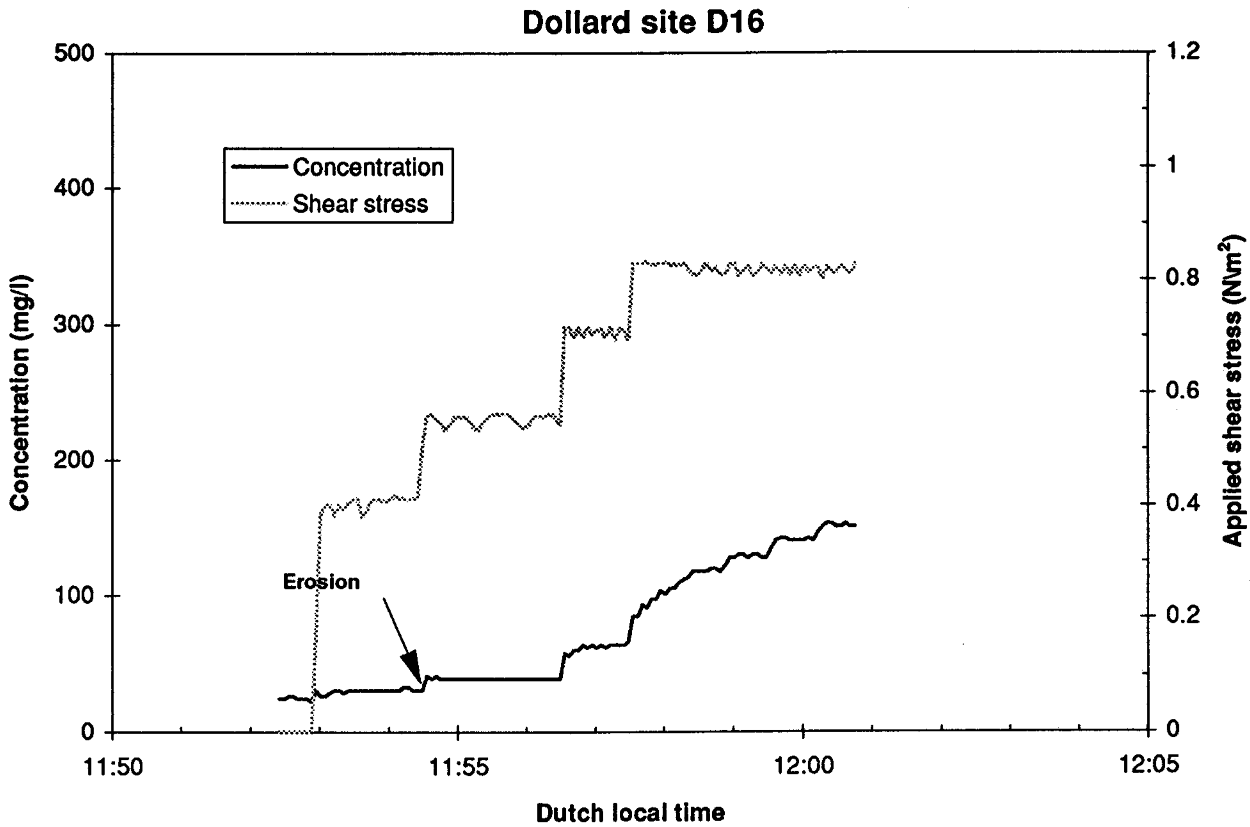
Bulk density: 1650kg/m^3
Sand content: 77.10%
Mud content: 22.90%
Organic carbon (by ignition): 3.59%

Shear vane:	33mm vane
Observer:	N.Feates
Measurements (kPa):	3.0
	4.4
	4.0
	4.0
	5.0
Average:	4.1

Photographs: Film 3

Time: 11:21	Number: 28
Time: 11:21	Number: 29
Time: ~	Number: 30

Critical erosion shear stress: **0.56N/m^2**



Site: **Dollard Estuary, Netherlands**
Time: 11:48
Date: 23/05/96
Operator: H.J.Mitchener

Data file: (downloaded from Squirrel data logger)
Path: ..\sediments\helen\intrmud\dollard\d16.l01

Site description:
texture: medium
colour: medium
covering: algal film
topography: pitted / smooth / on flat
biologically activity: active
composition: mud / sand / homogeneous
other features: algae

Surface sample: (from top 5mm) - D16
Bulk density: 1610kg/m^3
Sand content: 73.43%
Mud content: 26.57%
Organic carbon (by ignition): 4.29%

Shear vane: 33mm vane
Observer: N.Feates
Measurements (kPa): 3.7
3.6
3.5
3.4
3.4
Average: 3.5

Photographs: Film 3
Time: 11:46 Number: 31
Time: 11:46 Number: 32
Time: ~ Number: ~

Critical erosion shear stress: 0.56N/m^2

Appendix 3

HR Floc camera

Appendix 3 HR Floc camera

1. Instrumentation

A video image analysis technique has been developed at HR Wallingford as a result of an investigation into available instrumentation packages for determining the size and settling velocity of cohesive sediments (Dearnaley, 1991). Images are obtained using a standard CCD video camera with c-mount to Nikon mount adaptor, 200mm bellows and standard 135mm Nikon lens. The camera and light source are set up perpendicular to one another and focused on the settling column. Typically images of about 3mm by 4mm can be obtained with this apparatus. This gives an approximate resolution of 20 microns. The depth of focus in the image is estimated to be about 0.1mm and consequently very good images can be obtained even with a simple light source such as a standard spot lamp. The narrow depth of field is the means by which the calibration of the image is undertaken with varying bellows extension providing different magnifications.

The output from the camera is recorded on video tape. At the recording stage the video output is sent to a PC based image analysis system where real time filtering and image enhancement effects are available so that the quality of the images for subsequent processing can be appraised. The settings of the camera and light source can be modified if required.

2. Sampling

The water samples are obtained using the Valeport derivative of the Owen sampling Tube. The tube has an internal diameter of 50mm and is about 1m in length. The tube is lowered into the water and held at the required depth to allow alignment with the local current direction. A messenger weight is then dropped down the lowering line which triggers the closing mechanism and traps a sample of water. It is assumed that since the tube aligns itself with the flow, and because there is flow through the tube, the sample obtained in this manner is representative of the floc distribution in the immediate vicinity of the sampling position.

The sampling Valeport tube then remains in a horizontal position until it is placed vertically in a carefully positioned stand. After this only small adjustments of the bellows and light source should be necessary before filming begins. In order that the flocs are analysed as near to their in-situ state as possible filming is started as soon as possible after sample collection, which in practise is within one to two minutes of the sample being taken.

On completion of filming the tube contents were usually drained into 2 litre sample bottles for subsequent laboratory analysis for suspended sediment concentration and other parameters if required. The temperature of the sample is also recorded because the temperature during videoing may not be representative of that in the estuary at the time of sampling. This is because 20 minutes after sampling there may have been a small amount of heating of the sample by the spotlight used for illuminating the recorded image.

3. Analysis

The PC based system for determining the size, shape and position of flocs in suspension was obtained from Digithurst Ltd. The system, which was proved to work equally well from a video tape record as from a live image, was specially enhanced for HR Wallingford to include a routine which enabled two successive images to be grabbed from a video tape at a prescribed time interval.

The images are calibrated using the recorded bellows extension and the system is set up to capture two frames. Video frames comprise of two interlaced fields with a time interval of 0.02 seconds, and thus successive frames are separated by 0.04 seconds. The image processing card fitted to the PC has a minimum capture interval of 0.25 seconds. The required interval between two frames is typically selected between 0.3 and 0.5 seconds. The video tape is then played and selected images were grabbed.

Once a pair of images were grabbed some of the analysis is automatic. A grey scale level is chosen at which to form a cut off level, and this thresholding results in the monochrome image being converted into a binary image which could then be subjected to various analysis routines. Parameters such as detected object size, intensity, position (x-y co-ordinates in pixels) and orientation are automatically determined. From these records it is possible to produce a size distribution for selected objects in the image. Providing that an appropriate thresholding level had been chosen this can be assumed to be representative of the floc size distribution. By overlaying binary images from two successively grabbed frames with a known time interval it is possible to determine the relative movement between the two frames. It is thus possible to determine the size and settling velocities of individual flocs in selected pairs of images.

The process of capturing a water sample in a tube, raising it to the surface and then transporting it to, and righting it in the frame, is likely to induce significant turbulence and circulations within the column. As a result, in order to satisfactorily determine the gravitational settling velocity of the flocs it is necessary to make assumptions about the fluid motions through the section of the column that is in focus. The first assumption is to consider that the fluid motion is uniform across the image area. This is not always the case and can result in certain parts of recordings being unusable for settling velocity analysis. The second assumption is to assume that the fastest upward travelling floc, or slowest downward travelling floc, depending on the natural fluid motion in a pair of images, is actually moving at the same speed as the local flow. This speed is then used as a corrector to give a settling velocity and size distribution.

4. References

Dearnaley M.P. (1991). Flocculation and settling of cohesive sediments. HR Wallingford, Report No. SR 272, 1991.

Dearnaley, M.P.(1994). Direct measurements of settling velocity in the Owen Tube: A comparison with gravimetric analysis. Proceedings of 4th Nearshore and Estuarine Cohesive Sediment Transport Conference, INTERCOH '94, Wallingford, England.

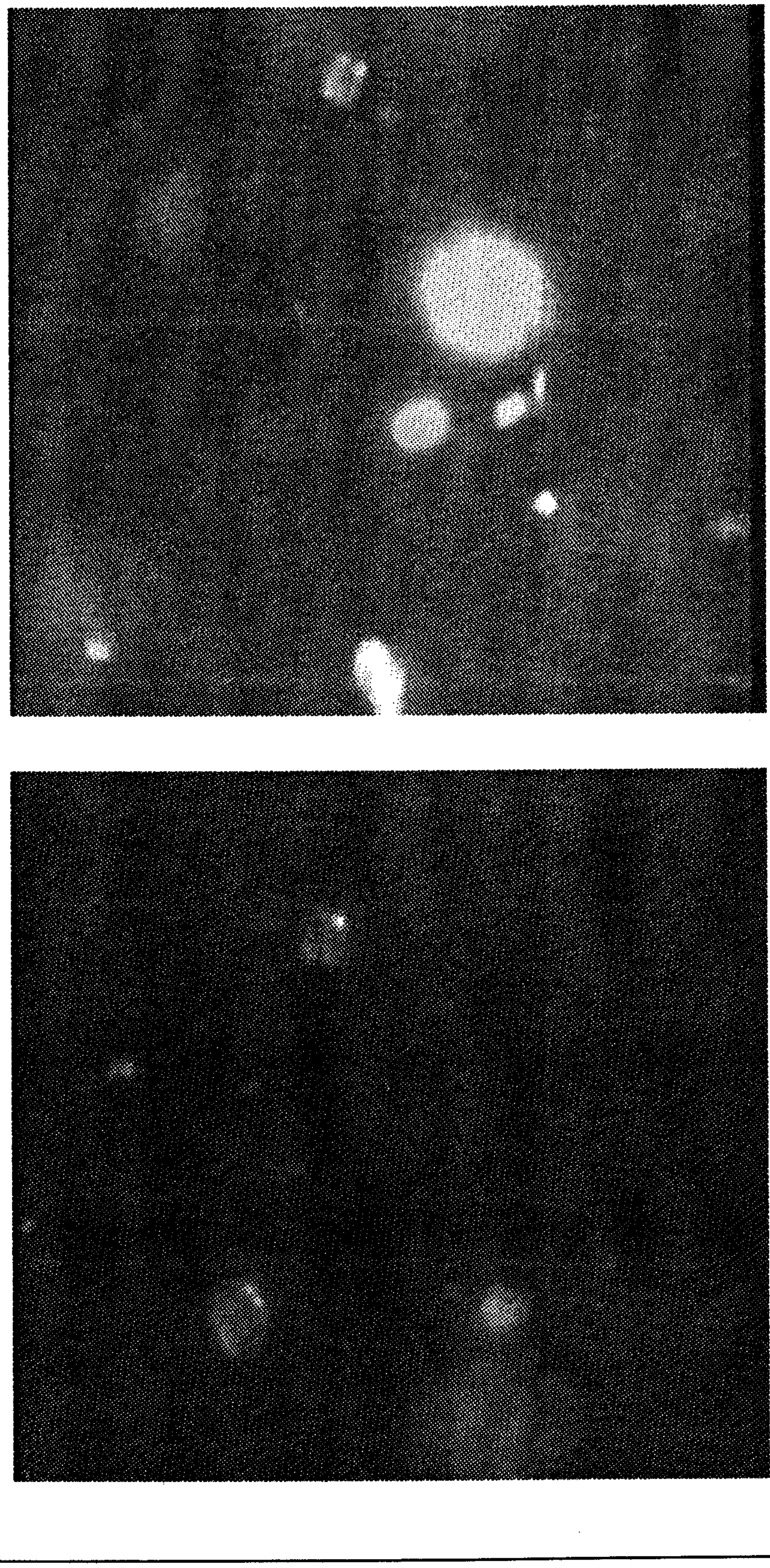


Figure A3.1 Images grabbed from video tape (area approx 4mm x 4mm)

Appendix 4

HR Floc Camera detailed results

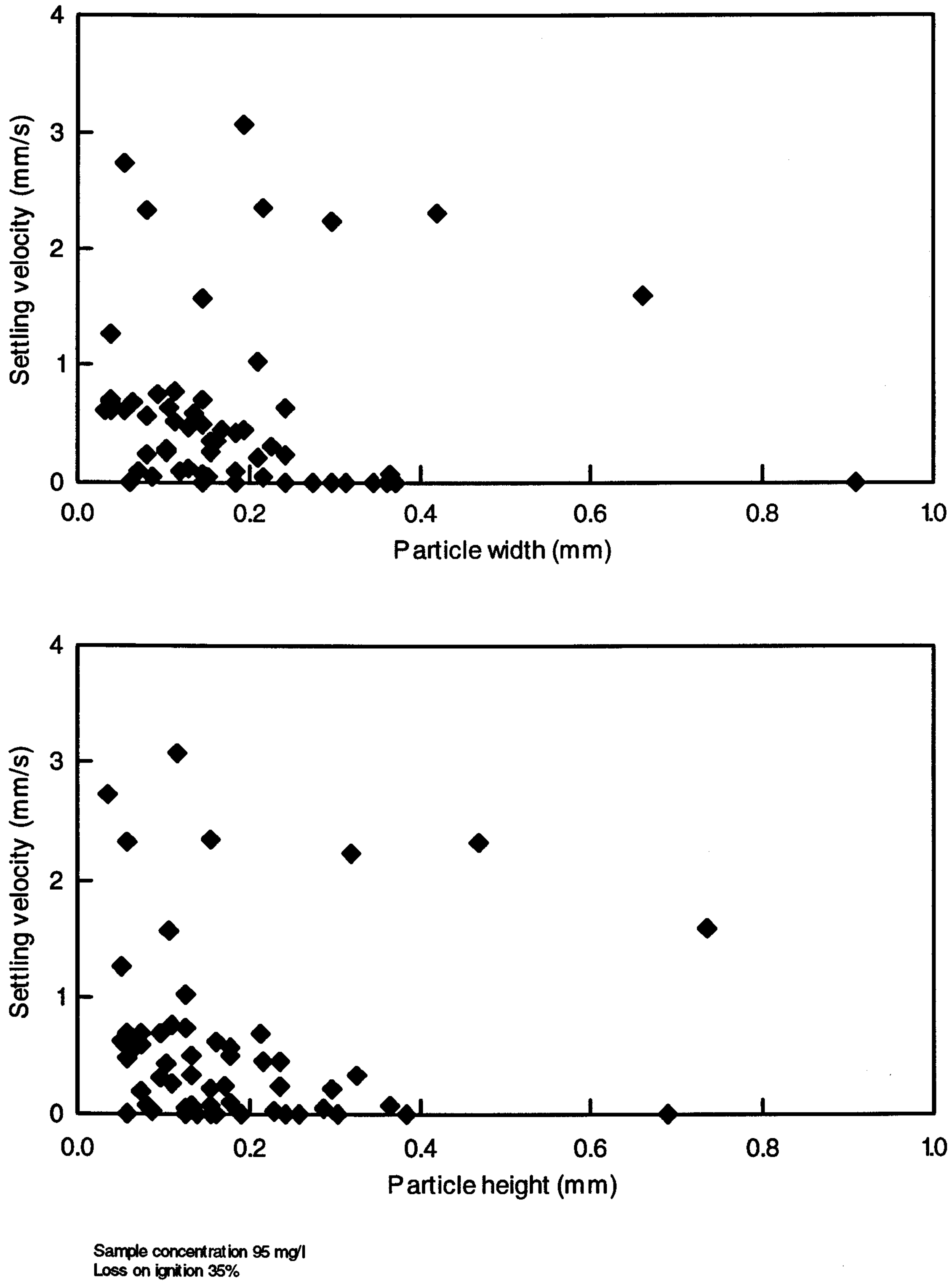
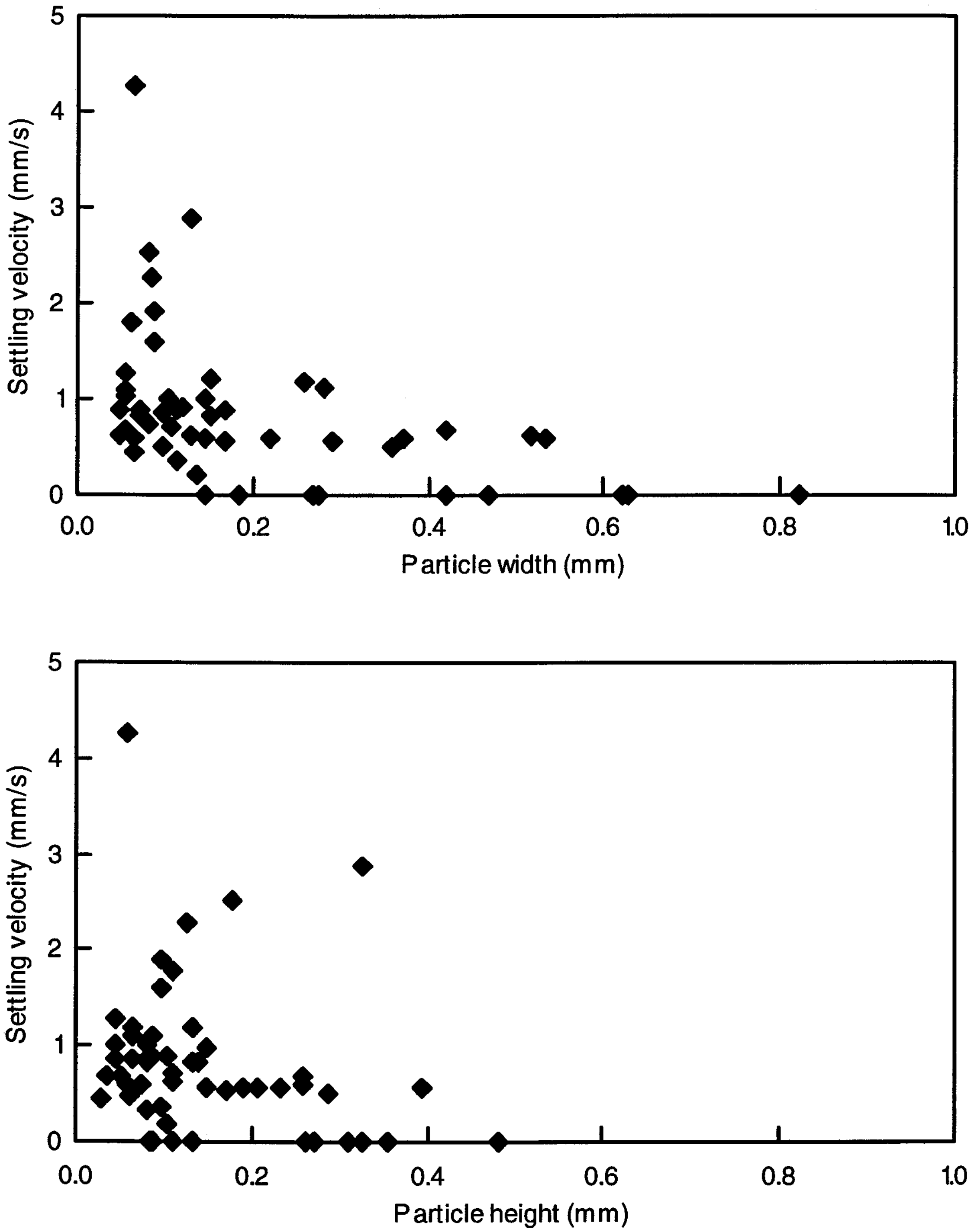


Figure A4.1 Variation of settling velocity with particle size - Tube 1



Sample concentration 14 mg/l
Loss on ignition 22%

Figure A4.2 Variation of settling velocity with particle size - Tube 2

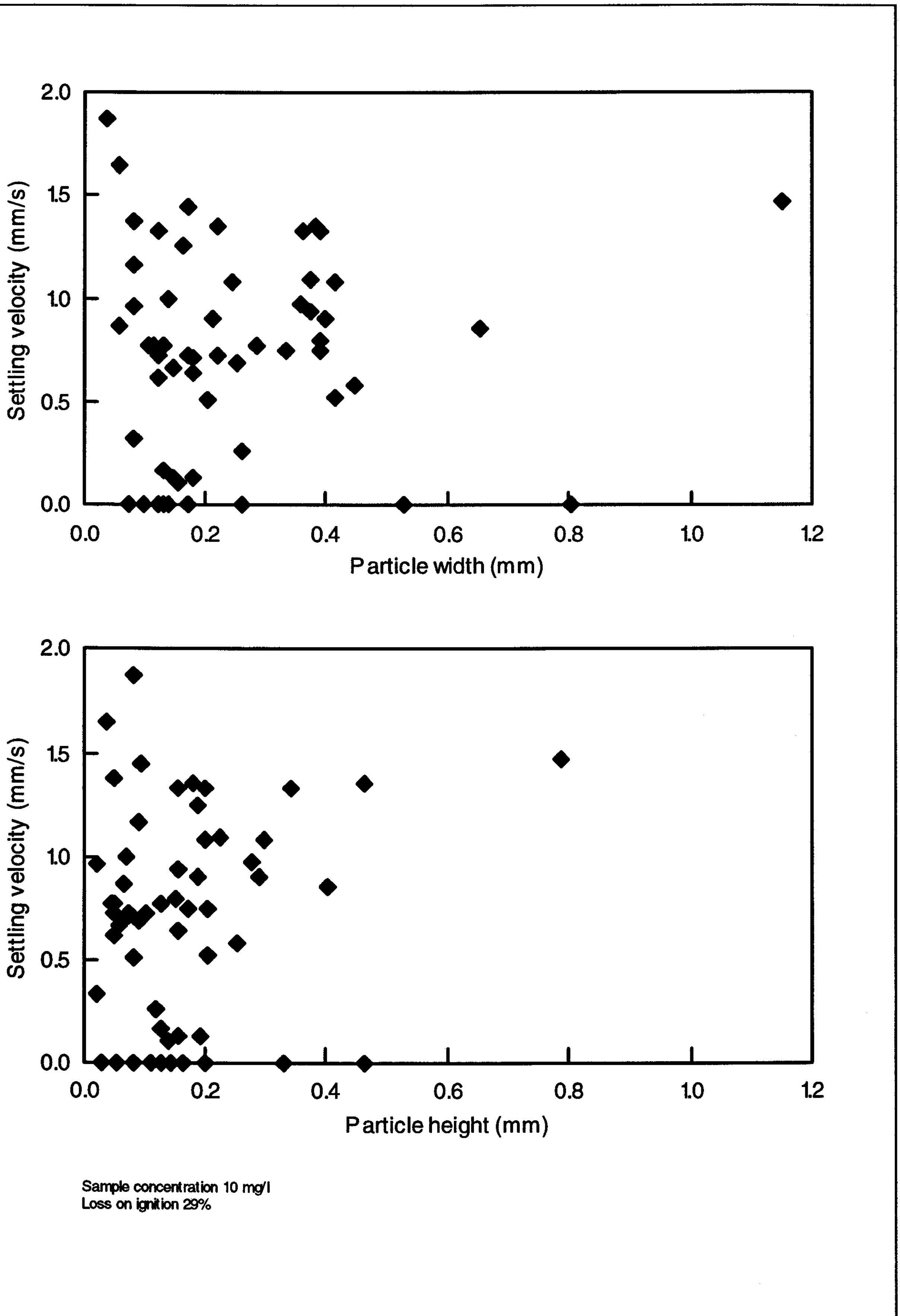


Figure A4.3 Variation of settling velocity with particle size - Tube 7

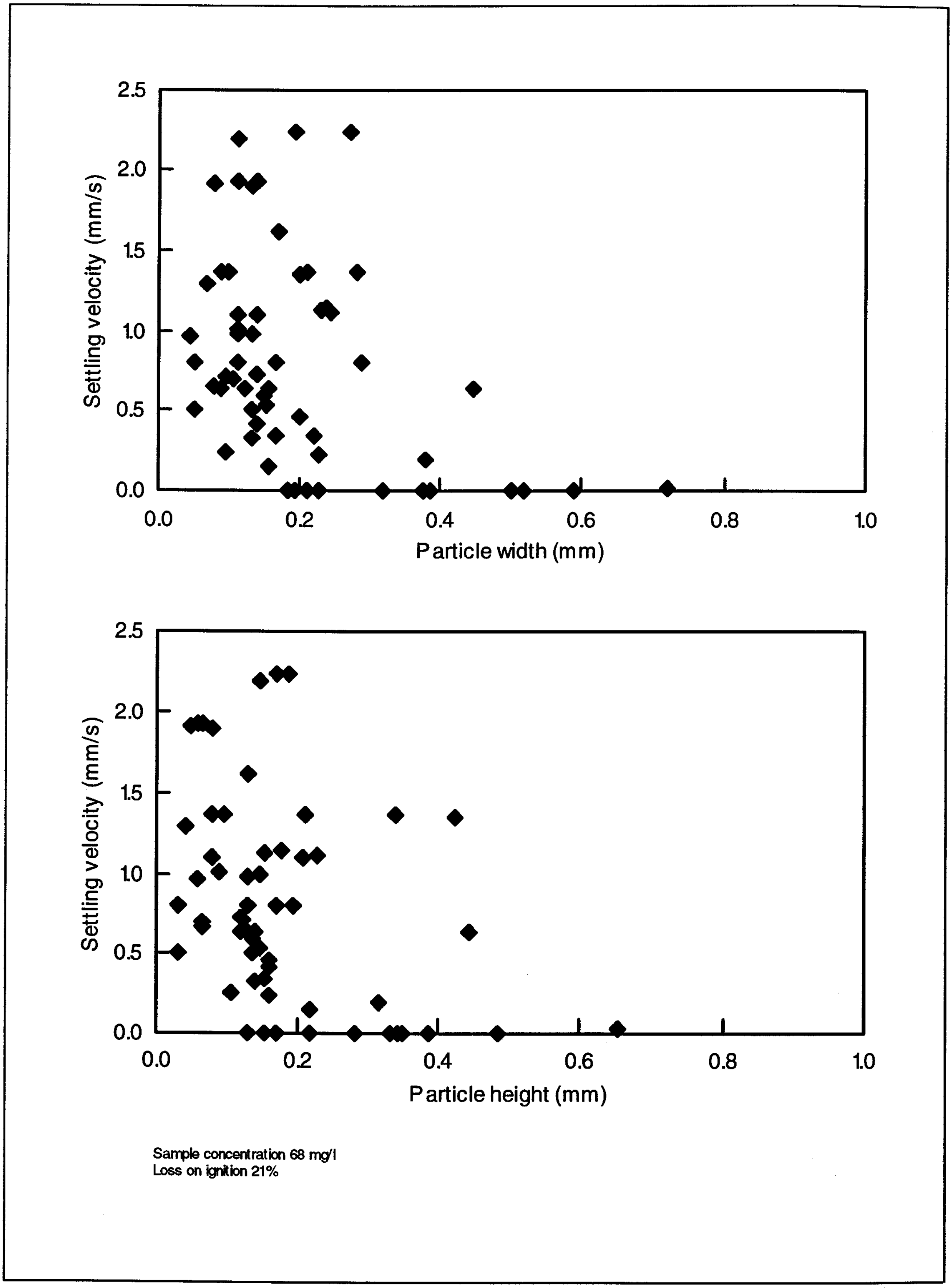


Figure A4.4 Variation of settling velocity with particle size - Tube 8

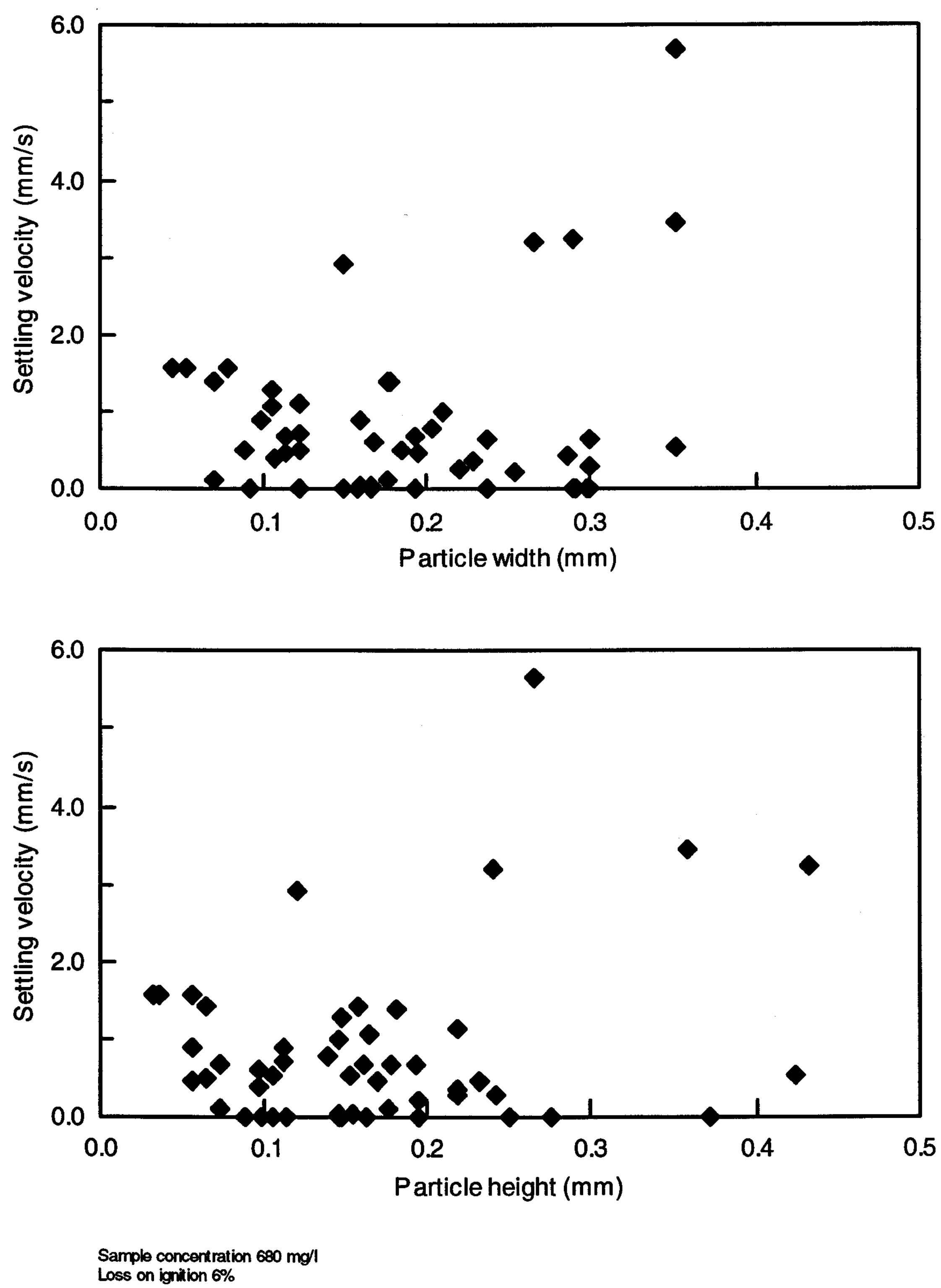


Figure A4.5 Variation of settling velocity with particle size - Tube 9

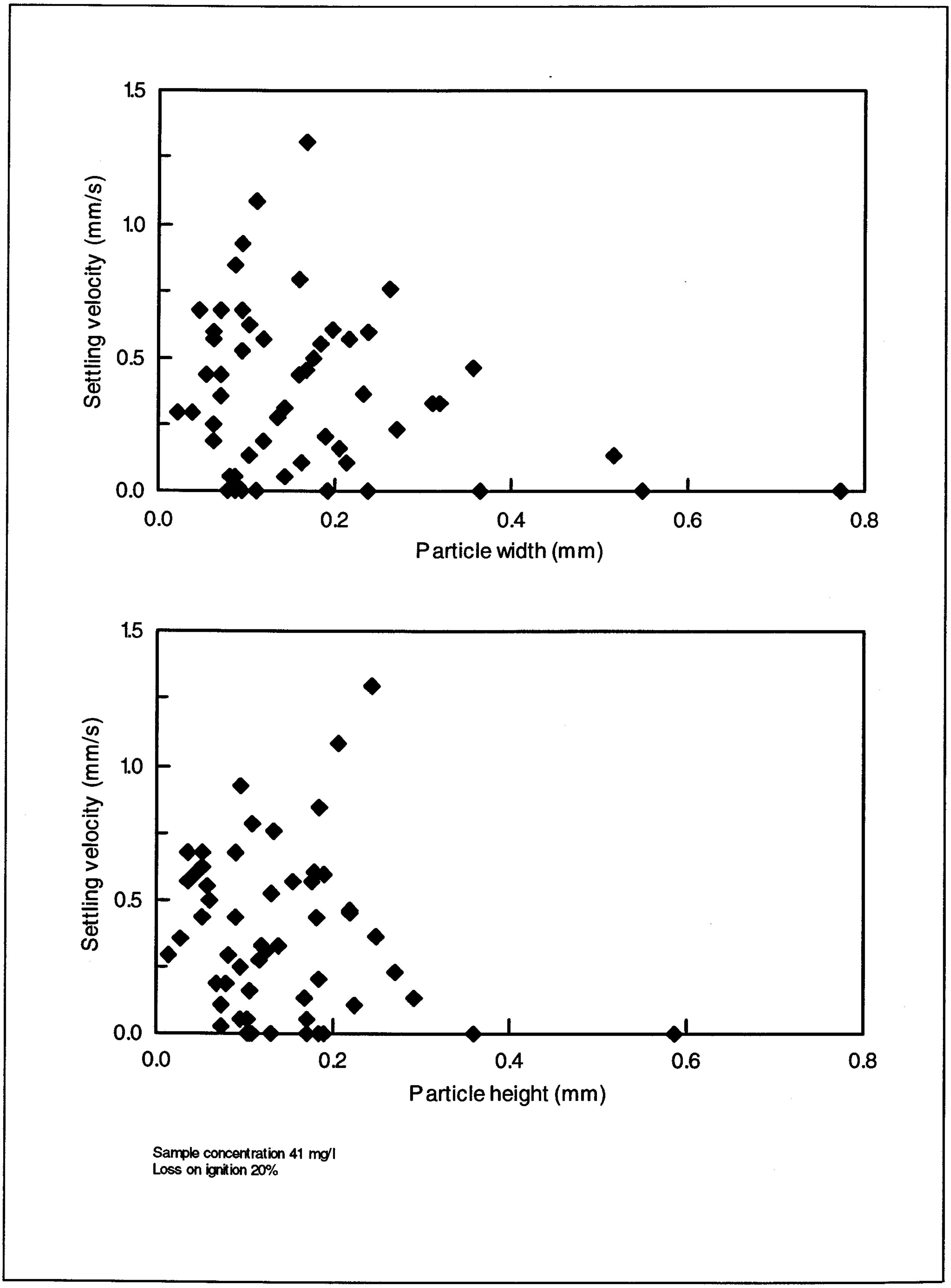
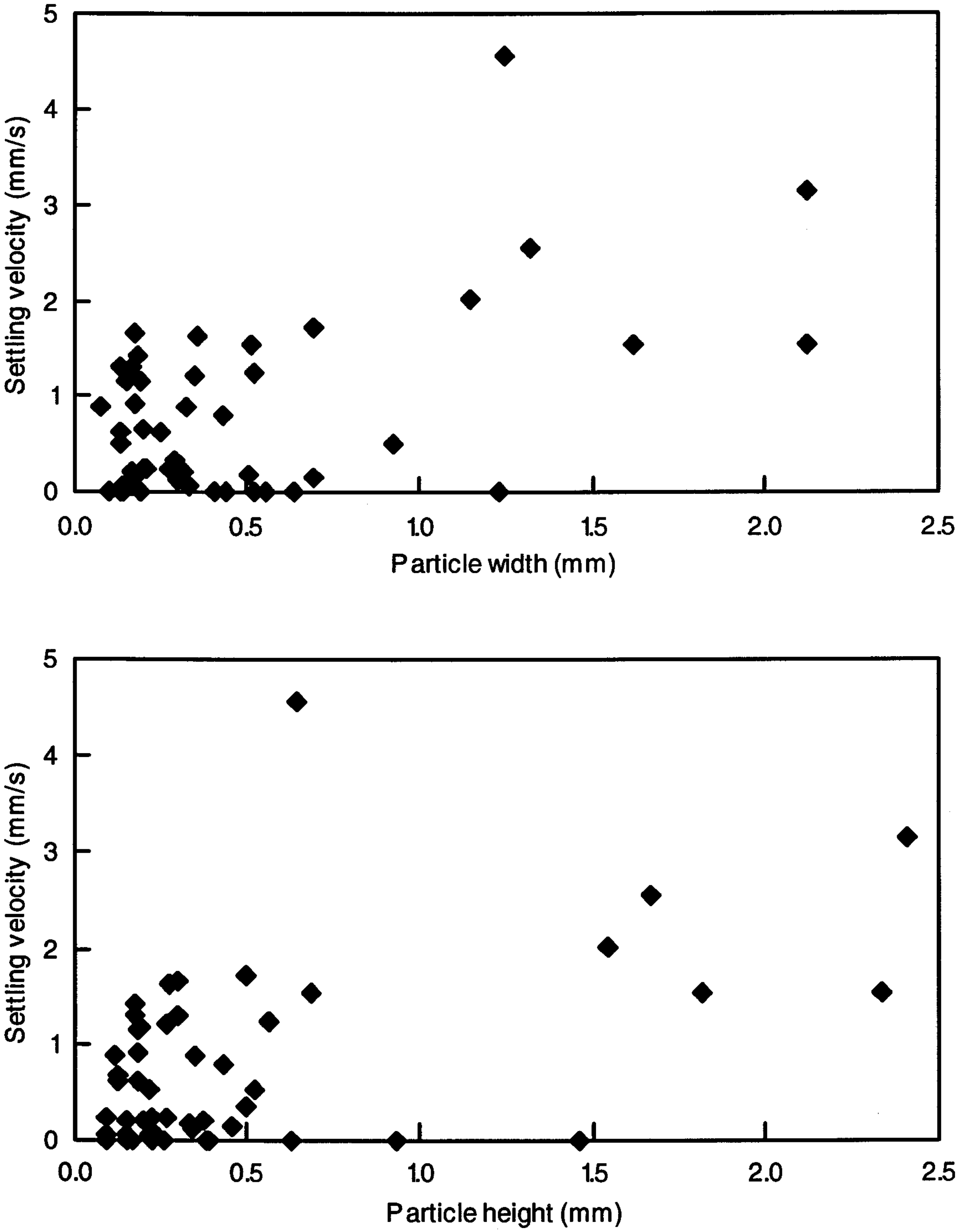
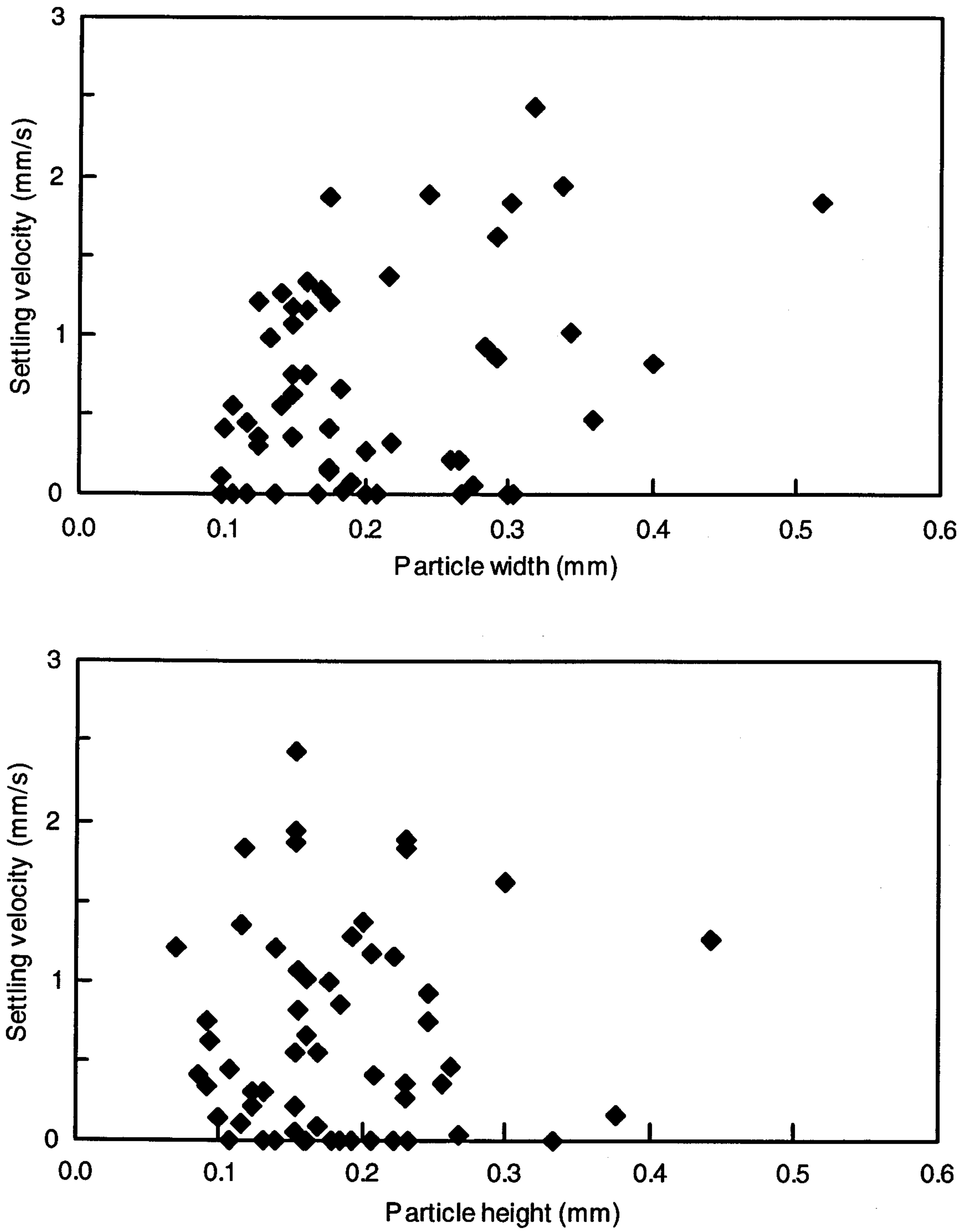


Figure A4.6 **Variation of settling velocity with particle size - Tube 11**



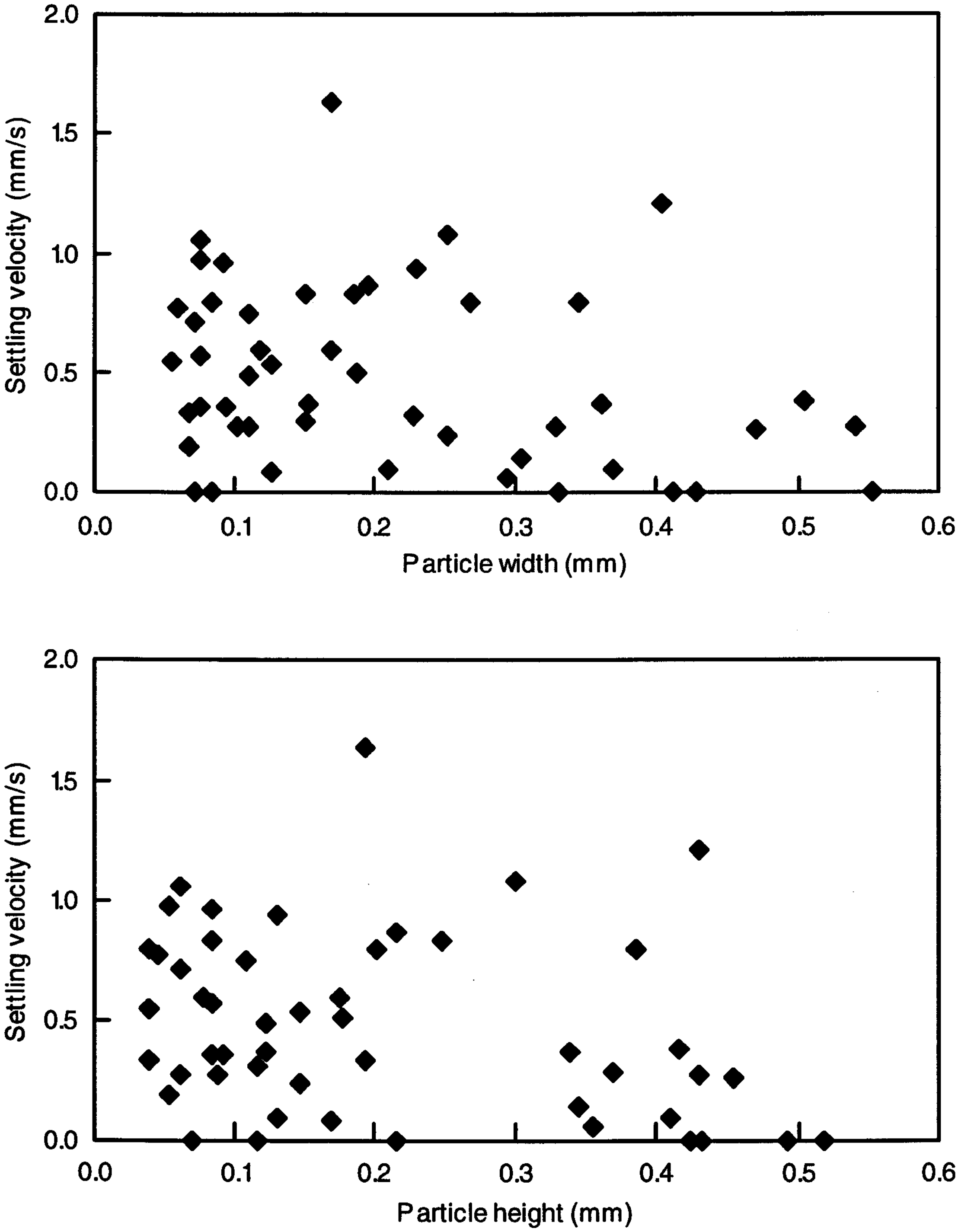
Sample concentration 19 mg/l
Loss on ignition 24%

Figure A4.7 Variation of settling velocity with particle size - Tube 14



Sample concentration 774 mg/l
Loss on ignition 5%

Figure A4.8 **Variation of settling velocity with particle size - Tube 18**



Sample concentration 119 mg/l
Loss on ignition 19%

Figure A4.9 **Variation of settling velocity with particle size - Tube 19**

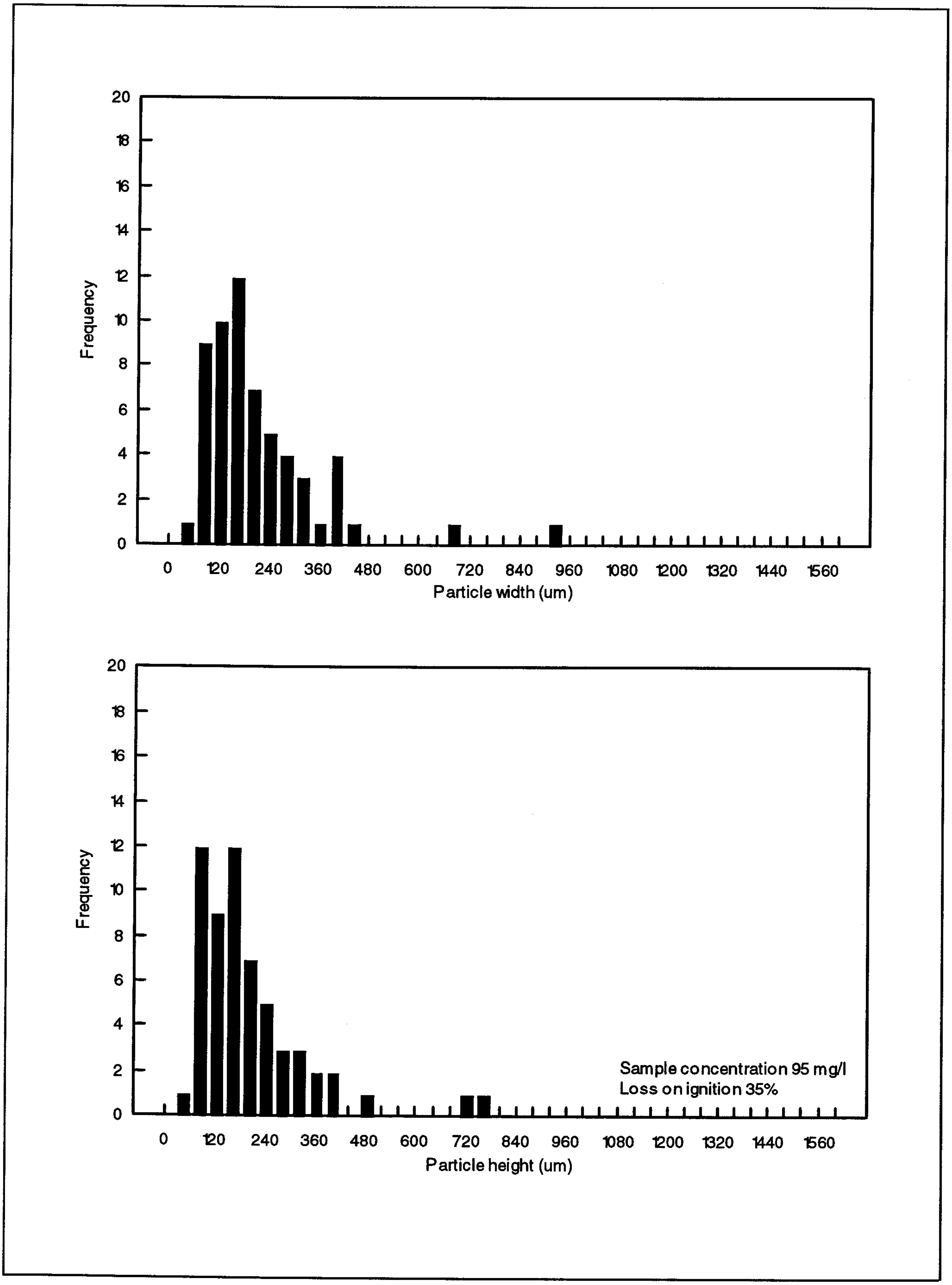
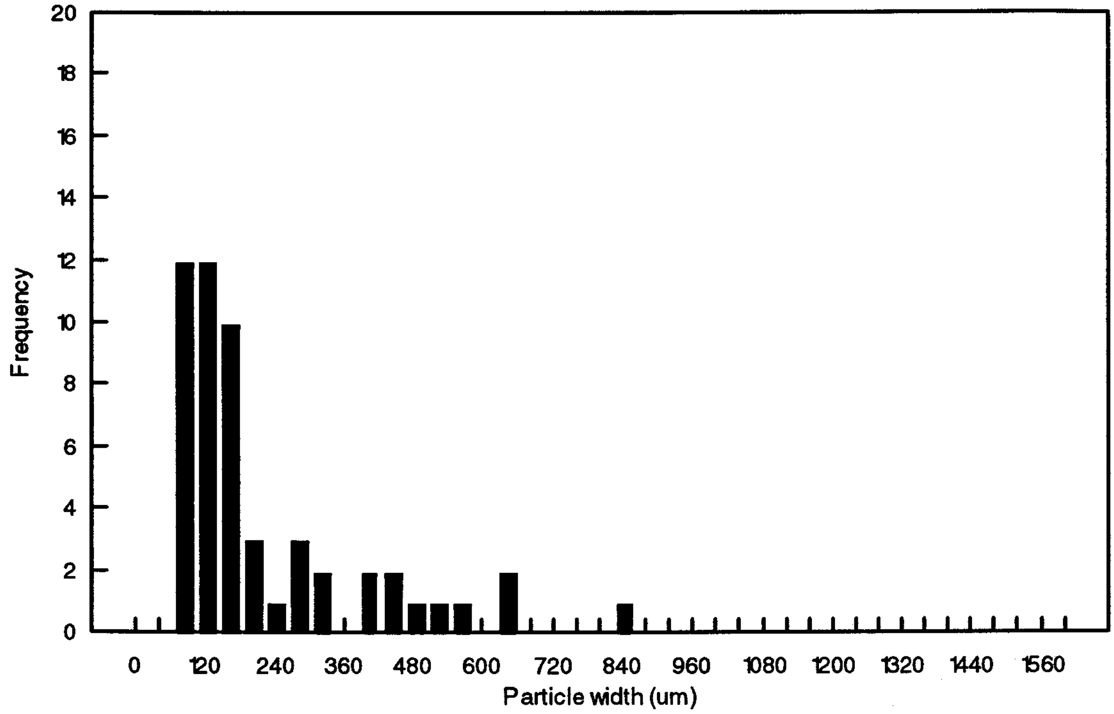


Figure A4.10 Particle size distribution - Tube 1



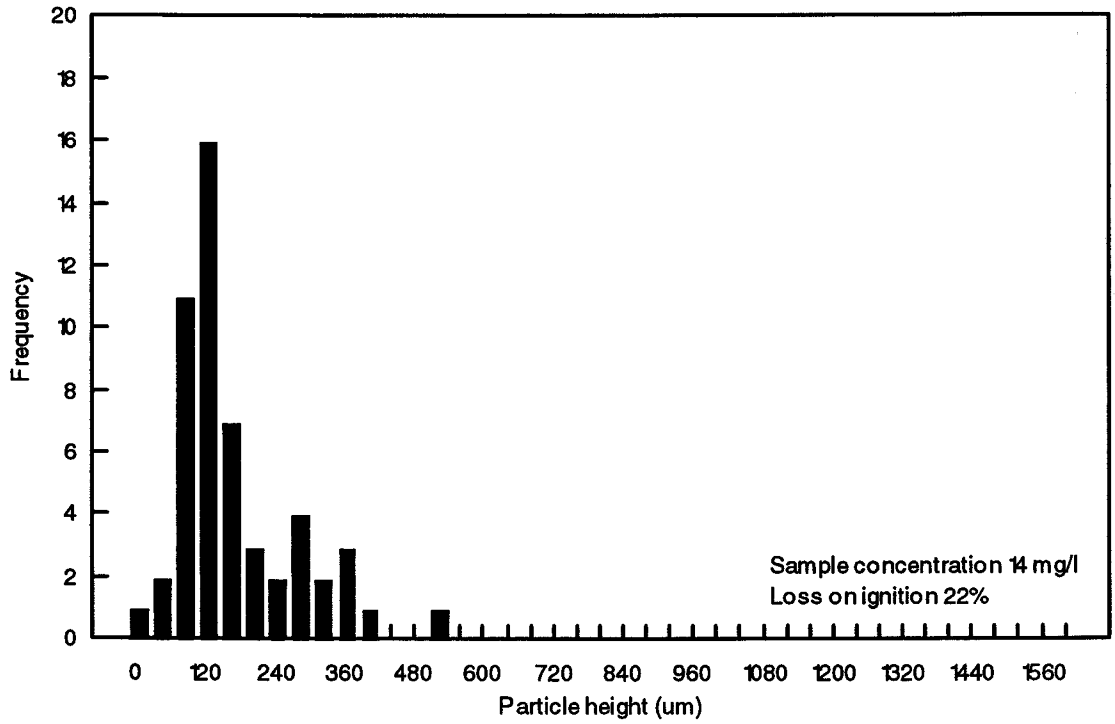


Figure A4.11 Particle size distribution - Tube 2

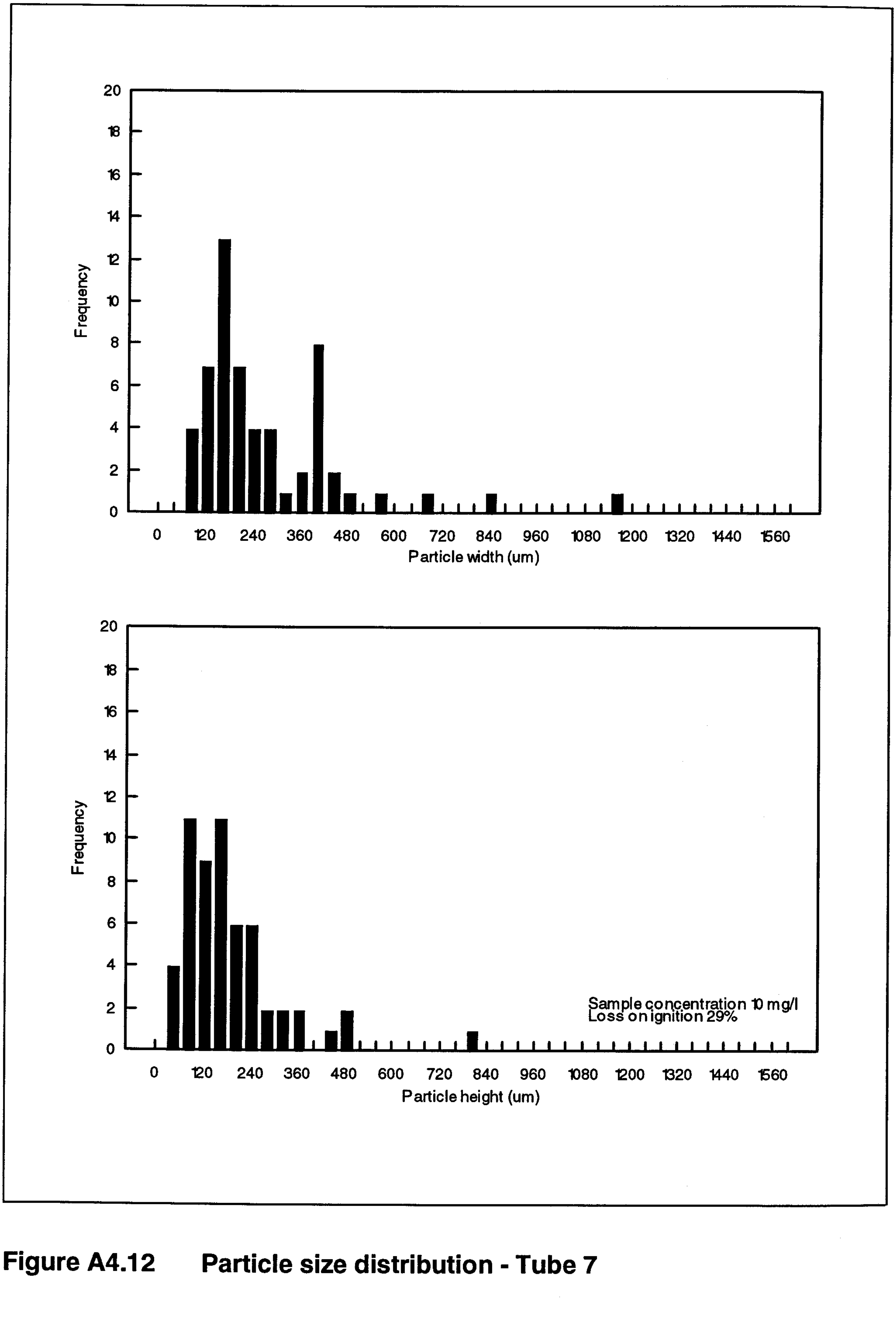


Figure A4.12 Particle size distribution - Tube 7

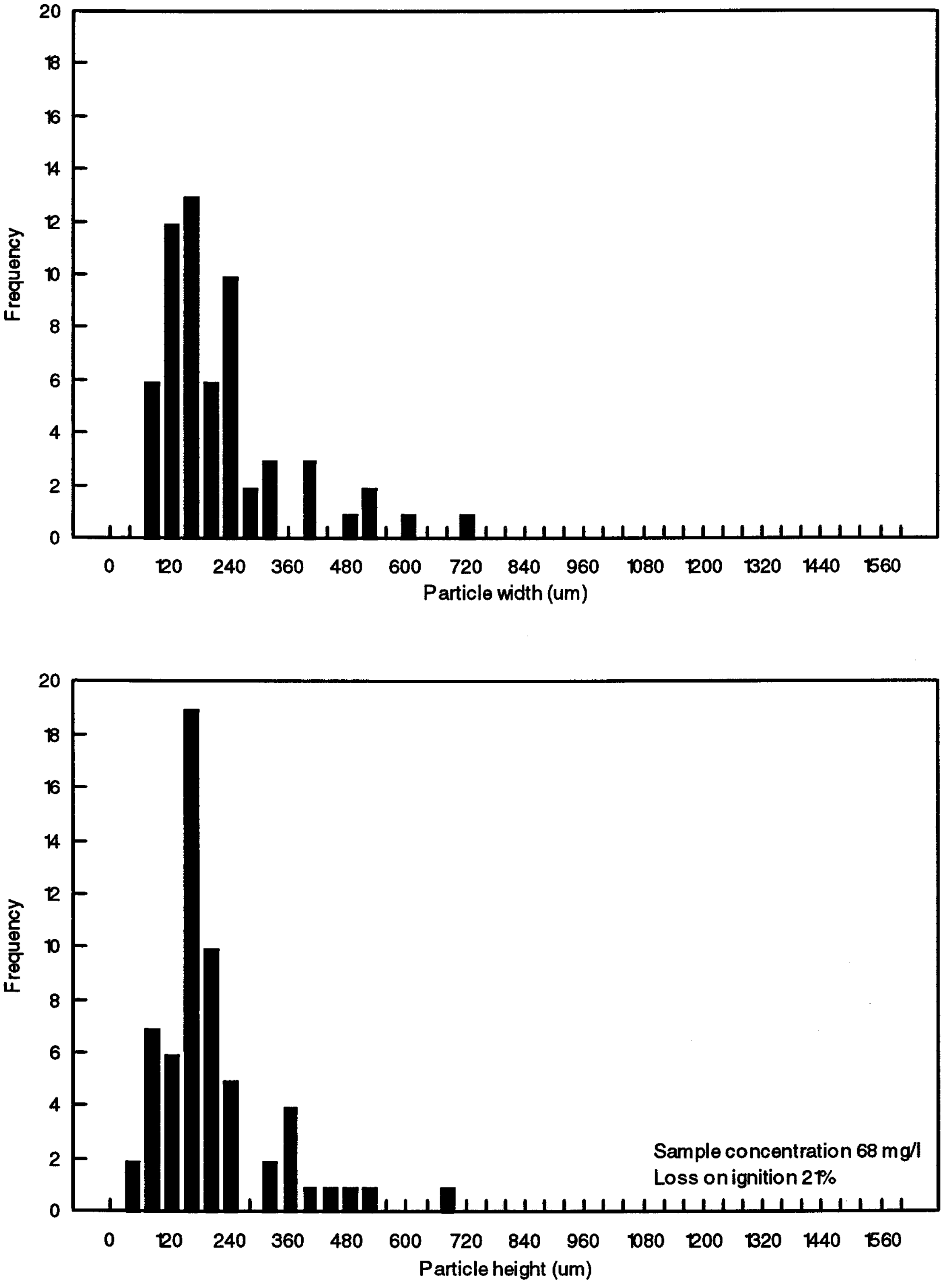
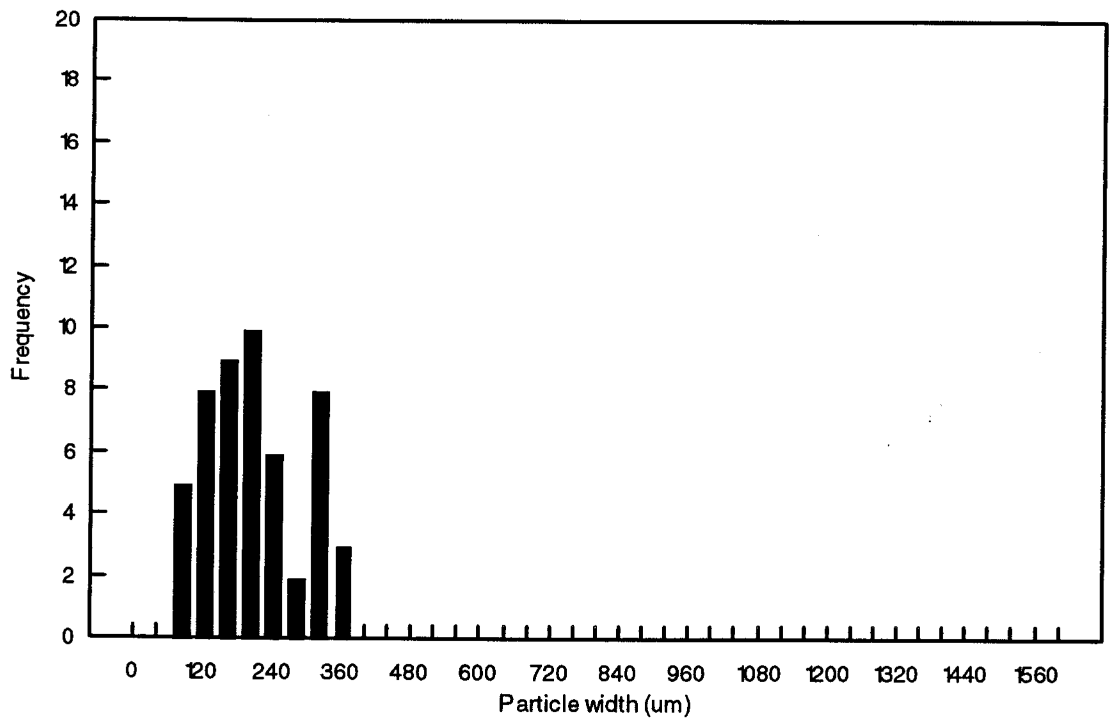


Figure A4.13 Particle size distribution - Tube 8



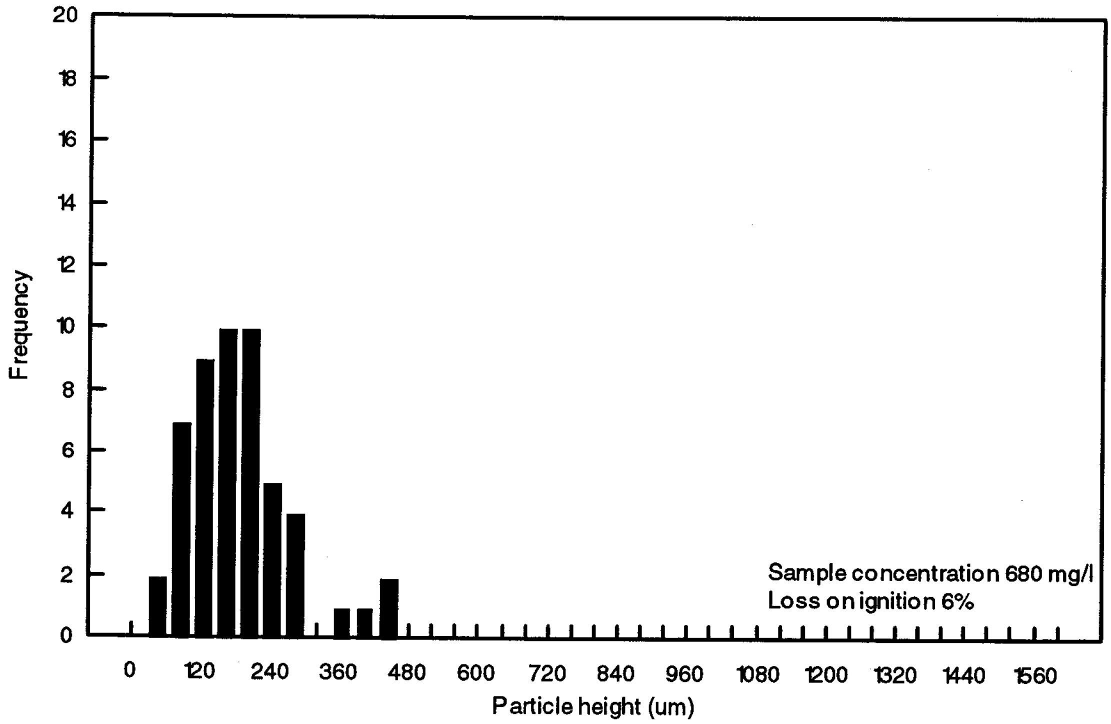


Figure A4.14 Particle size distribution - Tube 9

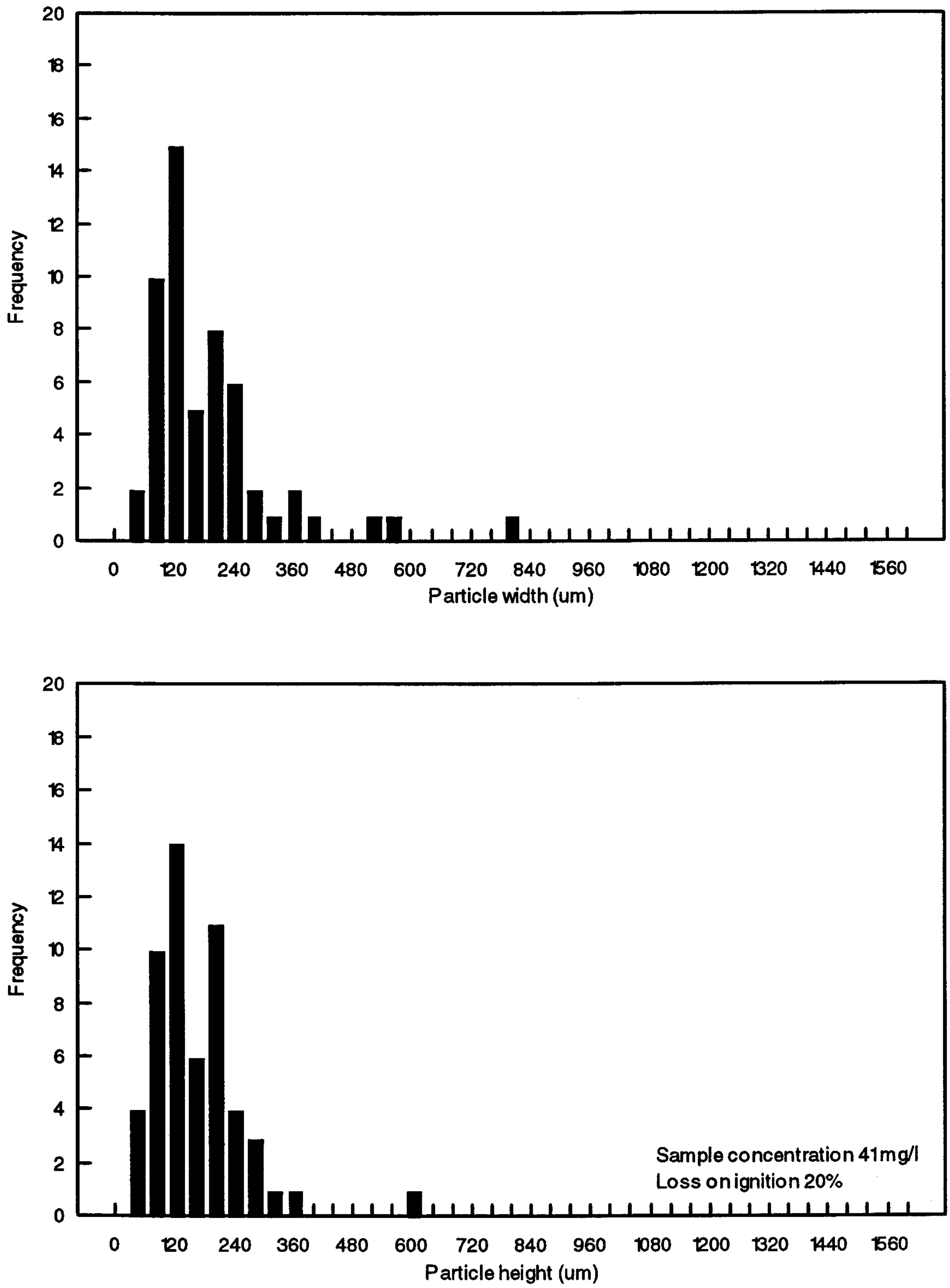


Figure A4.15 Particle size distribution - Tube 11

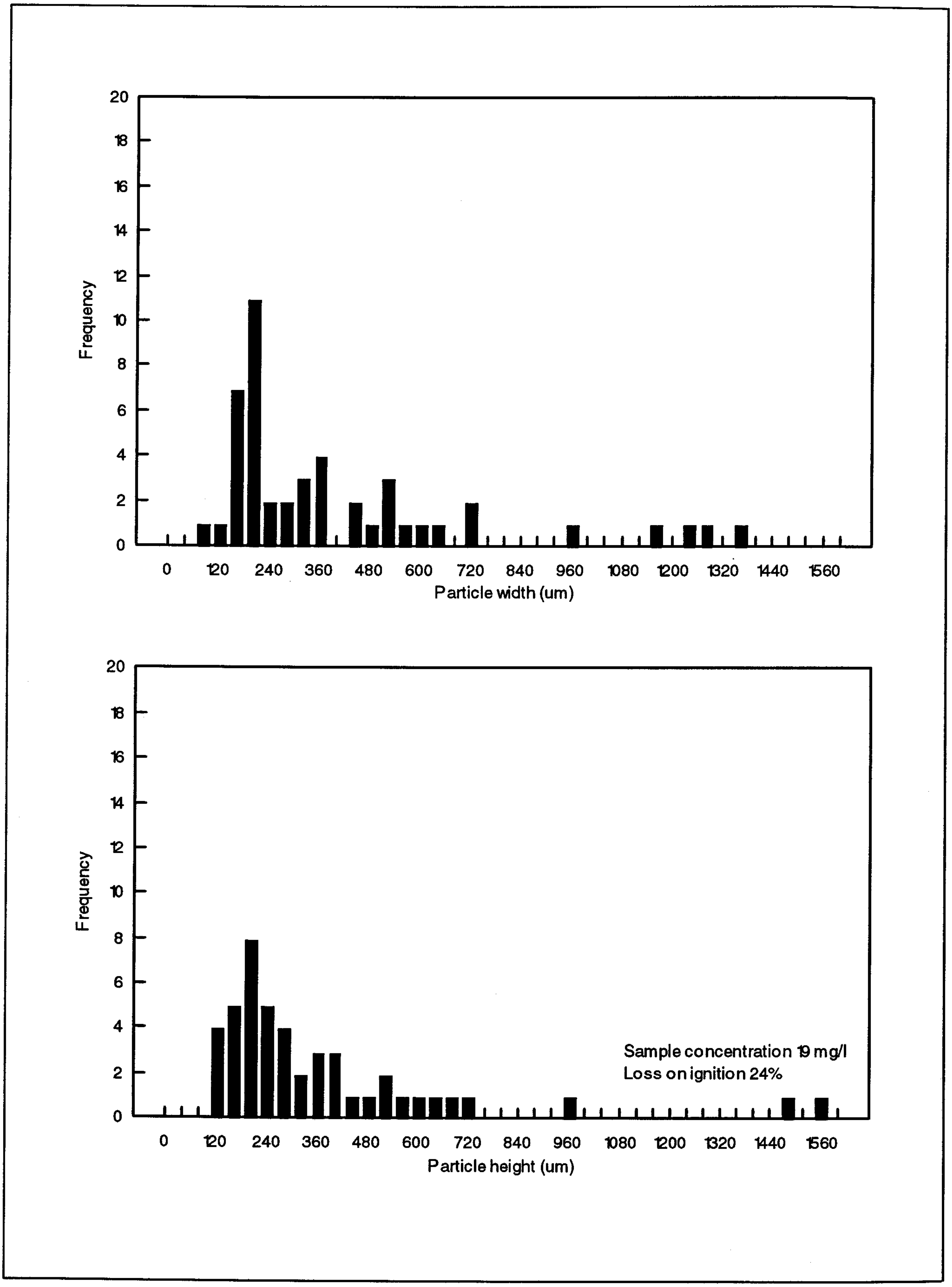
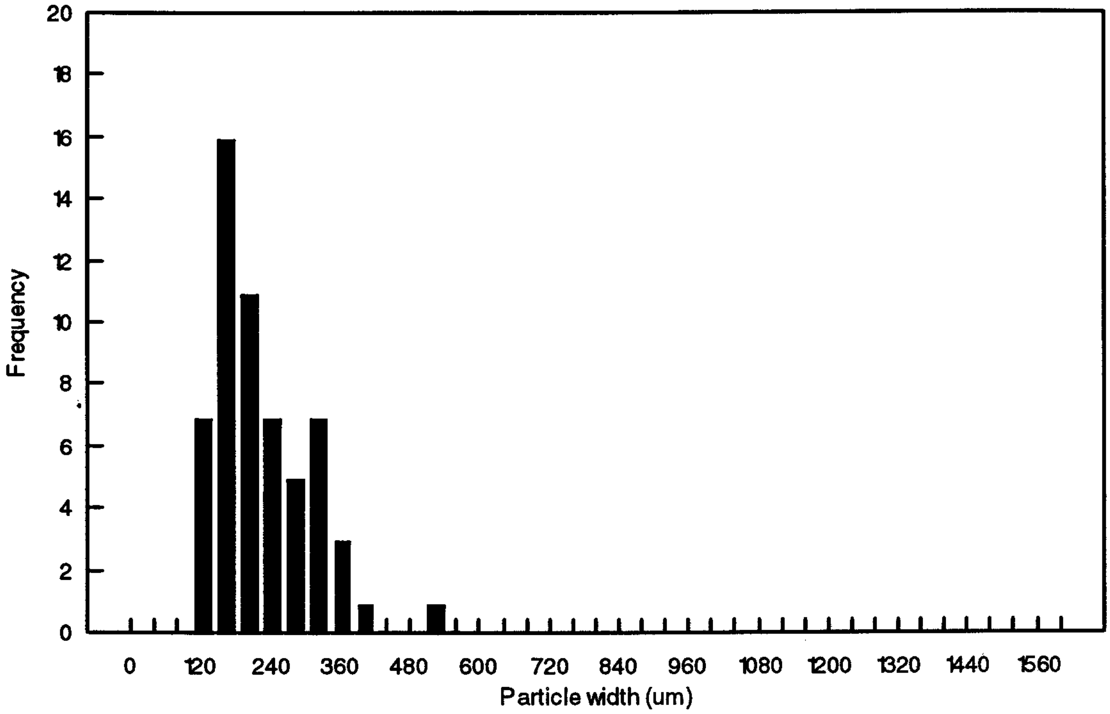


Figure A4.16 Particle size distribution - Tube 14



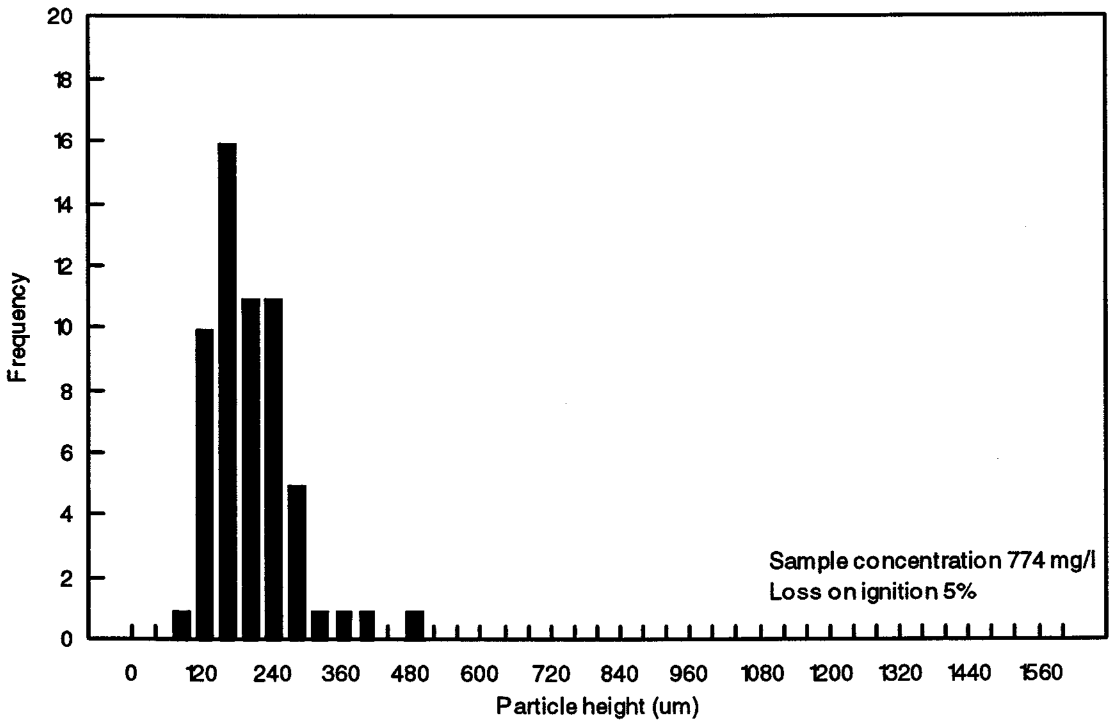


Figure A4.17 Particle size distribution - Tube 18

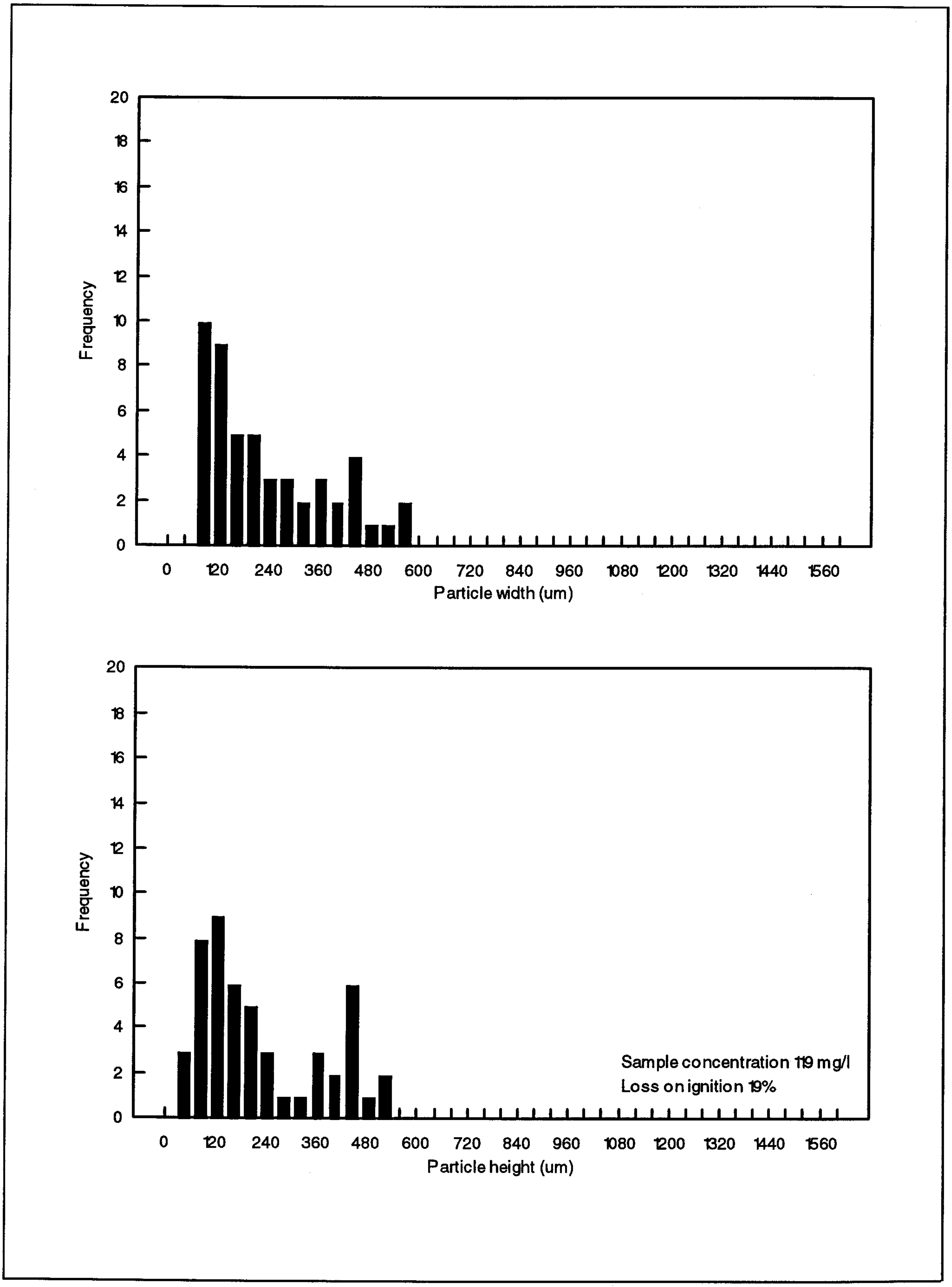


Figure A4.18 Particle size distribution - Tube 19

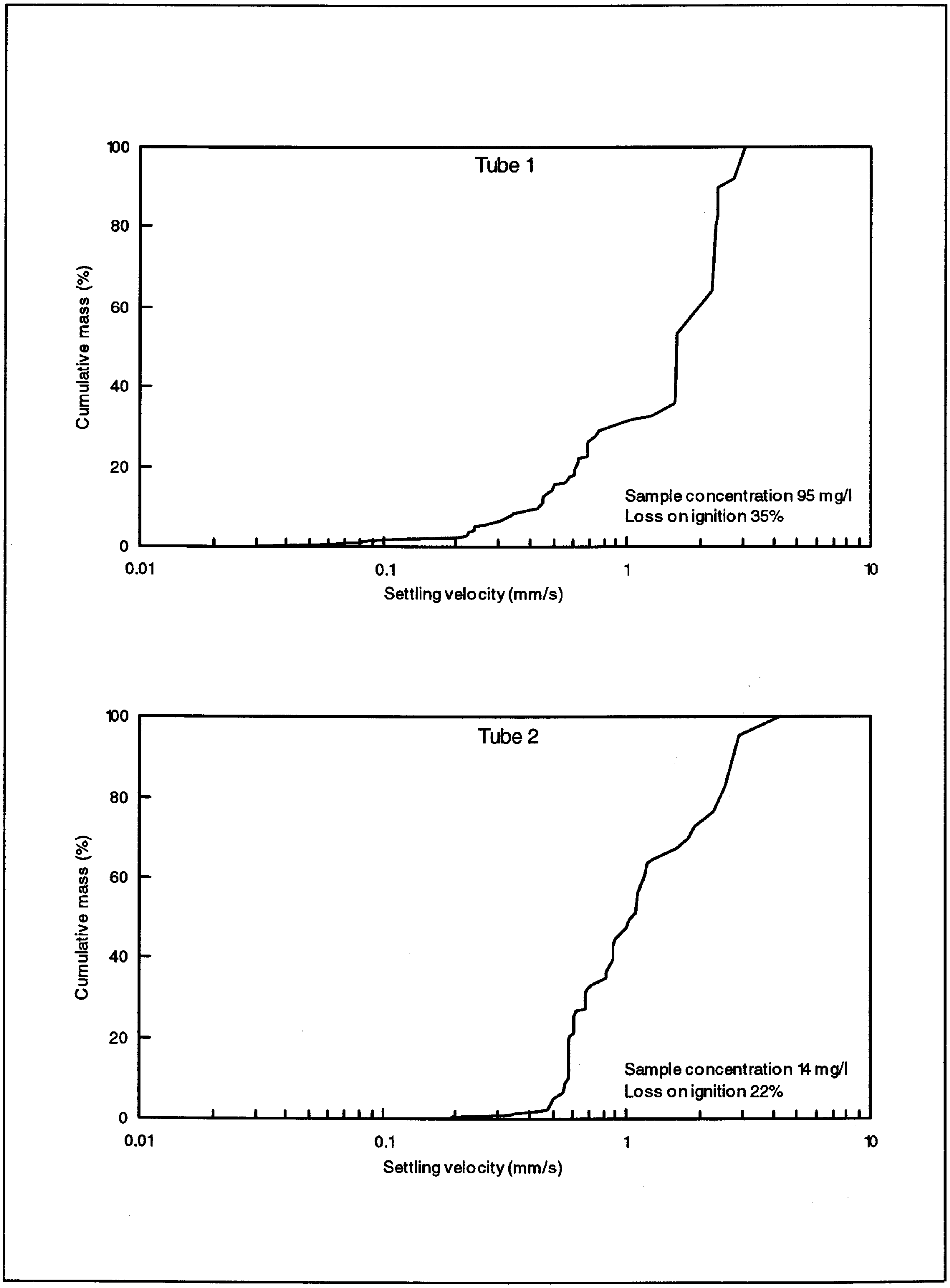


Figure A4.19 Cumulative mass versus settling velocity - Tubes 1 and 2

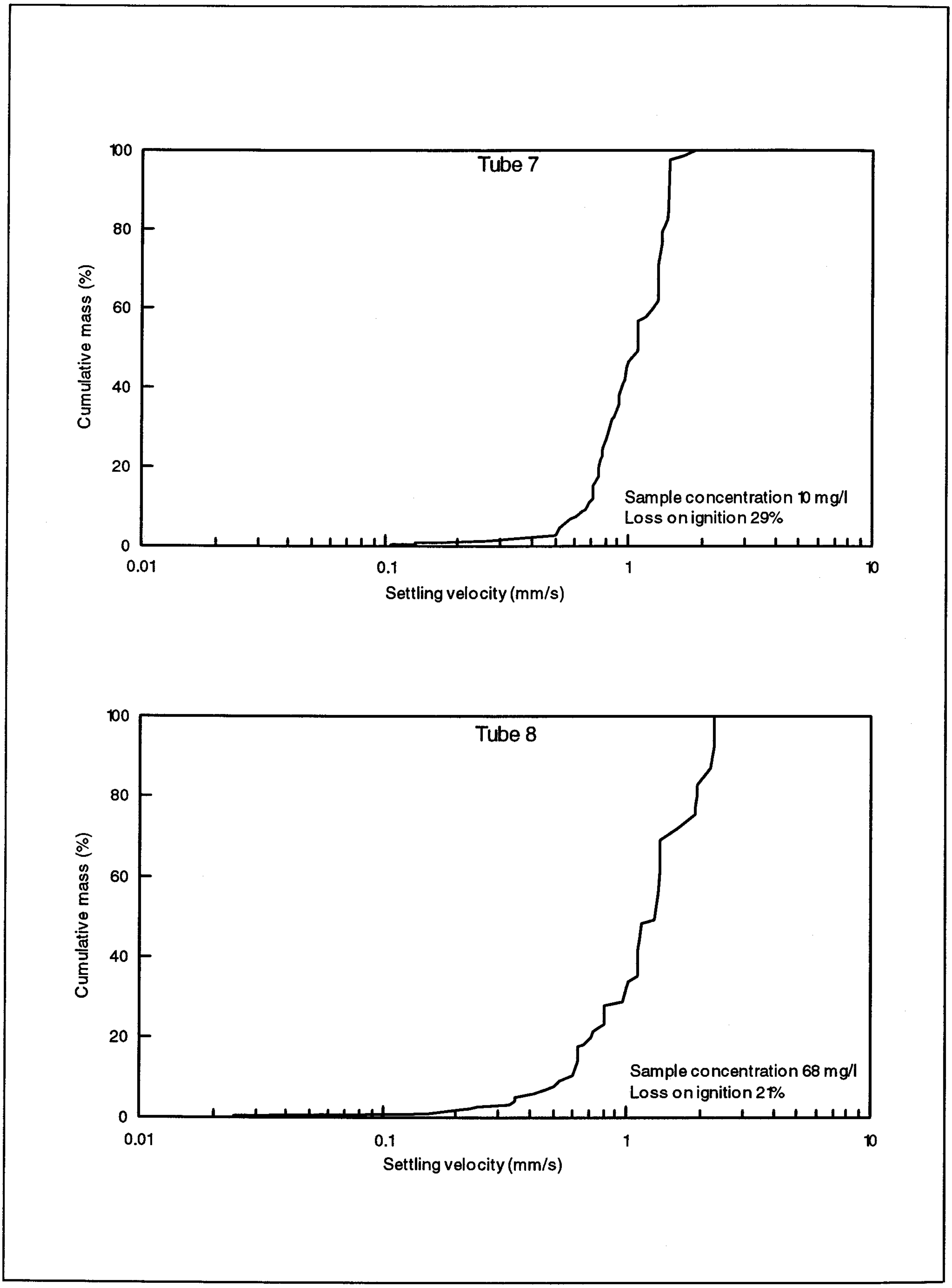
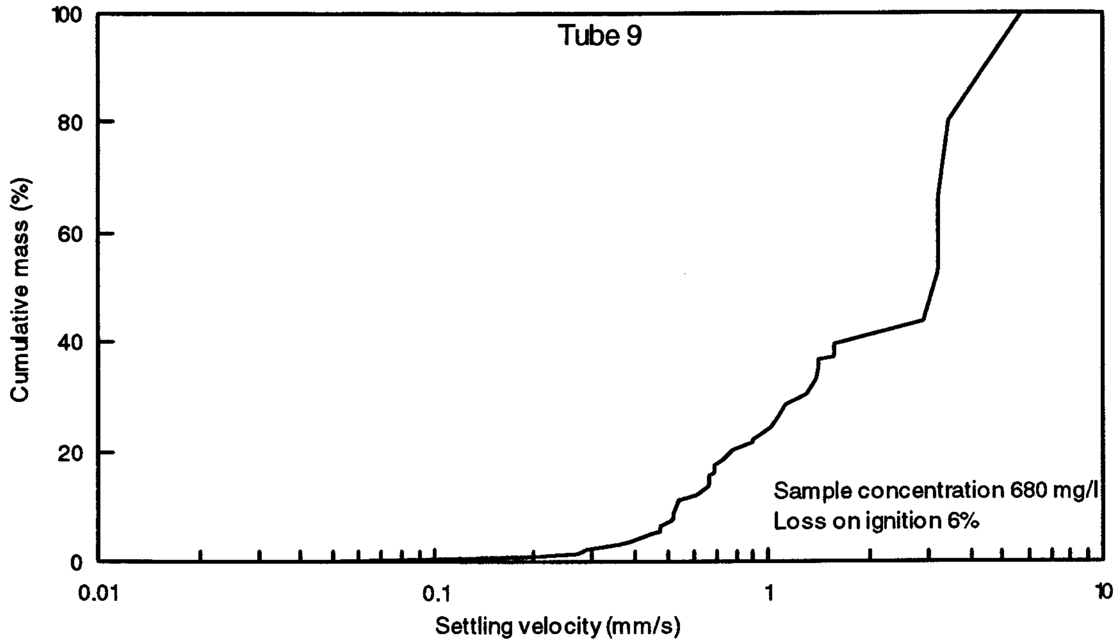


Figure A4.20 Cumulative mass versus settling velocity - Tubes 7 and 8



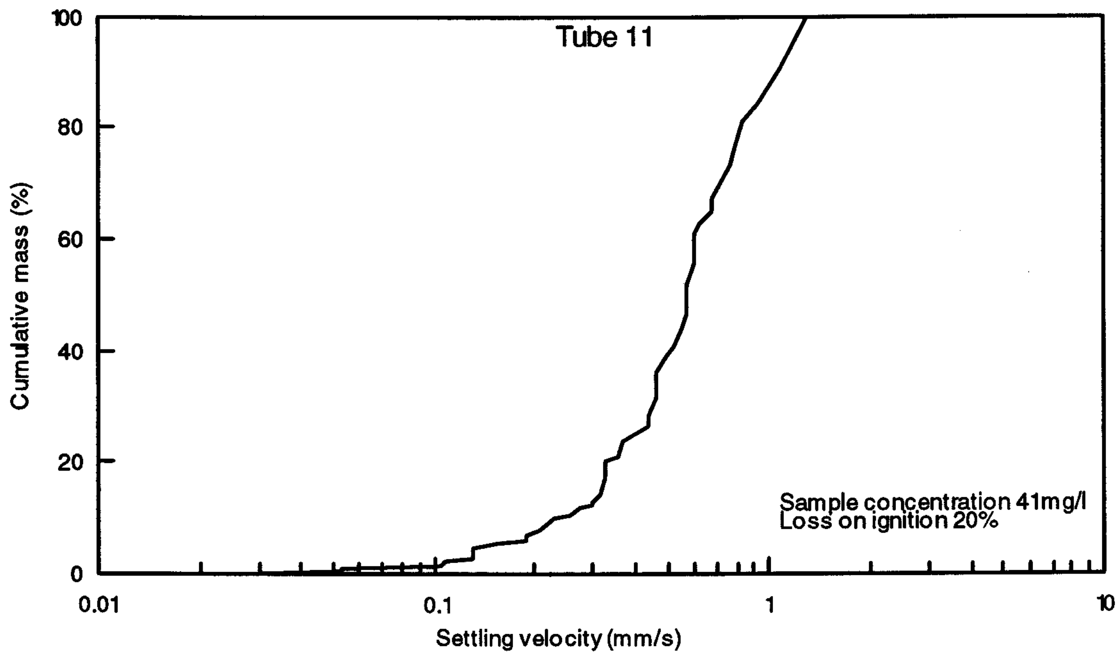


Figure A4.21 Cumulative mass versus settling velocity - Tubes 9 and 11

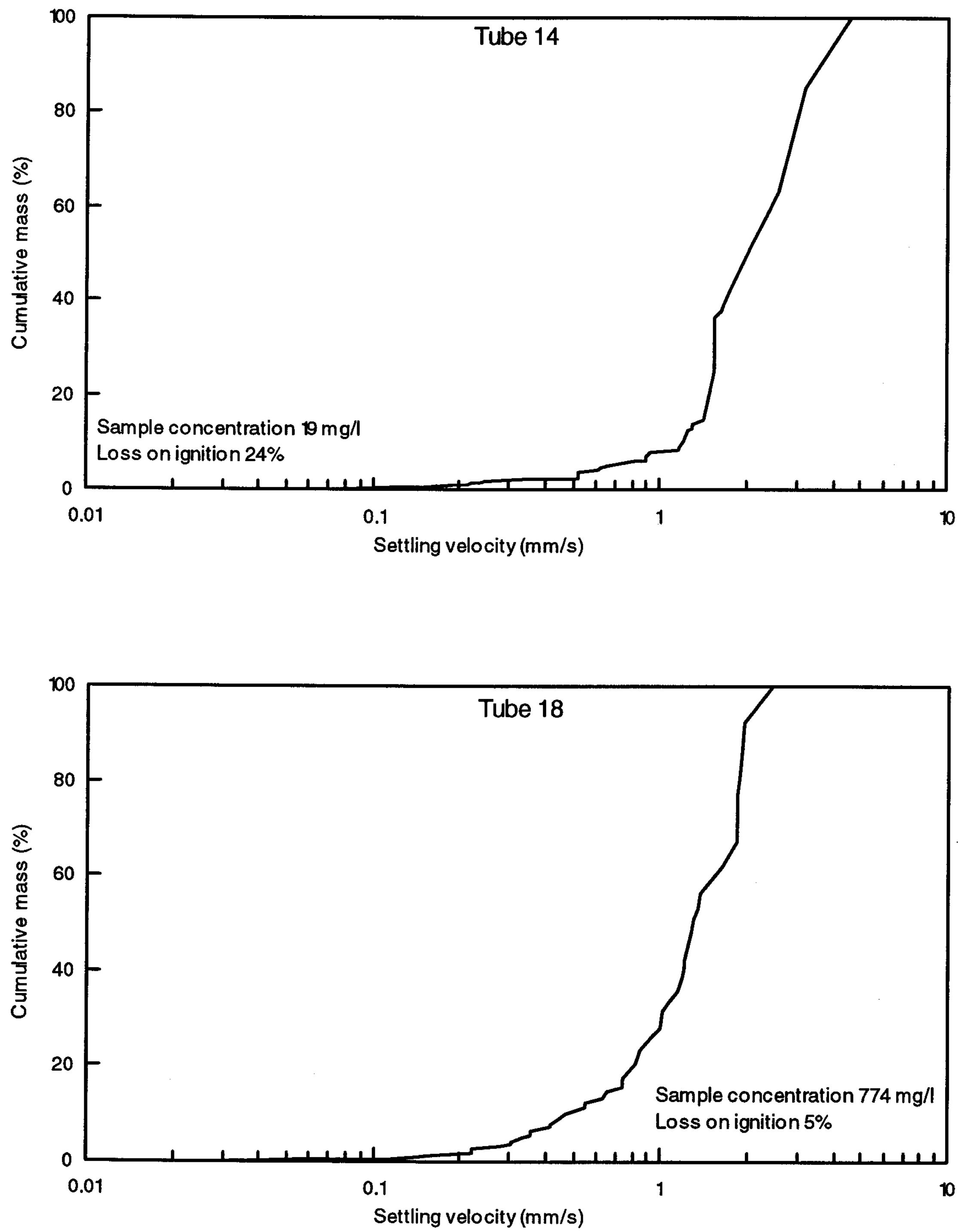


Figure A4.22 Cumulative mass versus settling velocity - Tubes 14 and 18

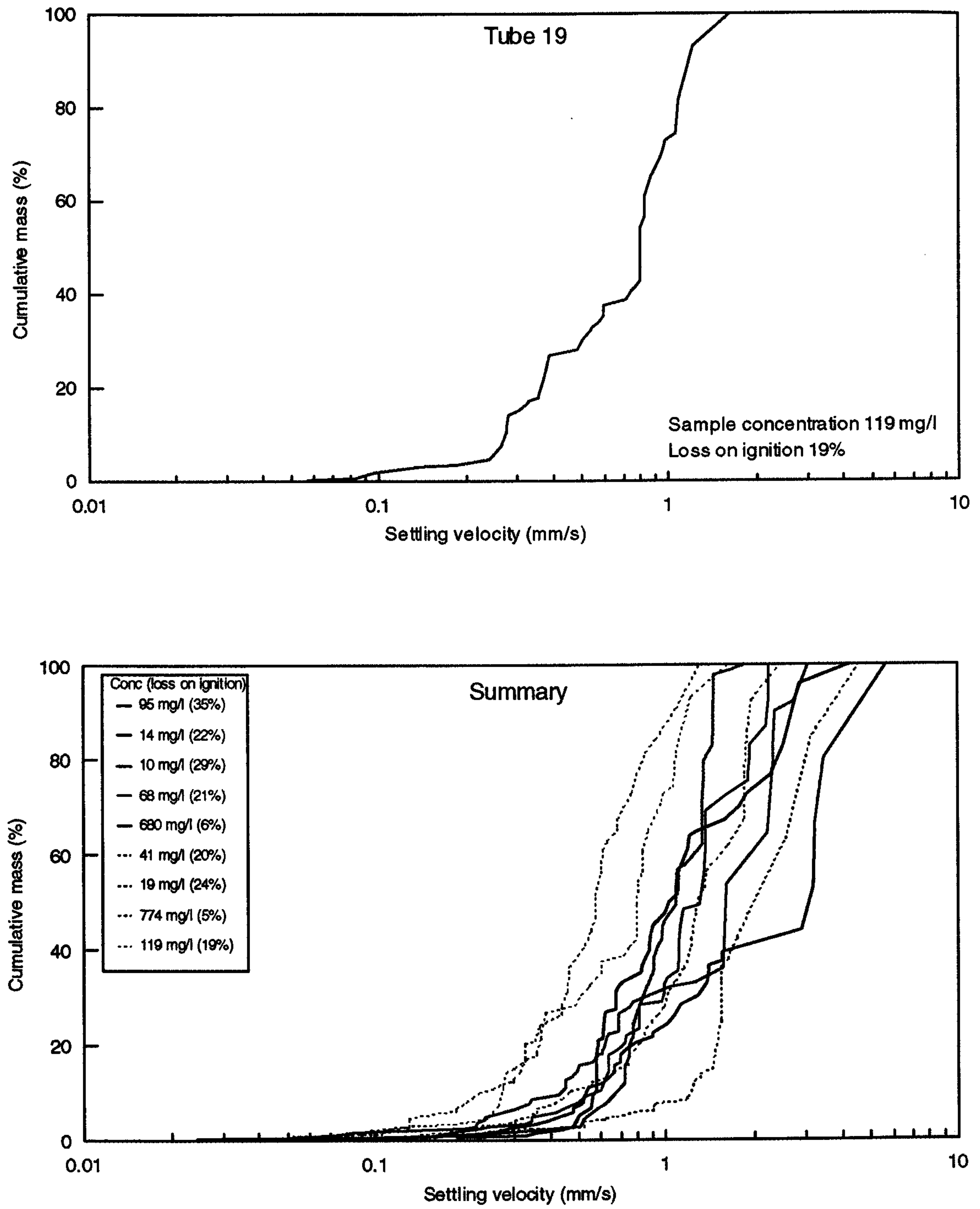


Figure A4.23 Cumulative mass versus settling velocity - Tube 19 and summary graph