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Dredging Research Technical Notes

The PLUme MEasurement System (PLUMES): First Announcement

Purpose

This technical note describes a field data collection system called PLUMES (PLUme MEasurement System) developed under the Dredging Research Program (DRP) to measure sediment concentration and three-dimensional (3-D) fluid velocity at dredging sites. The PLUMES provides synoptic and comprehensive information on suspended sediment dynamics and fluid motion, and has been used successfully at several open-water dredged material placement sites. This technical note describes capabilities presently available through the DRP and plans for the final, fully functional system.

Background

Suspended sediment clouds or plumes develop in open water both at the site of dredging operations and at dredged material placement areas. Such dredging activities and plume generation take place in estuaries, rivers, lakes, and the ocean. Environmental concerns often require an assessment by direct monitoring, numerical modeling, or both, of the extent, movement, and longevity of suspended sediment plumes. Typical environmental questions to be answered are whether suspended sediments leave the placement site, where the material goes, and how much material remains in the water column after a certain time. Such questions apply to shallow and deep water, high- and low-velocity flows, stratified flow, and other common conditions at dredging and dredged material placement sites.

To address these and similar questions, an instrument suite is under development by the DRP that will allow economic and reliable quantitative measurement of sediment plumes over the entire range of environmental conditions encountered in dredging practice. The instrument suite, the PLUMES, is an integrated package consisting of various measurement hardware, analysis software, and documentation aimed to allow Corps field offices to monitor moving suspended sediment and associated currents at open-water sites. The PLUMES has undergone three successful field tests in which valuable information was provided to field offices for managing or designating dredged material placement sites. A research version of the PLUMES is currently in use by DRP researchers. A prototype system is being developed for use by the US Army Engineer District, Jacksonville, in FY 92, and complete the PLUMES units for field-office use are expected to be available in FY 93. The purpose of this technical note is to provide information on the characteristics and capabilities of the PLUMES.

Additional Information

The PLUMES is presently operated as part of ongoing research and development activities of Technical Area 1 of the DRP. For further information, please call the authors, Dr. Nicholas C. Kraus, (601) 634-2018, or Ms. Michelle M. Thevenot, (601) 634-3301, or DRP manager, Mr. E. Clark McNair, Jr., at (601) 634-2070.

PLUMES Concept

Figure 1 illustrates the PLUMES in operation. The four main functional components of the overall system are:

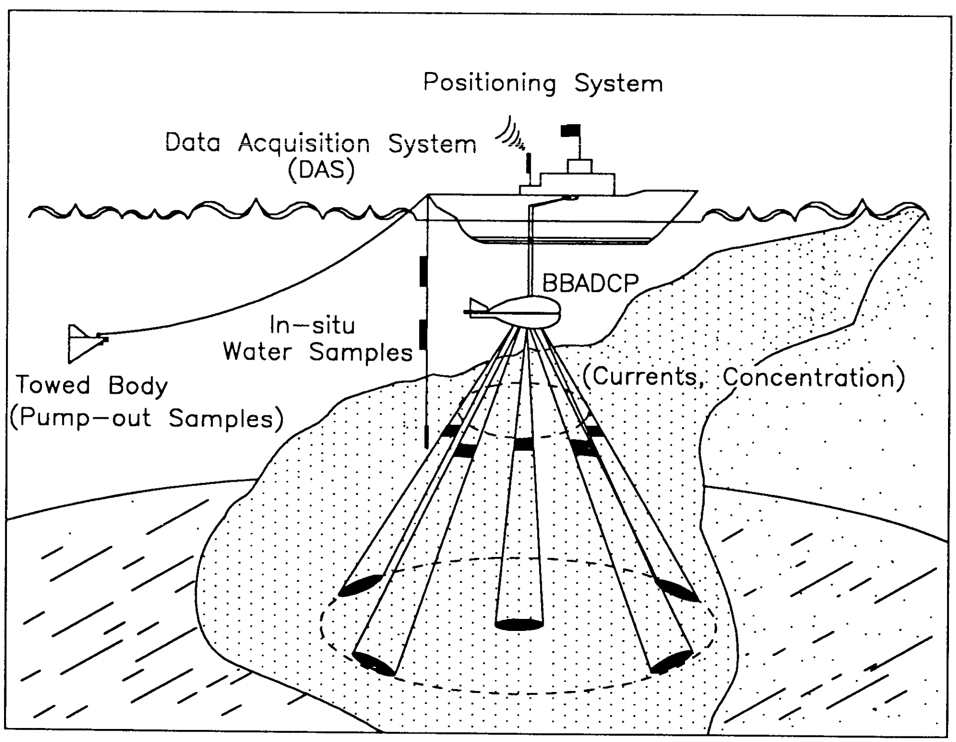

Figure 1. Conceptual drawing of the PLUMES

- A 5-beam broad-band Acoustic Doppler Current Profiler (BBADCP).
- In-situ samplers.
- Positioning system.
- Data acquisition system (hardware and software).

The PLUMES is a *remote-sensing* system that can be deployed from a ship, off a buoy, or from any platform. The acoustic sensor makes unobtrusive wide-area measurements of the water current velocity and the sediment concentration in the water column. For measurement of dredged material plumes in open water, deployment from a ship or boat allows the PLUMES to track the movement of the sediment cloud as it is advected with the current and disperses. The acoustic device samples adjacent water volumes on the order of square meters over depths as great as 100 m or more. This type of wide-area synoptic sampling cannot be accomplished with bottle samplers or water pump-out systems. Real-time display of the data allows tracking of suspended sediment clouds even when they are not visible from the water surface. Although the acoustic device is the central component of the PLUMES, in-situ samplers for calibration of the acoustic measurements and measurement of water quality are an essential part of the overall measurement system. The design concept for the system was developed in a comprehensive sediment plume field data collection project performed in 1989 at the site of dredged material placement operations off Mobile, Alabama. A DRP technical report (Kraus 1991) and a journal article (Kraus and Prickett 1989) document this project. The DRP has also produced a video report documenting this data collection effort which is available upon request.

The four main components of the PLUMES are described in the following paragraphs.

BBADCP

The heart of the system is the broad-band Acoustic Doppler Current Profiler (BBADCP). This is a multiple-beam Doppler sonar system that can measure vertical profiles of 3-axis velocities and acoustic backscattering strength by transmitting short acoustic pulses and processing their reflections from small particles in the water. The term "broad band" refers to the capability of the system to employ very short pulses and spread-spectrum techniques to achieve better vertical and temporal resolution than the traditional narrow-band ADCP used in the 1989 Mobile, Alabama, project (Lohrmann and Humphrey 1991). Both the traditional ADCP and the BBADCP measure water velocity by transmitting a short acoustic pulse along a narrow acoustic beam. The Doppler shift of the return echo (coming from acoustic reflection off small particles in the water column) is estimated at a number of range cells defined by time-gating the return signals. For a given range cell, the along-beam component of the relative velocity V of the scatterers with respect to the transducers is then derived from the corresponding Doppler frequency shift as $V = (F_D / 2F_t) C$, where F_D is the measured Doppler frequency shift, F_t is the transmit frequency, and C is the speed of sound in the water at the transducer face. To obtain 3-axis velocity components, three or more beams oriented in different directions are used. Standard ADCPs use the Janus configuration, consisting of four transducers arranged at 90-deg azimuth intervals and slanted 30 deg from the vertical.

In addition to measuring velocities, all ADCPs provide vertical profiles of echo intensity. In principle, the intensity of the return signals is related to the amount of particulate matter within the volume ensonified by the acoustic pulse. However, this relation is complicated by physical factors such as sound attenuation and particle size, shape, and composition. Also, the standard ADCP was not designed to measure echo intensity for the purpose of relating signal strength to sediment concentration. Instead, the signals are heavily filtered in the hardware and used for automatic gain control of the receiver amplifiers. Furthermore, there was no provision in the design of the instrument for making the measurements repeatable over time, repeatable across instruments, or invariant with respect to temperature change.

The BBADCP developed for the PLUMES overcomes these shortcomings by adding a fifth vertical beam specifically for measuring undistorted strength of the return signal. The system will undergo calibration beginning in winter 1992 to develop empirical relations between sediment concentration, sediment grain size, and acoustic backscattering strength.

The five-beam BBADCP was specially designed for the PLUMES development program based on experience gained in the 1989 tests off Mobile, Alabama. The BBADCP performs three major functions:

- It measures the water current in vertical bins through the combination of the four diagonal beams.
- It measures acoustic backscatter with the vertical beam, from which volumetric suspended concentration can be inferred through calibration with in situ water samples.
- If the four slanted beams can reach the bottom, it provides an estimate of the ship's speed and direction. Knowledge of the ship's velocity is needed to convert from relative motion of ship and water to the true motion of the water current. If the beams cannot reach the bottom, an independent positioning system must be used for this purpose.

Table 1
Estimated Vertical Resolution of the BBADCP

	Maximum vertical resolution:		
System	Current	Intensity	Range
1,200 kHz (BBADCP)	20-40 cm	2.5 cm	16-25 m
600 kHz (BBADCP)	40-60 cm	5 cm	40-70 m
300 kHz (BBADCP)	60-80 cm	10 cm	80-120 m
1,200 kHz (ADCP)	1 m	1 m	25 m

Table 1 summarizes characteristics of the PLUMES BBADCP that will become commercially available. The range of the instrument is given as a spread of two values, since the useful range depends, in part, on the density of the water and sediment mixture. As the principal frequency of an acoustic transmitter increases, the range and resolution of the instrument decrease. Because many dredged material placement operations conducted by the Corps are within a depth of 30 m (nominal 100 ft), the DRP has constructed the 600-kHz system first. Table 1 compares the 1,200 kHz ADCP and BBADCP systems, where it is seen that the effective range is the same, but the resolution of the BBADCP is much superior. The increased resolution and the addition of a fifth, vertical beam contributes to improved measurement of the sediment plume in the water column and near to the sea bottom.

In situ Samplers

Water sampling provides a direct measurement of sediment concentration, sediment type and grain size, and water salinity. The in situ instrument suite can be deployed from a towed body or "fish" that moves with the sampling vessel, or it can be deployed from a winch when the ship is stationary. In addition to water samplers, in situ instrument packages may contain such instruments as a transmissometer, optical backscatterence sensor (a device that measures sediment concentration at higher concentration ranges than a transmissometer), salinity sensor, temperature, and a pressure gage to determine depth of the measurement.

Positioning System

The principal function of a horizontal positioning system is to provide the location of a sediment plume as it moves with the current and disperses. The required degree of accuracy of the positioning system depends on the application. For example, in open water far from the coast, horizontal positioning with only 100-m accuracy may be sufficient. Such accuracy may be achievable with LORAN. As placement operations approach shore, accuracy on the order of 10 m may be required. Operations in rivers and estuaries may require the horizontal position of a plume to within 1 m. The PLUMES data acquisition system will allow direct interfacing with a differential Global Positioning System (GPS) receiver. Wherever a broadcasting differential GPS station is available, differential GPS positions will be computed by the PLUMES in real time and provide positions accurate to a few meters. In the absence of suitable broadcasting stations, a differential receiver can be installed onshore and the data recorded continually using a laptop PC. These data can then be merged, in postprocessing, with the data collected by the PLUMES to obtain equally accurate positions.

A second potential function of the positioning system is to provide an estimate of the ship's velocity when the acoustic beams do not reach the bottom. As previously discussed, the ship's motion must be known in order to obtain the true, and not relative, water velocity. Such information can be obtained manually from the ship's track. However, determination of the ship's velocity by this method is tedious and error-prone, and the results are difficult to combine with the electronically recorded acoustic measurements of relative water velocity. For these reasons, simultaneous recording of the current velocity by the PLUMES and the signal from a positioning system such as a GPS is strongly recommended.

Data Acquisition System (DAS)

The DAS consists of hardware (computer console, monitor, and optional printer/plotter) and software to operate the PLUMES and to record, analyze, and display data. A flux-gate compass is part of the PLUMES DAS. It is required so that the vessel orientation can be extracted from the measurements to give the true current direction. The DAS also records signals from the positioning system such as from a portable GPS or other common commercially available ranging system. The DAS operates the BBADCP and any electronics associated with the in situ sampling and records the output of these instruments. Measurements from the BBADCP can be viewed in real time. Screens on the control console of the PLUMES operating package can be switched to observe the recording ship track, vertical profiles of the intensity of backscatter in the sediment plume, and 3-D current velocity. If a plotter is available, graphical output can also be obtained.

Discussion

The BBADCP may be deployed from a towed body that remains just below the water surface. More commonly, however, the device is simply strapped to a pipe that is lowered vertically into the water and fastened to the sampling vessel's railing or superstructure. The sensors have to be at a depth nearly equal to the depth of the keel so that there is no interference of the acoustic beams with the vessel's hull. The DAS requires a clean, dry, flat area approximately equivalent to that of a small desk (to support a personal computer, keyboard, and optional plotter/printer).

Clean 110-volt power must also be available. Finally, there must be space on the deck of the vessel to accommodate the in situ sampling equipment; a "wet lab" to store and organize the samples and prepare the in situ sampling equipment is desirable but not necessary. Finally, there must be convenient communication between the vessel captain, the PLUMES operator, and deck crew members operating the in situ samplers and otherwise observing the dredging operation, navigation traffic, and sediment plume. In the plume data collection project described in the example below, the PLUMES was deployed from the *Lynnhaven*, a 40-ft-long vessel operated by the US Army Engineer District, Norfolk.

In many dredged material placement operations, sediment is either injected into the water by dumping from moving vessels or is discharged from a pipeline. In both cases, a relatively long and narrow plume results. As shown in Figure 2, systematic sampling of a long plume can be accomplished by crossing along its short axis (transverse sampling), or along its major axis (longitudinal sampling). Typically, many such transects are made to measure the dynamic behavior of the plume. The choice of sampling scheme depends on the environmental conditions, such as whether the plume remains intact or becomes sheared in the water column. In repeated monitoring operations, the two schemes may be used alternately to fully cover the periphery of the plume.

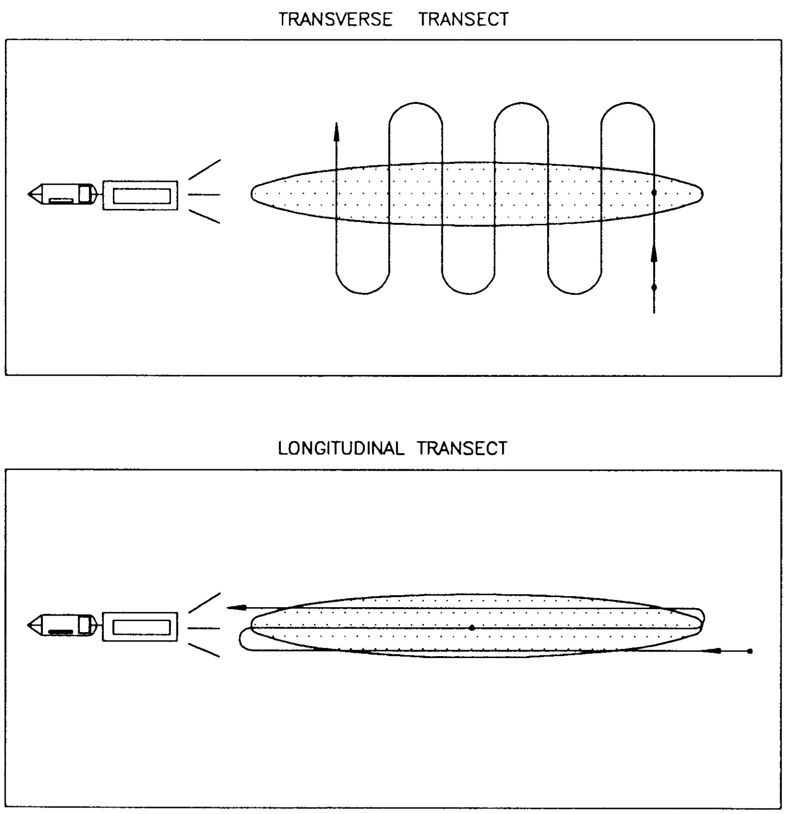

Figure 2. Sediment plume sampling schemes

Example Use and Results

In 1991, the PLUMES was successfully deployed during dredging operations at Tylers-Beach, Virginia. As seen in Figure 3, material was pumped from dredging operations at Tylers Beach Federal Navigation Project and discharged from the pipeline into a site in the James River, part of the Chesapeake estuary system. The objective of the project was to collect sediment concentration and current data to determine the potential for the discharged dredged material to reach Point of Shoals, a large shallow-water oyster seeding ground located adjacent to the placement site. Point of Shoals is an important fishery resource in the estuary and is an area of environmental concern. Data collected by the PLUMES would also be used to confirm earlier physical and mathematical predictions made by the Norfolk District on Tylers Beach placement operations. As previously discussed, the PLUMES was deployed from the *Lynnhaven*, the 40-ft survey vessel provided by the Norfolk District. Figure 4 shows the BBADCP strapped to a pipe and deployed from the *Lynnhaven's* superstructure.

Figures 5 and 6, respectively, contain typical results of the PLUMES surveys of the immediate area during discharge of sediment from the

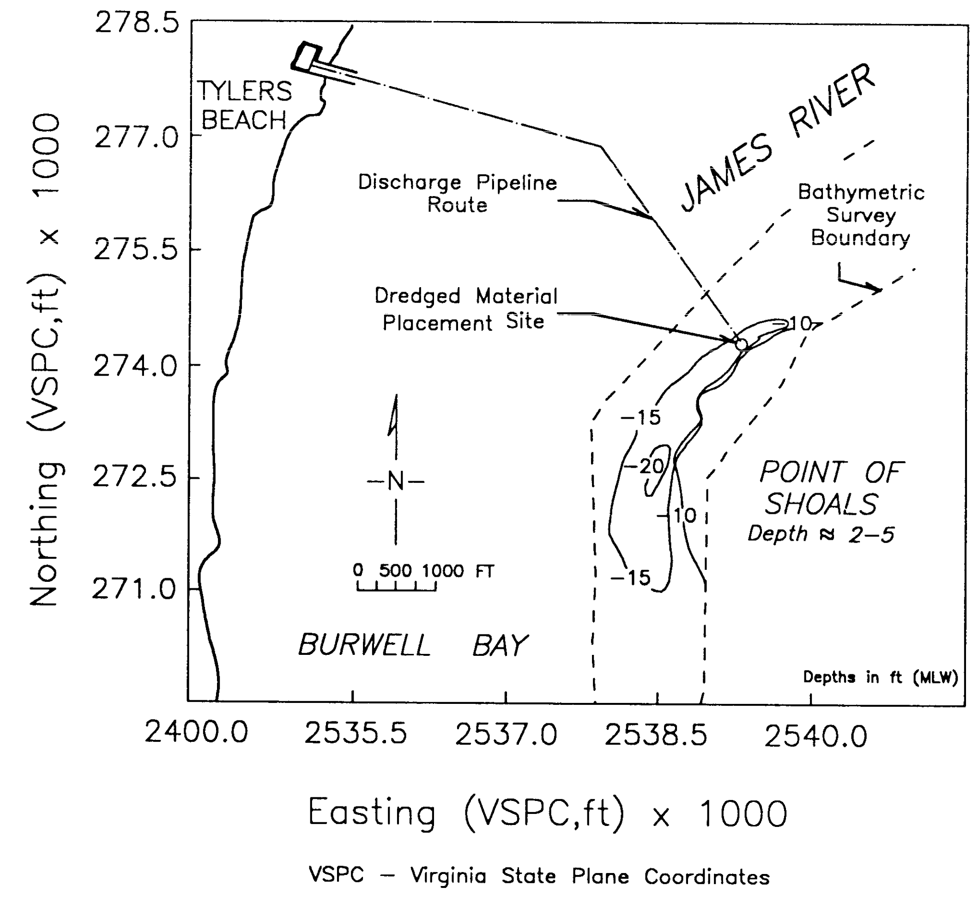

Figure 3. Location map for Tylers Beach Project

diffuser and two days later, when the dredging operation was stopped and the ambient background of sediment concentration was established for the existing current conditions. The horizontal axis gives distance across the channel, and the vertical axis gives depth. Material dredged from Tylers Beach was being placed in the relict channel, which had a depth of 25 ft. The plots are standard color graphics obtained from the PLUMES DAS and show contours of acoustic backscatter in decibel units (a decibel is an expression of the relative intensity of a sound). The numbers in the figures are an indication of the logarithm of relative concentration. In the survey made during the discharge, the concentration of sediment immediately adjacent to and on Point of Shoals (located to the right on the figures) is considerably less than that detected during the background survey. In fact, during the background survey, naturally occurring suspended sediment plumes were probably generated from material being swept off the shallow shoal and are comparable to concentrations of material found in the bottom of the channel during placement operations. These and the many other survey results indicate that discharged sediments did not reach Point of Shoals, naturally occurring suspended sediment concentrations are comparable to those at the bottom of the disposal channel, and concentrations in the upper water column during discharge are relatively low and less than typical background levels. Such conditions were observed during all cycles of the tide.

Figure 4. BBADCP deployed

Acknowledgements

The monitoring project at Tylers Beach was performed as a cooperative effort between the Norfolk District and the DRP. The guidance and assistance of Mr. Ronn Vann and Mr. T. D. Woodward, Norfolk District, is acknowledged. Mr. Mark Skarbek, Jacksonville District, has made significant contributions to the development of the PLUMES. The assistance of Mr. Pat Langan, US Army Engineer District, Mobile, during early stages of the PLUMES planning is acknowledged. Mr. Ramon Cabrera, Mr. Atle Lohrmann, and Mr. Craig Huhta, staff members of RD Flow (contractor responsible for the BBADCP development), are acknowledged for their field support as well as assistance in reviewing this technical note.

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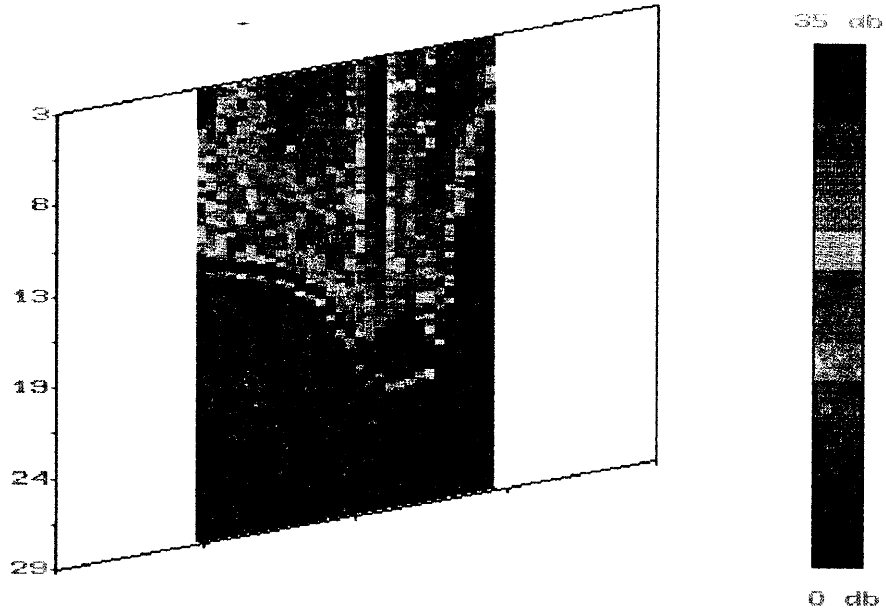

Figure 5. PLUMES survey during pipeline discharge

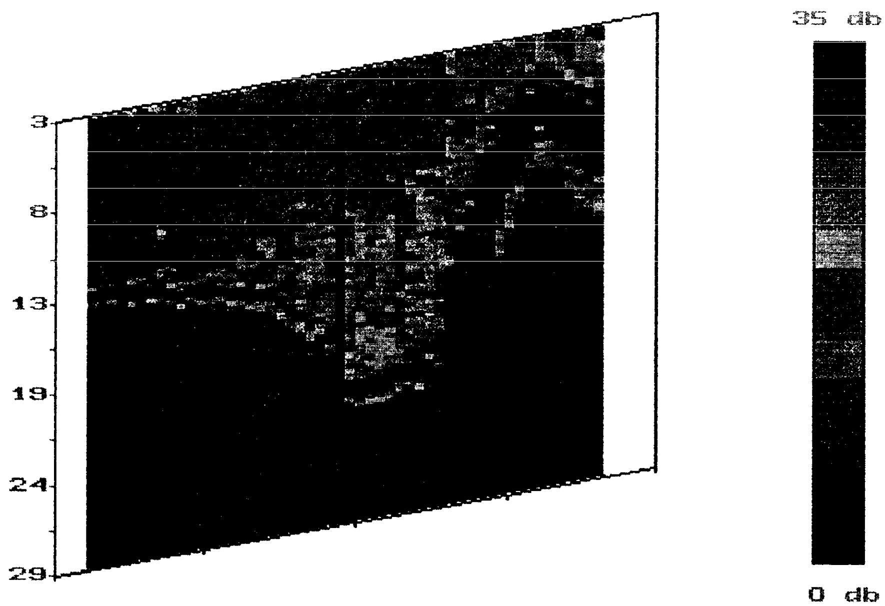

Figure 6. PLUMES survey of background suspended sediments