CHAPTER 106

SLED SYSTEM FOR PROFILING SUSPENDED LITTORAL DRIFT

by

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INTRODUCTION

There are many factors which suggest that littoral zone processes in the Great Lakes differ substantially from those of the marine coasts described in the existing coastal research literature. Among these factors are the lack of an appreciable tidal cycle; the predominance of relatively short, steep, waves; the virtual absence of swell waves; and the presence of shore fast ice in winter. As a result, many of the empirical relationships derived for marine coasts might be of questionable applicability to Great Lakes coasts. The present study, which represents only one phase of a long-term project designed to develop more specific littoral transport relationships, is aimed at obtaining accurate, direct estimates of the actual littoral transport at an experimental site located at the western end of Lake Ontario.

This paper will describe a mechanical system designed to collect a series of time-averaged samples of suspended sediment for concentration determinations as well as flow velocity and water depth at locations across the surf zone. Some preliminary results of the field program using the system will also be presented and discussed.

BACKGROUND

A number of researchers in the U.S.A. (Watts, 1953; Fairchild, 1972; Brenninkmeyer, 1974), Japan (Hom-ma and Horikawa, 1962; Noda, 1967), and other countries (Aibulatov, 1957; Jensen and Sorensen, 1972; and Kilner, 1976) have published techniques for measuring suspended sediment transport in the nearshore zone. Because of the variety of process factors operating there and the presence of breaking waves, this is usually not an easy task. From an operational point of view, the two most common problems involved in such measurement are the physical spanning of the zone (usually more than 100 m in width), and the designing of a measurement platform rugged enough to withstand the highly turbulent conditions that typify this area. Most of the work cited above has involved the use of pump samplers manipulated along a pier or a specially constructed tramway, or cumulative samplers such as the moored bamboo samplers used in the Japanese research. From an interpretation point of view, the main problem lies in the unsteadiness of the phenomenon both in time and space, due to the periodic or oscillatory nature of the driving processes in sediment suspension. This unsteadiness contributes to making the establishment of theoretical models of the process very difficult.

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Nevertheless, the concept of relating quantitatively the total suspended sediment transport to the total littoral transport rate is generally recognized to be a valid one (Dean, 1973) and has the potential of improving considerably on previous direct techniques such as sand tracers. Simply stated, the concept entails the determination of the suspended sediment volume along a transect normal to the longshore currents of the littoral zone. By coupling these data with concurrent measurement of the flow velocity of the water column in a manner analogous to river discharge measurements, it should be possible to obtain a good estimate of the rate and direction of littoral transport. The word "estimate" is deliberately chosen since the unknown proportion of total transport in the form of bed load is not taken into account. Our experience with profile changes in the Great Lakes, however, leads us to believe that the dominantly bed load transport which occurs between storms is relatively minor, so by concentrating on storms when most of the material transported is suspended above the bed for some period of time at least, we feel that the estimate we obtain still represents an improvement on other techniques described to date in the literature. Three important factors, however, must be taken into account. One; the unsteady nature of the process means that the suspended sediment concentrations at a given location vary with time at a frequency related mainly to the orbital motions of the water particles under the waves (Brenninkmeyer, 1974), so care must be taken to obtain measurements over a period long enough for these variations to be averaged out. The variation produced by unsteadiness should also be significantly reduced if measurements were taken during fully developed turbulent conditions, i.e. during storms of moderate intensity. Two; the distribution curve for both sediment concentration and flow velocity with respect to the vertical (or depth) axis is well-known to be of a quasi-exponential form with values for both changing rapidly in the lower part of the curve, and becoming more uniform in the upper part. This makes it essential that measurements be biased toward obtaining sufficient readings near the bed. Finally; studies by Komar (1971) and Aibulatov (1957) demonstrate that the littoral transport rate varies across the surf zone as well. Thus, measurements must be spaced at intervals along the surf zone transect so that this horizontal distribution can be taken into account. Furthermore, since a proper measurement of instanteous depth values is critical in a zone where rapid bottom topographical changes are occurring continually, the system must be designed to also measure depth, or height of the water column.

In summary, if the above constraints are successfully met, then the estimated total longshore sediment flux (Q_{long}) could be expressed as:

$$Q_{long} = \int_{j=0}^{x} \int_{i=0}^{z} (C_{ij} V_{ij} dz) dx$$

where: x = width of transect; V_{ij} = longshore component of the flow at level i and horizontal position, j; z = vertical axis (or depth); C_{ij} = concentration of suspended sediments at level i and position j; and dz, dx = vertical and horizontal gradient, respectively.

It is evident that, in such an experiment, onshore-offshore sediment transport would at best be only qualitatively indicated, mainly from the flow direction measurements. Also, variations in longshore transport rate parallel to the shore would require additional transects. Such a three-dimensional approach is beyond the scope of this experiment.

DESIGN OF THE PROTOTYPE SYSTEM

After a thorough investigation of all the techniques described in the literature, we finally chose the profiling system described below. The system consists of a low-slung, rugged sled towed and positioned along a fixed cableway by a shore-based winch (Figure 1). The system was designed and constructed at the National Water Research Institute and was used for the first time during a program of field measurements carried out in late 1977. The main components of the system are:

1. The Surf Sled Instrument Platform

The Surf Sled, shown in Figure 2, was adapted from a similar concept described in Reimitz and Ross (1971) and Teleki et al (1976). It measures 2.84 m in length, 1.68 m in width, and stands approximately 30 cm high. Because of its open-work frame and welded 0.5 cm gauge aluminium plate construction, its total displacement in water was only 340 kg. The sled was fitted with wide (35 cm) runners or skis to minimize excess loading and penetration into the sand substrate. Hinged towing yokes are attached to both ends for towing the sled out and in. The flat, open-work top surface carries the sampling accessories, power and electronics packages, and recorder cylinders.

Protruding forward from one of the corners of the sled, and aligned parallel to its length, is a 1.5 m long rigid boom, framed in the shape of an elongated parallelogram, and articulated at the base. At the end of this boom is located the two-axis current sensors and the intake for the sampler pump. During field operations, the sled was intended to be configured with the boom pointing lakeward or in front of the sled body.

At each sampling position the boom is programmed to move to three vertical sampling/sensing positions: 10 cm, 30 cm, and 100 cm above the lake bottom. The lake bottom is defined as being 5 cm above the forward projection of the sled runners, to allow for some settling of the sled into the sand substrate. The power and switching systems for moving the boom are described in a later section.

2. Sampling System

The sampling pump used presently, a Jabsco 12 V D.C. Mini Puppy model, is mounted inside the power distribution box and draws through a sample intake at the end of the boom. The intake is equipped with a 2 mm mesh strainer to remove large objects which might damage or clog the system. From the pump, which provides twice the desired flow, the sample goes to a flow splitter. One half goes to waste and the other goes to the distribution valve. This is a rotary, 60 position, valve driven by a commercially available, air operated rotary table. This table is operated via a solenoid valve operated by a momentary, 0.1 second, 12 V pulse from the sequencer through a monostable circuit. The valve output is divided alternately into 30 waste and 30 sample positions. In operation the valve is held in the waste position for 15 seconds while the pump purges the lines and is then shifted to a sample position to fill a sample bag in the rack at the stern of the sled. The sample bags are slightly modified urinary

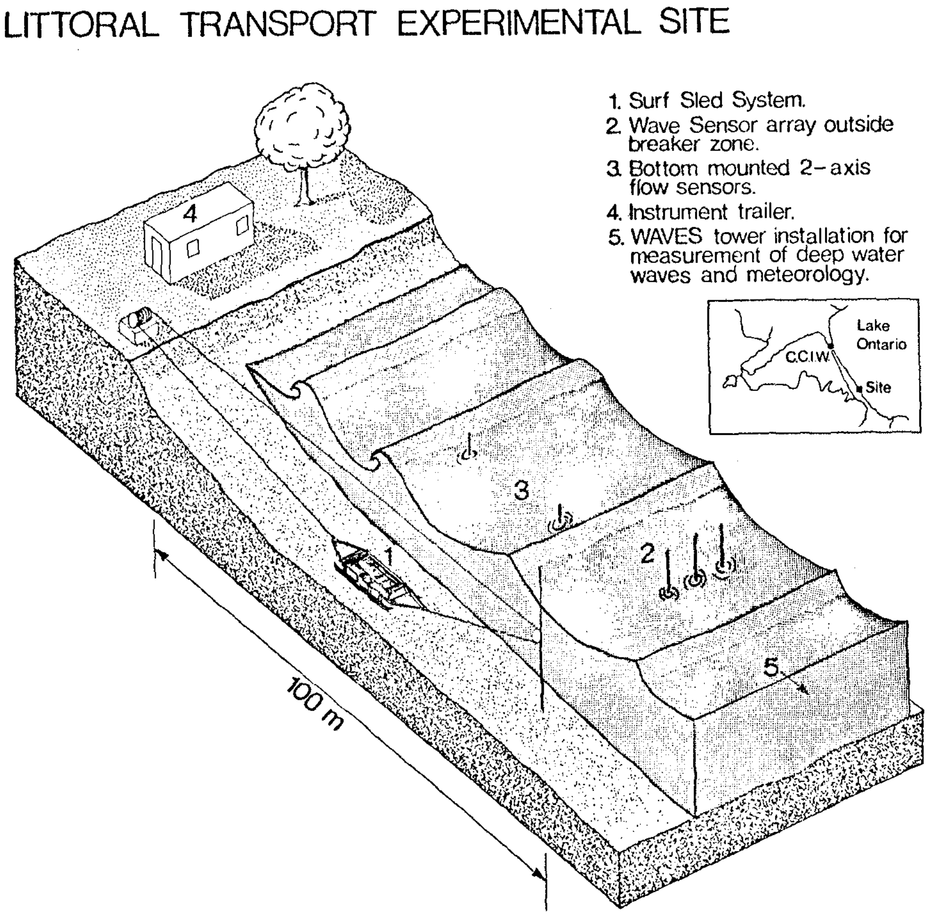

Figure 1 Sketch of the physical layout of the site where the system for profiling littoral drift was installed, showing winch-driven cableway and Surf Sled (not to scale). Other sensors for monitoring littoral processes are shown.

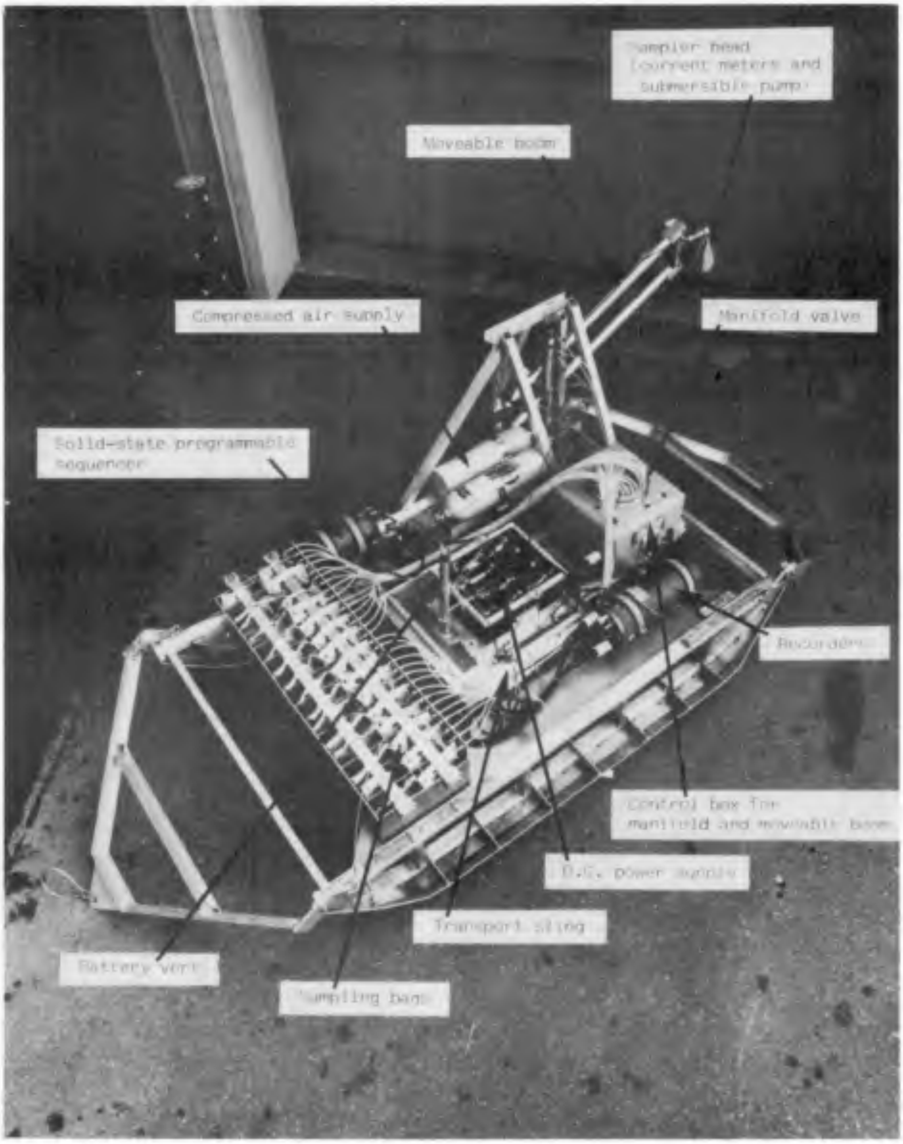

Figure 2 The Surf Sled, showing labelled major components. Overall length: 2.84 m.

catheterization bags, cutter Resiflex #950-19, with the air vent heat-sealed off. Sample size ranges from 1200-1800 ml of sand/water suspension.

3. Sensing and Recording Sub-System

The sensing of water flow is performed by two (Bendix B10 ducted impeller type) flow sensors mounted orthogonally, one above the other, at the end of the sled's 1.5 m moveable boom. The sensors have their central axes parallel to the horizontal plan and sense the water flow bidirectionally at the three preprogrammed boom positions, while suspended sediment samples are taken automatically just beneath them. The impellers of the sensors rotate and produce five pulses for each revolution. These pulses are converted to analog output which is 1 mV per 5.14 cm/s.

The sensing of instantaneous water depth is performed by a sensitive and fast (<.1 s response) pressure transducer (Gould PA 822-15) mounted on the sled platform 32 cm above the bed. The amplifier output is 18.4 mV/m.

The analog recording of water flow (two bidirectional axes "x" and "y") and the depth of the sled track is carried out by two Rustrak Potentiometric recorders (Model 3400 - dual channel for the x and y flow components, and model 400 - single channel for depth).

Two event markers are also used to record each boom position at a station on the x-y recorder and the arrival at each station on the depth recorder.

4. Programmable Sequencer and Control System

This apparatus controls, via timed electronic impulses to the various solenoid or on-off switching units, the sequence of functions performed by the sled during a sampling/sensing traverse of the surf zone. In brief, the system is activated on the beach prior to immersion and after a predetermined time lapse (sufficient to enable it to reach the first station), goes through the following sequence:

i) Pump is switched "on" at the exhaust mode; sampler arm is lowered by solenoid-controlled pneumatic action of both air cylinders to the lowest position (position 1-0.10 m above the bed). At this position, a switch on the moveable boom closes and causes an event mark to be made on the recorder chart. Exhaust mode lasts for 15 seconds exactly. This time is sufficient to purge the lines of water/sediment from the previous sample.

ii) Sampler is then switched (by solenoid impulse) to the sample mode and collects a sample over a period of 44 seconds.

iii) Solenoid switches sampler to exhaust mode; sampler arm rises to position 2 (0.30 m above the bed). This event is marked again on recorder. Exhaust cycle lasts for 15 seconds.

iv) Sampler is switched to sample mode, and collects a sample over a period of 44 seconds.

v) Sampler is switched to exhaust while the arm moves to position 3 (1.0 m above the bed); exhaust time - 15 seconds.

vi) Event marker indicates arrival at position 3 and sample mode is activated. Sample collected over a period of 44 seconds.

vii) Sequence ends and pump is shut off; event marked on both pressure and current records; sampler arm stays in "up" position; sampler itself switched to exhaust mode but this is not activated until the arrival at the next station when the pump is switched on again.

viii) Sled is towed to the next station where the above sequence is repeated. After the last station (up to 10 stations possible), all systems are shut down and the sled is returned to the beach for unloading and reactivation for the next run.

5. Power Supply Systems

i) The 12 V D.C. supply consists of two 150 A lead acid batteries arranged in parallel. The tops of the batteries are potted with polyester to electrically insulate all connections. Venting and pressure compensation are achieved by manifolding together all the battery vents and running the common vent line to the top of a sealed reservoir which is open at the bottom. The power is supplied through "E.O." connectors to the distribution box.

ii) The 115 V A.C. supply consists of an inverter, "Abbott KNGT-115-60, which draws 12 V D.C. from the terminal bus in the power distribution box and outputs up to 60 VA of 115 V 60 Hz sine wave power for driving the chart recorders.

iii) The compressed air supply consists of a pair of 224 m^3 capacity "SCUBA" cylinders and associated reducing valves. One cylinder is used to pressure compensate the power distribution box. The other provides air at 0.83 M Pa to move the sampling arm and the distribution valve via the solenoid valves.

6. Winch and Cableway

The sled is moved by means of a cableway extending 100 m out into the surf zone. The shore end terminates above the maximum wave runup point on the beach. Both ends of the cableway are secured to jetted-in piles which penetrate 5 m into the soil. The piles are in two parts joined with a bolted flange connection at ground level. A middle pile is located at the top of the beach 1 m away from the centreline of the cableway and carries an arm with sheaves to lift the cable over the abrupt change in slope at that point. The winch is housed in a sheet metal garden-type shed on shore and is of the friction wheel type having a 2.2 KW S.C.R. controlled motor through reduction gearing. The winch is free to move fore and aft on teflon sliders and tension is applied to the system by means of a counterweight and multiple purchase. The tension in each leg of the 9.5 mm diameter wire rope is approximately 7.8 KN which is sufficient to provide traction on the winch drive wheel and to avoid whipping caused by wave action yet provide an adequate safety factor.

The offshore pile is guyed to eight anchors jetted into a depth of 5 m and the two onshore piles are unguyed. Grease nipples and bronze sleeves are fitted to all sheaves.

An electronic meter wheel indicates the position of the sled to the nearest 1 m. The cable is also marked to give an emergency stop point should the meter wheel fail.

FIELD OPERATIONS

The system described above was tested and used in littoral drift studies during the fall of 1977. The field operations were located at Hamilton Beach at the western end of Lake Ontario (see inset, Figure 1). Length of the surf zone transect was approximately 100 m (cableway length was 135 m) and the transect terminated in roughly 3.5 m of water.

During the period October 21 - December 5, 1977, a total of 16 experiments, covering moderate to storm-wave conditions, were carried out. In spite of breaking waves as high as 3 m, the system suffered no structural damage. Seven of the runs yielded complete data sets, i.e. full sample bags and complete depth/flow records.

PRELIMINARY RESULTS

1. Reproducibility

In order to test the reproducibility of the measured data, the sled was positioned at a station roughly midway across the transect (depth 1.4 m) over a full cycle. Figure 3 shows the plotted results from a series of seven complete vertical profiles taken at that location. In spite of the small sample size, the results show reasonable internal consistency.

2. Effect of Sled on Flow and Suspension

Two tests of this effect were carried out. One involved the visual inspection of the sled operation by divers. This test was, of necessity, carried out in moderate wave conditions. However, the divers noted no resuspension phenomena that were obviously related to the presence of the sled in the oscillating flow field caused by the waves.

The second test was carried out during a storm and involved the reversing of the sensor/sampler boom position with respect to the sled, i.e. the sled's normal confirmation was altered so that these components were on the landward side. This placed them in the lee of the propogation direction of the wave bore. The discharge results obtained in this configuration were more than double those of a run immediately preceding it, in which the normal forward configuration of the sensor/sampler head was used (1050 m^3/hr versus 440 m^3/hr). This indicates clearly that there is a sled effect on the discharge quantitites calculated, and that the reversed configuration clearly overestimates the actual discharge. However, we do not yet know whether there is an appreciable sled effect on discharge values obtained using the normal configuration during storms. Experiments are presently being planned to investigate this further using a scale model and simulated wave conditions inside the HRD wind/wave flume.

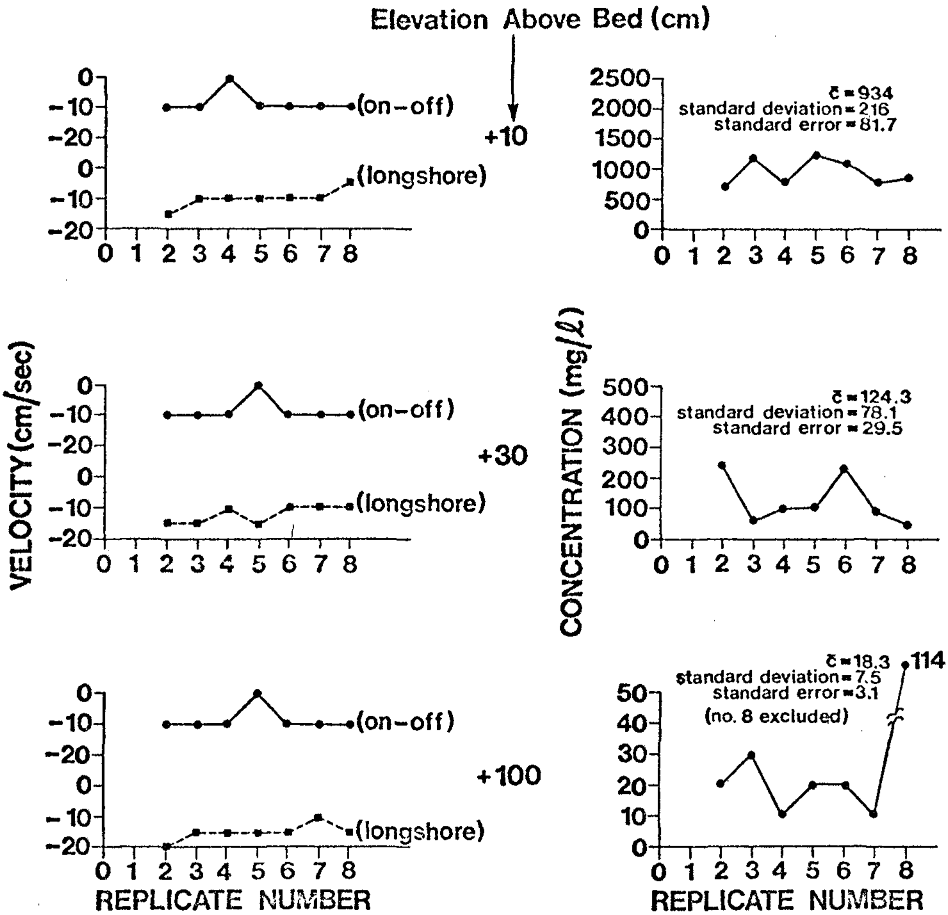

Figure 3 Plot of replicate measurements of two-axis flow velocity and concentration at a single station along the surf zone transect. The station was located 50 m from the shoreline at a depth of 1.4 m. Wave parameters during the run were: significant wave height - 0.8 m, and period - 2.5 s. For the flow values, negative indicates on-shore (on-offshore component) or toward the North (longshore component).

3. Magnitude and Distribution of Suspended Sediment Discharge

As stated previously, the number of complete data sets (flow velocity/suspended sediment concentration couples) is at this time too small to allow any broad statement on transport rates to be made. Furthermore, due to the fact that dry-weight/volume concentrations were used, we might want to revise the analysis procedure at some later date to make it more comparable with other studies. Nevertheless, in order to illustrate the final results of the system, we present a plot of the variables (concentration, longshore component of flow, calculated discharge versus distance along the surf-zone transect for a single experiment conducted during a severe storm on December 5, 1977 (Figure 4). Wave statistics were as follows: H_s-186 cm, T_s-6.1 sec, and wave angle -1.8^o. These wave data were measured during the experiment at a three-staff wave array just outside the breaker zone in 5 m of water (Figure 1). Waves at the time were mostly of the plunging type. The value shown for discharge is based on a dry weight-to-volume conversion factor of 1600 kg to 1 m .

The data appear to have an expectedly high variability both in time and space, so any further discussion of the results ought to await the collection of a more statistically valid data base. To this end, we are continuing our data collection into at least the winter of 1978 and spring of 1979.

CONCLUSIONS

The system described above was designed and constructed to collect profile data on suspended sediment concentration and flows velocity across a transect spanning the surf zone of western Lake Ontario. Experiments carried out to date have demonstrated that the system functioned well under conditions which at times exceeded the design criteria.

Because of the small data base compiled thus far, a full data analysis is still in the initial stages. However, preliminary analysis indicates that the figures obtained are reasonable and internally consistent.

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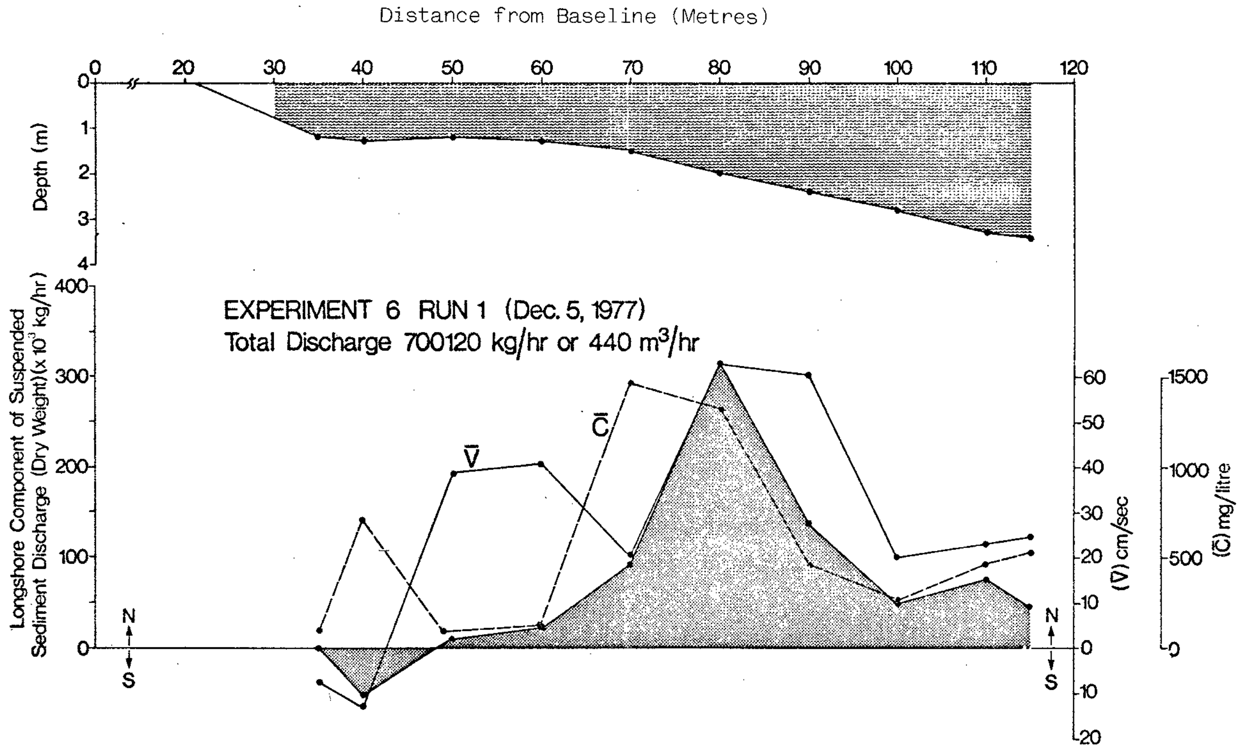

Figure 4 Sample distribution of depth-averaged longshore current velocity, suspended sediment concentration, and calculated suspended sediment discharge (shaded) across the surf zone transect for a single profiling run. At the top is shown the depth profile recorded by the sled.

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