Hydraulics Research
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# A NEW PUMP SAMPLING ARRAY FOR MEASURING THE FLUX OF FINE SAND SUSPENSIONS

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## ABSTRACT

An account is given of the development of a boat-borne system suitable for measuring near-bed suspended sand fluxes in deep fast flows. The underwater part of the system comprises a frame designed to rest on the river or sea-bed and supporting current meters and pump samplers at three levels over the bottom 0.6m of the flow. The unit retains the advantage of HR's standard sand flux samplers in extracting the sediment from large volumes of pumped water. It differs, however, from earlier versions in that the pumps and filtration are self-contained to the submerged frame rather than on the attendant boat, thus avoiding any need for a full-depth pump hose between the bed and the boat. Field trials of the new systems are described and confirm that it will offer distinct advantages in its ease of handling and operation when current drag is excessive.

**CONTENTS**

# 1 INTRODUCTION

Information on sediment mobility is often essential for judging the viability or environmental impact of engineering developments on estuaries and coasts. Maintenance of existing shipping access, the prediction of infill rates of proposed channels, and the changes in sediment behaviour brought about by reclamation works, are just a few examples where reliable site-specific and quantitative data on presentday sediment movement is essential.

It would be highly desirable if the sediment flux could be inferred from a knowledge of the water flow characteristics taken in conjunction with the size composition of the surface bed sediments. There is certainly a wealth of formulae for this purpose but they are principally founded on laboratory flume studies and none have gained general acceptance. The reluctance to accept the empirical formulae is attributable to the large divergence in transport values derived from the individual formulae; the high sensitivity of transport to changing flow velocity or shear; and lastly, the difficulty in the field case of assigning values to certain parameters that feature in the formulae, such as bed roughness. Where time and money allow, our preference, at least for those cases where sediment is moving primarily in suspension or by siltation rather than as bed-contact load, is to rely on direct measurement of sediment flux.

The present report describes the latest in a range of pump sampling arrays that Hydraulics Research have developed over the years to improve its capability of tackling such measurements in nature.

## 2 PRINCIPLE OF MEASUREMENT

The transport of sediment per unit width of channel can be determined from measurements of full-depth profiles of horizontal water velocity and of sediment concentration. In the case of fine sand travelling in suspension it is also desirable to know the size grading of the sediment over the depth profile. The standard approach is to measure the velocity, and to sample the concentration of individual size fractions at say ten different heights above the bed. Theoretical profiles are fitted to each set of ten points. Assuming the water body is well-mixed and acceleration/deceleration effects are small enough to be ignored, best-fit profiles are computed from:

$$u_y = u + 5.75u_* \log_{10} \frac{y}{d} + 2.5\ u_*$$

where $u_y$ = velocity at height y above the bed
$u$ = mean velocity
$u_*$ = shear velocity
$y$ = height above the bed
$d$ = flow depth

and $$c_y = c_{0.5d} \left(\frac{d-y}{y}\right)^z$$

where $c_y$ = concentration at height y above the bed for a single size fraction

$c_{0.5d}$ = mid-depth concentration for a single size fraction

$z$ = exponent which is part dependent on the fall velocity of the particles.

The total flux for each sediment fraction can then be derived by integration of uc(y) taken from theoretical profile pairs. Although extending to the nominal crest level of the bed irregularities the integration accounts only for sediment that is fully supported by the water. It neglects any transport occurring as surface creep where the grains are supported by the bed itself. Although the latter may be important in the movement of medium and coarse sands it is not considered to make a significant contribution to the fine sand transport that predominates in typical estuarial flows in Britain.

# 3 STANDARD PUMP SAMPLERS DEVELOPED BY HYDRAULICS RESEARCH

It is seen from the previous section that fine sand transport measurements are founded on accurately defining the depth profile of velocity and concentration. It follows that particular emphasis has to be placed on measurements in the near-bed zone, say from 0 to 60cm above the bed, where not only is the flux at its maximum but where the sand concentration and velocity gradients are steepest. Over the past 15 years Hydraulics Research have spent considerable effort on devising systems for accurate profiling in this near-bed zone. Frames that can be lowered to rest on the sea-bed and serve as a reference datum for traversing the bottom flow with a sampling intake and velocity meter have been developed. The reasons for the selection of pump sampling and in-line sediment filtration which are common to most of the systems are explained in Refs 1 and 2 together with descriptions of the various assemblies devised for differing flow environments. Sand flux frames 1 and 2 (SAFF1 and SAFF2) which are illustrated in Plates 1 and 2 respectively, have emerged today as the most widely used of these units. Backed by complementary pump sampling and flow measurements at points from one metre above the bed to the water surface using a wire-suspended package lowered and raised from the attendant vessel, the two units have been employed at numerous locations in the UK and overseas.

Both SAFF1 and SAFF2 carry a single measuring head, comprising a sampling intake and propellor or electromagnetic current meter, that can be positioned accurately with reference to the bed. With both instruments measurements at various heights are made serially. SAFF2 is a light-weight version designed for river or shallow estuary work from small survey craft (say 7 to 8m length). SAFF1 on the other hand is a much larger, difficult-to-handle system intended for more adverse working environments from vessels equipped with heavy winching facilities.

All systems developed by HR depend on a pumping line to connect the bed frame to the attendant vessel on which the filtration is carried out. In attempting measurements of sand flux for the pre-feasibility study of the Severn Tidal Barrage shortcomings were encountered in the operation of SAFF1 in the deep and fast flows of the Severn Estuary.

The main difficulty arose from the handling and stability of the frame when such high stream drag was put on the bulky umbilical that ran from bed to water surface. Data return on sand flux from the Severn study was poor and prompted the development of a third system, SAFF3, under the present contract, in an attempt to overcome the earlier problems. The design objective was to eliminate the largest component of the umbilical, namely the pumping line, by transferring the pumping and sediment filtration functions to the bed frame rather than on the deck of the boat. Adoption of this alternative brings about changes in operational practice compared with the earlier systems and these together with the major features of the design are described in the next section.

## 4 INSTRUMENT DESCRIPTION

SAFF3 is a three-channel sampling system. The support frame, shown in Plate 3, may be raised and lowered by its 12mm diameter electro-mechanical cable. This purpose-made cable incorporates 14 individual electrical conductors, a central Kevlar strain member and an overall polyurethane sheath. A large-area vertical fin attached to the rear of the frame assists in alignment with the flow as the frame is lowered to the bed. The sampling nozzles and current meters are attached to a smaller secondary fin, which is free to move about a vertical support bar, ensuring good flow alignment during sampling.

The main frame is constructed largely from aluminium alloy for ease of transport and additional weight is added on-site by loading each of 125mm diameter base tubes with lead ingots. The vertical sampler support bar, made from 32mm diameter stainless steel, slides in upper and lower bearings and has a 230mm diameter bed contact plate at its lower end. The lifting cable is attached to the upper end of this bar. When the frame is lowered to the bed, as soon as the base tubes touch the bed, weight is taken off the lowering cable allowing the vertical support bar to slide downwards. This descent is arrested when the contact plate touches the bed. The intake nozzles and current meters may be adjusted prior to deployment over the vertical range 50 to 850 mm from the bed contact datum.

The main dimensions and weights of SAFF3 are given in the following table:

Table 1 - Main dimensions and weights of SAFF3

| | | |
|---|---|---|
| Weight in air | - | Frame 80 kg |
| | - | Each lead ballast weight 12kg |
| | - | Frame and maximum of 12 ballast weights 224 kg. |
| Dimensions | - | Overall height 1.1m |
| | - | Base 1.3m long x 1.5m wide |

A block diagram showing the main component parts of one sampling channel is shown in Fig 1. An 8mm bore intake nozzle is connected to an in-line filter holder. The filter holder, which is mounted at the top of the support frame (see Plate 3), holds a 140mm diameter 40 $\mu$m pore size polyester filter, similar to those used in the SAFF1 and SAFF2 filtration units.

A low-power 12 volt submersible pump (Mag 12) connected to the downstream side of the filter, pumps water from the intake nozzle through the filter and discharges the filtrate via an impeller-type water flow meter (Platon Litre Meter).

The in-board control and display unit (Plate 4) gives an analogue display of flow rate and a digital display of total volume pumped through the filter. The pumping rate is monitored to ensure that a line velocity in excess of 1 m/s is maintained throughout the sampling period.

At each water sampling level a miniature Braystoke current meter is attached to measure the ambient velocity during the sampling period. The pulse output of the Braystoke meter is counted for 100 seconds and displayed on a second digital meter.

Suspended sediment finer than 40$\mu$ m is not captured representatively by the polyester filter. In order to obtain the concentration of this finer fraction of the load an independent 500 ml water sampler was incorporated on the sampling frame. The "CB" water sampler, described fully in Ref.3, is made from 50mm i.d. brass tube coated in vinyl plastic. The tube is sealed at each end by hard rubber balls which are connected together through the mechanism in a tensioned fuseable link. The rubber ball seals are held open by attachment to this fuseable link. To fire the mechanism and hence trap the water sample, a current sufficient to blow the fuse is passed through the firing circuit. The current is monitored on an ammeter and the moment of closure of the sampler, ie. when the fuse blows, is clearly indicated. The trapped water sample is collected for subsequent laboratory analysis.

A detailed circuit diagram of the three channels of the SAFF3 electrical and electronic circuitry is shown in Fig.2.

Incorporated in the circuitry are three "limit" indicators. Channel 1 incorporates a mercury switch, which is housed in the underwater unit, to indicate the horizontal attitude of the support frame. If the frame is greater than 20° from the horizontal in any direction the mercury switch opens and a green light emitting diode (LED), connected across the pump supply switch, remains off. The pump in this channel will not operate unless the level switch is within the 20° tolerance.

In Channel 2 a similar LED indicator is operated from a reed switch incorporated in the vertical support bar of the bed frame. The support bar, (and hence bed contact plate), has a vertical travel range of 200mm ie. ±100mm from the base level of the main bed support tubes. The green LED in Channel 2 remains on so long as the bed contact plate is less than 100mm above the base level of the support tubes and the pump supply switch is off.

Similarly the green LED in Channel 3 remains on so long as the bed contact plate is less than 100mm below the base level of the support tubes and its pump supply switch is off.

Each of the three sampling channels is powered by an individual 24 volt d.c. supply and draws a current of 1 amp when the sampling pump is running. Voltage drop down the cable reduces the supply to the underwater pump and the litre meter to about 12 volts. The "CB" water sampler triggering supply is obtained by connecting the three 24 volt supplies in series.

## 5 FIELD TRIALS

April 1981

An initial evaluation of the SAFF3 operating principle was carried out in the Severn Estuary in April 1981. At that time HR was carrying out preliminary studies associated with the proposed Severn tidal barrage scheme. The field measurement programme included sand flux determination at two sites in the estuary using the SAFF1 system. It was decided to evaluate at the same time a single channel version of SAFF3 using an existing steel bed frame and incorporating the underwater filtration unit.

Promising results were obtained from the short exercise and this led to the longer-term development programme covered by the present contract.

Summer 1983

The prototype version of the three-channel SAFF3 system was completed in early 1983. Laboratory tests were carried out in order to check the operation of the system and to calibrate the flowmeters.

In July 1983 a field trial of the system was undertaken. The HR survey vessel "Sir Claude Inglis" was at that time engaged in hydrographic measurements off Orford Ness, Suffolk. The opportunity was taken of using this vessel to carry out the initial trials of SAFF3.

The trials were carried out close to the mouth of the river Ore. At this location peak velocities of up to 2 m/s are experienced on spring tides and it was anticipated that significant amounts of sand would be carried in suspension. Measurements were undertaken throughout the ebb period of a spring tide. Water depths at the site were relatively shallow (maximum 7m) but the high velocities gave a useful test of the handling performance of the bed frame. No difficulties were experienced in handling the unit and good flow alignment was confirmed. During the course of the measurement a design fault on the filtration unit became apparent. The siphoning of water contained within the filter holder back through the intake nozzle when the bed frame was brought to the surface was seen to be removing some of the filtered sediment. Apart from this deficiency, control and operation of the system was found to be satisfactory. Laboratory tests were carried out to find a simple remedy for the siphoning problem. Various types of one-way valve on the intake line were tried but with high sediment concentration these valves invariably became clogged. The problem was finally resolved by redesigning the filter holder. The intake orifice was enlarged and displaced further from the filter surface. This modification reduced the flow velocity out of the holder and thereby prevented re-suspension of the sediment contained on the filter.

March 1985

A field trial of the modified 3-channel SAFF3 system was carried out in the Conwy narrows, Conwy Estuary, N. Wales in March 1985. A previous HR study had shown this location to have relatively high concentrations of suspended sand, particularly during the ebb flow period.

The main purpose of this trial was to investigate the effectiveness of the redesigned filtration system. It was decided therefore to take simultaneous measurements using the SAFF3 and a SAFF2 system and to compare the results obtained from the two.

Measurements were taken from a hired fishing vessel throughout the ebb period of a mean tide. The SAFF3 system was handled over the starboard side of the vessel and the SAFF2 system over the port side, giving a lateral separation of some 5 metres between the two sampling positions. Concurrent measurements were taken using a wire-suspended rig operated from the stern of the vessel in order to obtain data in the water column from 1m above the bed to the water surface. This suspended rig consisted of a Braystoke 001 current meter, a streamlined weight, an echo sounder for elevation control, a sampling nozzle and a hose to surface pump and filtration unit.

## 6 RESULTS OF SAFF3/ SAFF2 COMPARISON

In the course of six hours operations on the Conwy Estuary eight profiles of near-simultaneous velocity readings and water/sediment samples were taken on the two frames at nominal elevations of 0.1, 0.3 and 0.6m above the bed. Not surprisingly the individual velocity readings (integrated over 100s) display some scatter but no significant systematic differencies between SAFF3 and SAFF2 (Fig 3).

On the other hand, the suspended sediment concentrations (Fig 4) suggest that relative to SAFF2, SAFF3 was under-registering concentration and the difference increased with particle size. No satisfactory explanation has been found for this discrepancy. The pumping line velocity was well in excess of the required $1ms^{-1}$ on both frames. The intake velocity/ambient velocity ratios during sampling were too close for flow acceleration to account for SAFF3 under-sampling of the order of 20, 35 and 55 per cent for the 100 to 150, 150 to 250 and greater than 250$\mu$ m sediment, respectively. There is no suggestion from the velocity data that SAFF2 intakes were closer to the bed's surface and thereby biased to higher concentrations. Data obtained at the lowest position (1.0m) occupied by the wire-suspended rig, referred to at the end of the previous section, agreed more closely with SAFF2 than with SAFF3.

In the absence of any other plausible explanation we can only postulate that despite the proximity of the two frames there was a difference in the composition of the local bed material. Perhaps SAFF3 was at a disadvantage in being located downstream of the source that was locally deficient in the fine and medium sands that contributed to the load sampled by SAFF2 as well as to the wire-suspended rig.

## 7 CONCLUSIONS

A further system, adding to HR's range of sand flux samplers, has been developed and field tested. The new system, SAFF3, is specifically intended for measurements in difficult working environments of deep fast flows.

The handling and general operation of the three-channel unit has been demonstrated as satisfactory. However, differences disclosed by a recent field comparison between the new system and one of HR's well-tried standard samplers, gives cause for concern with regard to its sampling efficiency. In view of the apparent underregistration of sediment concentration it will be prudent to subject the new unit to further comparative tests under field operating conditions.

## 8 REFERENCES


1. Pump Samplers for measuring Sand Transport in Tidal Waters - M J Crickmore and R F Aked. IERE Conference on Instrumentation in Oceanography, Bangor, N Wales, September 1975.

2. Recent developments in pump samplers for the measurement of sand transport. M J Crickmore and C J Teal. Proc. IAHS Symposium - Erosion and Sediment Transport Measurement - Florence, June 1981.

3. A novel remotely-monitored water sampler - C B Waters - IERE Conference - Electronics for Ocean Technology, Birmingham, UK, September 1981.

## Plates

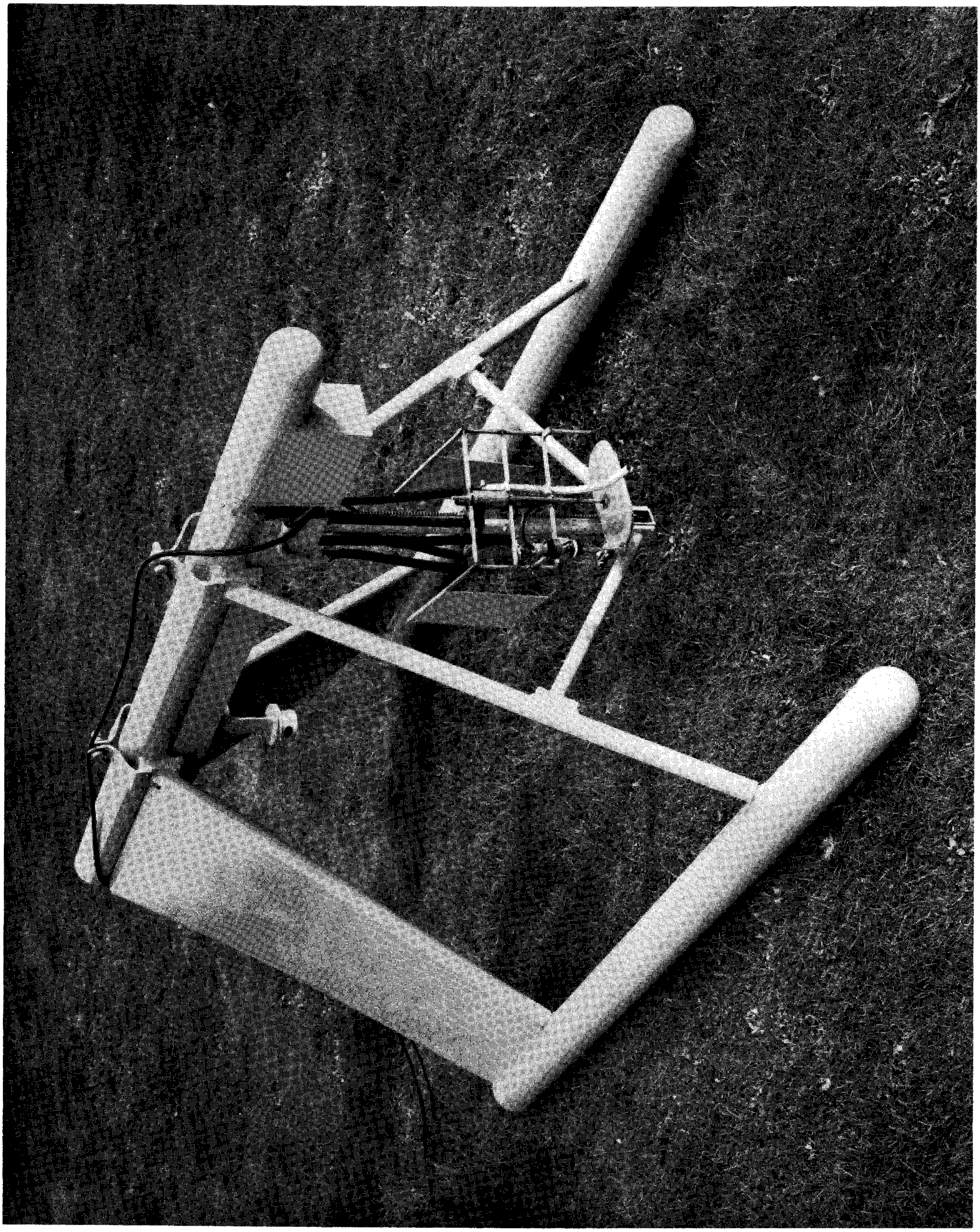

**PLATE 1** SAFF1 - Bed frame with motor controlled traversing head

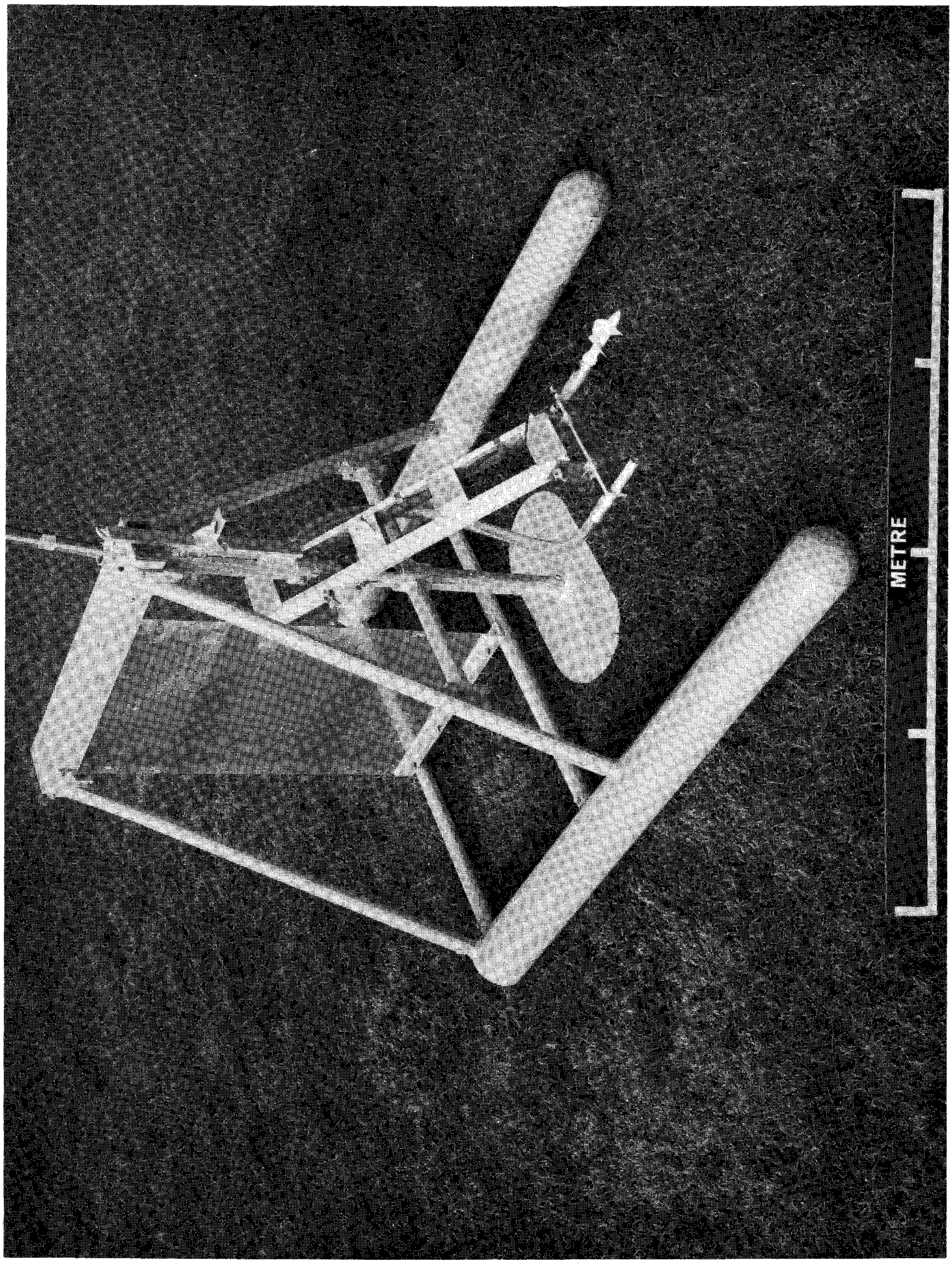


**PLATE 2** SAFF2 - Lightweight bed frame with cable controlled traversing head.

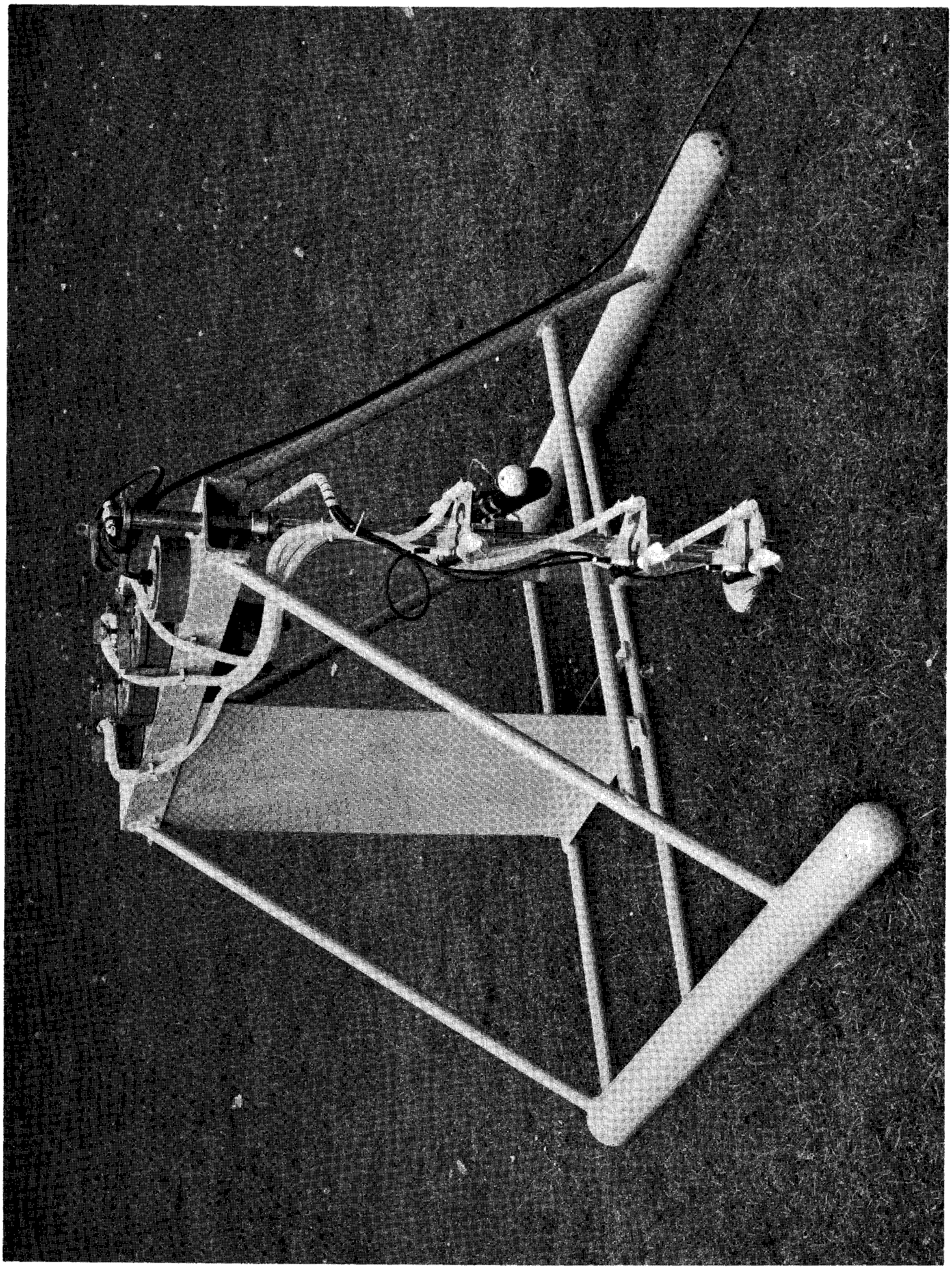

**PLATE 3** SAFF3 - Bed frame with adjustable multi-level sampling and self-contained filtration units.

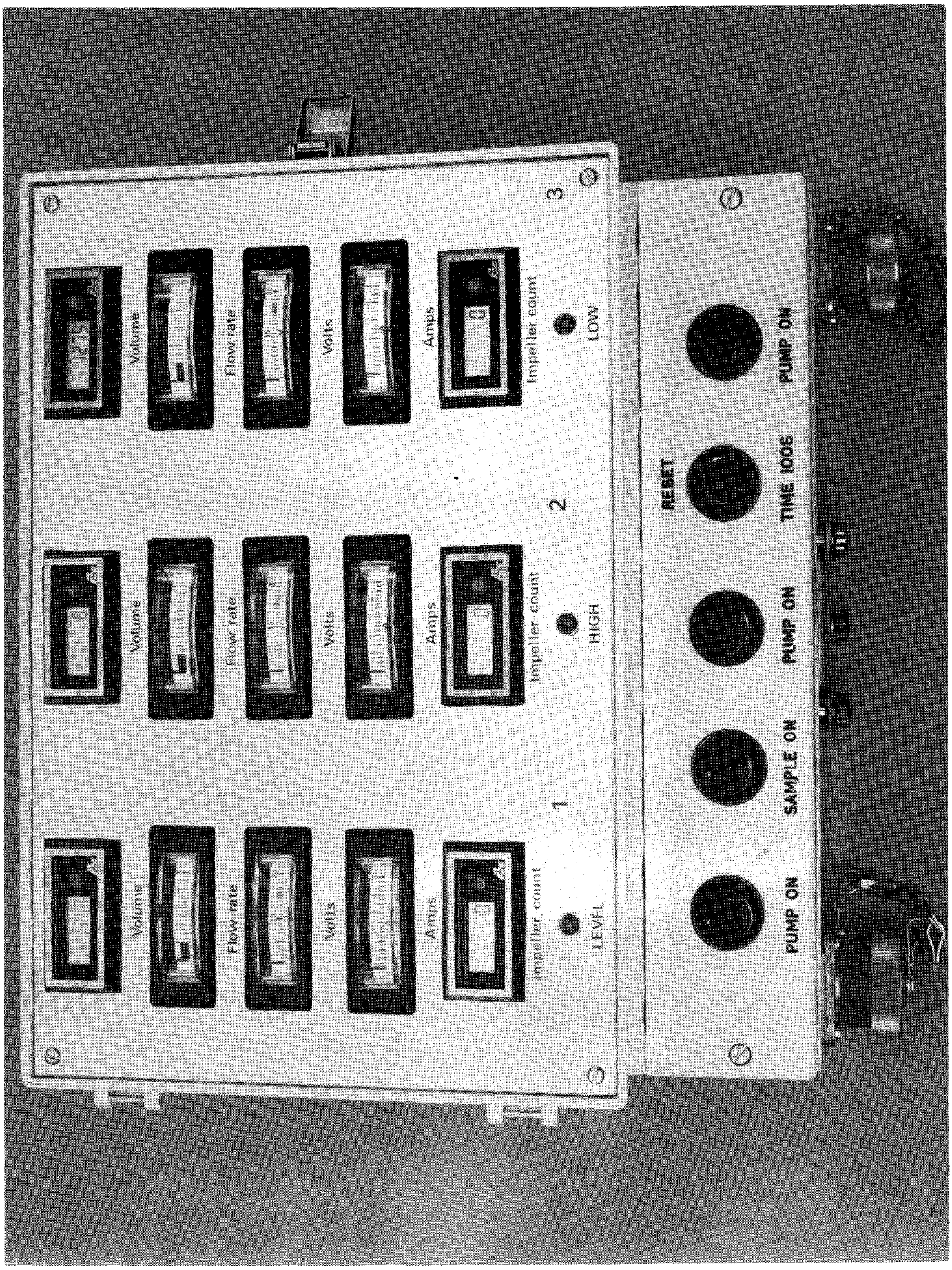


**PLATE 4** The inboard control and display unit.

## Figures

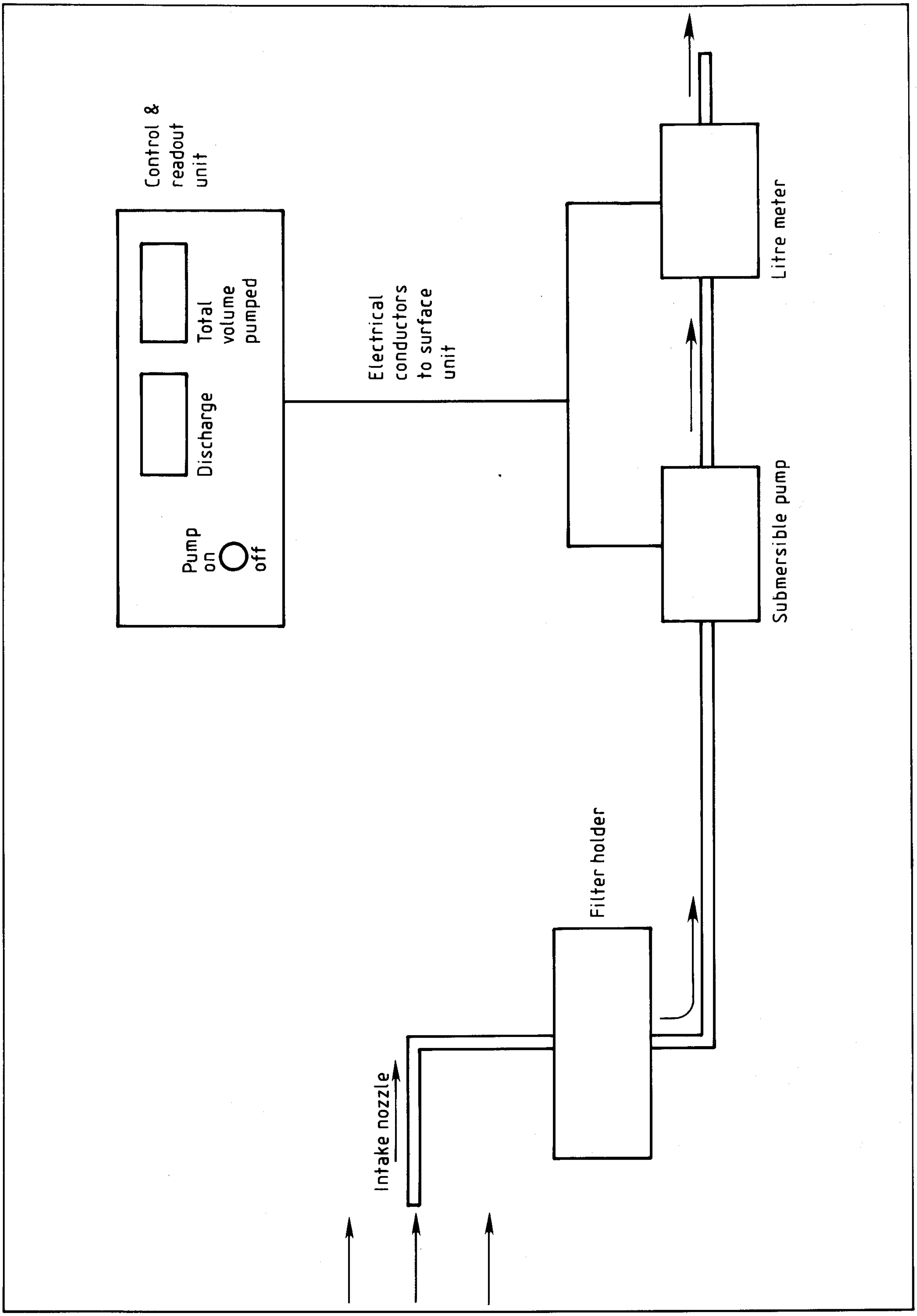


Fig 1 Block diagram of one channel of SAFF 3

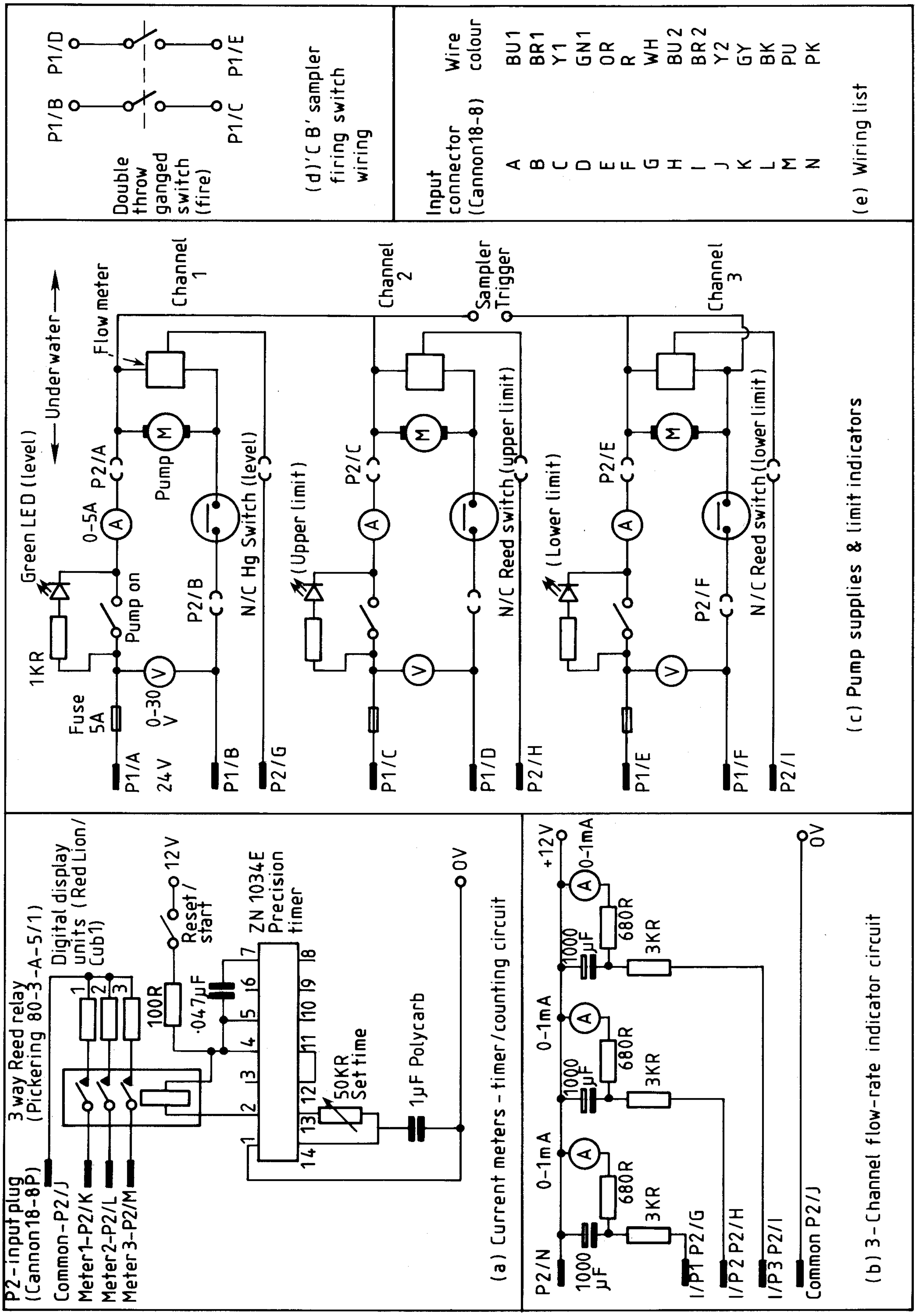


Fig 2 Circuit diagrams

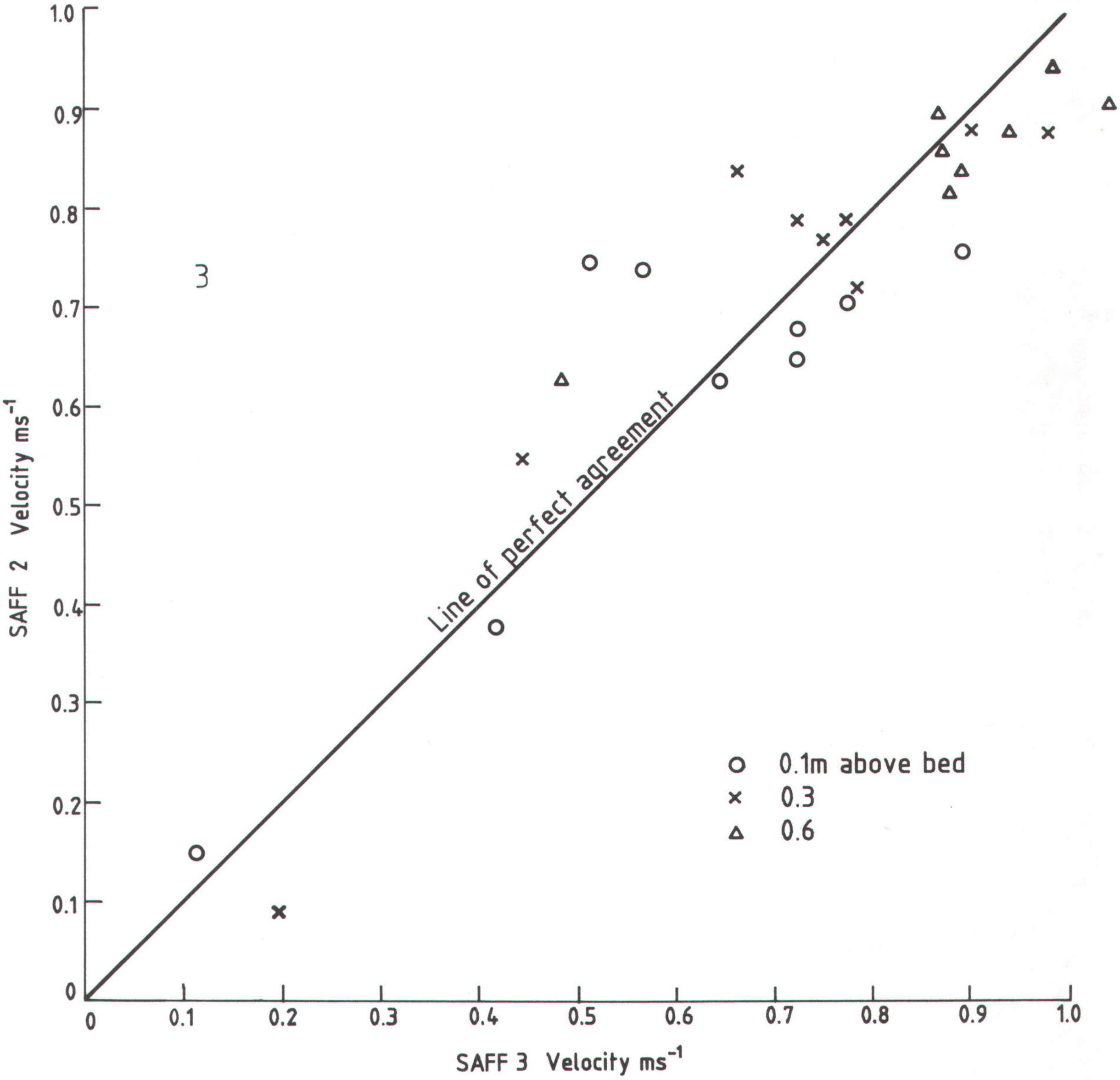


Fig 3 Comparison of velocity data, SAFF 3 vs SAFF 2

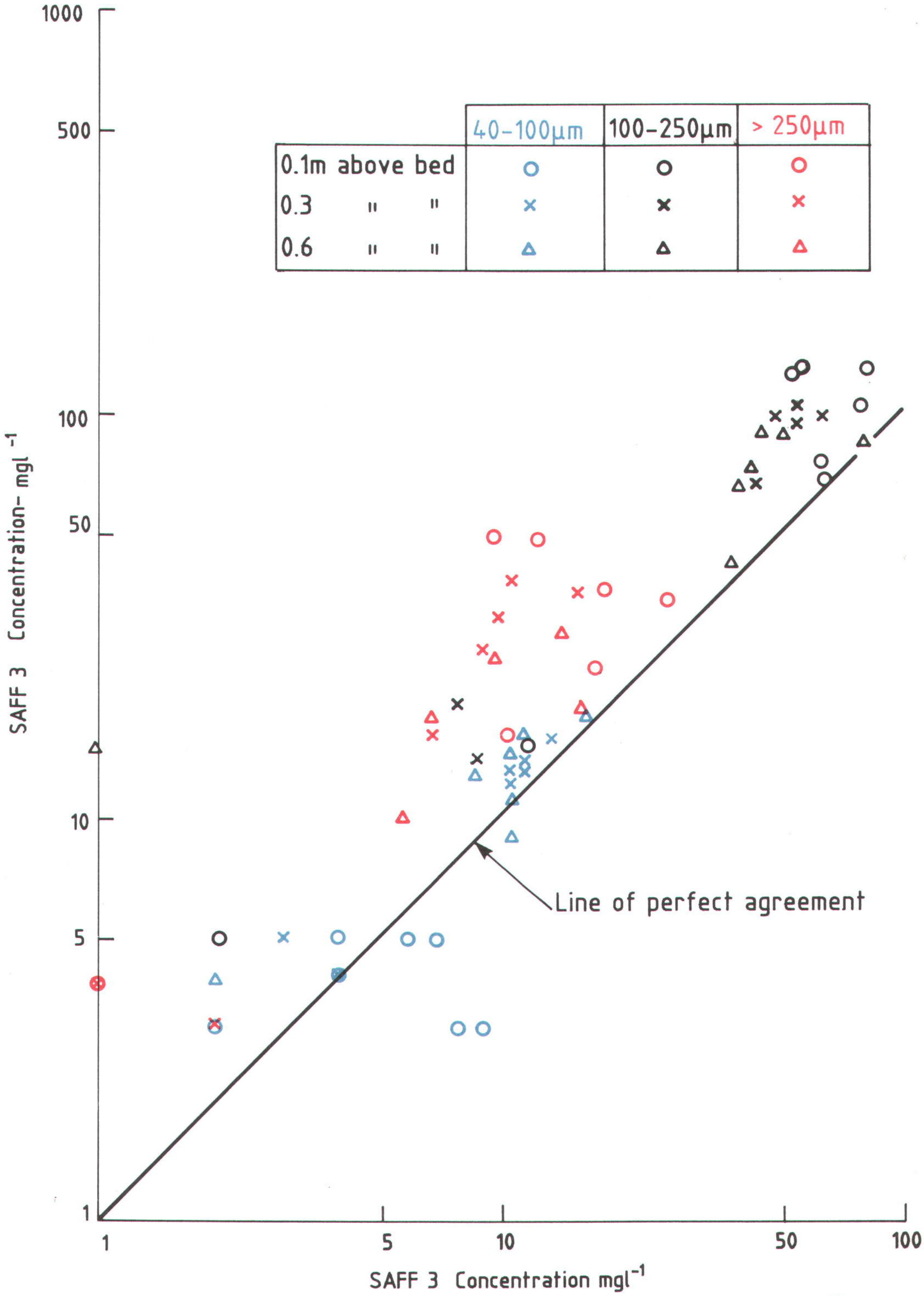


Fig 4 Comparison of concentration data, SAFF 3 vs SAFF 2