Development of a depth-integrating water sampler

Bengt Nilsson

UNGI Rapport 2

Nilsson, B., 1969: **Development of a depth-integrating water sampler.** *UNGI Rapport* 2, 17 pp.
Uppsala University, Department of Physical Geography, ISSN 0375-8109.

1.1 General

The movements of the investigated object in space and in relation to the water has a decisive consequence on the sampling method. If the relative movements are negligible the object is homogeneously mixed within the water volume if the water itself is homogeneous. Such a water quantity may slowly move into another water volume as an interflow spreading out at a level corresponding to the density of the volume. Thus a homogeneous water volume becomes inhomogeneous and the object concentration may differ horisontally as well as vertically. These two different mixings occur in lakes where the flow-through is very slow.

The movements in running water are often very irregular. Consequently the concentration of extraneous bodies within the water may differ very rapidly. If the object movements in the water are negligible the concentration of it may be constant in a whole cross-section. The object is then homogeneously mixed. If the sampling point is situated downstream from the inflow of a tributary river there may be horisontal concentration differences that may be sustained for a long distance downstream.

When the investigated object moves in relation to the water the concentration also may vary vertically. The concentration of suspended material for instance, varies depending on i.a. grain-size, water velocity and degreee of turbulence. When macroturbulent bodies of water move downstream with the main flow the object concentration will vary even during sampling time.

This summing up demonstrates the difficulties in collecting a representative sample. If the object is homogeneously mixed only one sample collected at any place in the cross-section is needed. The sample may be collected instantaneously. For inhomogeneously mixed objects there must be different sampling methods depending on how the concentration of the object varies.

In almost stagnant water several samples must be collected at different depths in each vertical of the cross-section. To adjust small concentration divergences that may occur during sampling time a sample, collected by carefully pumping up the required volume is to be prefered.

Samples collected in running water must be corrected for differences in water velocity. If macroturbulence causes larger concentration variations, within for instance one minute, than the variations caused by the object movements, due to the settling velocity, the sample should be collected with a time- or point-integrating sampler in at least four points per vertical (Hjulström 1939, p. 68).

Such a sampler usually consists of a container cased in a heavy fusiformed body. The container is filled through an inflow tube and the air in the container is exhausted through another tube. The tubes are usually placed and designed in such a way that the inflow is equal to the natural water-flow in velocity and direction.

Before the sampler is opened at the depth of submergence the air in the container must be compressed from its atmospheric pressure to the hydrostatic pressure at that depth.

When using a good time-integrating sampler all samples from one vertical may be put together into one representative comprehensive sample, provided that the filling time is the same for all samples.

A cross-section where the concentration variation during sampling time is smaller than the vertical variation is, however, to be prefered. A depth-integrating sampler is then the most suitable to use. The inflow in this is continuous when the sampler is lowered to the bottom and again hoisted to the surface. If the intake velocity is the same as that of the external flow at every point in the vertical the sample is representative for the whole vertical. The variation in the concentration with time is partly compensated for by the passage of each level at two different times. Depth-integrating samplers are commonly used in large research programs of sediment transport.

2 REQUIRED CHARACTERISTICS FOR DEPTH-INTEGRATING SAMPLERS

a "The sampler must fill at a rate proportional to the stream velocity". .....

b "The intake nozzle should point into the stream and protude ahead of the sampler". ....

c "Sampler should be smooth filling". ....

d Sudden inrush must be avoided.

e The sample container should be removable.

f "Sampler should permit sampling close to the stream bed". ....

g Some general features in design.

(Quoted from "A study of methods used in measurement and analysis of sediment loads in streams", Report No 6, Hydr. Lab. Univ. Iowa, 1952)1)

Some comments to the above characteristics will be given below:

a If the proportionality factor is assumed to be equal to the area of the intake tube, the sampler will fill at such a rate that the velocity in the nozzle at point of intake is equal to the local stream velocity. This is a principal condition reflected in most of the points mentioned above. Even small differences in intake velocity give big errors in concentration and are difficult to avoid. The energy required to alter the velocity vector is a function of particle density. Consequently the sediment concentration will be too low if the intake velocity is higher than the stream velocity and visa versa (see Fig. 1). This relationship has been verified in a laboratory test. (Report No 5, 1941. Hydr. Lab. Univ. Iowa.)

b This condition is partly a consequence of point a. If the inflow is too near the body of the sampler the streamlines into the nozzle will be disturbed and the direction of the flow will change. The orifice of the inflow tube should be perpendicular to the streamflow, but deviations up to 20° have small effect upon the sediment concentration (Report No 5, Hydr. Lab. Univ. Iowa, 1941, p. 96). It should be noted that this maximum angle limits the transit rate of the sampler. The angle between the stream velocity vector and the resulting vector and the transit vector must not exceed 20°. For practical reasons the maximum transit rate is usually stated to be 4/10 of the mean velocity in the vertical (Report No 14, Hydr. Lab. Univ. Iowa, 1963, p. 44). This limit also takes into consideration the relationship of inflow velocity and pressure changes due to the depth.

c In order to get a smooth inflow that varies with water velocity the air exhaust must be separated from the intake tube.

d When a sampler without a pressure-equalizing device is opened

---

1) Will be shortened "Report No ...., Hydr. Lab. Univ. Iowa"

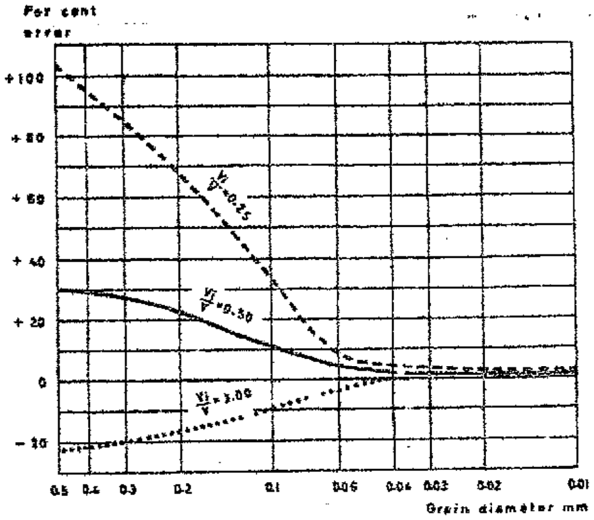

Fig. 1

Percentage error in the sediment concentration of water samples for various inflow conditions plotted against the grain size. Inflow tube pointing into the approaching flow. V_1 = inflow velocity. V = flow velocity in the free water (after Sundborg 1956).

below the surface the pressure will be equalized by a sudden inrush of water. At a depth of for instance 10 m the container is half-filled within a second or two.

If a depth-integrating sampler is lowered too rapidly there will be too low a pressure in the container which will be compensated by a higher inflow rate than the local stream velocity. On the other hand, if the sampler is raised up too rapidly there will be too high a pressure in the container causing too low an inflow.

e The desire of a removable container depends on the fact that the sediment particles often tend to adhere to the sides of the container. Such particles can be more carefully removed in the laboratory than in the field. The container should be made of polyethylene not only because of the transport factor. Some soft-glass bottles and even Pyrex bottles may alter the chemical quality of the water, for instance by increasing the silicia, sodium and boron content (Rainwater and Thatcher 1960, p 8). The container should be of a cheap standard type in order to facilitate the supply.

f Experiments have shown that at least 95 % of the vertical should be sampled to get a sufficiently representative sample (Report No 3, Hydr. Lab. Univ. Iowa, 1941, p 79).

As the amount of suspended material usually increases with depth in the vertical it is, however, especially important to collect samples as near the bed as possible. On the other hand it should be noted that there is a risk for bed material to be included in sampling too near the bottom. This is especially true for rivers with high and steep bed forms.

g A sampler should be of a sufficient weight and fusiformed to avoid excessive drag. The suspension has to be straight above the centre point of the deplacement in order to balance the sampler horisontally in the water. As the sampler, in its sampling transit, will be exposed to water resistance acting vertically, the exposed areas on each side of the suspension must be of the same dimension.

If the back part of the sampler is made heavier than the fore part without changing the deplacements, the sampler will tip back when raising it from the surface and thus avoid the risk of loss of water. The stability of the sampler is to a great deal determined by its stabilizer. The best stability will be reached if the suspension and the stabilizer are as far as possible from each other and yet fulfil the requirements mentioned above.

3 THE DEVELOPMENT OF A DEPTH-INTEGRATING SAMPLER

The construction of a new water sampler was started in 1965. On the basis of the reasons discussed above it was decided that the sampler should be of the depth-integrating type. A drawing of the sampler in its final shape is shown in Fig 2.

3.1 The inflow- and exhaust tubes

From accessible literature and experiences of different samplers gathered by the scientists of the department, a modified type of the Andersson-Einstein tube combination was considered to be suitable (Report No 1, Hydr. Lab. Univ. Iowa, 1940, p 151, Fig 59). This combination, slightly modified, has i.a. been used in a Russian sampler.

The inflow tube is 39 cm long with outer and inner diameters of 0.8 cm and 0.6 cm. The orifice is 12 cm in front of the sampler and 0.5 below its centre line. The exhaust tube has the diameters 0.6 and 0.4 cm respectively and it is fastened above the inflow tube. Both tubes, which are made of brass, are bent up in their back part, in order to maximize the sample volume in the horisontally placed container. The exhaust tube is in the fore part, bent up with a radius of 3 cm and its orifice points back 8 cm above the orifice of the inflow tube. The difference of the hydrostatic pressure between the intake level and the level of exhaustion will reduce the loss of water velocity, due to the bending up in the back part of the intake tube. The tubes are welded in a rest on to which a lid fitting the container is fastened.

The fore orifice of the tubes are furnished with exchangeable nozzles with opening diameters of 0.6 och 0.4 cm respectively. The nozzles are screwed on to the tubes, so there are no open joints inside the tubes. The fore part of each nozzle has the form of a straight frustrum of a cone with a top angle of 12°. The intake characteristics of different nozzle diameters were tested in a flume. The best combination at velocities below 25 cm/sec was 0.4-0.2 cm and the combination 0.6-0.4 cm had the least divergence from the ideal inflow at velocities higher than 25 cm/sec. Divergences from the theoretical inflow velocity depend upon friction, contraction and the level differences in the inflow tube. The latter especially limits the use at low velocities. Verticals with a surface velocity less than 16 cm/sec cannot be integrated. When the inflow is started it will continue even at a velocity of 2 cm/sec. Tests in a flume with a stationary sampler have shown, that the exhaust tube fills with water at velocities below 2 cm/sec. Integrations in verticals with a warped velocity distribution (a surface velocity of about 100 cm/sec and at 2/3 depth 0 cm/sec) gave intake volumes less than 2 % from the theoretically computed. The vertical was

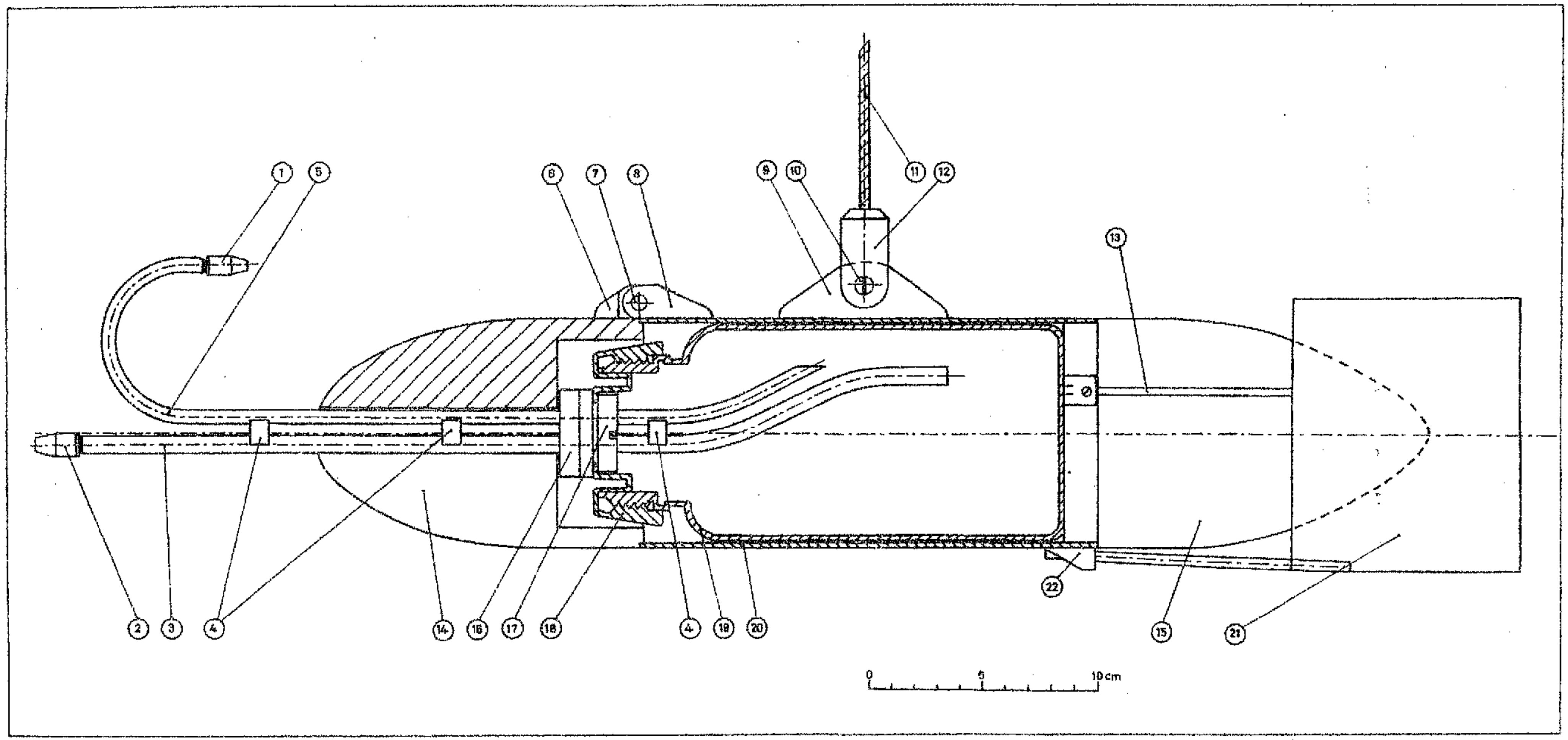

Fig. 2 Drawing of the new depth-integrating sampler. 1 Nozzle; 2 Nozzle; 3 Intake tube; 4 Rest; 5 Exhausting tube; 6 Part of a hing; 7 Axle; 8 Part of a hinge; 9 Firmament; 10 Axle; 11 Wire; 12 Schackle; 13 Stay; 14 Cone of lead; 15 Cone of lead; 16 Tube firmament; 17 Nut; 18 Lid; 19 Container; 20 Body; 21 Stabilizer; 22 Stay firmament.

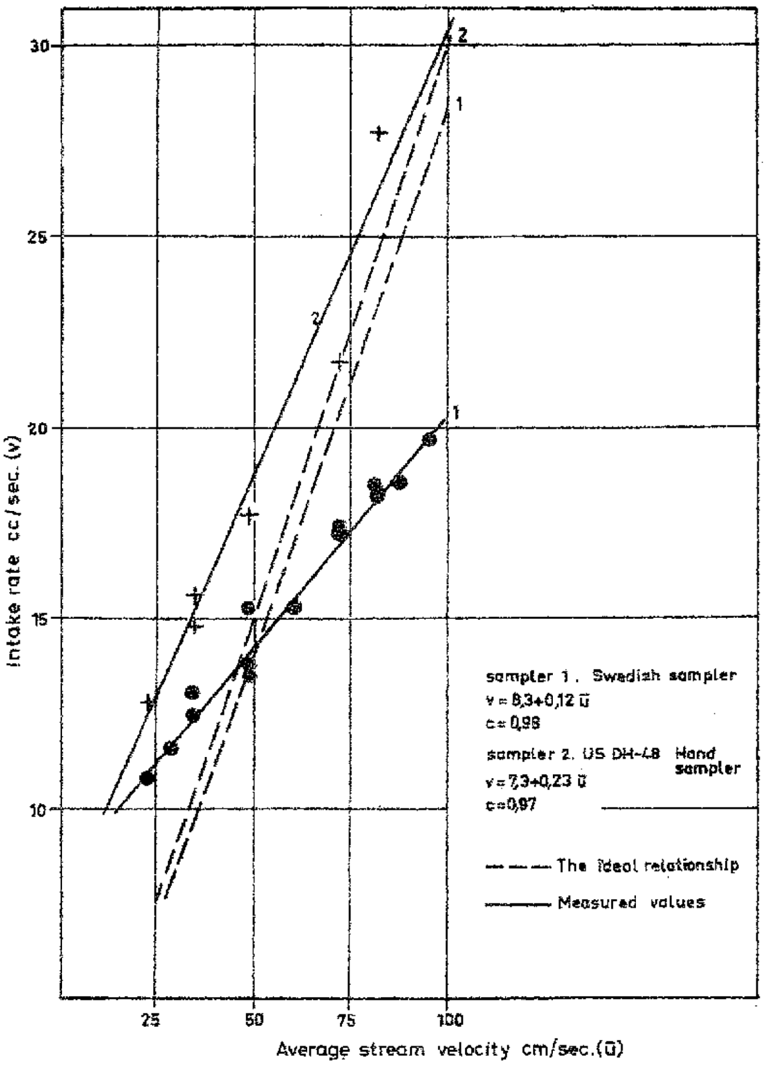

Fig 3 Intake characteristics of the Swedish depth-integrating sampler, No 1, and of the US DH-48 hand sampler, No 2. The values are based on laboratory tests with stationary samplers.

in this test integrated three times, at first to 1/3 of the depth, then to 2/3 and finally the whole vertical.

Similar investigations in the field show an intake error of ±5 % but very high turbulence may cause larger errors.

If the surface velocity is about 25 cm/sec or less the sampler has to be lowered especially slowly over the first two decimeters (Report No 6 Hydr. Lab. Univ. Iowa, 1952, p 29, Fig 2). Repeated testing of the intake velocity at different sample volumes and stream velocities have proved that the intake rate is exclusively a function of the stream velocity.

At the same stream velocity and sampling time the sample volume may vary ±2 %, (Fig 3).

The tube combination may be used in a hand sampler as well as in a suspended sampler. The hand sampler consists of a container holder with a vane and a rod. The holder may be uncoupled from the rod to facilitate orientation after the flow direction.

3.2 The suspended sampler

The suspended sampler consists of a 20 cm long brass tube, which tightly fits the container. The tube has fusiformed weights of lead in each end. The back one is screwed up to and the front one is hinged on to the tube (see Fig 4).

The first model had a vane as a stabilizer. This, however, caused a rather disturbed action in the water which necessitated tests with different types of stabilizers. The tests were made in a flume with a plane weir placed just in front of the testing point. The stream velocity varied between 75 cm/sec and 100 cm/sec with a rather high turbulence

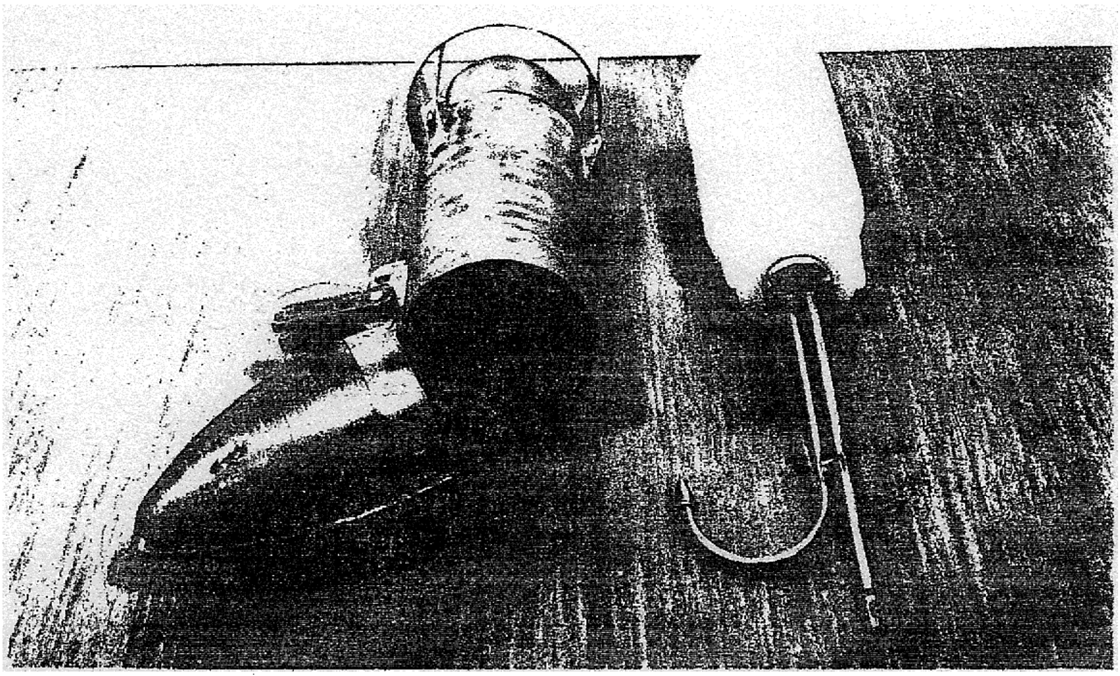

Fig 4 The sampler with the front cone open and the container with the tube combination.

The sampler was fixed to a rod which was hanged on an edge in such a way that it could move horisontally around the edge. Four springy pencils were fastened to the rod and they transferred the movements of the sampler to a paper. By comparing the size of the black areas and the grade of blackness developed by these movements the stabilizers could be compared. The best one consisted of a 10 cm long brass tube with a diameter of 12 cm which was fastened 8. 5 cm from the brass body.

The total length of the sampler is 65 cm, the tube combination included, and its maximum diameter is 12 cm. The container made of polyethylene has a diameter of 9. 4 cm and a length of 20. 5 cm and is supplied with a tight lid (Fig 4). It is kept horisontally placed in the sampler. The new stabilizer gives the sampler a very smooth movement in the water even at velocities as high as 200 cm/sec in spite of the fact that the sampler weighs only 11 kg.

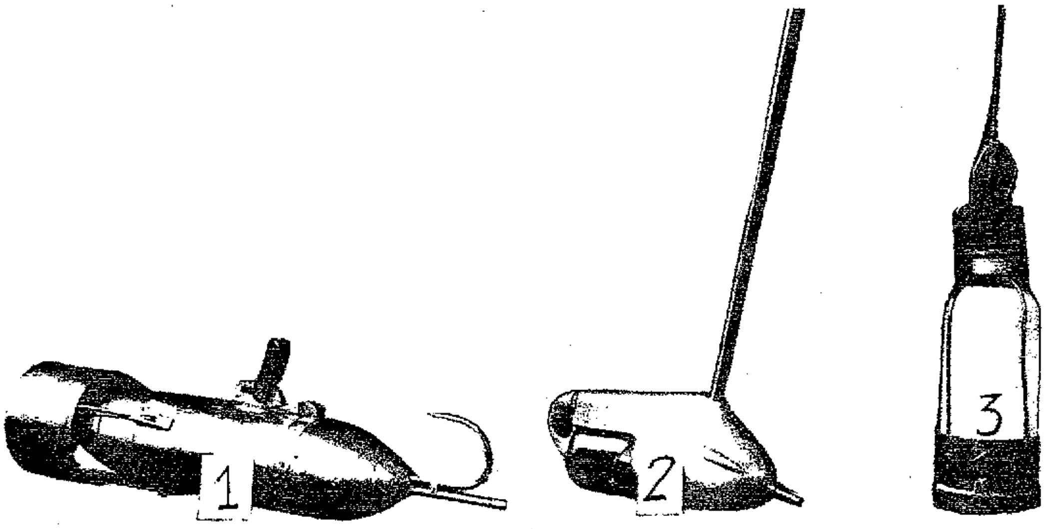

Fig 5 Photo of the three tested samplers. No 1 The Swedish depth-integrating sampler, No 2 US DH-48 hand sampler, No 3 Swedish momentary sampler.

3.3 Calibration of the sampler characteristics

Because of the big sources of errors during water sampling, which are inherent during investigations of suspended material, it was considered valuable to make a comparative test between the new sampler (1), the US DH-48 hand sampler (2) and an instantaneous sampler (3) which has often been used in Sweden (see Fig 5).

The test was made in a flume in the Geomorphology laboratory (see Hjulström and Sundborg 1962). The water was pumped in a closed circulating system. The capacity of the pumps permitted a stream velocity of about 26 cm/sec and 29 cm/sec respectively at a water depth of 40 cm at sampling point. In order to smooth out the pulsations caused by the pumps, a 100 cm wide stone-filter was placed in the upper part of the flume and a 60 cm high weir 6 m upstream of the sampling point. Material was fed by a feeder over the weir to get as a complete mixing as possible.

There are important fundamental differences between the conditions in a natural stream and in the laboratory experiment described above. In streams the suspended material partly comes from exchange between the river bed and the water by means of turbulence, while the suspended material in this investigation is introduced from the surface. In the experiment the largest part of the material was left in the pumping basin and in the section upstream of the weir. In the sampling section the bed-load was negligible.

The material introduced was well sorted (S O according to Trask 1.2) and had a median grain size of 42 microns. The particle shape was very flat with a great deal of mica flakes. The behaviour in water of such a particle and its fall velocity are quite different from that of more cubic or spherical particles.

Irregular feeding of the material made it impossible to make quantitative calculations of the amount of suspended material. The investigation was instead built up in such a way that the material was fed during 15 minutes at an amount of about 120 g/sec. After that, one sample was collected every other minute using in order sampler No. 1, 2, 3, 1 etc. until 21 samples in all had been collected. The test was repeated 3 times with stream velocities of 25, 39 and 53 cm/sec. The samples were collected in one point at a constant level above the bottom.

The two integrating samplers were carefully lowered to the sampling point and were rapidly hoisted up after the end of the sampling time. With the American sampler (No 2) in which the volume of the container is one pint, about 570 cc, and the diameter of the intake nozzle is 0.6 cm, samples were collected during 25, 20 and 15 seconds respectively. The Swedish sampler (No 1) which has a bigger container and a slightly narrower

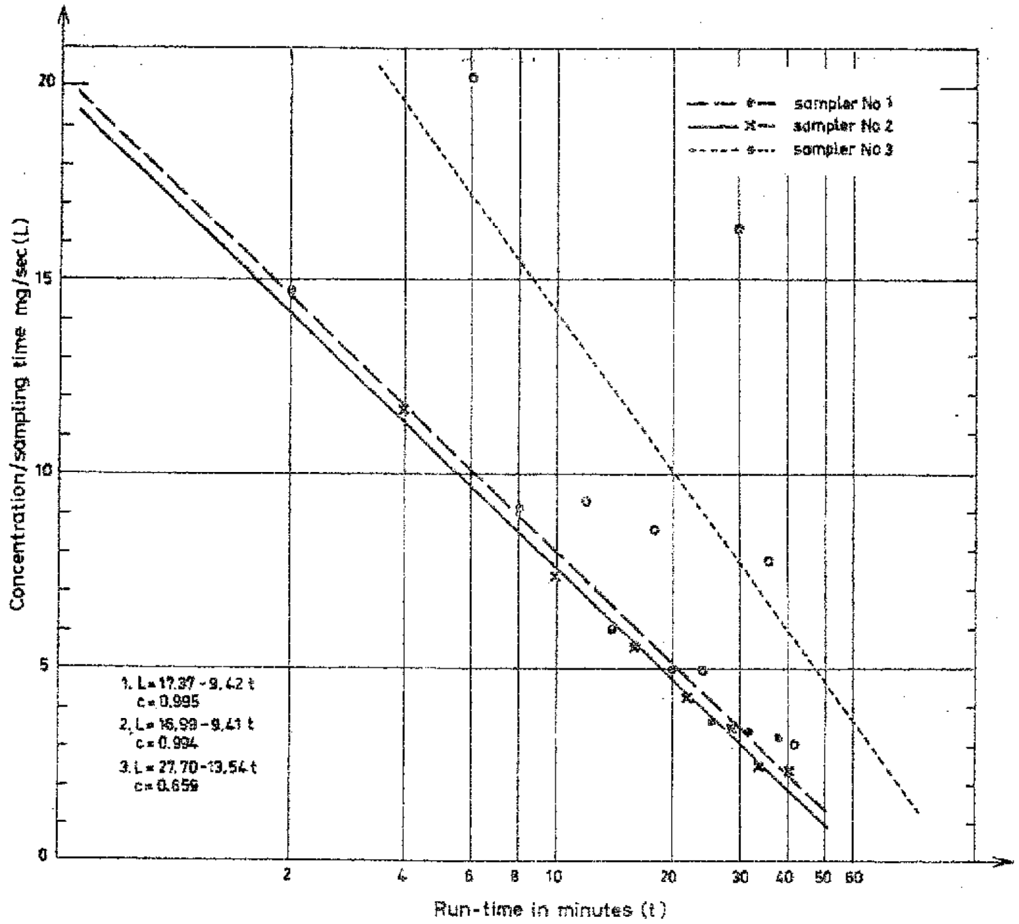

Fig 6 Relationship between collected material per sampling time and runtime measured with the three samplers shown on Fig 5.

intake nozzle collected samples during 30 seconds.

The instantanenous sampler (No 3) was placed upright on the bottom with its opening at the same level as that of the intake nozzles of the integrating samplers. The sampling time varied from 10 seconds up to 90 seconds because the sampler was filled at a very irregular rate. In order to get a similarity between the samples the sampler should be completely filled every time. However, in a few cases the sampler was not filled even after 90 seconds when the sampling had to be stopped for practical reasons. Such samples are in spite of this included in the figures.

All samples were filtrated through a membrane filter in accordance with the standard method of the laboratory (Nilsson, in preparation).

Figure 6 shows the quantity of suspended material collected per second in the different samplers (concentration/sampling time) at the different sampling occasions. The samples during the test were collected at a stream velocity of 39 cm/sec.

The values from sampler No 3 show poor statistics and the regression line is steeper than that of the two others. This depends on the intake characteristics of the sampler. The low air pressure in the container corresponds to a water volume of about 20 cc due to the higher hydrostatic pressure. This alone could not cause the irregular intake. As the air and the water are passing through the same intake the inflow cannot be uniform. It was observed several times that an air bubble could prevent the inflow for many seconds.

The concentration of the suspended material decreased logarithmically with time according to the test with the three different samplers (see Fig 7). The correlation coefficients of the curves are very close to unity. According to the figure the first value of the instantaneous sampler is 15 % higher than expected from the two other samplers at the same time. The deviation is less for lower concentrations which in this experiment corresponds to a decreasing grain-size (cp Fig 1). There seems to be no connection between sampling time and the deviation. It is evident from the figure that the regression lines for the two integrating samplers are practically parallel to each other. This fact grants that investigations in which either of these samplers have been used are comparable, if the percentage errors of the analysis are known. According to this investigation the Swedish sampler gives one per cent higher concentration than the American one. Comparisons between any of these two samplers and sampler No 3 show that the latter one gives too high values if the concentration is more than 400 ppm and as much as 40 per cent too low values at concentrations below 100 ppm. The latter was established during sampling before and between the different test series. The above mentioned is only valid if the samples are collected at such small depths that initial inrush is negligible and if the suspended material consists of fine-sand to silt. The magnitude of the errors at different grain-sizes can be estimated from Fig 1, if one considers the fact that V_1 in the figure increases with increasing pressure difference and thus with sampling depth.

The vertical distribution of suspended material may be measured also with a depth-integrating sampler. Increasing parts of the vertical are then integrated from the surface. Samples collected from the surface to 1/4 depth, 1/2, 3/4 and the whole depth give four values on the distribution curve. This method gives a rough measure of the distribution.

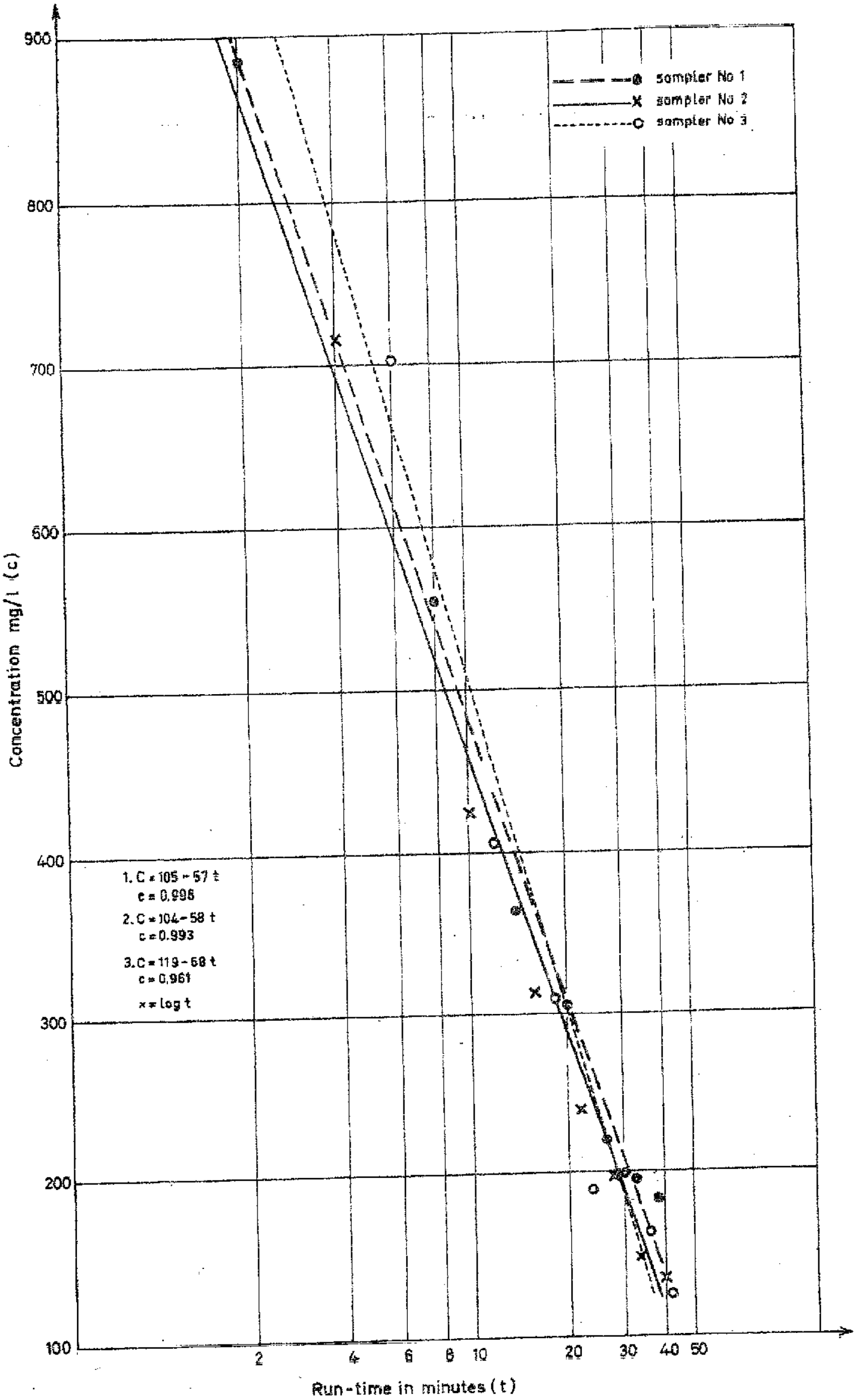

Fig 7 Relationship between concentration of suspended material and run-time, based on values from the same test as in Fig 6.

4 SUMMARY

According to the investigation described, there is not a definite relationship between values from an instantaneous sampler and values from an integrating sampler. The comparisons made between the Swedish sampler and the US DH-48 hand sampler gave practically identical values. Almost parallel regression lines indicate that the grain-size has the same influence on the intake characteristics of the two samplers. The stream velocity within the range investigated does not seem to deflect from this pattern.

The new Swedish sampler has been used in the Swedish research programme for the International Hydrological Decade since the autumn 1966. After gradual improvements the sampler has satisfactorily proved to meet the requirements of a depth-integrating sampler.

5 ACKNOWLEDGEMENTS

A number of people at the Department of Physical Geography were most co-operative and helpful in the construction and testing of the sampler. The staff of the Laboratory workshop have, under Mr E Zetterström, helped construct and make the sampler. The draft of the sampler was drawn by Mr J Lööv and then slightly modified by Miss K Andersson who has also drawn the diagrams. The photographic reproductions were made by Mr A Lindberg. Personnel paid by the State Council of Scientific Research assisted in tests and analysis. The manuscript was critically read by Dr J O Norrman and the English revised by Mr R Corner.

LIST OF SYMBOLS

C	Suspended sediment concentration (in dry weight per unit volume)
c	Correlation coefficient
L	Suspended sediment transport
SO	Sorting coefficient
t	Time
U	Average stream velocity (cm/sec)
v	Intake rate (cc/sec)

REFERENCES

Measurements and analysis sediment loads in streams, 1940-63. A study in methods used in measurements and analysis sediment loads streams. Reports No 1, 3, 5, 6, 14, publ by Hydr. Lab. Univ. Iowa, Iowa City.

Hjulström, F, 1935: Studies of the morphological activity of rivers as illustrated by river Fyris. Bull. Geol. Inst. Uppsala, 25.

Hjulström, F, 1939: The principles of construction of instruments for procuring samples of water containing silt. Geogr. Annaler, 21.

Hjulström, F and Sundborg, Å, 1962: The geomorphological Laboratory. Acta Universitatis upsaliensis, C 3 Uppsala.

Nilsson, B, Analysmetodik av vattenprover. Dept. Phys. Geogr. Uppsala (typewritten, in preparation).

Sundborg, Å, 1956: The river Klarälven. A study of fluvial processes. Geogr. Annaler, 38:2-3.

Rainwater, C D and Thatcher, L L, 1960: Methods for collection and analysis of water samples. U S Geol. Survey, Water-supply Paper, 1454.

APPENDIX

Instructions for sampling

The sample should be collected from the surface down to about 1 dm from the bottom. If the bottom is solid and the sampling is made from a stationary point, for instance a bridge, a mark should be put on the wire of the winch for desired depth. If the depth is not constant, i.e. if sampling is made from a boat or if the bed varies, the depth must be sounded before each sampling. Within the first two decimeters below the surface the sampler must be lowered especially slowly in order to get a smooth inflow. Thereafter the sampler should be lowered at a uniform rate and raised back to the surface at a uniform rate, but not necessarily at the same rate. If the volume of the sample is less than 500 cc after one round-trip integration another one may be made, but this time at a higher transit rate, to get additional water with total volume still less than 800 cc.

The minimum transit rate is determined by sampling depth and stream-velocity. To avoid flow through the container and simultaneous sedimentation the desireable maximum volume of the sample is 800 cc but may rise to about 950 cc without outflow through the exhaust tube of the container.

The table below shows in round numbers the maximum transit rates at different mean velocities. The sampling time is calculated on a volume of 800 cc and has been adjusted for the characteristics of the intake. Corresponding sampling depth is given in column 4 and the maximum sampling depth is calculated for a volume of 950 cc.

average stream velocity cm/sec	sampling-time sec	max sampler rate cm/sec	sampling depth m	max sampling depth$^{x)}$ m
20	140	8	5.5	6.5
30	100	12	6	7
40	80	16	6.4	7.5
50	65	20	6.5	7.7
60	55	24	6.7	7.8
70	50	28	7	8.4
80	45	32	7.1	8.5
90	40	36	7.2	8.6
100	37	40	7.2	8.6

x) sampling volume 950 cc

The staff at the sampling stations should have some spare nozzles and if possible a whole set of tubes. If the nozzle or the tube is deformed, the characteristics of the intake will be altered. To avoid ice forming in the tubes during the frozen period the tubes should be kept at room temperature before use.