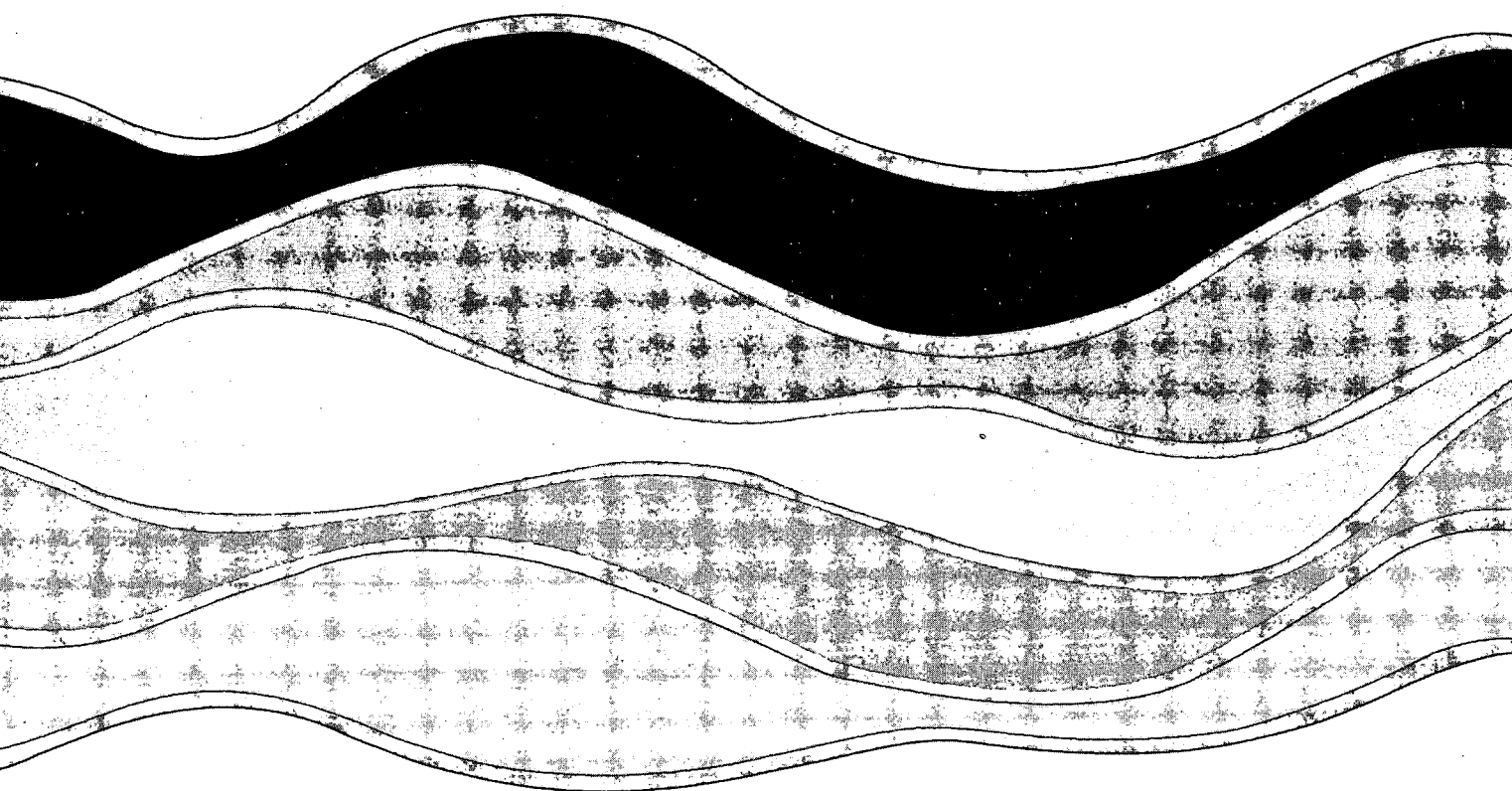


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CONSIDERATIONS IN THE CALIBRATION
OF THE P-63 SUSPENDED SEDIMENT
SAMPLER

P. Engel

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**CONSIDERATIONS IN THE CALIBRATION OF
THE P-63 SUSPENDED SEDIMENT SAMPLER**

by

P. Engel

MANAGEMENT PERSPECTIVE

Suspended sediment concentrations are an important indicator of water quality in rivers. To ensure that reliable data are obtained, the Water Survey of Canada Division of the Integrated Monitoring Branch (IMB) is developing a quality assurance program for the 500 samplers of various types currently in use by Environment Canada. The National Water Research Institute is assisting IMB in the development of a calibration strategy for suspended sediment samplers used in the national program.

Tests of five P-63 suspended sediment samplers have shown that individual samplers can be calibrated with reasonable certainty, but there can be large performance variabilities from sampler to sampler. In addition, the P-63 sampler over-samples at low velocities and under-samples at medium to high velocities. As a result, each sampler should be tested in a towing tank and adjusted to bring its performance within acceptable tolerances. Normal fabrication variances in nozzle geometry do not affect the sampler performance. This means that nozzles can be replaced in the field without further calibration.

SOMMAIRE À L'INTENTION DE LA DIRECTION

Les concentrations de sédiments en suspension constituent un indicateur important de la qualité des eaux courantes. Pour garantir la fiabilité des données, la Division des relevés hydrologiques du Canada de la Direction de la surveillance intégrée est en train d'élaborer un programme d'assurance de la qualité pour les 500 échantillonneurs de divers types qu'utilise Environnement Canada. L'Institut national de recherche sur les eaux aide la Direction à mettre au point une stratégie d'étalonnage des échantillonneurs de sédiments en suspension employés dans le cadre du programme national.

Des essais réalisés sur cinq échantillonneurs de sédiments en suspension P-63 ont révélé que chaque échantillonneur peut être étalonné de manière à afficher une répétabilité satisfaisante, mais qu'il y a des variations importantes de performance d'un échantillonneur à l'autre. En outre, l'échantillonneur P-63 surévalue les concentrations pour des vitesses de courant faibles tandis qu'il sous-évalue, dans le cas de vitesses moyennes à élevées. Chaque échantillonneur doit donc être soumis à des essais dans un canal à chariot mobile et réglé de manière à ce que sa performance se situe dans des limites acceptables. Les variations normales de fabrication de la géométrie de la buse n'ont pas d'effet sur la performance de l'échantillonneur, ce qui veut donc dire qu'on peut remplacer les buses sur le terrain sans refaire l'étalonnage.

ABSTRACT

Tests were conducted in a towing tank on five P-63 sediment samplers fitted with carefully selected nozzles. Statistical analyses of the test data were conducted. It was shown that individual samplers can be calibrated with reasonable certainty but that the variability of calibrations from sampler to sampler can be unacceptably high. It was further shown that the P-63 sampler over-samples at low velocities and under-samples at medium to high velocities. Normal fabrication variances in nozzle geometry do not affect sampler performance.

RÉSUMÉ

Des essais ont été réalisés dans un canal à chariot mobile sur cinq échantillonneurs de sédiments en suspension P-63, dont les buses avaient été sélectionnées avec soin. On a ensuite fait des analyses statistiques des données recueillies. Les résultats ont révélé que chaque échantillonneur peut être étalonné de manière à afficher une répétabilité satisfaisante, mais que la variabilité des étalonnages d'un échantillonneur à l'autre peut être trop élevée. Il a aussi été démontré que l'échantillonneur P-63 surévalue les concentrations pour des vitesses de courant faibles tandis qu'il sous-évalue, dans le cas de vitesses moyennes à élevées. Les variations normales de la géométrie de la buse qui se produisent à la fabrication n'ont pas d'effet sur la performance de l'échantillonneur.

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CONSIDERATIONS IN THE CALIBRATION OF THE P-61 SUSPENDED SEDIMENT SAMPLER

by
*P. Engel*¹

INTRODUCTION

Data on suspended sediment concentrations in rivers have become increasingly important indicators of water quality because the particles are known to be carriers of contaminants. The accuracy of all suspended sediment samplers must be checked to ensure that reliable data are obtained throughout the data collection program conducted by the Department of the Environment. At the present time, the Water Survey of Canada (WSC), Integrated Monitoring Branch (IMB), with the assistance of the National Water Research Institute (NWRI), is developing a calibration strategy for all suspended sediment samplers used in the national data gathering program. This report presents the results of performance tests conducted on the P-63 sampler in the towing tank of the NWRI Hydraulics Laboratory at Burlington, Ontario.

PRELIMINARY CONSIDERATIONS

The purpose of the suspended sediment sampler is to obtain a sample that is representative of the water-sediment mixture moving in the vicinity of the sampler. During the sampling, a volume of the water-sediment mixture is collected in the sampler over a measured interval of time, using predetermined transit rates (Guy and Norman 1970, Beverage 1979). From the measured volume and the transit time, the flow rate into the sampler is determined. The velocity of the flow through the nozzle is computed by dividing the flow rate by the cross-sectional area of the nozzle flow passage.

Suspended sediment samplers are operated on the premise that the velocity of flow through the nozzle is equal to the velocity of the stream flow surrounding the nozzle (Beverage 1979). This condition is known as iso-kinetic sampling. For sediment sampling quality control, the nozzle velocity V_n and the stream flow velocity V_s are expressed as a ratio given by

$$K = \frac{V_n}{V_s} \quad (1)$$

where K is the sampler performance coefficient. For iso-kinetic conditions, $K = 1$ and it is assumed that the flow entering through the nozzle contains the same sediment-water mixture as the stream flow being sampled. When the suspended sediment is sand and $K > 1$, the sampler will under-sample the suspended sediment concentration, whereas when $K < 1$, the sampler will over-sample (Beverage 1979, Beverage and Futrell 1986). For a given flow velocity, errors in sample concentration

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become increasingly sensitive to the value of K as the particle size increases. For silts and clays, the sample concentration is less sensitive to variations in K .

The performance of the P-63 sampler can be evaluated by examining the variation of K with towing velocity. The accuracy of a given sampler calibration is reflected by the uncertainty in the value of K at different towing velocities over its operating range. The sampler to sampler variability can be determined by comparing values of K for different P-63 samplers for the same towing velocity. Finally, the effect of using different nozzles of a given size and type, can be determined by examining the change in the sampler performance coefficient.

EXPERIMENTAL EQUIPMENT AND PROCEDURE

Towing Tank

The towing tank used to test the samplers is 122 m long by 5 m wide and is constructed of reinforced concrete founded on piles. The full depth of the tank is 3 metres, of which 1.5 metres are below ground level. Normally the water depth is maintained at 2.7 metres. Concrete was chosen for its stability and to reduce possible vibrations and convection currents.

At one end of the tank is an overflow weir. Waves arising from towed objects and their suspensions are washed over the crest, thereby reducing wave reflections. Parallel to the sides of the tank perforated beaches serve to dampen lateral surface wave disturbances.

Towing Carriage

The carriage is 3 metres long, 5 metres wide, weighs 6 tonnes and travels on four precision machined steel wheels. The carriage is operated in three overlapping speed ranges:

0.005 m/s - 0.06 m/s

0.05 m/s - 0.60 m/s

0.50 m/s - 6.00 m/s

The maximum speed of 6.00 m/s can be maintained for 12 seconds. Tachometer generators connected to the drive shafts emit a voltage signal proportional to the speed of the carriage. A feedback control system uses these signals as input to maintain constant speed during tests. The average speed data for the towing carriage is obtained by recording the voltage pulses emitted from a measuring wheel. This wheel is attached to the frame of the towing carriage and travels on one of the towing tank rails, emitting a pulse for each millimeter of travel. The pulses and measured time are collected and processed with a micro computer data acquisition system to produce an average towing speed. Analysis of the towing speed variability by Engel (1989), showed that for speeds between 0.20 m/s and 3.00 m/s, the error in the mean speed was less than 0.15% at the 99% confidence level. Occasionally, these tolerances are exceeded as a result of irregular occurrences such as "spikes" in the data transmission system of the towing carriage. Tests with such anomalies are recognized by the computer and are automatically abandoned.

The P-63 Sampler

The P-63 sampler consists of a 91 kg streamlined cast bronze shell, an inner recess to hold a round 0.6 l (1 pint) milk bottle, a pressure-equalizing chamber, and a tapered two-position rotary valve operated by a solenoid and air vent passages. This arrangement makes it possible to use

the sampler for depth integration and point integration to stream depth of at least 55 m (180 ft). When the solenoid is not energized, the valve is in the non-sampling position whereby sample intake and air-exhaust passages are closed, the air chamber in the body is connected to the cavity in the sampler head, and the head cavity is connected through the valve to the sample container. When the solenoid is energized, the valve is in the sampling position, whereby the sample intake and air-exhaust are open and the connection from the sample container to the head cavity is closed.

The sampler is used with a 4.8 mm (1/4") teflon nozzle and is designed to operate at velocities up to 1.8 m/s. When the sampler is lowered into the flow, with the solenoid valve energized, air is expelled through the air vent located in the side of the sampler body and slightly above the centreline of the nozzle flow passage. This position results in a small, positive, net hydro-static pressure between the nozzle and the air vent which is independent of the depth of submergence of the sampler. The sampler is shown in Figure 1.

Selection of Test Nozzles

The nozzles were selected from samples tested by Engel (1991) using a new static test chamber, developed to determine the variability in the coefficient of velocity for suspended sediment sampler nozzles. Prior to testing, a nozzle was selected and fastened to the nozzle mount which was then secured in the base of the test chamber. The measurements consisted of the water level elevation above the nozzle entrance in the test chamber stilling well, the volume of water passing through the nozzle and the time required to pass that volume of water. For each value of static head, the discharge was measured by intercepting the outflow jet from the nozzle with a graduated cylinder and measuring the time to collect the water. The data were used to compute the velocity coefficient for each nozzle from the relationship

$$C_v = \frac{V_n}{V_t} \quad (2)$$

where C_v = the nozzle velocity coefficient, V_n = the flow velocity through the nozzle and V_t = the theoretical velocity of flow through the nozzle. The uncertainty in the velocity coefficients obtained with this method is less than 0.3% at the 95% confidence level (Engel 1990). Tests were conducted for each of 25 nozzles of the size and type used with the P-63 sampler.

To determine the uncertainty in the sampler calibrations, the nozzle having a velocity coefficient closest to the mean value for the sample of 25 nozzles was selected. This nozzle, numbered S61-4, was designated as the "standard nozzle" and was used with each of the 5 samplers tested.

To determine the effect of changing nozzles on the sampler performance coefficient K , the nozzle, for which the difference between its value of C_v and the mean value for the sample was the greatest, was selected. This nozzle was numbered S61-13 which had a deviation in the velocity coefficient C_v from the standard nozzle of 11%. This nozzle was used only with one of the five samplers.

General Test Procedure

For a given sampler, the volume of water that can enter the sampler bottle in a given period of time should primarily depend on the physical properties of the nozzle and the air vent (Engel and Droppo 1990, Engel 1991 and Engel and Droppo 1992). In order to determine the uncertainty in the sampler performance coefficient, a series of runs, each repeated 10 times for each velocity specified in Table 1, was conducted. Each set of 10 runs constituted a test.

Each sampler was carefully inspected to ensure that the solenoid valves and air venting systems were working properly. At the beginning of each test, the nozzle was inserted into the sampler nose and the sampler assembled in its standard configuration. Once the sampler was prepared, the towing carriage was set in motion. When the carriage had reached its preset constant velocity, the solenoid was energized, the sampler was submerged and held at 0.2 m below the surface of the water for the set period of time given in Table 1. The filling times in Table 1 are the maximum allowable without over-filling the bottle, thereby ensuring that there is no interference in the air flow through the vent. The tests were conducted in a towing tank because this afforded better control over the reference velocity than can be obtained in a flume. It has been shown that there is little difference between sampler calibrations obtained in a flume and in a towing tank (Beverage and Futrell 1986). When the set period of sampling time had expired, the sampler was removed from the water and the volume of water determined with a 1000 ml graduated cylinder. The velocity of flow through the sampler nozzle was then computed from the equation

$$V_n = \frac{1.273V_w}{d^2 t_s} \quad (3)$$

where d = the diameter of the flow passage through the nozzle in mm, V_w = the volume of water collected in c.c., t_s = the time over which the sampler was submerged in seconds. Each test was repeated 10 times to determine the mean values and the standard deviations for the performance coefficient K . Each series of tests was begun at the lowest towing velocity given in Table 1 and continued at each subsequent velocity until the maximum was reached. The data are given in Table 2 and Table 3.

DATA ANALYSIS

Performance Coefficient of P-63 Sampler

Mean values of the performance coefficient from Table 2 were plotted as \bar{K} versus V for the five samplers in Figure 2. Average curves were fitted to the plotted data to facilitate the analysis. The curves clearly show that, for four of the five samplers, \bar{K} decreases continuously as the towing velocity increases with the rate of change decreasing. The shapes of the curves are very similar and the differences in sampler performance are small. The differences are likely due to minor variations in energy losses through the air vent passage. The performance of sampler CAL71-1 is shown to be noticeably different from the other four samplers. Given, that each sampler was tested with the same standard nozzle, the differences in the performance curves must be attributed to physical differences in the samplers themselves. It is most probable, that the source of the differences lies in the air venting system or some unique behaviour in the solenoid valve mechanism. These results suggest that all samplers must be examined carefully before being used in the field.

Further examination of the curves shows that sampler CAL71-1 under-samples by about 60% at the lowest test velocity and this deficit decreases to a value compatible with the other four samplers when $V \approx 1.8$ m/s. The average performance curve for the other four samplers shows over-sampling by more than 5% for velocities less than 0.3 m/s. When $V > 0.6$ m/s, the samplers under-sample by more than 5%, with the discrepancy increasing to values of 20% to 30% as velocity increases. These discrepancies further confirm that each P-63 sampler should be tested in the towing tank to determine its behaviour before it is used in the field. Attempts should be made to adjust each

sampler in some suitable way to ensure that $\bar{K} = 1.0 \pm 0.10$. It may be possible to achieve this by changing the size of the air vent passage.

Uncertainty in the Value of K for a Particular Sampler

The true value of K , at a given velocity, for a particular sampler is the mean value of a very large sample, each determined experimentally under the same conditions. Such large samples are not feasible and values of K are inferred based on limited sample sizes. The true value of K is then said to lie between confidence limits defined by the relationship

$$\mu_K = \bar{K} \pm \frac{t_{0.975} S_K}{\sqrt{n-1}} \quad (4)$$

where μ_K = the mean value of K from a very large sample, \bar{K} = the mean value of K from a limited sample, $t_{0.975}$ = the confidence coefficient at the 95% confidence level from Student's t distribution for $(n-1)$ degrees of freedom (Spiegel, 1961), S_K = the standard deviation of K about the sample mean \bar{K} and n = the number of values of K composing the limited sample. Equation (4) can be made dimensionless by dividing both sides by \bar{K} . In addition, by denoting the coefficient of variation as C_K , then $C_K = \frac{S_K}{\bar{K}}$ and one obtains

$$\frac{\mu_K}{\bar{K}} = 1 \pm \frac{t_{0.975} C_K}{\sqrt{n-1}} \quad (5)$$

The quantity $\frac{t_{0.975} C_K}{\sqrt{n-1}}$ in equation (5) represents the relative uncertainty in determining the value of K at the 95% confidence level obtained from n different observations of K and may be expressed as

$$E_K = \frac{100 t_{0.975} C_K}{\sqrt{n-1}} \quad (6)$$

where E_K = the relative uncertainty in percent. Values of E_K were computed from the test data for $n = 10$ and these are also given in Table 2.

The values of E_K are presented in the form of bar graphs in Figure 3 for the five samplers at the towing velocities used for the present tests. Results show that the uncertainties are dependent on individual sampler properties and the towing velocity. Generally, the largest uncertainties occur at the lowest velocities and decrease as velocity increases. These characteristics vary from sampler to sampler, however, the uncertainty in the calibration of a given sampler is always less than about 5%, which can be considered to be quite good.

Effect of Changing Nozzles

An important consideration is the effect that different nozzles of the same type and size may have on the performance coefficient of the P-63 sampler because of small differences resulting from fabrication variances. It would be of great operational advantage, if small variations in the geometric properties of nozzles do not significantly alter the value of the performance coefficient. If this is the case, individual calibrations with a particular nozzle will not be necessary as long as the sampler is operating under nozzle control. In addition, it will be possible to exchange nozzles in the field without compromising the performance of a given sampler. Data on the effects of changing nozzles are given in Tables 3.

The mean values of K obtained with sampler CAL72-1 (No.3) and nozzle No. S61-13 from Table 3 were plotted in Figure 4 together with the results for the same sampler used with the standard nozzle No. S61-4 from Table 2. The plots show that differences in values of \bar{K} for the two nozzles are virtually insignificant over the full operating range. The fact that these results were obtained with two nozzles, having velocity coefficients which differed by 11%, suggests that the sampler is operating under vent control and therefore, small differences in nozzle geometry do not affect the sampler performance. This means that any 4.8 mm nozzle of the type used with the P-63 sampler, having critical dimensions within normal fabrication tolerances, can be used with a given sampler without significant loss in sampling accuracy at the 95% confidence level.

CONCLUSIONS

Tests, conducted in a towing tank, on the P-63 suspended sediment sampler have resulted in the following conclusions:

The P-63 sampler tends to over-sample at low velocities and under-sample at medium to high velocities.

The calibration of a given P-63 sampler has an uncertainty of less than 5% at the 95% confidence level.

Variability in the performance characteristics of the five samplers tested, indicates that all P-63 samplers need to be tested in a towing tank before being used in the field.

The 4.8 mm nozzles, prescribed for use with the P-63 sampler, can be replaced from stock without further calibration.

ACKNOWLEDGEMENT

The towing carriage was operated by B. Near and the sampling tests were conducted by C. Bil. The writer is very grateful for their support.

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TABLE 1 Towing Velocities and Sampling Durations

<i>d</i> [mm]	<i>V</i> [m/s]	Time [s]
4.8	0.30	35
	0.60	30
	0.90	22
	1.20	16
	1.50	12
	1.80	10

TABLE 2 Test Data for Standard 4.8 mm Nozzle (No. S61-4)

Test	V [m/s]	\bar{K}	S_K	E_K [%]	Sampler No.
1	0.30	0.3965	0.02328	4.42	CAL71-1 (No. 1)
2	0.60	0.3810	0.00840	1.66	
3	0.90	0.4627	0.02647	4.31	
4	1.20	0.5705	0.01534	2.03	
5	1.50	0.6350	0.01369	1.62	
6	1.80	0.6819	0.00371	0.41	
1	0.30	1.2171	0.02135	1.32	CAL71-2 (No. 2)
2	0.60	0.9347	0.00606	0.49	
3	0.90	0.8215	0.00977	0.90	
4	1.20	0.7910	0.00772	0.74	
5	1.50	0.7830	0.00756	0.73	
6	1.80	0.7723	0.00879	0.86	
1	0.30	1.1353	0.04224	2.80	CAL72-1 (No. 3)
2	0.60	0.9559	0.00897	0.71	
3	0.90	0.8909	0.00920	0.78	
4	1.20	0.8528	0.00480	0.42	
5	1.50	0.8309	0.00567	0.51	
6	1.80	0.8259	0.00234	0.21	
1	0.30	1.2443	0.01578	0.96	CAL78 (No. 4)
2	0.60	0.8696	0.00403	0.35	
3	0.90	0.8039	0.00346	0.32	
4	1.20	0.7470	0.00296	0.30	
5	1.50	0.7216	0.00271	0.28	
6	1.80	0.7065	0.00366	0.39	
1	0.30	1.0952	0.01255	0.86	OTT P63-4 (No. 5)
2	0.60	0.8180	0.00528	0.49	
3	0.90	0.7654	0.00380	0.37	
4	1.20	0.7292	0.00464	0.50	
5	1.50	0.7198	0.00430	0.45	
6	1.80	0.7029	0.00349	0.37	

TABLE 3 Test Data for 4.8 mm Nozzle (No. S61-13)

Test	V [m/s]	\bar{K}	Sampler No.
1	0.30	1.1156	CAL72-1 (No. 3)
2	0.60	0.9826	
3	0.90	0.9624	
4	1.20	0.9177	
5	1.50	0.8884	
6	1.80	0.8733	

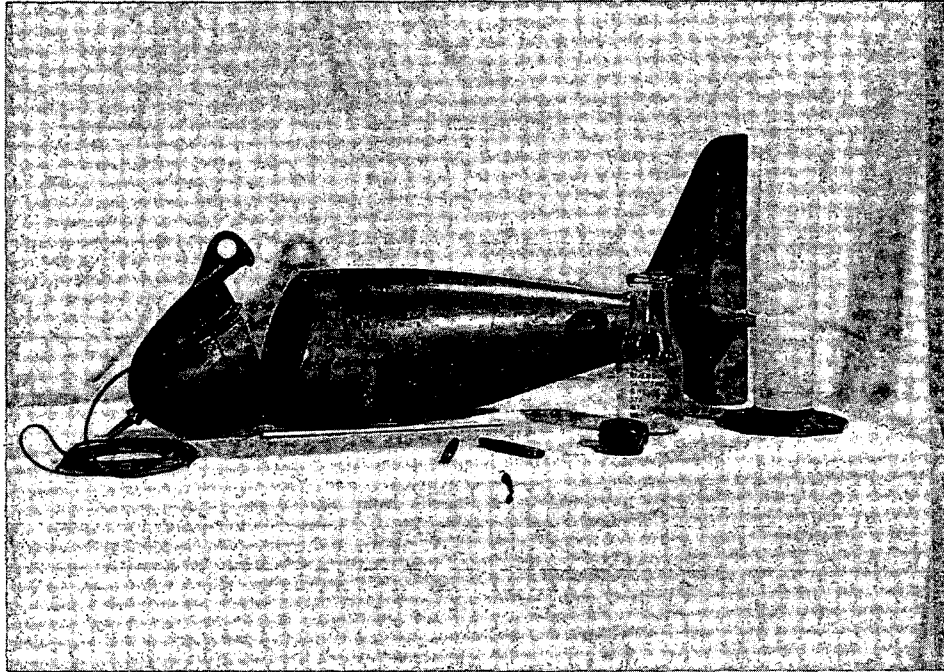


Figure 1. P-63 Suspended Sediment Sampler

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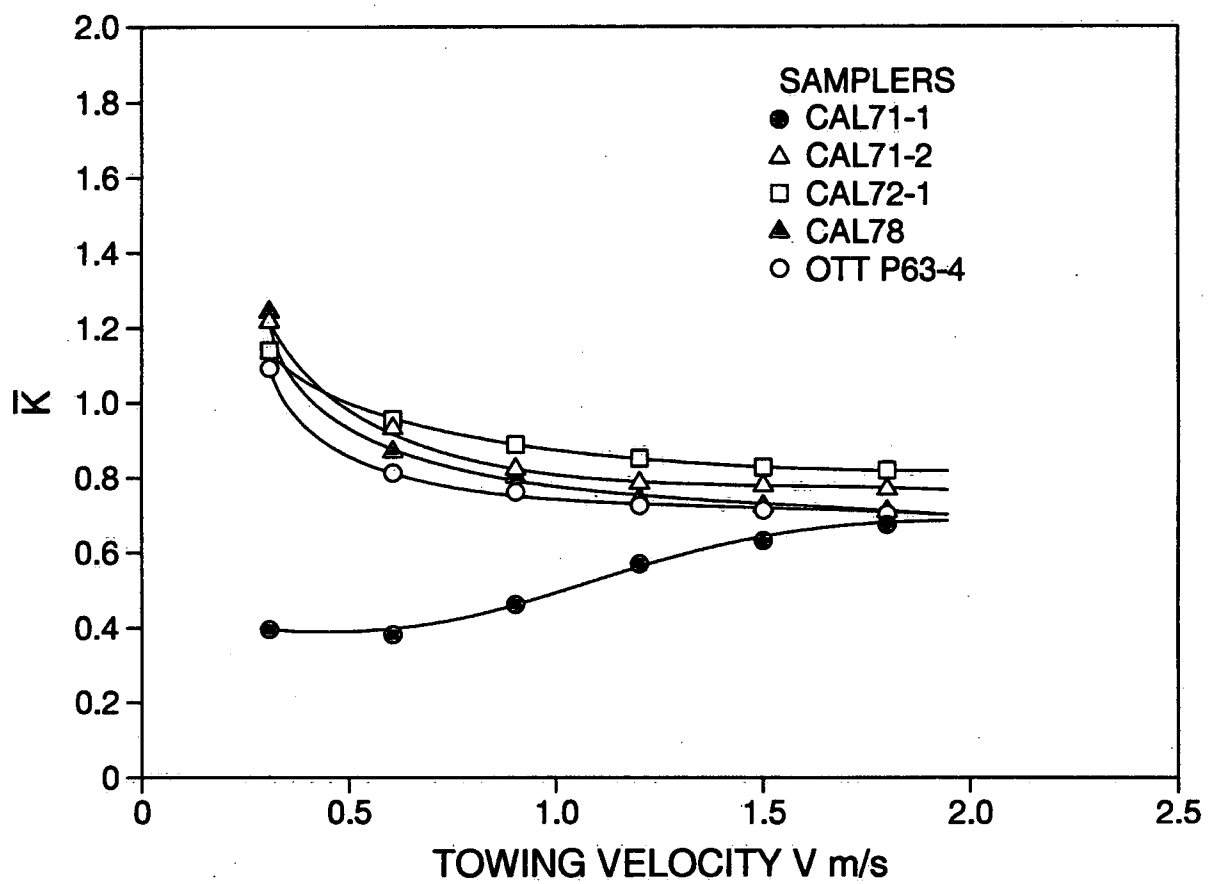


Figure 2. Variation of K with with towing velocity

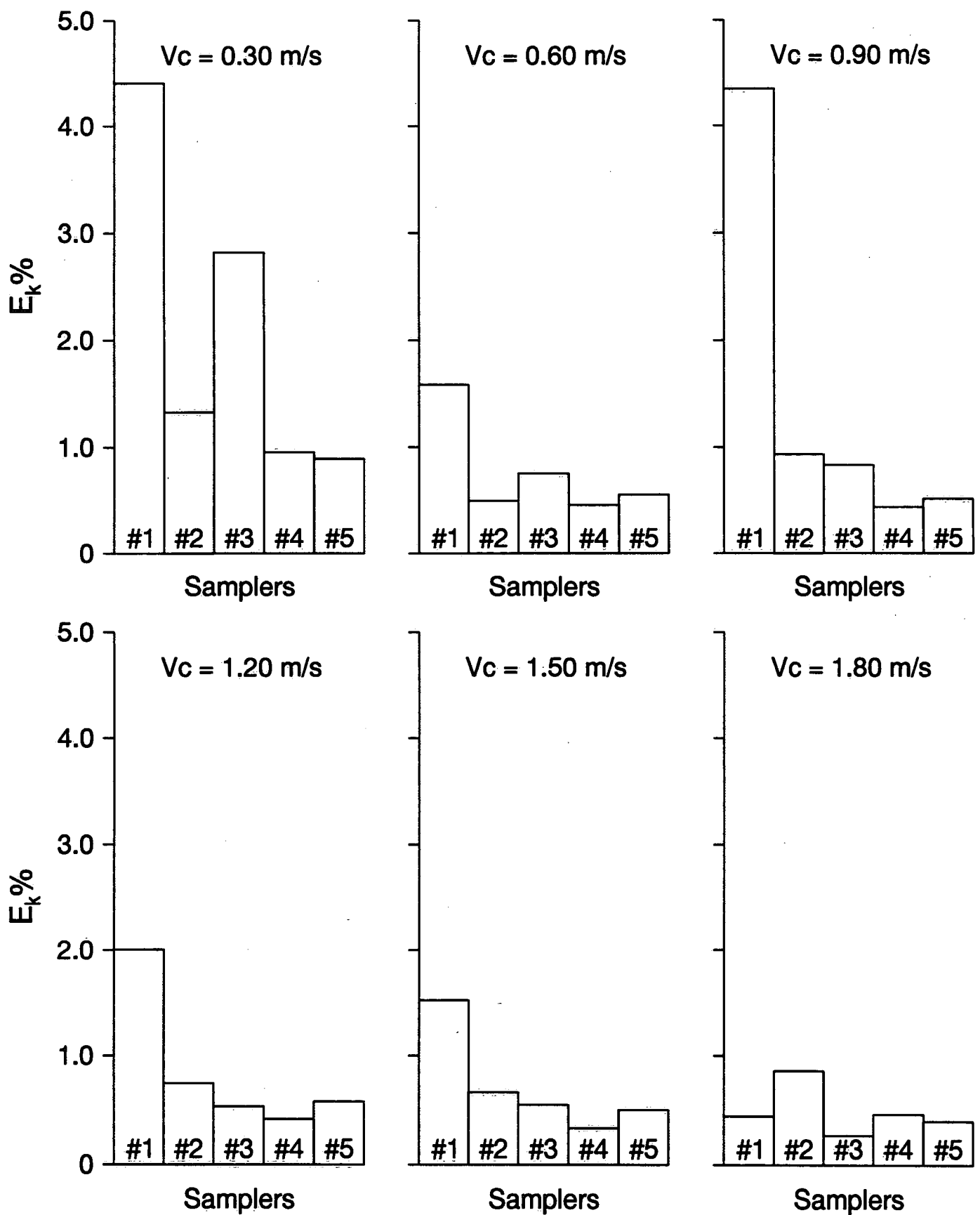


Figure 3. Uncertainty in \bar{K} at the 95% confidence level

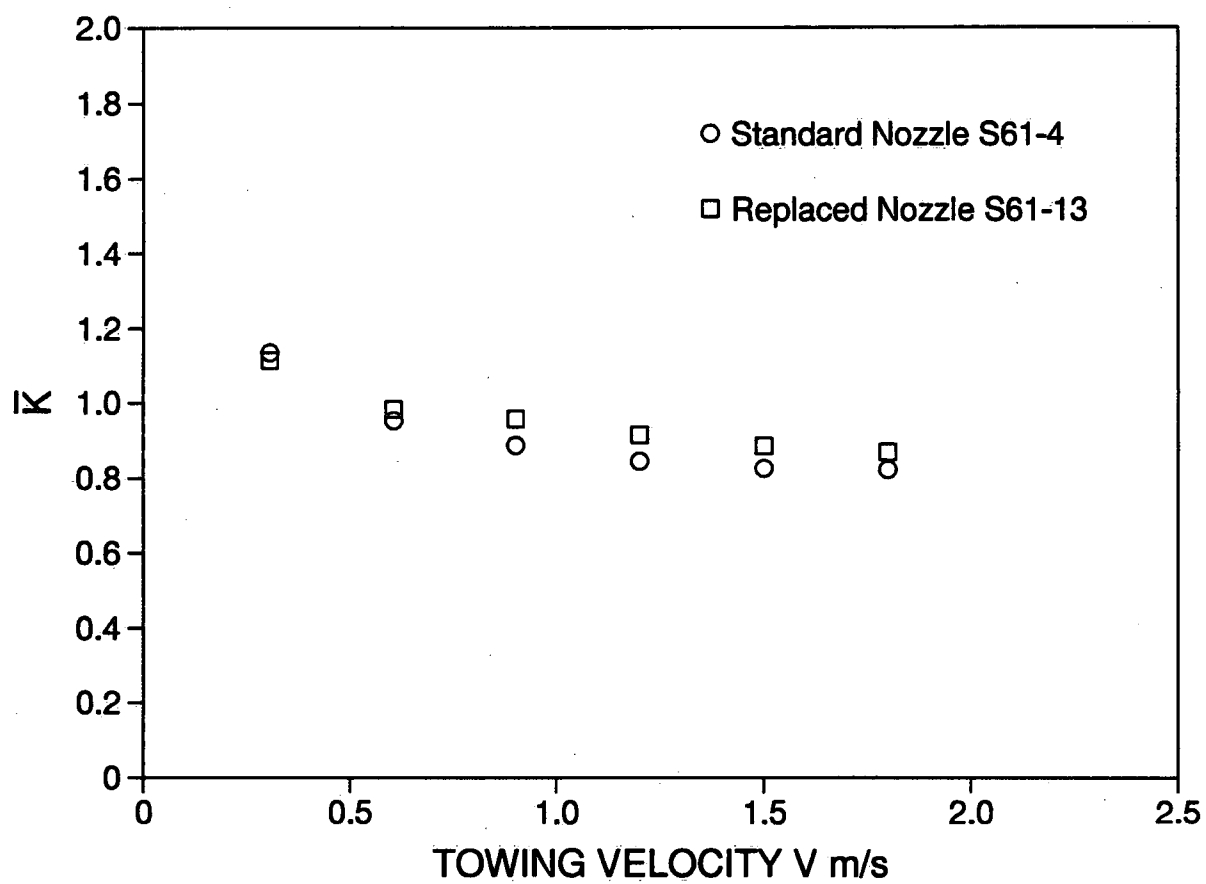
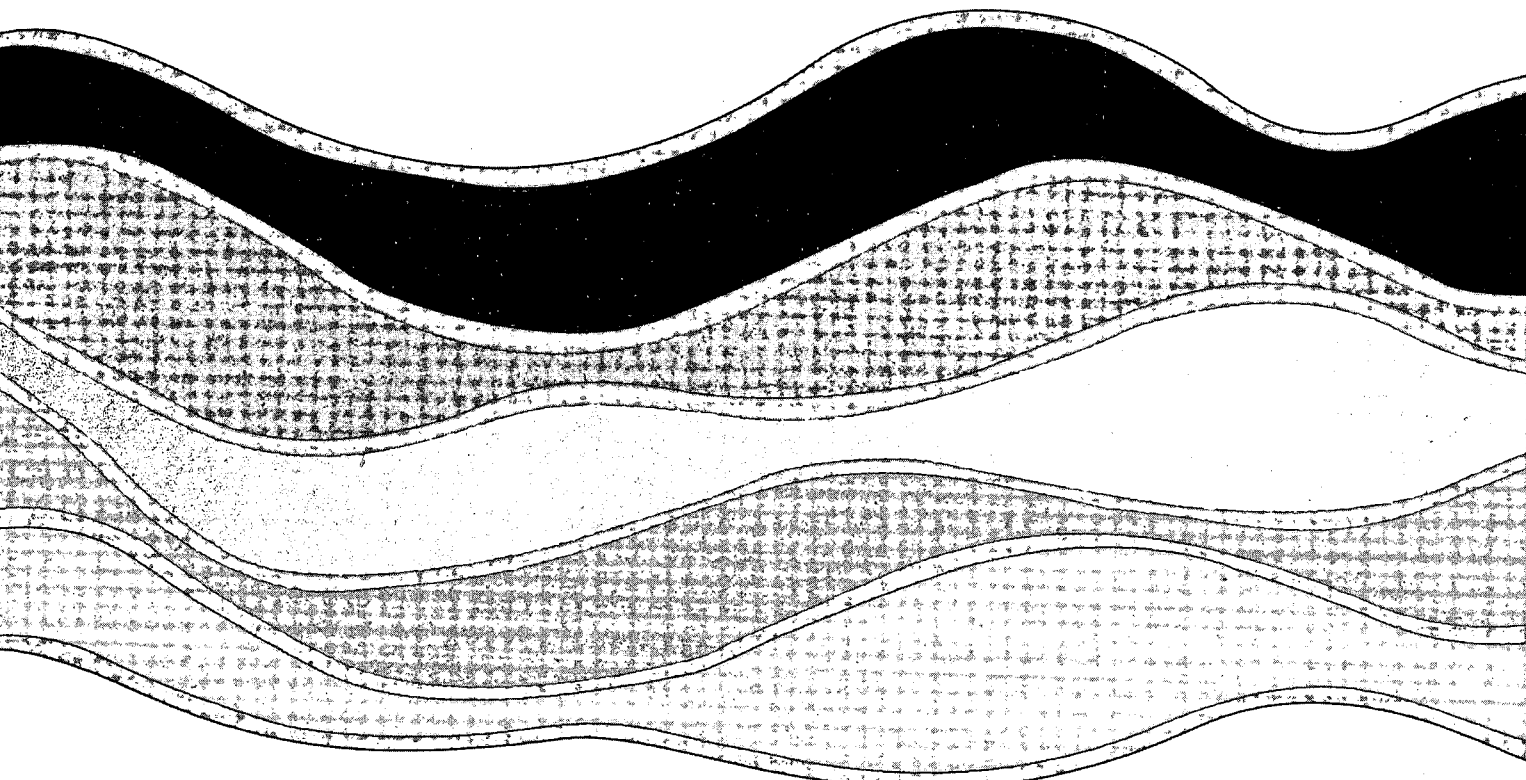


Figure 4. Effect of changing nozzles



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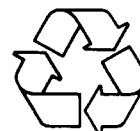


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