# COMPARISON OF FLUME AND TOWING METHODS FOR VERIFYING THE CALIBRATION OF A SUSPENDED-SEDIMENT SAMPLER

U. S. GEOLOGICAL SURVEY
WATER-RESOURCES INVESTIGATIONS REPORT 86-4193

PREPARED IN COOPERATION WITH THE
U. S. AGRICULTRAL RESEARCH SERVICE,
U. S. BUREAU OF RECLAMATION,
U. S. FOREST SERVICE,
U. S. BUREAU OF LAND MANAGEMENT,
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U. S. FEDERAL HIGHWAYS ADMINISTRATION

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## CONVERSION FACTORS

For use of readers who prefer to use International System (SI) units, rather than the inch-pound terms used in this report, the following conversion factors may be used:

| Multiply | By | To obtain |
|---|---|---|
| inch (in.) | 25.4 | millimeters (mm) |
| foot (ft) | 0.3048 | meter (m) |

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## ABSTRACT

Suspended-sediment samplers must sample isokinetically (at stream velocity) in order to collect representative water samples of rivers. Each sampler sold by the Federal Interagency Sedimentation Project or by the U.S. Geological Survey Hydrologic Instrumentation Facility has been adjusted to sample isokinetically and tested in a flume to verify the calibration. The test program for a modified U.S. P-61 sampler provided an opportunity to compare flume and towing tank tests. Although the two tests yielded statistically distinct results, the difference between them was quite small. The conclusion is that verifying the calibration of any suspended-sediment sampler by either the flume or towing method should give acceptable results.

## INTRODUCTION

Suspended-sediment samplers must sample isokinetically (at stream velocity) in order to collect truly representative samples of river water. Each sampler sold by the Federal Interagency Sedimentation Project (FISP) or by the Hydrologic Instrumentation Facility (HIF) of the U.S. Geological Survey has been adjusted to sample isokinetically. Each sampler is then tested in a flume to verify the calibration.

There is a general feeling of uneasiness about the acceptability of the towing method for verifying the calibration of suspended-sediment samplers. The primary reason for this is the lack of turbulence in towing tanks. A sampler in a river is in a naturally turbulent environment. Therefore, it has been assumed that the sampler should be calibrated in a similar environment. A few attempts to compare the two methods were made in the past, but the data available are quite limited.

In 1983, the Hydrologic Instrumentation Facility sought to improve the design of the US P-61 sampler--one of the standard point-integrating, suspended-sediment samplers in use within the United States. The valve mechanism was the focus of the redesign effort for two reasons: (1) a need to reduce the energy required to cycle the valve and (2) a need to lessen the potential for sample contamination by trace metals. Testing of the new design offered an opportunity to check the comparability of towing and flume calibration verification. This report summarizes and compares the results of both methods.

### Acknowledgements

The authors wish to acknowledge the support provided by the following agencies: Agricultural Research Service, Bureau of Reclamation, Forest Service, Bureau of Land Management, and the Federal Highway Administration.

## TEST PROCEDURE

### Flume Test

The modified P-61 used in this study was first adjusted for balance and tested for leakage. The P-61 sampler undersamples (samples at less than an isokinetic rate) when manufactured to the engineering drawings, and the modified P-61 was no exception. Therefore, the downstream end of the nozzle was reamed slightly with a tapered (0.25 inch-per-foot) reamer. The intake end of the nozzle was undisturbed. The sampler was tested in the flume and, as necessary, reamed further. The procedure was repeated until the target intake ratio of 1.00 had been achieved. The same sampler was used in both tests and no reaming was done after testing was begun.

The flume test was performed by FISP personnel in the calibration flume at the St. Anthony Falls Hydraulic Laboratory of the University of Minnesota in Minneapolis, Minnesota. The non-recirculating flume used in this study is 300 ft (feet) long, 8 ft wide, and 8 ft deep, and is supplied by the Mississippi River. The narrowed test section (at the downstream end) is approximately 18 ft long, 3 ft wide, and 8 ft deep.

For these tests, the flow was adjusted to the approximate desired velocity with hydraulic controls. The velocity at the intended nozzle depth then was checked with a type AA Price current meter. The sampler was lowered to the 2.0-ft sampling depth with a dry container and the valve was opened and the mechanical stopwatch was started simultaneously. At the end of the predetermined sampling period, the valve was closed and the sampling time was recorded. The sampler was raised, the container was removed from the sampler, and the volume of sample was recorded. Two more samples were obtained before the velocity was checked again. The flume was then adjusted to a higher velocity and the procedure was repeated. The nozzle intake velocity was computed from the sample volume, sampling time, and nozzle diameter.

## Towing Test

The towing test was performed in the U.S. Geological Survey Tow Tank Facility within the Hydraulics Laboratory at the National Space Technology Laboratories near Bay St. Louis, Mississippi. This test facility is a 450 ft long tow tank that is 12 ft wide and 12 ft deep, with the water depth maintained at 11 ft. The electrically powered carriage travels on rails atop the tank and contains a data-acquisition system that collects travel-time and distance data. This tow carriage facility has a speed range of 0.01 to 14 ft/s (feet per second) and has a speed accuracy of 0.01 percent.

The sampler was lowered to a sampling depth of 2 ft and the towing carriage was started. The sampler valve was opened and timing of the sampling interval began when the carriage had attained the correct predetermined speed as indicated by the "AT SPEED" light on the data-acquisition system. The sampler valve was left open for a predetermined length of time that was calculated to fill the container from half to two-thirds full. The sampling procedure was repeated three additional times at the same towing velocity. The entire procedure was repeated for subsequent selected towing velocities.

Recorded data included both gross and tare sample-container weights, sampling time, towing distance, and the carriage travel time for that distance. From this raw data, the net sample weight, intake velocity, and carriage velocity were computed.

## TEST RESULTS

A summary of the data is given in table 1. The tow-tank data are from a report submitted to the HIF by Computer Sciences Corporation (written commun., 1985). Both the flume velocity and the carriage velocity are assumed to be the approach velocity of the nozzle. The averaged data are plotted in figure 1. The lines of relation for both sets of data plot above the line of equality at low velocities and plot below at high velocities. The two regression equations are:

| | | |
|---|---|---|
| Flume | $V_n = 0.534 + 0.873\ V_s$ | (1) |
| Tow Tank | $V_n = 0.630 + 0.846\ V_s$ | (2) |

$V_n$ is the intake (nozzle) velocity in ft/s, and $V_s$ is the approach velocity, also in ft/s. The $r^2$ values are 0.9993 for the flume equation (1), and 0.9999 for the towing tank equation (2). An $r^2$ value close to unity indicates a very close agreement between the data and the equation, and corroborates the visual impression given by figure 1.

An analysis of covariance of the data in table 1 was kindly provided by E.J. Gilroy (written commun., 1986) using a regression model of the form:

$$V_n = b_0 + b'_0X + b_1V_s + b_2(X \cdot V_s) \quad , \qquad (3)$$

where X is a dummy variable equal to zero for flume data and unity for towing tank data. The analysis showed that both slope and intercept were significantly different between the two tests.

While statistically distinct, the two curves of figure 1 are also very similar. Gilroy suggested describing the similarity as a percent difference, PDIF, between estimates of $V_n$ based on equations 1 and 2 for a given $V_s$. PDIF is the difference between estimates divided by the mean of the estimates multiplied by 100:

$$PDIF = 100(-0.096 + 0.027V_s) \ / \ (0.5820 + 0.8595V_s) \quad . \ (4)$$

PDIF varies smoothly from -8.01 percent for $V_s = 0.515$ ft/s to 1.92 percent for $V_s = 10.22$ ft/s. For approach velocities greater than 2 ft/s, the difference between the two curves is less than 2 percent. The two curves are thus quite similar while being statistically distinct.

## DISCUSSION

The main finding of this study is the close similarity in the results of the two tests. Indeed, the two equations plot more closely to each other than to the line of equality. The difference in turbulence between the flume and towing tank did not have much effect on the intake rate in these tests. Of course, the flume does not have the level of turbulence found in a natural stream because it lacks bed forms, meanders, and bank vegetation. However, these natural stream features tend to generate large-scale turbulence, and the sampler will respond by reorientation to this turbulence. Consequently, the

**Table 1.--Approach and intake velocity data for flume and towing tank tests.**

[All velocities are in feet per second]

| Flume data, September 1985 | | Towing tank data, November 1985 | |
|---|---|---|---|
| Approach velocity | Computed intake velocity | Approach velocity | Computed intake velocity |
| 0.515 | 1.01 | 0.515 | 1.05 |
| .515 | 1.01 | .517 | 1.13 |
| .515 | 0.952 | .516 | 1.00 |
| .515 | 1.06 | .515 | 1.07 |
| 1.01 | 1.44 | 1.01 | 1.47 |
| 1.01 | 1.46 | 1.01 | 1.47 |
| 1.01 | 1.44 | 1.01 | 1.48 |
| | | 1.01 | 1.46 |
| 1.93 | 2.16 | 2.01 | 2.26 |
| 1.93 | 2.22 | 2.01 | 2.32 |
| 1.93 | 2.19 | 2.01 | 2.28 |
| | | 2.01 | 2.33 |
| 3.70 | 3.58 | 3.52 | 3.67 |
| 3.70 | 3.63 | 3.53 | 3.66 |
| 3.70 | 3.63 | 3.53 | 3.63 |
| | | 3.54 | 3.63 |
| 5.45 | 5.37 | 5.54 | 5.43 |
| 5.45 | 5.37 | 5.54 | 5.38 |
| 5.45 | 5.37 | 5.56 | 5.40 |
| | | 5.56 | 5.31 |
| 7.92 | 7.60 | 8.08 | 7.58 |
| 7.92 | 7.60 | 8.08 | 7.49 |
| 7.92 | 7.48 | 8.12 | 7.42 |
| | | 8.11 | 7.41 |
| 10.12 | 9.21 | 10.19 | 9.30 |
| 10.12 | 9.34 | 10.20 | 9.16 |
| 10.12 | 9.34 | 10.20 | 9.16 |
| | | 10.22 | 9.33 |

difference in turbulence between the flume and towing tank is a good test of the effect of turbulence on the intake rate. Because the two tests gave such similar results, either method of verifying calibration appears acceptable.

The statistical distinctness of the two similar equations is still quite interesting. Several explanations may account for this. One is the presence or lack of turbulence in the flume. Another explanation is that the two data sets were obtained at different water temperatures. Water temperature was measured in only one of the tests, however. The relation between intake and stream velocity is temperature dependent (Interagency Committee, 1952, p. 78-79). Figure 41 of that report shows that the ratio of intake to approach velocity increases 0.004 for every $^{o}F$ (degree Fahrenheit) increase above 32 $^{o}F$ for a 3/16-inch nozzle diameter. A change of this magnitude should apply uniformly over the entire velocity range. However, the two lines in figure 1 cross, and this would not be the case if temperature differences caused the difference in the two relations. The towing-tank equation plots higher than the flume equation at low velocities, but the reverse is true at high velocities. Because flume velocities are checked with a type AA current meter, it is possible that the low-velocity performance of the meter may have degraded slightly after many years of use in silt-laden river water. The small, low-velocity differences may result from such a condition. Turbulence is greater at high velocities and might be responsible for the small differences between the two equations in this velocity range.

The difference between the line of equality and the two equations is small. The difference can be magnified if it is displayed as an error ratio: $(V_n - V_s) / V_s$. Figure 2 shows the variation of the error ratio with approach velocity using averaged data from table 1. The very high ratios for approach velocities less than 2 ft/s are the result of a deliberate design feature. The elevation of the air exhaust on a P-61 is nearly 1 inch above the intake nozzle to insure that the water enters the nozzle and not the exhaust. A consequence of this feature is that the sampler will collect a sample even in still water, such as in a lake. However, the error in concentration should be low at low velocities, because the coarser sediment particles normally are not in suspension.

What then is causing the errors in concentration at higher velocities? The effect of under- or oversampling on sediment-concentration errors is quite small, except for sediment particles larger than 0.062 millimeters (Interagency Committee, 1941, p. 37-39). Figure 3 relates the concentration error to the velocity ratio for 0.06- and 0.45-mm particles. Generally speaking, the sampling error caused by undersampling is more serious than that by oversampling. The curves are steeper on the left-hand side of figure 3 than on the right-hand side. Errors increase with increasing particle size. The error curve for 0.06-mm particles is quite flat and closer to the x-axis than the curve for the 0.45-mm particles. For the 0.45-mm curve, undersampling by half causes an almost 30 percent error in concentration, whereas oversampling by twice causes about a 16 percent error. The modified P-61 used in this study undersampled primarily at velocities greater than 6 ft/s. At 10 ft/s, this P-61 undersampled by less than 10 percent. For 0.45-millimeter particles, the error in concentration is less than three percent for 10 percent undersampling. However, figure 3 shows that, for the present study, the range of the relative

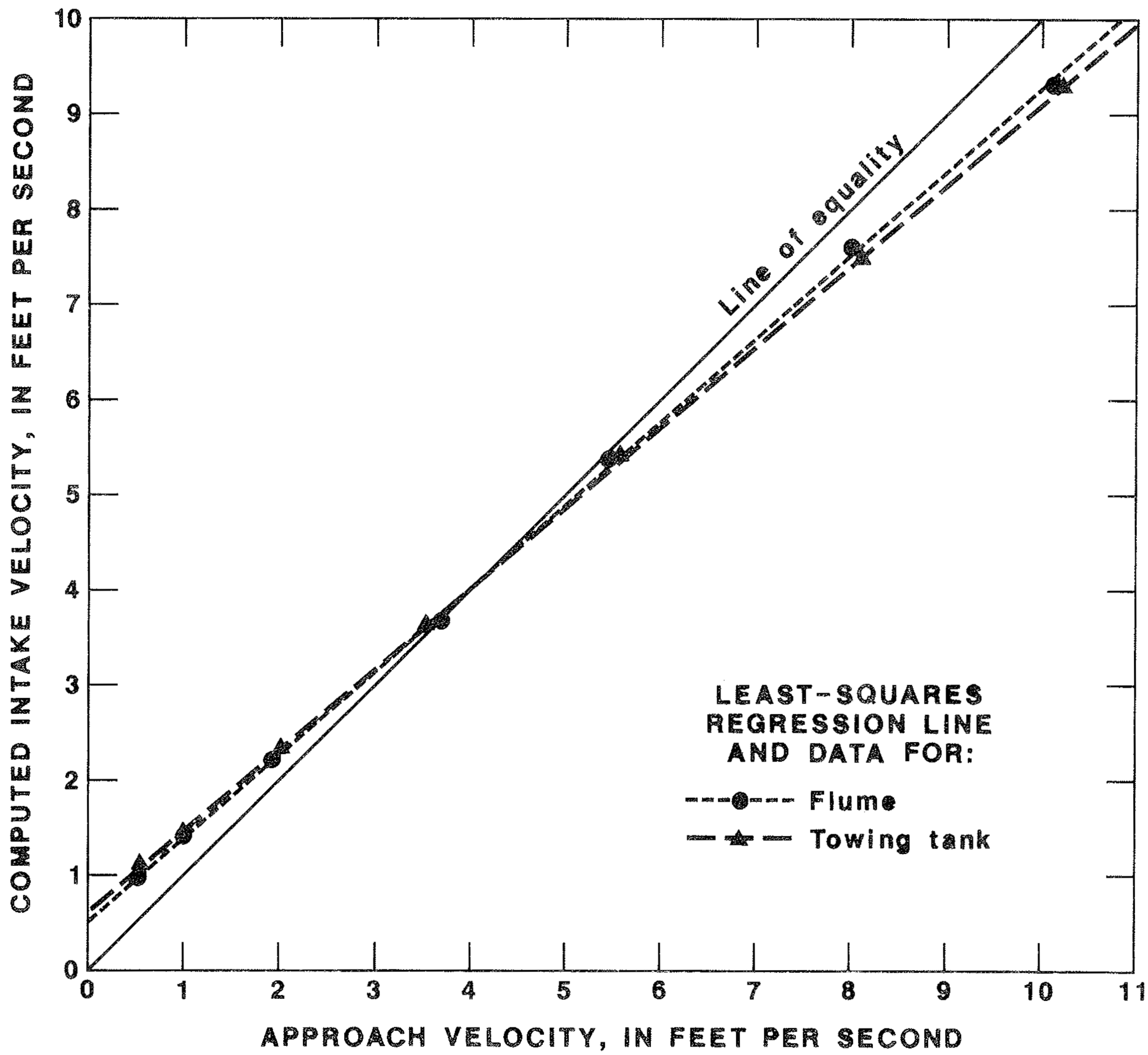


Figure 1.--Relation between intake and approach velocities for a modified P-61 sampler

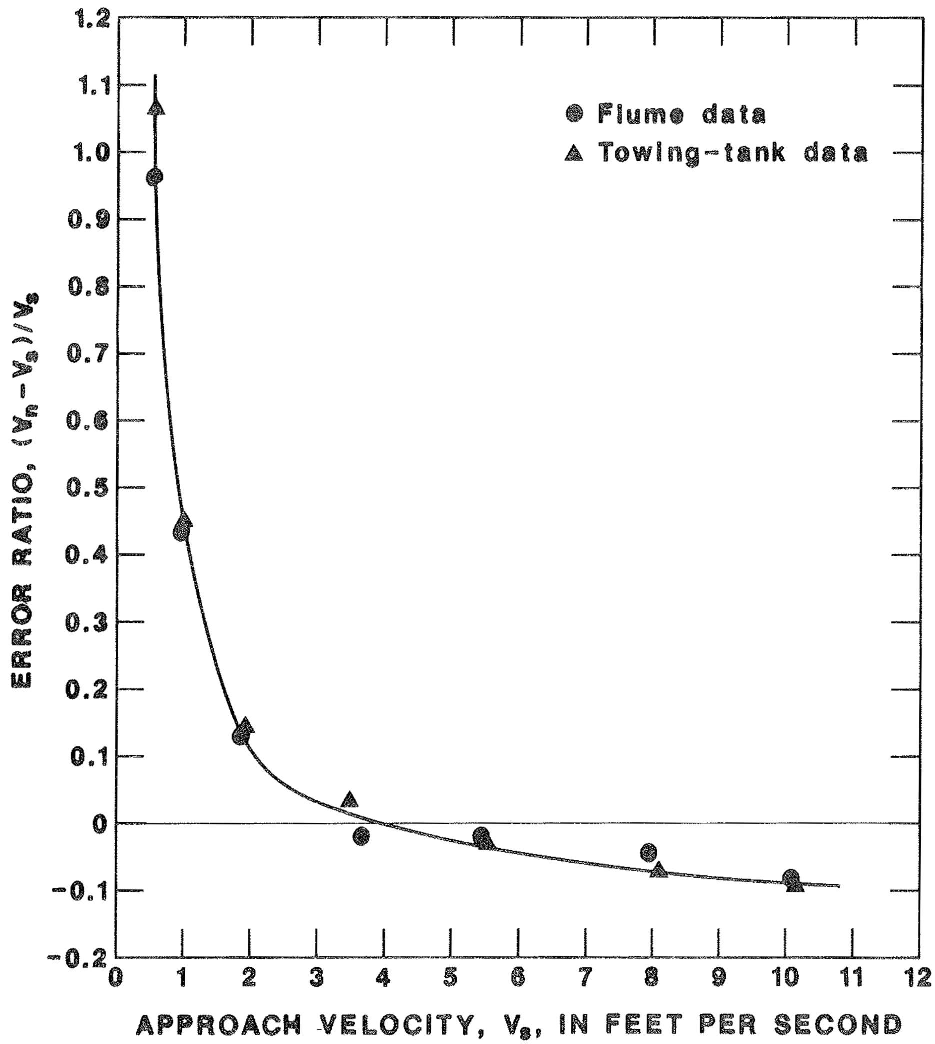


Figure 2.--Relation between error ratio, $(V_n - V_s)/V_s$, and approach velocity

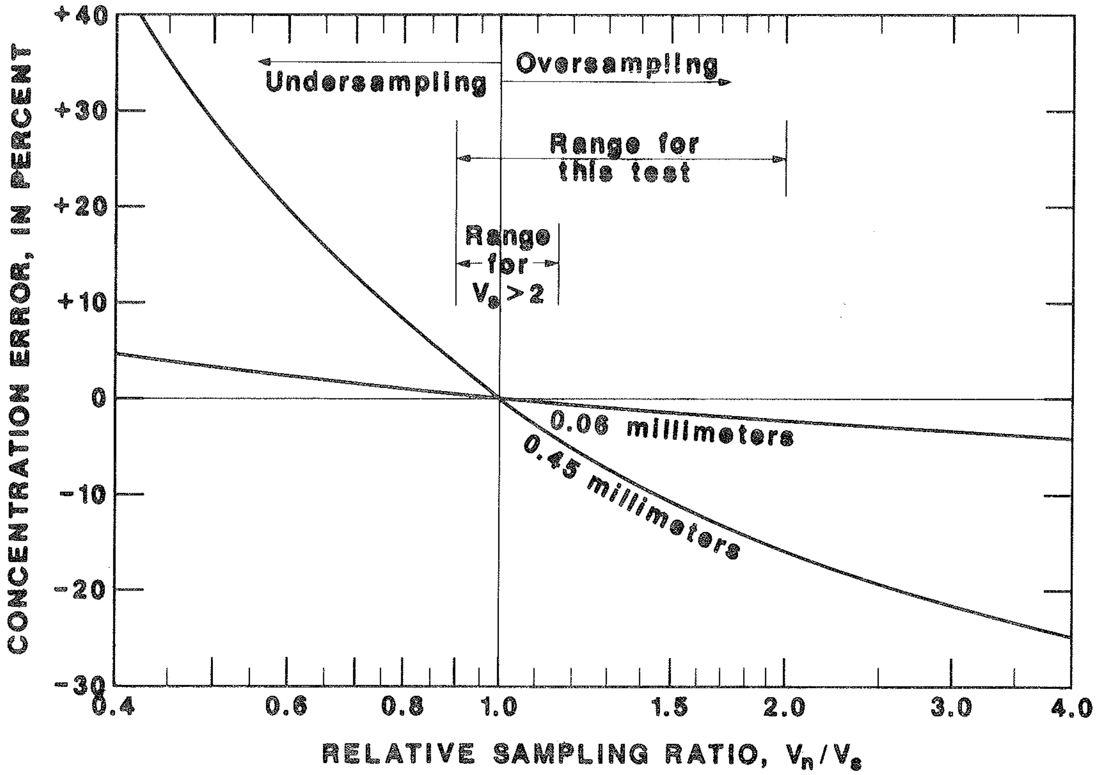


Figure 3.--Relation between concentration error and relative sampling ratio, $V_n/V_s$, for 0.06 and 0.45 millimeter particle sizes

sampling ratio was roughly from 0.9 to 2.0. The apparent corresponding concentration errors would range from +3 to -16 percent, respectively, for 0.45-mm material. These coarser particles are not normally found in suspension at velocities below 2 ft/s, however. The range in relative sampling ratio for velocities greater than 2 ft/s is from 0.9 to 1.15, as shown on figure 3. For this range and particle size, the corresponding concentration errors are between +3 and -5 percent. Figure 4 more clearly shows the concentration errors of the individual data points as a function of the approach velocity. The concentration errors were obtained from figure 3. However, the reader should understand that the concentration errors discussed in this paragraph relate only to those caused by under- or oversampling. This caveat is noted because there are other avenues for the introduction of error--namely, mechanical problems or dynamic sampler motion under certain operating conditions.

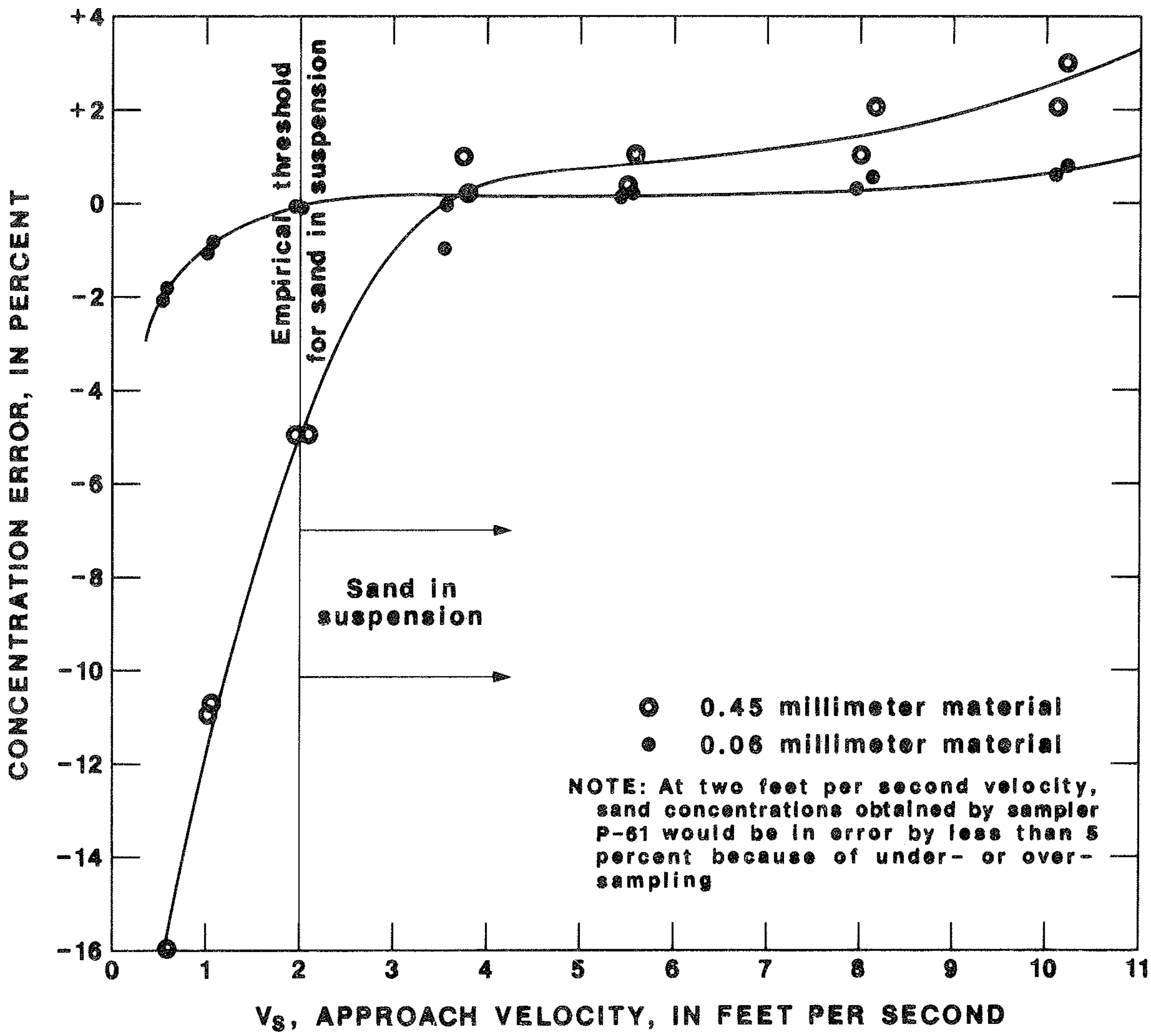


Figure 4.--Relation between approach velocity and concentration error for the modified P-61 sampler used in the present study

Not all flumes or towing tanks will meet the minimum requirements of size or accuracy. The sampler needs to be tested at a depth of more than one sampler diameter to minimize the effect of surface-wave resistance. For the P-61 sampler, a test depth greater than 1.5 feet is recommended. The sampler should be at least this same minimum distance from the bottom and side walls to avoid wall effects. The flume test section does not quite qualify in this regard. However, there does not appear to be any effect of blockage of the flow passing the sampler at high velocities. Refering again to figure 1, the flume curve is closer to the line of equality at higher velocities than is the towing tank curve. Any blockage effect should lower the flume curve in this region. In addition to minimum wall distances, a flume should have uniform flow lines approaching the sampler.

A towing tank should be long enough for the towing carriage to reach constant velocity, travel a sufficient distance to collect a proper sample, and have enough room remaining to stop safely. An advantage of indoor testing is that the water temperature will be more consistent throughout the year than if the towing tank were outdoors and supplied by river water. The towing method also offers the advantage of direct and very accurate measurement of velocity. For a nonrecirculating flume, the factors that affect the suitability of the tests are the availability of sufficient water, and the clarity and temperature of the water . For a recirculating flume, the energy cost for the pumps can be considerable.

## CONCLUSIONS

There is little difference in the results of the two methods (flume test and towing tank test) used to verify the calibration of the U.S. P-61 suspended-sediment sampler. Therefore, either method should give acceptable results. Statistically, the relations between intake and stream velocities for the two methods are not the same, but the difference is small. The lack of turbulence in the towing test probably accounts for the slight disparity between the two relations.

The findings of this study should apply to other types of samplers. However, this report presents the results of one pair of tests using only one sampler. A larger study may be needed before a permanent switch of procedures is adopted.

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