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# Contamination of Successive Samples in Portable Pumping Systems

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Automatic discrete sample pumping systems used to monitor water quality should deliver to storage all materials pumped in a given cycle. If they do not, successive samples will be contaminated, a severe problem with highly variable suspended sediment concentrations in small streams. The cross-contamination characteristics of two small commonly used portable pumping samplers are compared to each other and to reference measurements under conditions of sudden and severe changes in suspended sediment concentrations. The pressure-vacuum sampler showed greater cross contamination, especially when changing from high to zero concentrations, than the peristaltic sampler. Both samplers, however, cross-contaminated to some degree. The contamination was primarily due to the sand size particles rather than to the finer sizes.

## INTRODUCTION

Nonpoint source pollution of natural waters is a primary target of current monitoring efforts by government agencies and other groups concerned with land management. In wildland areas the nonpoint source pollutant of most concern is sediment. Suspended sediment is commonly monitored because it often represents a large proportion of the total sediment load and because it is easier to sample than bedload.

Sampling suspended sediment, however, has its own set of problems, which need to be considered to obtain accurate estimates. Depth-integrated hand sampling with specially designed equipment and proper techniques is thought to be the best approach to measuring suspended sediment accurately [*Federal Inter-Agency Sedimentation Project* (FIASP), 1963]. These techniques, however, require expensive structures such as bridges and cableways to be effective during high flow conditions and, of course, require people to operate the samplers. Because of these problems and because budgets for these activities are shrinking in relation to costs, several agencies are using small portable pumping samplers designed for wastewater sampling.

These samplers were not primarily intended to deal with the conditions existing when sampling solid-liquid mixtures. From the time the sample enters the sampler nozzle, it is subjected to hydraulic conditions that are different from those in the river. If the sampler is to represent the ambient stream concentrations accurately, it must deliver all of the mixture to the storage bottles. To achieve full delivery, the sampler depends primarily on velocity to keep the sediment in suspension. If part of the sediment is left in the hydraulic system, it is available to contribute to the next sample. This condition, known as cross contamination, was tested for early models of several commonly used samplers [*Skinner and Beverage*, 1981]. The tests showed significant cross contamination for the models of ISCO and Manning samplers tested. (The use of trade names in this paper does not constitute endorsement by the U.S. Department of Agriculture.) When samplers are used on small flashy streams and are set to sample at long intervals, drastic changes in concentration are possible, and the resulting cross contamination can be very misleading.

On the basis of these results, the Manning sampler design was changed, and the new model tested by *Wood* [1977]. Because the design changes appeared to have corrected the cross-contamination problem and because the sampling hose velocities are easily adjustable, we purchased three Manning model S4050 samplers for research on suspended sediment sampling procedures. These samplers use an air pump to cause alternate pressure and vacuum in a measurement chamber to purge the sampling hose and draw a sample. The upper part of this chamber is cylindrical with a conically shaped lower portion leading to an outlet. A short piece of flexible hose connects the outlet to a distributor arm positioned over the mouth of a sample bottle. During a sample cycle, except when actually transferring a sample to a bottle, the hose is kept closed with an electrically operated pinch valve. The sample mixture is admitted to the measurement chamber from a J-shaped tube positioned so that the mixture is swirled in the chamber. This swirling motion is designed to keep the sediment in suspension. When the chamber fills to a preset level, the pinch valve opens, emptying its contents into a sample bottle. The machine is powered by a 12-V lead-acid storage battery and draws from 8.6 to 10 A while sampling.

Another commonly used sampler is the ISCO model 2100. These samplers have a peristaltic pump which produces a short air purge and then draws samples directly from the stream through the pump to a distributor arm. Because the samplers lack a measurement chamber, sampling velocity is governed by head, pump velocity, and hose size. The ISCO is powered by a 12-V nickel-cadmium battery or 115-V line current. The sampler draws from 2 to 2.5 A when the pump is running.

After some experience with the Manning samplers we noticed sediment remaining on the lower conical portion of the chamber between samples. We decided to test our machines for possible cross contamination and also to compare them to the model 2100 ISCO samplers. This paper reports a study to test the effects of severe sudden increases or decreases in concentration on several subsequent samples.

## METHODS

### Equipment Used

We used six samplers for the tests: two new ISCO model 2100's, two new Manning model S4050A's supplied by the

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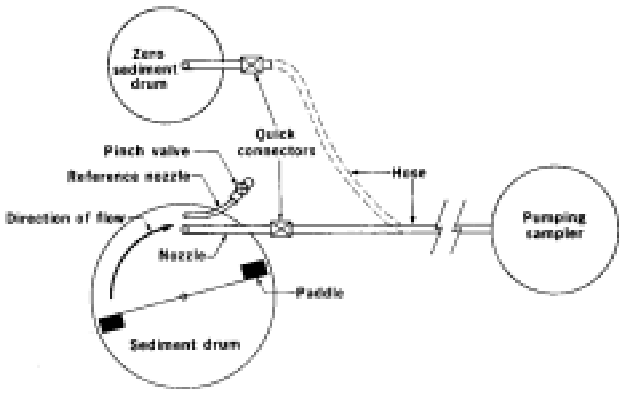

Fig. 1. Schematic diagram of experimental setup. Sampler being tested can easily be changed from the sediment drum to the zero sediment drum with quick connectors.

Manning Corporation, and two of our S4050's, which had been used for three seasons. Our two older machines had been modified to incorporate the same features as the factory-supplied models except for a new purge chamber. Each machine has 24 sample bottles.

The ISCO pumping samplers had an intake line velocity of 0.62 m/s in a 6.1-m-long intake hose with an inside diameter of 0.95 cm. The Manning sampler had a 7.6-m-long intake hose with 0.95-cm inside diameter, which produced a line velocity of 1.01 m/s.

Evaluating the response of a pumping sampler to sudden changes in suspended sediment concentrations requires control of velocities and concentrations during the test procedure. A cost effective alternative to using a flume for this purpose is using an open drum with its axis vertical to hold the water/sediment mixture. Contents of the drum are stirred with a paddle rotating on a shaft coaxial with the drum's axis (Figure 1). The water velocity and sediment distribution can be controlled by adjusting the paddle shape, velocity, and position within the drum. We used a variable-speed drill press to control paddle speed and experimented with paddle shape to obtain a stable sediment distribution. With 100 l of water in the drum, a velocity of approximately 1.1 m/s was produced in the vicinity of the nozzles.

A steel oil drum was cut to 60 cm and fitted with a nozzle made from brass tubing with the same inside diameter (0.94 cm) as the pumping sampler hoses. The nozzle passes through a hole in the drum wall, its open end pointing into the flow, and is joined to the machine being tested with a quick connector. This 19.0-cm-long nozzle is mounted 22.5 cm above the floor of the drum with its open end 6.5 cm from the drum wall. A second similar nozzle of 0.63-cm inside diameter is mounted parallel to the first and 1.7 cm to its outside. This nozzle also passes through the wall and is used to collect reference samples. It has a short section of flexible tubing attached to its outlet, which is kept closed by a pinch valve when not sampling. A second drum used to collect `zero sediment samples' was fitted with an identical intake nozzle and quick connector.

### Test Procedure

Each sampler was run with three repetitions of an eight-sample pattern: four at a high sediment level followed by four at essentially zero level. Reference and pumped samples were collected simultaneously at high sediment values.

Concentrations for the low sediment levels were assumed to be zero.

The pumping sampler being tested was placed on a platform with a head of 1.28 m relative to the water level in the drum. A ramp ensured a smooth, continuous drop in the intake hose from the machine to the nozzle in the test drum.

Sediment for the tests was collected from a small lake near the Forest Service's Redwood Sciences Laboratory in Arcata, California. The sediment was wet-sieved and dried. The sediment was prepared by combining predetermined weights of material in seven size classes ranging from 0.062 to 0.707 mm with a set weight of particles smaller than 0.062 mm. Particle sizes smaller than 0.062 mm were determined by the Bouyoucos hydrometer method (Figure 2). Arbitrary selection of the size fractions larger than 0.062 mm, and using a hydrometer to measure the material that passed through the smallest sieve accounts for the abrupt slope change at 0.062 mm (Figure 2).

The sediment drum was filled with 100 1 of tap water. A sampler was randomly selected, placed on the platform, and the controls set. All chambers and intake hoses were rinsed before the test. The samplers were set to collect a sample volume of 300 ml.

A randomly selected sample containing 100 g prepared sediment was added to the drum after the paddle brought the water to the proper velocity. This gave a nominal concentration of 1000 mg/l.

The sediment was mixed for 3 min before each test was run. Eleven replacement samples, 550 ml each, were with-

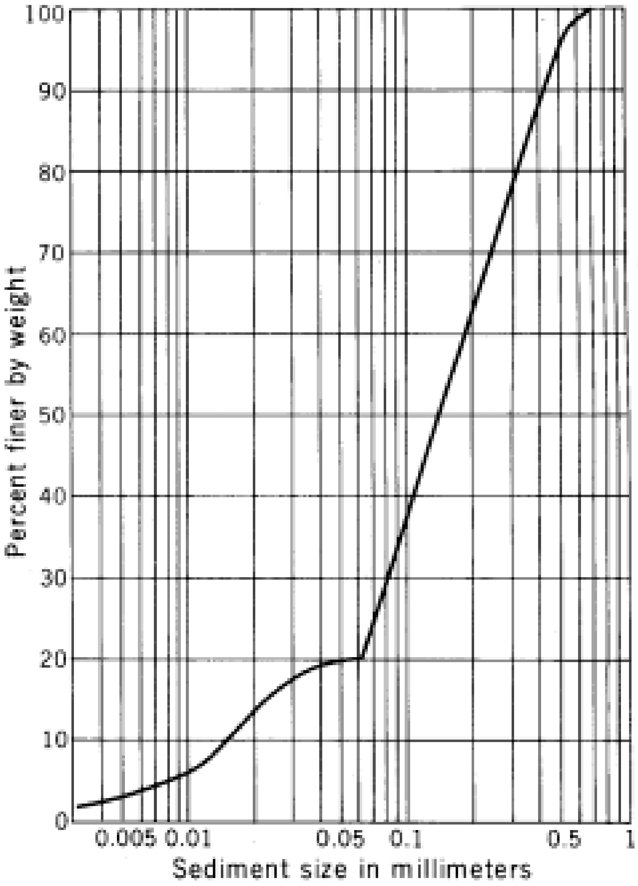

Fig 2. Particle size distribution of material used in cross-contamination tests. The seven particle size classes ranged from 0.062 to 0.707 mm.

drawn through the reference nozzle and set aside. The replacement samples were returned to the drum in reverse order, one after each sediment sample. This maintained the approximate volume and concentration in the drum. The zero sediment drum was filled with tap water to the same level as the high sediment drum.

The pumping sampler was manually triggered, and when the sample entered the intake hose, a simultaneous 300-ml reference sample was withdrawn. A replacement sample was then added to the sediment drum. This procedure was repeated until four sediment samples were collected.

The intake hose was disconnected from the sediment drum and drained of any remaining water. The hose was connected to the zero sediment drum, and four zero sediment samples were collected. The hose was returned to the sediment drum and the process repeated until 24 samples were collected.

The pumped and reference samples were analyzed in the laboratory for turbidity and sieved into fine and coarse fractions. The standard gravimetric-Gooch crucible filtration method [*United States Geological Survey*, 1977] was used to determine suspended sediment concentrations.

## EXPERIMENTAL RESULTS

A sequence of eight samples for each brand of sampler illustrates results of the tests (Figure 3). (The Manning data are from one of the new machines.) The concentrations of the fine (less than 0.062 mm) and coarse fractions are given separately. Corresponding reference concentrations for the high sediment levels are plotted with dashed lines; reference concentrations for low levels are assumed to be zero and are not shown. These examples are similar to the other sequences for the respective brand of sampler. A formal analysis of all of the data is described later.

For both samplers the total concentration of the first in a group of four high- or low-sediment pumped samples tended to lag behind the actual change in concentration, and the subsequent three samples then adjusted to the new level. Two important factors relate to this pattern: the lags resulted mainly from the coarse rather than the fine fractions; and the new level to which the samples adjusted was not always close to the reference level (Figure 3).

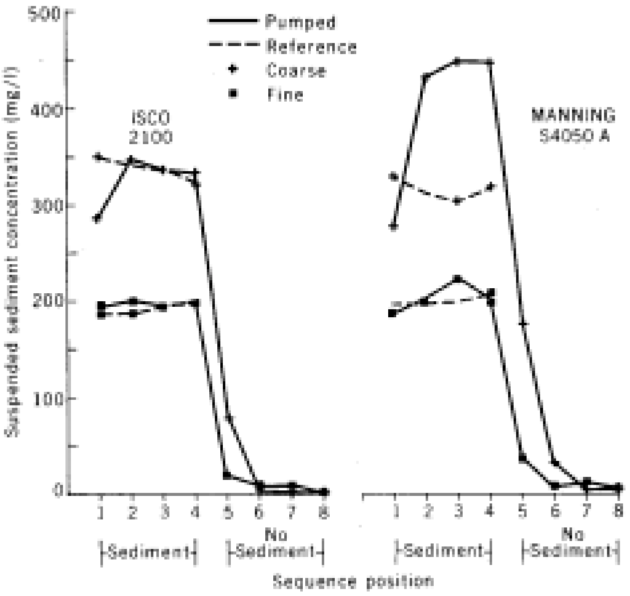

Fig. 3. Selected sequences of pumped and reference suspended sediment concentrations related to sequence position for two pumping samplers. Reference concentrations for samples from the zero sediment drum are assumed to be zero and are not shown.

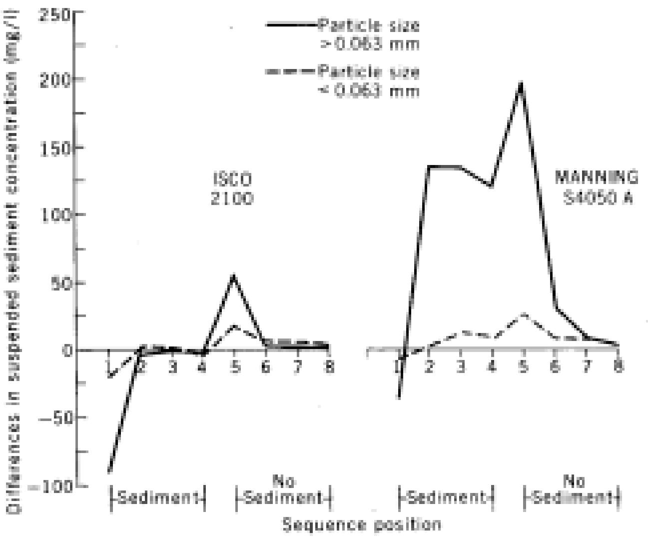

Fig. 4. Medians of six differences between pumped and reference concentrations from corresponding sequence positions for two brands of pumping samplers.

Pumped samples taken by the ISCO sampler followed their referents closely except for moderate lags at positions 1 and 5 for the coarse fraction. The fine fraction for the Manning sampler performed similarly, but the coarse fraction exhibited a greater lag which persisted longer. Also, the high-sediment samples adjusted to a concentration about 125 mg/1 above the reference values.

Medians of the six differences between pumped and reference concentrations for corresponding sequence positions by brand (considering only the factory-supplied Manning samplers) give a more comprehensive look at the data (Figure 4). That is, the median of the differences of samples 1, 9, and 17 from both ISCO runs is plotted as sequence position 1, of samples 2, 10, and 18 as position 2, and so on. Fine and coarse fractions are shown separately.

The plots corroborate the points evident in Figure 3. The lags were greater for the ISCO samplers when changing from high to low concentrations for both size classes. Conversely, when changing from high to low concentrations the Manning machines showed greater lags, especially with the coarse fraction. The tendency for the Manning samplers to home on concentrations different from the reference levels is also evident.

The plots in Figures 3 and 4 were affected by the relative abundance of particles in the two size classes. Although the sediment samples were constructed with 80% of their weight in the sand size class, average percent sand at the level of the nozzles in the drum averaged about 60%, as determined from the reference measurements. The significance of cross contamination under particular field conditions depends on the proportion of large-sized particles in that situation.

An analysis of variance (ANOVA) provides a more rigorous test of brands, machines, and positions within a sequence. All experimental data were used for the analysis, including the older Manning samplers to compare used machines with new ones. The two older samplers were

TABLE 1. Main Effects and Interactions From Four Analyses of Variance of Suspended Sediment Concentrations Run at High and Low Particle Sizes and Two Nominal Concentrations

| | High Concentration | | Zero Concentration | |
|---|---|---|---|---|
| Source of Variance | Particle Size < 0.063 mm | Particle Size ≥ 0.063 mm | Particle Size < 0.063 mm | Particle Size ≥ 0.063 mm |
| Brand | 0.308 | 0.024** | 0.008*** | 0.004*** |
| Machine | 0.011** | 0.038** | 0.661 | 0.063* |
| Position[a] | 0.001*** | 0.000*** | 0.000*** | 0.000*** |
| Brand/position | 0.130 | 0.070* | 0.044*** | 0.000*** |
| Machine/position | 0.410 | 0.520 | 0.001*** | 0.056* |

*P*: $0.10 < P$, not significant. *P**: $0.05 < P \leq 0.10$, almost significant. *P***: $0.01 < P \leq 0.05$, significant. *P****: $P \leq 0.01$, highly significant.

[a] 'Position' refers to placement of a datum in a sequence of four high or low sediment measurements.

considered a third `brand.' Four ANOVA's were done: one each for all combinations of high and low nominal sediment concentrations and for the fine and coarse sediment size classes. For each analysis there were three brands (a fixed factor), two machines per brand (a random factor), three replications per machine (a random factor) derived from the three groups of four measurements per run made at a given sediment level and size class, and four positions within these groups (a fixed effect). The significance probabilities for the analyses for main effects and interactions are given in Table 1. We have accepted the usual level of $p = 0.05$ for inference purposes, but have indicated the strength of significance by asterisks.

Inference is simplest for the analysis of high-sediment concentration because interactions for both the fine and coarse fractions are nonsignificant. For the fine fraction, the brand is nonsignificant, implying that under high sediment conditions, the fine fraction is measured much the same by all of the machines. This is not true for the coarse fractions, however, since the brands' main effect is significant. Tukey's pairwise multiple comparison tests [*Scheffe,* 1959] used on the brand means show that the new and old Manning samplers are not significantly different from each other, but are both different from the ISCO machines. This agrees with impressions given by the graphs.

For both the fine and coarse fractions under high-sediment conditions, the machines' main effects are significant, which is disturbing. This finding suggests that the data may depend on the particular machine being used. That is, even when controlling for brand of machine and sequence position, the individual samplers performed differently when sampling high concentrations. Direct inferences cannot be made about this situation with these experimental data, so it is not clear what brand or brands show the problem. The significant main effects, however, support the general need for calibrating each machine with a standard instrument.

The positions' main effects for both particle size classes are highly significant. This finding, too, is consistent with indications in the graphs. It implies that for this experimental setup the measurement of high sediment levels with these pumping samplers will be different depending on which of a sequence of four values is selected, and this is true for both fine and coarse particle sizes.

Inferences for the low-sediment concentrations are more difficult to make because three of four interactions are highly significant. In spite of this, however, both the brands' and positions' main effects for fine and coarse materials are highly significant, showing that the effects are strong enough to be indicated in spite of the lack of additivity. For the coarse fraction, multiple comparison tests indicated that the ISCO and Manning samplers differ as they did with the sand size particles at high sediment levels. For the fine particles, however, the ISCO and factory-supplied Manning samplers are not significantly different from each other, but both are different from the older Manning samplers. This difference tends to support the contention that measurements are dependent on individual machines.

The lack of significance of the machines' main effects for either fine or coarse fractions may result from no difference or from interactions.

## DISCUSSION

Results indicate that with a rapid rise or fall in suspended sediment concentration, two commonly used portable pumping samplers may not give accurate representations of actual stream conditions. The machines lag and then adjust to a new level over several samples that does not always approximate the actual reference concentration. Cross-contamination error is more serious for large particle sizes than for small ones, but even the fine materials cross-contaminate to some extent. Machine design appears to affect both of these problems.

The ISCO machines respond to a sudden increase with one or two low values for the coarse materials and then adjust to the reference level. The small particle sizes adjust to the reference level after one low value. With a sudden change from high to zero concentration, one sample lags-with a larger lag for coarse materials-followed by three samples near zero.

The Manning samplers performed less well in general, with longer and larger lags for more samples on both rising and falling concentrations. The Manning samplers also handled the fine size classes better than they did the coarse ones. Of particular concern is that these machines adjusted to a level in excess of 100 mg/1 high for the high concentrations; this was caused primarily by the sand size class.

The results reported here appear to contradict those from the study mentioned earlier [*Wood,* 1977]. Further consideration, however, suggests that the earlier work may not have shown the kind of cross contamination we have described. Cross contamination was much worse for our coarse particle size class (larger than 0.062 mm), and presumably, the contamination is a continuous, increasing function of size. Our samples had particles up to 0.7 mm. The earlier study used materials with three size distributions, but only one of these ($d_{50}$ = 0.33 mm) had particles over 0.3 mm. Unfortunately, the part of the earlier test that used this coarser material involved measurements made at different points throughout the flume cross section and at relatively low nominal and actual concentrations. It was impossible, therefore, to disentangle the effects of nozzle placement in the flume and sampler performance. If contamination is largely confined to the particles larger than 0.3 mm, this would not have been detected in the earlier study.

These results are not presented as an exhaustive test of the capabilities of these machines. Rather, they indicate that large changes in sediment level may not be reflected in samples taken from pumping samplers of certain designs. Further tests could be done for different particle size classes, sampling velocities, and hydraulic heads, but these would be onerous and costly.

The results provide two insights: manufacturers producing machines intended for use in sampling suspended solids should subject their designs to intensive testing under commonly experienced field conditions; and hydrologists who use these devices should be aware of possible cross contamination when planning sampling programs and when analyzing and interpreting the resulting data. Hydrologists can reduce the effects of cross contamination by sampling more frequently (so concentrations will not change greatly), or by using the multiple bottles feature to ‘condition’ the sampler to a changed state and discarding the first of, say, two samples. The major effect of cross contamination on widely varying concentrations is to reduce the estimate of variance, thereby indicating higher precision than is warranted.

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