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VOLUME I

SMALL WATERSHED AUTOMATIC WATER QUALITY SAMPLER

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ABSTRACT

A total-load, automatic sediment sampler has been developed for use with precalibrated runoff-measuring devices in association with small watershed water quality research. The system collects individual samples periodically during a runoff event at the exit of the precalibrated measuring flume. The system consists of two parts, the sampler and the sample storage mechanism. The sampler is a vertical slot which traverses across the flume exit on a horizontal rail. The traverse speed of the slot is controlled by the design criteria of the sample storage mechanism. On early models of the unit, sample storage was a revolving table with a capacity of 18 two-liter bottles. For these early units, the traverse speed was made variable and regulated by the flow depth and, in turn, by the discharge rate. Subsequent designs have replaced the revolving table with a continuous chain to which the sample bottles are attached. In this design, the slot makes multiple traverses until a preset sample size is obtained. Following filling, the bottle is lifted from the position where the discharge from the slot fills the bottle. Each traverse (bottle filling) is recorded on the water stage recorder. System power is obtained from a 12-volt battery charged by a photovoltaic cell. This allows sampler operation in remote areas where conventional electrical power is not economically available.

INTRODUCTION

The need for water quality sampling has been greatly increased by non-point pollution legislation associated with Section 208 of PL 92-500. To accomplish the mandates of the legislation, information was required on the pollution resulting from management alternatives for the infinite combination of climatic, soil, topographic conditions, and land uses in the United States. Such data then, when used with physically based models, allow making the decisions necessary to eliminate and/or control nonpoint pollution sources.

Water quality sampling in small watershed studies is difficult because unpredictable storms cause rapid watershed response to precipitation events, and precludes personnel being present; conventional AC power is often not available to power equipment that might be used to collect samples; and most battery operated pumping-type samplers (widely used in many nonpoint pollution research efforts) have intakes at fixed positions in a flow cross-section. Since sediment and other pollutants vary widely with depth and across the stream, fixed intakes become a variable position relative to the cross section and discharge of an individual flow. As such, it is difficult to resolve these point concentration estimates into total discharge rates or yields.

In ephemeral streams of the southwestern U.S., stream channels are characteristically steep (slopes > 1%), contain large quantities of coarse alluvium (geometric mean grain size of 1 to 3 mm), and the flow depths and discharges vary rapidily in time in response to air-mass thunderstorms which are of high intensity and short duration. Collecting water quality samples under such conditions requires that the sampler can:

(1) obtain discrete samples throughout the hydrograph,
(2) sample the entire flow depth and width,
(3) sample at remote sites using battery power,
(4) sample unattended,
(5) sample coarse and fine sediments and chemicals,
(6) sample multiple runoff events,
(7) sample at different frequencies because of expected concentration variations.

The sampling equipment developed in response to these design requirements evolved from a series of experiments and experience with a number of prototype designs at the Southwest Rangeland Watershed Research Center. The earliest example of this concept of automated sampling equipment was developed by Libby (1968) for use on Walnut Gulch large supercritical flumes. Libby's sampler only traversed half the width of flow, required AC power, was not automatic, and sampled only the bottom 30 cm of flow. Dendy (1973) developed a sampler similar to the one described here, except that his only collected bulk samples, not discrete ones through time, and did not use photovoltaic battery chargers. The first generation of this automatic sampler was reported at the Third Interagency Sedimentation Conference (Renard et al., 1976). The current version includes the use of a supercritical flow measuring flume (Smith et al., 1981), a multistage timer for sampling interval control, and a sample-bottle storage-mechanism on a continuous chain that lifts filled sample bottles from the filling position to the storage facility. Throughout the development, simplicity and low maintenance were essential design considerations. The flume and sampler were built for under $20,000.

Figures 1a and 1b show a typical flume-sampler installation on the Walnut Gulch Experimental Watershed near Tombstone, Arizona. The 1.4 m^3/s supercritical flume measures the surface outflow from a 3.68 ha watershed. A schematic diagram of the essential features of the sampler and flume is given in Figure 2.

GENERAL SAMPLER OPERATION

Essential features of the sampler consist of: (1) energizing switch (activated from water level recorder), (2) traversing slot at flume exit, (3) power system for traversing slot, (4) fixed slots beneath flume exit, (5) continuous chain for sample storage, (6) bottle filling sensor, (7) photovoltaic cell for charging 12-volt DC battery, (8) marking system to show sample collection time on stage graph, and (9) a system of electronics to control the sampling sequences and other mechanical operations.

Energizing switch: The sampler is activated by an on-off switch that has been attached to a gear on the flume water-level recorder. In applications used in Arizona, the switch was set so sampling cycles would start when the flow was deeper than 5 cm (smaller flows require too many traverses of the slot to obtain an aliquot sufficiently large for laboratory analysis).

Traversing slot: The traversing slot (made of stainless steel to minimize

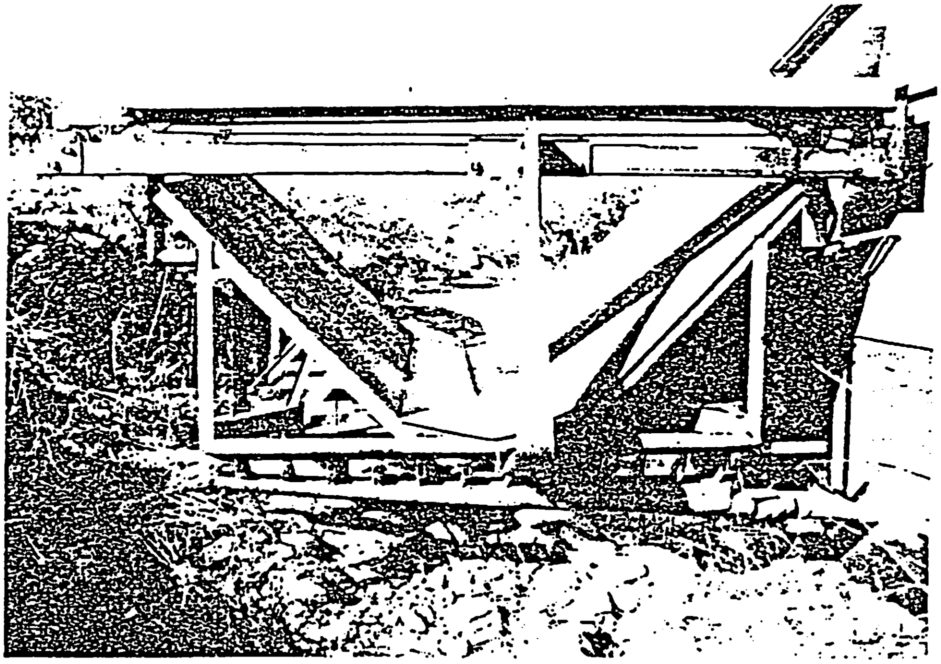

Fig. 1a. Typical slot sampler as installed on a 1.4 m^3 s^{-1} super critical flume. The downstream view shows the moveable and fixed slots, the flume, and the bottle storage mechanism house.

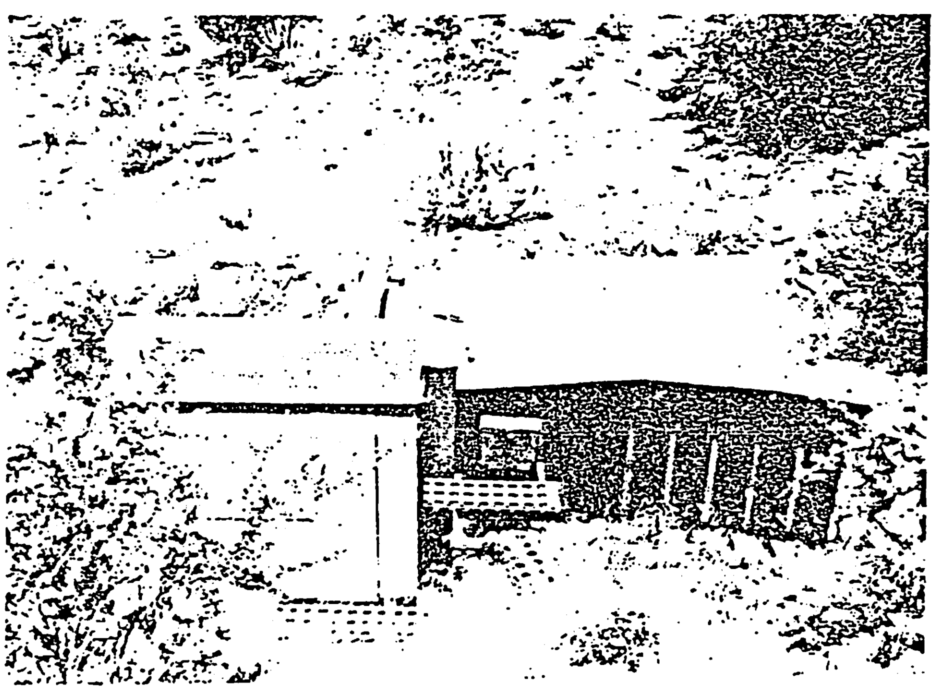

Fig. 1b. A side view of the flume and sampler installation.

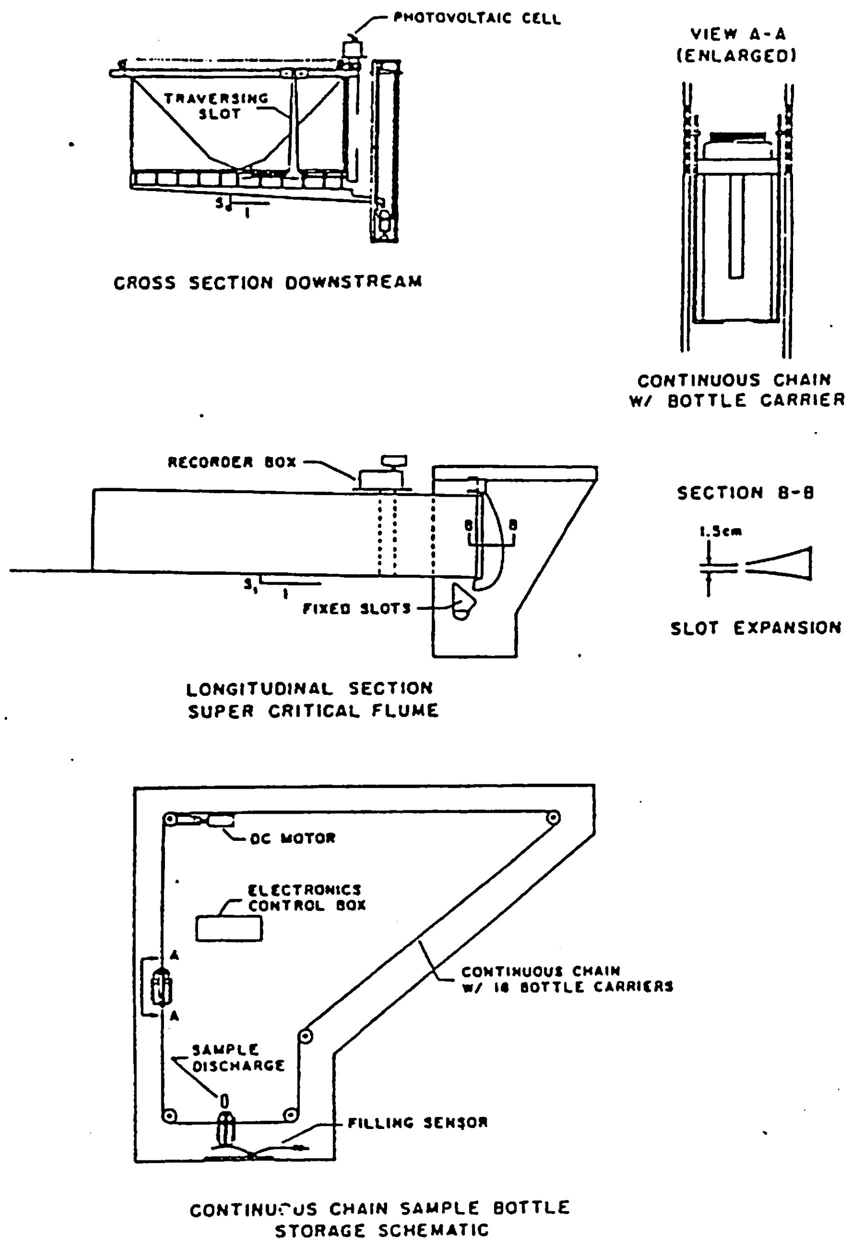

Fig. 2. Schematic diagram of slot sampler mechanism.

sample chemical contamination) has a constant 1.5 cm opening at the flume exit. The slot diverts an aliquot of the water-sediment-chemical mixture from the flume exit water jet as the slot traverses the flow. The slot's flared design diverts the mixture from a horizontal to a downward direction, and the mixture is then directed onto the fixed slots beneath the flume. This design eliminates pressure buildup in the slot, and prevents flow expulsion above the water surface at the flume exit. Because the slot moves through the flow at a constant rate, an integrated (velocity) sample of the mixture is taken.

Power for traversing slot: A 12-volt DC motor is used to drive the traversing slot across the flume exit. A continuous chain imparts the power at the top of the slot with wheels running on a horizontal rail affixed to the flume. Bearing-equipped wheels at the bottom of the slot absorb the horizontal force of the water impinging against the slot and hold the mechanism in a vertical position.

Fixed slots: Ten fixed slots are positioned immediately beneath and evenly spaced across the flume exit such that the water from the traversing slot discharges onto the fixed slots and further splits the sample. The spacing of the fixed slots is the same as the exit port width of the traversing slot, and the opening of the fixed slot is the same as that of the traversing slot so both can sample the same sized material. The water-sediment-chemical mixture then flows by gravity through the slot collector tube to the sample storage facility, where it is deposited in individual sample bottles. The fixed slots and slot collector tube are made of stainless steel and PVC to minimize chemical contamination.

A note of caution is needed at this point. Care must be taken to ensure that tailwater does not become high enough to cause water to flow into the fixed slots or the bottom of the storage compartment where the filling sensor is positioned. Thus, the flume and sampler can be used only in locations where there is sufficient gradient to install the equipment.

Continuous chain for sample bottle storage: Eighteen sample bottles are stored on a continuous chain driven by a 12-volt DC motor similiar to the one used to drive the traversing slot. The drive motor is activated by the timer and a sample bottle is moved into sampling position just before the traversing slot begins its traverse. After the traversing slot has completed its sampling sequence, the continuous chain drive motor is again activated and the filled bottle is moved from its sampling position. Thus, no bottle is under the slot collector tube during a non-sampling period. This eliminates the possibility of sample contamination if water should enter the fixed slots because of dripping at the flume overfall or rain entering these slots during non-sampling periods.

Bottle-filling sensor: During a slot traverse, a bottle is positioned in the sampling position which is located under the collector tube from the fixed slots and over a weighing mechanism that determines when a sufficient sample has been taken to meet laboratory processing criteria (approximately 1 liter). The weighing mechanism consists of two counterweighted arms that direct the sample bottle into position for weighing. The weighing mechanism is connected to a filling sensor switch that is switched off when the sample reaches a predetermined weight. If, after each slot traverse, the sample bottle and water are not heavy enough to activate the filling sensor, the slot will traverse the flow again. This sequence continues until either the filling sensor is activated, indicating an adequate sample weight has been taken, or the preprogrammed sample time interval is exceeded. Limit switches at either end of the traversing slot chain mechanism cut power to the slot drive motor at the end of a traverse if (a) the bottle filling sensor has indicated an adequate sample, (b) the sample time interval has been exceeded, (c) all the sample bottles are filled, or (d) the flow is less than 5 cm deep.

Photovoltaic cell for battery charging: The single 12-volt automobile-type battery used to power this sampling equipment is trickle charged with a 0.125 amp photovoltaic cell. Experience with this mechanism has been excellent, and the battery has maintained a charge for as long as 5 years.

Sample time marking: A solenoid activated pen marks sample times on the lower edge of the chart of the flume's analog water level recorder simultaneously with each sample bottle filling.

SAMPLER LOGIC

Figure 3 details the logic flow path of the sampler sequencing. The sampler is in a standby condition when there is no flow or a flow less than 5 cm depth is ocurring in the flume and the sample storage unit has empty sample bottles. In this condition, the traversing slot is on the limit switch at one side of the flume exit; the sequential timer is off and ready to begin cycle one of the timing sequence; and a sample bottle is not directly under the collector tube from the fixed slots.

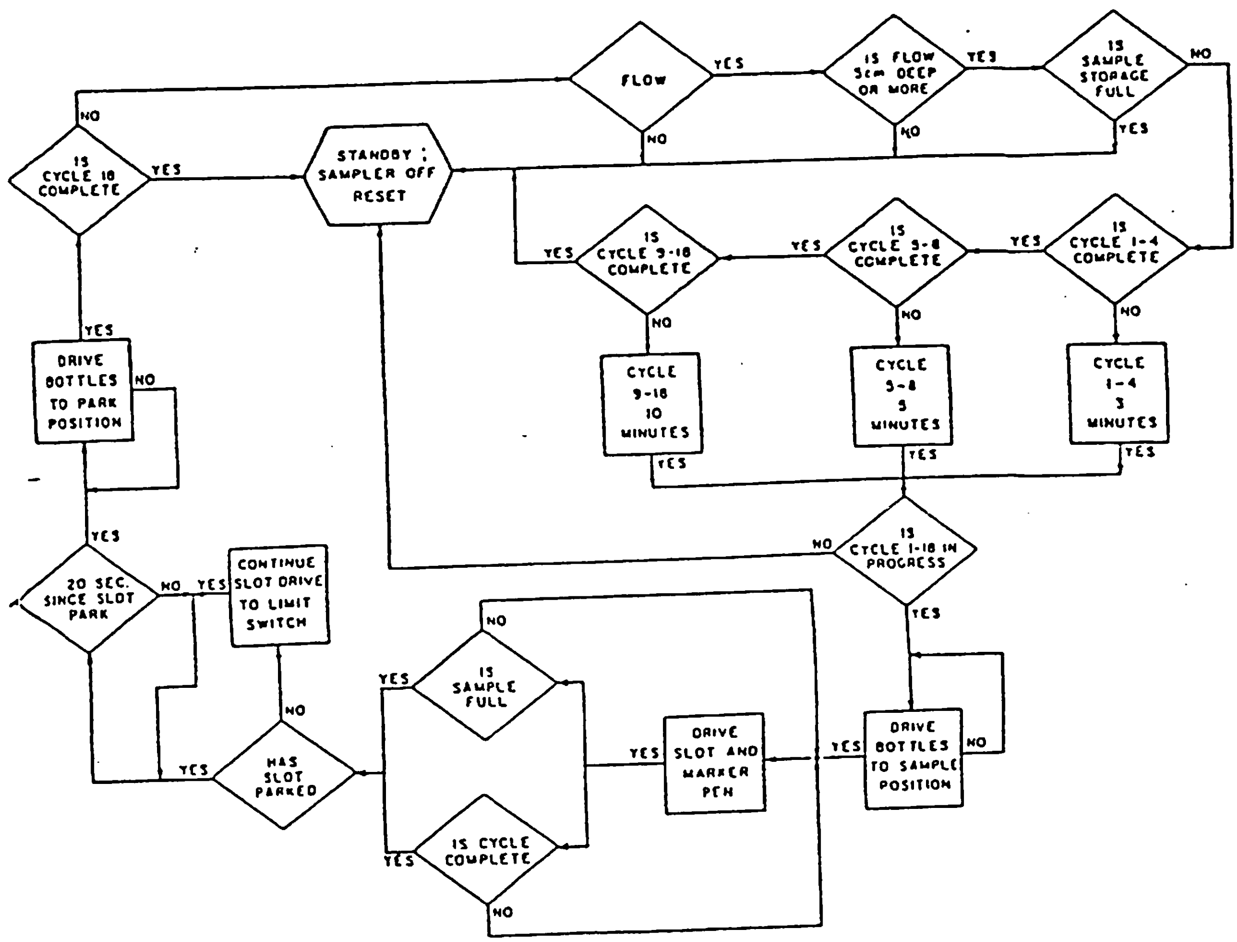

Fig. 3. Logic flow path for traversing slot sampler.

If a flow occurs when the sampler is in this standby condition and the depth exceeds 5 cm, the energizing switch on the water level recorder activates the sequential timer which is set to take 4 samples at 3 min intervals, 4 samples at 5 min intervals, and 10 samples at 10 min intervals (the number of samples, at any interval, and the interval time are variables that can be adjusted on the sequential timer). This sampling sequence insures that the most rapidly changing portion of the hydrograph will be adequately sampled and that, as often occurs in our environment, more than one storm a day can be sampled without forfeiting complete quantification of the sedigraph. Sampling safeguards provided for include: not refilling a sample bottle (the continuous chain is limited to just one revolution), assurance that the traversing slot is not in the flow during a non-sampling sequence, and efficient use of electrical power (all circuits are off during the standby condition).

SAMPLER PERFORMANCE

The traversing slot sampler has performed well on experimental subwatersheds at Walnut Gulch and the Santa Rita Experimental Range near Tucson, Arizona. An example of a hydrograph and corresponding sedigraph from a small watershed at Walnut Gulch is shown in Figure 4 (Simanton et al., 1980). The sharp rise at the beginning of the hydrographs of this storm with two periods of rainfall excess shows the importance of short-interval sampling. Without the short interval between samples, much of the sediment concentration variability (circles), and the associated sediment transport variations, would have to be estimated. Furthermore, this two-event storm, with less than 20-min between periods of rainfall excess, also illustrates the need for the sampler to reset to the short sampling interval, and having a relatively large capacity for sample bottles (note that 14 of the 18-bottle total capacity were used for this event). The storm occurred late in the evening, when there would have been no one available to sample the remote watershed.

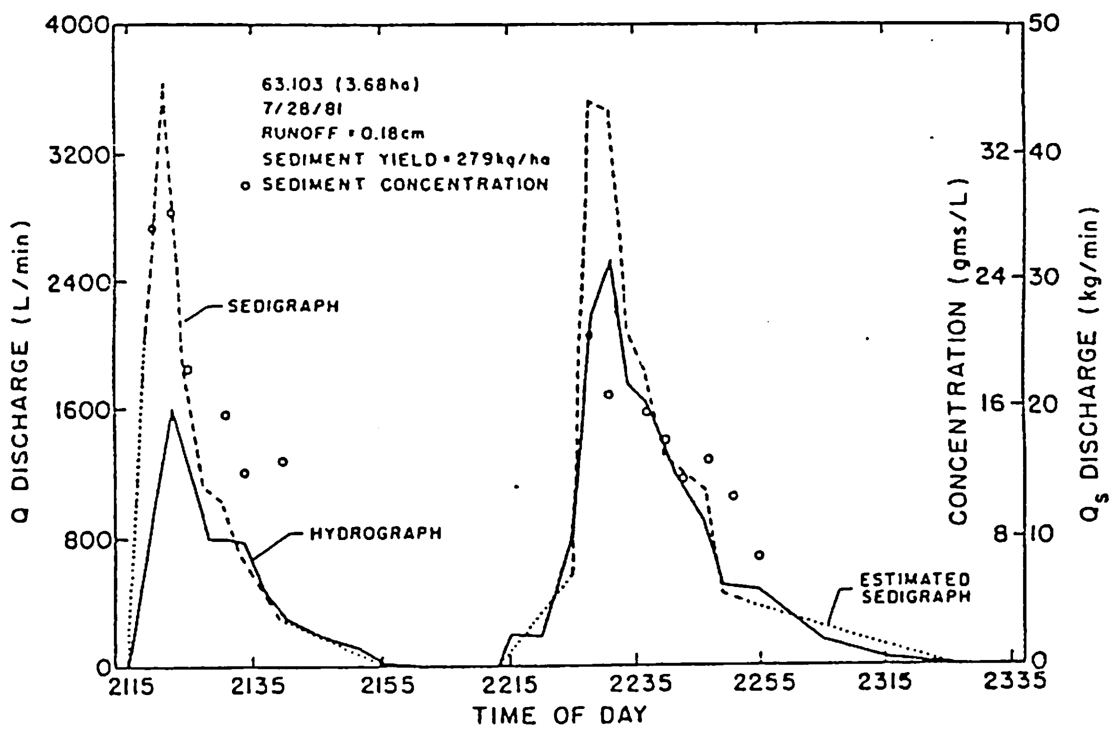

Fig. 4. Hydrograph and sedigraph for the double peak storm event on the 3.68-hectare Lucky Hills Watershed on Walnut Gulch.

A full-scale prototype of the traversing and fixed slot mechanism was tested in the perennial flow of the San Pedro River adjacent to Walnut Gulch. This testing, with carefully controlled conditions, although restricted to flows of only 0.3 m3 S -1, showed that the concentration determined with the slot sampler agreed almost perfectly with depth integrated samples collected with a US D-48 sampler through the flume overfall.

Using known inputs of sediment concentration, we found that the traversing slot indicated concentrations were about 10 percent higher than those obtained with a US D-48 depth-integrating sampler and with dip-sampling methods. As the concentrations of coarse sediment increase, we would expect that the traversing slot would give a more reasonable estimate of the mean concentration when compared to other sampling methods.

SUMMARY

A traversing slot sampler has been developed which provides discrete aliquots of the water-sediment-chemical mixture leaving small watersheds. The sampler was designed to operate at remote sites using stored DC battery power charged by a photovoltaic cell. The sampler diverts aliquots of the outflow from a precalibrated measuring device, and deposits the material in individual sample bottles. The sampler has an electro-mechanical timer which allows samples to be taken throughout rapidly changing discharges, and thereby define concentration variations. In comparison tests between the traversing slot, US D-48 hand sampler, and dip samples, concentrations were about 10% higher in samples obtained with the traversing slot sampler.

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