MASTER

AN INEXPENSIVE WEIR AND PROPORTIONAL SAMPLER FOR MINIATURE
WATERSHED ECOSYSTEMS

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ABSTRACT

A weir system with proportional sampler for use on miniature watershed ecosystems is described. Eight weir collection systems were evaluated for their ability to measure and sample the inputs and outputs of soil-island ecosystems which occur on granite outcrops. The proportion of water actually collected by the weir systems was generally less than the proportion the systems were designed to sample, but adequate for supplying data needed for estimating elemental budgets. The weir systems were not able to account for 25 to 50% of the variation in total water passing over the cutoff wall. Several ways of improving overall performance of the weir systems are discussed.

Key words: stream-gaging station, proportional sampler, watershed ecosystem, granite outcrops, Georgia.

INTRODUCTION

Small montane watersheds have permitted study of complex ecosystems on an experimental basis (Bormann et al. 1974, Monk et al. 1977). Watershed elemental and hydrologic budgets have served to evaluate ecosystem behavior. Accurate measurement of ecosystem response to perturbations has been possible through stream gaging stations and proportional samples. A gaging station is a device for controlling the flow of stream water to measure discharge (Hewlett and Nutter 1969). It consists of a ponding basin, a wall anchored to bedrock, a weir or flume, and a stilling well where the water level is continuously recorded (Reinhart and Pierce 1964). Dissolved solids and suspended particulates are sampled proportional to discharge by instruments called proportional samplers. Samplers are generally of two types: those which utilize a pump (Fredriksen 1969) and those which use the hydraulic head as a driving force, e.g., Coshocton wheel samplers (Parsons 1954). These devices require a large capital investment and are not optimally operational or impossible to install below a certain minimum watershed size. Therefore, samples of those types are not useful for short term studies on miniature watersheds.

The small ecosystems we have studied occur in depressions on granitic outcrops. Numerous granite outcroppings occur throughout the Piedmont region of the southeastern U. S. Weathering of the rock surface results in depressions which accumulate disintegrated rock and organic debris. Plants invade and form distinct aggregations surrounded by naturally exposed rock which Burbank and Platt (1964) called island communities, and Shure and Ragsdale (1977) called soil-island communities. These rock outcrop communities are natural

ecosystems resulting from evolutionary adaption. The microenvironment of outcrops in the southeastern U. S., is desert-like (Duke and Crossley 1975). They are characterized by intense solar radiation, extreme temperatures, and drought due to rapid runoff of precipitation and low water-holding capacity. Many characteristic outcrop species have evolved in this severe microclimate (Murdy 1968). Island ecosystems are distinctly delineated. System boundaries are well defined, and drainage inputs and outputs can be readily identified for many systems. These ecosystems are generally irregularly circular, only several meters in width, and the soil is usually deepest in the center or upslope edge. They are isolated except during rain, at which time they may be interconnected by runoff.

In this we describe a modified weir and proportional sampler designed to measure and sample water and elemental flow into and out of these ecosystems, and evaluate the accuracy and precision of design.

METHODS

Description of modified weir.

A weir collection system consisted of a dam, a modified V-notch weir (Fig. 1), a proportional sampler (Fig. 2), and two collection bottles. The dam was made from polyurethane foam (ISOFOAM^R, Witco Chemical, New Castle, Delaware) poured on the rock surface which had been brushed to remove lichens and loose rock. Forms made of plywood and/or cardboard were used and removed after the ISOFOAM^R had set. ISOFOAM^R adheres to the rock surface to make a watertight seal. Dam dimensions were variable: 10 to 20 cm high and wide, and as long as needed. The modified weir (Fig. 1) was of V-notch (100°) design

containing a flow splitter (25°) which diverts a fraction (about 25%) through a 2.22 cm ID opening at its base into Tygon tubing (2.54 cm ID). The weir was made from stainless steel and 15 cm wide (front to back). It was held in soft ISOFOAM^R until the foam hardened. Excess ISOFOAM^R inhibiting flow through the weir was cut away. The modified weir was designed with three exits at the back of the flow splitter (Fig. 3) opening toward the inside of the V-notch. The openings were designed so that as a lower hole filled with water the one above immediately began to collect the sample. During the study, only the lowest was used because of economic restrictions. Openings not used were closed with PVC pipe caps and sealed with silicone adhesive.

Nylon netting (≈ 1.2 cm) stretched over a stainless steel rod frame (Fig. 1) was placed in the flow splitter to collect suspended coarse particulate organic matter (CPOM). Suspended fine particulate organic matter (< 1.2 cm) was allowed to enter the collection system. Heavier particulate matter collected in front of the dam just below the weir (Fig. 1). The diverted fraction from the weir was further split into 23 portions by a proportional sampler (Fig. 2), one portion going to the collection bottles. The sampler consisted of a 2.54 cm slice of polyvinylchloride (PVC) pipe (20.3 cm ID) molded to PVC sheet (22.9 x 22.9 x 6.4 mm) on its lower surface, and a circular PVC sheet (22.9 mm diam.; 6.4 mm thick) bolted to its upper side. Twenty-three holes (2.54 cm diam.) were drilled through the pipe. A stainless steel strip containing 23 holes (6.35 mm) each with a knife-edge was placed next to the inside surface of the pipe and sealed with silicone adhesive. The proportional sampler was mounted on three bolts embedded in the rock and leveled. The diverted fraction from the weir entered the sampler through the center of the cover. If collected samples were too small, one or more holes in the proportional sampler were plugged

from the outside to increase sample quantity. Samples were rinsed with distilled water after each sample collection. Collection bottles consisted of two 22.3 liter polyethylene G. I. jugs. A stainless steel tube was used to prevent back-pressure as collection jugs filled. Inputs and outputs were measured as soon as possible after every precipitation event; i.e., every frontal system or thunderstorm if separated by 8 to 12 hours.

Accumulated sample in the collection bottles was filtered through plankton netting, mixed and measured in a 20 liter graduated cylinder. Particulates retained by the plankton netting were considered to be fine particulate matter (FPOM). Nylon plastic pipe fittings were used throughout the collection system and silicone adhesive or stainless steel hose clamps were used to make the system watertight.

The highest water level attained at the weir during a precipitation event was measured with plexiglas tubing and powdered cork (Fig. 1).

Tubing (6.35 mm ID) was cut and remolded to form an "L" shaped tube (short arm: 5.1 mm, long arm: 25.4 cm). This tube was mounted upright ca. 3 cm in front of the weir on a stainless steel rod embedded in the rock. A short rod was placed to keep the short arm opening perpendicular to flow. The upper surface of the lower arm was level with the bottom of the weir. Powdered cork was introduced through the top and copper screen in the short arm minimized loss. Cork floated on the surface of water as water level rose and remained attached to the tube after the water level dropped. Highest water level (peak head) attained was the distance from the upper surface of the short arm to the cork ring minus one millimeter. The cork ring was obliterated with a small brush. A plastic culture tube cap was placed over the top to exclude raindrops and organisms.

Study Area

This study was conducted on a flat rock outcrop located in northern Rockdale County, Georgia, southeast of the junction of Big Haynes Creek and Harrison Mill Road (Nabholz et al. 1977). Four island ecosystems of the lichen-annual herb type (Burbanck and Platt 1964) were studied. Three of these ecosystems occurred on a rock face where water inflow came only from the surrounding rock upslopes (Fig. 4). One ecosystem also had a lichen-annual herb ecosystem directly above it. Watershed boundaries were located by pouring water on the outcrop. Watershed area was then determined graphically. Weir collection systems were used to sample input from the rock watershed area to the ecosystem and ecosystem output. The weir collection system that sampled input from the rock watershed area divided the rock watershed area into two parts (Fig. 4). The upper slope was termed the upslope watershed area (IWS) and the rock immediately surrounding the ecosystem was termed the community watershed area (CWS).

Ecosystem Water Budgets

Water budgets for each ecosystem were calculated by mass balance since the hydrologic characteristics of these rock outcrop ecosystems are greatly simplified in comparison to larger mountainous watersheds.

The water balance equation was

$$Q = P + WSI - E_t - S$$

where Q = system discharge, P = precipitation received directly by the system, WSI = inflow from rock upslopes, E_t = evapotranspiration, and S = basin storage. Precipitation (1) equaled precipitation (mm) times ecosystem area (m^2).

Precipitation was measured with two USDA standard rain gauges.

Inflow (1) from IWS (rock watershed area) and CWS (community watershed area) was calculated as the product of precipitation (mm) and the area (m^2) minus storage (1) by the rock surface, pools, imbedded island community and/or the weir collection system. Only one system had a large amount of pool storage. Storage by pools and imbedded communities equaled their basin storage less losses due to evapotranspiration (E_t), not to exceed their basin storage. Basin storage was determined by flooding each system or pool with distilled water during a drought. Basin storage (S) was full when data collections began and when they were ended. Losses from storage were entirely from E_t .

Water flow in all systems can be characterized as ephemeral. Flow begins after the rock surface has absorbed ca. 0.9 mm precipitation and ends quickly following a storm event. Total discharge is comprised almost entirely of direct runoff (stormflow).

Water loss by evapotranspiration was estimated by multiplying average seasonal E_t rate (1/da) by the number of days since the last precipitation event. If E_t exceeded the basin storage of the system, E_t was set equal to storage. Seasonal evapotranspiration rates were determined from literature. McCormick et al (1974) enclosed island ecosystems in plastic chambers and reported data for a favorable June day. Rate of soil moisture loss was determined by Ragsdale (1969) from 19-25 October during a period of seasonably warm, clear weather. Fall E_t rates was also used for spring because of similarity between mean temperatures. Winter evapotranspiration rate was estimated about

half the spring-fall rate based on changes in seasonal E_t rates and mean temperature. Evaporation from pools was estimated from observed drying times: 2, 4, and 6 days for summer, spring-fall, and winter, respectively.

Method Evaluation

The performance of the weir collection system was evaluated by comparing the proportion of water the system was designed to collect with the proportion actually collected. The weir collection system was designed to collect 0.011 of the total water passing over the dam. This proportion is obtained by dividing the proportion diverted by a modified weir (0.25) by the number of holes in a proportional sampler. The actual proportion collected by a system was calculated by dividing the amount of water collected during a precipitation event by the total amount which flowed over the dam. This total amount was estimated by mass balance.

Performance of the modified weir alone was accomplished by attaching the tubing from the weir directly to the collection jugs by passing the proportional sampler.

Data analysis using the Statistical Analysis System (Barr et al. 1976, Helwig 1977) were performed with a computer. Statistical significance is indicated by asterisks (* = $P < 0.05$, ** = $P < 0.01$ and *** = $P < 0.001$) throughout the study. When regression analysis was used b_0 indicated the Y intercept, and $b_1, b_2, \dots, b_k$ the regression coefficients. Means were reported with one standard error ($\bar{X} \pm SE$).

RESULTS

The proportion of water actually collected by the weir collection systems was generally less than the proportion the system was designed to take (Table 1). The estimated proportions for weir systems E1 and E2 were larger than for systems E3 and E4. Initial measurements showed the need to increase the size of sample collected. Accordingly ten openings in the proportional samples of the input systems of E1 and E2, and the output system of E2 were plugged with corks. Eleven openings of the output sampler of E1 were similarly closed with corks from the outside. Actual proportions collected by the weir systems were significantly smaller than they were designed to take in all cases but two (Table 1). In addition, the mean actual proportion removed by each output system was significantly ($P < 0.001$) less than that collected by the corresponding upslope input system. This difference was probably the result of a lower head of water at the output systems. The island ecosystems significantly ($P < 0.05$) reduced the peak flow rate $15 \pm 1\%$, as measured by the tube gauges at the input and output weirs.

The proportion of water collected by a weir system was generally not related to the amount of water flowing over the dam. Although four systems had significant ($P < 0.05$) relationship, water volume explained less than 70% of the variation in the proportion collected, and the systems showed different relationships between the variables. Three systems had direct relationships while one showed an inverse relationship.

The performance of the modified weir could only be evaluated when the proportional sampler was bypassed, and when the precipitation event was small

enough that the capacity of the collection jugs was not exceeded. These conditions occurred only twice during the study. On the first occasion, the proportion split off by three input weirs averaged $27 \pm 3\%$ and two output weirs were $24 \pm 7\%$. The mean proportions during the second rainfall event were $13 \pm 2\%$ for four input weirs, and $8 \pm 3\%$ for the output weirs. The smaller proportions resulted from higher peak heads during the rainfall event. Water levels greater than 32 mm exceeded the capacity of the opening at the base of the flow splitter, and the mean peak head during this event was 50 ± 9 mm. Peak heads during the first storm averaged 6 ± 2 mm.

Observation of these weir systems during rainfall events led to the conclusion that the amount of water collected was a function of volume of water passing over the dam, the intensity of the water flow and the amount of suspended particulates collected during a storm event. The multiple regression relationships between the amount of collected water and the three independent variables for each weir system are presented in Table 2. All relationships were highly significant ($P < 0.0001$). The independent variables accounted for between 73% to 49% of the variation in the dependent variable. The volume of water passing over the dam explained the greatest amount of variation in the collected water volume, followed by flow intensity. The amount of suspended particulates accounted the least variation.

DISCUSSION

The proportional samples collected by the weir collection systems were adequate for elemental analysis and provided sufficient data for calculating elemental budgets. Although the proportional sample was less than the weir systems were designed to collect, sample was obtained throughout an entire precipitation event. The greatest danger to sample accuracy is exceeding the capacity of the system (determined by the size of the collection bottles). Under this condition, an incomplete sample will be collected. Only part of a storm event, i.e., that portion of the storm before system capacity is reached, is reflected in the collected sample.

The weir systems described in this study exceed their collection capacity after about 4050 l of water has passed over the dam. Collection capacities can be easily increased by increasing the volume of the collection bottles, adding holes to the proportional sampler, or placing several samples in series where output of the first is partitioned further by another sampler. Regardless of the method used, we must emphasize that optimal performance of a proportional sampler occurs when water flow is near maximum rather than near minimum. A decrease in efficiency of the output weir systems was observed because of the reduction in water flow intensity by the island ecosystems.

The weir collection systems are not accurate enough to measure inflow from rock upslopes, ecosystem discharge, or changes in evapotranspiration. Fortunately, we were able to calculate water budgets for each ecosystem by mass balance. These weir systems were not able to account for 25 to 50% of the variation in total water passing over the dam. Losses due to evapotranspiration (E_t) from

these lichen-annual herb ecosystems are small. The proportion of the water budget attributable to E_t was estimated to range from 6-2% in June to 0.3% in December (Nabholz 1978). Stream-gaging stations used to measure runoff from larger experimental watersheds would probably be inadequate to measure such small differences in E_t . Rothacher and Miner (1966) estimated that the minimum error obtainable with gaging stations even under the best conditions is probably about three to five percent.

Overall performance of the weir collection system can be improved and maximized in several ways. The flow splitter in the modified weir and the proportional sampler had to be continually cleaned. Most of the suspended particulates in runoff on rock outcrops was fine (<1.2 cm), and only occasionally was the nylon netting in the flow splitter covered with material. Yet, in spite of the netting, one or more holes in the proportional sampler would become partially blocked. A modification suggested especially on watersheds where the bulk of the suspended particulates is coarse (>1.2 cm), would be to move the netting outside the flow splitter in front of the weir. Such trash screens are used to prevent floating debris from clogging the weir blade of gaging stations (Reinhard and Pierce 1964). This modification would probably work well when measuring discharge, but when the weir system samples inputs from an upslope watershed area (Fig. 4), the screen would prevent all coarse suspended particulates from reaching the island ecosystem. Depending on the importance of this component, provisions in sample collection would have to be made to lessen the impact. Weir system performance can also be maximized by making sure the dam and modified weir are at right angles to water flow. Most

soil-island ecosystems have water flow channels along one of their edges. Water flow can approach a weir at an oblique angle, and can create eddies that can either float suspended material into or out of the flow splitter.

Several design changes should be implemented by anyone intending to use this system. First, the exit holes at the back of the flow splitter (Figs. 1 and 3) should open toward the dam side of the V-notch and not toward the inside. Secondly, a minimum of three exit holes should be used to divert water from the flow splitter to the proportional sampler. Thirdly, the base plate and sides of the proportional should be made entirely out of metal. This would ensure better precision during their machining, and a greater capability of reaching and keeping them level while in use. Lastly, plastic pipe should be used whenever possible. It performs as well as Tygon tubing over long flat stretches, and is considerably less expensive.

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Table 1. Comparison of estimated theoretical and measured ($\bar{X} \pm SE$) proportions of water sampled by the weir collection systems. Sample size (N) and coefficient of variation (CV) are also given. Significance of mean differences determined by t test.

Weir Systems	Estimated Proportion	Actual Proportion	N	CV
Input from the upslope watershed area.				
E1	0.019	0.010 $\pm$ 0.0012***	51	90
E2	0.019	0.009 $\pm$ 0.0012***	51	99
E3	0.011	0.012 $\pm$ 0.0012	73	85
E4	0.011	0.011 $\pm$ 0.0009	74	67
Output				
E1	0.018	0.006 $\pm$ 0.0009***	51	100
E2	0.019	0.008 $\pm$ 0.0011***	51	93
E3	0.011	0.009 $\pm$ 0.0008*	71	81
E4	0.011	0.006 $\pm$ 0.0008***	73	108

Table 2. The multiple regression relationship of collected water sample (Y) in liters to total water volume passing over the dam (X_1) in liters, highest head (X_2) in millimeters, and suspended particulate organic matter (X_3) in grams dry weight. The regression line fitted to these data are $Y = b_0 + b_1 X_1 + b_2 X_2 + b_3 X_3$.

Ecosystem	b_0	b_1	b_2	b_3	N	F-Value	R^2
Input from rock watershed area.							
E1	-5.5116	0.0088	0.2320	-7.7645	37	29.4***	0.728
E2	-3.2220	0.0118	0.1396	-25.8564	37	23.4***	0.680
E3	0.4530	0.0070	0.1376	4.6056	60	32.7***	0.637
E4	7.4143	0.0045	0.1218	-12.3428	61	22.7***	0.544
Output							
E1	-5.6551	0.0049	0.2938	-3.9011	35	10.0***	0.493
E2	-3.4681	0.0108	0.1534	-3.3316	34	34.6***	0.776
E3	1.4215	0.0054	0.1776	-0.5070	50	18.0***	0.540
E4	4.9195	0.0047	-0.0030	-1.6372	57	33.6***	0.656

Fig. 1. Modified V-notch weir mounted in ISOFOAM^R dam. Nylon netting stretched over rod frame is in the flow splitter. Tubing leading to a proportional sampler can be seen leaving the base of the flow splitter. Plexiglass tubing used to measure peak water levels is in the foreground.

Fig. 2. Proportional sampler mounted on the rock surface. The cover has been removed to show the inside. Diverted flow from the weir enters through the cover. Tubing leaving the sampler enters collection bottles.

Fig. 3. A schematic drawing the locations of the openings at the base of the flow splitter of the modified weir.

BACK

FRONT

Fig. 4. A generalized island ecosystem (E) and surrounding rock upslopes. Weir collection systems sample inputs (I) from the rock watershed area (IWS + CWS) to the ecosystem (E), and ecosystem outputs (O). Inputs from the community watershed area (CWS) were estimated from IWS data. Measuring devices include: a standard rain gauge (R), polyethylene precipitation collector (P) and thermometer (T).