PROPORTIONAL SAMPLER FOR MONITORING SURFACE RUNOFF

by

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INTRODUCTION

Water pollution has been long recognized, in this country, as a serious problem that must sooner or later be corrected. However, pollution control is entangled in the legal and political arena. Part of the problem is that it is difficult to determine and verify the culpability of non-point sources of pollutants. Even if the polluting source can be identified, monitoring pollutants with conventional methods requires extensive equipment and is expensive. Therefore, it is impractical to monitor by conventional methods the runoff from every farm that drains into a watercourse.

If runoff were to be monitored with conventional methods, the apparatus would consist of a flume (probably a Parshall flume), a water level recorder with an automatic starting mechanism, and an automatic water sampler. Runoff would be measured by directing flow through the flume and recording the hydraulic head on the flume with the water level recorder. The automatic starting mechanism is needed to operate the measuring equipment only when runoff is present so as to avoid using up reams of chart paper during dry weather when no runoff occurs. The automatic sampler is used to pull a sample of the runoff passing through the flume at regular time intervals during the runoff event. The sampler must be of a type that keeps the individual samples separate and not a conventional composite sampler. A composite sampler, which pulls a sample of fixed size at regular intervals and combines them into one sample, gives an accurate sample only when flow rates are relatively constant. Unfortunately, runoff flow rates are anything but constant so the composite sampler has limited application. One disadvantage of the flume-recorder-sampler setup is its high cost ($1500 to $2000 per unit). Another problem is its low reliability. Because of all the moving parts involved, it is not uncommon for the starting mechanism to malfunction or for the automatic sampler to fail in some way. In addition, when every thing does function properly, analyzing the data takes a lot of work. This involves analyzing each of a large number of samples for each pollutant. The hydrograph from the water level recorder has to be converted from a continuous record of hydraulic head to instantaneous flow rates taken at frequent intervals for the entire duration of flow (for example, every five minutes for a two hour duration). These instantaneous flow rates are then used for integrating a total flow volume and for correlating the runoff sample analysis results with corresponding flow rates. The amount of each pollutant in the runoff is found by summing the product of the concentration in each sample, the corresponding flow rate, and the time interval between samples. Another shortcoming is that the sampler operates for a fixed time period and runoff may continue beyond that time depending on the storm. If runoff occurs for three hours and the sampler only operates for two hours, the third hour of runoff goes unsampled. Even though this method is time consuming, it does have the advantage of recording peak flow rates and peak pollutant concentrations.

The alternative to monitoring runoff is to regulate all land use practices, including farming, and eliminate practices that appear to have a high water pollution potential. The landowner or operator would be required to use legally prescribed practices and structures to control runoff. This type of approach is favored by Senator Morris Udall and other conservationists but opposed by others as being an unconstitutional infringement on the right to one's own property. In all probability, land use control would have an undesirable effect on the agricultural industry.

A simpler method is needed, to monitor surface runoff from non-point sources that does not have the short-comings of the flume-water level recorder-sampler method. This method should be far cheaper, have higher reliability, and, above all, be much easier to use, so that large numbers can be used with limited funds and personnel. If such a sampling method were available, legislation could be written setting limitations on the runoff itself and not on the use of the land. The landowner would be allowed to use whatever means he (or she) chooses to control runoff rather than being forced to use the legally prescribed method. Violations would be verified by analyzing samples from the runoff samplers.

A proportional sampler can meet the most important criteria of being easy to use and, if no moving parts are involved, it can meet the need for reliability. In operation, a proportional sampler would collect a small but constant fraction of the flow passing through it. The collected flow would be directly proportional to the total volume of flow. The concentrations of various pollutants in it would be equal to the average concentrations in the runoff. Total flow through the sampler could be determined by dividing the volume of the collected flow by the sampling ratio, which is the ratio of collected flow to total flow. Average pollutant concentration could be determined by analyzing a sample of the collected flow. To determine the amount of pollutants that passed through the sampler, one can multiply the concentration by the volume of total flow. It would not be limited in the length of time that it could sample runoff. If a second storm would occur before data from the first storm could be collected, the collected flows of the two storms would combine to form one sample that would be representative of the sum of both storms.

PURPOSE OF STUDY

Ten proportional samplers were needed to collect runoff samples from beef manure application plots located on property of the Pratt Feedlot, Inc. of Pratt, Kansas. The plots were two hundred feet long and thirty feet wide, with runoff from the center ten feet of width being measured. Corn was grown on these plots with a thirty inch row spacing and an irrigation furrow for every two rows. Each plot had twelve rows and six furrows with four rows and two furrows in the area producing runoff for sampling. The two furrows were combined at the bottom end of the plot to direct runoff through a sampler. Tailwater drainage from these plots was known to be poor resulting in the bottom end of the plots being flooded quite often. In addition, the plots had a rather flat grade of 0.5 percent. Given these conditions and the fact that the sampler was to be placed in the furrow, it was apparent that no more than six inches of head was available to operate the sampler. The maximum flow expected to pass through the sampler was forty gallons per minute. In addition to handling a range of flow rates from zero to forty gallons per minute within six inches of available head, the samplers had to be built within available funds with available manpower, both of which were limited. Another limitation was that electricity was not available. It was also desired that the samplers have no moving parts that would increase the complexity of the samplers and decrease their reliability.

The objectives were: a) to design a sampler that would satisfy all of the above conditions, b) to test the sampler in the laboratory, and, if it passed the laboratory test, c) to build ten samplers and test them in the field at Pratt.

REVIEW OF LITERATURE

A search of the literature was made to find proportional samplers that have already been designed and used to see if any of these would meet all of the conditions necessary for use at Pratt. The proportional samplers described in the literature were a slotted conduit placed to intercept the flow from a drop spillway structure, a series of small buckets mounted on a moving chain, the Coshocton wheel, a two-stage multi-weir divisor, and another two stage device involving weirs and a sampling wheel.

The slotted conduit and drop structure arrangement shown in Figure 1 was developed for use on large watersheds (ten to a thousand acres) by Barnes and Frevert (1954) and Barnes and Johnson (1956) at Iowa State University. A conduit with a narrow sharp-edged slot in its top side was placed just beneath the discharge of a drop structure which had a rectangular weir with suppressed end contractions. The conduit was placed with one end a few inches below the weir crest and the conduit extended away from the weir at an angle of five to twenty degrees below horizontal. The concept was to intercept a small, fixed proportion of the flow width with the slot and convey the collected flow in the conduit to a collection tank. In laboratory tests, it worked quite well over the range of flow rates tested and proved to be trash resistant because of the scouring action of the flow over the slot. However, the lowest flow rate tested was 0.5 cubic feet per second (224.4 gallons per minute) which was substantially more than the forty gallons per minute expected from the manured plots. It was stated that accurate adjustment of the slot width was critical in maintaining the accuracy

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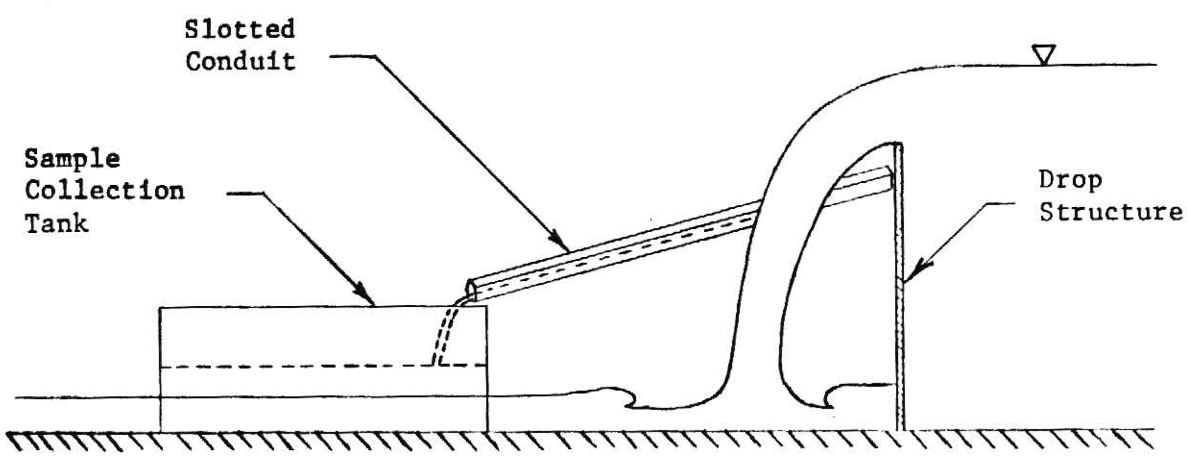


Figure 1. A slotted conduit and drop structure arrangement for sampling runoff.

of the sampler. It was noted during field tests that accurate sampling was impossible when the head on the weir was 0.1 foot or less because the flow was clinging to the wall of the weir. If a sampler of this type were scaled down to fit the conditions at Pratt, it would have a weir crest length of 1.67 inches and a slot width of 0.0167 inch (for a one percent sampling ratio). A slot width of this size clearly cannot be set accurately. Also it is uncertain whether or not the sampler would function below 6.57 gallons per minute, which should be the flow rate when there is 0.1 foot of head on the weir. For these two reasons, this type of sampler was not considered for use.

Schwab and Brehm (1974) reported on a proportional sampler consisting of small buckets on a moving chain. The sampler consists of a series of small tubes or buckets of different lengths mounted on a chain running around two sprockets in a vertical plane. This arrangement was placed over the surface of the water flow being sampled with the water level being controlled by a weir, flume, or channel configuration. Each bucket, as it is carried around by the chain and sprockets, picks up a fixed amount of water (if it reaches water), and dumps its load into a collection pan as it is carried on around. The lengths of the buckets are set at various lengths so that the number reaching water is proportional to the flow rate past the sampler, thereby collecting a proportional sample. The sampler described in the literature had a sampling ratio of 0.1 percent and operated at heads between 0.04 feet and 0.3 feet which is acceptable. What is not acceptable is the fact that it takes an electric motor to turn the chain and sprockets and electricity is not available on the site.

The Coshocton wheel shown in Figure 2 was first developed in 1947 by

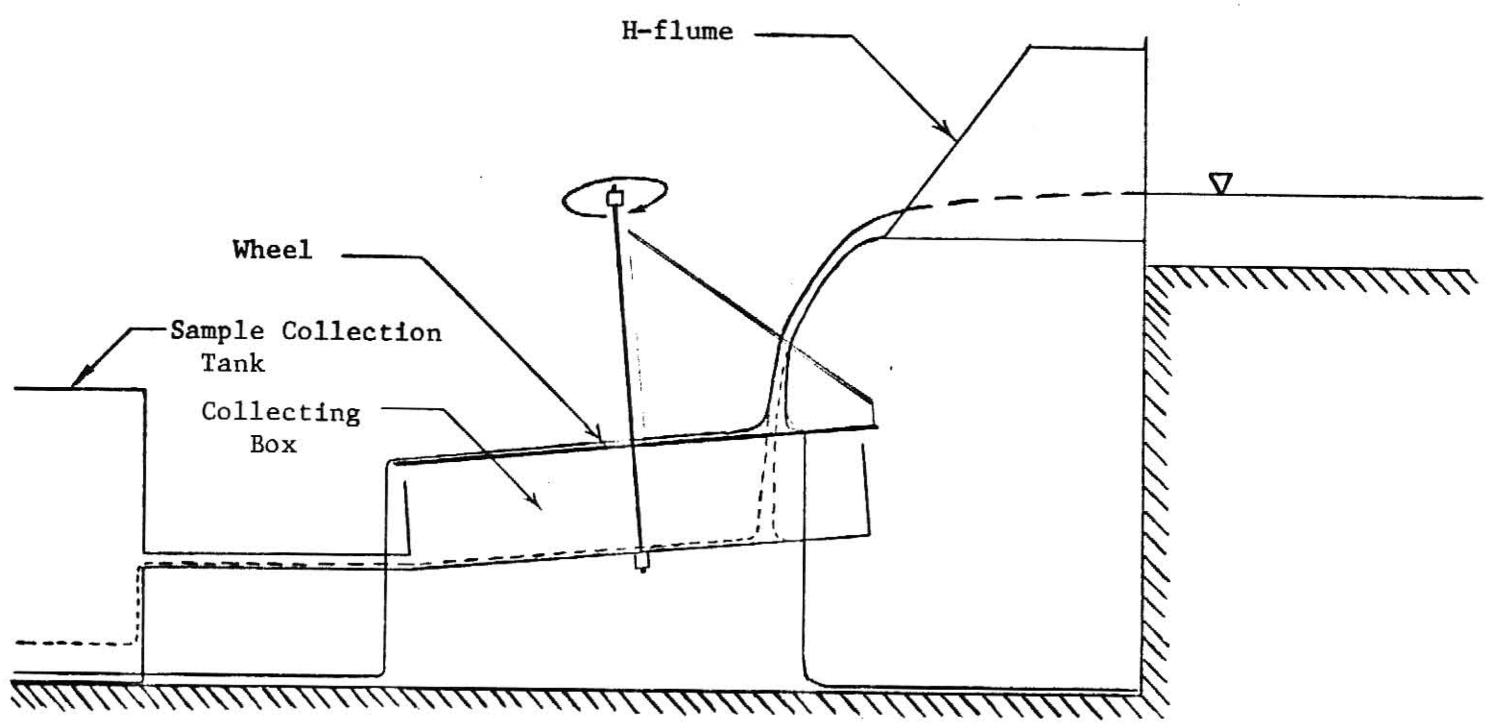


Figure 2. Coshocton wheel sampler.

W. H. Pomerene and was further developed by Carter and Parsons (1967). It consists of a circular plate mounted on a freely turning axle that is tilted slightly from vertical with a sampling head mounted on the circular plate. The sampling head has a slot facing the perimeter of the plate. The slot lies on a line that runs between a point on the perimeter of the plate and a point on the axle above the plate. In operation, an H-flume directs the flow onto the plate causing it to spin. When the plate is spinning, the slot in the sampling head cuts across the nappe from the H-flume. Flow is sampled at regular intervals. The water that enters the slot passes through the plate and is funnelled into a collection tank. In essence, it collects all of the flow one percent of the time rather than one percent of the flow all of the time. The accuracy of the Coshocton wheel is acceptable even at very low flow rates. Tests by Carter and Parsons on a one percent sampler and on a one-half percent sampler determined the sampling error of the first at plus or minus five percent and that of the second at plus or minus ten percent. The one percent sampler was tested at flow rates ranging down to two gallons per minute and the one-half percent sampler was tested down to five gallons per minute.

The Coshocton wheel is trash resistant and has no problem with suspended silt, clay, or fine sands. However, larger sands tend to settle out in the H-flume which changes the approach of the flow to the wheel and this approach is critical to the operation of the sampler. The main failing of the Coshocton wheel is that it requires too much head to operate because of the drop from the bottom of the flume to the wheel. This drop is necessary to assure that there is sufficient energy to turn the wheel at low flow rates. At forty gallons per minute, a 0.5 foot H-flume requires about 3.3 inches of head in addition to a drop of about four inches from flume to wheel. Another two inches is needed to keep the wheel from being flooded by tail-water. Altogether, this means that a minimum of nine to ten inches of available head is required but only six inches were available. Consequently, the Coshocton wheel was not considered for use.

A two-stage multi-weir divisor shown in Figure 3 was developed for measuring and sampling tile effluent by John M. Laflen (1975) of the Agricultural Research Service in Iowa. Each stage consisted of a flume that discharged through a weir plate that had thirteen identical 22.5 degree vee-notch weirs. In each stage, the flow from twelve of the weirs was wasted while the flow from the center weir was collected. The flow that was to be sampled entered the first stage where it was split, and a thirteenth of it entered the second stage to be split again. The flow from the center weir of the second stage was collected in a tank. The only information given on accuracy was a statement that flow rates above twenty-five gallons per minute could be determined to within three percent by measuring the head in the first stage.

Another reference described a small one-stage divisor, developed by Coote and Zwerman (1972), that was used to reduce the sampling ratio of a one percent Coshocton wheel sampler to 0.1 percent. A single plate, having ten small sixty degree vee-notch weirs where the flow from one was collected, was incorporated into the sample collection box beneath and behind the wheel. This was done in order to reduce the Coshocton-collected flow by ninety percent. In order to make a divisor that would be accurate, it had to be stamped out with a special-made die and then tested and adjusted with a triangular file.

Apparently, these measures would be necessary to make the second stage

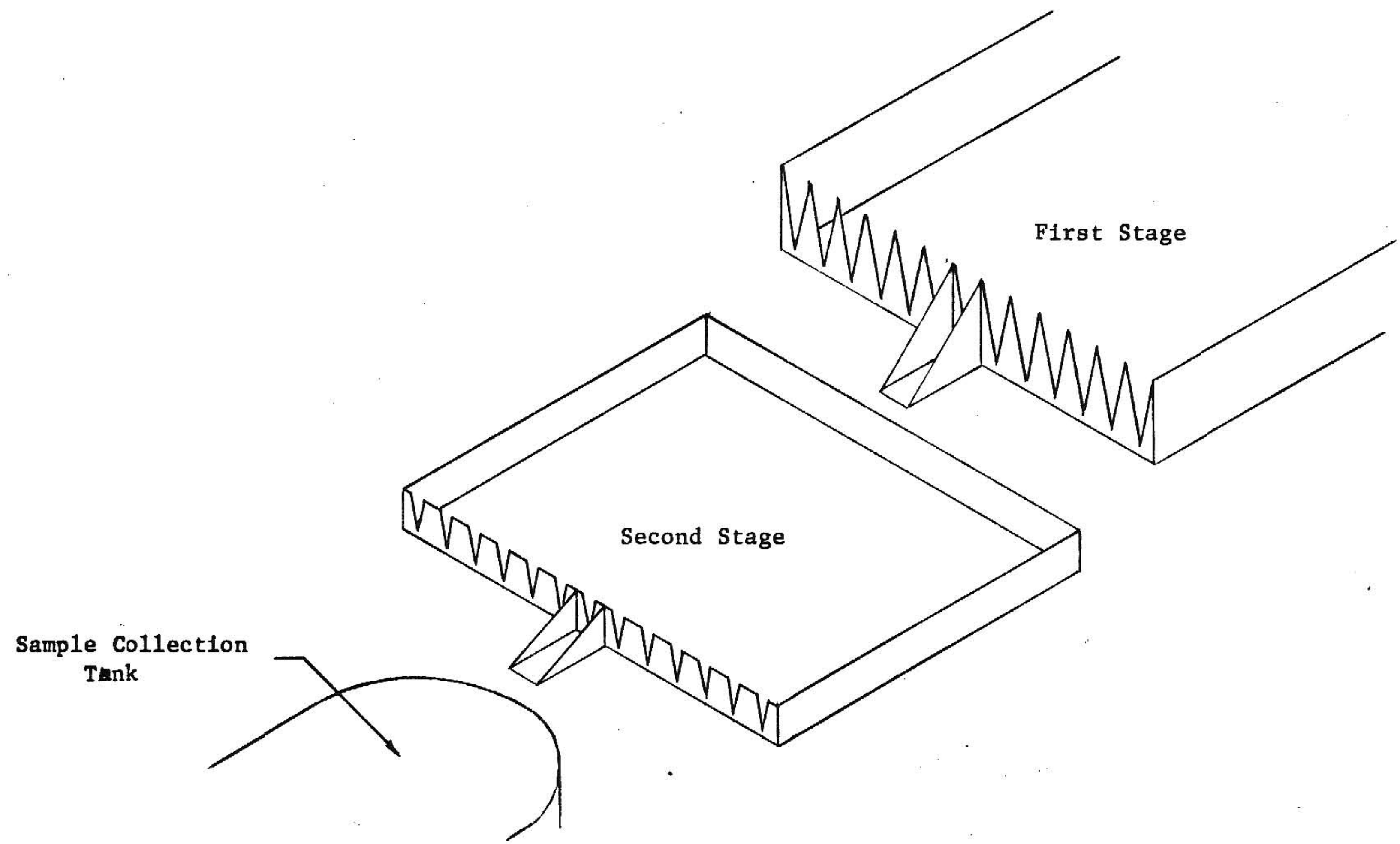


Figure 3. A two-stage multi-weir divisor.

of Laflen's sampler accurate at low flow rates. It is quite probable that the first stage of the multi-weir divisor would also need to be manufactured by this method. Another consideration is that this type of device is not trash resistant because the small triangular weirs are good places for debris to collect on. Laflen's device was used for measuring tile effluent which does not have any trash in it, and the other device did not have a problem with trash because it was intercepted by the Coshocton wheel which can handle trash. In order to use a multi-weir divisor for measuring surface runoff, adequate interceptor screens must be used. What could not be done, however, would be to invest in a special die for only ten samplers or spend the man-hours necessary to test and adjust twenty weir plates. For these two reasons, a two-stage multi-weir divisor was not used.

Eisenhauer (1973) used a two-stage sampler on two plots (one plot had an area of 1.55 acres and the other had an area of 3.6 acres). The first stage was a flume that discharged through two Cipolletti (modified, rectangular) weirs. One weir had a crest length that was one-ninth the crest length of the other weir. In this way, the smaller weir carried one tenth of the flow, which then became the flow through the second stage. The second stage was a sampling wheel similar to the Coshocton wheel except that the rotation of the wheel was in a vertical plane that was parallel to the weir, and the wheel was powered by an electric motor. It had the disadvantages of requiring electrical power, of needing too much difference in elevation between where runoff entered the sampler and where it left, and of being an elaborate and complicated device to build. It was not considered for use because of these reasons.

The slotted conduit device and the two-stage multi-weir divisor could not be used, primarily, because of the extreme precision needed to scale either of them down to fit the situation at Pratt and still maintain an accurate sampling ratio. The small bucket series and Eisenhauer's device were not considered because both required electrical power.

The Coshocton wheel sampler was not used because there was not enough available head to operate them. A proportional sampler was still needed that could sample low flows accurately with little available head and without an outside power source. In addition, it needed to be easily and economically constructed. Because such a sampler was not found in the literature that met all of the requirements, it was necessary to develop something new.

INVESTIGATION

Various alternatives were considered in trying to come up with a design for a proportional sampler that would meet the requirements of the situation at Pratt. First of all, the sampler needed to have a capacity of at least forty gallons per minute with no more than six inches of head. Secondly, it must be of a type that does not require an external power service to operate. It must maintain a constant sampling ratio over the entire range of flow rates expected. In addition, it must be easily and economically constructed and installed.

The first alternative considered was a plate with two Cipolletti weirs cut in it like the first stage of Eisenhauer's device. However the wide weir would have a weir crest length that would be ninety-nine times the weir crest length of the narrow weir instead of nine times as in the previous case. If the large weir were sized by the maximum expected flow rate and the available head, the small weir would have a very small weir crest, making it a triangular weir. If the head were limited to one-half of the crest length of the small weir as should be done with Cipolletti weirs, then the crest length of the small weir would be 0.674 inches and that of the large weir would be 66.74 inches. A large weir of this size would be much too long for practical use. It would be nearly impossible to get it level enough to be accurate at low flow rates. Consequently, this alternative was dropped from consideration.

The next alternative considered was a plate with a horizontal series of one hundred identical orifices (shown in Figure 4) where the flow from

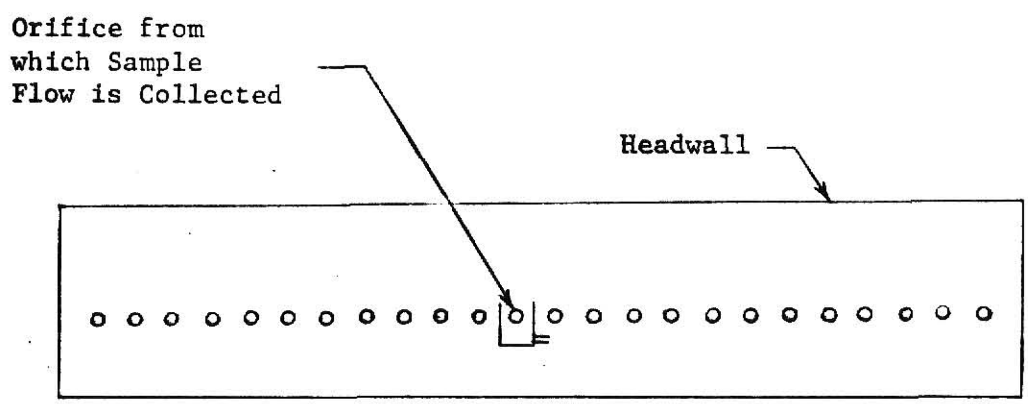


Figure 4. A proportional sampler using one hundred orifices with the same size and elevation where the flow from one is collected.

one orifice in the center was collected as the sample. It was dropped from consideration for the reasons that one hundred orifices were too many to drill for one sampler and that it would need to be about eight feet long in order to have room for all the orifices. This long length would make it difficult to install the sampler in the field so that the orifice at one end would be at the same elevation as the orifice at the other end.

The next possibility considered (shown in Figure 5) involved discharging the main flow through a weir and carrying the sample flow through a vertical series of orifices sized and spaced to simulate the response of the weir. In other words, the sum of the flows through the orifices is equal to one percent of the total flow through the sampler. A computer program was developed to design such a series of orifices when given the size and shape of the weir. The concept was dropped when the computer specified a huge number of very small orifices spaced at irregular intervals. The small size of the orifices would make it difficult to prevent clogging by floating debris. The complexity of the series of orifices would clearly involve more work in fabrication than what would be practical.

Previously, a simple vertical plate with two orifices, one large and one small, was not considered because it was readily apparent that the sampling ratio would not be constant when the flow rate was too low for the large orifice to flow full. A horizontal plate, with two orifices, where the direction of flow was downward, was not considered either because at low flow rates the large orifice would not flow full. Instead, the large orifice would act as a weir with the circumference of the orifice as the weir crest. A constant sampling ratio would not be obtained until the

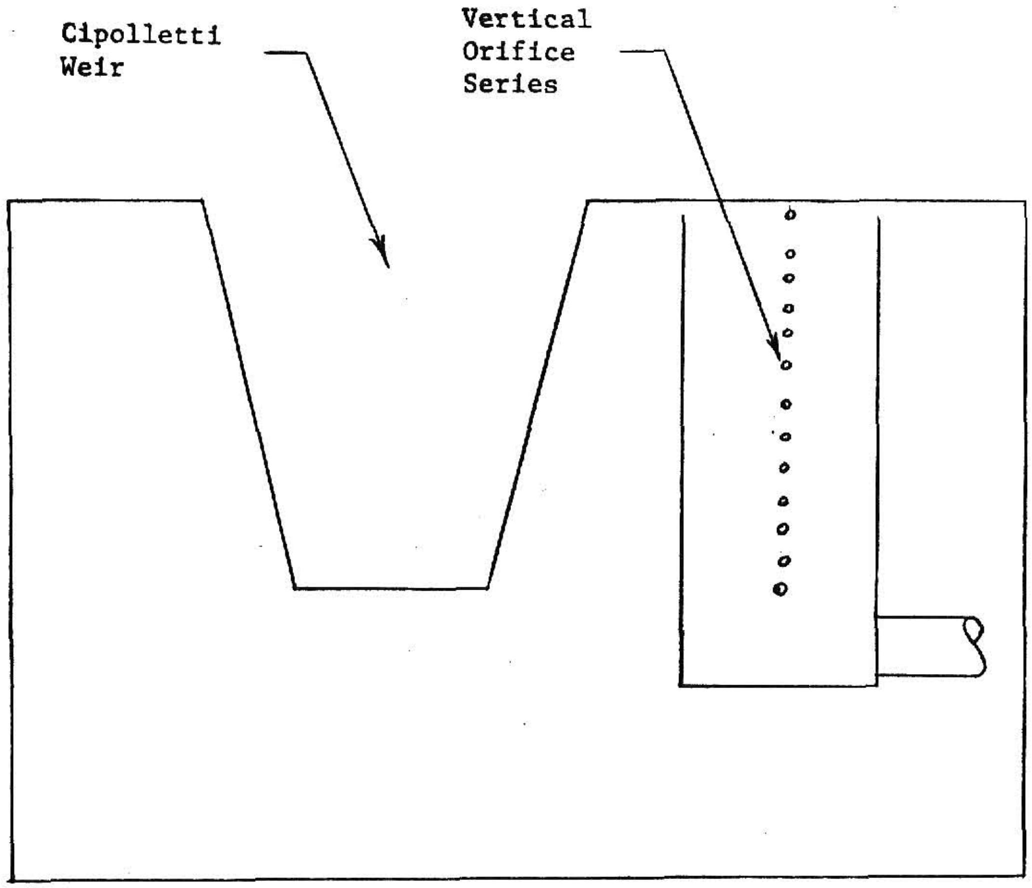


Figure 5. A proportional sampler involving a Cipolletti weir and a vertical orifice series where the orifice size and spacing are varied so that the series has one percent of the flow that the weir has.

flow rate was high enough for full flow to begin in the large orifice. However, if the direction of flow were upward, there would be full flow at even very low flow rates, and a constant sampling ratio would be maintained. Short tubes were used instead of orifices (as shown in Figure 6) to provide better control of discharge. Unlike the other samplers in the literature review, this type can tolerate being flooded by tailwater, if the sample flow is collected in a thin plastic bag floating in the discharge pool of the sampler, rather than a rigid tank. Then, if the main flow tube becomes flooded by tailwater, the sample flow already collected rises with the tailwater, flooding the sampling tube to the same degree as the main flow tube because of the flexibility of the bag. This action produces the same head differential for the sampling tube that exists for the main flow tube. In this way, the sampling ratio should remain constant in spite of flooding. None of the samplers in the literature could tolerate being flooded.

The equation for the sampling ratio for either unsubmerged or submerged flow is:

$$R = \frac{q \times 100}{Q + q} \qquad (1)$$

where:

R = the sampling ratio in percent

q = the flow rate through the sampling tube in gallons per minute

Q = the flow rate through the main flow tube in gallons per minute

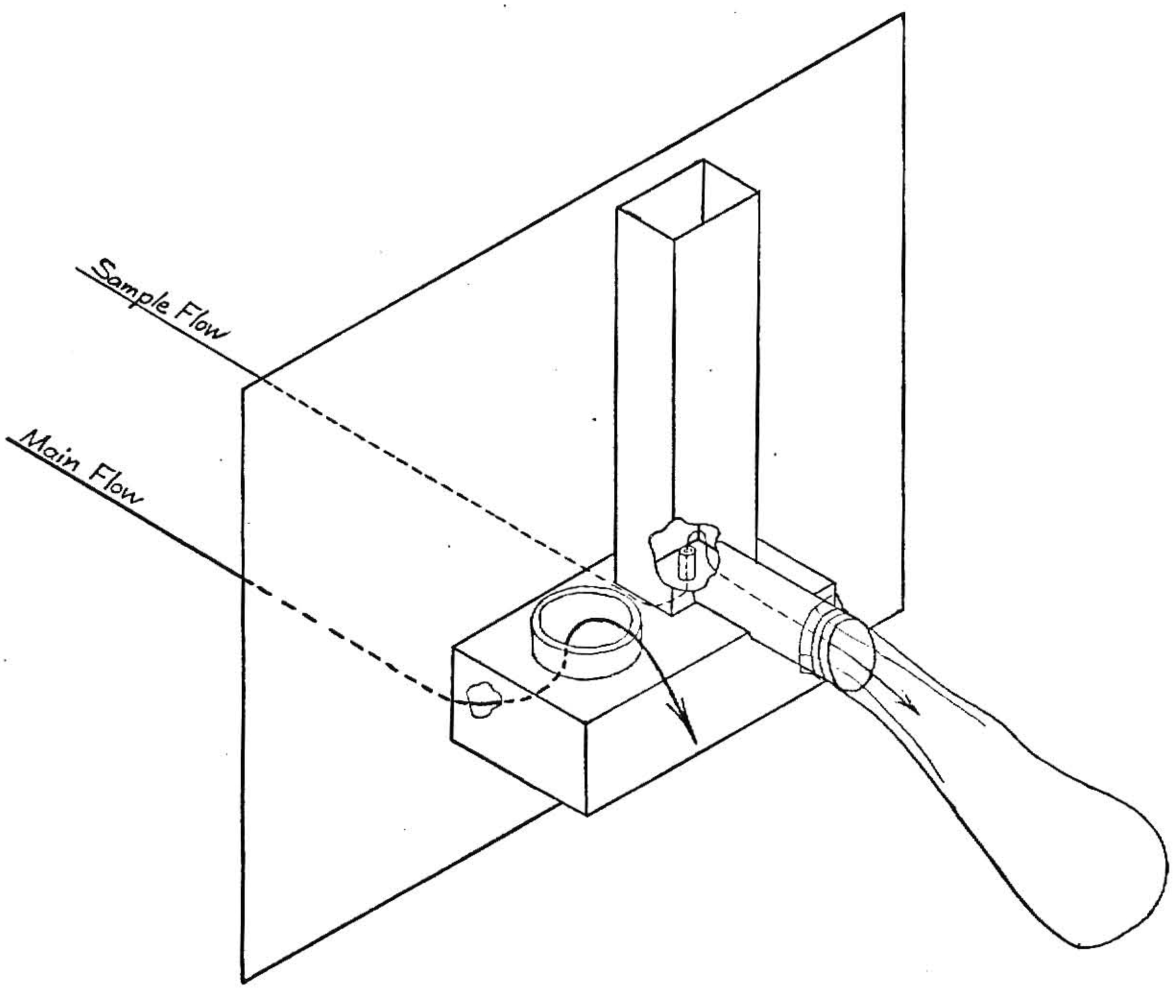


Figure 6. First model of runoff sampler shown with sample collection bag attached.

The equation for the unsubmerged flow rate through the sampling tube is:

$$q = 448.8ca\sqrt{2gH} \tag{2}$$

where:

c = the coefficient of flow for the sampling tube

a = the cross-sectional area of flow through the sampling tube in square feet

g = the acceleration of gravity in feet per second squared

H = the height of water, above the tube exit elevation, on the upstream side of the sampler

The equation for the unsubmerged flow rate through the main flow tube is:

$$Q = 448.8CA\sqrt{2gH} \tag{3}$$

where:

C = the coefficient of flow for the main flow tube

A = the cross-sectional area of flow through the main flow tube in square feet

By substituting equations (2) and (3) into equation (1), the sampling ratio becomes:

$$R = \frac{448.8ca\sqrt{2gH} \times 100}{448.8CA\sqrt{2gH} + 448.8ca\sqrt{2gH}} \tag{4}$$

Equation (4) reduces to:

$$R = \frac{ca \times 100}{CA + ca} \tag{5}$$

This establishes the unsubmerged sampling ratio as being independent of the flow rate if the assumptions made so far are correct.

When the sampler is submerged, equation (1) still holds for the sampling ratio but different equations are needed for the flow through the tubes. The equation for the flow through the sampling tube changes to:

$$q = 448.8ca\sqrt{2g(H - hs)} \qquad (6)$$

where:

hs = the height of water in the sample collection bag above the tube exit elevation in feet

Flow through the main tube changes to:

$$Q = 448.8CA\sqrt{2g(H - hm)} \qquad (7)$$

where:

hm = the height of tailwater above the tube exit elevation in feet

By substituting equations (6) and (7) into equation (1), the equation for the submerged sampling ratio becomes:

$$R = \frac{448.8ca\sqrt{2g(H - hs)}}{448.8CA\sqrt{2g(H - hm)} + 448.8ca\sqrt{2g(H - hs)}} \times 100 \qquad (8)$$

If hs is equal to hm as it is assumed, equation (8) reduces to:

$$R = \frac{ca \times 100}{CA + ca} \qquad (5)$$

Since the equation for the submerged sampling ratio comes out to be the same as the equation for the unsubmerged sampling ratio, the sampler should be able to operate satisfactorily under either condition.

It was realized, prior to testing, that when the flow rate was low and tailwater was not submerging the tube exits, there would be some increase in the sampling ratio over what it would be for higher flow rates. This was because the tubes, oriented as they were, were also weirs and at low flow rates weir flow was dominant over tube flow. The sampling ratio would rise, as flow rate decreased, because the ratio of the weir capacities was the ratio of the circumferences of the tubes, which yielded a higher sampling ratio than that of the tube capacities. One objective of testing was to determine the seriousness of the effect of weir flow.

A test model was constructed with the sampling tube having an inside diameter of 0.25 inch and the main flow tube having an inside diameter of 2.5 inches. Both tubes extended above the plate that they were set in, by three-quarter of an inch. Then the test model was installed in a test rack as shown in Figure 7. Water was pumped from a reservoir into the left end of the test rack where it passed through the test model. A sample was drawn off and collected, with the main flow exiting out the right end of the test rack. When unsubmerged tests were run (with no tailwater flooding) the flow from each tube was collected simultaneously for a set period of time at a constant flow rate. Each collected flow was measured by weighing and the sampling ratio and the total flow rate were computed. Testing was done by this procedure over a range of flow rates from two gallons per minute to over fifty, with enough repetition to guard against chance variation. The results showed a

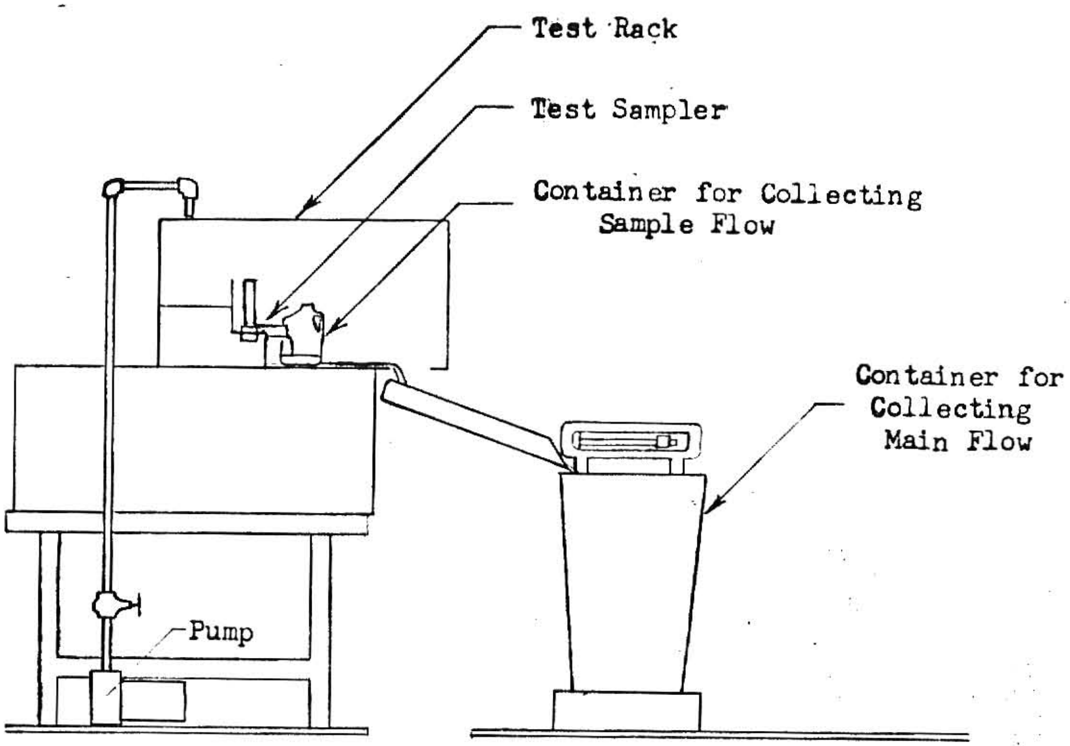


Figure 7. Apparatus for testing unsubmerged behavior of sampler.

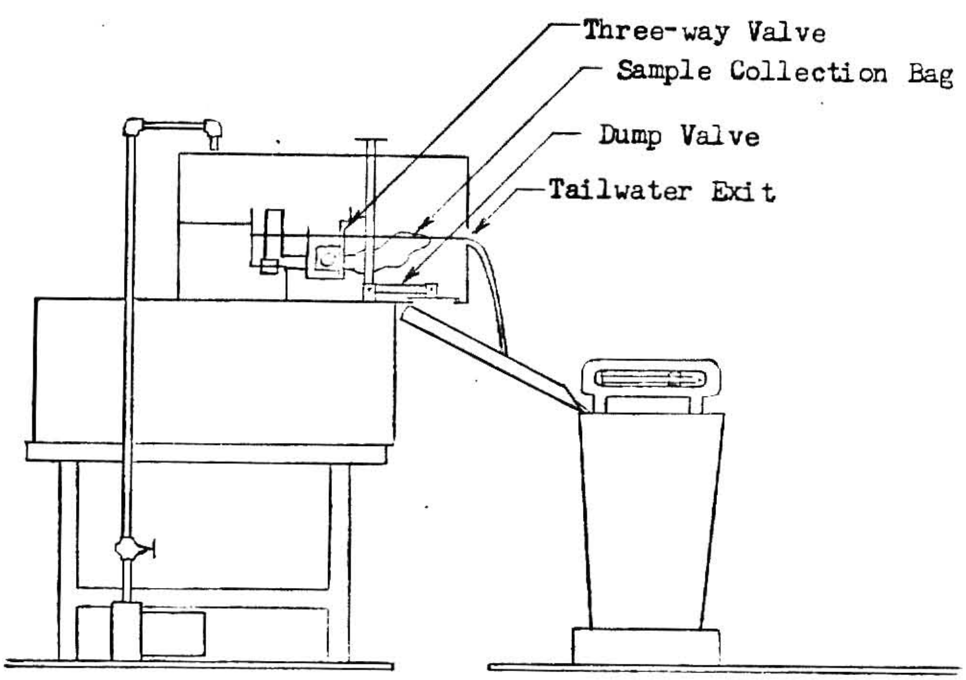


Figure 8. Apparatus for testing submerged behavior of sampler.

fairly constant sampling ratio of 1.05 percent for flow rates above thirty gallons per minute. However, as shown in Figure 9 the sampling ratio was anything but constant at lower flow rates, reaching a peak value of two percent at a flow rate of four gallons per minute. At flow rates below four gallons per minute, the sampling ratio fell off considerably. The peak sampling ratio should have been highest at the lowest flow rate if the assumption, that the test model was absolutely level, was correct. As was discovered later, the sampling tube was minutely higher than the main flow tube, resulting in the sampling ratio dropping off at flow rates below four gallons per minute. With this kind of performance, a sampler with the same tube dimensions as the test model could only be used for situations in which flow rates above thirty gallons per minute were predominant. At thirty gallons per minute, the test model was using about two inches of head. For samplers of different dimensions, the critical flow rate would be different, but two inches would still be the head at that flow rate. Since the sampling ratio was higher at low flow rates, the composition of the runoff at low flow rates would be over-represented in the composite sample. In some cases this may be desirable. However, the flow rates expected at Pratt were far too low for this type of sampler to be relied upon under unsubmerged conditions (in which the tube exits were above the tailwater).

Next, the test model was tested under submerged conditions (in which the tube exits were flooded). The test rack, as shown in Figure 8, was modified to produce submerged conditions by cutting a new tailwater exit in the right end of the tank, high enough to cause the tubes to be flooded. The old tailwater exit was used as a dump valve and a three-way valve was mounted between the sampling tube and the sample collection bag. To make a test run,

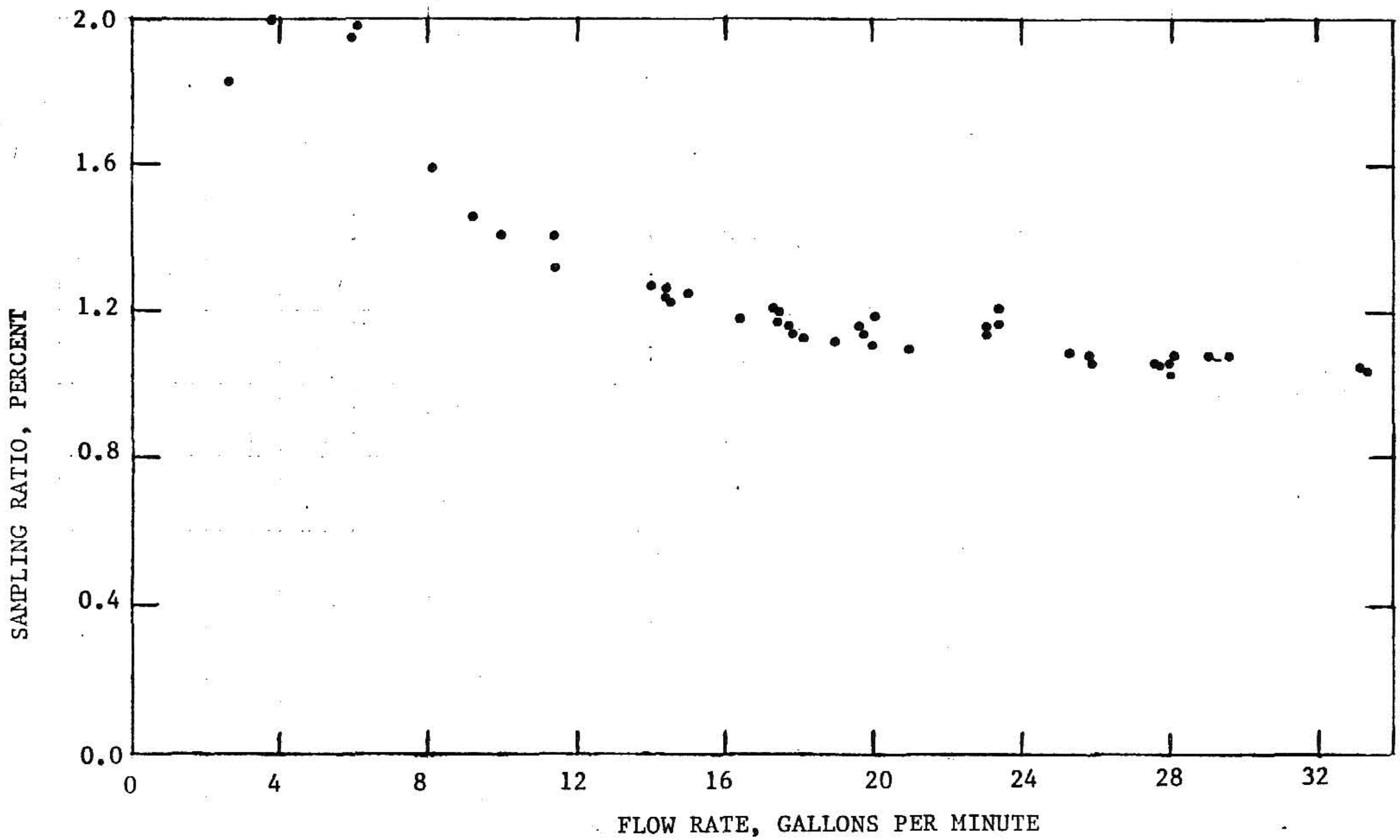


Figure 9. The response of the sampling ratio to flow rate for the first design in laboratory tests of its unsubmerged behavior.

first the flow rate was set. Then the bag (with a small amount of water in it to fill an air pocket in the three-way valve) was attached to the valve while the sample flow was diverted elsewhere. Next, the dump valve was closed in order to raise the tailwater level. When the water level had stabilized (when outflow through the raised tailwater exit equaled pump inflow), the actual test was started. Simultaneously, the three-way valve was switched to divert flow into the bag, the flow from the tailwater exit was diverted into a thirty gallon container setting on a scale, and a stopwatch was started. When the stopwatch reached the shutoff time (which ranged from fifteen seconds to ten minutes as needed), both flows were diverted elsewhere and the dump valve was opened to empty the test rack of water so that the bag could be retrieved. Again, the collected flows were weighed and the sampling ratio and total flow rate computed. The results showed a constant sampling ratio, over the entire range of flow rates tested, of about 0.88 percent. This was much better than the unsubmerged results. Figure 10 is a plot of the results of submerged tests on the test model that was described. There was some contradiction in the test results at the lowest flow rates but it was attributed to variability in the test procedure having a greater effect at low flow rates and the contradictory results were left for later investigation. Since the sampling ratio was constant to a much greater extent when the test model was submerged than when it was unsubmerged, it was concluded that the field samplers should be installed in pits to obtain submerged conditions as soon after the flow started as possible.

For field testing, ten samplers were built using the same tube dimensions as the test model, but in other respects were designed for field conditions as shown in Figure 6. The samplers were built for a materials cost

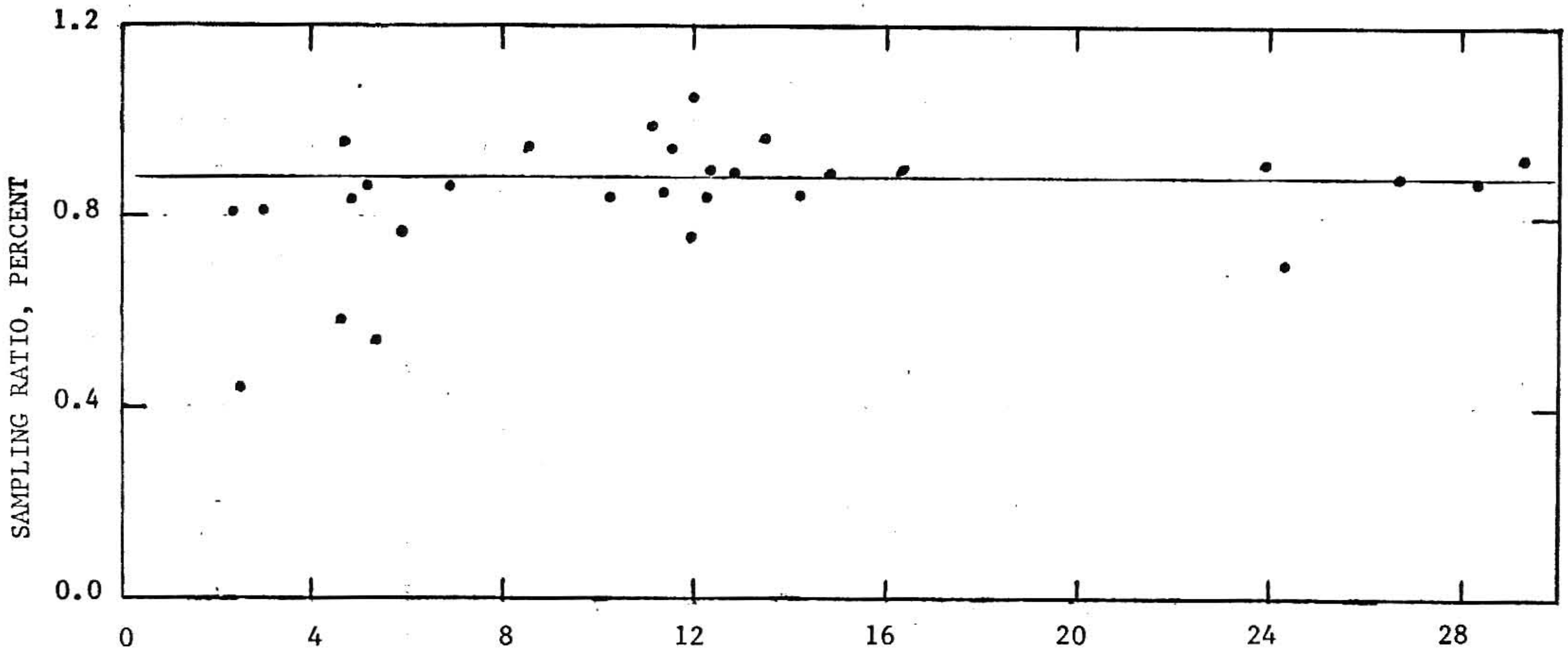
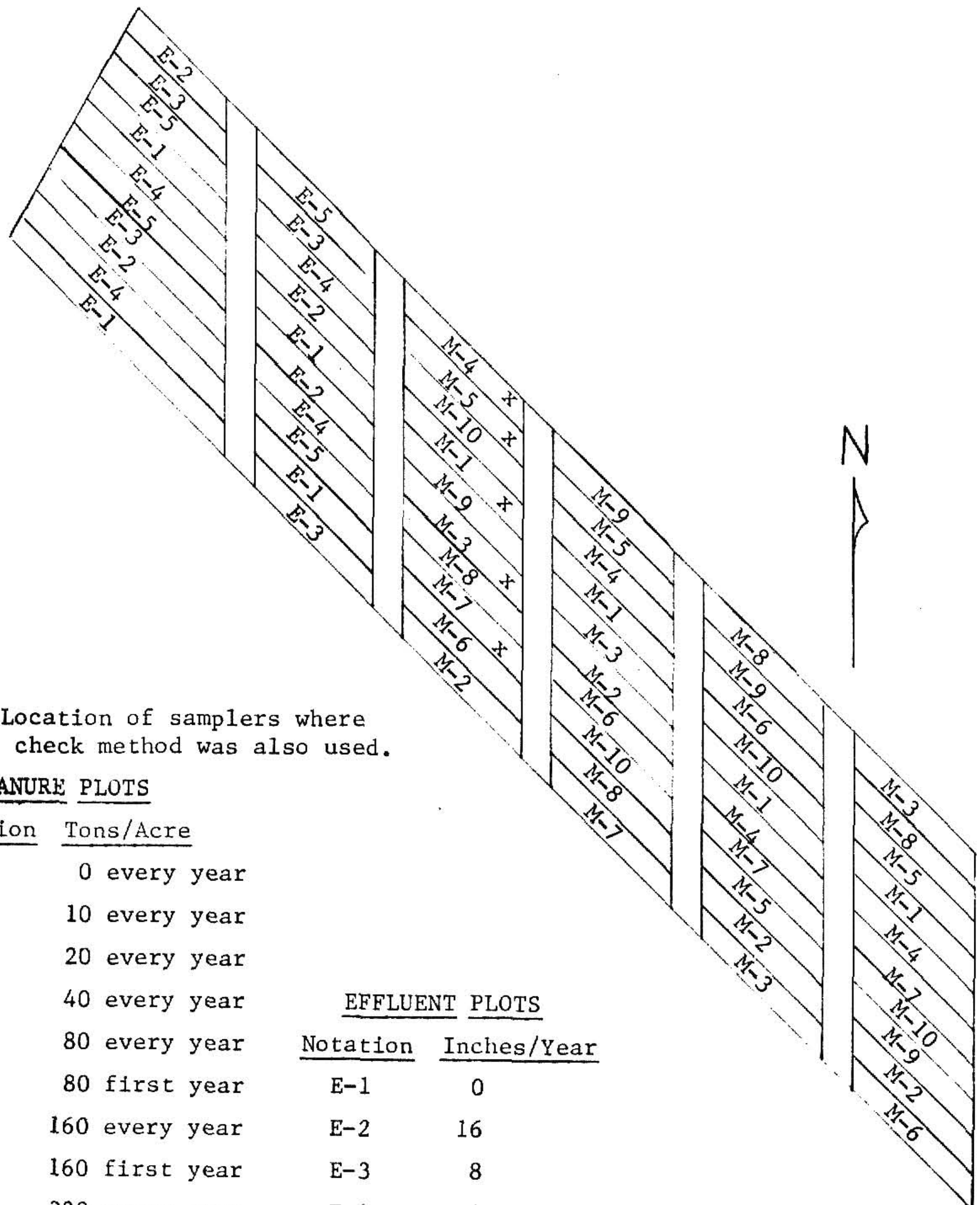


Figure 10. Response of the sampling ratio, to total flow rate, for the first design in laboratory tests of its submerged behavior.

of approximately seven dollars each, which was less than any cost reported in the literature review and far less than the cost of more conventional equipment. One of these field samplers was placed in the test rack and calibrated in submerged tests in which the sampling ratio was found to be 1.29 percent, which was higher than the value of 0.88 percent found for the test model. This increase in the sampling ratio was due to a sharper entrance on the main flow tube of the field sampler than on the one in the test model.

Figure 11 shows how the plots and replications of plots were laid out at Pratt, Kansas, where the samplers were used. The replications (ten plots each) were numbered from the west (one through six) and the plots, within each replication, were numbered from the north. Each plot location was designated by a letter, for the type of treatment used (M for manure), and by two numbers (the first was the rank of the replication within the treatment and the second was the rank of the plot within the replication). Five plots, each, were used on the third and fourth replications, that had the treatment rates of approximately zero, twenty, forty, eighty, and one hundred and sixty tons per acre of dry beef feedlot manure every year. On each of the five plots in the third replication, a flume-recorder-sampler setup was used to measure the flow rate of the runoff and sample it as it flowed into the proportional sampler. In Figure 11, the locations of these samplers, in the third replication, are marked with an 'x'. On the fourth replication, only the proportional sampler was used, because there was not enough of the flume-recorder-sampler equipment for both replications.

The flume-recorder-sampler setup shown in Figure 12 consisted of a sixty-degree trapezoidal flume with a forty gallons per minute capacity, a



x- Location of samplers where check method was also used.

MANURE PLOTS

Notation	Tons/Acre
M-1	0 every year
M-2	10 every year
M-3	20 every year
M-4	40 every year
M-5	80 every year
M-6	80 first year
M-7	160 every year
M-8	160 first year
M-9	320 every year
M-10	320 first year

EFFLUENT PLOTS

Notation	Inches/Year
E-1	0
E-2	16
E-3	8
E-4	4
E-5	2

Figure 11. Test plot layout.

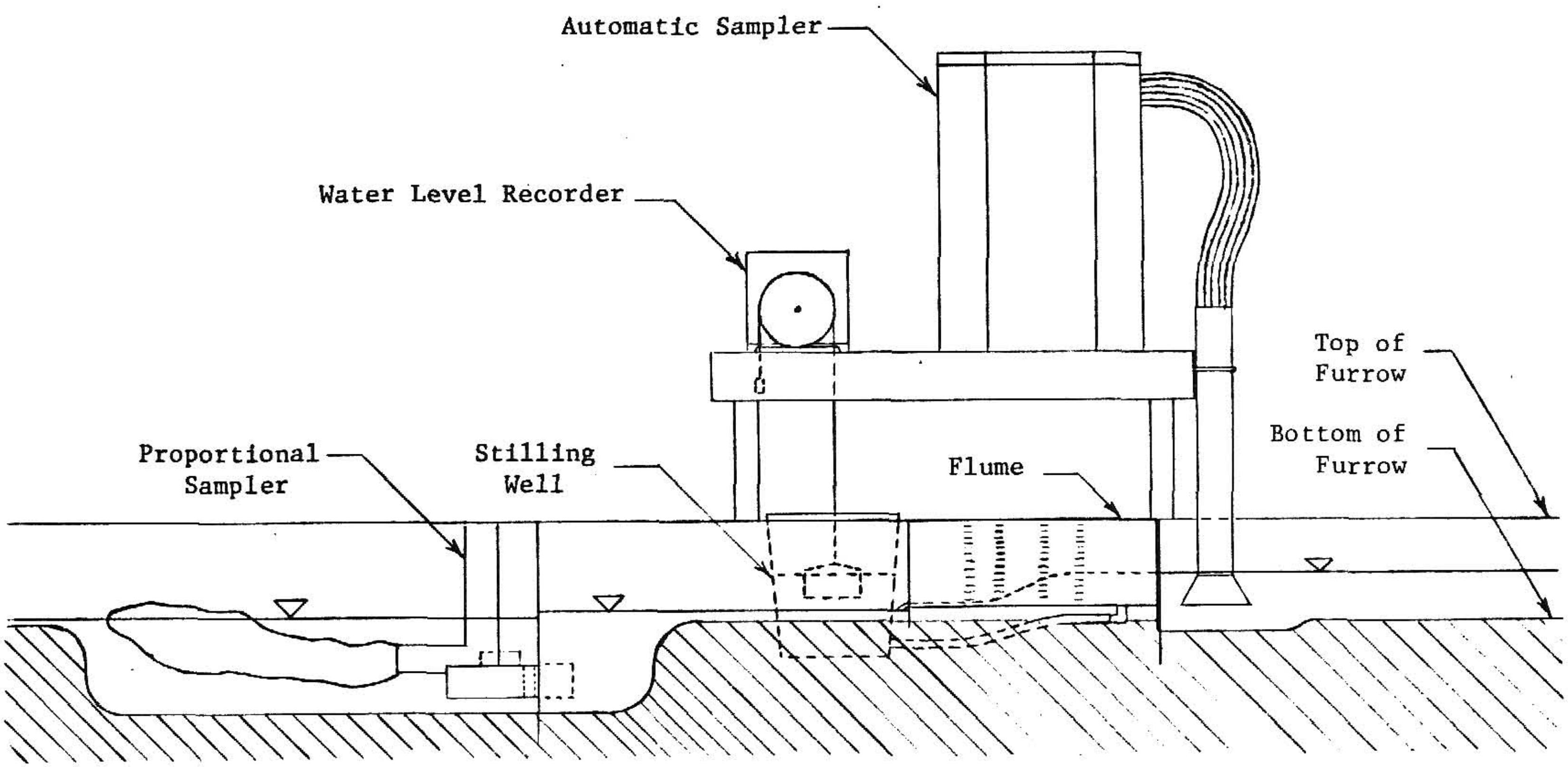


Figure 12. The arrangement that was used to test the proportional sampler in the field.

stilling well, a water level recorder, and an automatic water sampler. The water level recorder was a self-starting type with a clock-motor drive, manufactured by Leupold and Stevens, Inc. The automatic water sampler, a product of Serco Laboratories of Minneapolis, Minnesota, consisted of a clock motor and twenty-four evacuated bottles with each connected by a clear vinyl plastic tube to a sampling head. The sampling head was positioned to sample water entering the flume. The clock motor, which was started by the water level recorder, released the vacuum in each bottle in timed sequence (one every five minutes). When the vacuum in a bottle was released, a sample of the water flowing past the sampling head was sucked through a plastic tube into the bottle.

When water started flowing through the flume, water flowed from its entrance section through a tube into the stilling well, which raised the water level in the stilling well to the same level as the water in the entrance section of the flume. This rise of the stilling well's water level raised the water level recorder's float, which released a switch arm on the recorder and allowed the recorder to start. A mercury switch on the switch arm closed a circuit that energized a solenoid that started the clock motor in the automatic water sampler.

As might be imagined, the reliability was poor. It was common for the system to start prematurely and finish the sampling procedure before runoff occurred, or it did not start at all. It was also common for only part of the system to function by itself. A common problem was a tendency for the evacuated bottles in the automatic water sampler to lose vacuum after a few days. In addition, there was trouble with some of the clock motors in the automatic samplers and the water level recorders involved that were not working properly. It was against this method of measuring runoff that the proportional samplers were tested but not many tests could be made.

Additional data was lost because of problems with the proportional samplers. There were problems with bags that leaked, sedimentation in the sampler, floating debris that clogged intake screens, and wind-blown debris that managed to get inside the samplers during dry weather. Bag leaks were also responsible for the loss of data through loss of the collected sample. The first bags were made of clear polyethelene and were exposed to sunlight and wind. The ultra-violet in sunlight degraded the plastic rapidly making it brittle. The wind would whip the bag around and both factors combined to make cracks in the material after no more than a few days. As a remedy, the clear bags were replaced with opaque ones that were less susceptible to degradation by ultra-violet. In addition, plywood covers were placed over the pits where the bags were installed. The plywood covers provided further protection from the sun and kept the wind off of the bags. The plywood covers did solve the problems caused by sun and wind but created another one involving field mice. A few weeks after the covers were put in place, field mice were found making nests underneath them and chewing holes in the bags to obtain nesting material. At first, only one or two samplers were affected but the problem grew until, in September, nine out of ten bags installed were ruined by field mice in less than two weeks. Another problem was sedimentation in the samplers. It was anticipated that sediment would accumulate in the pits where the samplers were installed. This meant that the pits needed periodic cleaning to keep the samplers from being filled up with sediment. However, the cleaning was not done at first and the accumulation of sediment filled up some of the proportional samplers. As a result the proportional samplers were overtopped during the following storm. The intake screens also proved to be inadequate as, after a few storms, they became clogged with floating debris. The screens were built in two stages with a large screen size for the first stage and a smaller size for the second stage. The two stage concept was all right but the screen areas of the two stages were far too small to accommodate the volume of material that needed to be screened out without restricting water flow. Another oversight was that the exit of the main flow tube was not covered with a screen to prevent wind-blown material from entering the sampler during dry weather. When water would start to flow through the sampler, there was a good chance that this material, trapped inside, would block the intake of the sampling tube. If this happened, the sampling ratio would drop precipitously, possibly to zero.

Table 1 shows the results of field tests where there was enough data to compute the measured sampling ratio by dividing the volume, collected by the sampler, by the total volume of flow measured by the flume-recorder-sampler setup. From the results, it was readily apparent that the samplers were not working properly because the measured sampling ratios were scattered all the way from zero to 1.68 percent with an average of 0.592 percent. All but two of the readings were below the expected value of 1.29 percent. In Figure 13, the measured sampling ratio for each test was plotted against the volume of flow with the latter on a log scale. When this was done, a negative correlation was found when there should not have been any correlation. In other words, the sampling ratio was decreasing as more water passed through the sampler. Excessive sedimentation in the sampler or clogging of the intake screens which would force the runoff to overtop the screens would

Table 1. Data from Field Tests

Date	Rainfall (Inches)	Plot	Hydrograph Volume (Gallons)	Sample Volume (Gallons)	Ratio (Percent)	Peak Flow Rate (Gallons Per Minute)
5/29/75	.62	M-16	9.046	.08478	.9372	.2114
6/08/75	1.08	M-11	87.06	.2491	.2861	1.805
6/08/75	1.08	M-12	23.80	.1283	.5390	.7209
6/08/75	1.08	M-14	73.001	.5042	.6907	1.3789
6/08/75	1.08	M-16	14.76	.2296	1.556	.748
6/16/75	2.00	M-14	400	0.0000	0.0000	12.29
6/16/75	2.00	M-16	417.08	.9851	.236	10.119
6/26/75	.875	M-14	254.69	0.0000	0.0000	15.97
6/26/75	.875	M-16	180.08	1.206	.6697	9.12
8/13/75	.66	M-11	25.36	0.0000	0.0000	.8622
8/13/75	.66	M-14	131.44	.02851	.02169	6.805
8/13/75	.66	M-16	10.40	.1748	1.681	.2977
8/18/75	1.16	M-14	97.120	.9	.927	1.1816
8/18/75	1.16	M-18	40.28	.3	.745	.966

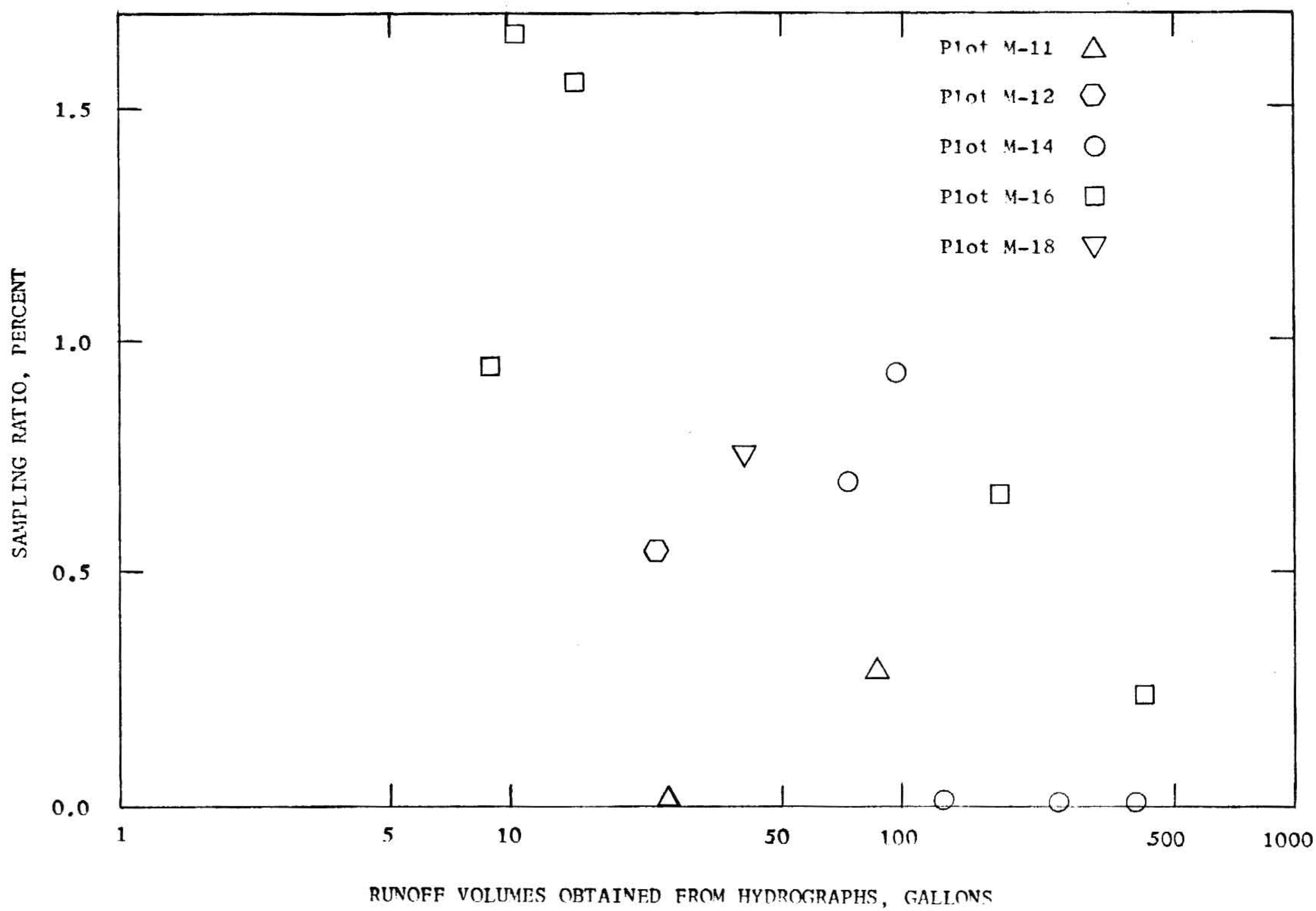


Figure 13. A semi-log plot showing the relationship between the hydrograph volumes and the sampling ratios measured in the field tests.

not explain the correlation because if this happened the flume would have been flooded, ruining the water level recorder data. The likeliest possibility is that the wind-blown debris, caught in the sampler, was responsible for the negative correlation. If the intake of the sampling tube were clogged shortly after the beginning of runoff, the sampling ratio would decrease as more flow passed through the sampler.

Another problem, but a minor one, was the problem of toads falling into the stilling wells, which were only three gallon buckets set in the ground. The disturbance of the water surface, made by their swimming, was registered as static by the water level recorder. This static made a rather wide trace on the hydrograph which reduced the accuracy of flow measurement.

Data from field tests were lost by sedimentation in the sampler, by clogging of the intake screens, and by leakage from damaged bags. The data that was obtained in spite of this revealed another problem in which the sampling tube was being clogged by debris entering the sampler through the main flow tube. Sedimentation in the sampler could have been have been solved by periodic sediment removal from the sampler pit. Clogging of the intake screens could have been prevented by using more screen area. Bags could have been protected from mice by using hail screen. Wind-blown debris would have been kept out of the sampler by putting a screen over the exit of the main flow tube. With these changes the results of the field tests would have been much better.

About the time that the field installations were being completed, an alternative to using tubes came into mind that would improve certain characteristics of the sampler. One of these characteristics was that, above thirty gallons per minute, the sampler had a sampling ratio of 1.05 percent for unsubmerged flow but another sampling ratio of 0.88 percent for submerged flow. The probable explanation for the difference in sampling ratio was that there was difference in the tube flow coefficients caused by the difference in conditions from one type of flow to the other. Another characteristic was that the unsubmerged sampling ratio was not known until the sampler was tested because the coefficients of flow were not known for the tubes involved which put the design process on a trial-and-error basis. The alternative to using tubes for flow control was to replace the vertical tube with a horizontal orifice that is surrounded by a ring-shaped weir that is substantially larger in diameter than the orifice. With regard to the first characteristic mentioned, the orifice would be submerged, whether or not the sampler was, because the weir would keep it submerged even when the sampler was not submerged. Thus at high flow rates where the influence of weir flow would have disappeared, there should be only one sampling ratio for both submerged and unsubmerged conditions. The design process would be improved because orifices are easier to design than tubes and much more is known about the coefficient of flow for submerged orifices. As a result, it was possible to set the capacity of the sampler and the sampling ratio accurately without trial and error. Since, the diameter of the weir ring around the main flow orifice was larger than the diameter of the tube that it replaced, the weir capacity was increased and its effect on the unsubmerged sampling ratio reduced. In addition, for the purposes of study, the effect of weir flow can be isolated with this design since the effect of orifice flow can be accurately calculated and taken into account. Since it appeared advantageous to redesign the sampler, on paper, the next step was to test the new design in the laboratory.

A second test model, shown in Figure 14, was built with a main flow orifice diameter of 2.5 inches, and a sampling orifice diameter of 0.25 inches. A two inch length of four inch inside diameter PVC pipe was placed for a weir around the main flow orifice, and a two inch length of one inch inside diameter PVC pipe was used for the weir around the sampling orifice. The test model was placed in the test rack where the first test model was tested, and unsubmerged and submerged tests were made. Both test procedures were modified, to reduce variation due to testing, by collecting the sample flow for twice as long as the main flow. This was done because the collection capacity of the test equipment for the main flow was limited to 190 pounds. For a one percent sampling ratio, this meant that the sample flow volume was limited to 1.9 pounds, but, with the change in procedure, 3.8 pounds of sample flow could be collected. In this way, inherent error in measuring the collected sample volume had less effect on the measured sampling ratio. To accomplish this, the main flow was collected during the time that the sample flow was being collected, from when one-fourth of the sample flow was collected to when three-fourths was collected.

The results of the unsubmerged tests represented by the circled points in Figure 15 peaked with a sampling ratio of 1.54 percent at 3.7 gallons per minute and declined as the flow rate increased, to approach the design sampling ratio of one percent. Also, it was apparent that the effect of weir flow on the sampling ratio had been substantially reduced, but it was not by any means eliminated. An attempt was made to mathematically model the unsubmerged behavior of the test sampler with the standard equations for orifice and weir flow. However, the sampling ratios produced by the mathematical model were much higher than the ones obtained with the test model.

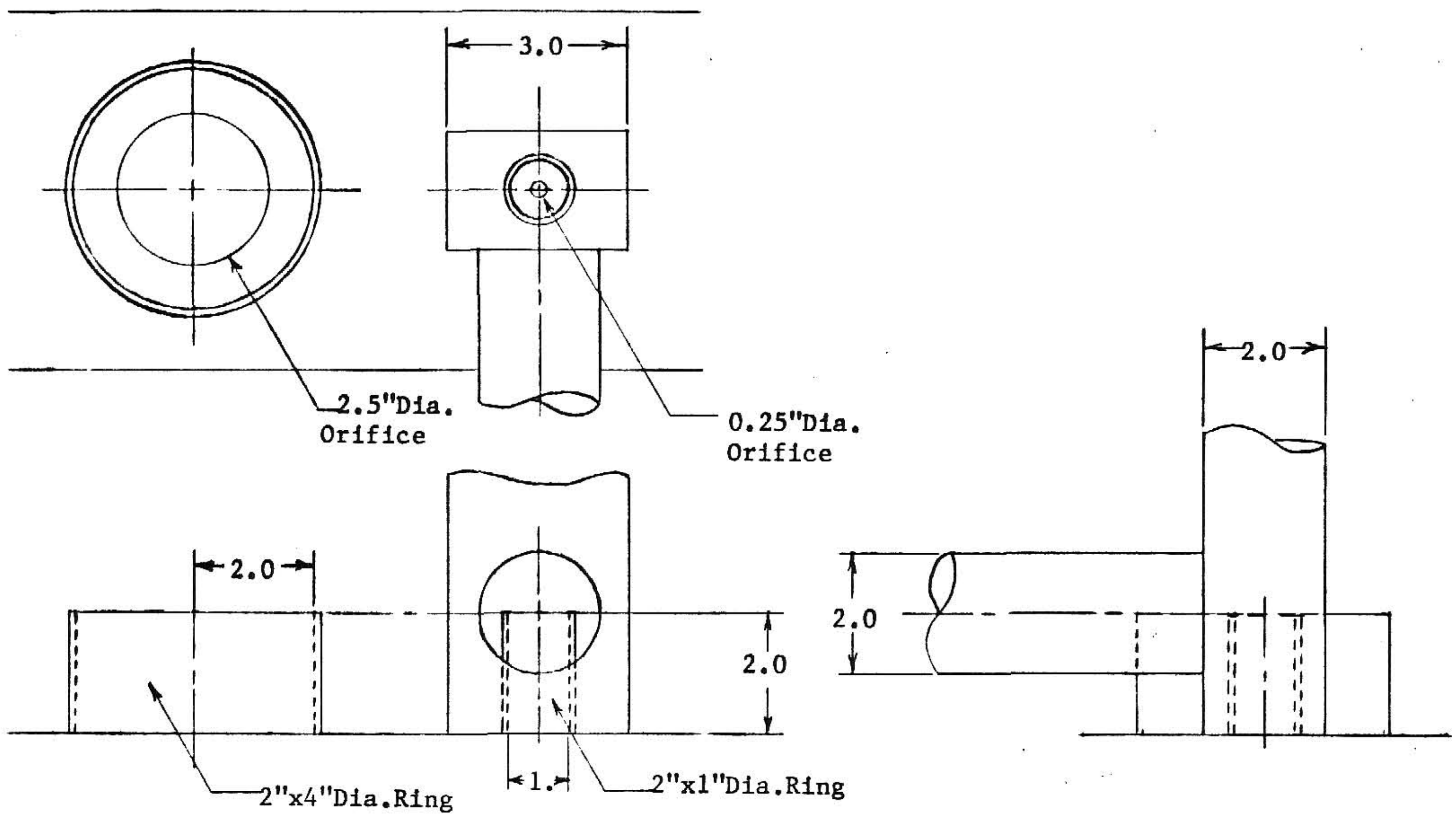


Figure 14. Orthographic view of the test model used after the sampler design was revised.

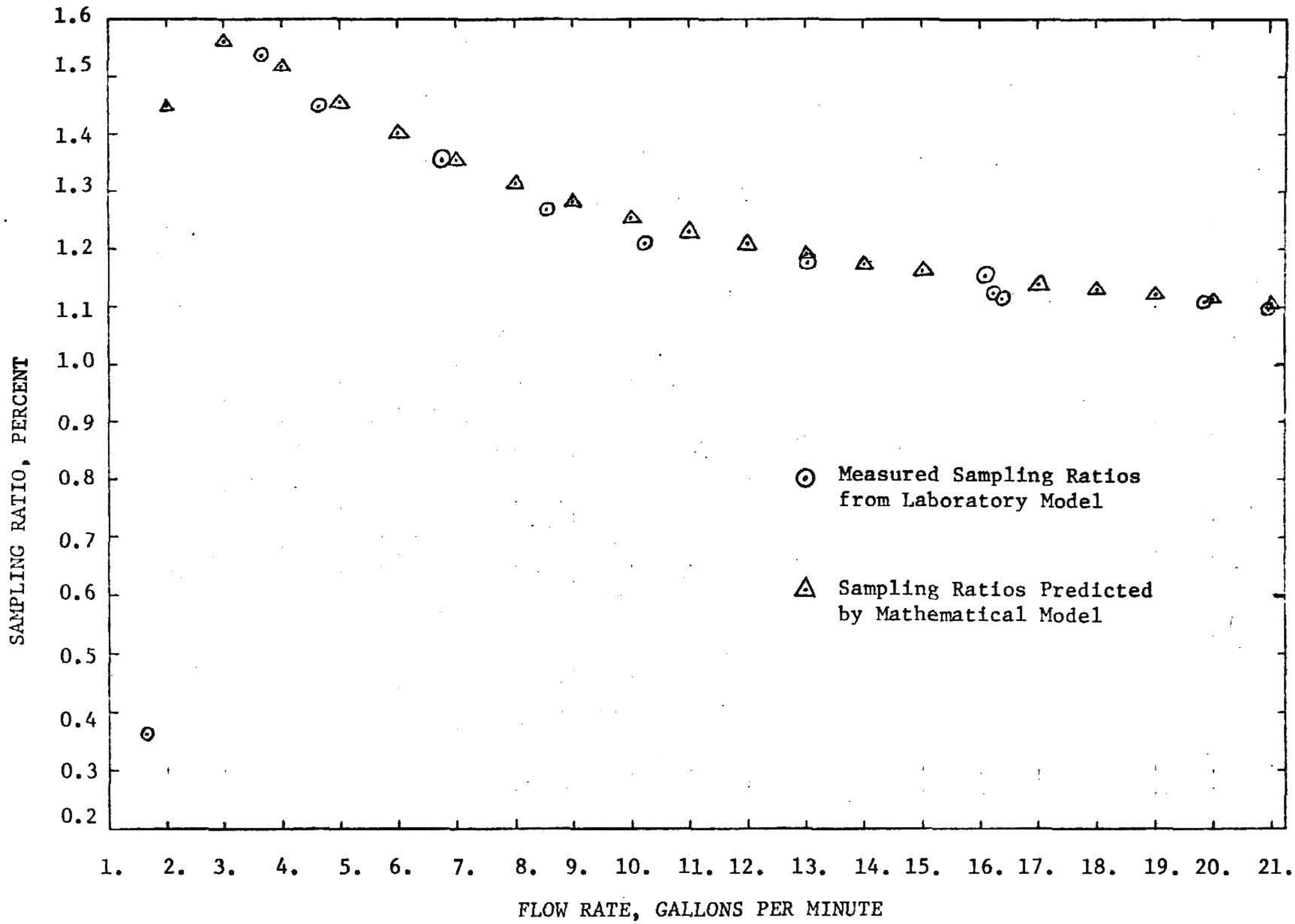


Figure 15. Comparison of measured sampling ratios with those predicted by a mathematical model for unsubmerged behavior.

Apparently the effect of weir flow on the sampling ratio was being overestimated which indicated that a new weir flow equation was needed. By trial and error, the standard weir equation was modified by changing the equation coefficients to make the mathematical model fit the actual data. The triangled points in Figure 15 were produced by the model. Admittedly this was not the best procedure for estimating the weir flow formula, but since unsubmerged flow was not being relied upon for sampling in the field, no further effort was made to obtain a better equation. The mathematical model was used to roughly estimate sampling ratios for samplers of varying orifice and weir sizes in unsubmerged flow. It should be noted that the sampling ratio at low flow rates is drastically affected by whatever misalignment there is in the sampler, even if it is quite small. In the unsubmerged tests on both test models, the sample flow exit elevation was discovered to be slightly higher than for main flow which changed the sampling ratio, at very low flow rates, from being too high to being too low. However, the effect of this misalignment disappeared as the flow rate increased.

Next, the submerged behavior of the test model was tested to see if the submerged sampling ratio matched the predicted value. In addition, rigorous testing was done at low flow rates to check for a suspected effect on the sampling ratio caused by the sample collection bag. A bag effect was first suspected when measurements on irrigation tailwater, made with the field samplers, came out consistently low. The flow rates involved were all about four gallons per minute or less. It was reasoned that since the operating head in this range of flow rates is so low (0.00074 feet at two gallons per minute) that if there was any resistance to flow in the sample collection bag, it would cause a significant reduction in the sampling ratio when the flow rate was low enough. The test procedure for submerged flow was modified to reduce variation due to testing. The first change was to double the sample collection time as was done for the unsubmerged test procedure. For low flow rates, a second pump was added to help raise the water level in the tank to near equilibrium at the beginning of the test to save time. Otherwise, a pump set at one-half gallon per minute would take two hours to pump approximately sixty gallons at the start of each test. A hook gauge was the most important addition to the test equipment. It was mounted on the three-way valve to monitor the water level inside the valve. This was done to account for changes in tank storage that occurred during testing. Earlier, it was assumed that such changes were small enough to be ignored but subsequent hook gauge readings showed otherwise. The reason changes in storage occurred during testing was that the test was often started before equilibrium was fully established. The error would show up as an extra loss or gain in the amount of water collected in the plastic bag (because of a change of storage in the three-way valve). Some of these errors were quite large, resulting in some sampling ratios, at low flow rates, that were way off scale, and other sampling ratios that were misleading. When hook gauge readings were used to correct the collected sample-flow volumes, the variation at low flow rates was substantially reduced, producing meaningful results at flow rates as low as 0.5 gallons per minute. Without the hook gauge, reliable results could not have been obtained at flow rates below ten gallons per minute.

According to the test results, the bag did have an effect on the sampling ratio below four gallons per minute. Above that flow rate, the sampling ratio averaged 1.01 percent which is only 0.02 percent higher than the predicted value of 0.99 percent. Using Student's t-test, the ninety-five percent confidence interval with twenty-two degrees of freedom on individual readings was from 0.954 percent to 1.066 percent for flow rates of four gallons per minute and more. Figure 16 is a plot of the test results with five percent and ten percent error bands shown. As shown by Figure 16, the sampling ratio decreased as the flow rate decreased from four gallons per minute. At the lowest flow rate tested, 0.5 gallons per minute, the sampling ratio was only 0.5 percent.

The calculated head differential, for that flow rate, was 0.0000461 feet, by the orifice equation, but at four gallons per minute, it was 0.00295 feet. Since the head differential for four gallons per minute was sixty-four times the head differential for 0.5 gallons per minute, it was obvious that a small head loss that would be insignificant at the higher flow rate could be very significant at the lower flow rate. It is evident, from the reduction in the sampling ratio at 0.5 gallons per minute, that there was a small head loss in collecting the sample flow and that it was less than the head differential at that flow rate since the sampling ratio had not yet dropped to zero. The probable cause of this head loss was the sample collection bag.

The sample collection bags used in these tests were about a gallon in size, were made of polyethelene, and had a wall thickness of 0.0015 inches. The bags used in the field were made of the same material, but had a wall thickness of 0.002 inches and had a capacity of thirty gallons. The relationship between the stiffness of the two bags can only be guessed at because the stiffness of a bag should increase as the wall thickness increases, but it should also decrease as the bag size increases. The bags used in the field tests were too large for testing in the test rack. As a result, it was not known whether the bags, used in the field, had more or less effect

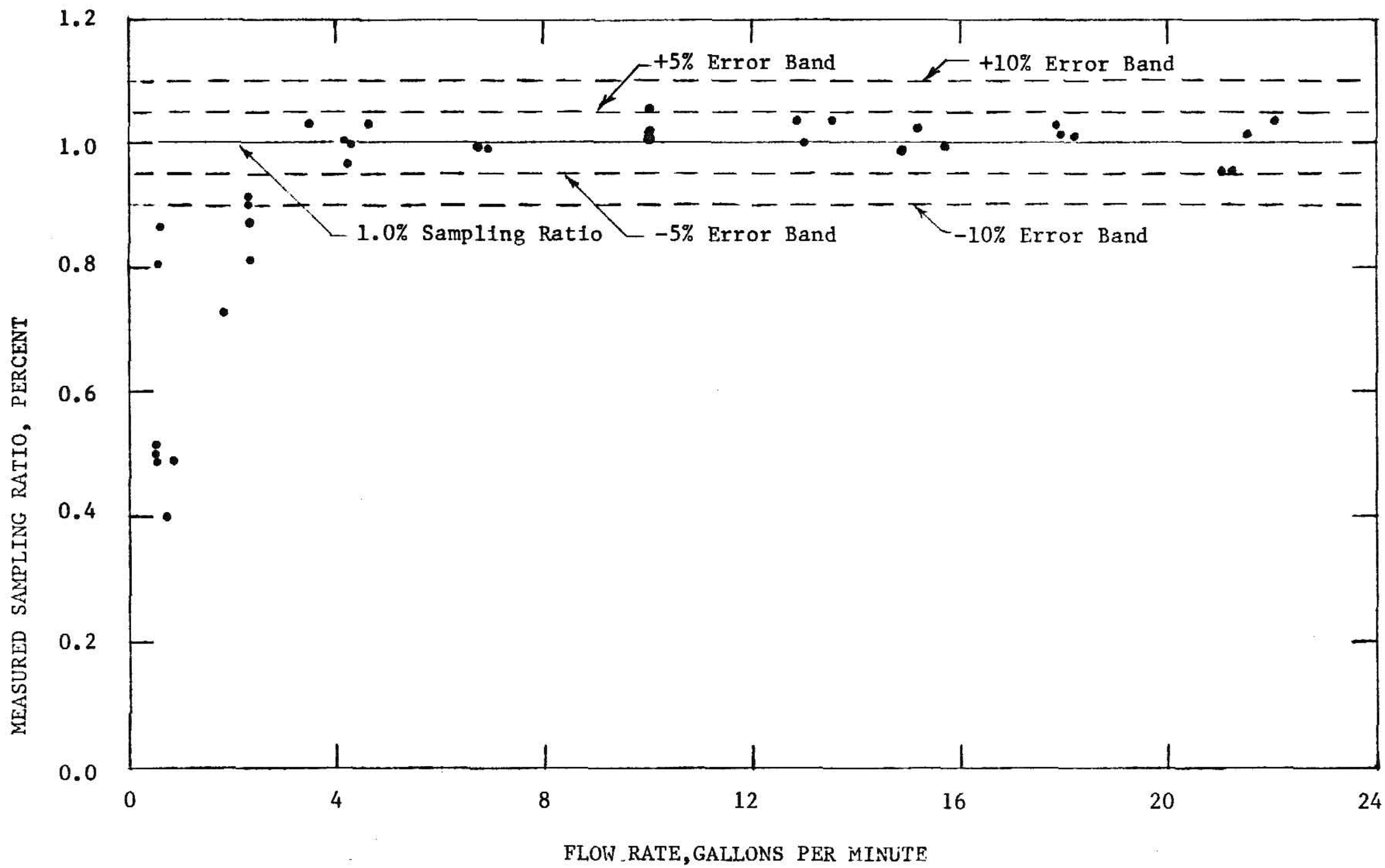


Figure 16. Results of laboratory tests on second sampler prototype with 5% and 10% error bands.

on the sampling ratio.

From the runoff hydrographs obtained in the field tests, it was noted that most of the flow rates were in the range where sampling ratio was reduced. None of the fourteen events, where full data was obtained, had peak flow rates below two gallons per minute, and two of these were below 0.5 gallons per minute. Furthermore, these were peak flow rates and not average ones. The highest flow rate, that was recorded, was sixteen gallons per minute, while the sampler capacity was forty gallons per minute. If the design capacity of the sampler had been lowered to use more of the available head, the flow rate, at which the bag effect becomes significant, also would have been lower.

If this bag effect were responsible for the poor performance of the field samplers, then the results should have been better at the higher runoff volumes than at the lower ones. Also, there should have been a positive correlation between the runoff volume and the measured sampling ratio rather than the negative one shown in Figure 13. On both counts, the actual data was just the opposite, which leaves the original explanation as the probable one. Waterborne material still remains as the major obstacle to practical use in the field, with bag effect as a secondary consideration.

SUMMARY

The abatement of water pollution by runoff from agricultural, non-point sources will soon be legally mandated and the Environmental Protection Agency will be forced to use some type of scheme to carry out this mandate. It will be impractical to monitor the runoff from even a small fraction of the farms situated on waterways with the standard flume-recorder-sampler method. The method is impractical because of the high cost of the equipment involved, the low reliability of the equipment, and the sheer amount of work involved in analyzing the data. If runoff from farms is not monitored, the alternative is to use strict land use control legislation which could have a devastating effect on the agricultural industry. A cheaper, more reliable, and easier method of monitoring runoff is needed.

A proportional sampler would at least meet the last requirement of being easier to use. By collecting a small, representative fraction of the volume of runoff, the analysis of data is reduced to measuring the volume of the sample and analyzing it for the concentrations of various pollutants. To obtain the total volume of runoff, the volume of the sample is divided by the sampling ratio. The total amount of each pollutant is obtained by multiplying its concentration in the sample by the total volume of runoff. This is in contrast to the flume-recorder-sampler method which produces a hydrograph of the hydraulic head in the flume and a series of runoff samples. Compositing the samples or using a composite sampler that collects a fixed volume at regular intervals is inappropriate where flow rates are not relatively constant which is seldom the case with runoff. Before a

representative composite can be formed, the individual samples must be correlated with flow rates and weighed accordingly.

A proportional sampler was needed for use on beef feedlot manure application plots located on property of the Pratt Feedlot of Pratt, Kansas. The plots were small, two hundred feet by thirty feet, and had a rather flat plot slope of 0.5 percent. Corn was grown on the plots with a thirty inch row spacing and a furrow for irrigation between every two rows. The two center furrows in each plot were brought together at the lower end for measurement of flow. Tailwater drainage from the plots was known to be poor. Given these conditions, the maximum expected rate of runoff was estimated to be forty gallons per minute and the available head for sampler operation was estimated to be six inches. In addition, the samplers had to be economically and simply constructed so that ten units could be built within a limited budget.

A search of the literature was made to find a proportional sampler that could be adapted to meet the requirements at Pratt. The proportional samplers described in the literature were a slotted conduit placed to intercept the flow from a drop spillway structure, a series of small buckets on a moving chain, the Coshocton wheel, a two-stage multi-weir divisor, and another device involving weirs and a sampling wheel. The slotted conduit and drop spillway structure arrangement and the two-stage multi-weir divisor were unsuitable primarily because of the extreme precision needed to scale either one down to handle only forty gallons per minute and still be accurate. The small bucket series and the weir-and-sampling wheel device both required electrical power which was not available. The Coshocton wheel required too much available head to operate. Nothing turned up in the literature that fit all the requirements for use at Pratt.

Various possible designs for a proportional sampler were considered on paper until a design looked good enough to test in the laboratory. The first sampler tested in the laboratory consisted of a horizontal plate with two short tubes set in it with the top ends of the tubes at the same height. The inside diameter of one tube was 0.25 inch and the diameter of the other tube was 2.5 inches with the ends of both tubes raised 0.75 inch above the plate. The flow to be sampled entered the tubes from the bottom, flowed upward with the flow from the small tube channeled into a plastic bag. The volume of this collected flow was measured to determine the total volume of flow and a sample of it was analyzed as a composite representative of the total flow. Because of the flexibility of the plastic bag, the sampler was able to operate when the tubes are completely underwater, because the head differential for the small tube was equalized with the head differential for the large tube. So long as both tubes had the same head differential the sampling ratio remained constant.

In laboratory tests, the sampling ratio for unsubmerged flow was 1.05 percent for flow rates above thirty gallons per minute, but as the flow rate decreased from that level the sampling ratio increased to a high of 2.0 percent at four gallons per minute. However, when the tubes were submerged, the sampling ratio remained constant at 0.88 percent over the entire range of flow rates tested (four gallons per minute to thirty gallons per minute). Consequently, the samplers built for field testing were designed so that the tubes would become submerged as soon as possible after runoff started.

In field tests, conducted at Pratt, Kansas, a proportional sampler and a flume-recorder-sampler arrangement was placed on each of five plots, using the latter to test the former. Five more proportional samplers were installed on another five plots without the flume-recorder-sampler arrangement. This was done in case the first five samplers proved to be reliable, in which case the data produced by the second five could be used. However, the case was otherwise. The test results showed a negative correlation between the apparent sampling ratio and the volume of flow obtained with the flume-recorder-sampler apparatus. The measured sampling ratio, the ratio of the sample volume collected in the bag to the total volume of flow, ranged from zero to 1.68 percent, while the total volume of flow ranged from nine gallons to 417 gallons. Laboratory tests on an actual field sampler indicated that the sampling ratio should have been 1.29 percent, indicating that the apparent sampling ratios measured in the field were predominantly too low. It is believed that this was due to inadequate protection against debris.

While field testing was going on, an alternative came into mind to using tubes, which would facilitate the design process, produce a single sampling ratio for both submerged and unsubmerged conditions at high flow rates, and decrease the deviation of the sampling ratio at lower flow rates. Each tube was replaced with an orifice cut in the horizontal plate and a ring-shaped weir, which had a diameter much larger than that of the orifice. The weir was placed around the orifice to control the discharge elevation during unsubmerged flow. A test model was made with a sampling orifice diameter of 0.25 inch, a weir around it of 1.0 inch diameter and 2.0 inch height, a main flow orifice diameter of 2.5 inches, and a weir with a diameter of 4.0 inches and a height of 2.0 inches. Unsubmerged tests were run on it with the results showing a decrease in the deviation of the sampling ratio in that it only reached 1.55 percent at 3.7 gallons per minute. An attempt was made to model the sampling ratio using the standard orifice and weir equations but it was necessary to change the weir equation in order to fit the test data. The resulting model was used to get an idea of what would happen if the capacity and the sampling ratio were changed. In submerged tests, the sampling ratio above four gallons per minute tested out at 1.01 percent rather than the predicted value of 0.99 percent. The difference, although statistically significant at the .05 level, was small. Below four gallons per minute, the sampling ratio decreased from 1.01 percent at four gallons per minute to 0.5 percent at 0.5 gallons per minute. An inherent resistance in the sample collection bag was believed to be responsible for this effect. At the flow rates where the sampling ratio was affected, the head differential for sampler operation was very small - small enough for any resistance that may be in the bag to make a significant difference in the head differential for the sampling orifice. This effect necessitates that the sampler be designed to make efficient use of the available head.

CONCLUSIONS

The test model using short tubes failed to hold a constant sampling ratio below thirty gallons per minute when unsubmerged, but did an adequate job when submerged.

In the field tests, where the sampler was submerged, the sampling tube clogged with debris that may well have entered the sampler through the main flow tube during dry weather. The main flow tube needed to have been protected against this by a screen.

The intake screen area of the samplers was much too small. Two screens with different size openings were used but it was not enough as too much floating debris lodged in too little screen, causing the samplers to be overtopped at least once. If the screen area had been doubled, the head loss through the screens would have been reduced by at least three-fourths.

The polyethelene bags seemed to be adequate for collecting the samples in that they were highly flexible and could hold a reasonable amount of water but they needed to be protected from sunlight, wind, and mice.

There was some loss of suspended solids that the sampler causes to settle out on its upstream side due to settling because of reduced velocity, but the solids that pass on downstream from the sampler were accurately sampled. The water soluble pollutants were not affected.

Since the sampler operated in a submerged manner, no available head was wasted in freeboard as would have been the case with other proportional samplers.

There was a small amount of resistance in the plastic bag at low flow rates. For the test model using orifices, flow rates had to be below four gallons per minute for the sampling ratio to be affected. This effect can be minimized by designing the sampler to use as much of the available head as possible, and by using a very flexible bag material.

SUGGESTIONS FOR FURTHER STUDY

It is felt that the unsubmerged behavior of the sampler can be made to be proportional (to have the same sampling ratio at all flow rates). In order to do this, the ratio of the weir capacities of the two flow devices involved must be made equal to the ratio of their orifice capacities. The orifice design could be more easily modified to accomplish this than the short tube design.

The way to accomplish this, is to modify the weir rings as this is where weir flow occurs. Since the weir crest is the top edge of the ring, the ratio of the weir capacities is equal to the ratio of the circumferences of the two rings. One possiblity of course is to use as small a ring as possible around the sampling orifice and make the weir ring around the main flow orifice ninety-nine times the size of the small ring (for a one percent sampling ratio). The minimum diameter of the small ring is determined principally by the size of the sampling orifice. The size of the sampling orifice is determined by the size of the main flow orifice and the desired sampling ratio. The size of the main flow orifice, in turn, determined by the desired capacity and the available head. Also, the ring around the sampling orifice needs to have a diameter at least four times that of the sampling orifice to prevent a significant head loss due to pipe flow in the ring. In most cases, the inside diameter of this ring would range from one-half inch to one inch, depending on the sampling orifice size. This means that the other ring around the main flow orifice would have to be four to eight feet in diameter, which is much too large for practical use. However, if a small rectangular weir were cut in the top edge of the small tube and the tube were lengthened to accommodate the weir depth, the circumference of the large ring would only have to be ninety-nine times the crest length of the small weir. For a quarter-inch weir crest, the large ring would only be eight inches and not eight feet. Edge effects in the small weir will have a significant but unknown effect on the sampling ratio at low flow rates. However, the magnitude of this edge effect can be minimized by smoothing the sides of this weir.

A bag material needs to be found that would be more flexible than polyethylene and more resistant to sunlight, tolerant of wind, and in some way repellent to rodents. With such a material, the cost of protecting the bag from these could be eliminated. If it had greater flexibility, the accuracy of the sampler would be increased at low flow rates.

More study needs to be done on sample collection resistance to determine how the factors of bag material, bag thickness, and bag size affect this resistance. With this information a better job can be done in selecting a bag for a given sampler.

Guidelines need to be found concerning the design of the intake screens. It needs to be determined how much screen area is needed for a given watershed size. It also needs to be determined how different cropping practices affect the amount of screening needed. Also it should be determined if using multiple screens with different size screen openings decreases the total amount of material needed for screens in a given situation. In addition guide-lines are needed for setting the size of the screen openings. If this can be done, the design of installations for new situations can be simplified from the 'cut and try' method.

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PROPORTIONAL SAMPLER FOR MONITORING SURFACE RUNOFF

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ABSTRACT

The abatement of water pollution by runoff from agricultural sources will soon be legally mandated and the Environmental Protection Agency will be forced to use some type of scheme to carry out this mandate. It will be impractical to use the standard flume-recorder-sampler method to monitor the runoff from even a small proportion of the farms sited on waterways because of its high cost, low reliability, and high labor requirements. The alternative to monitoring runoff is strict land use control legislation which could have a devastating impact on the agricultural industry. What is needed is a cheaper, more reliable, and easier method of measuring runoff, The proportional sampler was designed with these objectives in mind.

Various other proportional samplers have been designed and built but were either too expensive or too limited in their application or both. Other possible designs were conceived, considered, and dropped until one was arrived at that looked good enough to try out in the laboratory. This design consisted of two short tubes set in a horizontal plate and raised to the same height above the plate. The inside diameter of one tube was 0.25 inches and the inside diameter of the other tube was 2.5 inches. Water entered the tubes at the bottom and the flow from the small tube was collected in a plastic bag for later measurement and analysis. Because of the flexibility of the plastic bag, the sampler is able to operate when the tubes are completely underwater. In fact, laboratory tests indicated that the only time that the sampler was accurate was when the sampler was submerged. Consequently, the samplers, built for field tests, were designed so that they became submerged as soon after runoff started as possible.

The field tests, conducted at Pratt, Kansas, had a proportional sampler and a flume-recorder-sampler arrangement on each of five plots. Both devices were used to measure the same runoff flows, with the flume-recorder-sampler method used as the standard. The results of the field tests showed that the proportional samplers were not working as expected and that they were becoming clogged with debris because of inadequate screening.

While field testing was going on, the basic design was revised to facilitate the design process for future samplers, to simplify manufacture, and to improve the unsubmerged behavior of the device. Instead of a tube, an orifice was cut in the horizontal plate and a ring-shaped weir of much larger diameter was placed around it. A test model was built and submerged and unsubmerged tests were run. The unsubmerged tests verified that the unsubmerged behavior was improved. In the submerged tests, the predicted sampling ratio was confirmed except at the lowest flow rates where the sampling ratio was decreased due to an inherent resistance in the plastic bag. This effect necessitates that the sampler be designed to use as much of the available head as possible.