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MONITORING SUBSURFACE DRAINAGE FLOW AT REMOTE LOCATIONS

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ABSTRACT. *Laboratory evaluations and field results are presented for a slotted weir used to measure discharge from subsurface drains. The head–discharge curve for the vertical slot is a simple power function with an exponent of 1.5. There was excellent agreement ($r^2 > 0.99$ and 1:1 slope) between predicted and observed discharge in laboratory testing of 12 test weirs representing five slot widths. The primary advantages of the vertical slot weir are its simplicity, ease of maintenance, and ability to measure small flow rates. Disadvantages include a tendency for the slot to close a small amount over time as a result of creep when using a PVC pipe and the possibility for material to become clogged in the slot. The use of a spacer in the slot eliminated the tendency for the slot to close.*

Keywords. *Weir, Discharge, Drainage.*

A study of poultry litter application on poorly drained soils was initiated in western Kentucky in 1998. The chosen sites for the study were remote with no utilities. Since one of the key aspects of the project was the measurement of drainage flows from the area, a variety of discharge measurement techniques were investigated. Although subsurface drainage flows have been measured in a wide variety of studies, the methodologies were generally not appropriate to the conditions at this particular site.

Kanwar et al. (1999) have described the common methodologies to monitor drain discharges. The methods can be categorized as 1) weirs or flumes, 2) sump pumps with flow meters, and 3) tipping buckets. In our study, sufficient fall was not available to place a tipping bucket under the drain and also allow water to flow by gravity away from the measurement station. Electricity was not available which eliminated the sump pump method.

Schwab and Theil (1963) used 30–degree V–notch weirs to measure drain discharge in a long–term study in Ohio. Bolton et al. (1970) used a device to measure flow that consisted of a plate with small circular orifices positioned such that flow was proportional to head. Witherspoon and Hore (1957) used a Rettger proportional weir to measure flows. Grant (1992) described a variety of special weir shapes in addition to various V–notch weirs.

As a result of the limited area being drained and volume of drain discharge, the flow characteristics of a vertical slot for use as a flow–measuring device was studied. Laboratory tests of the devices, proposed design, and some sample observations are presented.

METHODOLOGY

SYSTEM DESCRIPTION

The measurement system is contained in a vertical housing constructed of 0.305–m (12–in.) diameter double wall corrugated PVC pipe with an end cap (fig. 1). The length of the section depends on the depth of the drain line to be monitored. A 102–mm (4–in.) diameter hole was cut approximately 102 mm (4 in.) from one end of the pipe. An outlet pipe consisting of a 102–mm (4–in.) Schedule 40 PVC pipe was placed through the hole. A 90–degree elbow was glued to the end of the outlet pipe inside the 0.305–m (12–in.) double wall pipe. The vertical housing/outlet pipe combination was positioned vertically in a 0.5– × 0.5– × 0.3–m (20– × 20– × 12–in.) high concrete form. A 76–mm (3–in.) gap between the end of the 0.305–m (12–in.) vertical housing and the bottom of the concrete form allowed concrete to fill around and into the vertical housing. Approximately 76 mm (3 in.) of the vertical section of the 90–degree elbow was showing above the concrete.

A steel rod was placed through two 40–mm (1.5–in.) diameter holes located near the top of the vertical housing and used with a chain to lift the housing for loading and installing the unit. After installation, these holes were plugged to inhibit wildlife and insects from entering the unit.

A 0.305–m (12–in.) long slot was machined near one end of a 102–mm (4–in.) schedule 40 PVC pipe for use as a vertical riser (slot widths are presented in table 1). The vertical riser was chamfered on the weir end (bottom) and a groove was machined around the periphery. An O–ring was inserted in the groove helping to assure there was no leakage between the vertical riser and elbow at the base of the housing. A mounting bracket was attached to the vertical

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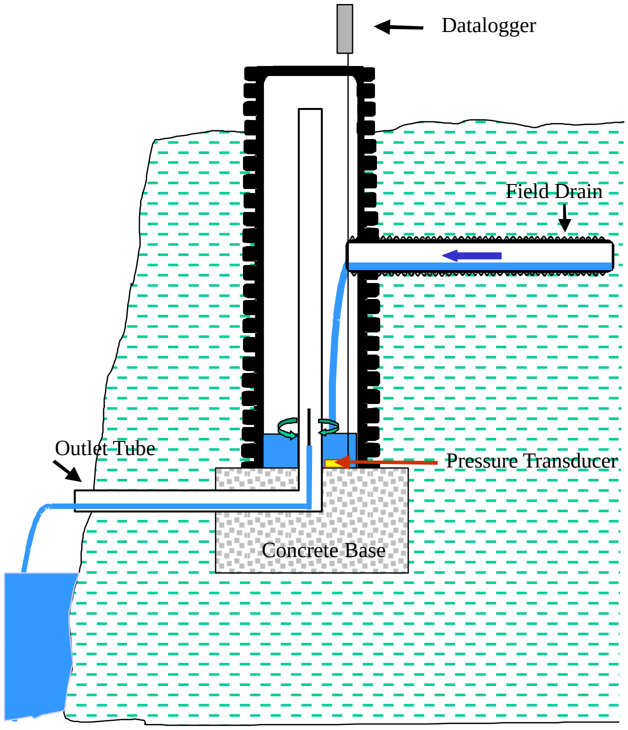

Figure 1. Schematic of the flow monitoring system. Flow enters the system through the field drain. Water is contained in the vertical riser, exits through the slotted weir, and is discharged into the outlet tube. Some dimensions are exaggerated to indicate the process.

riser to hold a pressure transducer. On the opposite end from the machined slot, two 8–mm (5/16–in.) holes where drilled on opposing sides 25 mm (10 in.) from the top of the vertical riser. A metal rod was installed through the holes and secured using cotter pins. This rod formed a handle, which was useful for removing the vertical riser for maintenance.

During operation, water enters the vertical housing from the drain and exits through the slot in the vertical riser into the outlet pipe, which empties into the drainage ditch. Water levels in the housing are monitored with a pressure transducer and datalogger.

Laboratory Study

No available data existed on the characteristic equations to convert head of water to flow rate through the vertical slot at the base of the vertical riser. In the laboratory, a test stand was fabricated according to the procedures mentioned earlier with a vertical housing approximately 0.61 m (24 in.) tall. Replicate risers were constructed with slot widths of 1.6, 2.4, 3.2, 4.8, and 6.4 mm (1/16, 3/32, 1/8, 3/16, and 1/4 in.) (table 1). Water from a constant head tank was used to simulate drainage flow through the test stand. Incremental rates of water flow were added to the test stand and both water level (head) and flow rate were monitored. Flow rate was calculated by capturing a volume of flow in a bucket over a known time period. These data were plotted and equations were developed for each slot width.

Table 1. Inventory of slotted weirs tested in the laboratory.

Slot Width (mm)	No. of Tubes Tested	Discharge Rate	Observed vs. Predicted Discharge	r^2
1.6	2	$Q = 3.67H^{1.5}$	y = .996x	.991
2.4	2	$Q = 4.67H^{1.5}$	y = .989x	.973
3.2	3	$Q = 7.12H^{1.5}$	y = .998x	.996
4.8	3	$Q = 10.51H^{1.5}$	y = .997x	.997
6.4	2	$Q = 13.79H^{1.5}$	y = .999x	.998

Field Installation

Eleven flow measuring devices were fabricated and installed on drain lines near Madisonville, Kentucky. A backhoe was used to dig down to the drain tubing 3 to 4 m (9 to 12 ft) away from the drainage ditch. The base of the excavation site was leveled with gravel and the housing was lowered into place with the backhoe using a steel rod and chain. A 102–mm (4–in.) hole was cut in the vertical housing to allow the drain tubing from the field to be inserted. A trench was dug from the weir housing to the drainage ditch and a 4–m (12–ft) piece of non–perforated 102–mm (4–in.) diameter PVC pipe was connected to the outlet pipe.

A pressure transducer was attached to the 102–mm (4–in.) PVC using 19–mm (3/4–in.) stainless steel conduit hangers. The pressure transducer cable was attached to the wall of the riser using plastic ties. The assembly was inserted into the 90–degree outlet and seated using a rubber mallet. The datalogger for the pressure transducer was placed inside a NEMA4 enclosure fastened to a wooden post located 2 m (6 ft) from the weir unit. A 0.305–m (12–in.) lid was used to cover the weir housing.

Results and Discussion

Laboratory Tests

The five slot widths evaluated in the laboratory yielded distinct head versus discharge curves similar to the one shown in figure 2. Data from each tube were repeatable and fit the standard power curve:

$$Q = CH^{k} \tag{1}$$

where Q is the discharge rate (mL/s), H is the head above the bottom of the slot (cm), and C and k were coefficients. For the two tubes with a 1.6–mm (1/16–in.) slot width, the C values were 4.33 and 3.62 and the k values were 1.465 and 1.482. The data were combined for each slot width and an equivalent equation was obtained. To simplify the equations, the k value was set to 1.5 and only the C value was determined for each slot width (3.67 for the 1.6–mm tubes). The equivalent equations are presented in table 1. The observed discharge rates were compared to the discharge rates predicted with the equivalent equations (fig. 3).

Ideally, there should be a relationship between the C value and the slot width. The following relationship was found:

$$C = 2.2W \quad r^2 = 0.995 \tag{2}$$

where W is the slot width (mm) and C is the discharge coefficient.

Field Results

The slot weirs have been in place near Madisonville, Kentucky since 1998. The primary advantage of the weirs has been the ease of maintenance. Figure 4 presents discharge rates as measured with three of the slot weirs for a 10–day period in April of 1999. Similar results were obtained with all of the weirs at the study site. Drought conditions occurred

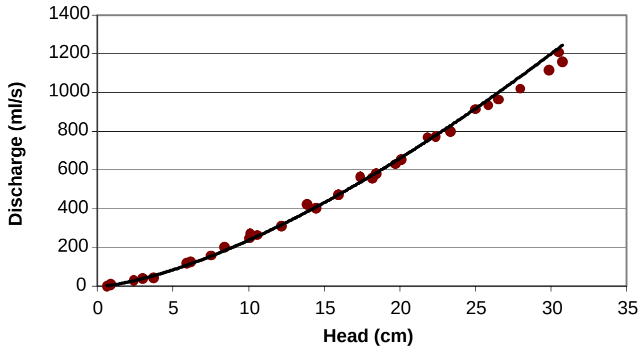

Figure 2. Discharge curve for the 3.2–mm slotted weirs. Data from three test weirs are shown.

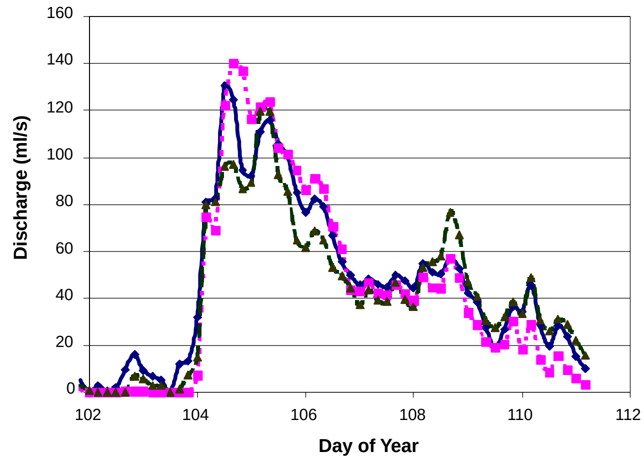

Figure 4. Plot of observed discharge measured with three of the slot weirs near Madisonville, Kentucky during April of 1999. Over days 103–106, 25 mm of rainfall was distributed. Approximately 2 mm of rainfall occurred on Day 109. The nearest rainfall station was located 60 km away from the site.

over much of the two–year period limiting the number of discharge events.

Rainfall [approximately 25 mm (1 in.)] occurred on days 103–105 of 1999. The nearest rainfall station, located 64 km (40 miles) from the site, indicated intermittent periods of rainfall over the three days. Prior to the event on day 103, discharge through the weirs was very low. The 25–mm (1–in.) event caused increased flow in the drainage system and a maximum discharge of 140 mL/s. Approximately 2.5 mm (0.1 in.) of rainfall occurred on day 109. Although no rainfall was measured at the gauging station on day 110, a small increase in discharge indicates that some localized rainfall may have occurred at the drainage measurement site.

The area under the discharge rate curve should have some correlation to the total rainfall over the drainage area of a drain tube. The drains were 213 m long (700 ft) with a drain spacing of 24.4 m (80 ft). If all of rainfall that fell over the drains was discharged, then approximately 52 m^3 of water could be expected to drain from the system assuming no direct runoff or soil water storage. The computed area under the drainage discharge curve was 36 m^3 of water. Based on the calculations, 70% of the rainfall was discharged through the drain system and 30% was probably added to soil water storage.

The slot weir system has worked well. However, during scheduled maintenance events in the spring of each year, shrimp–like crustaceans have been found in the 1.6–mm (1/8–in.) slot weir. These crustaceans were later identified as freshwater amphipods. The mechanism for their transport into the drainage system is uncertain. In future applications, a wider slot will be used which will allow the amphipods to pass through the system.

In addition, the slot deforms when a long slot is machined into a PVC pipe. Even though a Schedule 40 PVC pipe was used, the material did not maintain a precise slot width. The slot tends to narrow at the midpoint as a result of material creep. In the laboratory–tested tubes, the reduction in slot width was as much as 30% for the narrow slots (1.6 and 2.4 mm). For the larger slot widths, the slot was machined with a small 1–mm spacer left in place at the midpoint of the slot. The change in discharge caused by the spacer was not perceptible in the results. The reduction in slot width with the addition of the spacer was less than 5%. In most cases, the shorter slot length–spacer combination and a slightly wider slot width is recommended. The shorter slot length would provide more strength for the PVC riser and the change in width would allow higher flow through the system. A metal riser was not included in the study.

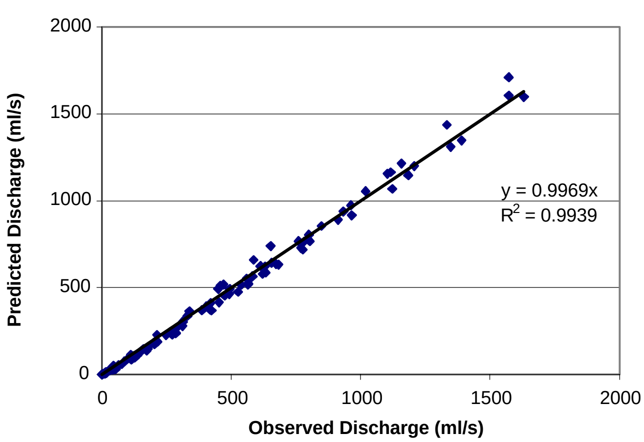

Figure 3. Plot of observed and predicted discharge for the 12 tubes used in the laboratory analysis (1.6–, 2.4–, 3.2–, 4.8–, and 6.4–mm slot widths)

Conclusions

A slotted weir has been developed and tested for continuously monitoring discharge from subsurface drains. The head–discharge relationship was found to follow a simple power equation with an exponent of 1.5. The discharge coefficient was related to the width of the slot allowing the user to quickly determine the head–discharge relationship for a wide range of slot widths. The primary advantages of the system are the ease of construction and the ability to remove the riser for maintenance. The system has worked well in the field. However, each year since the units were installed, quantities of amphipods entered the drainage system above the slot and were transported with the flowing water into the slot and became lodged. There is a small deformation with the slot width with time as a result of the material used. Machining the slot with a small spacer is recommended.

REFERENCES

Bolton, E. F., J. W. Aylesworth, and F. R. Hore. 1970. Nutrient losses through tile drains under three cropping systems and two fertility levels on a brookston clay soil. *Can. J. Soil Sci.* 50(2): 260–261.

Grant, D. M. 1992. *Isco Open Channel Flow Measurement Handbook*, 3rd Ed. Lincoln, Nebr.: Isco, Inc.

Kanwar, R. S., D. Bjornberg, and D. Baker. 1999. An automated system to monitor the quality and quantity of shallow groundwater in artificially drained agricultural fields. *J. Agr. Eng. Res.* 73(2): 123–129

Schwab, G. O., and T. J. Thiel. 1963. Hydrologic characteristics of tile and surface drainage systems with grass cover. *Transactions of the ASAE* 6(2): 89–92.

Witherspoon, D. F., and F. R. Hore. 1957. Design for a proportional weir for use in a flowmeter. *Agricultural Engineering* 38(12): 867.