CONTINUOUS FLOW MEASUREMENT FOR EVALUATING THE PERFORMANCE OF CONSTRUCTED WETLANDS

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INTRODUCTION

Current EPA regulations prohibit the direct discharge of agricultural wastewater, treated or otherwise, into public waterways. These regulations have forced animal producers to create zero-discharge wastewater systems employing land application. Wastewater effluent must be reused or applied to land. The amount of land required for land application of the waste is determined by the amount of the nutrients (nitrogen and phosphorous) present in the waste. Land application is an effective method of waste disposal; however, it requires capital and is labor intensive. Excessive land application of nitrogen and phosphorous can limit the application interval for the application area. To remain viable, animal production enterprises must have functional and sustainable waste management systems (Hunt et al. 1995). There is a perceived need for improvement in existing systems which would make them more efficient while lowering cost, labor, and land requirements.

There has been a great deal of interest in evaluating the use of constructed wetlands to improve wastewater quality and reduce wastewater quantity, minimizing the land required for disposal. Many studies have shown the effectiveness of free water surface constructed wetlands for removing nutrients such as nitrogen and phosphorous from wastewater (Richardson and Davis 1987; Gersberg 1983; Tanner et al. 1995; van Oostrom 1995; Cronk and Mitsch 1994; Gearheart et al. 1989; Cronk and Shirmohammadi 1994). The goal for constructed wetland treatment of animal wastewater is mass reduction of contaminants, reducing the amount of land area required for the application of contaminants to the land treatment site (Hunt et al. 1995). If a constructed wetland could be shown to reliably reduce nutrient mass, it could improve existing treatment systems.

The object of the project reported here was to develop and evaluate an inexpensive continuous flow measurement system used to monitor effluent flow from a free water surface constructed wetland. The impetus for the work was the belief that accurate computation of effluent mass transport (nutrient or water) required, at the least, continuous measurement of effluent water flow. Use of timed "grab" samples has been a common method to acquire flow rate data at the time of sampling. Estimates of total flow of water between sampling periods has typically been based on the assumption that mean flow rate during that period is approximately the mean of the 2 timed measurements that bracket it. Total flow is then computed as the product of the mean rate multiplied by the time interval between measurements. As will be seen below, the mean of 2 grab samples is not always a good indicator of mean flow rate between sampling dates.

MATERIALS AND METHODS

This research project was conducted at the Coastal Plains Branch Experiment Station of the Mississippi Agricultural and Forestry Experiment Station. Work on the project began during May 1995 and continued through September 1996. The Coastal Plains Branch Experiment Station maintains a dairy herd of 170 cows. Solid and liquid wastes from the milking parlor and loafing shed are flushed into a 0.44 ha primary lagoon. The primary lagoon receives approximately 26.5 m^3 of water per day. The primary lagoon empties into a 0.61 ha secondary lagoon.

During 1989, a system of constructed wetlands was added to augment existing treatment. The constructed wetland originally consisted of six parallel subsystems. Each subsystem was made up of a long (4.5 m x 30 m) wetland in series with a short (4.5 m x 15 m) wetland. Cell loading was from the secondary lagoon. Loading rate was regulated using orifices and the relatively static pressure head of the lagoon. The constructed wetlands were used from 1989 until 1993. They were inactive from 1993 until the beginning of the current study. During April and May of 1995, the system was reconditioned and modified. Each of the six long cells was planted with the emergent macrophyte maidencane (*Panicum hemitomon*). Four of the six short cells were also planted with maidencane, while the remaining two contained healthy stands of cattails (*Typha latifolia L.*). A marsh-pond-marsh design was utilized with the last 4.5 m of the long cells left open to elevate the dissolved oxygen concentration. In order to decrease the mass loading rates on the wetlands, the six parallel sets were re-plumbed to create two systems. Each of the two systems contained three sets of long and short cells in series, decreasing the hydraulic loading rates by one third to 1.71 cm day^{-1}.

During this project, flow rate was measured in two ways. Throughout the project, flow rate was measured via weekly "grab" samples, using a stopwatch, graduated cylinder, and a bucket. Measurements were taken at the influent and effluent end of the wetlands each time samples were collected. Beginning June 6, 1996, effluent flow rate was measured at 15 minute intervals using an automated measuring system. The system was designed by personnel from the Agricultural and Biological Engineering Department, Mississippi State University. It was modified, constructed, and tested by the present researchers. The measuring system is shown in Figure 1. Effluent flowed into a 154 liter plastic collection tub and exited via an aluminum weir secured into an opening cut in the side of the tub at an elevation of 22.86 cm. Baffles were placed in the tub to ensure a fully developed flow entering the weir. A galvanized steel housing provided protection from wind and rain. A Belfort stage recorder and a NEMA 4x enclosure were mounted on separate aluminum stands bolted to the bottom of the tub. A one kilo-ohm single-turn wire wound precision potentiometer was mated to the main shaft of the Belfort stage recorder. As the water depth (stage) in the tub varied, the Belfort float rose and fell accordingly.

The float movement rotated the main shaft which was attached to the one kilo-ohm potentiometer. The variable potentiometer produced an output voltage which varied with tub depth. The output voltage was sent to a circuit board (circuit diagram, Figure 2) designed to adjust output voltage range. A zero adjust pot set the low end of the voltage range corresponding to zero flow. A second pot set the upper end of the voltage range corresponding to maximum flow. A minimum of eight timed flow rates were used to calibrate the system. Equations relating voltage output to flow were then developed. Circuit board output voltages in the range of -2.5 V to +2.5 V were logged every fifteen minutes by a data logger (Campbell Scientific CR10).

The flow meters were calibrated weekly. First, flow into the tubs was halted. Adjustments to the low end zero adjust pot set the desired voltage output for zero flow. Flow into the tubs was resumed after the zero flow voltage was set. Flow rates into the tubs were controlled by swiveling the wetland effluent pipe to different heights. Flow rate for each effluent pipe elevation was determined using a timed "grab" sample. Tub effluent flow was allowed to stabilize for ten minutes once the desired flow rate into the tub was attained. The first flow rate used was above the expected range for the operating period. Additional flow rates were used during calibration at intervals through the expected operational range. Typically, eight to ten flow rates and corresponding voltages were used to establish a regression equation relating flow rate to voltage (Figure 3).

Measurements of effluent flow using the automated system were compared to measurements from the weekly "grab" samples. The difference between the automated measurement just prior to re-calibration and the grab sample provided an indication of system accuracy. Both grab sample and automated flow rates were used to compute total flow of water out of the system. Comparison of total flows based on the 2 methods were then used to shed light on the importance of continuous flow monitoring when computed total discharge from a constructed wetland.

RESULTS AND DISCUSSION

Table 1 represents the results of the accuracy checks which were made just prior to re-calibration. The percentages reported represent the difference between measurements from the automated systems and grab sample measurements made at the same time. As such, they are a good representation of the accuracy of the automated systems. Overall mean error for system 1 was approximately 11 percent. Mean error for system 2 was slightly less than 30 percent. Most of the latter error occurred during the initial weeks of operation. These errors were later reduced as the calibration procedure became more refined and initial problems with the second measuring system were addressed.

Figures 4, 5, and 6 illustrate three different sets of conditions which may exist when relying on grab samples to estimate total flow. The first of these (Figure 4) shows a case in which use of grab samples grossly exceeds the automated measurements. A relatively high flow rate at the beginning of the 8 day period and a relatively low rate at the end were measured using both methods. The automated measurements revealed that the rate declined precipitously early in the week. As a result, the total flow as computed using the automated system was much lower than the flow computed using the arithmetic mean of the grab samples (Table 2). Assuming a worse case error of 30% for the automated system (actual error was probably much less), use of the grab samples overestimated flow by almost 200%.

Under some conditions, use of grab samples may result in relatively accurate estimates of total flow. This will occur if changes in flow rate between grab samples is linear over time or, as illustrated in Figure 5, if a rain event compensates for a non-linear change. Much of the effect of the rain on effluent flow (everything between hours 120 and 150) was missed by the grab sample method. Yet the area under the grab sample curve is within about 14% of the area beneath the automated measurement curve (Table 2). The discrepancy is within the range of possible automated system error.

A third possibility is underestimate of total flow using grab samples. Figure 6 illustrates this possibility. Rain events inject relatively short term changes in the effluent flow rate of constructed wetlands. Use of grab samples to estimate total flow may either largely or totally miss the effect of these events, leading to underestimate of total flow. The data summarized in Figure 6, even assuming a worst case (30%) error in the automated system, shows that actual total flow was greatly in excess of that computed using grab samples alone.

As mentioned above, changes in flow rate that are essentially linear during the interval between samples will result in good estimates of total flow using the grab sample approach. Unfortunately, rain events can create highly non-linear changes in flow rate. Even temperature, wind velocity, and cloud cover can affect flow rate in a non-linear fashion by altering rates of evapotranspiration in the constructed wetlands. As a result, it appears that large potential errors are to be expected regularly in the use of grab samples to estimate total flow in constructed wetland research.

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Table 1. Percent error of the automated systems calculated using grab samples just prior to recalibration (error = discrepancy / grab sample rate).

Julian Date	System 1 (%)	System 2 (%)
226	2	94
234	24	56
241	15	15
248	12	6
255	16	0
262	4	2
269	4	30

Table 2. Total flow as calculated during 3 weeks using the automated measuring system and the arithmetic mean of two "grab" samples.

	Example 1	Example 2	Example 3
Automated System	7.4 m^3	31.7 m^3	29.7 m^3
"Grab" Sample Method	17.4 m^3	36.1 m^3	16.4 m^3

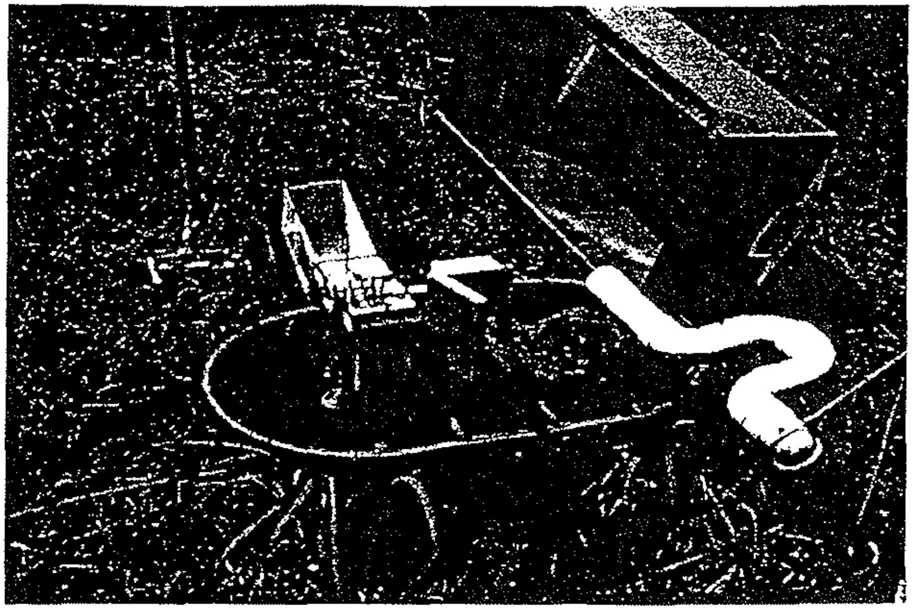

Figure 1. Automated Flow Measurement System and Effluent Flow Adjustment Swivel.

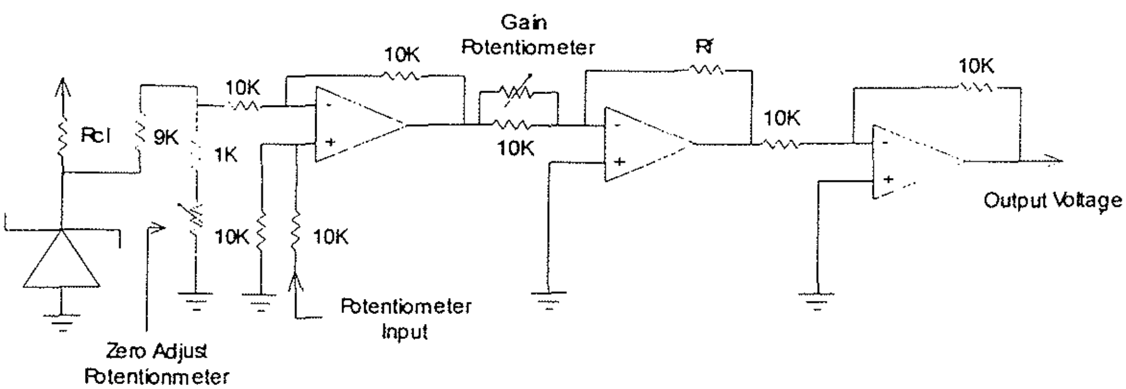

Figure 2. Circuit diagram for flow measurement circuit board.

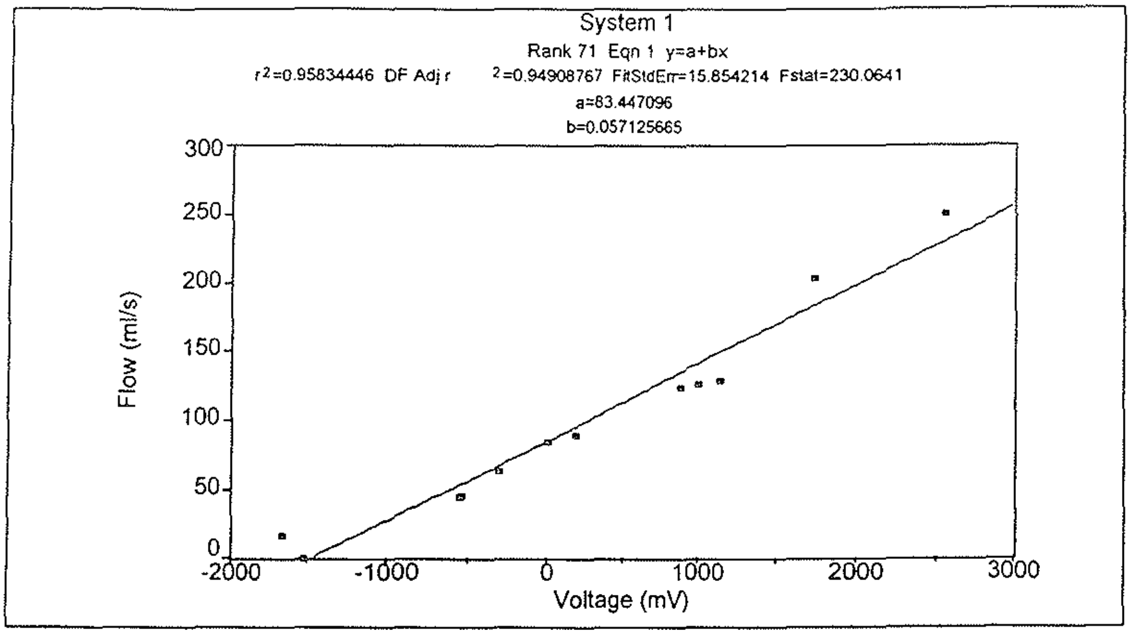

Figure 3. System 1 Calibration Curve (8/27/96).

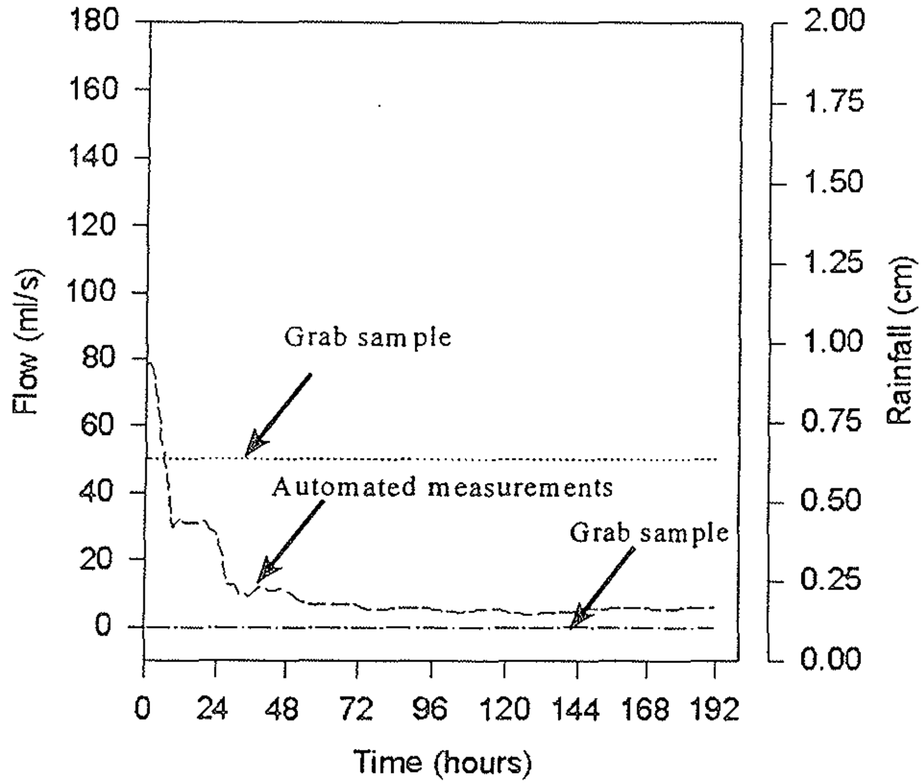

Figure 4. Record of flow rate measurements showing over-estimate of total flow using grab sampling method.

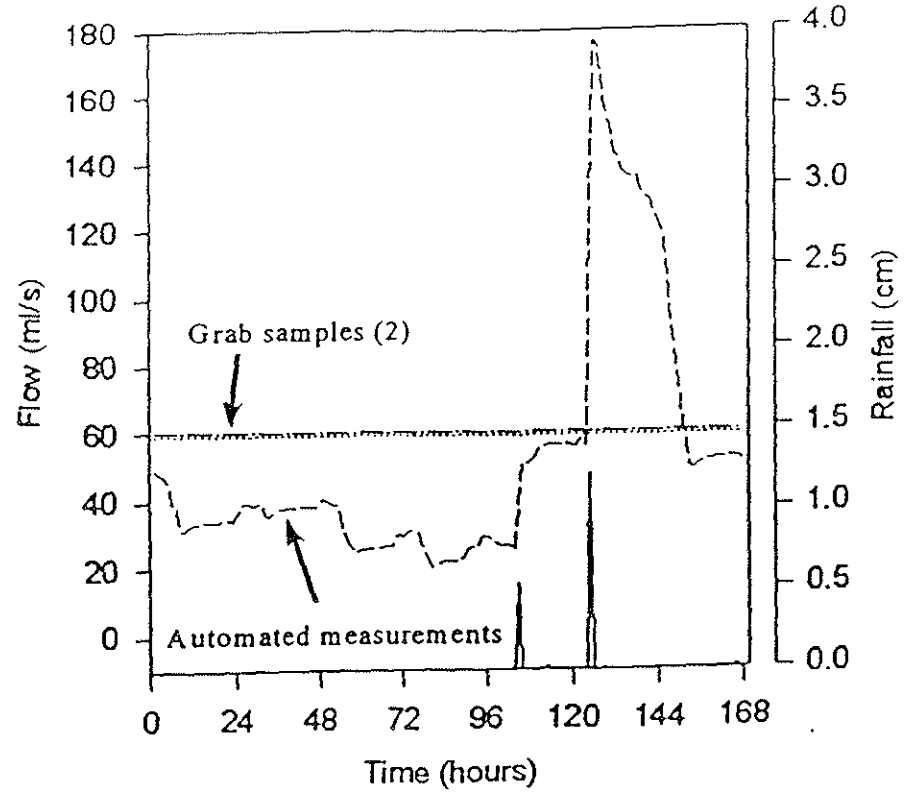

Figure 5. Record of flow rate measurements showing approximate equality of the 2 methods.

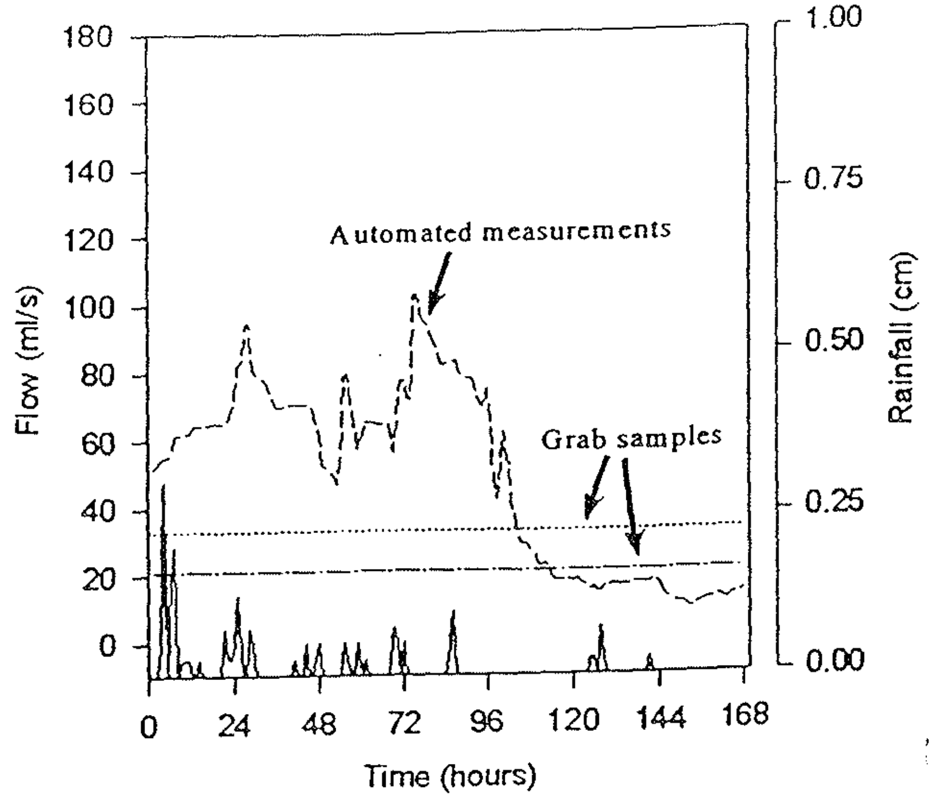

Figure 6. Record of flow rate measurements showing under-estimation of total flow using the grab sample method.