TECHNICAL NOTES:

ELECTRONIC VERSUS FLUID MULTIPLEXING IN RECORDING TENSIOMETER SYSTEMS

J. J. McDonnell

ABSTRACT. *Although several recording tensiometric systems have been developed and compared, few studies have applied this information to hillslope hydrologically oriented research, where large shifts in soil matric potential occur over short time intervals. A comparison is made between two recording tensiometric systems, in order to alert potential users to benefits/disadvantages of each system. Results show that for detailed hillslope rainfall-runoff research, electronically multiplexed systems are superior to fluid multiplexed systems, because individual tensiometers can be scanned, and data stored more easily, at much shorter time increments.* ***Keywords.*** *Hydrology, Tensiometer, Watersheds.*

While many electronic and recording tensiometer systems have been developed using stationary tensiometer-transducer systems (Watson, 1967), capacitance manometer systems (Thony and Vachaud, 1980), portable (Mullins et al., 1986) and stationary (Trooien et al., 1986; Hoover, 1987;1990) tensiometer-transducer systems, few recording systems have been designed to address the magnitude and direction of water movement over the entire hillslope scale.

In this situation, tensiometers must be deployed in sufficient numbers with adequate time resolution to assess soil matric potential (ψ) changes in response to precipitation. Burt (1978) described a fluid switch wafer system in which 22 tensiometers and two water references were multiplexed to a single pressure transducer connected to a chart recorder. Subsequent studies (Anderson and Burt, 1978; Ahuja and El-Swaify, 1979; Crabtree and Trudgill, 1985) used this technique for monitoring hillslope soil water movement.

The rationale behind the selection of fluid multiplexing systems in previous studies was based on the high cost of accurate pressure sensors. Recent developments in electronic data acquisition and inexpensive thermally stable pressure transducers (Dowd and Williams, 1989), however, provide additional possibilities for rapid response recording of multiple tensiometers. New electronic multiplexers are able to scan multiple tensiometers at rates in excess of solenoid stepper drives used in fluid switching techniques.

The objective of this article is to describe a new electronically multiplexed recording tensiometer system and compare its use to traditional fluid multiplexing techniques. The relative advantages and disadvantages of each are examined and related to such things as data resolution, ease of data logging, and sensor robustness. The study was motivated by a lack of available information on this subject for hillslope hydrologic research as part of a larger research initiative in humid watersheds (McDonnell, 1989). Product names hereafter mentioned are used to assist the reader and should not imply promotion or endorsement of any kind.

METHODS

Tensiometers were made from 20-mm OD Perspex pipe. Standard 100-kPa porous ceramic round-bottom neck top cups (Soil Moisture Equipment Corp., Santa Barbara, CA, Model 655X1-B1M1) were cemented to the pipes after the pipes had been cut to the desired length. Clamp assemblies (Soil Moisture Equipment Corp., Model 2326) coupled 4.7-mm OD nylon tubing to the pressure sensors. Both systems were controlled and recorded by a data acquisition and control system (DAC) (Campbell Scientific Inc., Logan, UT, Model 21X) using single-ended analog input, switched excitation, digital control port and continuous analog output functions in the logger. A 24 V DC supply was regulated to 12 V DC for all devices. This ensured a precise constant supply voltage to the transducers since the sensor output was directly related to voltage input.

PRESSURE SENSOR CHARACTERISTICS

Pressure sensors (Sensym Inc., Santa Barbara, CA, Model SCXl5DN 0-1.02 × 10s Pa) were used in the recording tensiometer systems. The SCXl5DN is a cost-effective temperature-compensated sensor with high accuracy over a wide temperature range. Temperature-induced offset shift calibrations were conducted for 37 sensors with measurements of the difference in output offset voltage at 35.5 ± 0.5° C and 3.0 ± 0.5° C, at an excitation voltage of 12 V DC. Absolute shift (and standard deviation) averaged 95 (86) µV, with maximum 300 µV shift recorded on a single sensor. Response time was rapid (±100 µs) with repeatability in the order of 0.2 to 0.5% of full scale output.

TENSIOMETER MULTIPLEXING

A multiplexer (Campbell Scientific Inc., Logan, UT, Model AM32) was used to link 30 tensiometers and two

Article was submitted for publication in February 1992; reviewed and approved for publication by the Soil and Water Div. of ASAE in November 1992.

The author is **Jeffrey J. McDonnell**, Watershed Science Unit, Dept. of Forest Resources, Utah State University, Logan.

water reference pressures to 32 SCX15DN sensor inputs, and then into one differential analog channel on the DAC (fig. 1). The system was configured so that all transducers were mounted on a single circuit board and housed in a waterproof container. Fluid lines connected the tensiometers with the remote circuit board. Power was supplied to the unit from a remote 24 V DC supply, regulated down to 12 V DC at the transducer box.

A fluid wafer switch (Scanivalve Inc., San Diego, CA Model W0602/1p-24T) and solenoid stepper drive (Model WS5-24) were used to timeshare 22 tensiometers and two water reference pressures to a single SCX15DN pressure sensor. In previous applications of this system (e.g., Burt, 1978), 555 (clock) timing circuits were used to activate a stepping relay output directly to a chart recorder. In this case, the system was reconfigured to link with the 21X micrologger for control of the stepper drive rate, drive initiation, and signal recording. In addition to more efficient data reduction, this system offered more flexibility in scanning rate and programming than used by Burt (1978).

Results and Discussion

Laboratory Calibrations

Laboratory calibrations of the electronically multiplexed recording tensiometer system were conducted to examine maximum tensiometer response time for data scanning. Three factors were tested in relation to tensiometer tubing effects on pressure response and attenuation downline: tube material, length, and diameter. An inexpensive, readily available non-toxic tubing (4.2 mm OD) was initially selected as a tubing to connect the tensiometer pipes to transducer ports. Lab tests showed, however, the flexible-walled tubing exhibited large pressure attenuation (in 15 m of tube) in response to 460-mm head changes (fig. 2). This concern led to a test of two rigid-walled nylon vacuum tubing configurations, 4.7 and 1.6 mm OD, in order to reduce these effects.

Both tube diameters were subjected to multiple increases and decreases in head by simply raising and lowering a water reference bottle. The DAC was used as a volt meter and recorded voltage output changes from the SCX15DN sensors. Figure 3 shows that although the 1.6-mm OD tubing displayed immediate response at varying lengths (and therefore no pressure attenuation), the relative voltage difference between the 15- and 1-m length increased with increasing head. The 4.7-mm OD tubing

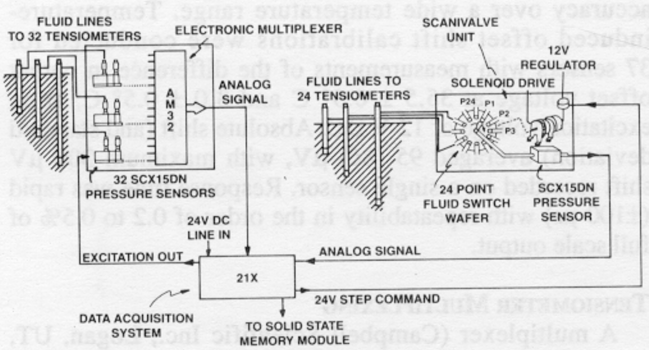

Figure 1–Schematic diagram of recording network.

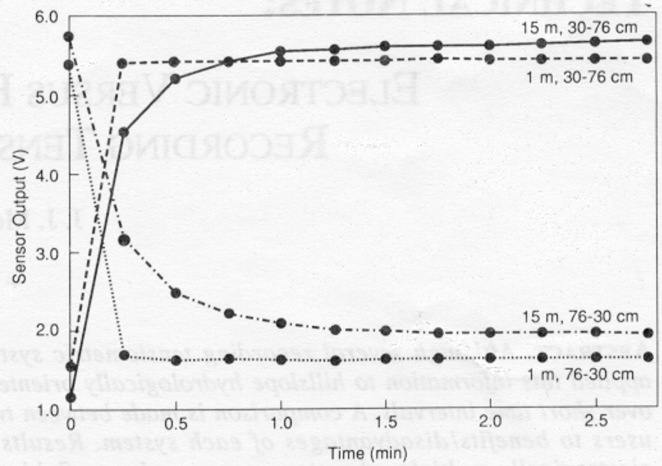

Figure 2–Effect of 460-mm head change on 1- and 15-m flexible tubing.

showed no pressure attenuation and low relative voltage change between 15- and 1-m lengths (fig. 3B). These data, combined with the potentially higher latent heat storage in the 4.7-mm OD tubing (i.e., in relation to possible freezing in winter months) led to the selection of the 4.7-mm OD nylon vacuum tubing for field experimentation.

Field Tests

Figure 4 shows the ψ response at one hillslope site monitored using the electronically multiplexed system. The

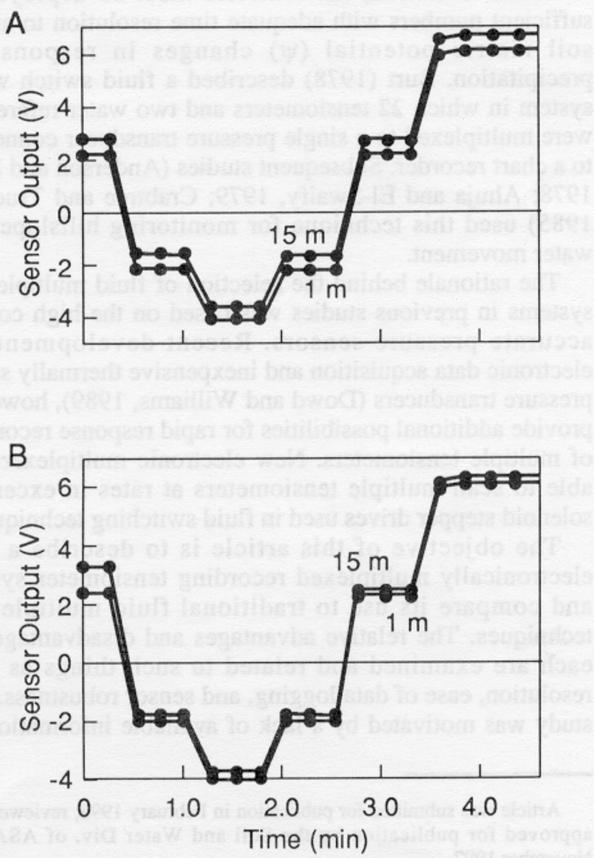

Figure 3–Effect of hydraulic head changes on pressure response through 1- and 15-m tubing for 1.6 (A) and 4.7 mm (B) diameters.

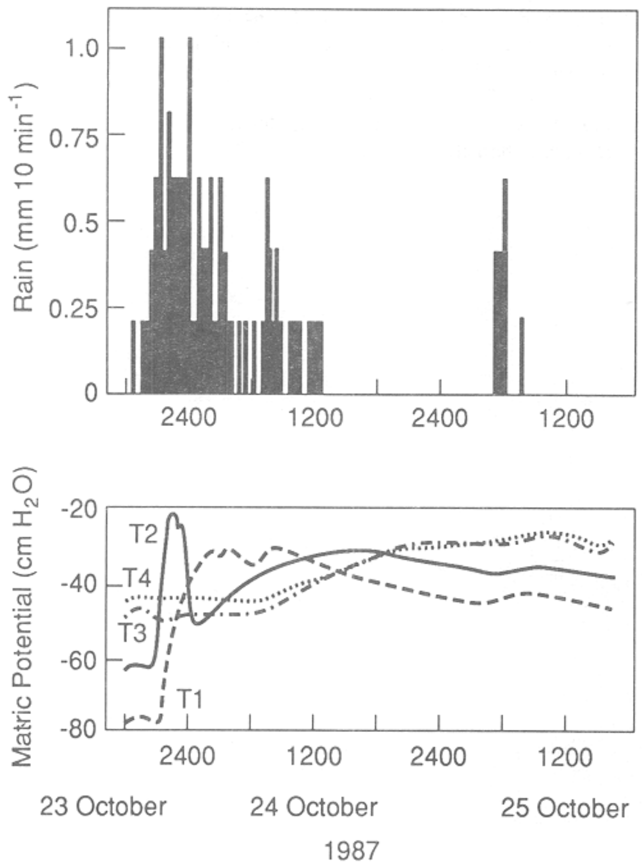

Figure 4–Tensiometric response to a natural rainstorm with ψ recorded via electronic multiplexing techniques.

shifts in ψ are rapid, and fluctuations at tensiometer T2 (370 mm below soil surface) and T1 (190 mm below soil surface) represent bypassing to depth via macropores [described by McDonnell (1990)]. The slower shift in the deeper sites T3 and T4 (760 and 1002 mm below soil surface, respectively) are representative of a matrix-driven wetting front, propagating down through the soil mass.

Direct comparisons between the two systems were not made for this event. Nevertheless, rapid response characteristics observed in this example would not be documented adequately using the technologically out dated fluid multiplexing system. The scan rate of the solenoid stepper drive would not allow such high temporal resolution of rapid ψ shifts. Because the Scanivalve switches the transducer to each tensiometer in turn, pressure fluctuations are caused in the system. Dowd and Williams (1989) note that the minimum time required for the system to stabilize with each tensiometer is about two minutes, meaning that each tensiometer is scanned about once an hour. Under rapidly changing soil water conditions, this would not allow proper documentation of dynamic hillslope hydrological processes as demonstrated by the rising and falling limb of tensiometer T2 in figure 4.

Summary

For hillslope applications where ψ is generally less than 200 cm tension, and $+\psi$ is encountered temporarily, both systems described above are highly applicable. The electronically multiplexed system is better than the Scanivalve technique because it allows:

1. Greater temporal resolution of scan frequency, where the air entry characteristic of the porous cup is the only limiting response factor.
2. Decreased likelihood of mechanical failure. The Scanivalve used in this experiment required regular maintenance of moving parts, whereas the AM32 multiplexer had no moving parts and was maintenance-free.
3. More efficient managing and processing of recorded data. Even though the Scanivalve was linked directly to the 21X, several separate programs were required to achieve the same data format as other instrumentation recorded through the micrologger.

Other advantages of the system components described in this article include:

4. Use of wire leads rather than fluid leads from the data logger to the tensiometer, which reduced the amount of tubing and resulting fluid heating and any related pressure change.
5. Use of rigid-walled tubing in fluid lines to eliminate pressure attenuation.

Acknowledgments. Walter Gallagher assisted on all aspects of electronic design and construction. Thanks go to Dr. M. Skalsh (University of Windsor) for loan of the Scanivalve unit, Dr. C. Trotter (NZ Ministry of Works) for calibration of sensors and Dr. R. Jackson (NZ Forest Research Center) for assistance with tensiometer tubing design. This research was funded by the NZ University Grants Committee, Commonwealth Scholarship and Fellowship Program, and American Geophysical Union Horton Research Grant. The research was supported by the Utah Agricultural Experiment Station as journal paper 4220.

References

Ahuja, L. R. and S.A. El-Swaify. 1979. Determining soil hydrologic characteristics on a remote forest watershed by continuous monitoring of soil-water pressures, rainfall and runoff. *J. Hydrol.* 44:135-147.

Anderson, M. G. and T. P. Burt. 1978. Toward a more detailed field monitoring of variable source area. *Water Resource Res.* 14:1123-1131.

Burt, T. P. 1978. An automatic fluid-scanning switch tensiometer system. *British Geomorphology Research Group Technical Publication* 21:1-30.

Crabtree, R. W. and S. T. Trudgill. 1985. Hillslope hydrogeochemistry and stream response on a wooded permeable bedrock: The role of stemflow. *J. Hydrol.* 80:161-178.

Dowd, J. F. and A. G. Williams. 1989. Calibration and use of pressure transducers in soil hydrology. *Hydrol. Proc.* 3:43-49.

Hoover, J. R. 1990. Seep and runoff detector design and performance to determine extent and duration of seep/runoff zone from precipitation on hillsides. *Transactions of the ASAE* 33(6):1843-1850.

————. 1987. Instrumentation system for determining watershed hydrology characteristics. *Transactions of the ASAE* 30(4):1051-1056.

McDonnell, J. J. 1990. A rationale for old water discharge through macropores in a steep, humid catchment. *Water Resource Res.* 26:2821-2832.

———. 1989. The age, origin and pathway of subsurface storm flow in a steep humid headwater catchment. Ph.D. thesis, University of Canterbury, Christchurch, New Zealand.

Mullins, C. E., O. T. Mandiringana, T. R. Nisbet and M. N. Aitken. 1986. The design, limitations and use of a portable tensiometer. *J. Soil Sci.* 37:691-700.

Thony, J. L. and G. Vachaud. 1980. Automatic measurement of soil-water pressure using a capacitance manometer. *J. Hydrol.* 46:189-196.

Trooien, T. P., A. R. Bender and J. H. Bischoff. 1986. The tensiometer: An alternative method of soil moisture measurement in slowly permeable soils. *Ground Water Monitoring Review* 6(2):99-105.

Watson, K. K. 1967. A recording field tensiometer with rapid response characteristics. *J. Hydrol.* 5:33-39.