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AN AUTOMATED PAN EVAPORATION SYSTEM

by

T. P. Harvey, C. R. Camp
Agricultural Engineers
and
E. J. Sadler
Soil Scientist

USDA-ARS, Coastal Plains Soil and Water
Conservation Research Center
Florence, SC

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SUMMARY: An automated pan evaporation (APE) system was designed to interface with an otherwise fully-automated weather station. The APE system can automatically measure evaporation from 2 evaporation pans and drain or fill pans to maintain water level within an optimum range. The system is controlled by a datalogger, programmed to record pressure transducer measurements and to control solenoid valves. Implementation of the system was successful after compensating for thermal effects.

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INTRODUCTION

Daily pan evaporation is measured at many U.S. Weather Bureau stations throughout the country. This network provides the most complete set of daily evaporation values for many regions and can be used in various methods for scheduling irrigation and in crop modeling (Sadler and Camp, 1986). The standard for measuring daily evaporation is the National Weather Service Class A evaporation pan with measurements made manually using a micrometer hook gage (U.S. Dept. of Comm., 1970). Pan evaporation is not routinely measured in most automated weather stations because an acceptable measurement system has not been developed and frequent maintainence is required to maintain the proper water level.

Phene and Campbell (1975) successfully automated the measurement of pan evaporation in an automatic, AC-powered weather station using a linear variable differential transformer (LVDT) and a float device. Experience with this system indicated that significant maintainence was required to prevent erratic readings caused by excessive friction between the float rod and LVDT core. McKinion and Trent (1984) developed an automated pan evaporation measurement system and evaluated two types of differential pressure transducers. These transducers were reported to be temperature-compensating but were calibrated for only a limited range of temperature (31.1-34.4°C). In practice, pressure transducers used in pan evaporation measurement systems must operate satifactorily for much larger temperature ranges. Burgess and Hanson (1981) developed a battery-operated pan-filling system for use in remote locations. Operational for up to six months, this system utilized DC-powered integrated circuitry to control the fill cycle, and a water-stage recorder to make water level measurements.

An automatic pan evaporation (APE) system designed for unattended operation must have the following components: (1) a device to measure the water level in the pan, (2) a device to fill the pan to some reference level, and (3) a device to drain the pan when rainfall occurs. The APE system described in this paper was designed to satisfy these requirements. The objective of this study was to develop a completely automated pan evaporation system that (1) maintained pan water level within an optimum range, (2) provided an electrical signal proportional to pan water level, (3) maintained accuracy over the annual temperature range, and (4) provided resolution sufficient for both daily and hourly measurements.

DESIGN

An automated weather station was implemented at the Coastal Plains Soil and Water Conservation Research Center in Florence, South Carolina, in 1984 (Sadler and Camp, 1984). The weather station measured and recorded nine parameters, some redundantly to assure accuracy or to compare sensors. All of these measurements were fully automated and logged at 30-min intervals using a Campbell CR7 datalogger[1]. The datalogger was connected by buried cable and short-haul modems to a microcomputer in the laboratory. The microcomputer interrogated the datalogger at midnight and transferred, processed, and stored all data. Processed data were printed and posted daily in the laboratory. Additionally, manual measurements of rainfall, pan evaporation, and maximum and minimum temperature were made to supplement data from the automatic station. Although it did not measure pan evaporation, the automated weather station was designed to accommodate an APE system when developed.

This APE system was designed for measuring and controlling the water level in both a standard pan and a screen-covered pan. This paper reports the implementation and evaluation of the standard pan only. Pan water level was measured with a differential pressure transducer, and water level measurements were controlled and stored by a datalogger. The pressure transducer was installed in an insulated box to reduce temperature variations and was located about equal distance from both pans in a position that would not interfere with fetch requirements for the pans (Fig. 1). The pan water level measurement was selected by switching a relay to energize the solenoid valve for that pan. Drain and fill operations were performed by an arrangement of solenoid valves located in insulated boxes adjacent to each pan and were energized via relay switches controlled by the datalogger.

CONSTRUCTION

A water column was maintained from the pans to the pressure transducer through 6 mm (1/4 in.) diameter copper tubing buried below the freeze line. A tee, needle valve, and standpipe were installed at the connection between the tubing and pressure transducer to allow purging of air from the system and to position an air-water interface in the tubing. A small volume of air was maintained within the pressure transducer to reduce transducer damage in case of freezing temperatures and to minimize errors caused by the meniscus effect. The air-water interface was positioned in a vertical section of uniform-diameter tubing which offered minimal resistance to movement of the meniscus. Air was purged from the system by opening the needle valve and forcing water through the tubing. The transducer was connected to the tubing with the valve open and with water flowing from the tubing and standpipe. This procedure limited the air volume to approximately the internal volume of the pressure transducer. With the needle valve closed, the position of the air-water interface was held nearly constant.

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[1] Mention of trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by the U.S. Dept. of Agr. and does not imply its approval to the exclusion of other products or vendors that may also be suitable.

The pressure transducer (Setra Model 239) measured the difference in pressure between the water column and the atmosphere. A tube filled with dessicant was attached to the pressure transducer reference port to reduce moisture entry. The pressure transducer was located about 130 mm (5 in.) below the top of the evaporation pans which allowed utilization of the full range of the transducer and minimized the danger of overpressuring.

The pressure transducer used was a variable capacitance device constructed of an insulated electrode and a stainless steel diaphragm. Transducer capacitance changed with pressure, providing a linear DC signal proportional to the pressure exerted by the water column. According to manufacturer literature, this transducer was designed to minimize zero shifts and sensitivity shifts caused by environmental temperature variations. Transducer specifications were 0.018%/ °C thermal effects, 0-1380 Pa (0-0.2 psid) pressure range, 0-5 V output, 0.02% repeatability, and 0.14% FS accuracy at constant temperature.

At each evaporation pan, the measurement tubing was connected to a solenoid valve located inside an insulated box. Water in each pan was connected to the pressure transducer by energizing solenoid valve #3 (Fig. 2) for the pan selected. With only one pan automated, solenoid #3 remained energized continuously. The measurement tubing was connected to a bulkhead fitting in the side of each evaporation pan. Inside the pan, tubing extended from the bulkhead fitting through the side of a stilling well and terminated near its center. The stilling well reduced measurement error caused by water surface flucuations.

The drain/fill system consisted of 13-mm (1/2 in.) diameter copper tubing connecting each pan to solenoid valves that provided both drain and fill capabilities. A pressurized water supply provided water for the fill cycle. Solenoid valves for draining and filling the pans were closed when not energized. The fill cycle was initiated when solenoid #1 was energized, and the drain cycle was initiated when solenoid #2 was energized (Fig. 2). Water was supplied to and drained from each pan through tubing connected to a bulkhead fitting in the sides of the pans. Inside the pan, a copper screen was connected to the bulkhead fitting to prevent debris from entering and plugging solenoid valves during the drain cycle.

A 24-VAC transformer controlled by relay switches provided power for the solenoid valves. Excitation voltage (24 VDC) for the pressure transducer was provided by a regulated power supply. These components and the datalogger were located in an instrumentation box at the weather station primary mast (Fig. 1). Cables for power, control, and measurement were buried in conduit and connected the instrumentation enclosure to the solenoid boxes at each pan. Power (120 VAC) was also supplied to operate heat sources at the insulated boxes. A heat supply at each pan and at the transducer prevented damage to components during freezing weather. Measurement cables were located in a separate conduit to reduce electrical noise caused by AC power.

OPERATION

During evaluation of the APE system, a Campbell CR21X datalogger was used to record data and control the system rather than the CR7 datalogger. This allowed evaluation of the APE system without interference with normal operation of the weather station. The datalogger controlled frequency of measurements and operated relays for controlling the solenoid valves to drain or fill the pan. Pan water level measurements were made, and a weighted average was calculated every minute, and this average was stored every 30 minutes.

The datalogger was programmed to maintain the pan water level within an optimum control range [50 mm ± 25 mm (2 in ± 1 in.)] below the top of the pan (U.S. Dept. of Comm., 1970). The time chosen to increase pan water level was 0400. Interruption at this time introduced minimal error because the evaporation rate was negligible. The datalogger checked pan water level at 0400 each day to determine whether the water level was within the control range. If the pan water level had dropped to a level > 75 mm (3 in.) below the top of the pan, the datalogger switched a relay energizing solenoid #1 (Fig. 2). The datalogger monitored the pan water level during the filling operation. When the water level reached the upper limit of the range (25 mm below top of pan), a relay switched the solenoid off and filling ceased. The pan was filled to 25 mm (1 in.) above the optimum level in order to limit the filling frequency to once each week. Pan water level measurements made during the fill cycle were not stored.

The drain operation occurred whenever necessary, regardless of the time of day, to prevent pan overflow during heavy rainfall. When the pan water level was < 25 mm (1 in.) from the top of the pan, the datalogger initiated the drain cycle by switching a relay which energized solenoid #2 (Fig. 2). As in the fill cycle, the pan water level was monitored constantly by the datalogger. When the pan water level reached the optimum value (50 mm below top of pan), draining was terminated. As during the fill cycle, a relay controlled by the datalogger de-energized the solenoid valve to stop the drain cycle, and pan water level measurements during the cycle were not recorded.

After termination of either drain or fill cycles, the datalogger returned to normal operation, measuring and storing pan water level values. In addition, it measured and recorded the pressure transducer excitation voltage and temperature every 30 minutes. Excitation voltage was measured to insure that stable excitation was provided by the power supply. Temperature was measured with a copper-constantan thermocouple attached to the casing of the pressure transducer and was monitored in order to evaluate the effect of temperature on system performance.

EVALUATION OF PERFORMANCE

The manufacturer furnished a calibration for the pressure transducer over the full pressure range (1380 Pa) at 21 ± 3 ^{o}C. Using this calibration and the manufacturer's specification for thermal effects, 0.018% FS/ ^{o}C (0.01% FS/ ^{o}F), transducer sensitivity to temperature was calculated to be 0.025 mm water/ ^{o}C (.0006 in/ ^{o}F). To test the APE system for thermal effect, the pan was covered with polyethylene film and plywood to prevent any evaporation. Automated pressure and temperature measurements were made in the normal manner for a period of 4 days during which the temperature ranged from 0 to 18 $^{\circ}$C (32-65 $^{\circ}$F). A regression analysis of transducer output and temperature resulted in an R^2 value of 0.85 and the equation

$$V = 2488.58 + 11.085*T$$

where
V is transducer output (mV), and
T is temperature ($^{\circ}$C).

A large thermal effect and the high correlation between temperature and pressure indicated the need for correction of the transducer output for temperature variations. The following equation was derived from the regression of pressure on temperature to provide this correction:

$$VC = V + ((25 - T)*11.085)$$

where
VC is transducer output (mV) corrected to a reference temp of 25°C,
V is measured transducer output (mV), and
T is temperature ($^{\circ}$C).

The APE system was calibrated in the field using a micrometer hook gage. After filling the evaporation pan to the upper limit of the hook gage, the water level was decreased in increments of approximately 10 mm for the full range of the hook gage (64 mm). Multiple hook-gage measurements (7-9) were made at each water level, and pressure transducer measurements were also recorded by the datalogger at 3-s intervals for a period of 75 s. Mean pressure transducer values were corrected for temperature and compared to the mean hook-gage values at each water level. A regression analysis between transducer and hook-gage means resulted in an R^2 value of 1.00000 (Fig. 4) and the equation

$$V= 671.66 + 35.047*H \qquad [3$$

where
V is transducer output (mV), and
H is hook-gage measurement (mm).

Rearranging this relationship allows the expression of water level as a function of transducer output, which can be used as a calibration equation.

Using this system calibration (mV/mm) and the slope of the temperature correction equation ($^{\circ}$C/mV), the thermal effect for the APE system was calculated as 0.32 mm/ $^{\circ}$C (.007 in/ $^{\circ}$F) or about ten times the manufacturer's specification for the pressure transducer alone. Further laboratory testing will be necessary to ascertain whether the thermal sensitivity is within specifications. In the field, factors such as expansion and contraction of copper tubing and entrapped air probably contributed to this thermal effect.

Corrected and uncorrected transducer outputs and transducer temperature are illustrated in Figure 3 for 30-min intervals over a 24-h period. Uncorrected measurements show a strong positive effect of temperature: 3.5-mm increase water level for 12^{o} C increase in temperature. After correction using Eq.[2], the water level measurements remained nearly unchanged by temperature.

Manual readings with a micrometer hook gage were also made daily to compare daily pan evaporation amounts with those measured by the APE system (Fig. 5). Manual hook-gage measurements were made at 0700 each morning, and daily evaporation rates were calculated for the period of November 3-10. During the same time period, pressure transducer measurements at 0700 were also used to calculate daily evaporation. Data consisted of five values: four consecutive daily values, and a mean daily value for a weekend. A mean daily value was calculated because manual measurements were unavailable on the weekend. Regression analysis of these data resulted in a linear relationship described by

$$D = 0.10 + 0.89*H \qquad [4$$

where

D is transducer daily evaporation (mm) and
H is hook-gage daily evaporation (mm).

This analysis resulted in an R^2 value of 0.87. The intercept and slope for this relationship are slightly different from that of the ideal 1:1 relationship. However, the standard error associated with the intercept was about four times the deviation from the expected value, indicating that the intercept is probably not different from zero. Likewise, the standard error associated with the slope was double the deviation from the expected slope indicating that the slope is probably not different from 1.0. Additional data will be required to conclusively determine the accuracy of the automated system for daily evaporation measurements.

The drain and fill control logic performed in an acceptable manner. The water supply provided a flow rate sufficient to fill the pan from the lower limit to the upper limit in less than a minute. This allowed the fill cycle to be completed without interrupting the water level measurements made every minute by the datalogger. However, the solenoid valve that currently controls the drain cycle does not have a sufficient water flow rate at low hydraulic head to allow the drain cycle to be completed without a significant loss of data. A low-cost solenoid for low-head conditions has not yet been identified. A motorized ball valve would probably provide an adequate flow rate at this low head, but is moderately expensive.

SUMMMARY & CONCLUSIONS

The automated pan evaporation (APE) system was designed to operate two evaporation pans in conjunction with a fully-automated weather station. This system was implemented for a standard Class A evaporation pan. It automatically measured and maintained pan water level within an optimum range. Measurements were made with a differential pressure transducer, and a weighted average was calculated every minute and stored every 30 minutes by a datalogger. The datalogger also controlled relay switches that activated solenoids for draining or filling the evaporation pans. The system was found to be sensitive to temperature changes, and a temperature correction equation was developed to correct for thermal effects over the range 0-18 °C. Evaluation over a greater temperature range will be made to develop a more precise correction and to ascertain whether the transducer sensitivity is within specifications. The system was field-calibrated using a micrometer hook gage, resulting in a calibration equation for pressure head (depth of water) as a function of transducer output in millivolts. A limited number of daily evaporation rates calculated from APE measurements were compared to daily evaporation as measured manually with a hook gage. The drain and fill control logic performed in an acceptable manner, but the drain solenoid did not provide sufficient flow to allow the drain cycle to be completed without considerable loss of data. A solenoid valve for low-head operation will be necessary to allow increased flow for the drain cycle.

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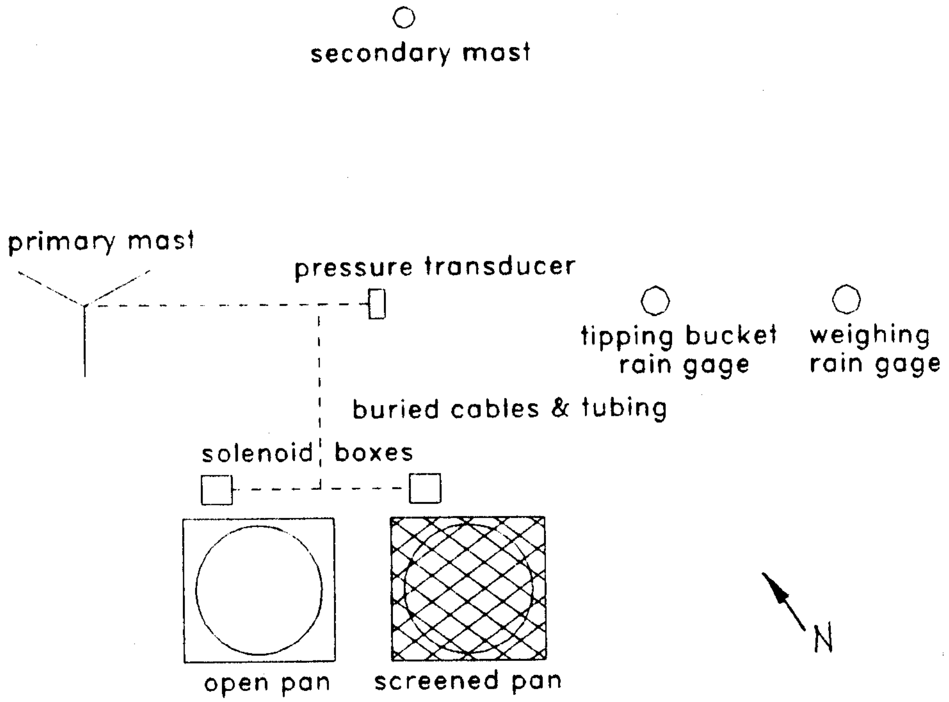

Fig. 1 Location of evaporation pans, pressure transducer, solenoid boxes, and interconnecting cables and tubing within automated weather station.

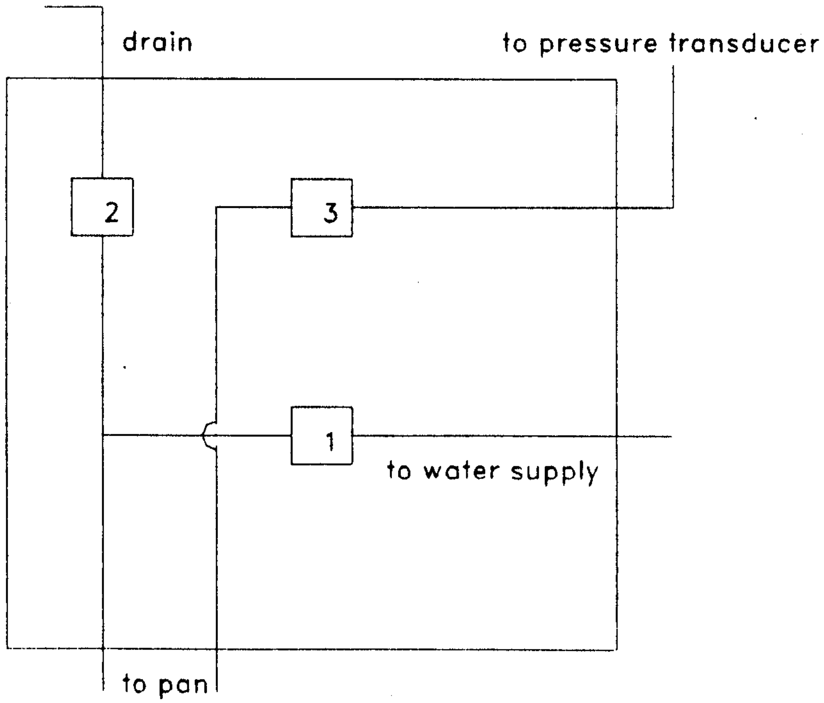

Fig. 2 Schematic diagram of solenoids controlling fill (1), drain (2), and water level measurement (3) located inside box adjacent to evaporation pans.

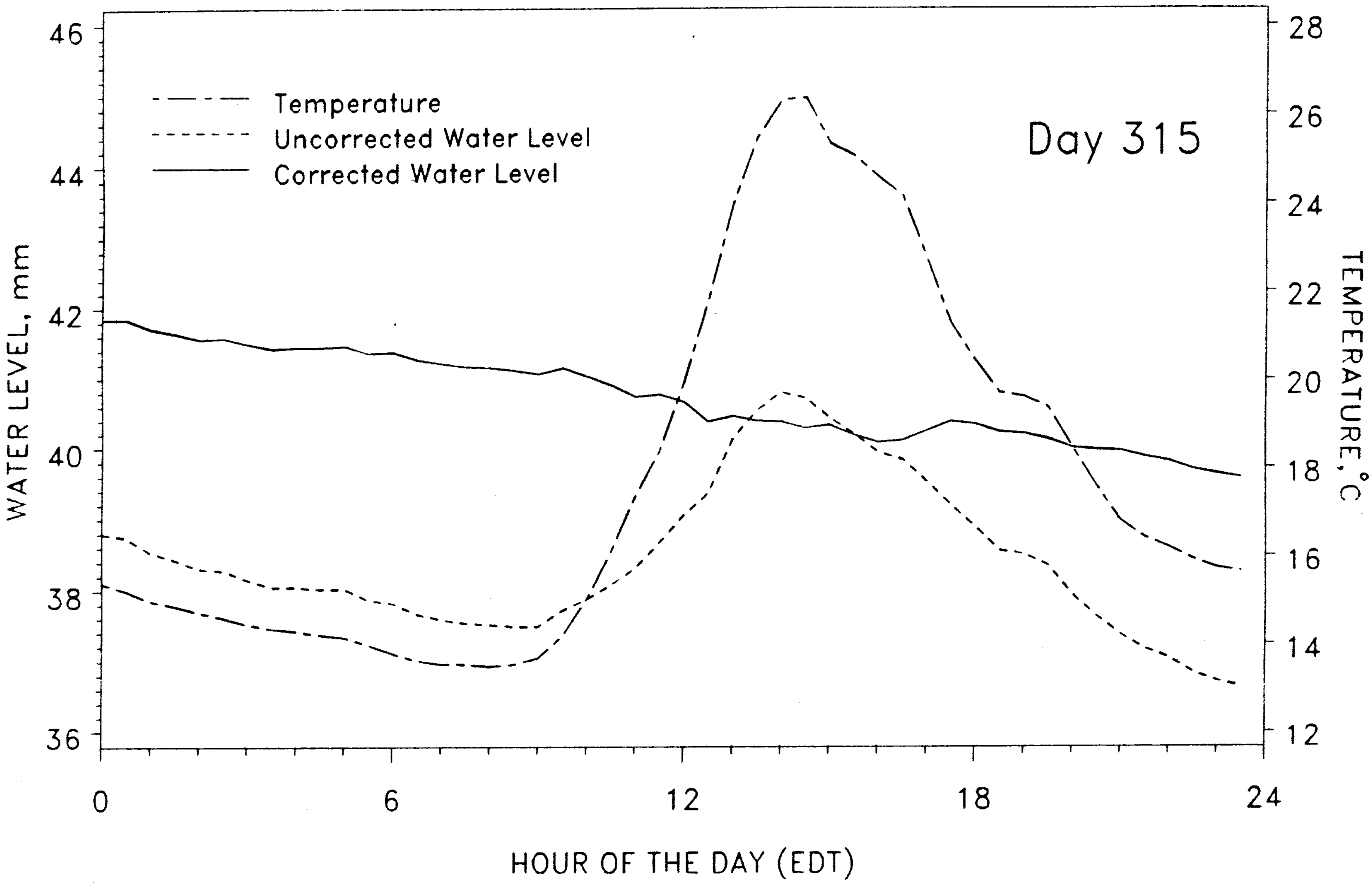

Fig. 3 Temperature and evaporation pan water level measurements, both before and after correction for temperature, at 30-min. intervals for a 24-h period (Nov. 11).

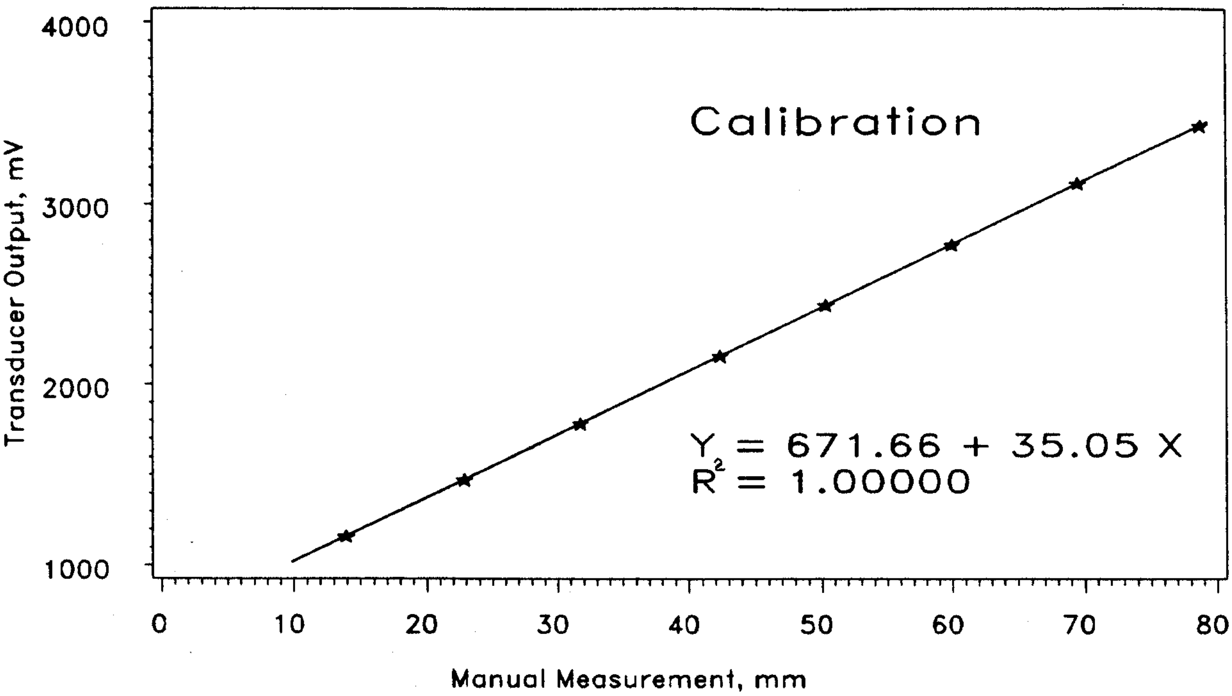

Fig. 4 Calibration curve for pan water level measurement system, indicating pressure transducer output (temperature corrected) in relation to manual measurements.

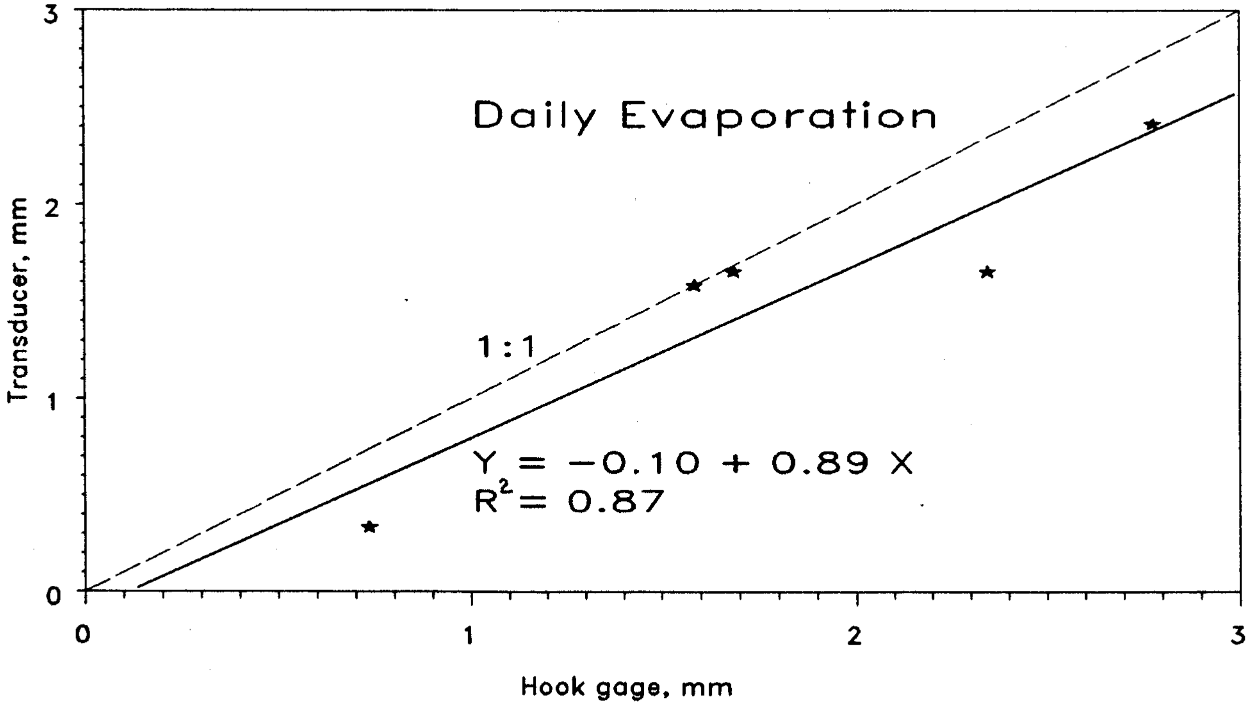

Fig. 5 Relationship between daily pan evaporation amounts as measured automatically with APE system and manually with a micrometer hook gage.