INDIRECT FLOW MEASURING DEVICES FOR AGRICULTURAL WATER USE DATA COLLECTION

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WEST PALM BEACH, FLORIDA 33402
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For Presentation
at the 12th International Higher Hydrological Course
Moscow State University; Moscow, USSR
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> "Among those treasures of our land is water - fast becoming our most valuable, most prized, most critical resource, a blessing where properly used . . ."
>
> Dwight D. Eisenhower

INTRODUCTION

In south Florida (Figure 1) water was, at one time, considered an inexhaustible resource (55 inches of rainfall per year) available for use in whatever quantities man desired. As the population increased, so did the demand for fresh water - not only for public water supplies (614.83 million gallons per day), but for rural domestic, livestock, industrial, irrigation, and thermoelectric purposes. Increased demands for fresh water have created a need to analyze the functions and uses of this vital resource. So, for better understanding, sound planning, management, and operation of regional water resource systems, a detailed account of the types of available supplies such as rainfall, surface and subsurface inflows and outflows, and the types of demand such as water used by natural vegetation, supplemental water withdrawals for irrigation of crops, and water used by municipalities, commerce and industry is required.

In south Florida information on water demand (especially the quantities of water being used by the agricultural sector) needs to be improved. Concerning agricultural needs, there are many demands: for supplemental crops, frost protection, nematode protection, etc. Irrigation water maintains high yield/high quality crops (citrus, vegetables, sugar cane) when there is insufficient or unpredictable rainfall during the crop growing season. Irrigation use, especially in the southern United States, has increased rapidly in recent years. in south Florida it is estimated that irrigation is the largest user of fresh water (in excess of 50% of the total) at present. South Florida is known as the winter vegetable capital of the world.

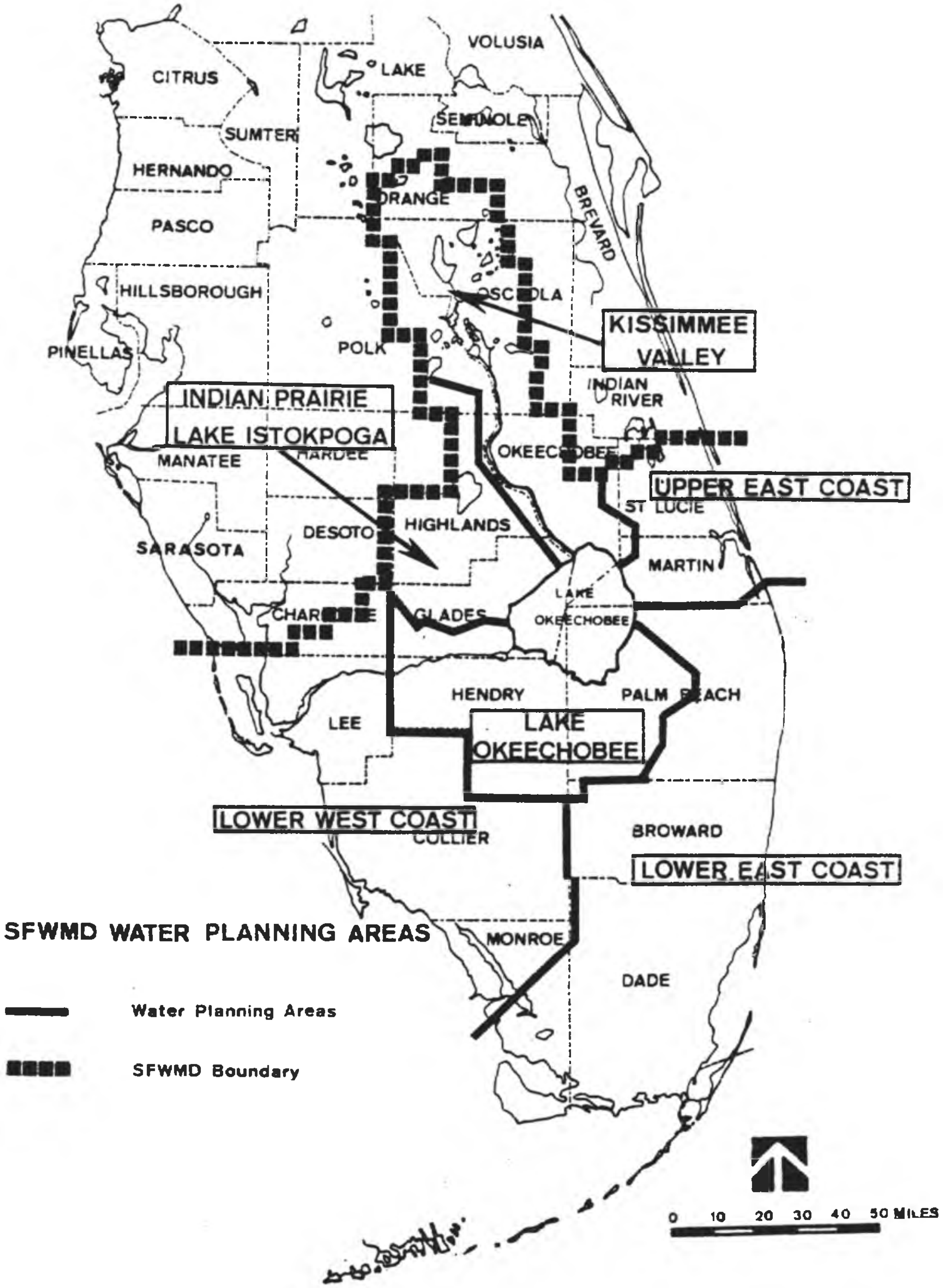


Figure 1. Water Planning Areas

This paper will describe the basic procedure used by the South Florida Water Management District in an attempt to improve the accuracy of agricultural water use data for sound planning, management, and operation of the system.

CONVERSION TABLE

Multiply inch-pound unit	By	To obtain metric (SI) unit
	Length	
inch (in)	25.4	millimeter (mm)
	.0254	meter (m)
foot (ft)	.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Volume	
gallon (gal)	3.785	liter (L)
	3.785×10^{-3}	cubic meter (m^3)
million gallons (Mgal)	3785	cubic meters (m^3)
	3.785×10^{-3}	cubic hectometers (hm^3)
	Flow	
cubic foot per second (ft^3/s)	28.32	liter per second (L/s)
	.02832	cubic meter per second (m^3/s)
gallon per minute (gal/min)	.06309	liter per second (L/s)
	6.309×10^{-15}	cubic meter per second (m^3/s)
million gallons per day (Mgal/d)	.04381	cubic meters per second (m^3/s)

MEASUREMENT OF IRRIGATION WATER

Measurement of irrigation water can be accomplished by use of both invasive and non-invasive methods.

Invasive Methods

On a limited basis surface water for irrigation use has been estimated by use of flumes, weirs, gated structures, etc. At present, acoustic, lazer, and electromagnetic flowmeters are being tested for surface water flow measurements. In south Florida, however, most of the water used for irrigation comes from groundwater. For measuring flow through these closed conduits, mechanical devices such as commercial flowmeters have been used by a few landowners. These commercial flowmeters are generally classified as to type of operation (i.e., displacement, velocity, or bypass). These meters record total volume making it unnecessary to compute volume from the observed discharge records. The greatest limitation of the many commercial volumetric meters, however, is their relatively high cost.

Even though landowners within the District area are required to submit pumpage records as one of the conditions for issuance of a District consumptive use permit, it is unrealistic to assume, based solely on economic reasons, that they will comply with this requirement. As stated earlier, the agricultural water use data base needs to be improved. It is this factor that led the District, in cooperation with the U. S. Geological Survey, to the investigation of indirect flow measuring devices (non-invasive type). This type of equipment can monitor liquid levels or flows without physical intrusion into a pipe, with new standards of reliability, ease of installation, and economy beyond that of any previous liquid measuring technique.

Non-Invasive Flowmeters

Ultrasonic flowmeters are non-invasive types of devices. They are a totally different type of flow measuring device designed to measure the amount of water passing through a pipe. The basis of operation of the non-invasive type of flowmeter is the Doppler effect, which is the apparent change in frequency of sound, light, or radio waves caused by motion. There are two basic types of non-invasive flowmeters: Doppler meters (Figure 2) and Transient type meters (Figure 3).

Doppler meters have one head (transducer) and require bubbles and sand in the flowing water. The transducer is mounted externally on the irrigation pipe (Figure 4). A transmitting crystal sends a continuous ultrasonic pulse into the water. When the transmitted frequency is reflected back to the transducer, from an air bubble or other particle, the frequency change will be proportional to the velocity of the moving object.

Theoretical Development of the Doppler Flowmeter

In Figure 5 is shown a transducer head on a pipe wall with the path of a single narrow ultrasonic beam through the pipe wall into the liquid.

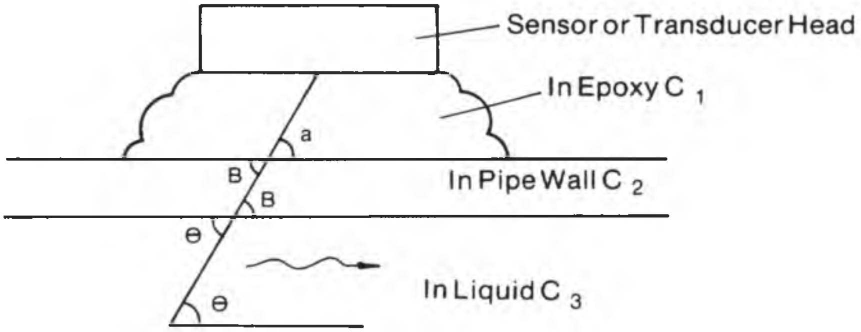


Figure 5. Transducer Head on a Pipe Wall

Let: C_3 = velocity of sound in the liquid

C_2 = velocity of sound in the pipe wall

C_1 = velocity of sound in the transducer head epoxy

Figure 2. Doppler Meter

Bestobell Doppler Flowmeter, Model No. P12
Manufactured by Bestobell Meterflow, Ltd.

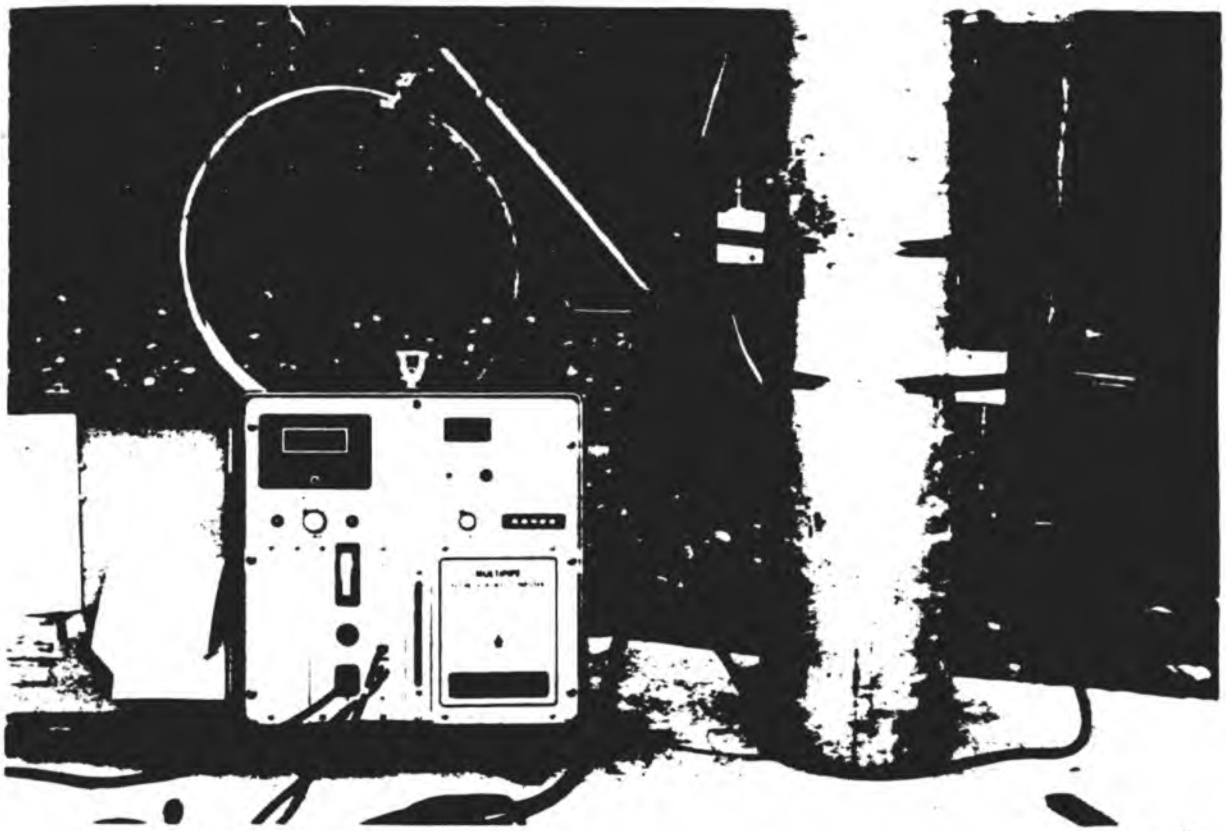


Figure 3. Transient-time Meter, 240 Series. Clampitron Flowmeter. Manufacturer - Controltron Corp., Hauppage, N. Y.

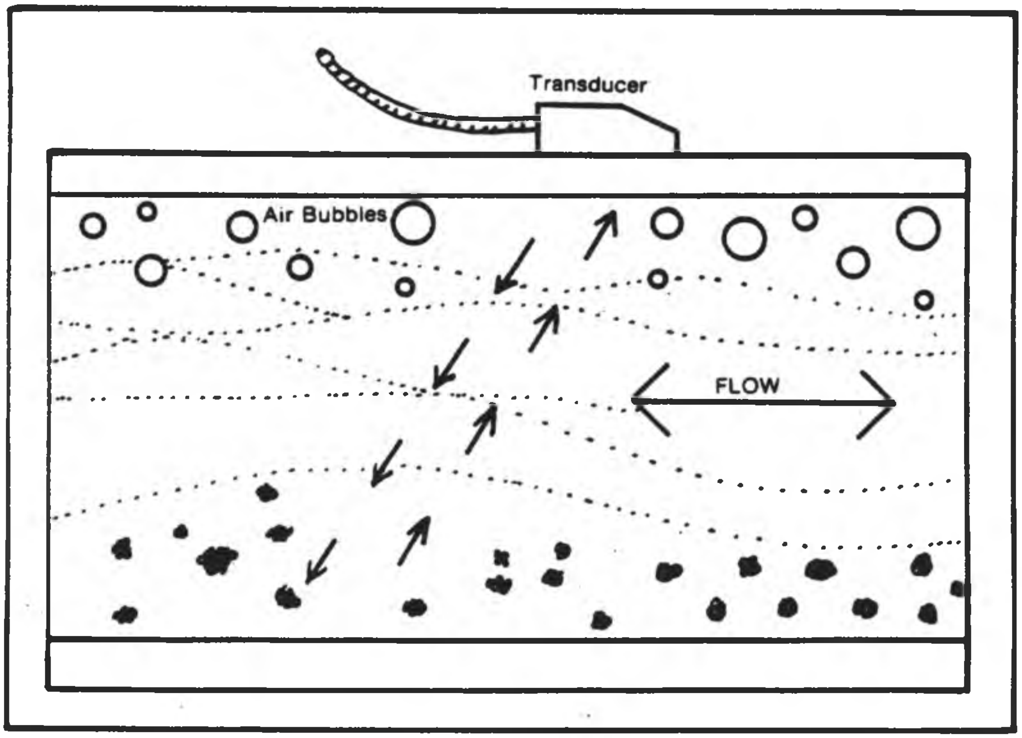


Figure 4. A Doppler Meter reflects frequency change in proportion to the velocity of moving objects.

Typically, C_3 in a liquid is 1500 m/sec; C_2 in PVC (Polyvinyl Chloride) is 2300, or in metals is 3000 m/sec; and C_1 in epoxy is 2000 m/sec.

Because the internal and external walls of the pipe are parallel to one another, the two angles β are equal. Because the low velocity, V, down the pipe is assumed to be parallel to the pipe walls, the two angles θ are also equal.

Using Snell's law of refraction one can relate α, β, and θ to the speed of the wave motion in the respective media. Snell's law concludes that the wave velocity (C) divided by the Cosine of the angles as labelled here, is constant for any given ray passing from one medium to another. Therefore, for the epoxy to pipe walls interface, $C_1/\text{Cos}\ \alpha = C_2/\text{Cos}\ \beta$. For the pipe wall to liquid interface, $C_2/\text{Cos}\ \beta = C_3/\text{Cos}\ \theta$. This is shown in Figure 5 where the term $C_3/\text{Cos}\ \theta$ can be seen equal to $C_1/\text{Cos}\ \alpha$. The flow speed formula can then be derived as follows:

$$V = \frac{(f_2 - f_1)}{f_1} \times \frac{C_1}{\text{Cos}\alpha} \times \frac{1}{2} \tag{1}$$

Now, the expression for flow velocity no longer contains liquid dependent variables, but contains C_1, the velocity of sound in the transducer head epoxy, and the consine of α which is set up in the manufacture of the head to be 60°. The flowmeter measurement on this basis should therefore be independent of manufacturing variables in the transducer.

The result of all this theory is important only in that it concludes that the flow velocity of a liquid can be measured by multiplying the Doppler frequency shift, $f_2 - f_1$, by various constants associated with the materials of manufacturers, the design of the transducer head, and the design of the electronics. Theoretically, the flowmeter can be seen to be independent of the liquid composition, temperature, and density of viscosity; however, practical trials, tests, and field experience to date have shown that the theory is not strictly correct. To a limited extent, the calibration is dependent on the liquid in the pipe. Practical tests have shown small variations in the different liquids; variations which are much smaller than the ratio of the respective speeds of sound, indicating that the refraction effects very nearly make the meter self-compensating.

Within a normal temperature range of ± 20°f, the change in output was found to be in the order of 1 to 2%.

Transient type flowmeters normally utilize two transducers mounted on opposite sides of the pipe (Figure 6). An ultasonic pulse is transmitted from transducer X to transducer Y at an angle of approximately 45°. The speed of sound from X to Y represents the speed of sound of the liquid plus a contribution caused by the rate of flow. A pulse is then sent from the transducer Y to transducer X which represents the speed of sound less the

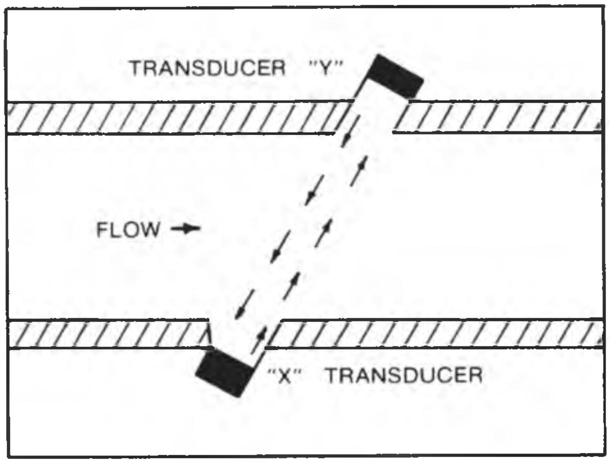


Figure 6. Transient Type Flowmeter

contribution due to rate of flow. When the Y to X speed is subtracted from the X to Y speed, the difference is proportional to flow rate (velocity). The alignment of the transducers is somewhat critical and must be accomplished in a spool piece provided by the manufacturer, or field-mounted using special features. Some field calibration is necessary for both types. Presented in Table 1 and in Figures 7 and 8 are the calibration curves developed from various tests of the equipment under different field conditions.

DETERMINING APPLICATION RATES

The non-invasive type of flowmeter measures only flow rates; however, in order to estimate the amount of water applied to crops, one needs to know the length of irrigation time.

Measuring the Length of Time - There are three primary ways to measure time: (1) intrinsic - involving a permanent component of the power unit; (2) extrinsic - involving the use of the vibration timer; and (3) by getting the farmer to estimate operating time.

(1) Intrinsic Method - The type of power unit a farmer uses to operate his pumps must be determined for the intrinsic method. The unit is either an electric motor (Figure 9), or an internal combustion engine (powered by diesel, gasoline, or LP fuel).

Figure 9. Electric Power Unit

Table 1.--*Calibration information for transient-time meter with typical pipes found in large irrigation systems*

[These calibrations can be used only for a 240 series Clampatron flowmeter manufactured by Controlotron Corp. for 8.625-inch outside diameter carbon-steel pipe with 0.125-inch wall thickness]

Pipe material	Outside diameter (inches)	Wall thickness (inches)	Spacing	Intercept	Slope	Coefficient of determination (r^2)
Steel	6.03	0.115	6.0	1.1	0.500	0.9999
Steel	6.03	.115	6.0	2.4	.499	.9960
Steel	6.03	.115	7.0	1.2	.568	1.0000
Steel	6.03	.115	7.4	1.6	.612	1.0000
Steel	6.65	.310	7.0	-1.5	.694	1.0000
Steel	8.00	.100	7.0	-3.9	.803	.9996
Steel	8.03	.125	7.0	4.5	.804	.9994
Steel	8.625	.122	7.0	-2.7	1.004	.9999
Steel	8.625	.191	7.0	18.3	.971	.9981
Steel	8.625	.284	7.0	-6.6	.962	.9968
Steel	8.65	.296	7.0	7.9	.946	.9961
Steel	8.65	.300	7.0	7.9	.946	.9961
Steel	10.05	.160	8.0	-26.2	1.445	.9993
Steel	12.00	.147	9.5	-11.6	2.201	.9999
Aluminum[1]	6.00	.04	5.0	5.4	.452	.9998
Aluminum[1]	8.00	.06	7.0	-12.2	.842	.9986
PVC	6.625	.121	6.0	6.8	.540	.9996

[1] Gated irrigation pipe; transducer heads placed 45° off plane of gates.

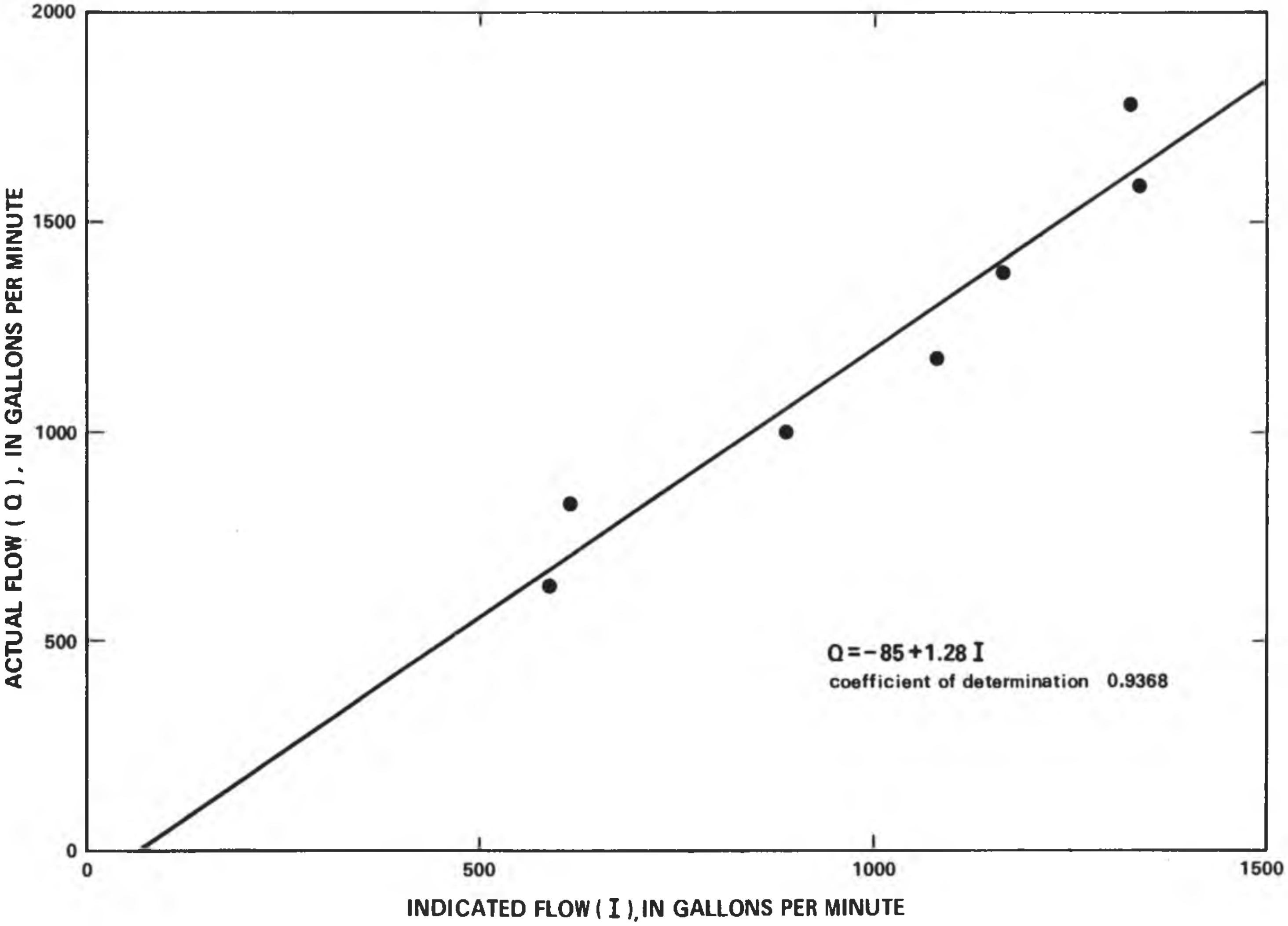


Figure 7.--Calibration curve for Doppler meter with 8-inch aluminum pipe.

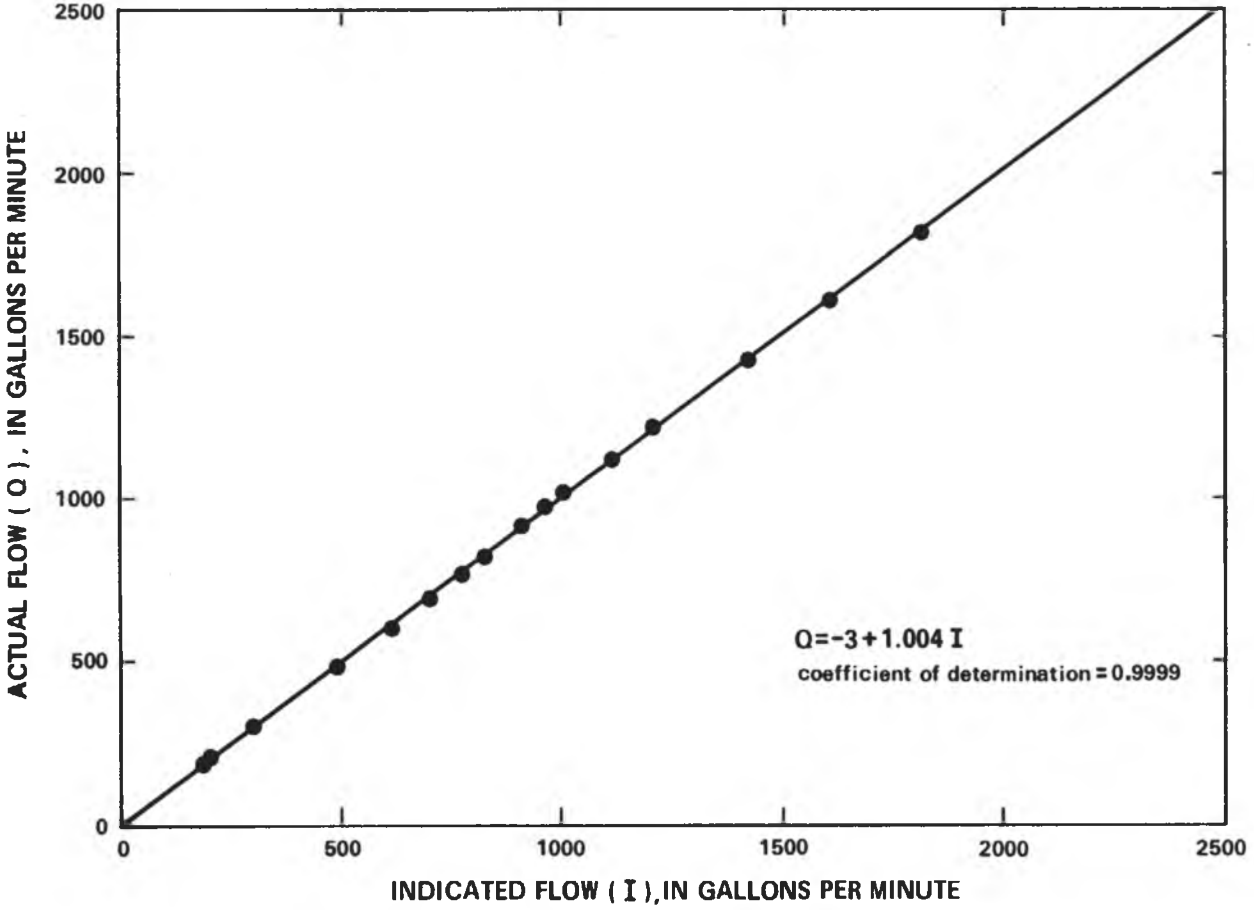


Figure 8.--Calibration curve for transient-time meter with 8-inch steel pipe.

Electric:

If the unit is electric, one has to determine the operating time by reading the kilowatt hour meter (Figure 10) that monitors the electrical energy consumption, and which is attached to a nearby utility pole. Using this method is accurate if the kilowatt meter measures electricity used only by the irrigation system. If a circuit breaker or junction box with electric outlets is nearby, however, it is necessary to determine whether the meter is also measuring usage by additional equipment. If this is the case, the meter

Figure 10. Kilowatt Meter
(In this example, the dials should be read from right to left.
In the example above, 2565 x 80 = 20,520 kwh.)

will give inaccurate readings since it will include the power used by the other equipment.

On the first visit, one has to read and record the kilowatt hours shown on the dials. On subsequent visits to the farm during the cropping season, the kilowatt hours must be read again. Directions for calculating time of operation are presented on the following page. A picture of a kilowatt meter, identifying various parts, is shown in Figure 10. For electrical power consumption, the dial that moves the fastest should be the last dial read.

ELECTRIC METERS

Calculation for time of operation of well pumps

Definitions of Terms

Scale factor = A multiplication factor for the meter reading.

Kh = Conversion factor; printed on face of meter.

Rev = Revolutions of meter disc.

Tsec = Time in seconds.

KWhr = Kilowatt hours; computed from meter readings.

KWi = Instantaneous kilowatt demand

TO = Computed time of pump operation; in hours.

HPd = Computed horsepower demand.

HPr = Rated horsepower of pump motor.

Site ID ____________________

Well No. ____________________

Owner ____________________

Pole Number ____________________

Meter Number ____________________

Account Number ____________________

Power Company ____________________

Date ____________________

Irr. System Type ____________________

Measurements by ____________________

Procedures

1. Multiple beginning and present dial readings by Scale Factor printed on meter face, if necessary, to get a correct water reading.
2. Subtract beginning meter reading from present meter reading to get KWhr.
3. Record Kh factor from meter face.
4. Time meter disc for at least 10 revolutions; and then record time and number of revolutions.
5. Compute KWi using the formula:
$$KWi = \frac{Rev * Kh * 3.6}{Tsec}$$
6. Compute TO using the formula:
$$TO = \frac{KWhr}{KWi}$$
7. Compute HPd using the formula:
$$HPd = KWi * 1.34$$
8. Compute % difference between HPd and HPr using the formula:
$$\% = \frac{HPd}{HPr} * 100$$

Dial Reading Scale Correct Reading

1. Present ________ * ________ = ________

   Beginning ________ * ________ = ________

2. KWhr = ________

3. Kh = ________

4. Rev = ________

   Tsec = ________

5. KWi = ____________ = ____________

6. TO = ____________ = ____________

7. HPd = ________ X ________ = ________

8. % = ________ * 100 ________ = ____________

Note: If % difference is less than 80 or more than 120, recheck all measurements and calculations.

Diesel or Liquid Propane:

If the unit operates on diesel or LP power, it must be determined whether there is an hour meter located on the unit. (Figure 11)

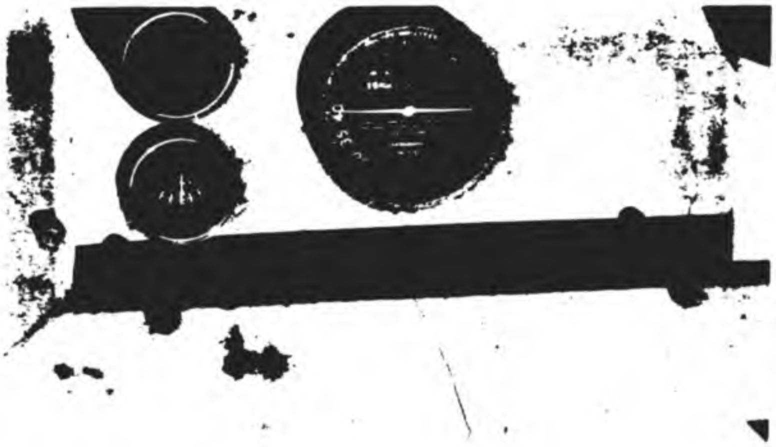


Figure 11. The hour meter is found within the tachometer in the center of the picture.

Gauges that record water temperature, oil pressure, and revolutions per minute are often included on the plate. In most instances there will be an "hours" meter that records, by hours and tenths, the length of time the system is in operation. Before using the meter, it must be determined if it is operating correctly. The hours must be recorded from the meter at the beginning and the end of the cropping season.

(2) Extrinsic Method

Timers (Vibration Timer or Vibration Time Totalizer:

If the previous methods mentioned are not available, or if consistency from one system to the next is important in the study, an external timing device must be used. A vibration timer, or time totalizer, has been developed for this purpose. Both are designed to monitor vibrations and record the running time of equipment. These devices indicate the amount of time an irrigation system is in operation during the season.

Basic Description of the VTT:

The VTT (vibration time totalizer) is a small (1.75" x 1.75" x 1.0") self-contained device which senses vibration from whatever it is mounted to, and electronically records operating time based on the assumption that vibration is present when the structure is operating and is not present when the structure is mechanically quiet.

The VTT contains its own power source, a 2.8 volt battery pack containing sufficient capacity to operate the VTT for a period of approximately 3 years. The recording device will record up to 1,000 hours of operation and is designed to be easily removed, read, and reset.

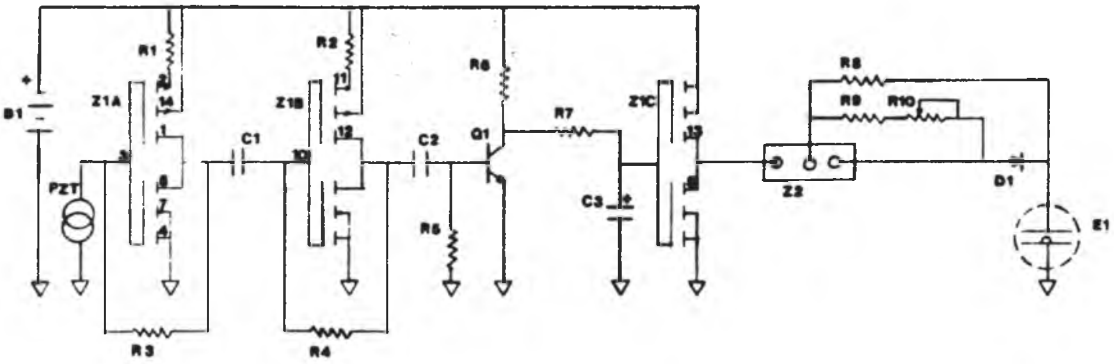
The VTT mounts in a small metal bracket and is held in place with a plastic strap (commonly known as a "tie-wrap"). The VTT bracket can be epoxied in place, with the five small holes in its back serving as tie-points for the epoxy. It may also be screwed in place utilizing these same holes. Additionally, the bracket may be strapped to larger irregularly shaped structures using plastic banding material (similar to that used to hold boxes on pallets) through the two larger holes on the bracket base.

Schematic Diagram and Parts List:

A schematic diagram and parts list for the VTT is shown in Figure 12.

Operation of the VTT:

Referring to the schematic diagram (Figure 12), PZT is a $BaTiO_3$ (Barium Titinate) crystal element which generates a small (30 millivolt) signal when it is mechanically flexed. Vibrations from the structure on which the VTT is mounted are transmitted to the PZT which is mounted on the printed circuit card. A small weight (lead shot), fastened to the PZT, causes it to twist and/or bend when vibration is present, thereby generating the output signal.



USGS-VTT
JWM - 00308
4/10/80

B1	2.8 v battery
C1	0.001 mfd
C2	0.001 mfd
C3	0.1 mfd
D1	1N457
E1	E-Cell
PZT	$BaTiO_3$ crystal
Q1	2N2222A
R1	680K ¼w cf
R2	680K ¼w cf
R3	18M ¼w cc
R4	18M ¼w cc
R5	1M ¼w cf
R6	10M ¼w cf
R7	1K ¼w cf
R8	2.4M ¼w cf
R9	330K ¼w cf
R10	200K pot
Z1	CD4007
Z2	LM334Z

Figure 12. Vibration Time Totalizer Parts List

Z1A and Z1B, two parts of the integrated circuit in VTT, are simple amplifiers which increase the voltage of the signal representing the vibration. When the voltage out of Z1B reaches a certain level (greater than 0.7 volts) transistor Q1 turns on and brings the voltage across C3 to zero volts. This causes Z1C's output to increase to the battery voltage (3.2 volts) supplying power to Z2.

Z2 is a constant output current regulator which supplies a constant 630 nanoampere current to E1, an electrocoulometer cell. This cell has the unique property of plating material from one electrode to the other, and the property is reversible. After use for a period of time, the E-cell is removed from the VTT and can be read by passing a reverse current of known magnitude through it. Running time of the structure being monitored can thus be determined.

At the end of the irrigation season the timer (Figure 13), or the E-cell from the VTT, must be placed on a "read-out" machine which will calculate the hours the system operated. Either unit should be mounted at a point on the power unit where there is sufficient vibration to activate the unit.

A vibration meter is used to determine the best location for either unit. The system should be in operation while the vibration meter is in use. One has to first determine, before installing one of the units, which part of the pumping unit vibrates sufficiently to activate the timer (Figures 14 and 15). Also, one has to avoid placing the units in locations that are subject to climatic extremes.

Figure 13. A timer can be used to measure the amount of time the system is in operation

Figure 14. A vibration meter is used to determine the best location for the timer.

Design specifications will vary according to the types of timers used. Distinct specifications are included with the timers.

Figure 15. Another type of vibration sensing meter

To attach the units, use epoxy putty on the mounting bracket and attach it to the selected site (Figure 16). Indication of the date and time of installation is marked on the front of the timing device and the timer unit is slipped in the mounting bracket.

Figure 16. The mounting bracket is placed on the gear head with epoxy. The timer is then placed in the mounting bracket

In Figures 17, 18, and 19 a few locations are shown where timers could be attached.

Figure 17. The gearhead

Figure 18. The motor or discharge pipe

Figure 19. The pump casing

Vibration Timer Service Log

The Vibration Timer Service Log is used when installing, checking, and removing the timers or E-cell batteries. Information on the log includes:

Manufacturers Date: Indicate the month and year the timer was manufactured. This information is important because timers have limited battery lives, and the timers should not be allowed to run down in the field.

Serial Number: Indicate the serial number of the timer.

Installation: Indicate the date and time the timer is installed or the E-cell battery is put into operation.

Manf. Date	VIBRATION TIMER SERVICE LOG	Serial No.	
	Date: ____________		Date: ____________
INSTALLED		REMOVED	
	Time: ________ AM PM		Time: ________ AM PM
	Cont.: ________		Pos.: ________
OPER. MODE		MOUNTING	
	Inter.: ________		Displ. ________
SERVICE TIME:	________ Hrs.(est)	READOUT TIME:	________ Hrs.

SERVICE LOCATION:

REMARKS:

Operating Mode: Check to see whether the pump operates continuously or if it is interrupted. Most pumps will probably be interrupted unless they are located in nurseries.

Service Time: Indicate the estimated time that the pump has operated during the irrigation period.

Removed: Indicate the date and time the timer or battery is removed.

Mounting Position: Indicate whether the timer is mounted horizontally or vertically.

*Displacement: Indicate the amount of vibration that occurs at the site where the timer is mounted. The measurement will be in millimeters of deflection, and it is determined from the vibration meter. This measurement can act as a check for the timer at the end of the irrigation season and help identify faulty equipment.

Readout Time: Indicate the hours that the system was in operation. The hours are determined from the timer or the E-cell after it is brought back in the office and placed in a "read-out" machine.

Service Location: Indicate the farm and the serial number of the pump in this space. Include the system number, if there is more than one system. Indicate the well number, if the system is on a large farm and there are several wells in different sections.

Remarks: Problems encountered while servicing the timers can be noted in the "Remarks" section. Also, indicate where the timer is mounted - whether on the gearhead, pump, etc. Note the crop or crops that are being irrigated by the system. On the back of the card indicate whether the system is a diesel, LP, electric, or gasoline powered unit. Record the operating hours from the "Hours" meter. Record the hours when the timer is first put on and again when the timer is removed. These hours should be compared to those read from the timer.

Calibration of Timers:

All of the first generation timer units were handmade and thus subject to

---

*Displacement refers to the degree of vibration measured at the timer mounting site during normal pump operation.

large variations in quality. In order to evaluate the reliability and accuracy of the units, an independent determination of time of operation was attempted at several sites. The most common and reliable alternative source of time of operation was the energy meter. Electric meters provided the most reliable alternative measure of operation for the irrigation wells. Gas meters also provide a measure of operation, but their reliability is much less (USGS WRI 80-111). The reliability curves are shown in Figures 20 and 21.

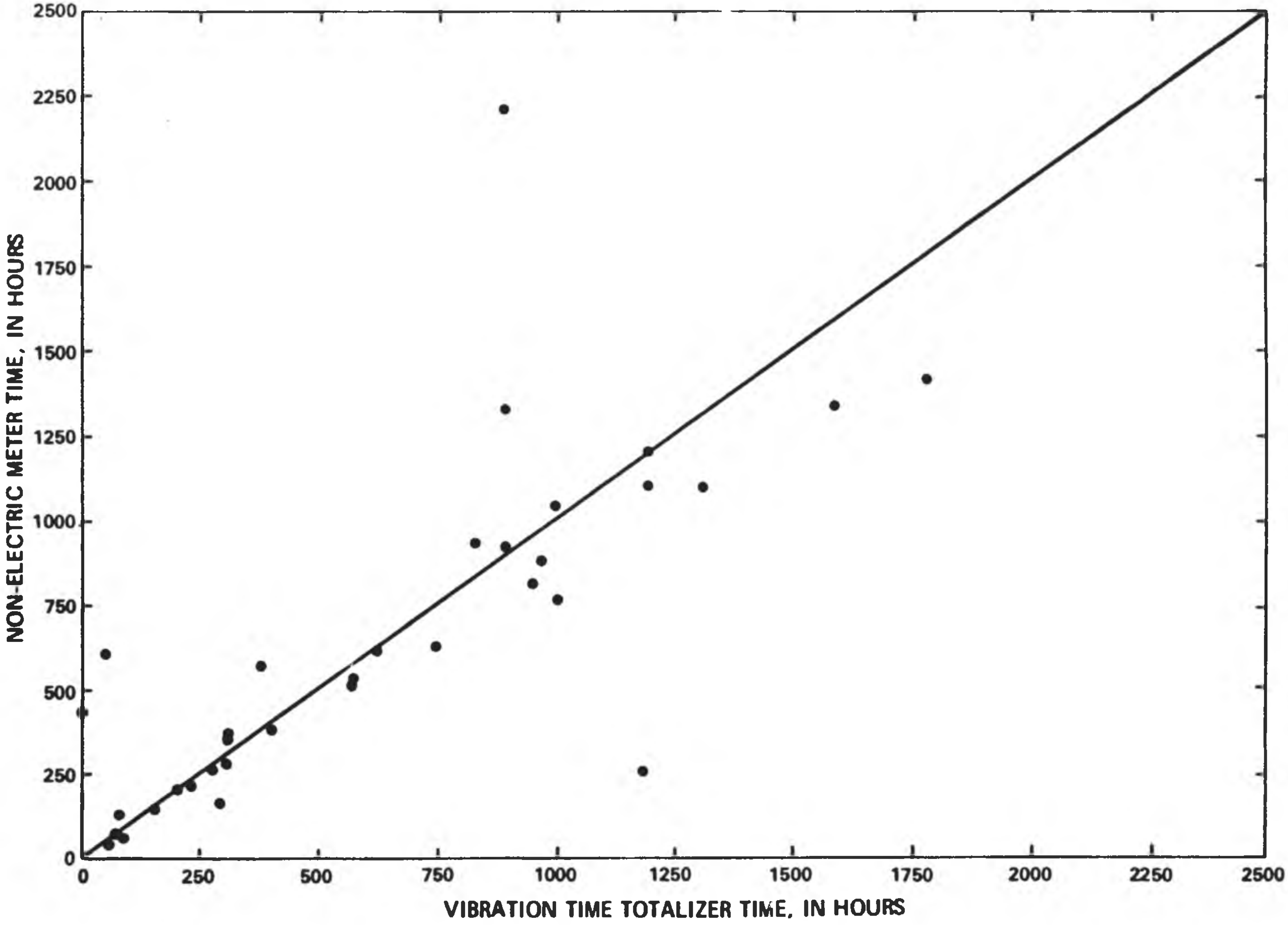


Figure 20.—Comparison of Vibration Time Totalizer time of operation with time of operation detormined from non-electric meter sources.

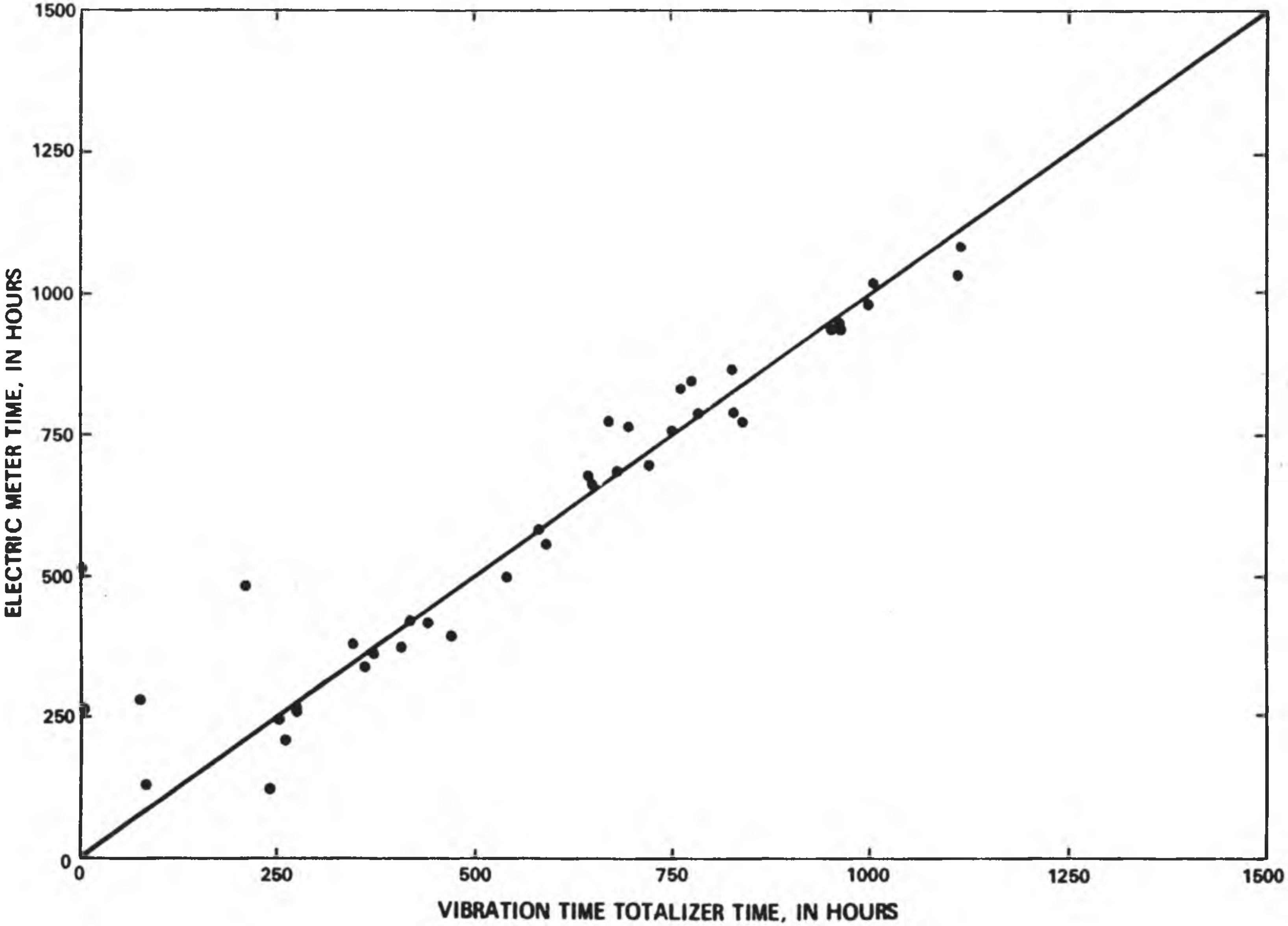


Figure 21. —Comparison of Vibration Time Totalizer time of operation with time of operation determined from electric meter sources.

STATISTICAL SAMPLING

Statistical sampling is a technique which is used when one has limited resources (in terms of time and money) and when one wishes to maximize the usefulness of the data collected. As applied to agricultural water use data collection levels, it is not feasible to install vibration timers and measure the flows in each and every farm. Instead, based on some sampling techniques, only a few farms are selected for more accurate data collection. Also, processing a small set of data not only takes less time, but can be accomplished with fewer errors. There are various methods of statistical sampling techniques; random sampling, stratified sampling, cluster sampling, multi-stage sampling, etc. So far, in agricultural water use data collection, only the stratified random sampling has been used. A brief description of random and stratified random sampling follows.

Simple Random Sampling: Assume one must estimate the total water used by the four farms in Figure 22's example district, but one can monitor only two. Two farms can be sampled at random from the four in the example district and the average of the possible estimates will be the actual amount of water applied (see Table 2). This is always true of simple random sampling. But,

Table 2. Random Sampling in the Example District

Two farms are selected at random from the four. (Estimate of total district water use = 4 x average water use in sample).

	All equally likely samples of 2 farms	
Farms in Sample	Estimate of District Water Use (Mgal)	Error (Mgal)
1,2	4 x (19 + 11)/2 = 60	-11
1,3	4 x (19 + 38)/2 = 114	+43
1,4	4 x (19 + 3)/2 = 44	-27
2,3	4 x (11 + 38)/2 = 98	+27
2,4	4 x (11 + 3)/2 = 28	-43
3,4	4 x (38 + 3)/2 = 11	+11

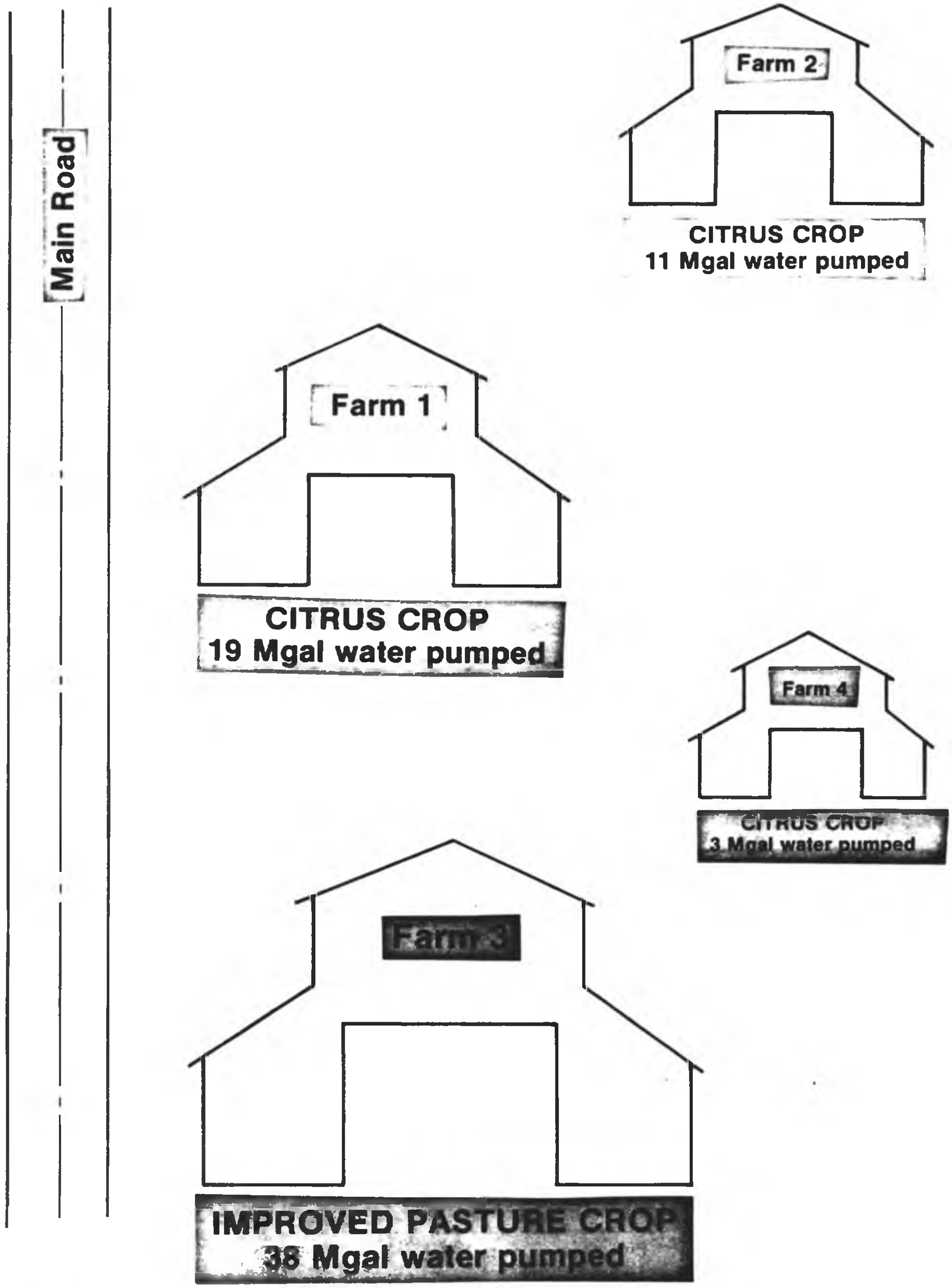


Figure 22. Example of district of 4 farms

if one knows: (a) which farm grows improved pasture, and (b) that improved pasture may require far more water than citrus, the reliability of the total water use estimate (see Figure 22) will be increased by "stratifying".

Stratified Random Sampling: "Stratifying" means separating the farms with similar water use characteristics into groups (strata). It is frequently useful to divide the total population into subgroups called "strata" for purposes of making the sample more efficient. Assuming that the amount of money to be spent on agricultural water use data collection has already been determined (budget allocations), and based on past experience, the methods and costs of data collection are known. Given these constraints, the efficiency of a sample is measured by the size of its sampling error relative to other samples that cost the same. Stratified sampling is intended to provide the smallest sampling error and hence the most information from the available resources. In the foregoing example, one stratum contains the citrus farms; the other contains only the improved pasture.

If two farms are selected for the stratified samples, the one improved pasture farm is chosen deliberately (see Table 3), and one of the three citrus farms is chosen at random. The water applied by the citrus farm is assumed to be typical of all three citrus farms in the district. The stratified random samples always include the one farm in the improved pasture

Table 3. Stratified Random Sampling in the Example District

The four farms are stratified by crop type. The one farm in the improved pasture stratum is randomly selected for the sample, and one of the three farms in the citrus stratum is randomly selected. (Estimate of total district water use = water use on pasture + 3X water use on sample citrus farm).

Farms	All equally likely samples of 2 farms Estimate of District Water Use (Mgal)	Error (Mgal)
1,3	38 + 3 x 19 = 95	+24
2,3	38 + 3 x 11 = 71	0
3,4	38 + 3 x 3 = 47	-24

stratum. In general, when some strata contain considerably higher volume water users, it is advisable to sample these strata more intensively, sometimes sampling all the members. As a rule, there is more variability in water use in a stratum with high water users, and it takes a larger sample to produce a reliable estimate. Also, some very large users may account for a large proportion of total water use. In the example district, the one improved pasture farm applied more than half the total irrigation water. Including such farms in the sample increases the reliability of the overall water use estimates.

Stratification divides the population into internally similar groups. The greater the internal similarity of a group, the smaller the sample needed to adequately characterize water use for the group. The greater the similarity within groups and dissimilarity between them, the more stratified random sampling increases the reliability of the water use estimates.

When to Use Stratified Random Sampling: Stratified random sampling can increase the reliability of estimates based on sample "means" (see Figure 23). The technique is used when there are known groups with particular water use habits (citrus, improved pasture, for example). Stratified random sampling works well when certain groups use much more water per member than others (very large farms, for example).

Stratified random sampling can also be used to make water use estimates for special groups; for example, if one needs to estimate water use for irrigation by truck crop farmers. Grouping truck crop farmers into a stratum insures the inclusion of some of the farmers in the overall sample.

FLOW MEASUREMENTS AND TIMER INSTALLATION IN SOUTH FLORIDA

The field work on installing timers and taking flow measurements started in May 1979, during which time the irrigation of seasonal crops had already

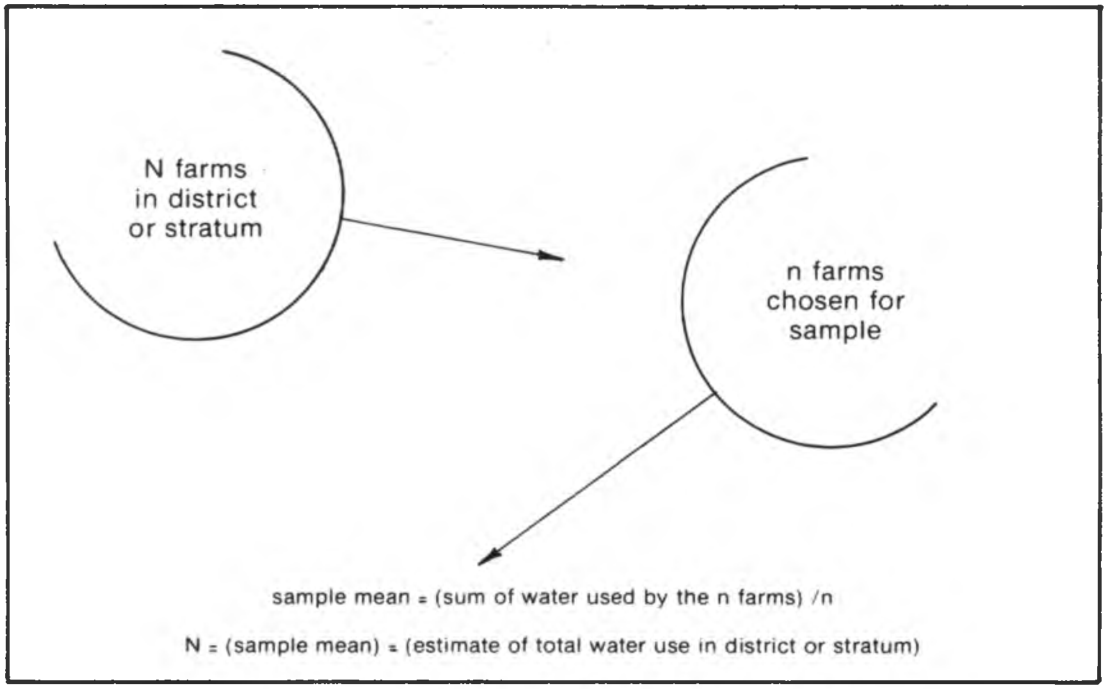


Figure 23. Total Water Use Estimates Based on Sample Means

ceased. Also, due to heavy rainfall, virtually all irrigation activity was stopped; therefore, timers could not be installed during this demonstration project on all the irrigated crops in Lee County. Nursery and golf courses, however, are irrigated on an annual basis and it was decided to test the timers and also measure the flows for these two irrigation activities.

According to the District's consumptive use permit file listing of February 27, 1979, there are 10 nursery farms and 10 golf courses in Lee County pumping in excess of 100,000 gallons of water per day. Twenty-two (22) vibration timers were installed near the pumps to measure the number of hours these pumps run. Most of the timers were installed on May 9, 10, and 11, and a few of them were installed on the 18th and 30th of the month. In the following table (Table 4) is presented the timer number, installed date and time, timer removal date and time, number of days, estimated time

TABLE 4. WATER USE PROGRAM; RESULTS ON TIMER INSTALLATION

TIMER NO.	INSTALLED DATE/TIME	REMOVED DATE/TIME	NO. OF DAYS	ESTIMATED TIME, HOURS	READOUT TIME HOURS	READOUT/ ESTIMATED TIME %	GENERAL COMMENTS
779	5-10-79 1030	8-2-79 843	84	570	592	104	4% underestimate
766	5-10-79 1400	8-1-79 1245	83	996	999	100	
776	5-9-79 1443	8-1-79 1555	84	96	101	105	5% underestimate
747	5-9-79 1405	8-1-79 1554	84	96	56	58	
717	5-30-79 1414	8-1-79 1315	63	756	857	113	
740	5-11-79 1145	8-1-79 1524	-	-	-	-	
714	5-18-79 1028	8-1-79 1237	75	900	944	105	
778	5-9-79 1507	8-1-79 1600	85	498	552	111	
770	5-10-79 1330	8-2-79 1180	85	2014	1988	99	
724	5-24-79 1458	8-2-79 1200	70	-	52	-	bad timer
689	5-30-79 1414	8-1-79 1315	63	-	3000	-	bad timer
773	5-10-79 1500	8-2-79 1120	84	150	149	99	
768	5-10-79 1027	8-2-79 950	84	58	63	109	
725	5-24-79 1458	8-2-79 1200	70	-	1635		bad timer
730	6-7-79 1830	8-1-79 1413	54	210	220	105	
720	5-30-79 1530	8-1-79 1335	63	610	609	100	
761	5-10-79 1027	8-2-79 950	84	190	193	102	

TABLE 4 (Cont'd). WATER USE PROGRAM; RESULTS ON TIMER INSTALLATION

TIMER NO.	INSTALLED DATE/TIME	REMOVED DATE/TIME	NO. OF DAYS	ESTIMATED TIME, HOURS	READOUT TIME HOURS	READOUT/ ESTIMATED TIME %	GENERAL COMMENTS
765	5-9-79 1800	8-2-79 920	84	300	-	-	wiped
764	5-9-79 1820	8-2-79 925	84	300	166	55	
775	5-10-79 1258	8-2-79 1055	85	300	302	101	
777	5-10-79 1107	8-2-79 1010	85	907	901	99	
780	5-10-79 1118	8-2-79 1030	85	440	434	99	

the pump ran (estimations from farmers or golf course superintendents), read out time in hours and percentage of read out time vs estimated time (Table 4). Flow velocity was measured by use of Doppler flowmeters. The readings are within 90% of the actual flow velocity.

Results

Out of the 22 vibration timers installed in the field, 4 timers became inoperative due to internal electrical shorts, pump removal, or disconnection. The rest of the timers were read and the pumping timers were within 90% of the range of time estimated by the farmers. The flow recorded is also within range.

Conclusions

Based on the above results it was concluded that: (1) flow estimates can effectively be made by use of non-invasive flowmeters, and (2) quantity of water used can be estimated by use of both flowmeters and timers.

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