FEASIBILITY OF USING PORTABLE, NONINVASIVE PIPE FLOWMETERS AND TIME TOTALIZERS FOR DETERMINING WATER USE

By Donald V. Arvin

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 91-4110

Prepared in cooperation with the

INDIANA DEPARTMENT OF NATURAL RESOURCES, DIVISION OF WATER

Indianapolis, Indiana
1992

U.S. DEPARTMENT OF THE INTERIOR

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Multiply	*By*	*To obtain*
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square foot (ft^2)	0.09294	square meter
square mile (mi^2)	2.59	square kilometer
foot per second (ft/s)	0.3048	meter per second
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
gallon per minute (gal/min)	0.06309	liter per second
gallon per day (gal/d)	0.003785	cubic meter per day
pound per square inch (lb/in^2)	6.895	kilopascal
horsepower (hp)	745.7	watt

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ABSTRACT

The feasibility of using noninvasive flowmeters for determining water use was investigated by attempting, and at some sites repeating, instantaneous pipe-flow measurements at 45 water-withdrawal sites by use of four portable noninvasive pipe flowmeters. The flowmeters measure flow in pipes; this flow is related to water use. Because actual water use can differ from the total flow in the pipe, water use is not, in itself, measured by the flowmeters.

The transit-time flowmeter successfully measured flow on 81 of 88 measurement attempts. The time-of-flight flowmeter successfully measured flow on 85 of 93 measurement attempts. One reflective-doppler flowmeter successfully measured flow on 71 of 75 measurement attempts. Another type of reflective-doppler flowmeter, which required air bubbles or particulate matter in the flow, successfully measured flow on 19 of 92 measurement attempts. Flows at most water-withdrawal sites selected for this study did not include particulate matter.

At 10 site visits where inline flowmeter measurements were available for comparison and where three of the four selected portable flowmeters were successful, the transit-time flowmeter measurements had a mean log-percent difference from the inline measurements of 2.8 and a standard deviation of 3.7. The time-of-flight flowmeter measurements had a mean log-percent difference of 7.5 and a standard deviation of 7.6. The reflective-doppler flowmeter measurements had a mean log-percent difference of -14 and a standard deviation of 18.

The feasibility of using time totalizers for determining water use was investigated by observing seven vibration time totalizers (VTT's) mounted at five sites. None of the units exhibited adverse effects from the heat, precipitation, or humidity associated with Indiana summers. One VTT was mounted at a public water-supply site where inductive time-totalizer measurements were available for comparison. The VTT agreed within 8 hours of the inductive time totalizer after 2,340 hours of pump operation. There were no mechanical problems with the VTT units used in this study.

INTRODUCTION

Water is one of Indiana's most valuable resources. Proper management of that resource includes assessment of current and future demands. Water-use information is essential to the proper management of water resources. For water-use information to be of assistance to managers, effective methods of determining the amounts of water withdrawn from surface- and ground-water sources need to be developed.

Water-use information estimated by previous methods may no longer be adequate for efficient management of the resource. For example, by estimating the number of cattle in a county, then multiplying that population by a coefficient, one could estimate the amount of water used for livestock. With increasing demands on water resources, such estimates may result in margins of error that are unsatisfactory. Requiring all users to install and maintain inline water meters would result in more accurate water-use data, but the expense incurred by the installation and maintenance of these devices may be, in many cases, too burdensome to be practical.

Alternative methods have been developed to determine water withdrawals by use of portable, noninvasive pipe flowmeters to measure flow rates, and running-time totalizers, relatively inexpensive devices, to monitor accumulative running time of a pump. At withdrawal sites where flow rates do not fluctuate substantially, knowing the flow rate and accumulative running time of the pump provides a method with which to determine water withdrawals at a relatively small cost. A study was conducted by the U.S. Geological Survey (USGS), in cooperation with the Indiana Department of Natural Resources (IDNR), Division of Water, to investigate the utility of these alternative methods of determining water use under field conditions.

Purpose and Scope

This report describes the feasibility of obtaining instantaneous flow measurements with four portable flowmeters at a variety of water-withdrawal sites, compares the success of the flowmeters in obtaining instantaneous flow measurements at those sites, and compares the measured rates of flow obtained by each of the flowmeters. Because manufacturers' testing conditions and resulting accuracies are not always directly transferable to unique field conditions (Controlotron, written commun., 1989), whenever possible, instantaneous flow measurements were compared with available site information, such as recent pump-test results or inline-flowmeter measurements. It was not within the scope of this study to establish the accuracy of the available inline flowmeters, or to determine if the accuracy of the inline flowmeters had decreased because of wear since the time of installation. This report also describes the use of running-time totalizers under field conditions. A discussion of potential advantages or disadvantages of each flowmeter in terms of future use as a survey-oriented water-withdrawal measuring device, based on field observations, is also presented.

There is no intent in this report to imply that the four selected noninvasive flowmeters used in this study represent the "best" available devices on the market. Beyond those used in this investigation, many other portable pipe flowmeters are available commercially. Because of financial limitations, however, it was not possible to include all available flowmeters in this study. There is no intent to identify the "best" portable flowmeter of the four used in this study.

Previous Studies

Measurement of pipe flow in association with water-use determinations has been discussed in previously published reports. Luckey and others (1980) investigated the suitability of a propeller-type gated-pipe meter, a reflective-doppler flowmeter, and a transit-time flowmeter for use in obtaining flow measurements on large irrigation systems. Marella and Singleton (1988) described the use of invasive and noninvasive pipe flowmeters in the collection of water-use data.

For the study described in this report, pipe-flow measurements were made during March through September 1989 at 45 sites by use of four selected types of portable, noninvasive pipe flowmeters. These flowmeters were (1) the Uniflow[1] transit-time flowmeter manufactured by Controlotron; (2) the Cross Correlation Flowmeter, a time-of-flight instrument, developed under contract for the U.S. Geological Survey Hydrologic Instrumentation Facility (HIF) at Stennis Space Center, Miss.; (3) the Hydra reflective-doppler flowmeter manufactured by Polysonics; and (4) the Spectra Fourier Flowmeter (another reflective-doppler device), also manufactured by Controlotron.

When selecting the four portable flowmeters used in this study, there was an attempt to select flowmeters that operated on different principles and had the potential to operate effectively under different conditions. The Uniflow meter is designed for measuring nonturbulent flows, such as those often found 10 to 15 pipe diameters downstream from elbows or pipe seams. The Cross Correlation Flowmeter is designed to measure turbulent flows, such as those found in straight pipes with high velocity flows or just downstream of elbows or pipe seams. The Hydra is primarily designed for measurement of fluids containing particulate matter or air bubbles, but also may be effective, according to the manufacturer, in some nonparticulate turbulent situations. The Spectra Fourier Flowmeter is designed for fluids containing particulate matter or air bubbles.

The Uniflow (fig. 1) and Spectra (fig. 2) flowmeters were selected for the study because they are available on the U.S. General Services Administration (GSA) supply schedule. When purchasing equipment, Federal agencies are required to select items from this schedule unless it can be shown that the items on the schedule are incapable of performing the

[1] The use of brand names in this report is for identification purposes only, and does not imply endorsement by the U.S. Geological Survey or the Indiana Department of Natural Resources.

Figure 1. Uniflow transit-time flowmeter and transducers mounted in direct mode on 6-inch outside-diameter steel irrigation pipe.

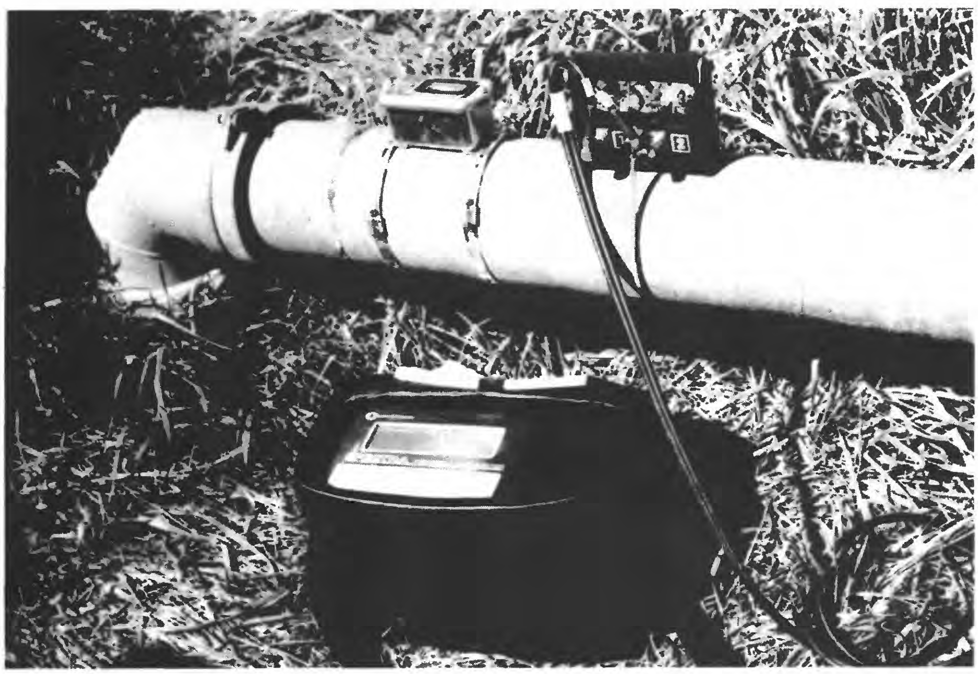

Figure 2. Spectra Fourier Flowmeter and transducers mounted on 6-inch outside-diameter steel irrigation pipe.

specific task for which the equipment is procured. The Cross Correlation Flowmeter (fig. 3) was obtained because it represented the only instrument of its type available. Although the flowmeter can be used in many situations, it is specifically designed to measure flows in turbulent situations. The development of this instrument was so recent that, at the time of this study, only five prototypes had been constructed. The Cross Correlation Flowmeter has since been made available commercially. The Hydra (fig. 4) was included in the study soon after data collection began when it became clear that the Spectra was not well-suited for most nonparticulate-flow situations.

Acknowledgments

The efforts of Siavash Beik, Douglas S. Campbell, and Greg Main of the IDNR Division of Water, Water Use Section, were instrumental in the development of this study, the selection of sites, and the scheduling of initial contact with site owners or managers. James E. Walsh of the Indiana Cities Water Corporation allowed repeated access to the corporation's public water-supply facilities for the purpose of flowmeter demonstration and training. The author also wishes to thank the numerous site owners and managers who allowed access to their facilities and offered the benefits of their many years of experience, which made the application of these new methodologies possible.

PORTABLE, NONINVASIVE PIPE FLOWMETERS

Description

A portable, noninvasive pipe flowmeter is an instrument that can measure the flow of a fluid through a pipe without having to come into direct contact with the fluid. The term "portable" means that the instrument can be easily carried to the measurement site and precludes the need for electrical outlets or generators.

The four flowmeters used in this study operate by sending and receiving ultrasonic signals through the pipe at the point of measurement. How each meter uses the ultrasonic signals to determine fluid velocity is described in the following sections. By incorporating site-specific information provided by the instrument operator and the velocity reading generated by the ultrasonic-signal processor, a flow rate is determined by the flowmeter.

Principles of Operation

For each of the four selected flowmeters, one or two pairs of ultrasonic signal-sending and receiving crystals, called transducers, were attached to the pipe walls to enable the ultrasonic signal to pass through the pipe wall and fluid. Transducers were clamped to the pipe walls with custom mounting brackets. The Spectra transducer assembly can be mounted to the pipe or held to the pipe by hand (fig. 5).

A successful pipe-flow measurement using an ultrasonic pipe flowmeter requires the mounting of transducers at a location where the pipe is flowing full and where the ultrasonic signal can be transferred through the pipe materials. For the signal to be transferred through steel, PVC, ductile iron, polyethylene pipes, and mortar liners, it is important that no air gaps be present in the path of the signal. Air gaps can form where paint on a pipe surface is blistered or where the pipe contains a sleeve.

The transfer of the ultrasonic signal from the transducer surface to the pipe wall, and vice versa, can be improved by applying a grease or a gel-like material called couplant to the contact face of the transducer prior to mounting (fig. 6). Also, to ensure successful transfer of the signal to the pipe wall, blistered paint and rust are removed from the pipe wall with a steel brush or bastard file. It is usually unnecessary to remove smooth coats of paint from pipe surfaces.

The amount of exposed pipe required to mount portable flowmeter transducers depends on the specific type of technology employed. The proximity of a pipe-flow measuring section to a turbulence-causing structure, such as a valve or elbow, also depends on the type of portable flowmeter being used.

Transit-Time Flowmeter

When using a transit-time flowmeter, a single pair of transducers are attached to the pipe walls. One transducer is mounted at an upstream location, the other at a downstream

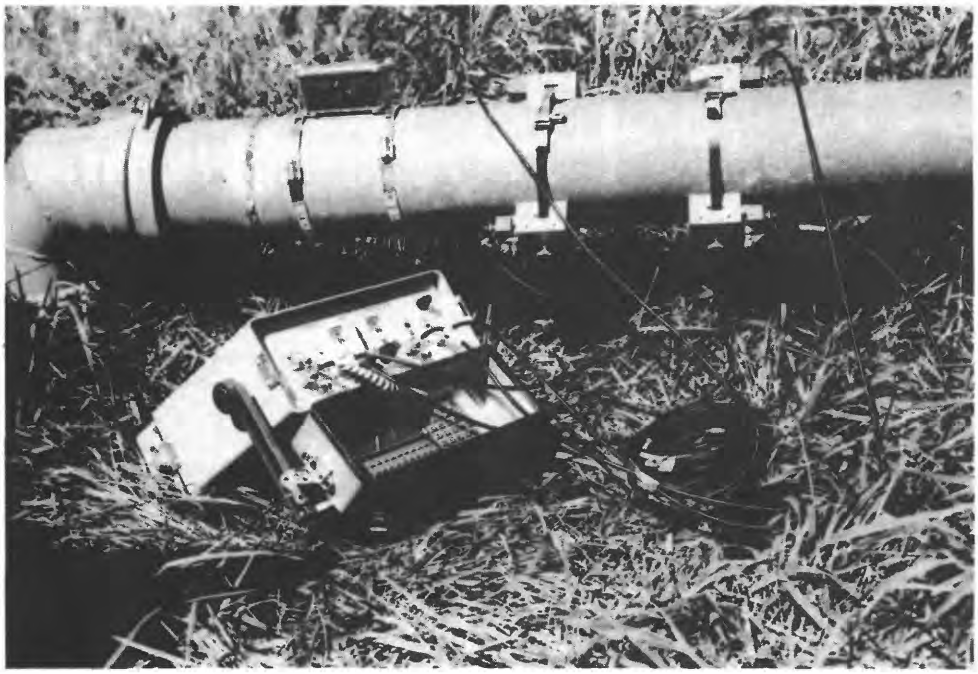

Figure 3. Cross Correlation Flowmeter and transducers mounted on 6-inch outside-diameter steel irrigation pipe.

Figure 4. Hydra reflective-doppler flowmeter and transducers mounted on 6-inch outside-diameter steel irrigation pipe.

Figure 5. Spectra Fourier Flowmeter transducers being hand held to pipe during pipe-flow measurement.

Figure 6. Silicon grease being applied as couplant to surface of transducer.

location. Each transducer acts as both a signal sender and receiver. The flow rate is determined by transmitting an ultrasonic signal alternately upstream and downstream. Because of the effects of flow, the signal slows when traveling upstream and speeds up when traveling downstream. The time difference between these signals is proportional to the rate of flow. This basic principle was documented in 1708 by William Derham, who observed that the transmission of sound in air depends on wind velocity (Jenny and others, 1987).

For a transit-time flowmeter to work effectively, it is necessary to mount the transducers at a location where flow disturbances are minimal. A straight piece of pipe 10 to 15 pipe diameters downstream from an elbow would be a typical measurement location. Fluids that contain more than 20-percent air bubbles may produce incorrect, high readings (Controlotron Corporation, written commun., 1988) because of the increased length of time required for the signal to travel from one transducer to the other. The Uniflow transit-time flowmeter used in this study warned the operator when excessive aeration or turbulent conditions were present.

Depending on site conditions, transducers are mounted in one of two ways. In the direct mode, also called the Z method, the upstream transducer is placed on the opposite side of the pipe from the downstream transducer. Rapid pulses of ultrasonic signal are transmitted from one transducer through the pipe wall, through the fluid, and through the other pipe wall to the receiving transducer. This process is then reversed. In the reflect mode, also called the V method, the upstream and downstream transducers are mounted on the same side of the pipe. Rapid pulses of ultrasonic signal are transmitted from one transducer through the pipe wall, through the fluid, reflected off the far wall, back through the fluid, and through the pipe wall to the receiving transducer. This process is then reversed.

Flow determinations by a transit-time flowmeter depend on known or calculated velocities of the ultrasonic signal through materials found at the measurement site. Certain information describing the measurement site needs to be entered into the instrument's computer processor. In operating the transit-time flowmeter used in this study, the required information is entered by pressing keys on the hand-held unit connected to the processor. The required information includes the outside diameter of the pipe, the pipe-wall thickness, the pipe material, the thickness and makeup of the liner if one is present, and the type of fluid. The Unifow flowmeter processes this information along with fluid and pipe-material properties available in its permanent memory, such as the velocity of the ultrasonic signal through specific materials. The flowmeter informs the operator where the transducers should be inserted into the mounting brackets, producing a signal path of known length. The flowmeter reports flows in gallons per minute. Although transit-time flowmeters have been available for many years, only recent developments in microcircuitry have allowed manufacturers to place the required elements of large memory storage and high-speed computations in such a light, compact, portable package.

Cross Correlation Flowmeter

The Cross Correlation Flowmeter determines flow by use of the principle of operation known as time of flight. The instrument measures the time it takes a fluid to move from one position in the pipe to a second position downstream (E.H. Cordes, U.S. Geological Survey, written commun., 1989).

When using a Cross Correlation Flowmeter, there must be disturbances in the pipe flow. Disturbances, such as turbulent eddies, shear waves, or slippage planes, generally are found downstream from an elbow, pipe seam, or flange, or where flow velocities are rapid enough to create turbulence within straight sections of pipe. Two pairs of transducers are used; one pair is mounted on opposite sides of the pipe from each other at an upstream location, and the second pair is similarly mounted a short distance downstream, typically 1 to 3 pipe diameters. As the ultrasonic signal passes through the pipe cross section where the upstream transducers are located, flow disturbances modulate the phase and amplitude of the signal (Cordes, 1989, p. 6). Modulations in signal also are identified at the location where the downstream transducers are mounted. The modulation in signal allows for characterization of fluid signatures. Through correlation analysis, by use of a real-time digital recognition system, the Cross Correlation Flowmeter searches for these fluid signatures. The time between signature identification at the upstream location and signature identification at the downstream location is measured. The fluid velocity is the distance between the transducers divided by this measured time. Although the degree of disturbance in the flow does not affect the measured discharge, either a lack of disturbance or too violent a disturbance may result in the inability of the flowmeter to perform a successful signature correlation, which results in a failed measurement attempt.

Information required by the Cross Correlation Flowmeter includes pipe circumference, pipe-wall thickness, and the distance between the upstream and downstream transducer pairs. The instrument operator enters the information through a preprogrammed calculator connected to the computer unit. On a digital display, the flowmeter reports velocity in feet per second and flow in gallons per minute and cubic feet per second.

Reflective-Doppler Flowmeter

The operation of reflective-doppler flowmeters is based on the concept established by Christian Doppler in 1843 (Polysonics, 1986, p. 2). The concept proposes that there is an apparent change in frequency of energy waves, such as sound or ultrasound, as a function of motion. In using a reflective-doppler flowmeter, a continuous, ultrasonic signal is transmitted from a stationary transducer through the pipe wall and into the flowing fluid. Discontinuities in the fluid, such as sediment or air bubbles, or, in some cases, disturbances in the stream, reflect the ultrasonic signal. A receiving transducer detects the frequency shifts of the reflected signal. These frequency shifts are processed to determine the velocity of the fluid.

Two reflective-doppler flowmeters, the Hydra and the Spectra Fourier Flowmeter, were used in this study. Although the two flowmeters operate on the same basic principle, the signal-processing techniques are somewhat different. The only site-specific information the operator needed to know when using reflective-doppler flowmeters was the inside diameter of the pipe.

The Hydra flowmeter utilizes a dual-head transducer. For pipes smaller than 24 in. in diameter, the transducer heads are mounted on opposite sides of the pipe. For larger pipes, or in situations where weak or erratic signals exist, the transducers are mounted on the same side of the pipe, within 2 to 6 in. of each other. The velocity measurement is indicated by a pointer on a circular dial. In the absence of particulates or air bubbles, the Hydra signal processor utilizes frequency shifts produced by shears that occur in turbulent flow. The type of turbulence formed by partly opened valves, venturis, and orifice plates should be avoided because the signals produced may be included erroneously in the flow-calculation process. Flow disturbances caused by fully opened valves, elbows, and flanged connections may provide conditions where proper ultrasonic signal frequency shifts occur so that successful flow-rate determinations can be made (Polysonics, 1986, p. 8).

The Spectra Fourier Flowmeter uses a single transducer assembly. Both the sending and receiving transducers are joined in a unit that can be held to the pipe surface by hand or mounted to the pipe with a spring and light chain. Information reported by the Spectra includes both graphic and digital displays. The availability of these displays, along with signal-processing and noise-filter enhancements, assist the user in removing nonflow-related noise signals, such as vibration and radio-frequency interference. These enhancements distinguish the operation of the Spectra from other reflective-doppler flowmeters (Controlotron, 1989, p. 5-40). A signal-strength readout on the Spectra is available to assist the user in determining the reliability of a measurement.

During this study, sufficient signal strengths were obtained where particulate-containing water was being pumped and at sites where air bubbles were present in the fluid, as in the case of submersible irrigation pumps set in shallow sand wells where cavitation occurred (see table 4, site index numbers 21 and 22, at the end of this report). At sites where particulate matter and air bubbles were absent from the flow, attempts were made to mount the transducer assembly near elbows of valves where microcavitation might occur. These attempts met with very limited success.

Data Collection and Analysis

Measurement Procedures

Pipe-flow measurement sites were selected to expose the four selected portable flowmeters to a variety of flow conditions. Sites were selected nonrandomly from the IDNR water-withdrawal data base. The data base includes all facilities in Indiana capable of withdrawing at least 100,000 gal/d. Managers of the selected water-withdrawal sites were contacted prior to actual site visits, and permission to attempt flow measurements was acquired. Whereas pipe diameters and pipe-wall thicknesses were measured by the field investigator, site managers provided other important information about the facility, such as the types and arrangement of pumps, the location of valves within the system, and the existence of pipe liners.

Whenever possible, each flowmeter was used in the manner suggested by the manufacturer to optimize the instrument's performance capabilities. For instance, at a single site, the Uniflow transit-time flowmeter transducers were mounted 15 pipe diameters downstream from an elbow in an attempt to avoid flow turbulence, whereas the Cross Correlation Flowmeter transducers were mounted only 3 pipe diameters downstream from the elbow in an attempt to utilize available flow turbulence. Typical of field situations, it was not possible to find ideal conditions for each flowmeter at all facilities. For flowmeters to be truly beneficial tools in improving or maintaining a water-withdrawal data base, the instruments must be able to perform under all sorts of adverse conditions. Flow-measurement attempts were made by each flowmeter at each site on each visit by using the best conditions available.

Each of the four noninvasive flowmeters used in this study assimilates signal data and calculates flow values in a different way. A method for determining a measured flow rate was developed for each meter and was used throughout the study period.

The Uniflow transit-time flowmeter offers many measurement-calculation and display options. The flowmeter can display digital values and graphs that represent instantaneous real-time flow and moving-mean flows of specified lengths of time. For this study, the Uniflow was set to display a 25-second mean flow every few seconds. The displayed values were observed for 1 minute. The mode of the values was recorded onto a note sheet along with the maximum and minimum flow values that occurred during the 1-minute period. The upstream and downstream transducers then were mounted in reverse locations according to the measurement procedures recommended by the manufacturer (James Robertson, Controlotron, oral commun., 1989), and a negative flow reading was taken. Flow values were recorded on the note sheet in the manner previously stated. The final measurement value was determined as the mean of the absolute values of the positive and negative modes.

When using the Cross Correlation Flowmeter, a measured flow value appears on a digital display panel after a successful correlation analysis. When performing flow calculations, outlying values are eliminated, and a limited number of values obtained earlier in the measurement attempt are incorporated in the statistical process. Thus, the displayed value is a smoothed running average of flow. The flow values are displayed every few seconds for at least 1 minute and recorded on the note sheet. The mode of the recorded values was assigned to be the measured flow.

The Hydra reflective-doppler flowmeter displays velocity with a circular dial and pointer. Fluctuations in the velocity display are smoothed by a dampening mechanism controlled, in part, by the operator. When the velocity display stabilizes, the velocity and pipe-size information are used to determine flow.

The Spectra Fourier Flowmeter has a digital display. Independent mean flows are displayed every few seconds. The instrument operator observes the digital readout and records flow measurements on the note sheet.

The instrument offers options for displaying various types of diagnostic information, including signal strength and noise reduction. Every attempt was made to use these options according to the manufacturer's guidelines to obtain the best possible flow measurements. When the displayed flow rate stabilized at optimum signal strengths, that rate was determined to be the measured flow.

For all of the selected noninvasive flowmeters, a successful measurement was not always achieved on the first setup (the first time the transducers were mounted to the pipe). At sites where a flowmeter had difficulty producing a measured flow value, the transducers were moved and remounted, in some cases, up to a dozen times, to ensure that there was ample opportunity to achieve a successful measurement with each flowmeter.

Throughout the study, pipe-dimension measurements were made in a consistent manner. Pipe-wall thickness was measured during each site visit with a Tokyo Keiki ultrasonic thickness gage. Outside pipe circumference was determined by use of a thin, flexible, metal tape. A Pioneer Digital Phototachometer was available for measuring revolutions per minute (rpm) of motor or engine drive shafts (fig. 7). Although pipe dimensions were needed to compute pipe flow, the rpm readings were used only as a potential reference for changes in flow rates. None of the flowmeters used in this study use rpm readings in flow computations.

Comparison of Measurement Results

A primary objective of this study was to determine the success of selected portable, noninvasive pipe flowmeters in obtaining flow measurements at withdrawal sites under a variety of field conditions. The overall success of the four selected flowmeters is summarized in table 1.

For a measurement to be considered successful in this study, a flowmeter simply needed to report a "reasonable" flow rate. At sites where flow rates were unknown, a reasonable flow rate was determined on the basis of pump size and flow conditions. For example, a flow measurement of 19 gal/min from

Figure 7. Digital phototachometer used to determine revolutions per minute of electric-turbine-pump drive shaft.

Table 1. *Number of attempted, succeeded, and failed flow measurements by four selected noninvasive flowmeters*

Flowmeter	Number of times attempted[1]	Number of times succeeded	Number of times failed			
			Failed[2]	Could not mount	Mechanical failure	Total of failures
Uniflow	88	81	2	5	0	7
Cross Correlation Flowmeter	93	85	8	0	0	8
Hydra	75	71	3	0	1	4
Spectra Fourier Flowmeter	92	19	72	0	1	73

[1] ATTEMPT is defined as a single site visit. Single or multiple tries during one site visit resulted in a succeed or a fail for each flowmeter.

[2] FAIL indicates the flowmeter reported an unreasonable flow reading or no reading at all.

an irrigation pump rated at 300 gal/min, when large amounts of water could be seen coming from the irrigation sprinklers, would not be considered a reasonable measured flow rate. The inability of a flowmeter to determine a measured value would also be considered a failed attempt.

Of the 88 measurement attempts using the Uniflow transit-time flowmeter, 81 were successful. Of the seven failed measurement attempts, five were due to a lack of exposed pipe length for mounting the transducers (see table 4, site index numbers 13, 33, 37, and 41), one was due to an apparent inability to transduce ultrasound successfully through the flow system (site index number 20), and one was due to a constantly changing flow rate coupled with brief and intermittent pump operating times during measurement initiation (site index number 40).

Of the 93 measurement attempts using the Cross Correlation Flowmeter, 85 were successful. Of the eight failed attempts, three were due to the apparent inability to transduce ultrasound through the flow system (site index numbers 7, 8, and 20), three were due to an apparent inability to cope with "noise" in the flow system (site index numbers 27 and 28), one was due to variable and intermittent flow conditions (site index number 33), and one was due to an apparent lack of turbulence in the flow system (site index number 11).

Of the 75 measurement attempts using the Hydra reflective-doppler flowmeter, 71 were successful. Of the four failed attempts, one failure was due to an apparent inability to transduce ultrasound successfully through the flow system (site index number 20), one was due to an apparent inability to cope with "noise" in the flow system (site index number 27), one was due to variable and intermittent flow conditions (site index number 33), and one was due to mechanical failure (site index number 11).

Of the 92 measurement attempts using the Spectra Fourier Flowmeter (a reflective-doppler device), 19 were successful. The Spectra Fourier Flowmeter is not well-suited to measure flows of water that lack air bubbles or particulates. Because a large number of the sites in this study involved "clean" ground-water withdrawals, this resulted in a large number of failures by the Spectra.

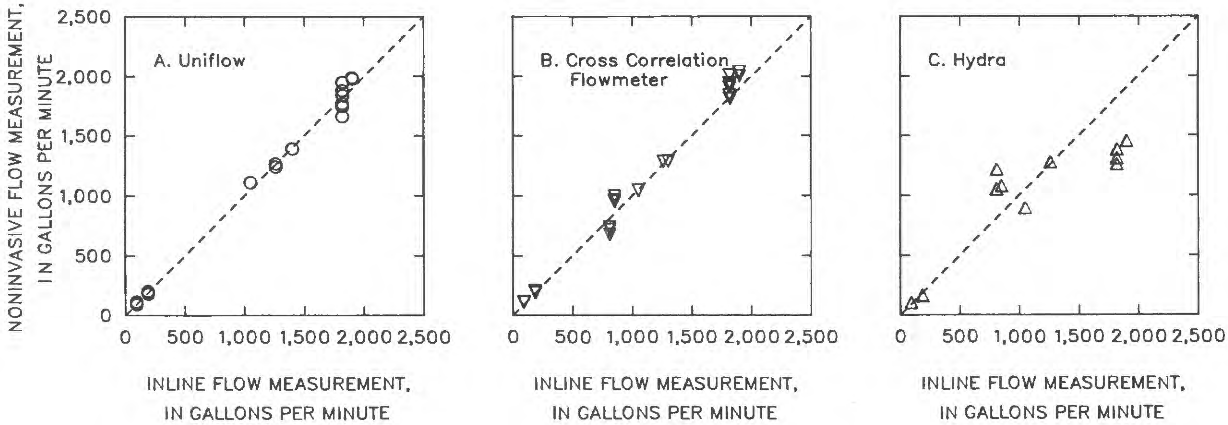

Figure 8. Relation of noninvasive flow measurements by (A) Uniflow flowmeter, (B) Cross Correlation Flowmeter, and (C) Hydra flowmeter to inline flow measurements.

At some flow-measurement sites, inline flowmeter measurements were available for comparison. A comparison of noninvasive and inline flow measurements is shown in figure 8. No measurements were obtained with the Spectra at any sites where inline flow measurements were available; therefore, no comparison of Spectra and inline measurements was made. It was not within the scope of this study to establish the accuracy of these inline flowmeters.

A comparison of the Uniflow, Cross Correlation Flowmeter, and Hydra measurements to inline measurements is provided in table 2. Values are shown only for sites where all three of the noninvasive flowmeters were successful. The table includes the means of flow measurements obtained during each visit by each flowmeter. One relation of the noninvasive flow measurement to the inline flowmeter measurement can be described as the log-percent difference in which the natural log of the ratio of noninvasive to inline flow measurement is multiplied by 100 (Tornqvist and others, 1985):

log (noninvasive flow measurement/inline flow measurement) X 100.

One advantage of comparing measurements in this manner is that the magnitude of the difference does not change whether the noninvasive flow measurement is compared to the inline flow measurement, or whether the inline flow measurement is compared to the noninvasive flow measurement. By reversing the numerator and the denominator, only the sign of the difference changes.

The Uniflow measurements agreed most closely with inline measurements. For the Uniflow, the mean log-percent difference was 2.8, with a standard deviation of 3.7 (table 2). The Cross Correlation Flowmeter had a mean log-percent difference of 7.5, with a standard deviation of 7.6. The Hydra had a mean log-percent difference of -14, with a standard deviation of 17.7.

Comparisons of mean measurements made using each of the four selected noninvasive flowmeters are shown in figures 9 to 12. On the basis of these graphic comparisons, the Uniflow measurements and Cross Correlation Flowmeter measurements agreed most closely with each other throughout the wide range of flows. Mean measurements were determined on the basis of successful measurements obtained from each flowmeter during each site visit. In table 3 at the end of the report, all flow measurements obtained during the study period are listed; however, many of the measured values are excluded from figures 9 to 12. More than one ultrasonic flowmeter cannot be operated simultaneously on the same pipe because of potential signal interference. Comparison of measured flows was made at sites where flow rates were stable through time. Sites with large fluctuations in flow rates during short periods of time were not included in figures 9 to 12. For instance, where ground water was delivered to chillers for temperature control of a large commercial building (site index number 18,

Table 2. *Comparison of noninvasive and inline flow measurements*

[All measurements are given in gallons per minute. Includes only those sites where inline flow measurements are available, and all three noninvasive flowmeters were successful]

Site index number	Date (month-day-year)	Inline measurement	Mean Uniflow measurement	Log-percent difference	Mean Cross Correlation Flowmeter measurement	Log-percent difference	Mean Hydra measurement	Log-percent difference
16	06-16-89	1,900	1,985	4.4	2,022	6.2	1,451	-27.0
19	06-23-89	1,260	1,252	-.6	1,284	1.9	1,274	1.1
34	07-11-89	90	97	7.5	109	19.2	102	12.5
35	07-11-89	185	188	1.6	206	10.8	167	-10.2
38	07-12-89	1,050	1,110	5.6	1,047	-.3	896	-15.9
16	08-09-89	1,820	1,840	1.1	1,869	2.7	1,380	-27.7
34	09-08-89	92	101	9.3	114	21.4	103	11.3
35	09-08-89	188	190	1.1	191	1.6	159	-16.8
16	09-11-89	1,818	1,812	-.3	1,978	8.4	1,309	-32.8
16	09-27-89	1,818	1,793	-1.4	1,876	3.1	1,257	-36.9
Minimum		90	97	-1.4	109	-.3	102	-36.9
Median		1,155	1,181	1.4	1,166	4.7	1,076	-16.3
Mean		1,022	1,037	2.8	1,070	7.5	810	-14.2
Maximum		1,900	1,985	9.3	2,022	21.4	1,451	12.5
Standard deviation		807	814	3.7	845	7.6	601	17.7

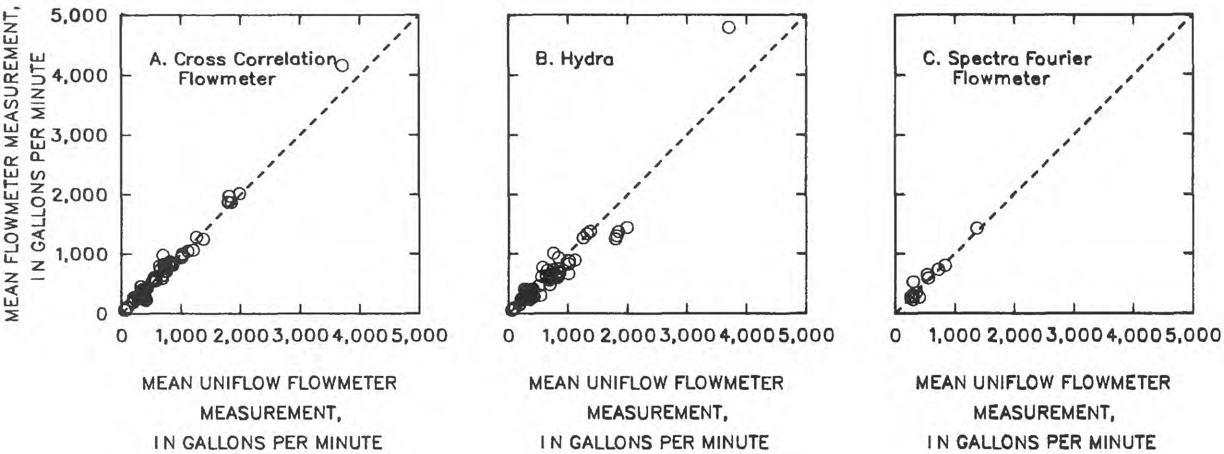

Figure 9. Relation of mean measurements reported by (A) Cross Correlation Flowmeter, (B) Hydra flowmeter, and (C) Spectra Fourier Flowmeter to mean measurements reported by Uniflow flowmeter.

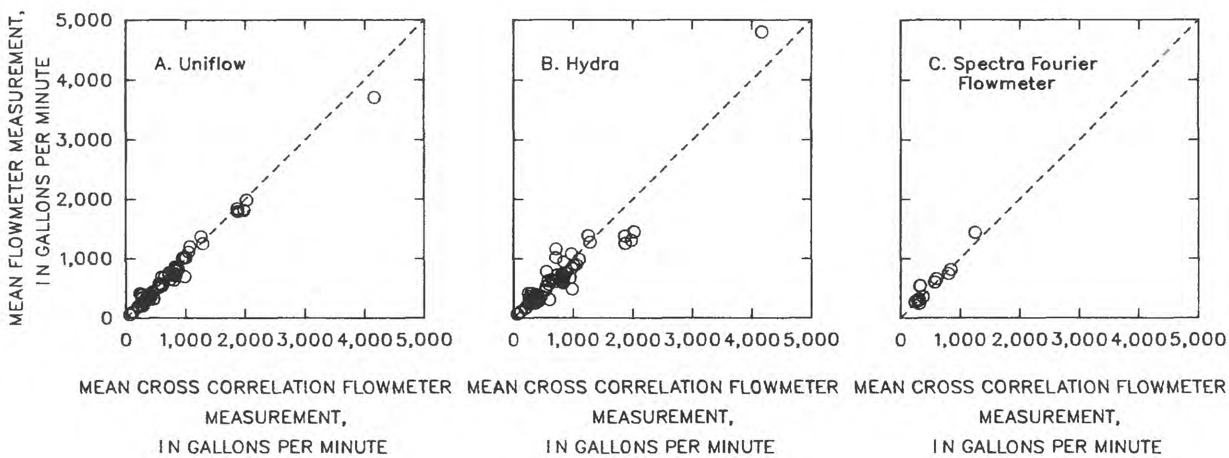

Figure 10. Relation of mean measurements reported by (A) Uniflow flowmeter, (B) Hydra flowmeter, and (C) Spectra Fourier Flowmeter to mean measurements reported by Cross Correlation Flowmeter.

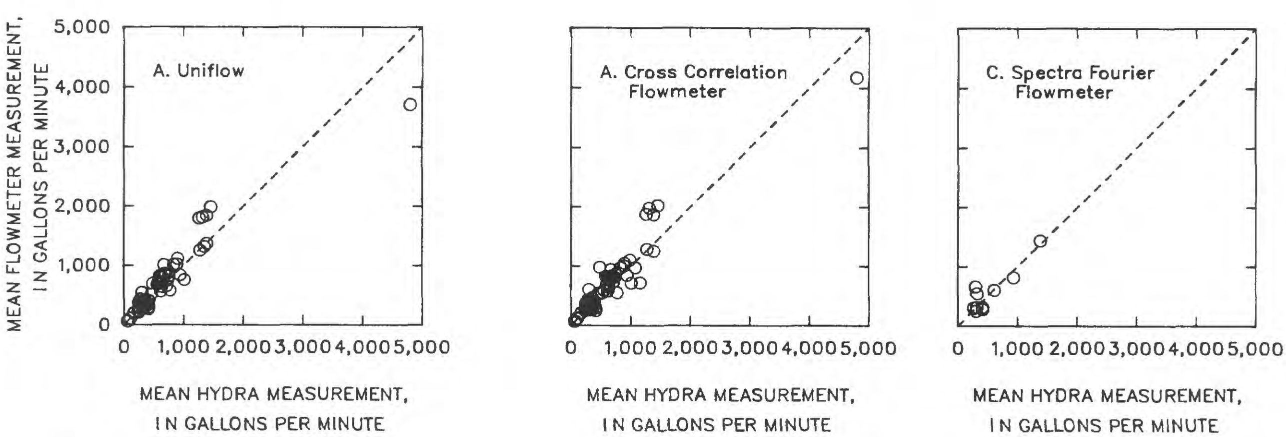

Figure 11. Relation of mean measurements reported by (A) Uniflow flowmeter, (B) Cross Correlation Flowmeter, and (C) Spectra Fourier Flowmeter to mean measurements reported by Hydra flowmeter.

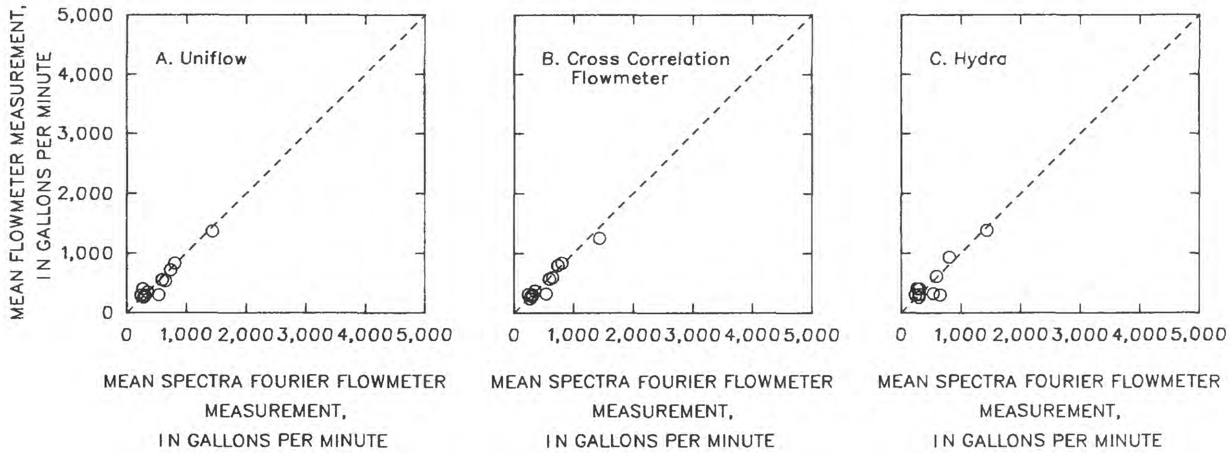

Figure 12. Relation of measurements reported by (A) Uniflow flowmeter, (B) Cross Correlation Flowmeter, and (C) Hydra flowmeter to mean measurements reported by Spectra Fourier Flowmeter.

table 4), flow varied erratically, depending on the demands of the cooling equipment. Because flow measurements could not be made simultaneously, the difference in measured flows reflected the change in flow as well as the change in pipe-flowmeter instrumentation. Also, some values were not included in figures 9 to 12 because the measurements were performed for the purpose of demonstration or training, and the author could not be certain that the methodologies used throughout the remainder of the study were strictly adhered to during those particular measurements. Flow measurements excluded from figures 9 to 12 are indicated in table 3.

Each pumping facility presented a unique combination of pipe configurations and flow conditions. Site descriptions and associated flowmeter measurements are shown in table 4 at the end of the report.

TIME TOTALIZERS

At facilities where pumping rates do not fluctuate significantly, estimates of water withdrawals can be determined by multiplying pumping rates by the time of pump operation. Methods available for determining the time of pump operation vary from one type of facility to another. At sites where pumps are turned on and off manually, operation times can be written into a log book. At sites where pumps are powered by electricity, diesel fuel, gasoline, liquid petroleum gas, and so forth, pump running time can be determined as a function of energy consumption (Hurr and Litke, 1989, p. 4). Many engines also have cumulative counters that record hours of running time (fig. 13). For electric pumps, time totalizers are available for installation within the electric current loop and are activated when the current passes through the time totalizer to the pump motor.

Two instruments have been developed recently at the U.S. Geological Survey, Hydrologic Instrumentation Facility that can provide an accurate and inexpensive method of determining running time of pumps. These instruments are the inductive time totalizer (ITT) and the vibration time totalizer (VTT).

The ITT is designed to monitor the running time of pumps and other equipment that are powered by electricity. It is a 2.2-in. by 3.8-in. box-shaped, battery-powered instrument that has a digital display of running time, precise to 0.01 hour (36 seconds). The batteries are replaceable. Basically, the flow of electric current to a pump is "sensed" inductively by wrapping a wire (connected to the ITT) around a lead wire that acts as a conductor to or from the pump (U.S. Geological Survey, Hydrologic Instrumentation Facility, written commun., 1989). Because the ITT senses current inductively and is not connected directly inline, the instrument generally is not subject to failure caused by power surges or lightning strikes. In this study, no ITT's were field tested.

The VTT is used to monitor the running time of pumps and other equipment and is

Figure 13. Gages on diesel engine that indicate revolutions per minute and running-time measurements.

activated by vibration. Earlier models of this instrument met with limited success; however, the most recent version appears to be accurate and reliable. The 2.5-in. by 5-in. box-shaped, battery-powered unit has a digital display that indicates running time to 0.01 hour. Properly charged, replaceable batteries can keep the unit in operation for many months.

The VTT is mounted at a location where vibration occurs when the pump is in operation. The VTT is capable of sensing vibration throughout a broad range of frequencies. The threshold level is achieved, and the cumulative-time unit is activated when vibration occurs in the frequency range of 20 to 2,000 hertz and the sustained acceleration is 0.5 gravity or more (Cordes and Minghua, 1988, p. 4). Although the VTT can be mounted to the pump, in many instances there is enough vibration found on the pipe carrying the flow of water. The unit can be mounted with glue, bolts, or tape, but the simplest method of installing the VTT is to clamp the unit onto the pipe with banding.

For this study, VTT's were mounted at five sites. At one public water supply (site index number 17, table 4), a VTT was banded to a 6-in. outside-diameter horizontal pipe about 2 ft downstream from an electric-turbine pump. The pump was operated intermittently. The VTT was activated by the vibration created by water flowing through the pipe. The facility had a permanent inductive time totalizer available for cumulative-time comparisons. The inductive time totalizer was housed in a protective shelter, whereas the VTT was exposed to the elements. The inductive time totalizer logged 2,340 hours of pump running time between May 16, 1989, and September 27, 1989, whereas the VTT logged 2,332 hours during that same period. The VTT operated without failure or need of maintenance.

At a sand-and-gravel mining operation (site index numbers 14 and 15, table 4), a sump pit is dewatered by means of two electric submersible pumps. Water is pushed from each of the pumps through a 4-in. outside-diameter wire-reinforced flexible canvas hose. The VTT's were banded to the canvas hoses within about 10 ft of the pumps, just downstream from a bend in the hoses. The units logged running time of their respective pumps with no apparent problems. When a VTT was banded to one of the hoses 50 ft farther downstream, the level of vibration was less than the activation threshold, and no running time was logged by the unit.

At an irrigation site (site index number 22, table 4), an electric submersible pump rated at 300 gal/min pumps water from a shallow sand well through a 6-in. steel pipe to a center-pivot irrigation system. Just above the pump, the pipe rises from the ground and travels horizontally about 10 ft, then bends downward and is again buried. The pipe travels underground about 150 ft, then rises near the center-pivot system. One VTT, described as the west VTT, was clamped onto the exposed horizontal pipe near the pump about 4 ft downstream from a 90-degree elbow. A second VTT, described as the east VTT, was clamped to the exposed horizontal pipe near the center pivot, about 1 ft downstream from a 90-degree elbow.

During installation of the two VTT's on July 6, 1989, the instrument operator noted that more vibration could be felt by hand at the west location than the east location. Upon the first inspection on July 8, both units logged similar running times. During an inspection on August 7, the west VTT was actively logging the operation of the pump, whereas the east VTT was not. By tapping the pipe near the east VTT with a screwdriver handle for more than 36 seconds, the east VTT was activated. This indicated that the unit did not fail. Rather, it indicated that, although the activation threshold was exceeded at both locations at the time of installation, the level of vibration at the east VTT had subsequently become less than the threshold. During an inspection on August 16, both VTT's were again actively logging the running time of the pump.

At the remaining sites where VTT's were mounted, there was no method available for comparing logged running times with other known running times. There were no mechanical failures with the seven VTT's mounted at the five sites.

On the basis of the performance of the VTT's installed at field sites for this study, the instrument appears capable of providing site owners with a means of determining the running times of pumps, provided they are installed in a location with sufficient vibration to activate them. The units appear unaffected by the heat, precipitation, and humidity associated with Indiana summers.

APPLICATION OF PORTABLE, NONINVASIVE PIPE FLOWMETERS AND TIME TOTALIZERS IN THE COLLECTION OF WATER-USE DATA

Portable, noninvasive pipe flowmeters and time totalizers have numerous potential applications. Although many site managers make a conscientious effort to report their very best estimates of withdrawals to IDNR, many are hampered in their effort simply because they do not know their actual pumping rate. Although site managers may see the benefits of knowing the actual amounts of water withdrawn for their fish ponds or corn crop, some may not see immediate economic benefits in the installation of inline flowmeters. With portable, noninvasive flowmeters, pumping rates can be determined at many sites without the mechanical disruption associated with conventional pump tests.

At sites where pumping rates do not vary significantly and perhaps, also, at sites where pumping rates vary in a predictable manner, time totalizers provide an easy and inexpensive way to determine pump running times for use in calculating water withdrawals. Instruments of this type are particularly useful at sites where pumps turn on and off automatically with no set time schedule or human interaction.

Although conditions at many water-withdrawal sites visited for this study were quite conducive to the use of portable flowmeters, conditions found at a number of sites posed problems. Where pumps are mounted flush with a concrete floor and all pipes are buried, easy access to exposed pipe may not be possible.

The Uniflow flowmeter required the greatest length of exposed pipe for mounting the transducers. To measure flow in pipes ranging from 1.25 to 8 in. in outside diameter, by means of standard mounting brackets, at least 16 in. of exposed pipe length is necessary. For pipes ranging from 6 to 24 in. in diameter, at least 28 in. of exposed pipe is required. To measure flows in 2- to 4-ft-diameter pipes, the standard mounting brackets for the Uniflow require at least 36 in. of exposed pipe. For some applications, shorter mounting brackets may be used and can be ordered specially from the manufacturer.

Depending on the flow conditions at a given site, use of the Cross Correlation Flowmeter requires at least one-to-three pipe diameters for transducer mounting. A minimum of 8 in. of exposed pipe is required. The Spectra and the Hydra could be mounted with only about 6 in. of pipe length exposed.

At some sites, pipes were wrapped in foam or fiber insulation. Because ultrasonic signals cannot be successfully transmitted through these types of materials, they were removed (fig. 14).

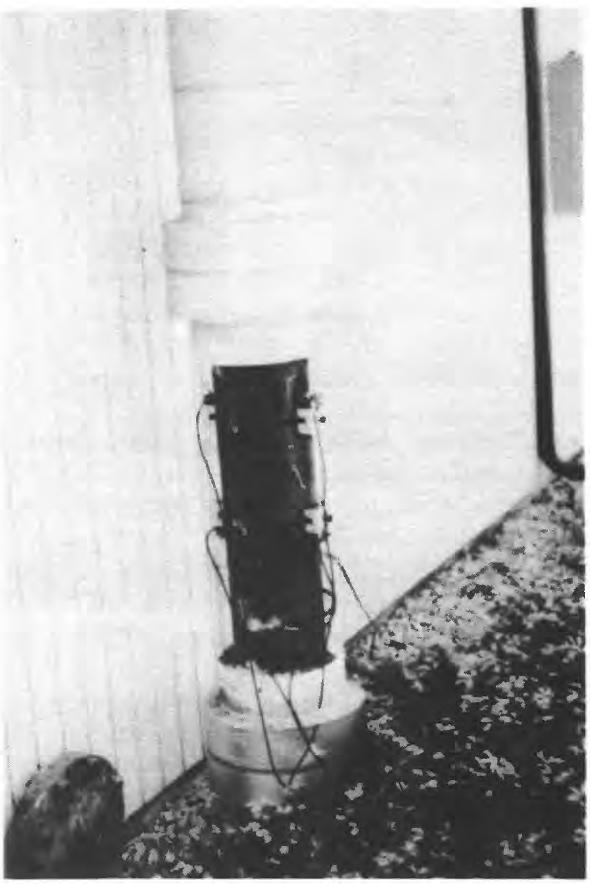

Figure 14. Pipe from which insulation has been removed to allow for mounting of ultrasonic transducers.

Pipe-flow measurements were less successful at sites where pumps force water into pressurized tanks (site index number 40, table 4). At these types of facilities, when pressure in the storage tank becomes less than a certain level, the pump is turned on automatically. The pump forces water into the storage tank until a certain pressure is achieved, then the pump automatically turns off. As the pump feeds water into the tank, the increasing pressure generally causes the water to flow at a decreasing rate. Rapid changes in flow rate, especially at sites where a pump may only run for a few seconds at a time, pose difficulties in flowmeter initiation procedures. For this study, because the reflective-doppler flowmeters required less time for start of measurement, there were fewer difficulties in situations where rapid changes in flow rate occurred.

In pipes where large amounts of scale have accumulated on the inner wall, the ultrasonic signal may be attenuated, which could prevent a successful pipe-flow measurement. This condition may be found at many types of facilities, including public supplies, limestone quarries, and industrial plants. Scale buildup was the suspected source of difficulties incurred at sites 7, 8, and 20 (table 4).

The amount of time required to obtain a measurement is always a consideration when budgeting time for data-collection activities. The reflective-doppler flowmeter transducers could be mounted and operational in less than 5 minutes. The Uniflow and the Cross Correlation Flowmeter generally required about 10 minutes. The Uniflow generally was successful in measuring flow on the first setup. The Cross Correlation Flowmeter often was successful in measuring flow on the first setup; however, remounting the transducers five or six times before a measurement attempt was successful was not uncommon. Remounting the Cross Correlation Flowmeter transducers required about 5 minutes.

The time required to make a typical pipe-flow measurement with a single non-invasive flowmeter was less than 45 minutes. This included unloading equipment from a vehicle, measuring pipe dimensions, preparing the pipe surface and mounting the transducers, obtaining a flow measurement, repeating the flow measurement, removing transducers, and reloading equipment back into the vehicle. This time did not include discussions with the site manager or searching a large facility for the optimum location at which to mount the transducers.

SUMMARY AND CONCLUSIONS

This report describes the results of a study to determine the feasibility of using portable, noninvasive pipe flowmeters and running-time totalizers at a variety of water-withdrawal facilities. One transit-time, one time-of-flight, and two reflective-doppler flowmeters were used for the study. Vibration time totalizers were installed and observed for the study.

Instantaneous pipe-flow measurements were attempted at 45 sites in Indiana. At many of these sites, measurement attempts were repeated. Of these sites, six had inline flowmeters available for comparison of measurements. Vibration time totalizers were mounted at five sites, with one site having an inductive time totalizer available for comparison.

Of the 88 measurement attempts using the transit-time flowmeter, 81 were successful. For this study, a flow measurement was successful when the instrument reported a "reasonable" rate of flow. A "reasonable" rate of flow was based on pump size and expected flow rates. Where inline-flowmeter measurements were available for comparison with noninvasive flowmeters, the transit-time flowmeter had a mean log-percent difference from the inline-flowmeter measurements of 2.8 and a standard deviation of 3.7. Of the three noninvasive flowmeters that succeeded at sites where inline flowmeters were located, the transit-time flowmeter agreed most closely with the inline-flowmeter measurements.

Of the 93 measurement attempts using the time-of-flight flowmeter, 85 were successful. Where inline measurements were available for comparison with the noninvasive flowmeters, the time-of-flight flowmeter had a mean log-percent difference from the inline measurements of 7.5, and a standard deviation of 7.6.

Of the 75 measurement attempts using one of the two reflective-doppler flowmeters, 71 of the attempts were successful. Where inline-flowmeter measurements were available for comparison with the noninvasive flowmeters, the reflective-doppler flowmeter had a mean log-percent difference from the inline measurements of -14 with a standard deviation of 18.

Of the 92 measurement attempts using the second reflective-doppler flowmeter, 19 were successful. The majority of failures were attributed to the difficulty that the reflective-doppler flowmeter exhibited in measuring flows that lacked sufficient particulates or air bubbles. Most of the sites in this study had nonparticulate flow. At sites where that reflective-doppler flowmeter was successful, no inline-flowmeter measurements were available for comparison.

During this study, the vibration time totalizers functioned well in the field. The instrument exhibited no adverse effects from the heat, precipitation, and humidity commonly associated with Indiana summers; however, observations at one site demonstrated that vibration time totalizers should be installed where vibration levels exceed the activation threshold during all times of pump operation. At one site where inductive time-totalizer measurements were available for comparison, the vibration time-totalizer measurements agreed with the inductive measurements within 8 hours after 2,340 hours of pump operation.

On the basis of observations made during this study, portable, noninvasive flowmeters and time totalizers currently available can be used successfully under a variety of field conditions. Use of these technologies is feasible for determining water use in Indiana.

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Table 3. *Noninvasive, pipe flowmeter measurements, March-September 1989*

[--, no measurement available]

Date (month-day-year)	Time (24-hour)	Site index number	Meter code[1]	Success code[2]	Measured rate of flow (gallons per minute)	Inline flowmeter rate of flow (gallons per minute)
03-14-89	1103	17	[3]2	1	404	--
03-14-89	1241	16	[3]2	1	1,286	1,300
05-10-89	1530	3	[3]2	5	--	--
05-10-89	1610	3	[3]4	1	200	--
05-10-89	1620	4	[3]4	1	216	--
05-18-89	1025	17	[3]2	1	383	--
05-18-89	1030	17	[3]4	2	--	--
05-18-89	1130	16	[3]2	6	3,418	1,400
05-18-89	1205	16	[3]1	1	1,390	1,400
05-22-89	1505	43	[3]4	1	225	--
05-22-89	1550	43	[3]1	5	--	--
05-22-89	1616	43	[3]2	1	216	--
05-23-89	0940	45	[3]1	5	--	--
05-23-89	0945	45	[3]4	2	--	--
05-23-89	1003	45	[3]2	1	795	--
05-23-89	1400	2	[3]1	1	730	--
05-23-89	1424	2	[3]2	1	791	--
05-23-89	1430	1	[3]4	2	--	--
05-23-89	1453	1	[3]2	1	816	--
05-23-89	1502	2	[3]2	1	781	--
05-23-89	1510	2	[3]4	2	--	--
05-30-89	1040	5	4	1	738	--
05-30-89	1135	5	1	1	920	--
05-30-89	1140	5	4	1	740	--
05-30-89	1229	5	2	1	798	--

Table 3. *Noninvasive, pipe flowmeter measurements, March-September 1989*--Continued

Date (month-day-year)	Time (24-hour)	Site index number	Meter code[1]	Success code[2]	Measured rate of flow (gallons per minute)	Inline flowmeter rate of flow (gallons per minute)
05-30-89	1239	6	2	1	371	--
05-30-89	1244	6	1	1	348	--
05-30-89	1254	6	4	1	350	--
05-30-89	1514	7	1	1	475	--
05-30-89	1450	7	[3]2	2	--	--
05-30-89	1530	7	[3]4	4	--	--
05-31-89	1204	9	[3]2	1	4,000	--
05-31-89	1210	9	[3]4	6	1,700	--
05-31-89	1223	9	[3]1	1	4,085	--
05-31-89	1235	9	[3]2	1	3,964	--
05-31-89	1355	10	[3]1	1	3,700	--
05-31-89	1408	10	[3]2	1	4,330	--
05-31-89	1415	10	[3]4	2	--	--
06-01-89	1041	12	[3]1	1	4,540	--
06-01-89	1122	12	[3]2	1	4,800	--
06-01-89	1133	12	[3]1	1	4,150	--
06-01-89	1140	12	[3]2	1	5,000	--
06-01-89	1145	12	[3]4	2	--	--
06-02-89	1017	8	1	1	1,067	--
06-02-89	1034	8	[3]2	6	575	--
06-02-89	1307	8	[3]2	6	5,959	--
06-02-89	1350	8	[3]4	6	540	--
06-02-89	1408	8	1	1	1,100	--
06-05-89	1351	5	4	1	781	--
06-05-89	1400	5	1	1	805	--
06-05-89	1430	5	2	1	838	--
06-05-89	1434	5	1	1	860	--
06-05-89	1445	5	4	1	834	--
06-05-89	1455	5	3	1	957	--
06-05-89	1545	5	3	1	920	--

Table 3. *Noninvasive, pipe flowmeter measurements, March-September 1989*--Continued

Date (month-day-year)	Time (24-hour)	Site index number	Meter code[1]	Success code[2]	Measured rate of flow (gallons per minute)	Inline flowmeter rate of flow (gallons per minute)
06-07-89	1342	13	2	1	996	850
06-07-89	1404	13	3	1	1,078	850
06-07-89	1408	13	2	1	953	850
06-07-89	1414	13	3	1	1,078	850
06-07-89	1428	13	2	1	964	850
06-07-89	1435	13	[3]4	2	--	850
06-07-89	1437	13	1	3	--	850
06-08-89	1139	14	[3]2	1	969	--
06-08-89	1200	15	1	1	1,200	--
06-08-89	1241	15	2	1	1,066	--
06-13-89	0937	1	3	1	648	--
06-13-89	0940	1	2	1	804	--
06-13-89	0952	1	1	1	780	--
06-13-89	0956	1	2	1	821	--
06-13-89	0958	1	3	1	648	--
06-13-89	1007	1	1	1	795	--
06-13-89	1015	1	[3]4	2	--	--
06-13-89	1046	2	1	1	810	--
06-13-89	1049	2	2	1	866	--
06-13-89	1053	2	3	1	768	--
06-13-89	1055	2	3	1	736	--
06-13-89	1100	2	[3]4	2	--	--
06-13-89	1210	3	3	1	236	--
06-13-89	1219	3	2	1	301	--
06-13-89	1228	3	[3]4	2	--	--
06-13-89	1236	3	2	1	244	--
06-13-89	1239	3	3	1	244	--

Table 3. *Noninvasive, pipe flowmeter measurements, March-September 1989*--Continued

Date (month-day-year)	Time (24-hour)	Site index number	Meter code[1]	Success code[2]	Measured rate of flow (gallons per minute)	Inline flowmeter rate of flow (gallons per minute)
06-13-89	1242	3	3	1	244	--
06-13-89	1357	3	1	1	202	--
06-13-89	1230	4	[3]4	2	--	--
06-13-89	1313	4	3	1	327	--
06-13-89	1324	4	2	1	278	--
06-13-89	1330	4	3	1	310	--
06-13-89	1414	4	1	1	265	--
06-13-89	1418	4	3	1	310	--
06-13-89	1421	4	2	1	285	--
06-14-89	0947	45	1	1	1,015	--
06-14-89	0950	45	2	1	984	--
06-14-89	0955	45	3	1	893	--
06-14-89	1000	45	2	1	1,021	--
06-14-89	1005	45	1	1	1,015	--
06-14-89	1010	45	3	1	880	--
06-14-89	1015	45	[3]4	2	--	--
06-16-89	1119	17	1	1	395	--
06-16-89	1123	17	3	1	366	--
06-16-89	1140	17	2	1	371	--
06-16-89	1152	17	1	1	385	--
06-16-89	1154	17	3	1	366	--
06-16-89	1157	17	2	1	376	--
06-16-89	1200	17	[3]4	2	--	--
06-16-89	1302	16	1	1	1,990	1,900
06-16-89	1308	16	2	1	2,004	1,900
06-16-89	1312	16	3	1	1,451	1,900
06-16-89	1316	16	1	1	1,980	1,900
06-16-89	1319	16	2	1	2,040	1,900

Table 3. *Noninvasive, pipe flowmeter measurements, March-September 1989*--Continued

Date (month-day-year)	Time (24-hour)	Site index number	Meter code[1]	Success code[2]	Measured rate of flow (gallons per minute)	Inline flowmeter rate of flow (gallons per minute)
06-16-89	1322	16	[3]4	2	--	1,900
06-19-89	1039	18	[3]2	6	2,464	--
06-19-89	1053	18	[3]3	1	596	--
06-19-89	1056	18	[3]3	6	988	--
06-19-89	1100	18	[3]2	1	665	--
06-19-89	1133	18	[3]1	1	535	--
06-19-89	1136	18	[3]3	6	1,082	--
06-19-89	1140	18	[3]4	2	--	--
06-23-89	1009	19	1	1	1,240	1,260
06-23-89	1024	19	2	1	1,284	1,260
06-23-89	1027	19	1	1	1,265	1,260
06-23-89	1035	19	3	1	1,274	1,260
06-23-89	1040	19	[3]4	2	--	1,260
06-23-89	1115	20	[3]1	2	--	--
06-23-89	1215	20	[3]2	2	--	--
06-23-89	1240	20	[3]3	2	--	--
06-23-89	1255	20	[3]4	2	--	--
06-26-89	1615	27	1	1	1,315	--
06-26-89	1619	27	[3]3	6	306	--
06-26-89	1630	27	[3]2	6	778	--
06-26-89	1638	27	[3]2	6	2,759	--
06-26-89	1657	27	[3]2	6	633	--
06-26-89	1705	27	1	1	1,312	--
06-26-89	1734	27	[3]2	6	3,161	--
06-26-89	1742	27	[3]2	6	3,891	--
06-26-89	1746	27	[3]4	6	141	--
06-26-89	1752	27	3	1	1,342	--
06-26-89	1756	27	1	1	1,315	--
06-26-89	1810	27	[3]2	6	864	--

Table 3. *Noninvasive, pipe flowmeter measurements, March-September 1989*--Continued

Date (month-day-year)	Time (24-hour)	Site index number	Meter code[1]	Success code[2]	Measured rate of flow (gallons per minute)	Inline flowmeter rate of flow (gallons per minute)
06-29-89	1208	15	[3]4	1	1,200	--
06-29-89	1229	14	[3]4	1	1,280	--
06-29-89	1348	15	[3]4	1	1,250	--
07-01-89	1132	21	2	1	317	--
07-01-89	1138	21	3	1	327	--
07-01-89	1156	21	1	1	300	--
07-01-89	1157	21	3	1	327	--
07-01-89	1200	21	2	1	329	--
07-01-89	1214	21	1	1	300	--
07-01-89	1323	21	4	1	356	--
07-01-89	1246	22	2	1	278	--
07-01-89	1251	22	3	1	411	--
07-01-89	1300	22	1	1	285	--
07-01-89	1304	22	2	1	302	--
07-01-89	1307	22	3	1	411	--
07-01-89	1315	22	1	1	290	--
07-01-89	1319	22	4	1	307	--
07-01-89	1454	23	2	1	603	--
07-01-89	1504	23	3	1	629	--
07-01-89	1509	23	[3]4	2	--	--
07-01-89	1529	23	1	1	685	--
07-01-89	1537	23	1	1	680	--
07-01-89	1541	23	3	1	644	--
07-01-89	1548	23	2	1	672	--
07-01-89	1550	23	1	1	680	--
07-01-89	1701	24	[3]3	6	135	--
07-01-89	1705	24	[3]4	2	--	--
07-01-89	1713	24	1	1	700	--
07-01-89	1723	24	2	1	595	--
07-01-89	1728	24	1	1	658	--

Table 3. *Noninvasive, pipe flowmeter measurements, March-September 1989*--Continued

Date (month-day-year)	Time (24-hour)	Site index number	Meter code[1]	Success code[2]	Measured rate of flow (gallons per minute)	Inline flowmeter rate of flow (gallons per minute)
07-01-89	1742	24	3	1	556	--
07-01-89	1737	24	2	1	576	--
07-01-89	1838	25	3	1	676	--
07-01-89	1841	25	[3]4	2	--	--
07-01-89	1847	25	2	1	831	--
07-01-89	1855	25	1	1	850	--
07-01-89	1857	25	[3]3	6	143	--
07-01-89	1901	25	2	1	836	--
07-01-89	1908	25	1	1	850	--
07-01-89	1950	26	3	1	631	--
07-01-89	1952	26	[3]4	2	--	--
07-01-89	1957	26	2	1	795	--
07-01-89	2010	26	1	1	630	--
07-02-89	1114	28	4	1	1,344	--
07-02-89	1145	28	[3]2	2	--	--
07-02-89	1157	28	3	1	1,431	--
07-02-89	1205	28	1	1	1,355	--
07-02-89	1252	28	[3]2	2	--	--
07-06-89	1241	28	1	1	1,370	--
07-06-89	1256	28	1	1	1,425	--
07-06-89	1258	28	3	1	1,355	--
07-06-89	1306	28	2	1	1,254	--
07-06-89	1313	28	4	1	1,533	--
07-06-89	1316	28	3	1	1,355	--
07-06-89	1339	28	[3]2	6	6,949	--
07-06-89	1350	28	1	1	1,410	--
07-06-89	1408	28	1	1	1,335	--
07-06-89	1414	28	3	1	1,402	--
07-06-89	1418	28	[3]4	6	1,025	--

Table 3. *Noninvasive, pipe flowmeter measurements, March-September 1989*--Continued

Date (month-day-year)	Time (24-hour)	Site index number	Meter code[1]	Success code[2]	Measured rate of flow (gallons per minute)	Inline flowmeter rate of flow (gallons per minute)
07-06-89	1549	27	1	1	1,218	--
07-06-89	1554	27	[3]3	6	345	--
07-06-89	1602	27	[3]2	6	1,685	--
07-06-89	1617	27	1	1	1,222	--
07-06-89	1623	27	[3]3	6	225	--
07-06-89	1625	27	[3]4	6	149	--
07-06-89	1632	27	[3]2	6	955	--
07-07-89	0953	24	[3]4	6	135	--
07-07-89	0956	24	3	1	481	--
07-07-89	1003	24	2	1	1,009	--
07-07-89	1013	24	1	1	688	--
07-07-89	1031	24	2	1	946	--
07-07-89	1045	24	1	1	690	--
07-07-89	1155	25	3	1	524	--
07-07-89	1145	25	1	1	815	--
07-07-89	1153	25	[3]4	6	115	--
07-07-89	1226	25	2	1	820	--
07-07-89	1233	25	1	1	800	--
07-07-89	1243	25	3	1	734	--
07-08-89	1132	26	[3]4	2	--	--
07-08-89	1143	26	3	1	674	--
07-08-89	1220	26	2	1	538	--
07-08-89	1301	26	1	1	570	--
07-08-89	1305	26	2	1	555	--
07-08-89	1311	26	3	1	869	--
07-08-89	1315	26	1	1	570	--
07-08-89	1500	23	[3]4	2	--	--
07-08-89	1509	23	2	1	710	--
07-08-89	1517	23	1	1	710	--
07-08-89	1527	23	2	1	708	--
07-08-89	1533	23	3	1	631	--

Table 3. *Noninvasive, pipe flowmeter measurements, March-September 1989*--Continued

Date (month-day-year)	Time (24-hour)	Site index number	Meter code[1]	Success code[2]	Measured rate of flow (gallons per minute)	Inline flowmeter rate of flow (gallons per minute)
07-08-89	1706	23	3	1	578	--
07-08-89	1640	21	3	1	414	--
07-08-89	1637	21	4	1	269	--
07-08-89	1728	21	2	1	236	--
07-08-89	1807	21	1	1	402	--
07-08-89	1810	21	3	1	409	--
07-08-89	1821	21	2	1	248	--
07-08-89	1856	22	2	1	290	--
07-08-89	1904	22	1	1	263	--
07-08-89	1905	22	3	1	409	--
07-08-89	1917	22	4	1	283	--
07-09-89	1035	29	2	1	708	--
07-09-89	1056	29	3	1	1,136	--
07-09-89	1103	29	1	1	744	--
07-09-89	1111	29	[3]4	2	--	--
07-09-89	1116	29	3	1	886	--
07-09-89	1118	29	2	1	708	--
07-09-89	1122	29	1	1	755	--
07-09-89	1232	30	2	1	560	--
07-09-89	1239	30	3	1	303	--
07-09-89	1242	30	2	1	596	--
07-09-89	1257	30	4	1	605	--
07-09-89	1320	30	1	1	536	--
07-10-89	1211	31	2	1	246	--
07-10-89	1221	31	1	1	222	--
07-10-89	1223	31	3	1	234	--
07-10-89	1225	31	[3]4	2	--	--

Table 3. *Noninvasive, pipe flowmeter measurements, March-September 1989*--Continued

Date (month-day-year)	Time (24-hour)	Site index number	Meter code[1]	Success code[2]	Measured rate of flow (gallons per minute)	Inline flowmeter rate of flow (gallons per minute)
07-10-89	1447	32	1	1	648	--
07-10-89	1451	32	2	1	730	--
07-10-89	1454	32	3	1	713	--
07-10-89	1458	32	[3]4	2	--	--
07-10-89	1506	32	1	1	642	--
07-10-89	1513	32	2	1	737	--
07-10-89	1516	32	3	1	721	--
07-11-89	1403	34	2	1	109	90
07-11-89	1414	34	3	1	102	90
07-11-89	1438	34	1	1	97	90
07-11-89	1505	34	[3]4	2	--	90
07-11-89	1447	35	1	1	188	185
07-11-89	1448	35	2	1	206	185
07-11-89	1452	35	3	1	167	185
07-11-89	1455	35	[3]4	2	--	185
07-12-89	1100	36	2	1	534	--
07-12-89	1113	36	3	1	460	--
07-12-89	1153	36	1	1	505	--
07-12-89	1200	36	[3]4	2	--	--
07-12-89	1236	37	2	1	1,100	--
07-12-89	1245	37	3	1	986	--
07-12-89	1250	37	[3]4	2	--	--
07-12-89	1255	37	[3]1	3	--	--
07-12-89	1354	38	1	1	1,110	1,050
07-12-89	1405	38	2	1	1,047	1,050
07-12-89	1412	38	3	1	896	1,050
07-12-89	1415	38	[3]4	2	--	1,050
07-12-89	1514	39	1	1	815	--
07-12-89	1517	39	[3]3	6	1,402	--
07-12-89	1521	39	2	1	850	--
07-12-89	1525	39	[3]4	2	--	--

Table 3. *Noninvasive, pipe flowmeter measurements, March-September 1989*--Continued

Date (month-day-year)	Time (24-hour)	Site index number	Meter code[1]	Success code[2]	Measured rate of flow (gallons per minute)	Inline flowmeter rate of flow (gallons per minute)
07-13-89	1139	40	[3]1	4	--	--
07-13-89	1117	40	[3]3	1	204	--
07-13-89	1131	40	[3]2	1	182	--
07-13-89	1142	40	[3]4	2	--	--
07-13-89	1359	41	3	1	520	--
07-13-89	1430	41	2	1	540	--
07-13-89	1435	41	[3]4	2	--	--
07-13-89	1435	41	[3]1	3	--	--
07-14-89	1017	42	[3]1	1	135	--
07-14-89	1028	42	[3]2	1	189	--
07-14-89	1035	42	[3]1	1	230	--
07-25-89	1120	10	[3]4	2	--	--
07-25-89	1132	10	3	1	4,812	--
07-25-89	1137	10	2	1	4,068	--
07-25-89	1147	10	1	1	3,670	--
07-25-89	1204	10	3	1	4,783	--
07-25-89	1200	10	2	1	4,265	--
07-25-89	1210	10	1	1	3,740	--
07-25-89	1413	9	[3]4	6	2,310	--
07-25-89	1416	9	[3]3	1	3,587	--
07-25-89	1420	9	[3]2	1	3,609	--
07-25-89	1436	9	[3]1	1	3,960	--
07-25-89	1442	9	[3]1	1	3,528	--
07-25-89	1443	9	[3]1	1	3,416	--
07-25-89	1446	9	[3]2	1	3,585	--
07-25-89	1447	9	[3]1	1	3,610	--
07-25-89	1452	9	[3]1	1	3,670	--
07-25-89	1453	9	[3]1	1	3,600	--
07-25-89	1457	9	[3]2	1	3,588	--
07-25-89	1458	9	[3]1	1	3,580	--
07-25-89	1459	9	[3]3	1	3,659	--
07-25-89	1502	9	[3]4	6	2,670	--

Table 3. *Noninvasive, pipe flowmeter measurements, March-September 1989*--Continued

Date (month-day-year)	Time (24-hour)	Site index number	Meter code[1]	Success code[2]	Measured rate of flow (gallons per minute)	Inline flowmeter rate of flow (gallons per minute)
07-27-89	1005	13	3	1	1,052	810
07-27-89	1048	13	3	1	1,214	810
07-27-89	1054	13	2	1	718	810
07-27-89	1058	13	2	1	739	810
07-27-89	1103	13	3	1	1,214	810
07-27-89	1120	13	2	1	677	810
07-27-89	1122	13	[3]4	2	--	810
07-27-89	1123	13	[3]1	3	--	810
08-01-89	1050	12	[3]3	1	2,735	--
08-01-89	1055	12	[3]2	1	4,250	--
08-01-89	1108	12	[3]1	1	4,020	--
08-01-89	1112	12	[3]2	1	4,265	--
08-01-89	1122	12	[3]1	1	3,990	--
08-01-89	1124	12	[3]3	1	2,601	--
08-01-89	1128	12	[3]3	1	3,135	--
08-01-89	1130	12	[3]4	2	--	--
08-01-89	1144	12	[3]2	1	4,220	--
08-01-89	1150	12	[3]1	1	3,990	--
08-01-89	1407	11	[3]4	2	--	--
08-01-89	1431	11	3	1	357	--
08-01-89	1441	11	1	1	328	--
08-01-89	1448	11	2	1	269	--
08-01-89	1516	11	1	1	326	--
08-01-89	1526	11	1	1	323	--
08-01-89	1535	11	2	1	368	--
08-01-89	1541	11	1	1	323	--
08-01-89	1543	11	3	1	300	--
08-03-89	1215	11	[3]4	2	--	--
08-03-89	1238	11	3	1	406	--
08-03-89	1307	11	1	1	330	--
08-03-89	1340	11	[3]2	2	--	--
08-03-89	1350	11	3	1	394	--

Table 3. *Noninvasive, pipe flowmeter measurements, March-September 1989*--Continued

Date (month-day-year)	Time (24-hour)	Site index number	Meter code[1]	Success code[2]	Measured rate of flow (gallons per minute)	Inline flowmeter rate of flow (gallons per minute)
08-03-89	1353	11	1	1	330	--
08-03-89	1438	11	3	1	283	--
08-03-89	1531	11	1	1	326	--
08-03-89	1544	11	3	1	283	--
08-03-89	1658	11	2	1	341	--
08-03-89	1704	11	1	1	326	--
08-03-89	1705	11	[3]4	2	--	--
08-03-89	1730	11	[3]4	2	--	--
08-03-89	1737	11	3	1	315	--
08-03-89	1740	11	2	1	255	--
08-03-89	1817	11	1	1	381	--
08-07-89	1503	22	4	1	292	--
08-07-89	1505	22	3	1	265	--
08-07-89	1516	22	1	1	266	--
08-07-89	1524	22	2	1	377	--
08-07-89	1538	22	1	1	269	--
08-07-89	1539	22	4	1	293	--
08-07-89	1540	22	3	1	265	--
08-07-89	1653	22	2	1	190	--
08-07-89	1719	21	4	1	306	--
08-07-89	1729	21	2	1	319	--
08-07-89	1753	21	1	1	290	--
08-07-89	1820	21	2	1	302	--
08-07-89	1831	21	1	1	289	--
08-07-89	1837	21	3	1	315	--
08-07-89	1842	21	4	1	304	--
08-08-89	1000	27	[3]4	2	--	--
08-08-89	1019	27	[3]2	6	324	--
08-08-89	1024	27	[3]2	6	2,810	--
08-08-89	1039	27	1	1	1,327	--
08-08-89	1045	27	[3]3	6	315	--

Table 3. *Noninvasive, pipe flowmeter measurements, March-September 1989*--Continued

Date (month-day-year)	Time (24-hour)	Site index number	Meter code[1]	Success code[2]	Measured rate of flow (gallons per minute)	Inline flowmeter rate of flow (gallons per minute)
08-08-89	1050	27	[3]3	6	210	--
08-08-89	1150	25	[3]4	2	--	--
08-08-89	1203	25	[3]3	6	180	--
08-08-89	1209	25	2	1	835	--
08-08-89	1219	25	1	1	861	--
08-08-89	1226	25	3	1	698	--
08-08-89	1233	25	2	1	791	--
08-08-89	1242	25	1	1	854	--
08-08-89	1325	24	[3]4	2	--	--
08-08-89	1337	24	[3]2	6	1,235	--
08-08-89	1340	24	3	1	578	--
08-08-89	1349	24	1	1	700	--
08-08-89	1402	24	2	1	824	--
08-08-89	1406	24	3	1	586	--
08-08-89	1414	24	1	1	703	--
08-09-89	1334	16	[3]4	2	--	1,820
08-09-89	1339	16	3	1	1,380	1,820
08-09-89	1355	16	2	1	1,926	1,820
08-09-89	1430	16	1	1	1,840	1,820
08-09-89	1435	16	2	1	1,812	1,820
08-09-89	1520	17	[3]4	2	--	--
08-09-89	1548	17	1	1	425	--
08-09-89	1554	17	2	1	420	--
08-09-89	1559	17	3	1	278	--
08-15-89	1120	43	4	1	232	--
08-15-89	1121	43	3	1	306	--
08-15-89	1202	43	1	1	296	--
08-15-89	1205	43	3	1	306	--
08-15-89	1215	43	[3]4	2	247	--

Table 3. *Noninvasive, pipe flowmeter measurements, March-September 1989*--Continued

Date (month-day-year)	Time (24-hour)	Site index number	Meter code[1]	Success code[2]	Measured rate of flow (gallons per minute)	Inline flowmeter rate of flow (gallons per minute)
08-15-89	1250	43	2	1	314	--
08-15-89	1404	44	[3]4	2	--	--
08-15-89	1405	44	3	1	61	--
08-15-89	1427	44	2	1	61	--
08-15-89	1429	44	3	1	61	--
08-15-89	1502	44	1	1	54	--
08-16-89	0914	45	1	1	1,004	--
08-16-89	0933	45	2	1	945	--
08-16-89	0943	45	3	1	831	--
08-16-89	0948	45	[3]4	2	--	--
08-16-89	0950	45	2	1	940	--
08-16-89	0954	45	3	1	504	--
08-16-89	1005	45	2	1	931	--
08-23-89	1238	5	1	1	561	--
08-23-89	1245	5	3	1	622	--
08-23-89	1253	5	4	1	595	--
08-23-89	1336	5	2	1	567	--
08-23-89	1338	5	3	1	626	--
08-23-89	1347	5	1	1	551	--
08-23-89	1350	5	4	1	595	--
08-23-89	1423	5	2	1	579	--
08-23-89	1426	5	3	1	604	--
08-23-89	1433	5	1	1	548	--
08-23-89	1439	5	2	1	570	--
09-08-89	1043	34	2	1	114	92
09-08-89	1112	34	1	1	89	92
09-08-89	1121	34	1	1	113	92
09-08-89	1137	34	[3]4	2	--	92
09-08-89	1224	34	3	1	103	92

Table 3. *Noninvasive, pipe flowmeter measurements, March-September 1989*--Continued

Date (month-day-year)	Time (24-hour)	Site index number	Meter code[1]	Success code[2]	Measured rate of flow (gallons per minute)	Inline flowmeter rate of flow (gallons per minute)
09-08-89	1150	35	1	1	202	188
09-08-89	1152	35	2	1	191	188
09-08-89	1201	35	1	1	179	188
09-08-89	1212	35	[3]4	2	--	188
09-08-89	1217	35	3	1	159	188
09-11-89	1350	16	2	1	1,945	1,818
09-11-89	1356	16	3	1	1,309	1,818
09-11-89	1424	16	1	1	1,745	1,818
09-11-89	1428	16	2	1	2,011	1,818
09-11-89	1444	16	1	1	1,880	1,818
09-11-89	1448	16	[3]4	2	--	1,818
09-11-89	1527	17	3	1	284	--
09-11-89	1601	17	2	1	389	--
09-11-89	1616	17	1	1	390	--
09-11-89	1620	17	[3]4	2	--	--
09-12-89	1245	11	[3]4	2	--	--
09-12-89	1256	11	1	1	332	--
09-12-89	1303	11	1	1	331	--
09-12-89	1308	11	2	1	380	--
09-12-89	1315	11	[3]4	2	--	--
09-12-89	1325	11	2	1	245	--
09-12-89	1336	11	2	1	202	--
09-12-89	1355	11	1	1	409	--
09-12-89	1438	11	[3]4	2	--	--
09-12-89	1443	11	2	1	395	--
09-12-89	1455	11	1	1	344	--
09-12-89	1458	11	2	1	414	--
09-12-89	1508	11	1	1	345	--

Table 3. *Noninvasive, pipe flowmeter measurements, March-September 1989*--Continued

Date (month-day-year)	Time (24-hour)	Site index number	Meter code[1]	Success code[2]	Measured rate of flow (gallons per minute)	Inline flowmeter rate of flow (gallons per minute)
09-20-89	0935	45	2	1	968	--
09-20-89	0954	45	1	1	1,009	--
09-20-89	0958	45	2	1	990	--
09-20-89	1020	45	3	1	856	--
09-20-89	1021	45	[3]4	2	--	--
09-20-89	1027	45	3	1	806	--
09-20-89	1030	45	2	1	956	--
09-20-89	1253	2	[3]4	2	--	--
09-20-89	1256	2	2	1	818	--
09-20-89	1259	2	3	1	640	--
09-20-89	1321	2	2	1	818	--
09-20-89	1346	2	3	1	560	--
09-20-89	1355	2	1	1	819	--
09-20-89	1402	1	[3]4	2	--	--
09-20-89	1359	1	3	1	760	--
09-20-89	1405	1	3	1	800	--
09-20-89	1417	1	1	1	740	--
09-20-89	1420	1	2	1	818	--
09-20-89	1430	1	2	1	790	--
09-20-89	1436	1	3	1	640	--
09-21-89	1125	11	[3]4	2	--	--
09-21-89	1144	11	3	1	382	--
09-21-89	1203	11	1	1	359	--
09-21-89	1205	11	3	1	382	--
09-21-89	1230	11	1	1	360	--
09-21-89	1241	11	3	1	382	--
09-21-89	1243	11	2	1	385	--
09-21-89	1304	11	2	1	395	--
09-21-89	1250	11	[3]4	2	--	--
09-21-89	1335	11	2	1	340	--

Table 3. *Noninvasive, pipe flowmeter measurements, March-September 1989*--Continued

Date (month-day-year)	Time (24-hour)	Site index number	Meter code[1]	Success code[2]	Measured rate of flow (gallons per minute)	Inline flowmeter rate of flow (gallons per minute)
09-21-89	1346	11	3	1	321	--
09-21-89	1417	11	1	1	304	--
09-21-89	1425	11	1	1	321	--
09-21-89	1428	11	3	1	312	--
09-21-89	1432	11	2	1	345	--
09-21-89	1439	11	1	1	322	--
09-21-89	1254	11	[3]4	2	--	--
09-21-89	1515	11	1	1	336	--
09-21-89	1533	11	2	1	256	--
09-21-89	1545	11	3	1	264	--
09-21-89	1553	11	1	1	337	--
09-21-89	1555	11	3	1	264	--
09-21-89	1559	11	2	1	262	--
09-27-89	1353	16	2	1	1,908	1,818
09-27-89	1406	16	1	1	1,950	1,818
09-27-89	1407	16	[3]4	2	--	1,818
09-27-89	1409	16	3	1	1,257	1,818
09-27-89	1419	16	1	1	1,660	1,818
09-27-89	1421	16	3	1	1,257	1,818
09-27-89	1425	16	2	1	1,843	1,818
09-27-89	1439	16	1	1	1,770	1,818
09-27-89	1521	17	[3]4	2	--	--
09-27-89	1527	17	2	1	358	--
09-27-89	1539	17	1	1	354	--
09-27-89	1544	17	3	1	238	--
09-27-89	1546	17	2	1	368	--

Table 3. *Noninvasive, pipe flowmeter measurements, March-September 1989*--Continued

Date (month-day-year)	Time (24-hour)	Site index number	Meter code[1]	Success code[2]	Measured rate of flow (gallons per minute)	Inline flowmeter rate of flow (gallons per minute)
09-27-89	1555	17	1	1	362	--
09-27-89	1556	17	3	1	238	--
09-27-89	1607	17	1	1	372	--
09-29-89	1241	6	1	1	326	--
09-29-89	1300	6	1	1	305	--
09-29-89	1315	6	[3]4	2	--	--
09-29-89	1325	6	3	1	356	--
09-29-89	1405	6	2	1	539	--
09-29-89	1416	6	2	1	376	--

[1] Meter code: 1 = Uniflow flowmeter; 2 = Cross Correlation Flowmeter; 3 = Hydra flowmeter; 4 = Spectra Fourier Flowmeter.

[2] Success code: 1 = succeeded; 2 = failed; 3 = failure because insufficient pipe length to mount transducers; 4 = measuring equipment failure; 5 = operator error; 6 = reading obtained by flowmeter, but measured value probably invalid based on expected flow.

[3] Measurement not included in figures 9 to 12 due to failure of measurement attempt, large fluctuations in actual flow, or possible variation in flow measurement procedure (see pages 12 and 15).

Table 4. *Description of measurement sites and flow measurements, March-September 1989*

[ID = inside diameter; DS = downstream; US = upstream; Corr FM = Cross Correlation Flowmeter; HP = horsepower; LBS = pounds. All measurements expressed in gallons per minute. --, not available]

Site number 1.
FISH HATCHERY # 1, SITE A.
Commercial. Ground water pumped to aeration tanks.
Ductile iron pipe, no liner. Vertical. Flow up.
8.09-inch inside diameter. 0.517-inch wall thickness.
MOUNTED: All flowmeters mounted at least 40 inches DS of elbow.
Electric-turbine pump.
Flow steady.

Date (month-day)	Flow measurement				
	Inline	Uniflow	Corr FM	Hydra	Spectra
5-23	--	730	816	no attempt	failed
6-13	--	780, 795	804, 821	648, 648	failed
9-20	--	740	818, 790	760, 800, 640	failed

Site number 2.
FISH HATCHERY # 1, SITE B.
Commercial. Ground water pumped to aeration tanks.
Ductile iron pipe, no liner. Vertical. Flow up.
8.09-inch ID. 0.517-inch wall thickness.
MOUNTED: All flowmeters mounted at least 40 inches DS of elbow.
Electric-turbine pump.
Flow steady.

Date (month-day)	Flow measurement				
	Inline	Uniflow	Corr FM	Hydra	Spectra
5-23	--	no attempt	791, 781	no attempt	failed
6-13	--	810	866	768, 736	failed
9-20	--	819	818, 818	640, 560	failed

Table 4. *Description of measurement sites and flow measurements, March-September 1989*--Continued

Site number 3.

FISH HATCHERY # 1, SITE C.

Commercial. Ground water that has been aerated is piped to fish ponds.

Ductile iron pipe, no liner.

4.11-inch ID. 0.350-inch wall thickness.

MOUNTED: Uniflow mounted on horizontal, 18 inches DS elbow.
Other meters mounted on vertical, about 10 inches DS of elbow, flow up.
Spectra attempted at several locations on pipe.

FLOW: 220 gallons per minute based on "depth of flow over drop box," and imprecise rating.
Flow steady.

	Flow measurement				
Date (month-day)	Inline	Uniflow	Corr FM	Hydra	Spectra
6-13	--	202	301, 244	236, 244, 244	failed

Site number 4.

FISH HATCHERY # 1, SITE D.

Commercial. Ground water that has been aerated is piped to fish ponds.

Ductile iron pipe, no liner.

4.11-inch ID. 0.350-inch wall thickness.

MOUNTED: Uniflow mounted on horizontal, 18 inches DS elbow.
Other meters mounted on vertical, about 10 inches DS of elbow, flow up.
Spectra attempted at several locations on pipe.

FLOW: 220 gallons per minute based on "depth of flow over drop box," and imprecise rating.
Flow steady.

	Flow measurement				
Date (month-day)	Inline	Uniflow	Corr FM	Hydra	Spectra
6-13	--	265	278, 285	327, 310, 310	failed

Table 4. *Description of measurement sites and flow measurements, March-September 1989*--Continued

Site number 5.
LIMESTONE QUARRY # 1, SITE A.
Mining. Surface water pumped from sump pit for dewatering. Water contains sediment.
Steel pipe, somewhat pitted. Pipe rises at about a 70-degree angle, flow up.
6.13-inch ID. 0.270-inch wall thickness.
MOUNTED: Uniflow mounted about 5 feet DS of elbow, Cross Correlation Flowmeter about 3.5 feet DS of elbow, and other meters attempted at several locations.
Diesel pump. A large amount of vibration and pump noise at measuring point.
Flow is fairly steady.
COMMENT: Uniflow reading on 5-30 is an outlier, possibly due to operator error.
Note: Diesel engine on pump was "throttled down" on 8-23, reducing flow.

Date (month-day)	Flow measurement				
	Inline	Uniflow	Corr FM	Hydra	Spectra
5-30	--	920	798	no attempt	738, 740
6-5	--	805, 860	838	957, 920	781, 834
8-23	--	561, 551, 548	567, 579, 570	622, 626, 604	595, 595

Site number 6.
LIMESTONE QUARRY # 1, SITE B.
Mining. Surface water pumped from sump pit for dewatering. Water contains sediment.
Steel pipe, somewhat pitted. Pipe rises at about a 70-degree angle, flow up.
6.13-inch ID. 0.270-inch wall thickness.
MOUNTED: Uniflow mounted about 5 feet DS of elbow, Cross Correlation Flowmeter about 3.5 feet DS of elbow, and other meters attempted at several locations.
Electric submersible pump (uses same pipelines as site number 5 diesel pump).
Flow is fairly steady.
COMMENT: In the 2 weeks prior to 9-29 visit, there was no rain, resulting in very clear water in sump pit. Lack of sediment in water is probable cause for Spectra failure on that visit.

Date (month-day)	Flow measurement				
	Inline	Uniflow	Corr FM	Hydra	Spectra
5-30	--	348	371	no attempt	350
9-29	--	326, 305	539, 376	356	failed

Table 4. *Description of measurement sites and flow measurements, March-September 1989*--Continued

Site number 7.
LIMESTONE QUARRY # 2, SITE A.
Mining. Surface water pumped from sump pit for dewatering.
Wound steel pipe. Horizontal with slight rise. Flow up.
11.72-inch ID. 0.153-inch wall thickness.
MOUNTED: Uniflow mounted about 20 feet DS of union, and other meters attempted at several locations.
One electric pump running.
Flow should be fairly steady.
COMMENT: Although there is no practical way to inspect inside of pipe, possible buildup of calcium carbonate is probable cause for two of the flowmeters to fail.

Flow measurement					
Date (month-day)	Inline	Uniflow	Corr FM	Hydra	Spectra
5-30	--	475	failed	no attempt	failed

Site number 8.
LIMESTONE QUARRY # 2, SITE B.
Mining. Surface water pumped from sump pit for dewatering.
Wound steel pipe. Horizontal with slight rise. Flow up.
11.72-inch ID. 0.153-inch wall thickness.
MOUNTED: Uniflow mounted about 20 feet DS of union, and other meters attempted at several locations.
Two electric pumps running simultaneously, pushing water through the single pipe.
Flow should be fairly steady.
COMMENT: Although there is no practical way to inspect inside of pipe, possible buildup of calcium carbonate is probable cause for two of the flowmeters to fail.

Flow measurement					
Date (month-day)	Inline	Uniflow	Corr FM	Hydra	Spectra
6-2	--	1067, 1100	failed	no attempt	failed

Table 4. *Description of measurement sites and flow measurements, March-September 1989*--Continued

Site number 9.
COAL MINE # 1, SITE A (COAL SLURRY).
Mining. This coal slurry containing about 10-percent fines is pumped from washing area.
Polyethylene pipe, lies on ground, somewhat horizontal. Many gradual bends in pipe.
12.1-inch ID. 1.0-inch wall thickness.
MOUNTED: All flowmeters mounted several hundred feet from any sharp elbows.
Flow very unsteady, due to many reasons such as friction in pipe, and so forth.
Due to unsteady flow, direct comparisons of flow readings should not be made.
COMMENT: The Spectra measured a much smaller flow. Probable cause for small flow measurement is that the signal is being reflected by the slower moving suspended particles near the pipe wall, and fails to penetrate to the faster moving fluid near the center of the pipe.

Date (month-day)	Flow measurement: Inline	Uniflow	Corr FM	Hydra	Spectra
5-31	--	4085	4000, 3964	no attempt	1700
7-25	--	3960, 3528, 3416, 3610, 3670, 3600, 3580	3609, 3586, 3588	3587, 3659	2310, 2670

Site number 10.
COAL MINE # 1, SITE B.
Mining. Surface water is pumped from lake and piped to mine for washing, and so forth.
Steel pipe, horizontal.
15.4-inch ID. 0.32-inch wall thickness.
MOUNTED: Uniflow mounted about 90 feet DS of pump. Cross Correlation flowmeter mounted about 90 feet DS of pump on 5-31, and 56 inches DS of pump on 7-25. Other meters attempted at several locations. No bends in pipe between pump and measuring sections.
350 HP electric pump.
FLOW: Site manager expects about 3,600 gallons per minute, based on general conversation at site.
Flow fairly steady.

Date (month-day)	Flow measurement: Inline	Uniflow	Corr FM	Hydra	Spectra
5-31	--	3700	4330	no attempt	failed
7-25	--	3670, 3740	4068, 4265	4812, 4783	failed

Table 4. *Description of measurement sites and flow measurements, March-September 1989*--Continued

Site number 11.

COAL MINE # 1, SITE C.

Mining. This electric-submersible pump was installed to withdraw ground water before it reaches the active mining pit.

This pump pushes ground water through 3.5-inch ID, polyethylene pipe a distance of 100 feet at a 45-degree angle to surface. At surface, after a 45-degree elbow, water travels horizontally about 50 feet through a 3.5-inch ID, black polyethylene pipe, which then connects to a 5.87-inch ID, steel pipe, and finally connects to a 7.09-inch polyethylene pipe. Water is pushed several hundred feet over a hill and down into a creek. Although measurements were made on the different pieces of pipe, on a given day the flow rate should be the same.

MOUNTED: On all three pipe sections, the Uniflow was mounted several feet DS of any turbulent-causing fixtures, and the Cross Correlation Flowmeter was mounted just downstream of unions or elbows. The other meters were attempted at several locations.

...ON 3.5-INCH ID BLACK POLYETHYLENE PIPE

	Flow measurement				
Date (month-day)	Inline	Uniflow	Corr FM	Hydra	Spectra
8-1	--	328	269	357	failed
8-3	--	381	255	315	failed
9-12	--	409	245, 202	no attempt	failed
9-21	--	336, 337	256, 262	264, 264	failed

...ON 5.87-INCH ID STEEL PIPE

	Flow measurement				
Date (month-day)	Inline	Uniflow	Corr FM	Hydra	Spectra
8-1	--	323, 323	368	300	failed
8-3	--	326, 326	341	283, 283	failed
9-12	--	332, 331	380	no attempt	failed
9-21	--	304, 321, 322	340, 345	321, 312	failed

Table 4. *Description of measurement sites and flow measurements, March-September 1989*--Continued

Site number 11--Continued.

...ON 7.09-INCH ID POLYETHYLENE PIPE

Date (month-day)	Flow measurement				
	Inline	Uniflow	Corr FM	Hydra	Spectra
8-1	--	no attempt	no attempt	no attempt	failed
8-3	--	330, 330	failed	406, 394	failed
9-12	--	344, 345	395, 414	mechanical failure	failed
9-21	--	359, 360	385, 395	382, 382, 382	failed

Table 4. *Description of measurement sites and flow measurements, March-September 1989*--Continued

Site number 12.
INDUSTRY # 1.
Industrial. Ground water piped almost 1 mile to measurement site, then about 3 miles to storage tank at plant.
Steel pipe, somewhat pitted, horizontal.
16.5-inch ID. 0.61-inch wall thickness.
MOUNTED: Uniflow mounted about 15 feet DS of valve. Cross Correlation Flowmeter about 1 foot DS of union. Hydra about 1.5 feet DS of union. Spectra attempted at several locations on pipe.
On first visit, four electric pumps running: "one big pump and three smaller ones."
On second visit, one of the smaller pumps was offline.
Water from all pumps fed into main line. Flow in main line measured.
Flow is fairly unsteady. High pressure and distance pumped results in flow variations.

	Flow measurement				
Date (month-day)	Inline	Uniflow	Corr FM	Hydra	Spectra
6-1	--	4540, 4150	4800, 5000	no attempt	failed
8-1	--	4020, 3990, 3990	4250, 4265, 4220	2735, 2601, 3135	failed

Site number 13.
PUBLIC WATER SUPPLY # 2.
Public-water supply. Ground water is pumped to treatment facility.
Steel pipe. Vertical. Flow down. Only 15 inches of pipe available for measurement.
7.92-inch ID. 0.58-inch wall thickness.
MOUNTED: Uniflow could not be mounted due to shortness of pipe between elbow and concrete floor. Other meters mounted about 10 inches DS of elbow.
Electric-turbine pump, 40 HP.
Flow should be steady.

	Flow measurement				
Date (month-day)	Inline	Uniflow	Corr FM	Hydra	Spectra
6-7	850 from inline meter	could not mount -failed	996, 953, 964	1078, 1078	failed
7-27	810 from inline meter	could not mount -failed	718, 739, 677	1052, 1214, 1214	failed

Table 4. *Description of measurement sites and flow measurements, March-September 1989*--Continued

Site number 14.

SAND AND GRAVEL QUARRY # 1, SITE A.

Mining. Surface water, dewatering from pit.
(This system runs parallel to system at site B but is a separate system.)
Pump feeds water up hill through a collapsible hose, which then feeds
a horizontal 6-inch polyvinyl-chloride pipe. Water free falls from this pipe.
Measurement was made on polyvinyl-chloride pipe. 5.94-inch ID. 0.345-inch wall thickness.
MOUNTED: All flowmeters mounted about 8 inches from end of pipe.
Electric-submersible pump.
FLOW: 850 gallons per minute measured at outflow with "calibrated stick."
Flow is very steady.

	Flow measurement				
Date (month-day)	Inline	Uniflow	Corr FM	Hydra	Spectra
6-8	--	no attempt	969	no attempt	mechanical failure
6-29	--	no attempt	no attempt	no attempt	1280

Site number 15.

SAND AND GRAVEL QUARRY # 1, SITE B. INDENTIFICATION # 290.

Mining. Surface water, dewatering from pit.
(This system runs parallel to system at site A, but is a separate system.)
Pump feeds water up hill through a collapsible hose, which then feeds
a horizontal 6-inch polyvinyl-chloride pipe. Water free falls from this pipe.
Measurement was made on polyvinyl-chloride pipe. 5.94-inch ID. 0.345-inch wall thickness.
MOUNTED: All flowmeters mounted about 8 inches from end of pipe.
Electric-submersible pump.
FLOW: 1,100 gallons per minute measured at outflow with "calibrated stick."
Flow is very steady.

	Flow measurement				
Date (month-day)	Inline	Uniflow	Corr FM	Hydra	Spectra
6-8	--	1200	1066	no attempt	no attempt
6-29	--	no attempt	no attempt	no attempt	1200, 1250

Table 4. *Description of measurement sites and flow measurements, March-September 1989*--Continued

Site number 16.

PUBLIC WATER SUPPLY # 1, SITE A.

Public-water supply. Ground water has been filtered. Water measured as it exits plant.
Steel pipe. Vertical. Flow up.
12.0-inch ID. 0.40-inch wall thickness.
MOUNTED: Uniflow mounted about 70 inches DS of elbow. Cross Correlation Flowmeter about 30 inches DS of elbow. Hydra about 40 inches DS of elbow. Spectra attempted at several locations on pipe.
Flow should be fairly steady.

Date (month-day)	Flow measurement				
	Inline	Uniflow	Corr FM	Hydra	Spectra
3-14	1300 from inline meter	no attempt	1286	no attempt	no attempt
5-18	1400	1390	3418	no attempt	failed
6-16	1900	1990, 1980	2004, 2040	1451	failed
8-9	1820	1840	1926, 1812	1380	failed
9-11	1818	1745, 1880	1945, 2011	1309	failed
9-27	1818	1950, 1660, 1770	1908, 1843	1257, 1257	failed

Table 4. *Description of measurement sites and flow measurements, March-September 1989*--Continued

Site number 17.
PUBLIC WATER SUPPLY # 1, SITE B.
Public-water supply. Ground water is pumped to filtration plant.
Steel pipe, horizontal.
6.11-inch ID. 0.28-inch wall thickness.
MOUNTED: Uniflow mounted 11 inches DS of pump. Cross Correlation Flowmeter 10 inches DS of pump. Hydra 33 inches DS of pump.
Spectra attempted at several locations on pipe.
Electric-turbine pump.
Flow should be fairly steady. However, because more than this one pump feeds water into a main line, output from this pump will be affected by how many other pumps will be on at the time of the measurement. Measurement at pump, not on main line.

Date (month-day)	Flow measurement				
	Inline	Uniflow	Corr FM	Hydra	Spectra
3-14	--	no attempt	404	no attempt	no attempt
5-18	--	no attempt	383	no attempt	failed
6-16	--	395, 385	371, 376	366, 366	failed
8-9	--	425	420	278	failed
9-11	--	390	389	284	failed
9-27	--	354, 362, 372	358, 368	238, 238	failed

Table 4. *Description of measurement sites and flow measurements, March-September 1989*--Continued

Site number 18.
INDUSTRY # 2.
Industrial. Ground water sent to chillers for climate control of building.
Steel pipe, horizontal.
8.00-inch ID. 0.340-inch wall thickness.
MOUNTED: Uniflow mounted 16 inches US of pressure plate. Cross Correlation Flowmeter 4 inches US of pressure plate. Hydra 14 inches DS of valve. Spectra attempted at several locations on pipe.
Electric-turbine pump.
To keep chillers at a constant temperature, pressure is varied to increase or decrease flow to chillers. Thus, water flowing through pipe at measurement site will vary substantially through time, and a direct comparison should not be made between flowmeter readings.

	Flow measurement				
Date (month-day)	Inline	Uniflow	Corr FM	Hydra	Spectra
6-19	--	535	665	596	failed

Site number 19.
INDUSTRY # 3, SITE A.
Industrial. Ground water is pumped for industrial use.
Steel pipe, horizontal, some corrosion and flaked paint.
10.1-inch ID. 0.372-inch wall thickness.
MOUNTED: Uniflow mounted about 25 feet DS of elbow. Cross Correlation Flowmeter 8 inches DS of elbow. Hydra 12 inches DS of elbow. Spectra attempted at several locations on pipe.
Electric-turbine pump.
Flow is fairly steady.

	Flow measurement				
Date (month-day)	Inline	Uniflow	Corr FM	Hydra	Spectra
6-23	1260 from inline meter	1240, 1265	1284	1274	failed

Table 4. *Description of measurement sites and flow measurements, March-September 1989*--Continued

Site number 20.
INDUSTRY # 3. SITE B.
Industrial. Ground water.
Steel pipe, 6.1-inch ID, thick coat of paint but very little flaking.

All meters failed to have a signal strong enough to produce a flow measurement. This was true even after the paint was scraped off completely to bare metal, and transducers were mounted in various locations. Although there was no practical way to inspect inside of pipe, the flowmeters behaved as though there was a buildup of material on inner pipe wall, interfering with the transfer of ultrasonic signal, but exact cause of failure unknown.

	Flow measurement				
Date (month-day)	Inline	Uniflow	Corr FM	Hydra	Spectra
6-23	--	failed	failed	failed	failed

Site number 21.
FARM IRRIGATION # 1, SITE A.
Irrigation. Ground water pulled from shallow sand well to irrigate corn.
Steel pipe, horizontal.
5.86-inch ID. 0.08-inch wall thickness.
MOUNTED: Uniflow mounted about 20 feet DS of valve. Cross Correlation Flowmeter about 3 feet DS of valve. Hydra and Spectra about 2 feet DS of valve.
Electric-submersible pump, 20 HP, rated 300 gallons per minute.
Two pumps feed a single center pivot system. This is the east pump.
COMMENT: There seems to be some air intake into system. Spectra success in measuring this system probably due to presence of suspended air bubbles. on July 8 "gulping" sounds could be heard in pipe, indicating a large amount of air intake. The high Uniflow reading on July 8 probably was due to the large amount of air in the system. The Uniflow indicated aeration faults.
FLOW: Pump rated at 300 gallons per minute.
Flow should be steady.

	Flow measurement				
Date (month-day)	Inline	Uniflow	Corr FM	Hydra	Spectra
7-1	--	300, 300	317, 329	327, 327	356
7-8	--	402	236, 248	414, 409	269
8-7	--	290, 289	319, 302	315	306, 304

Table 4. *Description of measurement sites and flow measurements, March-September 1989*--Continued

Site number 22.
FARM IRRIGATION # 1, SITE B.
Irrigation. Ground water pulled from shallow sand well to irrigate corn.
Steel pipe, horizontal.
5.86-inch ID. 0.08-inch wall thickness.
MOUNTED: Uniflow mounted about 20 feet DS of valve. Cross Correlation Flowmeter about 3 feet DS of valve. Hydra and Spectra about 2 feet DS of valve.
Electric-submersible pump, 20 HP, rated 300 gallons per minute.
Two pumps feed a single center pivot system. This is the west pump.
COMMENT: There seems to be some air intake into system, but no "gulping" sounds heard in pipe. Spectra success in measuring this system probably due to presence of suspended air bubbles.
FLOW: Pump rated at 300 gallons per minute.
Flow should be steady.

Date (month-day)	Flow measurement				
	Inline	Uniflow	Corr FM	Hydra	Spectra
7-1	--	285, 290	278, 302	411, 411	307
7-8	--	263	290	409	283
8-7	--	266, 269	377, 190	265, 265	292, 293

Site number 23.
FARM IRRIGATION # 2.
Irrigation. Ground water pulled from deep bedrock for irrigating green beans.
Steel pipe, horizontal.
7.83-inch ID. 0.10-inch wall thickness.
MOUNTED: Uniflow mounted about 4 feet DS of elbow. Cross Correlation Flowmeter about 3 feet DS of elbow. Hydra about 4 feet DS of elbow. Spectra attempted at several locations on pipe.
Electric-turbine pump.
Measured at center pivot, several hundred feet from pump.
Flow should be steady.

Date (month-day)	Flow measurement				
	Inline	Uniflow	Corr FM	Hydra	Spectra
7-1	--	685, 680, 680	603, 672	629, 644	failed
7-8	--	710	710, 708	631, 578	failed

Table 4. *Description of measurement sites and flow measurements, March-September 1989*--Continued

Site number 24.
FARM IRRIGATION # 3.
Irrigation. Ground water is pulled from deep bedrock to irrigate corn.
Steel pipe, horizontal.
7.83-inch ID. 0.10-inch wall thickness.
MOUNTED: Uniflow mounted about 7 feet DS of elbow. Cross Correlation Flowmeter about 3 feet DS of elbow. Hydra about 5 feet DS of elbow. Spectra attempted at several locations on pipe.
Diesel pump, 150 HP.
Measured at center pivot, several hundred feet from pump.
One pump distributes water to two center-pivot systems. This is west.
Flow should be fairly steady.

Date (month-day)	Flow measurement				
	Inline	Uniflow	Corr FM	Hydra	Spectra
7-1	--	658	595, 576	556	failed
7-7	--	688, 690	1009, 946	481	failed
8-8	--	700, 703	1235, 824	578, 586	failed

Site number 25.
FARM IRRIGATION # 4.
Irrigation. Ground water is pulled from deep bedrock to irrigate corn.
Steel pipe, horizontal.
7.83-inch ID. 0.10-inch wall thickness.
MOUNTED: Uniflow mounted 6 feet DS of elbow. Cross Correlation Flowmeter about 4 feet DS of elbow. Hydra about 2 feet DS of elbow. Spectra attempted at several locations on pipe.
Diesel pump, 150 HP.
Measured at center pivot, several hundred feet from pump.
One pump distributes water to two center-pivot systems. This is east.
Flow should be fairly steady.

Date (month-day)	Flow measurement				
	Inline	Uniflow	Corr FM	Hydra	Spectra
7-1	--	850, 850	831	676, 143	failed
7-7	--	815, 800	820	524, 734	failed
8-8	--	861, 854	835, 791	180, 698	failed

Table 4. *Description of measurement sites and flow measurements, March-September 1989*--Continued

Site number 26.
FARM IRRIGATION # 5.
Irrigation. Ground water is pulled from deep bedrock to irrigate corn.
Steel pipe, horizontal.
7.83-inch ID. 0.10-inch wall thickness.
MOUNTED: Uniflow mounted about 5 feet DS of elbow. Cross Correlation Flowmeter about 2 feet DS of elbow. Hydra about 1 foot DS of elbow. Spectra attempted at several locations on pipe.
Diesel pump, 100 HP.
Measured at center pivot, 300-400 feet away from pump.
Flow should be fairly steady.

	Flow measurement				
Date (month-day)	Inline	Uniflow	Corr FM	Hydra	Spectra
7-1	--	630	795	631	failed
7-8	--	570, 570	538, 555	674, 869	failed

Site number 27.
FARM IRRIGATION # 6.
Irrigation. Ground water is pulled from deep bedrock for irrigating corn.
Steel pipe, horizontal.
7.83-inch ID. 0.10-inch wall thickness.
MOUNTED: Uniflow mounted 10-16 feet DS of diesel pump. Other meters attempted at several locations on pipe. Lots of noise in line at all locations.
Diesel pump.
COMMENT: The Cross Correlation Flowmeter seemed to "lock" onto an extraneous signal, possibly coming from the diesel engine or the pumping mechanism.
FLOW: Site manager expects about 1,200 to 1,300 gallons per minute.
Flow should be fairly steady.

	Flow measurement				
Date (month-day)	Inline	Uniflow	Corr FM	Hydra	Spectra
6-26	--	1315, 1312, 1315	778, 505, 2529, 620, 3161, 6316, 857 -fail	306, 1342	failed
7-6	--	1218,1222	1685, 955 -fail	345, 225 -fail	failed

Table 4. *Description of measurement sites and flow measurements, March-September 1989*--Continued

Site number 28.
FARM IRRIGATION # 7.
Irrigation. Surface water pulled from ditch for irrigating corn.
Measurements made on both intake side and outflow side of centrifugal pump (noted in table).
INTAKE: Steel pipe, horizontal.
7.75-inch ID. 0.124-inch wall thickness.
MOUNTED: Uniflow mounted about 5 feet US of pump. Cross Correlation Flowmeter about 8 feet US of pump. Hydra about 7 feet US of pump. Spectra about 8 feet US of pump.
OUTFLOW: Steel pipe, horizontal.
7.76-inch ID. 0.134-inch wall thickness.
MOUNTED: Uniflow mounted about 5 feet DS of pump. Cross Correlation Flowmeter attempted at several locations. Hydra mounted about 7 feet DS of pump. Spectra about 4 feet DS of pump.
Diesel pump.
COMMENT: The outflow side of centrifugal mechanism clearly has more "noise" than intake side. Comparison of intake and outflow measurements appear to show the effects of this noise. Suspended particles in surface water allow Spectra to measure.
Flow should be steady.

Date (month-day)	Flow measurement				
	Inline	Uniflow	Corr FM	Hydra	Spectra
Measured on outflow side:					
7-2	--	1355	332	1431	1344, 1330
Measured on outflow side:					
7-6	--	1370, 1335	failed	1402	1025
Measured on intake side:					
7-6	--	1425, 1410	1254, 6949	1355, 1355	1533, 1025

Table 4. *Description of measurement sites and flow measurements, March-September 1989*--Continued

Site number 29.

FARM IRRIGATION # 8.

Irrigation. Ground water is pulled from deep bedrock, then fed into ditch where it soaks into sandy ground to irrigate corn.
A 4-foot horizontal steel pipe is output line from pump.
6.27-inch ID. 0.228 inch wall thickness.
MOUNTED: All flowmeters mounted about 2 feet DS of pump.
Electric above-ground motor, 20 HP.
Flow should be very steady.

Date (month-day)	Flow measurement				
	Inline	Uniflow	Corr FM	Hydra	Spectra
7-9	--	744, 755	708, 708	1136, 886	failed

Site number 30.

FARM IRRIGATION # 9.

Irrigation. Ground water is pulled from deep bedrock, then fed into ditch where it soaks into sandy ground to irrigate corn.
A 4-foot horizontal steel pipe is output line from pump.
6.22-inch ID. 0.256-inch wall thickness.
MOUNTED: All flowmeters mounted about 2 feet DS of pump.
Electric above-ground motor, 30 HP.
Flow should be very steady.
COMMENT: Submerged plants in ditch are covered with film. Possibly the material in water that is causing this film also allows Spectra to measure.

Date (month-day)	Flow measurement				
	Inline	Uniflow	Corr FM	Hydra	Spectra
7-9	--	560, 536	596	303	605

Table 4. *Description of measurement sites and flow measurements, March-September 1989*--Continued

Site number 31.
PARK # 1.
Commercial. Ground water is pushed a long distance up a high hill and free falls into top of water tank, so there is high pressure in water line.
Steel pipe. Vertical. Flow down.
6.07-inch ID. 0.316-inch wall thickness.
MOUNTED: Uniflow mounted 36 inches DS of elbow. Cross Correlation Flowmeter 10 inches DS of elbow. Hydra 16 inches DS of elbow.
Spectra attempted at several locations on pipe.
Electric-turbine pump.
Flow should be somewhat steady.

	Flow measurement				
Date (month-day)	Inline	Uniflow	Corr FM	Hydra	Spectra
7-10	--	222	246	234	failed

Site number 32.
FISH HATCHERY # 2.
Commercial. Ground water is pumped to fish ponds.
Steel pipe.
8.09-inch ID. 0.50-inch wall thickness.
MOUNTED: Uniflow mounted on vertical, about 1 foot DS of elbow, flow down.
All other meters mounted on horizontal, between 1 and 2 feet DS of pump.
Electric-turbine pump, 25 HP. Pump test in 1988 showed 682 gallons per minute.
FLOW: Pump rated at 682 gallons per minute based on pump test in summer 1988.
Flow should be steady.

	Flow measurement				
Date (month-day)	Inline	Uniflow	Corr FM	Hydra	Spectra
7-10	--	648, 642	730, 737	713, 721	failed

Table 4. *Description of measurement sites and flow measurements, March-September 1989*--Continued

Site number 33.

RECREATION AREA # 1.

Submersible pump sends water through buried lines to cistern. Water is pumped as needed into tanks to maintain pressure. There is a 1-foot piece of exposed 3-inch diameter, steel pipe downstream of pressure tank. Pipe was not long enough to mount Uniflow, but the three other flowmeters were mounted here. Flow was variable and intermittent, so Cross Correlation Flowmeter, Hydra, and Spectra all failed to obtain a flow reading (but throughout measurement attempts, there was probably no flow most of the time).

Date (month-day)	Flow measurement				
	Inline	Uniflow	Corr FM	Hydra	Spectra
7-11	--	could not mount--failed	failed	failed	failed

Site number 34.

PARK # 2, SITE A.

Commercial. Surface water measured DS of filtration system.
Steel pipe, horizontal.
4.08-inch ID. 0.254-inch wall thickness.
MOUNTED: All meters mounted about 10 inches DS of "T".
One pump running, electric, 10 HP.
Flow should be fairly steady.

Date (month-day)	Flow measurement				
	Inline	Uniflow	Corr FM	Hydra	Spectra
7-11	90 from inline meter	97	109	102	failed
9-8	92	89, 113	114	103	failed

Table 4. *Description of measurement sites and flow measurements, March-September 1989*--Continued

Site number 35.
PARK # 2, SITE B.
Commercial. Surface water measured DS of filtration system.
Steel pipe, horizontal.
4.08-inch ID. 0.254-inch wall thickness.
MOUNTED: All meters mounted about 10 inches DS of "T".
Two pumps running simultaneously. One electric, 10 HP, and a second pump of similar (but unknown) HP.
Flow should be fairly steady.

Date (month-day)	Flow measurement				
	Inline	Uniflow	Corr FM	Hydra	Spectra
7-11	185 from inline meter	188	206	167	failed
9-8	188	202, 179	191	159	failed

Site number 36.
INDUSTRY # 4, SITE A.
Industrial. Ground water.
Steel pipe. Vertical. Flow down.
6.13-inch ID. 0.312-inch wall thickness.
MOUNTED: All meters mounted about 6 inches DS of elbow.
Electric-turbine pump, 50 HP.
Flow should be somewhat steady.

Date (month-day)	Flow measurement				
	Inline	Uniflow	Corr FM	Hydra	Spectra
7-12	--	505	534	460	failed

Table 4. *Description of measurement sites and flow measurements, March-September 1989*--Continued

Site number 37.
INDUSTRY # 4, SITE B.
Industrial. Ground water.
Steel pipe. Vertical. Flow is down.
8.19-inch ID. 0.475-inch wall thickness.
MOUNTED: Uniflow could not be mounted because only 12 inches of pipe available. Other meters mounted about 6 inches DS of elbow.
Electric-turbine pump, 125 HP.
FLOW: Pump rated at 2,000 gallons per minute, but site manager expected much less output.
Only 12 inches of pipe length to mount transducers.

	Flow measurement				
Date (month-day)	Inline	Uniflow	Corr FM	Hydra	Spectra
7-12	--	could not mount -failed	1100	986	failed

Site number 38.
PUBLIC WATER SUPPLY # 3, SITE A.
Public-water supply. Ground water.
Steel pipe, horizontal.
6.11-inch ID. 0.39-inch wall thickness.
MOUNTED: Uniflow mounted 34 inches DS of inline propeller flowmeter.
Cross Correlation Flowmeter 10 inches DS of inline flowmeter.
Hydra 36 inches DS of inline flowmeter.
Spectra attempted at several locations on pipe.
Electric-turbine pump.
Flow is steady.

	Flow measurement				
Date (month-day)	Inline	Uniflow	Corr FM	Hydra	Spectra
7-12	1050 from inline meter	1110	1047	896	failed

Table 4. *Description of measurement sites and flow measurements, March-September 1989*--Continued

Site number 39.
PUBLIC WATER SUPPLY # 3, SITE B.
Public-water supply. Ground water.
Steel pipe, horizontal.
9.89-inch ID. 0.614-inch wall thickness.
MOUNTED: Uniflow mounted about 6 feet DS of pump. Cross Correlation Flowmeter about 8 feet DS of pump. Hydra about 8 feet DS of pump. Spectra attempted at several locations on pipe.
Electric-turbine pump.
FLOW: Site manager expected 700 to 900 gallons per minute.
Flow is steady.

Date (month-day)	Flow measurement				
	Inline	Uniflow	Corr FM	Hydra	Spectra
7-12	--	815	850	1402	failed

Site number 40.
PARK # 3.
Commercial. Ground water.
Ductile iron pipe, horizontal.
4.21-inch ID. 0.320-inch wall thickness. .062-inch cement liner.
MOUNTED: Uniflow mounted 3 feet DS of elbow. Cross Correlation Flowmeter 2 feet DS of elbow. Hydra mounted 1.5 feet DS of elbow. Spectra attempted at several locations on pipe.
Electric pump rated at 250 gallons per minute.
Flow rate decrease with time over each brief period of pump operation.
COMMENT: When large pressure tank gets low on water, electric pump turns on to push water into bottom of tank. So as pump runs, hydraulic head increases, and flow rate probably decreases. There is also noise from a chlorine pump attached to water line. All of these factors, variable flow rate, noise, and brief pump operation periods make it very difficult to obtain measurements.

Date (month-day)	Flow measurement				
	Inline	Uniflow	Corr FM	Hydra	Spectra
7-13	--	failed	182	204	failed

Table 4. *Description of measurement sites and flow measurements, March-September 1989*--Continued

Site number 41.
CORPORATE CENTER # 1.
Commercial. Ground water is pumped through top of water tank.
Steel pipe. Vertical. Flow down.
8.41-inch ID. 0.325-inch wall thickness.
MOUNTED: Uniflow could not be mounted because only 12 inches of pipe available.
Cross Correlation Flowmeter and Hydra mounted immediately DS of elbow.
Spectra attempted at several locations on pipe.
Electric-turbine pump.
FLOW: Pump rated 560 gallons per minute.
Flow should be steady.

	Flow measurement				
Date (month-day)	Inline	Uniflow	Corr FM	Hydra	Spectra
7-13	--	could not mount -failed	540	520	failed

Site number 42.
INDUSTRY # 5.
Industrial. Ground water pumped from about 2 miles away to measuring site.
Pipe is very corroded steel. Horizontal.
4.2-inch ID. 0.209-inch wall thickness.
COMMENT: Flow changed substantially. Readings from one meter should
not be compared with another due to variable flow rates.

	Flow measurement				
Date (month-day)	Inline	Uniflow	Corr FM	Hydra	Spectra
7-14	--	135, 230	189	no attempt	no attempt

Table 4. *Description of measurement sites and flow measurements, March-September 1989*--Continued

Site number 43.
SCHOOL # 1, SITE A.
Commercial. Surface water from lake is filtered and sent to water tank.
Measurements were made upstream of pump and upstream of filtration system.
Steel pipe, horizontal.
7.7-inch ID. 0.50-inch wall thickness.
MOUNTED: Uniflow mounted about 10 feet US of pump. Cross Correlation Flowmeter about 6 feet US of pump. Hydra and Spectra about 9 feet US of pump.
Pump is brand new, electric-centrifugal pump.
FLOW: Although the pump is rated at 250 gallons per minute, site manager expected "about 275 gallons per minute because it is new."
Flow should be fairly steady.

Date (month-day)	Flow measurement				
	Inline	Uniflow	Corr FM	Hydra	Spectra
8-15	--	296	314	306, 306	232, 247

Site number 44.
SCHOOL # 1, SITE B.
Commercial. Ground water is used to cool the building and for restroom facilities.
On the day of this measurement, the weather was fairly cool and cloudy, and no other people were in the building. So there was very little demand for water.
Steel pipe, horizontal.
4.0-inch ID. 0.24-inch wall thickness.
MOUNTED: Uniflow mounted 22 inches DS of elbow. Cross Correlation Flowmeter 23 inches DS of elbow. Hydra 18 inches DS of elbow.
Spectra attempted at several locations on pipe.
Electric pump.
COMMENT: While the Uniflow measured 54 gallons per minute, the site manager turned on two restroom faucets and flushed a toilet. The flow measurement increased to 99 gallons per minute, then gradually returned to 54 gallons per minute after the faucets were turned off.

Date (month-day)	Flow measurement				
	Inline	Uniflow	Corr FM	Hydra	Spectra
8-15	--	54	61	61, 61	failed

Table 4. *Description of measurement sites and flow measurements, March-September 1989*--Continued

Site number 45.
SCHOOL # 2.
Commercial. Ground water is pumped to top of storage tower.
Steel pipe. Measured at location where pipe angles down at a 45-degree angle, DS of a 45-degree elbow.
10.1-inch ID. 0.50-inch wall thickness.
MOUNTED: Uniflow mounted 36 inches DS of elbow. Cross Correlation Flowmeter 21 inches DS of elbow. Hydra 41 inches DS of elbow.
Spectra attempted at several locations on pipe.
Electric-turbine pump.
Flow is very steady.
COMMENT: Pump test in 1988 showed a rate of 781 gallons per minute at 90 LBS of pressure. But pump operates at about 70 LBS of pressure, so actual flow rate should be greater than 781 gallons per minute. After cleaning in 1983, pump test showed a pump rate of 1,004 gal/min.

	Flow measurement				
Date (month-day)	Inline	Uniflow	Corr FM	Hydra	Spectra
6-14	--	1015, 1015	984, 1021	893, 880	failed
8-16	--	1004	945, 940, 931	831, 504	failed
9-20	--	1009	968, 990, 956	856, 806	failed

U. S. GOVERNMENT PRINTING OFFICE: 1992-645-671