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R. C. Peralta
Utah State University

Vince Mazur

Paul Dutram

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MONITORING OF GROUNDWATER LEVELS FOR REAL-TIME CONJUNCTIVE WATER MANAGEMENT

Richard C. Peralta
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Agricultural Engineering Dept. University of Arkansas

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Arkansas Water Resources Research Center
University of Arkansas
Fayetteville, Arkansas 72701

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Richard C. Peralta
Vince Mazur and Paul Dutram
Agricultural Engineering Department, University of Arkansas
Fayetteville, Arkansas 72701

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223 Ozark Hall
Fayetteville, Arkansas 72701

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ABSTRACT

MONITORING OF GROUNDWATER LEVELS FOR REAL-TIME CONJUNCTIVE WATER MANAGEMENT

Water users in the Arkansas Grand Prairie wish to maintain sufficient groundwater levels to: insure adequate groundwater reserves for time of drought, protect themselves from litigation caused by wells going dry, and insure a sustained yield. Achievement of these goals requires regular measurement of groundwater levels. Review of monitoring practice and technology indicates that spring and fall measurements taken over the entire area using steel tape and acoustic device is preferred for most long range planning. Continuous monitoring is indicated for critical parts of the region where saturated thicknesses are small. Desirable attributes of a data collection/transmission system for such areas are as follow: Data should be stored in digital format on machine readable medium. Collection device should be installable in existing wells and not require special well construction. Device should be able to monitor pump status, and time and water level at programmable intervals. Device should be upgradable to be able to transmit data as it is collected. A system which has these capabilities was built. It consists of an acoustic probe, interface, computer and cassette recorder.

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OBJECTIVE

Water is managed in order to achieve predetermined objectives or goals. Possible goals of groundwater users in the Arkansas Grand Prairie are:

1) To insure an adequate groundwater reserve for time of drought when surface water supplies may not be available. (To do this the groundwater level must be kept above specified elevations in certain locations.)

2) To protect oneself from litigation. (Again the water table must be kept high enough that domestic wells do not run dry.)

3) To avoid the expense involved with obtaining water from the deeper Tertiary aquifer. (Once again, water users may wish to keep the water table above certain levels.)

4) To insure a sustained yield (a volume of groundwater which can be pumped each year without further significant decline in groundwater levels). Here the amount of recharge into the aquifer has to at least equal the amount of discharge. Therefore, the amount of recharge has to be accurately estimatable, requiring a knowledge of groundwater elevations along the periphery of the Grand Prairie.

Achievement of goals 1-4 all require the regular measurement of groundwater levels. The objective of this study is to select or develop a method for monitoring groundwater levels which can be included as part of a real-time conjunctive water management system for the Grand Prairie. Aspects of that determination include frequency of measurement and type of monitoring system.

PROCEDURE

Analysis of a Groundwater Monitoring Survey

Good sources of information concerning groundwater monitoring practices are those who monitor. Accordingly, a Groundwater Level

Monitoring Survey (Appendix A) was sent to fifty water management areas in six states. Thirty-two responses were obtained. These indicated that a chalked steel tape is the most often used manual measuring device (Appendix B). Most districts feel that adequate information is gathered by measuring elevations sometime in the spring and again in the fall. Respondents stressed the need for having adequate computer models to interpret collected data. Automatic measuring is performed almost solely by digital recorders (Appendix C). Continuous automatic recorders are programmed to read at fifteen minute to daily intervals. These are generally located where there may be trouble due to saltwater intrusion, etc. or in areas where more detailed information than usual is desired. Appendix C shows that many management areas conduct annual or semi-annual monitoring over their entire area, as well as continuous monitoring in localities of great need. The average area per measuring location for Appendices B and C is 43 sq. mi. Respondents generally acknowledge the importance of having good relations with land owners, especially when data is collected on their land.

Review of Data Collection/Transmission Systems

Appendix D describes several methods of measuring groundwater elevations. Among these is the use of a steel tape. As previously stated, an annual or semi-annual set of tape measurements made by district employees is the source of data used for long-term planning and simulation by most water management districts. After collection, the data is carried (ie. transmitted) to the district office where it is used in making management decisions. The data collection and transmission methods together comprise a system. This system may be described as a manual collection/ manual transmission system. The three major types of data collection/ transmission systems are:

(1) - Manual data collection/manual data transmission.

(2) - Automatic data collection/manual data transmission.

(3) - Automatic data collection/automatic data transmission.

In manual data collection and transmission:

An individual must be present at the site to make the measurement.

An individual must transfer the data to the district office by hand, mail, or phone.

One individual may be hired by the district to travel to each monitoring site and make the measurements. Alternatively, those who own the land on which monitoring sites are located can have that responsibility. In both cases, spot checks may be desirable to insure data reliability. If one individual makes all measurements, only one device would be operable at any given time. If measurements were being taken during the pumping season, that individual would probably have to coordinate his visits with the landowner to maximize the usefulness of his data. If the landowner were the one making the measurements, he could more easily time the measurement properly with respect to when the pump was last running. In this case, many devices would have to be purchased. Possibly one would be needed at each site, or the devices could be mailed or otherwise transported from site to site. The administrative problems of employing a single device for multiple users make that policy undesirable.

In automatic collection and manual transmission:

A device is installed at each monitoring site. Data is automatically collected and recorded. Recording may be on paper using a strip chart recorder, or on cassette tape using a portable tape recorder.

The data is transmitted to the district office by hand, mail or by phone using an acoustic coupler. The use of a telephone line is considered manual transmission because it requires hand carrying of the cassette tape.

In automatic collection and automatic transmission:

Measurement and data transmission are performed automatically

Transmission is by phone line, satellite, or some other radiative means.

Selection of Monitoring Systems

Preliminary economic analyses showed that the procedure currently used by most districts is by far the most economical means of collecting and transmitting annual or semi-annual data for a large area. To iterate, that procedure is the use of a district employee to collect and hand carry the data to the district office. This same procedure and frequency is desirable for the Grand Prairie. The difference in cost between the manual data collection methods listed in Appendix D is insignificant when one considers that probably fewer than four teams will be making measurements. Accordingly, selection of a manual method is based on accuracy and convenience. Because of the weaknesses of the methods (as discussed in the Appendix) it is recommended that each team have both a steel tape and acoustic device. The steel tape is the more accurate instrument. The acoustic device is not as subject as steel tapes to the problems caused by cascading water or wet well casing. Used together, reliable measurements can be assured.

Semi-annual monitoring is not sufficient, however, to insure that all four of the goals (see the introductory section) of water users will be met. More frequent monitoring will probably be needed for any area where saturated thickness is critically small. In such an area an additional monitoring system is necessary to aid in insuring that a minimum saturated thickness is maintained for litigation or drought protection. It is not within the scope of this report to deliniate the extent of these critical areas. Thus, we do not, at this time, recommend the number or location of automatic monitoring devices, but rather discuss the development of such a device. Desirable attributes of a collection/transmission system for a critical area are:

1) Data should be available in digital form and on a machine readable medium for ease of utilization in a simulation model.

2) The monitoring device should be installable in an existing well and not require special well construction.

3) The monitoring device should be able to monitor time, water level, and pump status (on or off) of the well itself (in case it is installed in an active well).

4) The device should be upgradable to be able to transmit data as it is collected (in "real" time) or on cue by wireless means.

None of the systems which were examined had all these capabilities. Accordingly, a new system was developed. The following section describes the system.

A Potential Real Time Monitoring System

An acoustic monitoring device was interfaced to a computer and cassette tape recorder. Figure 1 shows a block diagram of the system. This system, as configured, stores digital data on cassette tape and provides digital readout on a display. It can be used in any well with a nominal diameter of 2 inches or larger as long as a clear path (without any sharp 90° bends) exists to the water surface. The computer monitors and records the time of any changes in pump status and prompts the measurement of water levels at preprogrammed intervals. A more detailed theory of operation and description of operational cycle are found in Appendix E. The hardware for this system costs $1160. It is expected that further development could reduce the cost to $830. As presently configured it is an automatic collection/manual transmission system.

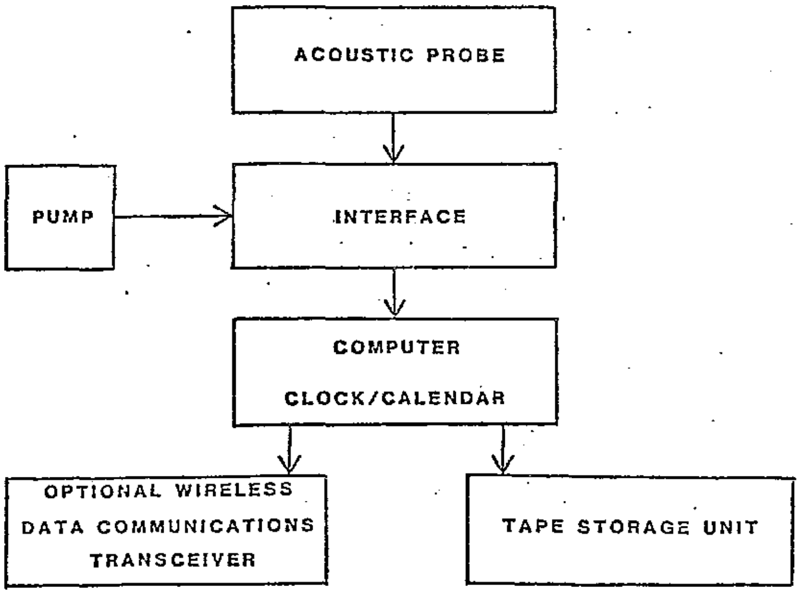

Figure 1: Data Flow Diagram of Automatic Acoustic Groundwater Level Monitoring System.

The system can be upgraded to use a wireless means of transmitting collected data to where it is needed. This would require the addition of a transmitter/receiver with RS-232 (a serial connector) compatibility. Such devices are currently available. The receiver function would enable the system to take a measurement in response to a command issued by a central office. System software would need to be modified. In addition, the central office would need appropriate transmitting and receiving capabilities. Assuming that this upgrade can be made, the designed system has the four attributes mentioned in the preceeding section.

The manufacturers of the acoustic measurement device report an accuracy of 1 foot when adjustments for temperature are made. The author tested this device in the summer of 1982 and found this to be the approximate range of accuracy. Calibration of this device to a particular well will probably reduce the measurement error. The fact that the system would make measurements and monitor status in response to programmed microprocessor directives was verified in the spring of 1983.

SUMMARY AND RECOMMENDATIONS

Two systems of groundwater level monitoring are necessary for water management in the Arkansas Grand Prairie. Semi-annual (spring and fall) measurements are needed across the entire area for long-term planning. An employee of the water management agency using a tape and acoustic probe is best suited for this task.

To minimize the chance of litigation due to wells going dry, more frequent monitoring is necessary in some parts of the Prairie. A microprocessor controlled, acoustically based system was developed for use in such areas. It:

- can store data in digital form on machine readable medium.
- is installable in most wells of 2" or greater diameter.
- can record time, pump status changes, and water levels at predetermined frequencies.
- is upgradable to be able to transmit data by wireless means.

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APPENDICES

APPENDIX A

Groundwater Level Monitoring Survey

1. (a) What devices or systems do you use to determine groundwater levels? (Please be specific)

   (b) What do you like most about your monitoring device/system?

   (c) What do you like least about your monitoring device/system?

   (d) What was the approximate initial cost of the device/system for each collection site?

   (e) What is the approximate annual maintenance cost for each site?

   (f) Are you satisified with the device/system?

   If not, how would you like to change it?

Groundwater Level Monitoring Survey

2. (a) How often do you collect water table elevations?

   (b) Do you run computer simulations of the aquifer (if so, how often)?

   (c) Do you feel that you sample frequently enough? If not, how often would you like to take a measurement?

   (d) How would more frequent measurements be useful to you?

3. (a) At how many sites do you regularly measure water table elevations (and how often, if different than that stated in 2a)?

   (b) What is the area of your district in square miles?

4. (a) What are the most important considerations for a district just establishing a water table monitoring system?

5. (a) What additional counsel or comments would you like to offer?

APPENDIX B

Survey Responses--Manual Collection Methods

	Location	Method	Frequency	# Wells	Area (sq.mi.)	Average Sq. mi./ Measuring Location
a.	Big Bend GWMD #5 St. John, KS	steel tape	annually	NA	NA	NA
b.	Central Platte NRD Grand Island, NE	steel tape	May & Oct/Nov	250	32,000	128.0
c.	Equus Beds GWMD #2 Halstead, KS	200' steel tape & electric tapes	annually (Jan)	113	800	7.1
d.	Lewis & Clark NRD Hartington, NE	chalked steel tape	spring & fall	29	1,467	50.6
e.	Little Blue NRD Davenport, NE	200' chalked steel tape	April & Nov	287	2,344	8.2
f.	Lower Niobrara NRD Butte, NE	chalked steel tape	April/May & Nov/Dec	49	2,641	53.9
g.	Lower Republican NRD Alma, NE	chalked steel tape	March & Oct	42	3,000	71.4
h.	Middle Niobrara NRD Valentine, NE	300' steel tape	spring & fall	58	5,460	94.1
i.	Middle Republican NRD Curtis, NE	300' steel tape	spring & fall	85	3,843	45.2
j.	North Plains WCD Dumas, TX	steel tape	annually (winter)	700	NA	NA
k.	North Platte NRD Gering, NE	300' steel tape	spring & fall	40	5,060	126.5
l.	Plains GWMD Burlington, CO	300' steel tape	annually	40	1,400	35.0
m.	Sand Hills GWMD Wray, CO	steel tape	annually	NA	NA	NA
n.	South Platte NRD Sidney, NE	300'& 500'chalked steel tape	spring & fall	110	3,096	28.1
o.	Tri-Basin NRD Holdrege, NE	chalked steel tape	March & Oct	89	1,520	17.1

APPENDIX B (con't)

Survey Responses--Manual Collection Methods

	Location	Method	Frequency	# Wells	Area (sq.mi.)	Average Sq. mi./ Measuring Location
p.	Upper Elkhorn NRD O'Neill, NE	steel tape	spring & fall	110	3,096	28.1
q.	Upper Loop NRD Thedford, NE	300' steel tape	annually	100+	5,000	50.0
r.	York County GWMD York, NE	chalked steel tape electric contact meter	April & Oct/Nov	580	2,100	3.6

APPENDIX C

Survey Responses--Combination Manual/Automatic Collection Methods

	Location	Method	Frequency	# Wells	Area (sq.mi.)	Average Sq. mi./ Measuring Location
a.	Capital Area GCC Baton Rouge, LA	steel tape digital recorder	semiannual continuous	100+	2,500	25.0-
b.	High Plains Underground WCD #1 Lubbock, TX	chalked steel tape electric line auto. recorder	Jan/Feb	950	8,149	8.6
c.	Lower Loop NRD Ord, NE	chalked steel tape elec well sounder digital recorders	spring & fall monthly monthly	223 2 4	7,992	34.9
d.	Nemaha NRD Tecumseh, NE	300' chalked steel tape auto recorder	Mar & Aug & Dec 15 min/summer hourly/winter	47 1	2,500	52.1
e.	NW Florida WMD Havanna, FL	steel tape steel tape auto recorder	semi-annually bi-monthly continuous	66 50 7	16,000	130.1
f.	NW Kansas GWMD #4 Colby, KS	steel tape continuous water level recorders	1st 2 wks Jan. continuous	284 NA	4,950	NA
g.	Orange County W.D. Fountain Valley, CA	steel & electric tapes Bristol Water Level Recorders	4x/year annually (Nov) continuous	95 300 12	320	.8
h.	Papio NRD Omaha, NE	Johnson Elec. Watermeter	2x/year	11	982	89.3
i.	S. Florida WMD	elec. digital recorder	monthly	350	16,000	45.7
j.	St. Johns RWMD Palatka, FL	steel tape steel tape auto digital recorder	quarterly month-end continuous (hourly)	800 50 50	12,400	13.8
k.	Suwannee River WMD Live Oak, FL	auto digital recorder NA	continuous 2-4x/year	50 220	7,600	28.2

APPENDIX C (con't)

Survey Responses--Combination Manual/Automatic Collection Methods

	Location	Method	Frequency	# Wells	Area (sq.mi.)	Average Sq. mi./ Measuring Location
l.	SW Florida WMD Brooksville, FL	tape measure auto recorder	monthly daily	400	10,000	25.0
m.	Upper Big Blue NRD York, NE	steel tape auto recorder	spring & fall continuous	600 12	2,865	4.7
n.	Upper Republican NRD Imperial, NE	300' chalked steel tape auto recorder	Mar/Apr & Oct/Nov continuous	154 11	2,697	16.3

APPENDIX D

Review of Methods of Determining Groundwater Elevations

Steel Tape

Survey responses indicated that the steel tape method is by far the most widely used means for measuring groundwater levels. To make a measurement, the user marks the bottom 5-10 feet of the tape with chalk. He lowers the tape into the well and observes the length of tape lowered by comparison with a benchmark on the well. The user then retrieves the tape and records the distance between the water/chalk border and the length of tape which was lowered. This measurement represents the distance to the water level. The accuracy attained by this method depends on the accuracy of the tape which is typically 0.1 ft. The chief disadvantage of this method is that in many wells, cascading water or a wet casing may wet the tape above the actual water level. This causes an inaccurate measurement. As the depth of the water level increases, the probability of entanglement increases (a disadvantage common to all submerged measuring devices). Many water management districts require that all newly dug wells have a small diameter PVC pipe installed the length of the well to eliminate the problem of entanglement. Steel tapes, when properly used, provide accurate measurements at a relatively low cost.

Drop Down Electrical Device

This method consists of lowering an insulated wire with a sensor at the end into a well. A light on the top end of the line illuminates when the sensor comes in contact with the water level or ammeter needle moves. The user then reads the measurement directly from the wire, which is typically marked in five foot increments. If oil from the well pump or other source is on the water surface, the sensor may fail to light upon contact with the water surface. This results in an inaccurate measurement. The possibility of entanglement is also present because of the drop down nature of this method.

Acoustic Device (Figure 2)

This method of water level measurement utilizes electronic circuitry combined with an acoustic transducer to measure the distance to the water surface. It measures the time between the transmission of an audio pulse and the reception of its echo. It

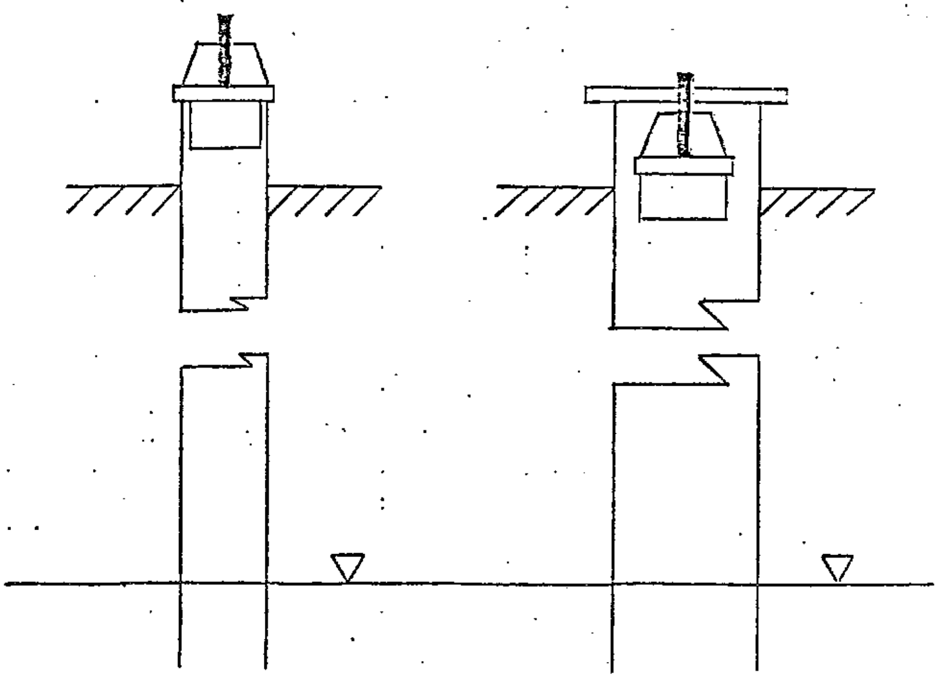

Figure 2: Acoustic Groundwater Level Measuring Device.

can be compared in operation to a sonar device. The units currently available provide a digital read-out. The user places the pulse-emitting transducer either directly over the well opening or over an auxilliary pipe leading to the well casing. Because no part of the device is lowered into the well, the possibility of entanglement is eliminated. Since the speed of sound changes with temperature, the temperature of the well is measured at the time of the depth measurement. When taking the temperature into account, an accuracy of 1 foot is attainable. The device also has a filtering capability which allows one to select the range of distance to be considered. Use of this option allows one to selectively avoid inaccuracies which may be caused by cascading water within the well. The authors' opinion at this time is that a steel tape should be used with this device during the first few measurements for any well. With that restriction, and depending on whether one foot accuracy is adequate, the method offers satisfactory results with easy operation.

Water Manometer Air Line Assembly

This method utilizes a pressurized air line and a water manometer to obtain the water level measurement. It is especially adapted to the rapid measurement of changing water levels during and immediately after pumping tests. The user attaches one end of an air line to the zero mark on a steel tape. He connects the other end to the water manometer. He then lowers the steel tape/tubing assembly into the well until contact with the water surface is made. Contact is indicated by a slight rise in the column of water in the manometer. He then purges the air line of water with an air pump and records the water level in the reservoir and the height at which the water column in the manometer stabilizes. The depth to water is the difference between the steel tape marking at the benchmark and the height of the water column in the manometer. The major advantage of this system is the ability to monitor changes in water level during pumping tests. It does, however, require the use of a submergible assembly. This presents the possibility of entanglement. A fairly high degree of accuracy can be obtained depending on the accuracies of the manometer and steel tape. The time required to take a measurement successfully is longer than with most other methods of measuring (Loetz, 1967). A chief disadvantage of this method is the possibility that after several years, the connections and fittings will lose their air-tight characteristics. Another disadvantage is the possibility of encrustation at the submerged lower end of the tubing.

APPENDIX D (cont'd)

Review of Methods of Determining Groundwater Elevations

Air Line-Gauge Methods

Several methods of implementing an air line and pressure gauge exist for water level measurement. The most common consists of a permanently installed and submerged air line. The user purges the line of water with a small hand pump, as in the manometer technique above. The measurement device in this case is a calibrated pressure gauge. The user reads the measurement directly from the gauge. A variation of this method is the charged air bell method (Babcock, 1971). This procedure is identical except for the addition of an air bell at the end of the permanently installed air line. This enables the tube to remain charged for up to two weeks without repumping. Therefore, subsequent measurements within a two week period can be readily made. These airline/gauge methods provide relatively accurate (up to 0.2 ft) measurements without the need for an external electricity source. The tube airline can be made of either copper or plastic. While metal tubing is more expensive, it does not tend to lose air as rapidly as does plastic tubing. The chief advantage of the method is low cost and ease of implementation. The major disadvantages are those of degradation of airtight fittings and encrustation of the air tube, mentioned in the previous section.

Continuous Level Recorder

A continuous level recorder consists of a permanently installed system with a float which rides on the water surface. A cable connects the float to a strip chart recorder. It transmits fluctuations in the water levels to a timed strip chart recorder. The commercially available units are extremely accurate (2/1000 inch) but as with every system that has a submerged unit, entanglement is possible. This system of measurement is applicable where continuous recording is desired.

Multiple Well Measuring and Recording

This system of measurement utilizes multiple probes that are electrically connected to individual strip chart recorders. The probes consist of a series of platinum electrodes which change electrical properties as the water level changes. The probes for the system investigated were only capable of measuring the water levels in water aquifers that are rapidly changing and shallow (0.5-2.0 m thick). This is not in the range that was required for this project. (Holbo, Harr, Hyde, 1975)

APPENDIX E

Theory of Operation

The heart of the system shown in Figure 1 is the COMPUTER, which prompts the collection of data and receives, converts and stores the data. The ACOUSTIC PROBE measures the depth to water. The INTERFACE converts the digital output from the probe to a format easily stored in the processor's memory. The interface also enables the computer to determine when the well PUMP is turned on or off so that the state of the pump is known at the time of the measurement. CLOCK/CALENDAR is an external circuit which is used to set and read the time and date, so that measurements can be taken at the selected time interval. The processor reads the probe's output and stores the measurement in memory. Then the measurement, time, date, and pump status is sent to the TAPE STORAGE UNIT where it is stored on magnetic tape for later viewing and analysis. Potentially, a wireless data transmitter can be used for control and data collection from a remote location. This type of arrangement would eliminate the need for an on-site storage device and the need for collection of the storage tape from the site.

Operational Cycle

The automated measuring system is designed to take well measurements at a user selectable 1.0 second to 10. year time interval. For the following discussion assume the time interval to be 1.0 hr. When the passage of an hour is detected by the computer (ie. the hours digit changes) the computer reads the well probe, checks the well pump status and outputs this data along with the time and date to the magnetic tape storage unit. The computer repeats this sequence of events when the next hour is reached. If, anytime during the cycle, the well pump status changes (ON to OFF or OFF to ON) the computer will stop any current action and immediately store the time, date, and pump status change on the tape storage unit. Upon completion of this task, the computer will return to its previous operation.

APPENDIX F

Print-Out of System Collected Data

This is a sample printout of the data obtained fom a 24 hour test of the system. The system was not installed in a well for this test. The external stimulus of a pump being turned on or off was simulated using a random number generator. Therefore the water level measurement, which was initially set by hand, did not vary despite pump status changes.

DATE	TIME	MEASUREMENT	PUMP STATUS (1 = ON, 0 = OFF)
032883	0	276	1
032883	100	276	1
032883	200	276	1
032883	300	276	1
032883	400	276	1
032883	500	276	1
032883	600	276	0
032883	700	276	0
032883	800	276	0
032883	900	276	1
032883	1000	276	0
032883	1100	276	0
032883	1200	276	0
032883	1300	276	0
032883	1400	276	0
032883	1500	276	0
032883	1600	276	0
032883	1700	276	0
032883	1800	276	0
032883	1900	276	0
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032883	2200	276	0
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