Research Technical Completion Report

DEMONSTRATION OF MONITORS FOR PUMPING STATIONS

by

C. W. Robison
C. E. Brockway
Idaho Water Resources Research Institute

Submitted to:

Idaho Department of Water Resources
Boise, Idaho

Contract No. DWR–86–03–21–704–37

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RESEARCH TECHNICAL COMPLETION REPORT

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ABSTRACT

Three pump station monitors, two developed by the University of Idaho and the Agricultural Research Service and one developed by Utah State University, were demonstrated on southern Idaho pumping stations in 1986. Discharge, pumping and lift measurements, power usage and efficiency can be displayed at any time and recorded at predetermined intervals. The UI/ARS monitoring units are solid state utilizing off-the-shelf components and cost generally under $2,000, whereas the USU unit cost about $6,000. Two demonstrations involving over 50 users, agency officials and media personnel were conducted. Pumping station monitors allow users to evaluate diversion and distribution system performance and determine potential change in operation and/or hardware to increase efficiency and reduce power costs. Estimated energy cost savings of $0.50 to $2.00 per acre could be achieved on a typical irrigation pumping system with only a one percent increase in overall pumping efficiency.

INTRODUCTION

Increasing energy costs for pumping water, coupled with rising production costs, are forcing water users to practice energy conservation. Energy conservation in irrigation pumping is best achieved by operating pumping stations near peak efficiency. However, pumping station operators seldom have the means or the equipment and time to determine operating efficiencies. Availability of pumping station operating parameters including efficiency, flow rate, and pumping head would allow operators to adjust the system to achieve the highest energy efficiency consistent with pressure and flow requirements. Generally, pumping station operators must contract with a consultant or local utility to perform a pumping station energy audit.

Pumping station monitors measure the variables associated with the efficiency of a hydraulic system and allow pumping station operators to evaluate station performance by simply pressing a button. Data available from a pumping station monitor will allow the operator to evaluate the effect of changes in operation of the irrigation system on the performance of the pumping station with regard to energy usage and other parameters. With adequate data, operators can increase pumping station energy efficiency through better management. Additionally, pumping station monitors can provide a record of station performance throughout the irrigation season reflecting changes in performance which could indicate needed pumping station maintenance.

The need for development and demonstration of reasonably priced, functional pumping station monitoring equipment in Idaho was recognized by the Idaho Department of Water Resources, who funded this report.

SYSTEM DEFINITION

Determination of pumping station performance requires the measurement of several parameters. These parameters, combined with additional calculated indicators, describe the operating characteristics and performance of the pumping station. A pumping station monitor cannot catalog performance of the irrigation distribution system or irrigation water usage. It can, however, provide data on the effect of distribution system management or energy costs and is therefore useful in evaluating irrigation system components.

Monitoring of pumping station performance requires sensing of four parameters on a real time basis. Location of parameter sensors will define how the monitor functions - as a pump efficiency monitor or as a pumping station monitor. The locations of the parameter sensors for a pumping station monitor are shown in figure 1, which depicts an idealized pumping station. Using these sensor locations, a pumping station monitor computes the energy efficiency of the station based on losses incurred by the motor, pump, trash screens, check and control valves, and the flow measurement device. A monitor used to determine only pump efficiency would sense pumping pressure immediately downstream of the individual pump and would not include losses in the plumbing system.

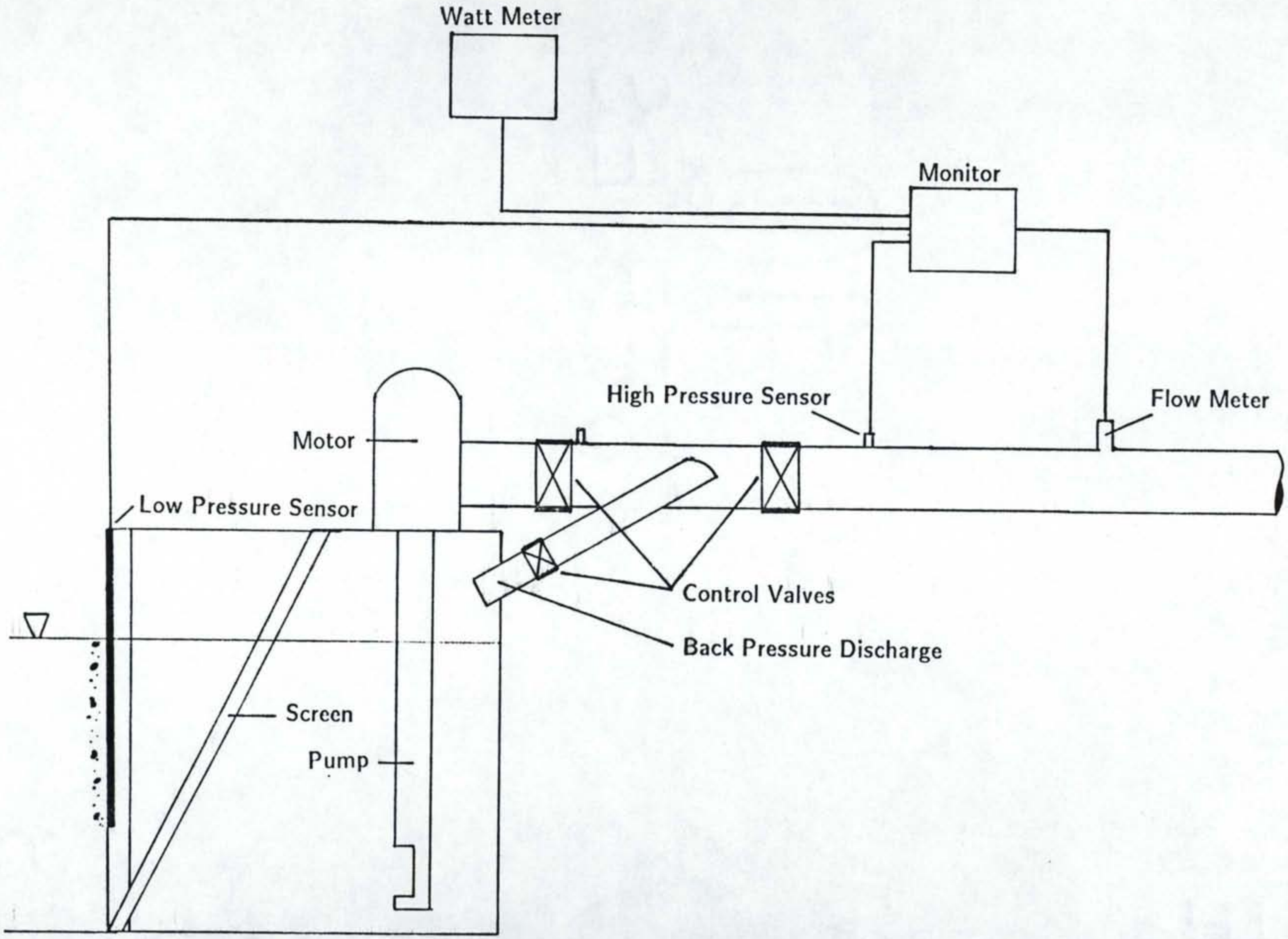

Figure 1. Schematic of Pumping Station Monitor Installation

MEASURED PARAMETERS

The four monitored parameters are electrical input power, water supply surface elevation, discharge pressure, and flow rate. In addition to sensing these parameters, the pumping station monitor requires static physical information about the hydraulic system and sensor installation. Static pumping station information includes the inside diameter of the line where the discharge pressure head is sensed and the elevation difference between discharge pressure sensor and the water level bubbler outlet. Calibration coefficients for the sensors used in conjunction with the monitor are also required.

The primary parameter sensors are for input power and flowrate. Electrical input power to a pumping station is measured by the utility supplying the energy which has control over the power meter selection and installation. Generally, meters provided by the utility do not provide external signals usable by a pumping station monitor. Since the monitor requires an electronic signal in proportion to the electrical power usage, the pumping station owner will need to have the utility install a special power meter with pulse output. The flow rate produced by the station is sensed using a flow meter installed in the discharge line by the owner. Various types of flow meters can be used as long as the meter has an electronic output. Selection of the flow meter is dependent on the hydraulic piping characteristics of the pumping station. The pumping station monitor utilized by the University of Idaho in this study currently accepts a pulse signal for flow where the frequency of the pulse train is proportional to the flow rate in the pipe.

The secondary parameter transducers are used to measure the discharge pressure head and the water supply level which partially define the total dynamic head. The discharge pressure head is sensed with a high range pressure transducer attached to the discharge line through a port located downstream of any flow control valves. The water level in the pumping bay is typically sensed with a float or bubbler system (air line). The components of the bubbler system are an air supply, pressure regulator, flow control valve, flow indicator, pressure transducer, and associated air lines. The air flow is adjusted to provide a steady stream of air bubbles at the outlet of the bubbler air line located in the water supply. The air pressure in the air line indicates the depth of water above the air line outlet and is sensed with a low range pressure transducer. The demonstration monitors used bubbler systems.

CALCULATED PARAMETERS

The primary indicator of pumping station performance is the energy efficiency of the pumping station as defined in the following equation:

$$E = 100.0(Whp/Ehp) \qquad [1]$$

where:

E is the energy efficiency, %

Whp is the output power, hp

Ehp is the input power, hp

The input power is obtained directly from the utility power meter. The output water horsepower of a pumping station is a function of discharge and total dynamic head as defined by equation 2.

$$Whp = 0.11345(Q)(TDH) \qquad [2]$$

where:

Whp is water horsepower, hp

Q is flow rate, cfs

TDH is total dynamic head, feet

The flow rate is obtained directly from the flow meter and the total dynamic head is determined from the discharge pressure and flow, the pumping lift, and water level as shown in equation 3.

$$TDH = DE + DH - WL + (Q/A)^2/64.4 \qquad [3]$$

where:

TDH is total dynamic head, feet

DE is the elevation difference between the discharge pressure sensor and the air line outlet, feet

DH is the discharge head, feet

WL is the water depth above the air line outlet, feet

Q is the discharge flow rate, cfs

A is the discharge pipe cross sectional flow area, sq.ft

An additional useful indicator for pumping station management is the variable energy cost associated with pumping a unit volume of water. The total energy cost associated with a unit volume of water pumped is comprised of two components: demand and consumption. The demand cost is a fixed cost for a billing period based on the peak energy use regardless of the volume of water pumped. The consumptive cost is a variable cost for a billing period based on the total amount of energy used. It is this variable cost factor which the monitor can use as a performance indicator and management tool. The energy cost is calculated from:

$$C = 9.023(Cop)(Ehp)/Q \qquad [4]$$

where:

C is the energy cost associated with one acre foot of water pumped, dollars/acre foot

Cop is the cost of energy per kilowatt-hour, dollars/kw-hr

Ehp is the input power, hp

Q is the flow rate, ft^3/sec (cfs)

This indicator of pump performance was not included in the monitors demonstrated. It has been added to the University of Idaho monitor software as recommended by project cooperators for future demonstrations.

OTHER PUMPING STATION MONITORS AND PROGRAMS

As part of energy conservation programs mandated by public utility commissions, many utilities have offered pump efficiency tests. The Bonneville Power Administration has an on going irrigation system efficiency program with cooperating utilities and will help pay for pump efficiency and irrigation system efficiency evaluations by private consultants. In a comparable program, Idaho Department of Water Resources will conduct an energy efficiency audit of irrigation systems upon request. These energy audits provide point measurements on the irrigation system efficiency, and highlight system improvements that may be implemented to decrease energy use. Because the audits are necessarily conducted for one operating condition, day to day feedback for operation management is not available for the pumping station operator.

Utah State University (USU) developed three pump efficiency monitors for the United States Department of Agriculture - Agricultural Research Service. The three monitors developed ranged from a manual unit where the pumping station operator served as the data assembler and processor to a fully automated unit. These units were demonstrated by the USU group during their development; however, the units were not totally operational. The monitors are more completely described in Water Well Pump Efficiency Monitor Units by Calvin G. Clyde, Duard S. Woffinden, and Graeme Duncan, 1986.[1]

By the end of the USU demonstration project, a commercially available pumping station efficiency monitor came on the market. The monitor has a base cost of 5000 dollars and is targeted for consultants who are performing system efficiency evaluations. The standard unit comes with various transducers required for monitoring a centrifugal booster pump with the exception of the flow measurement transducer.

PROJECT OBJECTIVES

The primary purpose of this project was to demonstrate pump efficiency monitors on selected pumping stations located in southern Idaho. Because one of the major transducers required for a pumping station monitor is a flow measuring device; the monitor demonstration sites were selected from locations of another project dealing with evaluation of flow measuring devices.

Because project personnel believed that pumping station operators would not make effective use of monitors requiring more than simple push button operation, the two low cost monitor units developed at USU were not used in the demonstration program. Two new monitor units were developed for this demonstration project with an objective of using existing "off-the-shelf" technology with costs under $3000.

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[1]Clyde, Calvin G., Duard S. Woffinden, and Graeme Duncan, 1985. Water Well Efficiency Monitor Units. Hydraulics and Hydrology Series UWRL/H-86/01. Utah Water Research Laboratory, Utah State University, Logan, Utah, November 1985.

MONITOR DESCRIPTIONS

THE UTAH STATE UNIVERSITY MONITOR

The fully automatic efficiency monitor developed by the Utah State University group incorporated a micro computer system for control and calculation of pump efficiency. The unit was capable of sampling the efficiency once a day at a predetermined time or continuously, and produced a printed hard copy of the measurement results. The unit consisted of a micro-computer control system based upon the Z-80A microprocessor and various transducers for sensing the four physical parameters describing energy efficiency of a pumping station.

Control System

The developers felt that because of the power availability at pumping stations; it was not necessary to base the electronics around a low power electronics suitable for battery operation. The Z-80A microprocessor controls the acquisition of the data from the various transducers, performs the pump efficiency calculations, and prints the efficiency results. Incorporated in the control system is a real time clock for controlling the time of sampling of pump efficiency.

Site data, including pipe size, elevation of bubbler tube outlet, and transducer coefficients, are maintained in the monitor by a series of miniature switches serving as read only memory which are set by the user. For the user to set the switches, they need to be familiar with the binary number system.

In addition to displaying the energy efficiency, the results are printed by the monitor on paper tape for a permanent record. The monitor prints the date and time of the sample, the pump efficiency, the input power, the pumping lift, and the flow rate.

Transducers

The monitor package used three transducers to sense the four basic pump efficiency parameters. The local utility supplied the electrical input power transducer, a pulse output watt hour meter. The flow rate was sensed with a impact tube flow sensor which converts the velocity head into a static differential pressure. This differential pressure is sensed by the monitor with a differential pressure transducer and subsequently converted to flow rate. The differential pressure seldom exceeds 3 psi and the background pressure is typically over 50 psi, requiring solenoid isolation valves to protect and zero the transducer. The USU monitor uses a single differential pressure to measure the difference between the discharge pressure head and the pumping water level.

THE UI/ARS MONITOR

The University of Idaho in cooperation with the Agricultural Research Service developed a pumping station monitor based upon commercially available technology. The development and field studies were conducted at the Kimberly, Idaho Research and Extension Center. The control and computation processor is an HP-41CX calculator interfaced to a Corvallis Microtechnology CMT 200 data acquisition unit, figure 2. The data acquisition unit was interfaced to the various sensors through an analog to digital (A to D) multiplexer unit, developed at the Kimberly laboratory. The HP-41CX calculator executes the control program, performs the necessary efficiency calculations, and stores the results for future use. The monitor sensor system consists of the following components: a pulse type watt hour meter, a flow meter, a discharge pressure transducer, and a bubbler system with a pressure transducer.

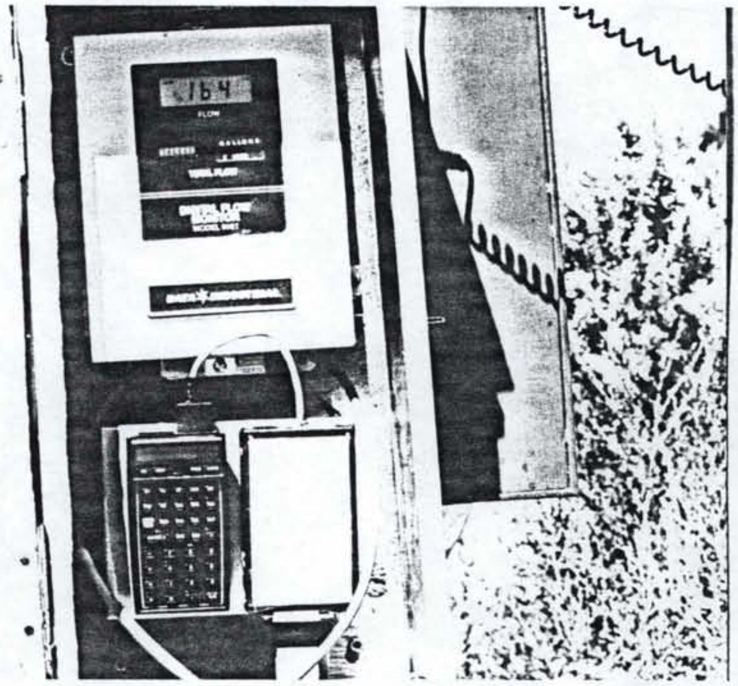

Figure 2. Pumping Station Monitor

Control System

The controller of the pumping station monitor developed by UI and ARS is the HP-41CX calculator. Internal to the calculator, a real time clock schedules the acquisition of performance data. The calculator can store upwards of 16 observation sets of performance data depending on the configuration of the purchased calculator. The calculator is battery powered and requires no external power to run. An optional printer can be interfaced to the calculator for producing a hard copy of the performance data.

The calculator is interfaced to the transducer conditioner (A to D converter) via the Corvallis Microtechnology CMT-200 data acquisition unit, which converts digital data from a specific channel into the format expected by the HP-41CX calculator in addition to performing timing functions on pulse signals. The unit is interfaced to the transducer with multiplexer unit built by the USDA ARS for this project.

The A to D multiplexer unit developed by project personal performs four important functions. The first function allows the CMT-200 data acquisition unit to select the parameter channel for scanning. The second function performed by the unit amplifies the low level analog voltage signals from the analog transducers to appropriate levels for A to D conversion. Thirdly the unit converts the amplified analog signal to a digital format which the CMT-200 can interpret and send to the HP-41CX. Lastly the unit provides the excitation power for the various sensors and protection from stray voltages which may be induced on the transducer leads.

Transducers

The pumping station monitors built by the University of Idaho currently utilize flow rate data from meters equipped with pulse output signals. The monitors could be modified to accept analog output signals that are available from other flow meters. In the demonstration project, the flow meters used were a Signet paddle wheel type meter and a Flow Research Corporation impeller type meter. These meters were already equipped with electronics for interpreting the electrical signal from the transducers and integrating flow rates. The electrical pulse signal indicating flow rate was available from the electronic instrumentation of the flow meters. On subsequent models, the multiplexer unit of the pumping station monitor has been modified to accept the flow rate signal directly from the flow transducer, thus eliminating the need of the flow meter computer. The pressure sensors used for sensing the discharge pressure and the water level were standard solid state piezo-resistive pressure transducers available from many firms.

The bubbler system constructed by the University for the pumping station monitor consists of an air supply, pressure regulator, an air flow control valve, an air flow indicator, and plastic tubing with associated fittings. Two different air supplies were evaluated with the monitors, bottled compressed air and a portable air tank. The portable air tank required weekly filling, whereas the compressed air bottle provided an adequate supply for the entire irrigation season. Standard compressed air regulators where required with both supplies to reduce and regulate the air pressure for the bubbler system. A properly functioning bubbler system requires only a single bubble to be emitted from the end of the tube every minute or so. A large stream of air flowing from the tube is not required and will lead to erroneous measurements. Serving as an air flow control, a simple needle valve offers the necessary regulation to produce intermittent air bubbles from the tube outlet. Because the operator usually cannot see the air bubbling out of the tube in the water supply, a flow indicator is required to adjust the air flow rate. A sealed canning jar partially filled with water functioned as a flow indicator for the developed monitors.

The two pumping station monitor components fabricated by the University and ARS consisted of the multiplexer unit and the bubbler system. The multiplexer unit requires some electronics expertise for a pumping station operator to build himself; however, an electronics repairman or hobbyist should have no problem building it using the circuit diagram. The water level bubbler system can be easily constructed from available materials by the pumping station operator.

Control Software

The control and computational instructions, or software, are necessary for the HP-41CX operate as a pumping station monitor. The software consists of many different subroutines which utilize the capabilities of the HP-41CX and the CMT-200. The general operation of the software begins when the pumping station monitor has been installed by requesting the pumping station physical characteristics and the coefficients associated with the various transducers and meters connected to the monitor and the sampling frequency for pumping station performance.

Sampling the pumping station performance under the automated mode, the monitor first will determine the electrical input power usage. If the monitor determines that the pumping station is not running, i.e., the power usage is below a threshold limit, the monitor records that the pumping station was not running and turns itself off until the next sampling time. When the power consumption by the pumping station is above a threshold limit, the monitor then proceeds to scan the flow meter and the pressure transducers. Upon completion of data channel scanning, the unit then performs all the necessary calculations and records the data. The unit then goes to sleep until the internal clock turns it on for the next scan. In the manual mode, the pumping station operator wakes up the unit by turning on the calculator and simply presses the button associated with the information wanted. If the user fails to put the unit to sleep (turn the calculator off), the monitor will automatically turn itself off.

The pumping station performance data gathered by the unit in the automated mode is retrieved from memory through the manual mode by pressing a button. The data will be displayed on the calculator and printed if the optional printer is attached to the calculator.

DEMONSTRATION SITE DESCRIPTIONS

Two of the demonstration sites were multiple pump units selected from several flow meter evaluation project locations because of flow meter availability. These locations were selected on the basis of ownership, access for demonstration tours, sufficient pipe for multiple meter installation, flow rate, pipe size, ease of installation of the pressure and power transducers, and the willingness of the station operator to cooperate.

The third station was selected for proximity to the Research Station for demonstration of the USU fully automatic unit because of the more frequent maintenance requirement and the need for a conditioned 110 volt power supply. The USU fully automated unit was therefore re-installed on the Kimberly Municipal Well. The flow meter and power meter for the unit were still installed at that location from the earlier USU demonstration.

KIMBERLY MUNICIPAL WELL

The City of Kimberly number one water well was selected as a demonstration location because the USU fully automatic unit had previously been installed at this location. The well is one of 4 municipal water supply wells operated by the city. The pump system discharges into the city water distribution main line which is connected to two storage tanks. The pump is automatically turned on and off by water level switches on the storage tanks. The well produces approximately 775 gpm at a discharge pressure of 35 psi.

The USU fully automated monitor was installed at this location from the middle of April to the first of September, 1986 when the city had the pump pulled for service. During the time of installation, the USU monitor had repeated electronic component failures. Through discussions with Dr. Calvin Clyde, the USU developer, it was determined that the failures were similar to those which had plagued the unit during initial demonstrations. When the unit was working, it recorded pump efficiencies shown in table 1, Appendix A.

ED POTUCEK IRRIGATION PUMPING STATION

The Potucek site is located 2 miles east of Glenns Ferry, Idaho, and consists of two Aurora vertical turbine pumps which supply pressurized irrigation water to a sprinkler irrigation system. The 225 horsepower pumping station has a discharge capacity of 5.3 cfs at 320 feet of head. The pumps discharge into a nominal 10 inch diameter steel pressure line with a flow regulation valve located approximately 30 feet downstream of the pumps as shown in figure 3. In addition to the pumping station monitor, six flow measuring devices were evaluated in conjunction with another project: a Miller Shunt Meter, a Sparling propeller meter, a Data Industrial Corp. impeller meter, a Water Specialties propeller meter, a Signet paddle wheel meter, and a McCrometer propeller meter.

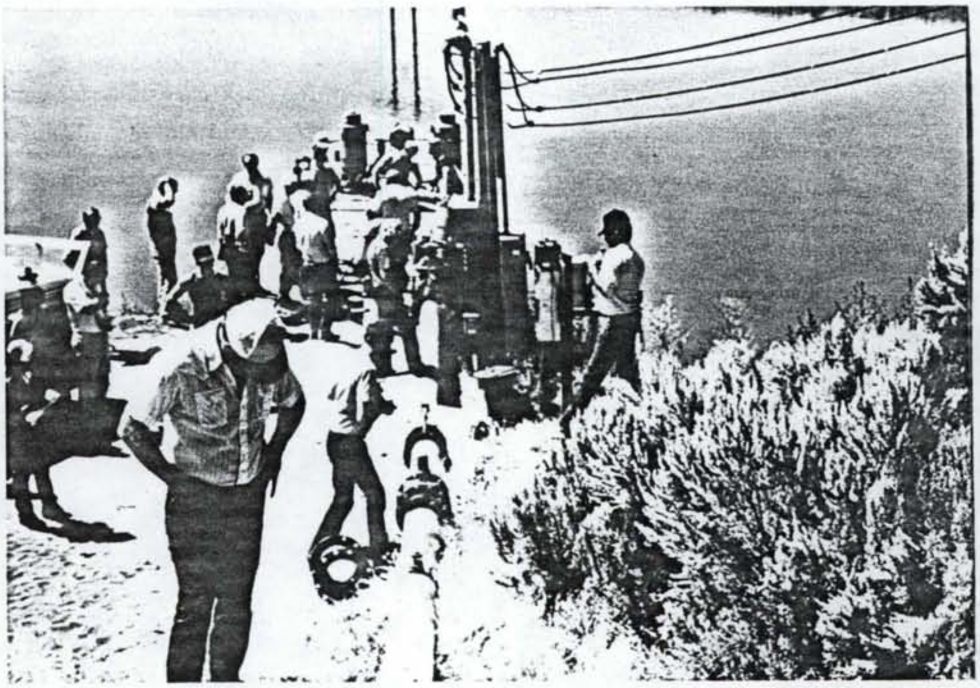

Figure 3. Ed Potucek Pumping Station

Mr. Potucek had a typical crop distribution of alfalfa, dry beans, sugar beets, pasture, and grains. His personal operation guideline for the pumping station is to maintain a pressure of 110 psi at the station. He first selects the appropriate pump combination for the day's irrigation needs and then uses the control valve on the pumping station to throttle the discharge for fine tuning the output pressure of the station.

The UI/ARS pumping station monitor was used at this location utilizing the flow signal from a Signet paddlewheel meter and associated electronics. The water elevation of the Snake River was sensed using a bubbler system with a portable air tank and a low pressure piezo-resistive pressure transducer. Discharge pressure was sensed downstream of the pumping station control valve using a standard piezo-resistive pressure transducer. The input power sensor was a pulse type watt meter supplied by Idaho Power Company.

There were various problems with installation and operation of the UI/ARS pumping station monitor at this location and at the other location on the Triangle Dairy farm near Grandview, Idaho. Particularly, the air supply from the small portable air tank was not sufficient for extended periods of time. The tank was able to supply the bubble system with air for a maximum of 7 days. In addition to the air supply, the operational amplifiers selected for use with the piezo-resistive pressure transducers were not appropriate and had non-linearity problems. This problem was also encountered on the Triangle Dairy monitor unit. During the installation and testing of the monitor, it was discovered that the CMT-200 unit had a software bug associated with pulse functions. It was determined with the help of the staff at Corvallis Microtechnologies that additional programming steps would temporarily solve the problem. They subsequently fixed the hardware problem and sent updated material after the irrigation season was over. As a result, the input power measurement accuracies were not consistent and several times the unit would indicate that the pumping station was not operating. The flow sensor used at the Potucek site experienced a paddlewheel shaft failure, thus limiting the amount of data collected. The monitored pump efficiencies for this pumping station are shown in table 2 in Appendix A.

TRIANGLE DAIRY RELIFT PUMPING STATION

The Triangle Dairy relift pumping station is located on the Bybee Lateral about 5 miles southeast of Grandview, Idaho, near the Rimrock Junior-Senior High School. At this location Triangle Dairy lifts irrigation water from the Bybee Lateral, 95 feet into their canal system. The water originates from the Snake River where a group of farms jointly operate a pumping station diverting the water into the lateral. The relift pumping station consists of 4 vertical turbine pumps with a combined horsepower of 525 and is shown in figure 4. The pumping station discharges into a nominal 30 inch diameter pipe which delivers water to a canal 95 feet above the pumps. In addition to serving as a demonstration location for pump monitors, four flow measurement methods were evaluated at this site in conjunction with another project: a McCrometer propeller meter, Wilgood dual turbine, Flow Research impeller, and a USGS gaging station.

Figure 4. Triangle Dairy Pumping Station

The station is operated by the farm staff to supply water to surface and sprinkler irrigated lands owned by the dairy. Changes in the quantity of water pumped by this station usually takes approximately four hours to move through the delivery canal before arriving at the place of use. The farm manager schedules crop irrigations by consumptive use, soil moisture monitoring, and crop appearance and adjusts the output of the station to meet the irrigation requirements by selecting the appropriate combination of pumps.

This demonstration site was equipped with the UI/ARS monitor, and utilized a pulse type watt-hour meter supplied by Idaho Power Company for the electrical input power signal. The piezo-resistive pressure transducers were used to determine canal water level and discharge pressure head. The discharge of the pumping station was sensed with a flow measurement system supplied by Flow Research Corporation. The electronic integration box of the flow system required modification to supply pulses to the pumping station monitor. The water level bubbler system used a compressed air bottle, instead of a portable air tank.

Electronic problems similar to those experienced at the Potucek site were also experienced at this location. The compressed air bottle did, however, last the entire season. The results of the pumping station monitoring are shown in table 3 in Appendix A.

DEMONSTRATION TOURS

Two demonstration tours were conducted during the project. These tours allowed pumping station operators, action agency personnel, and local media personnel to examine pumping station monitors in use. The first tour was conducted on July 28 and the second tour was held on August 18. Each of the three demonstration sites was visited during the tours and a luncheon was held with presentations from project personnel on the pumping station monitor and the state irrigation extension agent presented material on energy efficient irrigation practices and how a pumping station monitor could be incorporated into management of irrigation systems.

The tours were announced through the local media and through Idaho Department of Water Resources Publication *CURRENTS*. The tours were attended by various people; however, they were not well attend by irrigators. The occupational breakdown of the 51 people attending the tours is shown in table 1.

Table 1. Occupational Breakdown of Tour Participants.

Occupation	Number Attending
Governmental Agencies	22
Irrigation Companies/Districts	12
Farmers (irrigators)	7
Dealers and Manufacturer Representatives	8
Media	2

POTENTIAL BENEFITS OF USING A PUMPING STATION MONITOR

Pumping station monitors continuously measure discharge and energy input and output thereby allowing pumping station operators to evaluate station performance without scheduling system tests by a third party, such as their local utility or the Department of Water Resources. A pumping station monitor will allow the operator to immediately evaluate the effect of changes in the operation of the system on the performance of the station with regard to energy usage and other parameters. All performance parameters can be accessed by the operator by pressing a single button on the monitor. In addition, the monitor automatically records the station performance at fixed intervals thus allowing users to evaluate long term changes in the performance of the pumping station due to management or wear. Therefore, operators could increase the pumping station efficiency through better management.

MONITORS AS MANAGEMENT TOOLS

To increase pumping station operation efficiency through management, the operator must be willing to change some aspect of the total system operation. A knowledge, provided by the monitor, on alternative or optimum pump combinations or valve operation can assist in decisions involving operations. In addition, flow load management and demand scheduling can decrease water pumped and total pumping costs. For irrigation pumping stations the management objective is still to meet the irrigation requirements of the crops while operating the pumping station at the best efficiency possible or the lowest cost per acre foot of water pumped. The operator should be continually evaluating whether or not current irrigations could be postponed or future irrigations could be moved up so that the pumping station would be operating at peak efficiency rather than partial load at lower efficiency.

A monitor will also report several parameters that will help the operator to evaluate the health of the system. Any abrupt change in efficiency or flow rate can signal possible mechanical or hydraulic problems. Longer term measured decreases in efficiency can indicate wear in pump bowls or other mechanical or electrical problems.

POTENTIAL SAVINGS FROM INCREASING OVERALL EFFICIENCY

Pumping station monitors will allow an irrigator or station operator to potentially improve overall system efficiency. If the operator can implement changes in system hardware and/or operation which improve station efficiency, the potential energy saving in dollars per acre for a typical irrigation system in southern Idaho can be substantial. Potential savings in dollars per acre for a one percent increase in overall energy efficiency are shown in figure 5; annual energy costs are shown in figure 6 for various application efficiencies and summarized in table 2 for 60 percent application efficiency. This table was developed assuming a typical crop

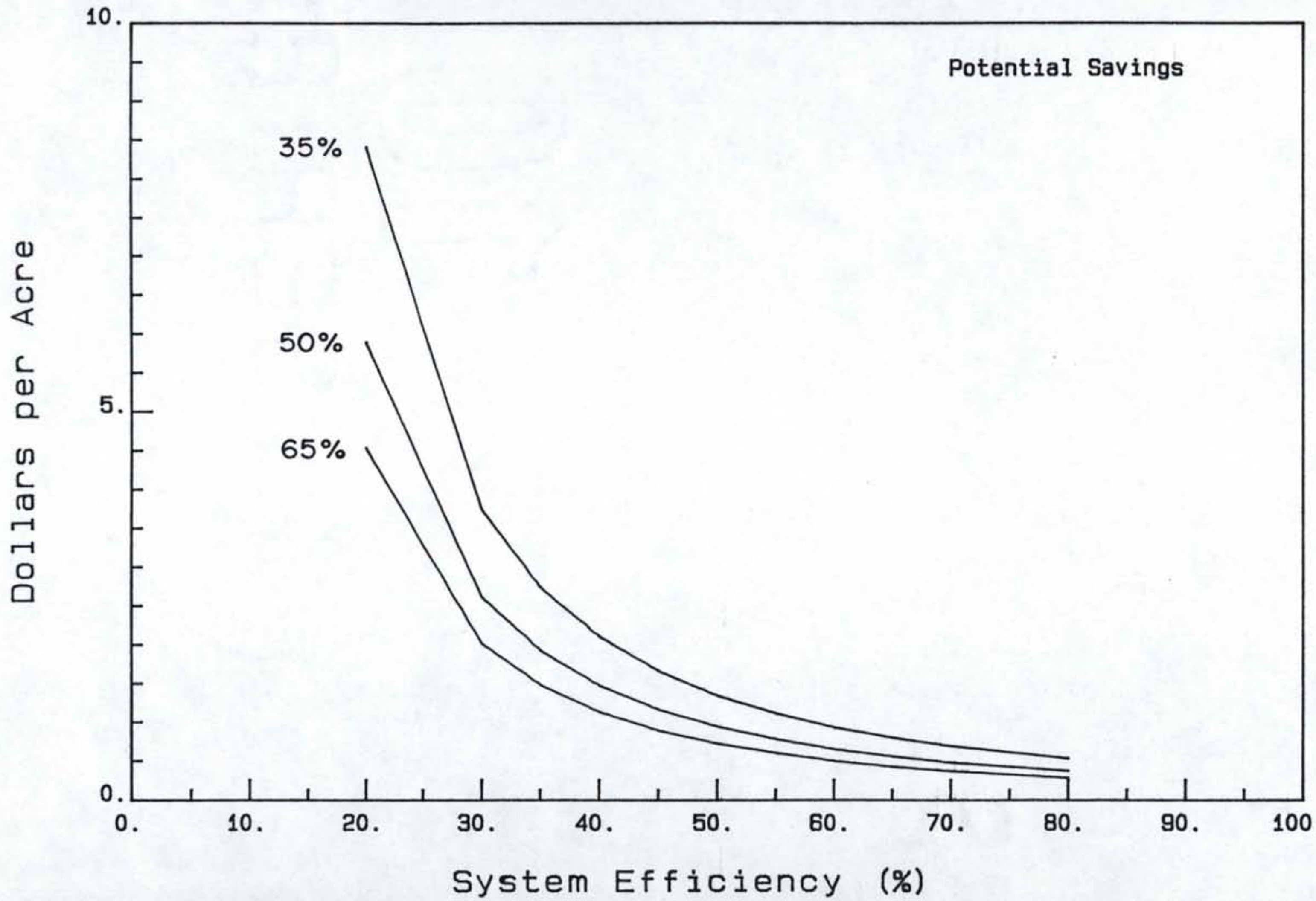

Figure 5. Potential Energy Savings as a Function of System Energy Efficiency for Three Application Efficiencies

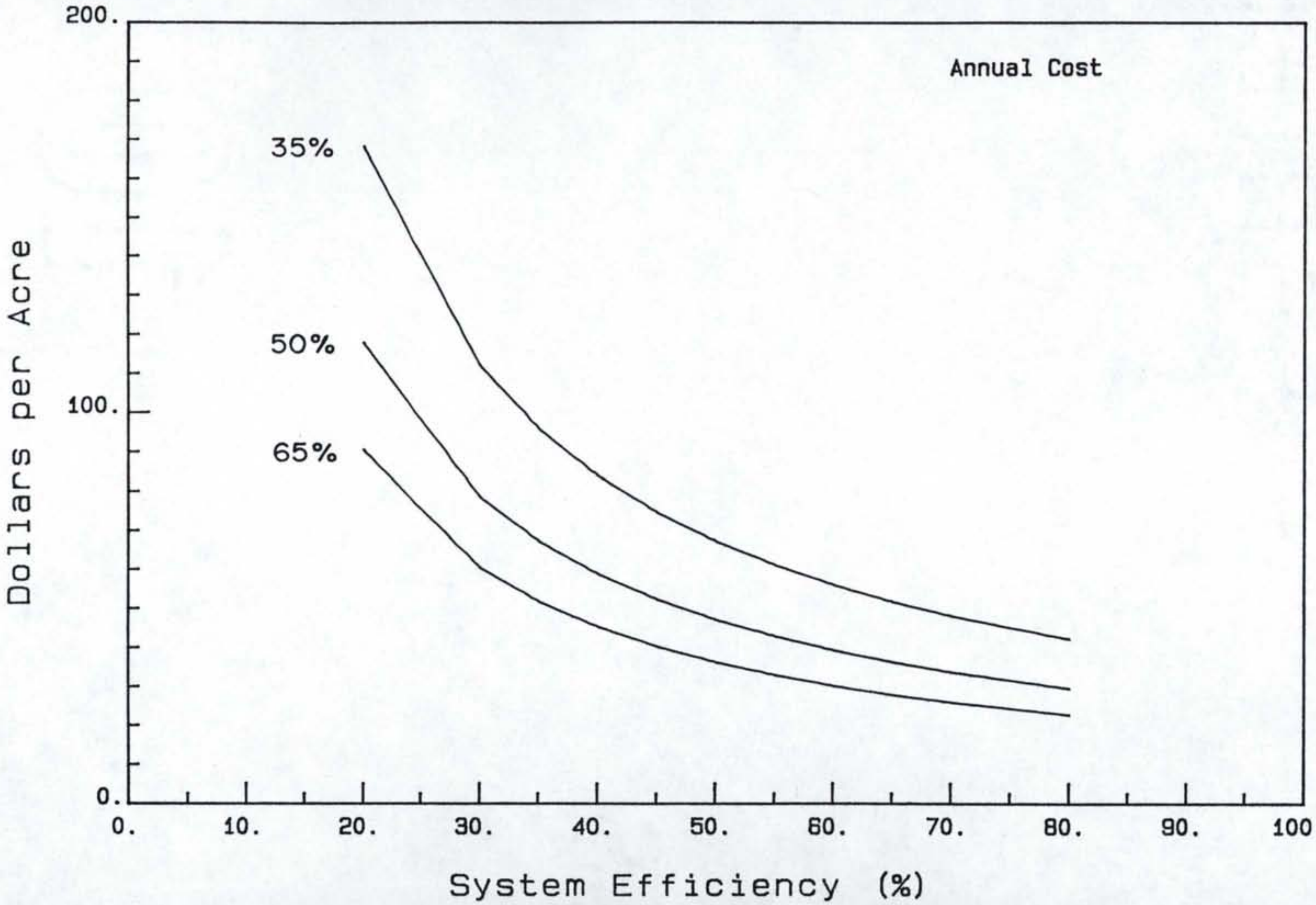

Figure 6. Annual Energy Cost as a Function of System Energy Efficiency for Three Application Efficiencies

distribution found in southern Idaho irrigated with a medium pressure sprinkler system from a surface water supply and assuming the cost of power to be 4 cents per kilowatt hour.

Table 2. Potential Savings by Improving System Efficiency by One Percent for Application Efficiency of 60 Percent.

System Energy Efficiency	Current Annual Cost $/acre	Potential Annual Savings $/Acre
30	65.36	2.18
40	49.02	1.23
50	39.22	0.78
60	32.68	0.54

The table indicates that a farmer irrigating 300 acres with a current system efficiency of 40 percent could save $369 by increasing the irrigation system efficiency by one percent. This improvement might be made through management of the irrigation system without changes in the pumping system. The system efficiency probably can increased by more than one percent with subsequent additional savings. If the system efficiency could be increased from 40 to 50 percent then the savings would be $2,940. These potential savings assume that the irrigator would not pump more water than he is currently pumping, thereby decreasing the water usage (application) efficiency of the irrigation system.

Kimberly Well

The Kimberly well is a single pumping station which is operated without any flow control valve. The pump operated at an average efficiency of 55 percent with a power demand of 68.9 kw and a developed flow rate of 1.61 cfs (1.04 mgd). This translates into an energy cost, assuming $0.04/kwh, of $20.84/af or $63.96/mg. Given the constant system characteristics, a properly selected pump should be able to achieve an energy efficiency of at least 65 percent, thus lowering the power demand to 58.3 kw and the energy cost to $17.54/af or $53.78/mg. If the duty cycle of the well is 8 hours per day, then the well would produce 126.6 mg in a year. At their current efficiency, the annual energy cost is $8,098. By increasing the efficiency to 65%, they could lower their cost to $6,809, with annual savings of $1,289.

Potucek Station

Mr. Potucek's pumping station averaged 56.5% energy efficiency during a 30 day period when the monitor was functioning. During that time, his average power requirement was 122.3 kw. If power costs, including demand, were $0.04/kwh, his energy cost for the 30 day period would have been $3,525. If he could have increased his station efficiency by one percentage point, he potentially could have saved 2 kw, or $61 during that 30 day period. Typically, when he runs both pumps, he has an input power requirement of 190 kw and produces a flow of 4.5 cfs. At $0.04/kwh this translates into a pumping cost of $20.62/af, with an average efficiency of 55.7 percent. When he runs his large pump, he has a power requirement of 109 kw and associated pumping cost of $18.08/af at an efficiency of 55.8 percent. The small pump was not really used during the 30 day period; however, the couple of times it was on, the indicated power requirement was 93 kw for a pumping cost of $20.03/af. This would indicate that Mr. Potucek would be well advised to use the large pump by itself whenever possible.

Triangle Dairy Re-Lift Station

At the Triangle Dairy re-lift station, energy costs varied from $6.63./af to $7.87/af depending on the pump combination running. Due to an unreliable discharge pressure transducer, a reliable estimate of the overall efficiency of the station cannot be made. It appears to range from 50 to 60 percent, depending on the pump combination running.

MONITOR ANALYSIS AND COSTS

The two units developed at the University of Idaho have a projected cost of under $2000. The other pump efficiency monitor which was previously developed at Utah State University has a projected cost of $6000. During the two tours conducted by the University of Idaho several manufacturers expressed interest in the pumping station monitors for incorporation into their product lines.

The monitors, especially the UI/ARS monitors, show promise for use by irrigators and pumping station operators. However, the UI/ARS monitors did have development problems during the project period. As of this report, these deficiencies have been corrected and the monitor system is functional. There are 18 similar units installed at this time. One season, during which there were some operation difficulties with the monitors, was not an adequate time period to evaluate the reliability of the units. However, similar units installed in 1987 have shown consistent results.

The cost of the UI/ARS pumping station monitor with flow transducer and watt hour meter installation is estimated to be $1,835 and is broken down in table 3.

Table 3. Cost of UI/ARS Pumping Station Monitor.

HP41-CX Calculator	190.00
CMT-200 Data Acquisition Unit	250.00
Analog to Digital Multiplexer	250.00
Low Pressure Transducer	50.00
High Pressure Transducer	150.00
Flow Transducer	300.00
Watt Hour Meter	400.00
Bubbler System less bottle	175.00
Enclosures	45.00
Miscellaneous parts	25.00
TOTAL	1835.00

This cost is very dependent upon the pumping station and local local utility operation. Some power utilities do not charge for the installation of a pulse type watt hour meter, whereas other utilities do charge for the watt hour meter and associated equipment that they feel is necessary to protect their equipment. The cost of the flow transducer will vary depending upon the configuration of the pumping station and can vary from the listed $300 to $2,500, depending upon the type and pipe size.

CONCLUSIONS

Three electronic pumping station monitors were demonstrated to governmental agencies, farmers, irrigators, dealers, and others during the summer of 1986. Two of the monitors developed by the University of Idaho and the Agricultural Research Service utilize primarily "off the shelf" components and cost less than $2,000. These units are simple and easy to operate, and do not require a conditioned power source. A third monitor, utilizing hardware and software developed by Utah State University, costs approximately $6,000. With these monitors, a pumping station operator has information for management and operation decisions at his fingertips which will allow him to evaluate his pumping operation and system, save energy, and lower pumping costs.

APPENDIX A. MONITORED PUMPING STATION EFFICIENCIES

Table 1. Monitored Pump Efficiency for the Kimberly Site

Kimberly Well Efficiency Monitor

Date	Time	Input Power (kw)	Pumping Lift (ft)	Flow (cfs)	Monitor Efficiency (%)	Comments
04/25/86	11.30	69.3	289	1.60	56.3	Install Monitor
04/25/86	11.36	69.1	289	1.60	56.5	
04/25/86	13.21	69.2	287	1.60	56.2	
04/25/86	13.28	69.2	287	1.59	55.9	
04/25/86	13.34	69.2	288	1.59	56.1	
04/25/86	13.42	69.2	288	1.59	56.1	
04/25/86	13.49	69.4	288	1.60	56.1	
04/25/86	15.03	69.2	287	1.60	56.1	
04/27/86	13.06	69.1	289	1.61	57.1	
04/27/86	13.13	68.6	289	1.61	57.2	
04/27/86	13.19	68.7	294	.73	26.5	Pump turned off
04/28/86	13.07	69.0	289	1.61	56.9	
04/28/86	13.14	68.9	288	1.61	56.8	
04/28/86	13.20	68.8	289	1.61	57.0	
04/29/86	14.05	69.2	287	1.60	56.3	
04/29/86	14.11	68.9	288	1.61	57.1	
04/29/86	14.18	68.9	287	1.60	56.6	
04/30/86	13.06	69.0	435	1.62	86.3	Bad Lift Chip
04/30/86	13.12	68.7	435	1.61	86.4	Bad Lift Chip
04/30/86	13.19	68.7	435	1.61	86.4	Bad Lift Chip

Discovered Malfunction with lift circuit.
Replaced bad lift voltage regulator chip.

Date	Time	Input Power (kw)	Pumping Lift (ft)	Flow (cfs)	Monitor Efficiency (%)	Comments
05/05/86	11.08	69.2	286	1.61	56.2	
05/05/86	13.06	69.1	286	1.61	56.3	
05/05/86	13.12	69.1	286	1.61	56.3	
05/05/86	13.19	68.9	285	1.61	56.5	
05/06/86	13.18	69.4	288	1.60	56.2	
05/06/86	13.24	69.0	288	1.60	56.4	
05/06/86	13.31	69.2	288	1.60	56.3	
05/07/86	10.37	69.7	434	1.61	84.8	Bad Lift Chip
05/07/86	10.37	69.7	434	1.61	84.8	Bad Lift Chip
05/07/86	10.37	69.7	434	1.61	84.8	Bad Lift Chip

Discovered Malfunction with lift circuit.
Replaced bad lift voltage regulator chip.

Date	Time	Input Power (kw)	Pumping Lift (ft)	Flow (cfs)	Monitor Efficiency (%)	Comments
08/29/86	13.07	68.3	291	1.62	58.4	
08/29/86	13.14	68.3	291	1.62	58.4	
08/29/86	13.20	68.1	292	0.64	23.1	
08/30/86	13.07	68.4	290	1.62	58.0	
08/30/86	13.14	68.5	289	1.62	57.8	
08/30/86	13.20	68.5	290	1.62	58.0	
08/31/86	13.07	68.4	285	1.62	57.2	
08/31/86	13.13	68.6	285	1.62	57.0	
08/31/86	13.20	68.7	283	1.62	56.6	
09/01/86	13.07	69.1	283	1.61	55.8	

Kimberly Well Efficiency Monitor

Date	Time	Input Power (kw)	Pumping Lift (ft)	Flow (cfs)	Monitor Efficiency (%)	Comments
09/01/86	13.13	68.8	283	1.61	56.0	
09/01/86	13.20	68.7	283	1.61	56.1	
09/02/86	13.07	68.5	284	1.62	56.7	
09/02/86	13.13	68.9	284	1.61	56.2	
09/02/86	13.19	68.8	284	1.62	56.4	
09/03/86	13.07	68.8	277	0.0	0.0	Pump off?
09/03/86	13.13	68.8	284	0.90	31.3	Bad Flow?
09/03/86	13.19	69.0	287	0.88	31.0	Bad Flow

Table 2. Monitored Pumping station Efficiencies for Potucek Pump Station.

POTUCEK Pump efficiency Monitor

DATE	TIME	Input POWER (hp)	Pumping FLOW (cfs)	LIFT (ft)	PRESS (ft)	TDH (ft)	Efficiency EFF (%)	COMMENTS
08/14/86	10.58	108.1	4.91	11.74	274.8	248.44	128.07	AC
08/14/86	10.66	169.9	4.91	12.18	247.7	248.00	81.32	AC
08/14/86	10.82	254.9	.29	12.49	253.8	252.41	3.26	BC
08/14/86	22.99	254.9	4.99	1.63	241.7	252.54	56.10	
08/15/86	.00	262.6	4.98	2.01	241.7	252.16	54.27	
08/15/86	.29	254.9	4.83	1.57	253.8	264.60	56.90	
08/15/86	1.01	262.6	5.00	2.01	241.7	252.17	54.43	
08/15/86	1.99	262.6	4.97	2.07	247.7	258.13	55.36	
08/15/86	3.00	262.6	4.96	1.69	241.7	252.46	54.09	
08/15/86	4.01	262.6	4.96	1.69	241.7	252.46	54.13	
08/15/86	4.99	254.9	4.96	1.63	247.6	258.57	57.06	
08/15/86	6.00	247.2	4.29	1.63	265.9	276.36	54.46	
08/15/86	7.99	262.6	5.23	1.36	229.6	240.84	54.38	
08/15/86	9.00	262.6	5.11	1.32	235.7	246.88	54.55	
08/15/86	10.01	254.9	4.88	1.13	253.8	265.07	57.56	
08/15/86	13.99	262.6	5.05	.75	290.1	301.79	65.79	CD
08/15/86	14.52	254.9	4.98	1.07	290.1	301.45	66.88	
08/15/86	14.59	254.9	4.98	1.07	284.0	295.40	65.43	
08/15/86	14.66	254.9	4.98	1.13	290.1	301.38	66.82	
08/15/86	15.22	177.7	4.98	1.19	290.1	301.32	95.77	A
08/15/86	15.26	204.7	4.99	1.26	290.1	301.26	83.26	A
08/16/86	.00	254.9	4.23	2.01	296.1	306.17	57.64	C
08/16/86	6.00	251.0	4.10	1.63	308.2	318.57	59.08	CD
08/16/86	12.00	258.8	4.57	.38	290.1	301.92	60.55	C
08/16/86	18.00	258.8	4.32	1.44	296.1	306.78	58.17	
08/17/86	.00	251.0	4.21	1.51	296.1	306.66	58.40	
08/17/86	6.00	251.0	4.18	1.38	296.1	306.77	57.98	
08/17/86	12.00	251.0	4.03	.94	308.2	319.23	58.17	D
08/17/86	18.00	243.3	3.76	1.44	278.0	288.40	50.54	
08/18/86	.00	251.0	4.06	2.01	259.8	269.83	49.49	
08/18/86	6.00	251.4	4.05	1.44	253.8	264.35	48.34	
08/18/86	12.00	239.5	3.63	1.44	290.1	300.43	51.65	
08/18/86	18.00	146.8	3.23	1.00	217.5	228.20	56.99	
08/19/86	.00	150.6	3.42	2.01	193.4	203.10	52.25	D
08/19/86	6.00	150.6	3.41	1.51	169.2	179.42	46.03	D
08/19/86	12.00	150.6	3.07	1.19	223.6	234.00	54.00	
08/20/86	.00	146.8	2.94	1.38	235.7	245.86	55.89	
08/20/86	12.00	142.9	2.76	1.44	253.8	263.87	57.91	
08/21/86	.00	142.9	2.52	1.13	271.9	282.24	56.54	
08/21/86	12.00	139.0	2.55	2.26	271.9	281.12	58.43	C
08/22/86	.00	142.9	2.59	1.32	265.9	276.03	56.74	
08/22/86	12.00	146.8	2.72	1.63	187.3	197.20	41.46	CD
08/23/86	.00	146.8	2.83	1.44	247.8	257.85	56.35	
08/23/86	12.00	146.8	3.00	1.07	229.6	240.15	55.15	
08/24/86	.00	146.8	2.85	1.44	241.7	251.81	55.52	

A = Problems with Input Power sensing.
B = Problems with Flow Rate sensing.
C = Problems with Water Level sensing.
D = Problems with Discharge Pressure sensing.

POTUCEK Pump efficiency Monitor

DATE	TIME	Input POWER (hp)	Pumping FLOW (cfs)	LIFT (ft)	Efficiency PRESS (ft)	TDH (ft)	EFF (%)	COMMENTS
08/24/86	12.00	150.6	3.04	1.44	229.6	239.79	54.86	
08/25/86	.00	146.8	3.07	1.13	223.6	234.07	55.53	
08/25/86	12.00	150.6	3.14	2.01	217.5	227.17	53.64	
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09/02/86	10.31	135.2	4.91	2.40	296.1	307.45	61.96	
09/02/86	12.45	135.2	2.20	2.07	193.4	202.70	37.43	
09/02/86	13.00	135.2	2.38	2.13	235.7	244.94	48.95	
09/02/86	13.15	146.8	2.78	2.13	259.8	269.22	57.76	
09/02/86	13.31	139.0	2.55	1.95	271.9	281.43	58.56	
09/02/86	13.45	139.0	2.56	2.20	271.9	281.18	58.68	
09/02/86	14.00	139.1	2.57	2.20	271.9	281.19	59.00	
09/02/86	14.15	139.0	2.60	2.20	271.9	281.20	59.63	
09/02/86	14.30	139.0	1.50	1.95	102.7	112.00	13.71	BD
09/02/86	14.46	104.3	2.13	2.26	54.4	63.46	14.67	AD
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09/04/86	12.00	146.8	3.07	2.20	229.6	239.04	56.83	
09/05/86	12.00	150.6	3.28	1.32	205.5	215.82	53.23	
09/06/86	12.00	146.8	3.17	1.13	211.5	222.01	54.36	
09/07/86	12.00	146.8	3.18	.75	205.5	216.35	53.21	
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.								
09/10/86	12.00	146.8	3.28	.06	229.6	241.25	61.09	C
09/11/86	.00	146.8	3.04	2.01	247.8	257.35	60.43	
09/11/86	12.00	142.9	2.97	2.26	253.8	263.12	62.09	
09/12/86	.00	142.9	2.95	2.76	253.8	262.61	61.44	
09/12/86	12.00	139.0	2.60	2.64	290.1	289.89	63.45	D
09/13/86	.00	146.8	3.04	2.45	247.8	256.91	60.43	
09/13/86	12.00	142.9	3.05	2.32	247.8	257.04	62.27	
09/14/86	.00	146.8	3.02	2.07	247.8	257.28	60.04	
09/14/86	12.00	142.9	2.97	2.57	253.8	262.81	62.07	
09/15/86	.00	146.8	2.97	2.57	253.8	262.81	60.43	
09/15/86	12.00	142.9	2.70	2.07	271.9	281.35	60.19	
09/16/86	.00	142.9	2.90	3.01	259.8	268.39	61.74	C
09/16/86	12.00	142.9	2.79	1.95	259.8	269.42	59.69	

A = Problems with Input Power sensing.

B = Problems with Flow Rate sensing.

C = Problems with Water Level sensing.

D = Problems with Discharge Pressure sensing.

Table 3. Monitored Pumping station Efficiencies for Triangle Dairy Relift Station.

TRIANGLE DAIRY EFFICIENCY MONITOR

Date	Time	Input Power (hp)	Pumping Flow (cfs)	Lift (ft)	Pressure (ft)	TDH (ft)	Efficiency EFF: (%)	Comments
07/28/86	9.14	509.8	30.38	1.48	96.9	102.39	69.23	A
07/28/86	13.44	533.0	27.03	1.20	96.9	102.52	58.99	
07/29/86	.00	533.0	27.06	1.04	66.6	72.41	41.72	D
07/29/86	12.00	533.0	25.55	1.37	96.9	102.30	55.64	
07/30/86	.00	533.0	26.08	1.37	96.9	102.32	56.80	
07/30/86	12.00	533.0	26.46	1.20	96.9	102.50	57.73	
07/31/86	.00	533.0	26.55	1.75	96.9	101.96	57.62	
07/31/86	12.00	533.0	25.59	1.42	96.9	102.25	55.71	
			⋮					
08/14/86	12.00	509.8	28.56	1.35	96.9	102.44	65.10	A
08/15/86	.00	533.0	28.87	1.91	96.9	101.88	62.61	
08/15/86	12.00	533.0	28.92	.83	96.9	102.97	63.38	C
08/16/86	.00	533.0	28.06	1.91	96.9	101.85	60.84	
08/16/86	12.00	533.0	28.81	.36	96.9	103.43	63.44	C
08/17/86	.00	533.0	29.22	1.35	96.9	102.47	63.72	
08/17/86	12.00	533.0	29.69	.00	96.9	103.83	65.63	C
08/18/86	.00	533.0	29.48	1.76	96.9	102.07	64.06	
			⋮					
08/19/86	10.75	533.0	24.48	1.27	102.9	108.42	56.51	
08/19/86	10.99	533.0	25.07	1.08	102.9	108.63	57.97	
08/19/86	11.26	533.0	24.65	1.03	102.9	108.66	57.02	
08/19/86	11.50	521.4	23.85	.80	102.9	108.87	56.51	
08/19/86	11.76	521.4	24.40	.75	102.9	108.94	57.84	
08/19/86	12.00	533.0	24.41	.45	102.9	108.94	56.61	
08/19/86	12.24	533.0	24.50	.56	102.9	109.13	56.91	
08/19/86	12.50	533.0	25.17	.52	102.9	109.20	58.50	
08/19/86	12.74	533.0	23.98	.47	102.9	109.20	55.75	
08/19/86	13.01	533.0	24.75	.33	102.4	109.37	57.62	
08/19/86	13.25	533.0	24.33	.33	102.9	109.35	56.64	
08/19/86	13.51	521.4	23.87	.23	102.9	109.43	56.84	
08/19/86	13.75	533.0	23.53	.28	102.9	109.38	54.79	
08/19/86	13.99	533.0	24.18	.33	102.9	109.35	56.28	
08/19/86	14.26	533.0	23.98	3.74	102.9	109.52	55.36	C
08/19/86	14.50	24.3	24.32	.09	102.9	109.59	56.72	AC
			⋮					
08/20/86	.00	533.0	24.86	1.64	102.9	108.06	57.19	
08/20/86	12.00	533.0	24.23	1.55	102.9	108.13	55.78	
08/21/86	.00	533.0	24.19	1.08	102.9	108.60	55.92	C

A = Problems with Input Power sensing.
B = Problems with Flow Rate sensing.
C = Problems with Water Level sensing.
D = Problems with Discharge Pressure sensing.

TRIANGLE DAIRY EFFICIENCY MONITOR

Date	Time	Input Power (hp)	Pumping Flow (cfs)	Lift (ft)	Pressure (ft)	TDH (ft)	Efficiency EFF: (%)	Comments
08/21/86	12.00	521.4	24.71	1.50	102.2	108.20	58.17	
08/22/86	.00	533.0	24.71	1.59	102.9	108.10	56.86	
08/22/86	12.00	533.0	24.71	1.50	102.9	108.20	56.90	
08/23/86	.00	521.4	24.58	1.59	102.9	108.10	57.82	
08/23/86	12.00	521.4	23.88	1.17	102.9	108.50	56.39	C
08/24/86	.00	521.4	.00	1.50	102.9	107.76	.00	B
08/24/86	12.00	521.4	.00	1.45	102.9	107.81	.00	B
			⋮					
09/04/86	.00	254.9	11.55	1.17	77.2	82.45	42.39	D
09/04/86	12.00	266.5	12.28	.28	70.8	76.92	40.20	CD
09/05/86	.00	254.9	12.50	1.08	77.2	82.56	45.93	D
09/05/86	12.00	254.9	12.19	.28	70.8	76.92	41.74	CD
09/06/86	.00	266.5	11.01	1.08	77.2	82.54	38.67	D
09/06/86	12.00	254.9	10.75	.47	102.9	108.88	52.11	C
09/07/86	.00	254.9	10.98	1.27	77.2	82.35	40.24	D
09/07/86	12.00	266.5	10.70	.28	102.9	109.06	49.68	C
09/08/86	.00	254.9	11.62	1.27	77.2	82.36	42.60	D
09/08/86	12.00	266.5	11.17	1.59	77.2	82.02	39.02	D
09/09/86	.00	266.5	10.95	4.50	70.8	72.68	33.88	CD
09/09/86	12.00	254.9	11.38	1.22	77.2	82.40	41.75	D
09/10/86	.00	254.9	11.26	1.13	77.2	82.49	41.33	D
09/10/86	12.00	254.9	12.40	1.03	70.8	76.17	42.05	D
09/11/86	.00	266.5	12.11	1.08	77.2	82.55	42.56	D
09/11/86	12.00	254.9	12.37	.75	102.9	108.62	59.82	
09/12/86	.00	266.5	12.31	.94	77.2	82.70	43.32	D
09/12/86	12.00	266.5	12.14	.23	102.9	109.13	56.39	C
09/13/86	.00	254.9	12.64	1.08	77.2	82.56	46.45	D
09/13/86	12.00	254.9	12.71	1.03	102.9	108.35	61.29	
09/14/86	.00	254.9	13.18	1.08	77.2	82.57	48.46	D
09/14/86	12.00	266.5	13.39	1.03	102.9	108.36	61.79	
09/15/86	.00	254.9	12.93	1.13	77.2	82.52	47.50	D
09/15/86	12.00	254.9	13.25	1.08	102.9	108.31	63.89	
09/16/86	.00	266.5	13.35	1.03	77.2	82.62	46.97	D
09/16/96	12.00	266.5	13.05	.98	102.9	108.40	60.20	

A = Problems with Input Power sensing.
B = Problems with Flow Rate sensing.
C = Problems with Water Level sensing.
D = Problems with Discharge Pressure sensing.