IRRIGATION FLOW MONITORING EQUIPMENT DEMONSTRATION AND COMPARISON

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ABSTRACT

Northern Water (Northern Colorado Water Conservancy District) conducted field demonstrations and comparisons of flow monitoring equipment at 18 canal and ditch sites in the lower South Platter River Basin during the 2006 irrigation season. Equipment included data loggers from 8 different manufacturers, 16 different models of water level sensors from 12 manufacturers, and 4 different types of telemetry from 7 manufacturers.

The data loggers that were demonstrated included four models of single-sensor with integrated data logger, four models of programmable multi-sensor data logger, and one model of basic, low-cost data logger without telemetry. Relative equipment costs for each data logger system are summarized in Table 6.

The water level sensors tested included submersible pressure transducers, optical shaft encoders, ultrasonic distance sensors, bubbler level sensor, float and pulley with potentiometer, buoyancy sensor, and a laser distance sensor. Bench checks of sensor calibrations were accomplished by Northern Water staff before field installation, and again at the end of the irrigation season. Observed sensor accuracy was compared to that expected from manufacturer specifications.

The telemetry systems tested in the field included license-free spread-spectrum radios from four manufacturers, licensed radio modems in the 450 MHz range, satellite radio modems to a web server, and cdma modems with static IP addresses. Increased mast height and high gain directional antenna improved radio telemetry as expected. Additionally, operational files were utilized to document telemetry performance when available.

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The purpose and intent of the equipment demonstration and comparison was not to identify a single best data logger, sensor, and/or telemetry system. Each has different features and strengths, as well as varying costs. For each specific flow monitoring application, different equipment may be preferred or better suited than other equipment. However, the 2006 demonstration and comparison should provide a reference point for those seeking to become more knowledgeable in equipment selection while avoiding unpleasant surprises.

INTRODUCTION

Background

In 2006 the Colorado Division of Water Resources, Division 1 – South Platte River, Districts 1 and 64 provided stimulus for irrigation companies to transition from paper chart recorders to electronic flow monitoring devices at their water measurement structures. In conjunction with this process and in response to the water users' interest regarding available equipment for such purposes, the Irrigation Management Department of Northern Water proposed and implemented field demonstrations of various data loggers and sensors utilizing ditch companies' existing, serviceable flow measurement structures. Additionally, the demonstration project was installed and operated partially to assist in meeting the needs of the State of Colorado to monitor flows at key river diversions within the lower South Platte River.

Terminology

Data processing and control is generally accomplished at a central location for *Remote Terminal Units* (RTU) which often do not include any onsite capabilities for data processing and logging to memory. They are essentially the non-programmable interface needed for a central site to access remote sensors and equipment. If communication to the remote stations is lost, data collection/processing and equipment control is typically suspended until telemetry operations are restored. However with *Programmable Logic Controllers* (PLC) the processing and control functions are disbursed to the remote sites and can continue without interruption even when communications with the central location go down. Sensors continue to be sampled and the data stored to memory. Gate control will continue according to pre-programmed algorithms in response to sensor information and stipulated constraints. In further contrast, *Data Loggers* will always include onsite data collection and storage, but may or may not incorporate data processing, telemetry and/or capabilities to control appurtenant equipment such as gates. However it is increasingly common for many data loggers to include telemetry capabilities and control functions, becoming interchangeable with PLCs. This paper will use the term data loggers as all referenced equipment included this functionality and no effort was attempted during 2006 to utilize available controller capabilities.

DATA LOGGER COMPARISONS

Data Logger Capabilities

Data logger capabilities can be quite extensive and this paper will not attempt to replicate manufacturer's specification sheets. However, the advantages of several features will be highlighted and Table 1 provides a brief summary.

Table 1. Data Logger Capabilities

	Telemetry utilized	Integrated sensor	Sensor input channels
Sutron SDR (stage discharge recorder)	AirLink Raven cdma modem	Shaft encoder	n/a
Hach/OTT Thalimedes	AirLink Raven cdma modem	Shaft encoder	n/a
INW PT2X Smart Sensor	AirLink Raven cdma modem	Submersible pressure transducer w/ temperature	n/a
Hach/OTT Nimbus	AirLink Raven cdma modem	Bubbler	n/a
Automata MINI-SAT Field Station	Satellite modem to web server	n/a	3 – analog 2 – pulse count
Campbell Scientific CR200	AirLink Raven cdma modem & spread-spectrum radios 100-mW & 1-W	n/a	5 – analog 2 – pulse count 1 – SDI-12
IC Tech C44P	Licensed 450 MHz radio-modem 5-W	n/a	6 – analog
Control MicroSystems SCADAPack100	Cirronet HN-291 spread spectrum radio 500-mW	n/a	3 – analog 1 – pulse count
HOBO H8 w/ Stevens Type F	Not available	Temperature	1 – analog

Data loggers are expected to operate reliably over wide temperature extremes. For deployment in remote locations they will typically utilize 12-VDC rechargeable batteries, photovoltaic panels, and a charge regulator to provide needed electrical power. They will typically record or log sensor values to memory on a schedule that is user selectable and which should preferably include the corresponding date/time stamp and site identifier. An internal backup battery should maintain accuracy of the onboard clock, even when external power is lost for brief periods.

Historically, most flow data records were constrained to end-of-period readings because of equipment and/or personnel limitations. This end-of-period data logging has been typical of RTU type systems. Whether the selected period was 15-minutes, hourly or even daily, the end-of-period reading was assumed to be representative of the entire time period. Modern data loggers make feasible the more rapid collection of water level data with their associated flow calculations. However, it is preferable that rapid or frequent readings be processed (averaged, totaled, etc.) by the data logger so the amount of data stored in memory and/or transmitted to a central site is reduced to manageable levels. Flow rates and volumes calculated on a higher frequency are mathematically more representative of the actual flows than those derived based on a more reduced or limited number of level readings, particularly if water levels fluctuate significantly over time.

When utilizing submersible pressure transducers, ultrasonic sensors and/or buoyancy sensors it is advantageous to utilize a data logger capable of onboard processing. The minor fluctuations in readings typical of these sensors can often be readily smoothed with short-term data averaging. Typically sensors might be sampled every 3 seconds, with 20 such values averaged every minute. This one-minute value could then be utilized by the onsite LCD display, if available. If it is desirable that an end of period reading be stored in memory (along with or in place of the average value for the given time period), then the most recent one-minute average value would be the reading logged to memory by the data logger.

To facilitate periodic site checks and verification of sensor readings, an LCD display at each remote station is generally desirable. The display may be built-in to the data logger (or sensor), be an optional feature mounted in the enclosure door, be a plug-in accessory portable from site to site, or even be a pocket PC device. Operators can quickly compare an on-site manual staff gauge reading to the water level reading by the data logger as viewed via the display. Appropriate corrections or adjustments can then be made expeditiously. In practice, the use of a pocket PC device is often more economical than a permanently installed LCD display as its cost is distributed over multiple sites. It may also provide an increased level of security over a built-in keypad used to configure the data logger.

Telemetry equipment provides a connection between the central site and the data logger at the remote location. Typically a data logger must be compatible with the Modbus protocol in order to utilize radio telemetry. Otherwise telemetry will be limited to direct wire connections, dial-up telephone modems, and cdma modems. Other data logger capabilities often found to be desirable are the ability to power down sensors and telemetry to conserve power, the ability to generate alarm calls for emergency conditions, and the ability to control gates, heaters, security cameras, etc. The data logger clock should continue to keep accurate time even when external power is lost to the data logger. Thus when power is restored and data logger functions resume, correct date/time stamps are recorded. Additionally, loss of external power should not result in loss of stored data at the remote site.

Data Logger and Sensor Compatibility

Sensor selection is often constrained by site conditions. If there is no existing stilling well it may be more economical to select an ultrasonic ‘down-look’ sensor or a bubbler sensor than incur the expense of installing a new stilling well. Similarly, if heavy silt loads periodically bury intakes to stilling wells and thus cause the water level in the stilling well to no longer track with the water level in the stream or canal, then an ultrasonic sensor may be preferred. Silt loads flowing into stilling wells as water levels rise will typically settle out and remain in the stilling well. Over time, this accumulation of silt in the stilling well can bury submersible pressure transducers and leave them less responsive to level changes. This silt build up can also prevent floats from following lowering levels down if they 'bottom-out' prematurely on silt deposits. Periodic cleaning or flushing of the stilling well would then be required to maintain sensor accuracy. In such circumstances, it is advantageous for the data logger to be compatible with a variety of sensors. Table 2 provides a quick reference for 2006 of which sensors could be connected to the various data logger systems.

Table 2. Data Logger and Sensor Compatibility

	KPSI 330	SR50	SE-107	Thalimedes	PTX 1230	PT2X Smart Sensor	TFLI	PS9800	MicroSpan LU05	Laser Level-Watch	SDR	SE-109	SPXD 500	Type F Chart Recorder	Level-Watch	Nimbus
Sutron SDR (stage discharge recorder)											X					
Hach/OTT Thalimedes				X												
INW PT2X Smart Sensor						X										
Hach/OTT Nimbus																X
Automata MINI-SAT Field Station	X		X		X		X	X	X	X			X	X	X	
Campbell Scientific CR200	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X
IC Tech C44P	X				X		X	X	X	X			X	X	X	
Control MicroSystems SCADAPack100	X				X		X	X	X	X			X	X	X	

WATER LEVEL SENSOR COMPARISON

Northern Water staff developed an in-house protocol for bench testing the calibration and accuracy of sensors. It should be noted that the average error measured on the test bench should always be less than the manufacturers' warranted accuracy for an individual measurement. Additionally, the bench tests were conducted in a controlled environment with near constant temperatures. Field conditions are generally harsher on sensor performance. Results of these bench tests are summarized in Table 3.

Table 3. Water Level Sensor Comparison

	Manufacturer	Model	Type	Signal	Expected accuracy ft	Bench test error, ft	2006 cost
1	Esterline/Keller	KPSI 330	Submersible pressure transducer	4-20 mA	0.005	0.0018	$736
2	Campbell Scientific	SR50	Ultrasonic distance	SDI-12	<0.033	0.0024	$1,200
3	Enviro-Systems	SE-107	Shaft encoder	Up/down pulse	0.01	0.0030	$799
4	Hach/OTT	Thalimedes	Shaft encoder	SDI-12	<0.007	0.0032	$850
5	GE Druck	PTX 1230	Submersible pressure transducer	4-20 mA	0.014	0.0032	$743
6	Instrumentation Northwest	PT2X Smart Sensor	Submersible pressure transducer w/ temperature		0.012	0.0034	$1,275
7	Vishay alpha beam load cell	TFLI	Buoyancy	0-5 VDC		0.0036	$195
8	Instrumentation Northwest	PS9800	Submersible pressure transducer	4-20 mA	0.012	0.0044	$612
9	Flowline Components	MicroSpan LU05	Ultrasonic distance	4-20 mA	0.008	0.0052	$561
10	Automata	Laser Level-Watch	Laser distance	0-5 VDC	0.016	0.0055	$395
11	Sutron	SDR	Shaft encoder	SDI-12	0.01	0.0071	$1,257
12	Enviro-Systems	SE-109	Shaft encoder	SDI-12	0.01	0.0074	$1,099
13	RMT/KWK Technologies	SPXD 500	Submersible pressure transducer	4-20 mA	0.012	0.0075	$645
14	Potentiometer on existing Stevens Type F Recorder	Vishay 533 25K	Gear set & after market potentiometer	0-2.5 VDC	0.013	0.0082	$156
15	Automata	Level-Watch	Submersible pressure transducer	4-20 mA	0.058	0.0082	$336
16	Hach/OTT	Nimbus	Bubbler	SDI-12	<0.03	0.0116	$1,325

Bench tests for all sensors typically consisted of 20 or more readings evenly distributed over their measurement range, with 50 percent during rising levels and 50 percent during falling levels. Test data was processed using a linear regression resulting in a calculated slope and offset, as well as an average error.

Bench tests of submersible pressure transducers, bubblers, and laser distance sensors were limited to a range of 9.5 feet because of the height of the available 6-inch diameter clear PVC well. Buoyancy sensors were limited to a range of 3 feet because of their designed range. Manual readings of the 'staff' or tape on the side of the clear PVC well were visually interpolated (best guess) to the nearest 1/1000 foot.

Bench tests of shaft encoders, ultrasonic distance sensors, and float and pulley potentiometers were limited to a range of 4 feet. These tests were accomplished ‘in-the-dry’ using stacks of ¾ wide particle board squares. These range limitations were not considered overly restrictive as the standard recorder chart used by the State of Colorado has a 4 foot range. Hence calibration of sensors over a 4 foot or greater range was applicable to nearly all irrigation flow measurement structures encountered in 2006.

TELEMETRY COMPARISONS

All of the data logger systems included telemetry except the HOBO H8. Each of the eight systems with telemetry was successfully configured for automatic polling on at least an hourly basis. In some cases (such as OTT Hydras 3), automatic polling was accomplished through use of third party software – Advanced Task Scheduler and Workspace Macro Pro.

Telemetry systems should first and foremost be reliable, with low error rates in data transmission. In addition they should be robust – with low susceptibility to storm damage and forgiving of poor site conditions (such as tall trees along river bottoms that attenuate radio signals). Initial telemetry costs are not wholly determined by per unit equipment costs. Radio equipment that minimizes the need for repeaters can potentially result in lower overall costs. This can be realized either through capabilities for communication over longer distances or through ‘store and forward’ technology where other remotes sites can retransmit data from outlying stations. Equipment also needs to be economical to operate with low ongoing costs or fees. Table 4 provides a simple summary comparison.

Table 4. Telemetry Comparison

		Antenna gain	Typical mast height	Typical transmission distance
AirLink Raven cdma modem on Verizon		3 dB gain omni	6 ft	n/a
Automata satellite modem		3 dB gain omni	6 ft	n/a
Campbell Scientific RF401 spread spectrum radio	100-mWatt	6 dB gain yagi	10 ft	1 – 5 miles
Cirronet HN-291 spread spectrum radio	500-mWatt	6 dB gain yagi	20 ft	6 – 9 miles
MDS 9810 spread spectrum radio	1-watt	6 dB gain yagi	20 ft	10 – 15 miles
FreeWave FGR-115RC spread spectrum radio	1-Watt	6 dB gain yagi	20 ft	10 – 15 miles
IC Tech licensed radio w/ ‘Tru-Lock Sync’	5-watt	9 dB gain yagi	16-20 ft	18 – 27 miles

Generally it does not take long for irrigation company staff to realize that once they have functional electronic flow monitoring equipment, the addition of telemetry back to a central site is desirable. The additional costs for telemetry are often recovered quickly in reduced operating costs, improved service to share holders, or prevention of damage to equipment and facilities. Telemetry can result in overall cost savings for their operations. The expense of routinely sending personnel to remote sites to download data is avoided. Additionally, proper operations at remote sites can often be confirmed without necessitating personnel traveling to that site, particularly during storm events when travel over unimproved roads could be hazardous.

SOFTWARE

Table 5 includes a brief summary of the principal software associated with each data logger system and its cost. Included are three third party software packages utilized to improve functionality, particularly in automated polling activities.

Table 5. Software Comparison

	Software	Version	Cost
Sutron SDR (stage discharge recorder)	Sutron SDRPoll Sutron SDRComm	2.3 2.3	n/c
Hach/OTT Thalimedes	OTT Hydras 3 Basic	2.12.0	$125
INW PT2X Smart Sensor	INW Aqua4Plus INW Aqua4Push	1.5.18 2.1.0	n/c variable
Hach/OTT Nimbus	OTT Hydras 3 Basic	2.12.0	$125
Automata MINI-SAT Field Station	Automata Field Vision 97 for Windows Automata Logger Vision Automata Field Vision Database Automata Mini Configuration Program	1.0 4.07s 4.01d 2.08s	$150
Campbell Scientific CR200	Campbell Scientific LoggerNet	3.2.2.76	$565
IC Tech C44P	IC Tech Software Toolbox	3.30	n/c
Control MicroSystems SCADAPack100	Control Microsystems SCADALog Control Microsystems TelePACE	2.0 3.00	$487
HOBO H8 w/ Stevens Type F	ONSET Boxcar Pro	4.3	$ 99
AirLink Raven cdma modem on Verizon	AirLink Raven CDMA Setup AirLink Raven Setup Wizard AirLink Wireless Ace 3G		n/c
Cirronet HN-291 spread spectrum radio	Cirronet HNWizard	5.20	n/c
MDS 9810 spread spectrum radio	MDS Radio Configuration Software	2.4.0	n/c
FreeWave FGR-115RC spread spectrum radio	FreeWave EZ Config	2.7	n/c
Automated schedule (OTT)	Southsoftware Advance Task Scheduler	1.5	$40
Create virtual COMM ports (cdma modems OTT & INW)	Tactical Software Serial/IP Redirector	4.6	$50 +$50/port
Automated polling (OTT)	Tethys Solutions Workspace Macro Pro	6.5.1	$65

COST COMPARISON OF DATA LOGGER SYSTEMS

The list price of a data logger may or may not include built-in sensors, voltage regulators, radios, etc. Related equipment, software, and additional telemetry costs can significantly affect the overall cost of a data collection system.

Although quite simplified, Table 6 attempts to provide a cost comparison of data logger systems complete with sensors, required appurtenant equipment, and available telemetry. The HOBO H8 data logger connected to a potentiometer retrofitted on an existing Stevens Type F chart recorder does not include any telemetry. It is simply an economical data logger that must be downloaded manually by personnel visiting the site. For comparison purposes, any ongoing monthly costs (such as Verizon Wireless billings) were summed for three years and included in the telemetry costs.

Table 6. Cost Comparison of Data Logger Systems

	LCD display	Data logger	Added sensor	Access-ories	Telemetry	Total
HOBO H8 w/ existing Stevens Type F recorder	Not available	$ 75	$ 164	$ 56	Not available	$ 295
Campbell Scientific CR200	Not included	$ 390	$ 195 TFLI	$ 514	$ 876 AirLink cdma modem	$1,975
Hach/OTT Thalimedes	Included	$ 820	n/a	$ 317	$ 926 AirLink cdma modem	$2,063
Control MicroSystems SCADAPack100	Not available	$ 608	$ 195 TFLI	$ 550	$1,034 Cirronet SS radio	$2,387
Sutron SDR (stage discharge recorder)	Included	$ 953	n/a	$ 579	$ 876 AirLink cdma modem	$2,408
INW PT2X Smart Sensor	Not available	$1,045	n/a	$ 275	$1,106 AirLink cdma modem	$2,426
Hach/OTT Nimbus	Not available	$1,125	n/a	$ 487	$ 876 AirLink cdma modem	$2,488
Automata MINI-SAT Field Station	Not included	$ 975	$ 395 Laser	$ 200	$1,073 Satellitemodem	$2,643
Control MicroSystems SCADAPack100	Not available	$ 608	$ 612 PS9800	$ 550	$1,034 Cirronet SS radio	$2,804
Campbell Scientific CR200	Included SE-109	$ 390	$1,099 SE-109	$ 514	$ 876 AirLink cdma modem	$2,879
IC Tech C44P	$ 195	$1,895	$ 195 TFLI	$ 367	$ 450 Licensed radio	$3,102
Automata MINI-SAT Field Station	$ 250	$ 975	$ 612 PS9800	$ 200	$1,073 Satellite modem	$3,110
Campbell Scientific CR200	$ 345	$ 390	$ 612 PS9800	$ 514	$1,451 FreeWave SS radio	$3,312
IC Tech C44P	$ 195	$1,895	$ 612 PS9800	$ 367	$ 450 Licensed radio	$3,519

If more than one sensor is needed at the same field site, the cost will double when using the four systems having single sensor with integrated data logger, as they are constrained to use only the single built-in sensor. However, the cost of the four multi-sensor data logger systems will increase by only the cost of an additional sensor. Hence these systems are less costly for sites requiring more than one sensor. Additionally, two or more configurations are included for each multi-sensor data logger to demonstrate their increased adaptability.

SUMMARY

The purpose and intent of the equipment demonstration and comparison was not to identify a single best data logger, sensor, and/or telemetry system. Each has different features and strengths, as well as varying costs. For each specific flow monitoring application, different equipment may be preferred or better suited than other equipment. However, the 2006 demonstration and comparison should provide a reference point for those seeking to become more knowledgeable in equipment selection while avoiding unpleasant surprises.

DISCLAIMERS

Northern Water does not in any way endorse or recommend equipment from any particular manufacturer or distributor. Mention of specific make or model of equipment is provided for informational purposes only and is not intended to imply any preference, higher quality, better value, etc. The authors recognize that numerous other manufacturers market comparable equipment well suited for irrigation flow monitoring. However, limited resources prohibited inclusion of all but a relatively few in the 2006 demonstration. No comprehensive review of available equipment or any formalized screening process for selection of equipment was attempted.

Listed equipment costs are provided for comparison purposes only and are not intended to constrain manufacturers in pricing and marketing their products. Northern Water neither implies nor guarantees equipment availability at referenced prices. Actual costs are independent of any and all information included in this paper and are set by equipment manufacturers and distributors according to their individual business practices, with ongoing adjustments as they so determine.

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