FRESNO STATE

California Water Institute

Kaweah Subbasin Groundwater Sustainability Agency Groundwater Metering Analysis Report

March 2022

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Introduction

The East Kaweah Groundwater Sustainability Agency (EKGSA) on behalf of the Kaweah subbasin Groundwater Sustainability Agencies (KSB-GSAs), requested that the California Water Institute (CWI) investigate the functionality of water meter systems to measure, collect, and aggregate pump discharges from groundwater wells. The KSB-GSAs anticipate future usage of the information from the water meters to monitor groundwater use within their GSAs and develop groundwater use regulations for the GSAs to meet the objectives of the Sustainable Groundwater Management Act (SGMA) of 2014.

The KSB-GSAs are currently using evapotranspiration data collected by satellite imagery to address SGMA and anticipate use of the data from this report to assist in making future decisions. The State of California passed the act to reduce the impacts of groundwater overdraft within the State.

The analysis included:

- In collaboration with the KSB-GSAs develop the evaluation criteria upon which water meters, telemetry units, and cloud data platforms would be evaluated
- A questionnaire upon the agreed criteria was sent to each water meter, telemetry, and data platform vendor which allowed all of the vendors to provide information on their product's conformance with the evaluation criteria
- A literature search of water meter technology to use published information to determine the conformance of the products to the evaluation criteria
- A desktop evaluation of alternative water meters
- The testing of a series of water meters in the Center for Irrigation Technology's hydraulic laboratory to determine their accuracy and head loss functions and conform to the water meter evaluation criteria
- The ability of telemetry systems to conform to the evaluation criteria to read, collect, and upload the water meter output to a cloud data platform
- The ability of the cloud data platform to conform to the evaluation criteria to store, display, and download data

Water meters are defined as the physical device that uses electronics or a mechanical device to measure the velocity of the water passing through the device. The discharge rate is derived from the velocity using the continuity equation ($Q = VA$, where Q is the discharge rate, V is the velocity, and A is the cross-sectional area of the device). The velocity (discharge) is represented by a pulse of current or a 4 to 20 milliamp output from the water meter. Thus, the faster the velocity, the more pulses per minute or the higher the current output is from the meter. Most water meters have a digital or mechanical display attached to the meter that registers instantaneous and/or accumulated discharge. Most also allow access to a set of system configuration menus accessed through buttons on the device's display. The water meter can be powered using batteries or with line power.

Telemetry is defined as the combination of the technology implemented to collect, store, and transmit the output from the water meter. Telemetry can be vertically integrated with the water meter or be a system provided by a third-party vendor. The telemetry is typically housed in a box that is connected with cables to the water meter. Storage of the output is typically in random access memory. The transmission of data can occur using cell phone technology, radio, or Bluetooth. The transmission devices are programmed to connect to only one data cloud platform. Most of the telemetry allows remote access to the water meter's system configuration menus. The telemetry is typically powered with batteries, but some solutions can use line power or solar power.

A cloud data platform is defined as the combination of software and hardware that receives the data uploaded from the telemetry unit, stores and aggregates it, and provides a graphical display of the data. Cloud data platforms can be vertically integrated with the telemetry/water meter, the telemetry, or provided by a third-party vendor that is independent of the water meter or the telemetry. The cloud data platform consists of a front end and a back end. The front end consists of the graphical user interface (GUI) software that allows the user to access and analyze the data and the water meter configuration menus. The back end consists of the hardware that collects, stores, and backs up the data.

A literature search of the various water meters was used to determine which vendors were well suited to this particular use and to invite these vendors to submit their meters for testing. Many of the vendors also provide telemetry and cloud data platform services as well. The telemetry and data cloud platform communities are fairly small and word soon got out to local vendors of telemetry and cloud data platform services of the testing program. They then contacted CWI and offered to provide telemetry and cloud data platform services for testing with the meters. All of the telemetry units and cloud data services that were received were tested.

Each participating vendor received a spreadsheet questionnaire that allowed them to uniformly report information regarding their meter, telemetry unit, and/or cloud data platform. The responses were double checked by CWI staff using literature on the unit or service, if that information was available. Water meters and telemetry units tend to be well documented, making the verification process relatively easy. Cloud data platform services are not as well documented. The testing of these services was used to confirm their assertions regarding the services. The questionnaires were used to rank each vendor's equipment based on a point system assigned to the particular characteristic being evaluated. The testing, conducted by the Center for Irrigation Technology (CIT) at Fresno State, was broken down into these three components to provide the KSB-GSAs with a diverse universe of options from which to select their preferred water meter, telemetry system, and cloud data platform. In most cases, each water meter that was tested also had a vertically integrated telemetry and cloud data platform system. As previously stated, there are numerous third-party vendors of telemetry systems with cloud data platforms or only cloud data platforms that may be attractive to the KSB-GSAs, which were also tested.

This report provides an overview and highlights of the criteria used to evaluate the different products as well as the findings of the investigations conducted. A detailed report for each of the investigations was provided to KSB-GSAs by CWI as each investigation was concluded.

Water Meters

Twelve meters were evaluated using the vendor's literature and the vendor's responses to questionnaires on their meter. Ten of those meters were evaluated in the CIT Hydraulics Laboratory, an ISO 9000 certified testing facility. The meters were not tested for certification. Instead, they were tested to provide a third-party verification of their accuracy.

The information provided in this section includes the evaluation of the meters using the literature, questionnaires, and the evaluation from the testing conducted in the CIT Hydraulics Laboratory.

Literature Review

Water meters (meters) were requested from all known vendors of agricultural meters. Six vendors responded to the request by providing one or more of their meters for testing. KSB-GSAs and CWI developed meter review criteria with which to evaluate each meter.

Those criteria used:

- Measurement Technology – Meters must be Propeller, Magnetic Resonance, or Ultrasonic
- Sizes – Meters must be available in 6, 8, 10, and 12-inch diameters
- Installation Type – Meters can be either flange, saddle/clamp, or insertion
- Accuracy – Meters must have a minimum accuracy of five-percent
- Life Span – Meters should have a minimum life span of five years
- Siting – Meters must have a maximum distance from a downstream disturbance of three pipe diameters or 10 feet (whichever is less), with five feet preferred
- Spare Parts – Meters should have easily available spare parts
- Meter Output – Meters must provide at least pulse or current loop (4 – 20 milliamp) output
- Configuration Options – Meter systems should be configurable
- Power – Meters should have standard sized battery power, rechargeable batteries with solar power, or line power
- Human Interface – Meters must have a human interface with touch screen or button access
- Security – Meters should be tamper-resistant or password protected and have auditing

A numeric scale was assigned to each criterion by KSB-GSAs and CWI's based on the criterion's importance. Criteria were further scored as listed in *Table 1*.

TABLE 1 - METER REVIEW CRITERIA

Criteria Ranking	Description	Points
Required	A meter must satisfy this criterion	5
Required/Preferred	A meter should satisfy this criterion and it is a preferred criterion	4.5
Preferred	A meter that meets this criterion is preferred	4
Ambivalent	A meter that meets this criterion is acceptable but not preferred or required	2
Disallowed	A meter that meets this criterion is disqualified	-1000

*A score of -1000 was used when a meter failed to meet a specific criterion. This resulted in a negative total score for that meter, making that meter easy to identify.

The meters fell into two categories, magnetic resonance meters (mag meters) and propeller meters. The meters were further subdivided into flanged or insertion meters. Installation of a flanged meter requires cutting the discharge pipe to remove a portion of the pipe longer than the meter, welding flanges to the remaining ends of the discharge pipe and bolting the flanged ends of the meter to the discharge pipe flanges. Usually, a thimble is used with a compression fitting to adjust the meter and the discharge pipe. The insertion meter only requires cutting a hole in the top of the discharge pipe and inserting the meter through the hole. The meter is secured to the discharge pipe using saddle compression bands or using a welded fitting. The list of meters that were provided for testing with their type and installation mode is provided in *Table 2*. The Manufacturer's Suggested Retail Price (MSRP) listed in *Table 2* are all for 8-inch diameter meters to provide a relative comparison of cost between the meters.

TABLE 2 – METER TYPES AND INSTALLATION METHOD REVIEWED BY LITERATURE AND QUESTIONNAIRES

Vendors	Model	Meter Type	Meter Diameters Avaialble (inches-nominal)	installation Method	Manufacturer Recommended Retail Price
Bermad	EuroMag 2200 EL	Magnetic meter	6-12	Flange	$2,245
Bermad	EuroMag 1222	Magnetic meter	6-12	Insertion	$
Bermad	EuroMag 2300	Magnetic meter	6-12	Flange	$2,444
In-Situ	Signet 2552	Magnetic meter	6-12	Insertion	$
Krohne	Waterflux 3070	Magnetic meter	6-12	Flange	$1,433
Krohne	EuroMag 2050	Magnetic meter	6-12	Flange	$1,988
McCrometer	McMag 2000	Magnetic meter	6-12	Insertion	$1,700
McCrometer	Duramag	Magnetic meter	6-12	Flange	$2,481
McCrometer	McPropeller	Propeller	6-12	Insertion	$1,258
Seametrics	AG 90	Magnetic meter	6-12	Insertion	$1,377
Seametrics	AG 3000	Magnetic meter	6-12	Flange	$1,870
TechnoFlo	PS 32	Propeller	6-12	Insertion	$1,148

Questionnaire

The meter vendors were invited to provide their answers to the meter review criteria by completing the form in the spreadsheet questionnaire. Those answers were reviewed and verified by CWI staff and each meter's rating was compiled to select the top ten meters for testing. The final rankings are listed in *Table 3*.

TABLE 3 - WATER METERS, SCORING, AND RANKINGS

Meter Manufacturer	Meter Model	Scoring	Ranking
Bermad	EuroMag 2300	104	1
Bermad	EuroMag 2200 EL	104	1
Bermad	EuroMag 1222	98.5	2
McCrometer	DuraMag	92	3
Seametrics	AG 3000	90	4
McCrometer	McMag 2000	86	5
TechnoFlow	PS32-06	86	6
McCrometer	McPropeller	84	7
Khrone	Waterflux 3070	83	8
Seametrics	AG 90	77	9
Khrone	Enviromag 2050	78	10

The primary differences between the Bermad meters and the other meters were the number of power supply options and robust electronic interface options provided by the Bermad meters. The Bermad meters provided battery, line power, and solar options. The other meters provided subsets of these options. In all other aspects, the meters scored very much the same. The Bermad meters also provided a full suite of electronic interfaces, including pulse, current loop, a standard protocol cable connection to the meters, and a wireless connection through telemetry. The other meters provided various subsets of these options.

The In-Situ water meter ranked last due to the requirement to locate the meter more than 10 feet downstream of a disturbance based on a 6-inch diameter meter, which is the smallest diameter that will be installed in the KSB-GSAs. A distance greater than 10 feet was a disqualification threshold for a meter based on the agreed-upon criteria.

CIT Hydraulics Laboratory Testing

The CIT Hydraulics Laboratory was contracted to test the top ten meters based on the rankings from the literature and the questionnaire. Of the twelve meters submitted, the CIT Hydraulics Laboratory could not test the Seametrics AG90 due to a bad battery power supply that could not be replaced. The Khrone Enviromag 2050 could not be tested because the vendor did not provide a power supply for the meter. This situation could not be remedied. Bermad did not supply a Euromag 1222 meter for testing. The In-Situ meter required an upstream pipe length that exceeded the criterion. Therefore, it was not tested. The remaining eight meters were tested in the CIT Hydraulic Laboratory in a standard configuration with minimum straight sections of pipe upstream and downstream of the meter. Each meter was tested at 11 different discharge rates for the minimum time required for the meter to stabilize the discharge measurement. The meter results were compared to the discharge rate measured by the Lab's certified venturi meter (BIF Universal Venturi Tube, Model 20181). The meters and their diameters, average errors, range of discharge rates, and range of velocities are presented in *Table 4*.

TABLE 4 - CIT HYDRAULICS LABORATORY METER TEST RESULTS

Meter Name	Diameter inches	Range of Discharge Rates GPM	Range of Test Velocities fps	Average Error Percent	Maximun Error Percent	Minimum Error Percent
Bermad EuroMag 2200 EL	8	102 - 1138	0.66 - 7.28	-0.95	-3.40	-2.0
Bermad EuroMag 2300	6	107 - 1114	1.22 -12.63	0.78	1,70	0.6
McCrometer DuraMag	8	104 - 1135	0.66 - 7.25	0.34	1.60	-0.10
Seametrics AG 3000	8	81 - 1246	0.52 - 7.96	-0.40	-0.90	-0.10
McCrometer McMag 2000	8	114 - 1266	0.72 - 8.08	-0.56	-1.70	-0.10
TechnoFlow PS32-06	6	119 - 985	1.38 - 11.15	1.96	1.70	3.00
McCrometer McPro-peller	8	97 - 1141	0.63 - 7.28	3.44	4.60	3.00
Khrone Waterflux	8	105 - 1164	0.66 - 7.42	1.23	2.00	-0.40

All of the meters fell within the accepted maximum allowable 5-percent error. The McCrometer McPropeller exhibited the highest error of 3.44-percent and the McCrometer Duramag exhibited the lowest error of 0.34-percent. The discharge rates produced velocities through the meters that ranged from 1 foot per second to 12 feet per second. The general operating range for velocities in pressure pipe systems is from 3 to 8 feet per second.

Annualized Cost to Own

The amortized or annual cost to own each of the meters was calculated assuming:

- 5-year life for each meter
- no intermediate service of the meter
- no salvage value at the end of 5-years
- and an annual interest rate of 3-percent

A five-year life period was assumed because this was the minimum acceptable life of a meter set by the KSB-GSAs. Five years was used for comparison purposes only and is not meant to imply any particular life for any of the meters.

No service on the meter was assumed because each of the vendors stated that they expected that their meters would operate within the specifications for at least 5 years.

The meters were assumed to have zero value at the end of the five years. This assumption was used to provide a uniform analysis of the meters. It is also probable that the owner of the meter may perceive that it has residual value, but there will probably be few, if any, buyers for a used water meter.

The annual interest rate of three-percent was assumed to be representative of the long-term interest rate. Figure 1 presents a bar chart of the meters and their amortized values for comparison. Figure 2 presents a scatter plot with error boxes for each meter. Figure 2 illustrates each meter, its maximum error, minimum error, and average error compared to its annualized cost.

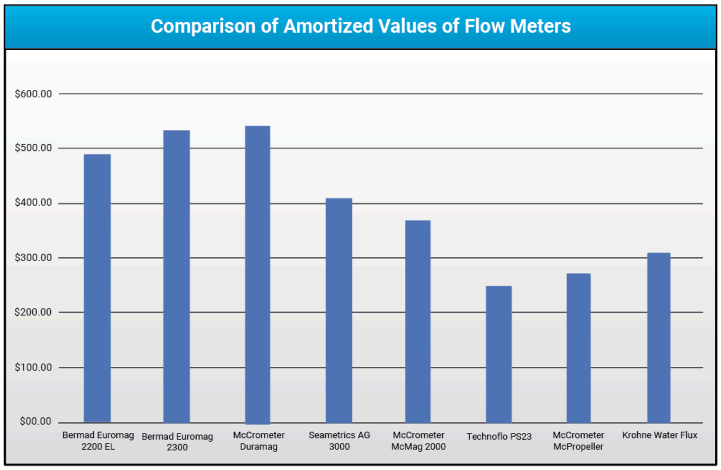

Figure 1- Amortized Values of Flow Meters

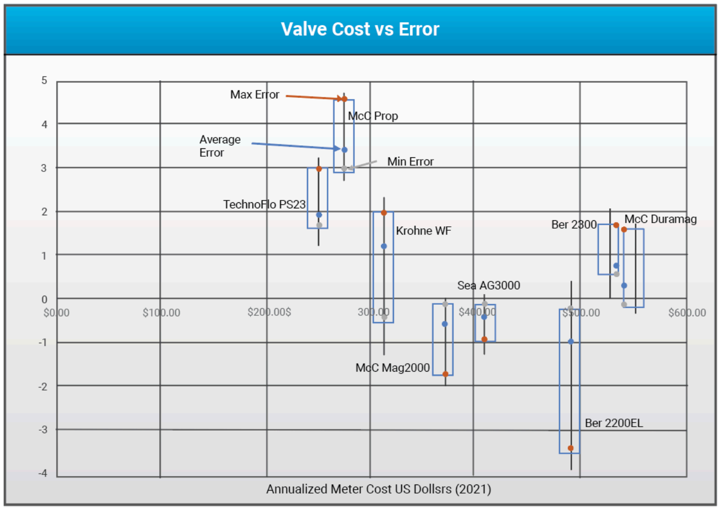

Figure 2- Amortized Valve Cost vs Error Ellispe

Telemetry

Telemetry systems were requested from all known vendors of telemetry systems used in the agricultural water delivery system. All of the participating meter vendors provided telemetry systems for testing except Seametrics. Independent telemetry vendors are also active in this area. They provided units for testing. The telemetry systems were evaluated and ranked using the literature and answers provided through the questionnaires. The ranking information is presented in the Literature and Questionnaire subsection below. The CIT Hydraulics Laboratory used the water meters to develop flow data which was captured by each of the telemetry units and uploaded to a cloud data platform. The testing results are presented in the CIT Hydraulics Laboratory Testing subsection that follows the Literature and Questionnaires subsection.

Literature Review

KSB-GSAs and CWI developed telemetry review criteria with which to evaluate each unit.

Those criteria are:

- Configuration Options – The telemetry systems should be configurable
- Power – A telemetry system should have standard sized battery power, rechargeable batteries with solar power, or line power
- Human Interface – A telemetry must have some form of human interface, either directly with touch screen or button access on the unit or through a computer interface via cable
- Security – A telemetry should have a tamper-resistant cover or password protected and have auditing
- Connection Protocol – A telemetry system should have an external means of data acquisition and configuration that may be either a hardwire connection to a computer, Bluetooth connection to a device, or through the web-based platform
- Wireless Connection – The telemetry system must have a wireless connection to the web either through a cell modem or radio connection to a gateway

The application of these criteria became slightly subjective because of the wide variety of ways in which the telemetry systems are implemented. Some are integrated into the meter with a digital display of discharge rates and configuring the meter's parameters using the buttons. In other words, the separation between the meter and the telemetry system was not a clear demarcation. Many other telemetry systems were third-party systems that consisted of an external device that accessed the meter and its output through data ports provided by the meter. There is an obvious demarcation between the meter and these telemetry systems. Access to the meter configuration and the data for the third-party telemetry systems was through a computer connected to the telemetry device. The connection was, in some cases, both a hardwire connection and via the web platform, or it was only through the web platform.

Because there are only six criteria for this section, all of the units submitted were tested in the CIT Hydraulics Laboratory to verify that the telemetry systems performed as stated by the vendors. The testing setup included connecting each telemetry unit to a water meter installed in the CIT Hydraulics Laboratory. The meters were installed in series in the Lab's pipe loop. Water was circulated through the pipe system for up to 8 hours per day for two weeks. The days were not continuous to simulate an irrigation operation with periods of pump-on and pump-off. *Table 5* presents the results of the rubric scoring of the telemetry units from the literature review.

Table 5 - Telemetry Manufacturers and Models Scoring and Ranking from the Literature Review

Telemetry Manufacturer	Model Tested	Scoring	Ranking
Bermad	Integrated Telemetry Unit	59	1
Ctek	z4550	54.5	2
Wildeye	Not Listed	50.5	3
McCrometer	Integrated Telemetry Unit	49	4
In-Situ	Agriflow XCi	47	5
Ranch Systems	RS 130	47	5
Hotspot AG	Controller	47	5
XiO	Cell Modem Controller	43	6

Questionnaire

The meter with integrated telemetry as well as telemetry only vendors were invited to provide their answers to the Telemetery review criteria by completing the form in the spreadsheet questionnaire. Those answers were reviewed and verified by CWI staff and each Telemetery rating was compiled to select the top ten meters for testing. The final rankings are listed in *Table 5*.

CIT Hydraulics Laboratory Testing Results

Table 6 present the laboratory evaluation results of the installation of the telemetry systems. All of the systems that were evaluated transmitted data and allowed access to the meter through the telemetry system. In the table, an Easy rating indicates that there were no issues during the installation of the telemetry unit or it was integrated with the meter. "Relatively Easy" means that there were some cabling or other configuration issues that were overcome with minimal effort. "Neutral" means that there were cabling of configuration issues that took some effort to overcome. "Difficult" means that there were cabling or configuration issues that took significant technical support to overcome.

The installation information only affected the ranking of the In-Situ telemetry unit. The suggested ranking due to the evaluation of the installation is provided in *Table 6*.

The number 1 ranking of Bermad is due to the tight integration of the telemetry with the meter and the power options that are available to this unit. However, this strength is also a downside because the telemetry unit will only function with the Bermad flowmeter. This is also true of the McCrometer unit, which was the other integrated telemetry unit.

Of the third-party telemetry units, the primary difference in ranking between the units was the power supply options that each provided. The Ctek unit ranked the highest due to its numerous power supply options. In-Situ, Ranch Systems, and Hotspot AG all had the next level of power supply options. XiO ranked the lowest due to the lack of power supply options.

All telemetry units acquired data from the meter and transmitted it to the cloud data platform with no errors.

Cloud Data Platform

Cloud data platforms were provided by all participating vendors that provided telemetry units, either integrated with their water meter or an independent third-party vendor of telemetry equipment. Two of the vendors provided only cloud data platform services. They state that they are telemetry and meter neutral, meaning that their cloud data platform will work with any hardware system that is currently available. Their only requirement is the ability to access the data collected by a meter or third party's telemetry through an Application Programming Interface (API).

The cloud data platform systems were evaluated and ranked using the literature and answers provided through the questionnaires. The ranking information is presented in the Literature and Questionnaire subsection below. The scoring developed for the cloud data platforms can be found on *Table 7*. The CIT Hydraulics Laboratory used the water meters to develop flow data which was captured by each of the telemetry units and uploaded to a cloud data platform. The testing results are presented in the CIT Hydraulics Laboratory Testing subsection.

Literature Review

The criteria agreed upon with KSB-GSAs for evaluating the cloud data platforms were:

- Type of data query – Must have push, can have pull, preferred that it have both push and pull
- Type of API integration – API must be provided, Open API is preferred, Additional cost to access the data through the API is disallowed
- Type of data recovery – Data stored for more than a year is preferred, Warning before data deletion is preferred, Daily backups are required, Recover deleted data within one week is required, Redundant servers are required,

Table 6 - Laboratory Results								
Question	**Bermad**	**Ctek**	**Wildeye**	**In-Situ**	**McCrometer**	**Ranch**	**Hospot AG**	**XiO**
Ease of use of hardware installation	Easy	Relatively Easy	Easy	Difficult	Easy	Neutral	Realitively Easy	Realitively Easy

Server failover 1 second or less is required

- Backend user interface – Available or unavailable are both acceptable
- User interface output – Flow vs. time is required, Cumulative flow for any time interval is required, System status is required, Meter configuration is preferred
- User cost structure – Services that are billed monthly is preferred, Services that are billed annually is preferred, A one-time fee is disallowed, Services that are paid by the users is preferred, Services that are paid per meter is preferred, Services that are paid per access is disallowed
- Hosting – Services that are hosted by the users is disallowed, Services that are hosted in the cloud is preferred
- Provisioning – User access to the data and platform functions is controlled by permissions is preferred, System that is controlled by group permissions is preferred, System that is controlled by access to the meter is preferred, System that requires each user to authenticate is preferred, System that requires an organizations to authenticate is ambivalent, System that allows some users to read-only access and others to read and write access is preferred
- User authentication – System that requires unique username and password is ambivalent, System that follows published authentication standards is ambivalent
- User Auditing – System that logs users' access to the system is preferred, System that tracks the activities of the users while accessing data is preferred, System that tracks changes to the data or the telemetry parameters is preferred

Questionnaire

Each vendor was invited to complete the questionnaire containing the criteria. Their answers were collated and entered into a ranking spreadsheet. Each of the responses was scored in accordance with the scoring values presented in *Table 7*. The results of the scoring are presented in *Table 8*.

Table 7 - Cloud Data Platform Review Criteria Scoring

Criteria Ranking	Description	Points
Required	A system must satisfy this criterion	5
Required/Preferred	A system should satisfy this criterion and it is a preferred criterion	4.5
Preferred	A system that meets this criterion is preferred	4
Ambivalent	A system that meets this criterion is acceptable but not preferred or required	2

Table 8 - Cloud Data Platform Rankings Based on Vendor Answer Scoring

Meter Manufacturer	Scoring	Ranking
Ctek	120	1
REDTrac	118	2
Wildeye	114	3
Bermad	112	4
SweetSense	112	4
Ranch Systems	106	5
HotSpot AG	104	6
XiO	104	6
In-Situ	94	7
Mammoth Water	94	7
Control Design	92	8
Seametrics	-918	9
McCrometer	-1890	10

CIT Hydraulics Laboratory Testing

The CIT Hydraulics Laboratory installed and tested each of the telemetry units and the cloud data platforms. Each platform was evaluated using the questions on *Table 9*.

Table 9 - Cloud Data Platform CIT Hydraulics Laboratory Results									
Question	Ctek	REDTrac	Wildeye	Bermad	Ranch Systems	Hotspot AG	XiO	In-Situ	McCrometer
Question 1: Does it have cloud service?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Question 2: Does it have API?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Question 3: Does it protect stored data?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Question 4: Is there a backup UI?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Question 5: Can data be downloaded?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Question 6: Is there a cost structure?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Question 7: Hosted online?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Question 8: Does it limit user ac-cess?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Question 9: Does the system maintain an audit trail of user's activities?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Question 10: Ease of Use of the platform	3	2	2	3	3	2	2	3	2

The user experience evaluated by the CIT Hydraulics Laboratory investigators did not indicate significant differences between the nine platforms being assessed. The rankings based on the literature review included four units: SweetSense, Mammoth Water, Control Design, and Seametrics, that the CIT Hydraulics Laboratory investigators did not test. The CIT Hydraulics Laboratory investigators were not able to get the SweetSense telemetry unit to collect and transmit data. Therefore, they were not able to evaluate the cloud data platform. The CIT Hydraulics Laboratory investigators contacted SweetSense to correct the issues with the telemetry unit, but the SweetSense staff did not respond to that contact. Mammoth Water was not a telemetry system. It utilizes an upload of a digital image of the meter to their cloud service. Therefore, it was not evaluated by the CIT Hydraulics Laboratory investigators. The Control Design system was not fully capable when it was received by the CIT Hydraulics Laboratory investigators. The system could not accept data output from the meters and upload the data to the cloud data platform. Therefore, it was not evaluated. Seametrics did not provide their integrated telemetry system with their meter. Consequently, it was not assessed.

The top four ranked cloud data platforms were Ctek, REDTrac, Wildeye, and Bermad. Of the four, REDTrac is a platform-only system meaning they do not have a telemetry system. Their selling point is that their cloud data platform is best used to acquire data uploaded to other systems. The REDTrac platform was evaluated using a third-party telemetry system provided by REDTrac. Ctek, Wildeye, and Bermad all provided their telemetry system and the platform to capture the data from the meters. Ctek and Wildeye are third-party telemetry systems that can connect to various meters. Bermad is an external telemetry unit, but there is no indication that it will work with meters other than the Bermad. It was not tested on any other meters.

Since the top four platforms scored relatively close together, the ease of use of the platform software was used as the additional criterion. The REDTrac and Wildeye platforms scored a 2 in ease of use of the software. The Ctek and Bermad platforms scored a 3. The use of these criteria advances the REDTrac and Wildeye platforms to a higher ranking than the Ctek and Bermad platforms. Other criteria could also be used as tiebreakers. For instance, the significant difference in the literature review between the Bermad, Ctek, RedTrac, and Wildeye systems was in pricing and auditing. Both REDTrac and Wildeye scored higher in Cost Structure. Both systems had multiple options for subscribing and paying for their service. Bermad and Ctek had a less robust subscription and payment options. Bermad and Ctek scored higher in auditing. They tracked user activities while accessing the data and any changes made by users to the data or the system variables. REDTrac and Wildeye only tracked user login and logout. A final criterion that KSB-GSAs may wish to consider, but the CIT Hydraulics Laboratory investigators did not evaluate, is the platform's ability to acquire data from multiple platforms. All evaluated systems provided API access to their data. REDTrac was the only platform that specifically structured its system to aggregate data from multiple platforms rather than from their telemetry system. The other systems may be able to do this but that was not verified, and the vendors did not specifically mention this capability. The weakness of this capability is the possible lack of willingness of other platform owners to allow access to their data.

Non-Standard Installation Meter Testing

Phase two of the analysis, explored the impact of installing five of the meters tested in Phases 1 in non-standard installation configurations. Non-standard installation is defined as not being installed in conformance with the manufacturer's recommendations. Water meters tend to be sensitive to excessive turbulence in the pipeline upstream and downstream of the meter. The turbulence will induce errors in the meter's determination of the discharge rate measurment of the velocity and, therefore, the discharge rate. For that reason, manufacturers recommend that the meters be installed with minimum distances of straight, undisturbed pipe lengths upstream and downstream of the meter. These distances are typically expressed in pipe diameters. For instance, for a water meter installed on a six-inch inside diameter pipeline, the upstream, undisturbed pipe length may be five diameters or 30 inches (= 5 diameters x 6 inches = 30 inches). It is common for owners to install water meters in non-standard configurations, meaning that they do not install them with the manufacturer's recommended lengths of straight, undisturbed pipe up and downstream of the meter. This usually occurs because the meter is installed at an existing pump location that was not originally planned for a water meter.

As was previously stated, five water meters were tested in non-standard configurations. The five selected meters had the lowest annualized cost compared to errors in measured discharge in a standard configuration. The five selected meters, in alphabetical order are:

- Bermad Euromag 2300 magnetic meter
- Krohne WF magnetic meter
- McCrometer Duramag magnetic meter
- Seametrics AG 3000 magnetic meter
- Technoflo PS32-06 saddle propeller meter

Each meter was also tested at three average velocities, 2 feet per second, 8 feet per second, and 14 feet per second in each configuration.

Thirty consecutive water meter readings were taken for each configuration and velocity to develop a population of measurements. Each population of measurements was analyzed for average error, standard deviation of the errors, coefficient of variance of the errors, and the skew of the errors. A histogram of the ranked errors was also created to visually inspect the tendency of the errors. The error results are presented for each configuration and velocity in the following tables. Error range plots were created for each water meter in each configuration and for the three velocities. The average percent error for each configuration was plotted against the velocity for each water meter.

Testing Results

Results derived from this testing of the five water meters will be discussed in three sections: 1) Comparison of Error Amounts by Configuration and Velocity, 2) Error Amounts for a Configuration by Water meter, and 3) Tendency of the Error Amounts.

Configuration and Velocity

All of the water meters displayed errors in readings when compared to the Venturi meter at all velocities and in each configuration. Errors tended to be less at the slower velocities and increase with increasing velocity. The greatest errors were all recorded at 14 feet per second. The plots of the average percent errors versus velocity generally displayed a linear or near linear relationship for each water meter. The notable exceptions were the McCrometer Duramag and the Krohne WP water meters at 2 and 8 feet per second, which displayed relatively small errors when installed with the check valve upstream and downstream of the water meter. A certified Venturi meter used by the CIT Hydraulic Laboratory to measure discharge rates to which the discharge rates from the various meters were compared.

This analysis concludes that these water meters, and potentially all water meters, should not be installed within one diameter of a flow disturbance. A safe extrapolation of this analysis is that water meters should not be installed closer to a flow disturbance than recommended by the manufacturer. If they happen to be installed in this configuration the velocities through the valve should be in the two feet per second range.

Configuration by Water meter

The errors as compared to the Venturi meter measured for each meter were compared for each configuration and each velocity. The results of that comparison were displayed in the plots. No firm conclusion can be drawn from this comparison. All meters performed better than others in certain configurations and less well in other configurations. This analysis concludes that installation of these water meters in non-standard configuration is not recommended.

Tendency of Errors

A visual representation of the distribution of the errors is displayed by the plot of the histograms. Generally speaking, all of the water meters displayed some central tendency for the distribution of the errors, meaning that there tended to be nearly equal number of larger errors when compared to the Venturi meter as there were smaller errors. However, this is not true in specific instances and the displayed tendency is not a classical bell curve shape. Some distributions were uniform across the entire error range, and some showed a noticeable left skew. A left skew means that there were more instances of smaller errors than there were of the larger errors. A uniform distribution means that there were an equal number of smaller errors and larger errors when compared to the average error across the entire spectrum of errors.

This analysis concludes that the average error is not a reliable measurement of the error that can be expected from these water meters when installed in a non-standard configuration.

The following figures illustrate the results of the eight feet per second testing.

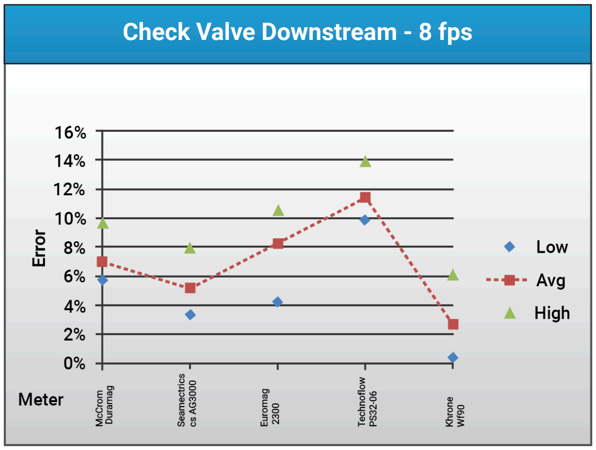

Figure 3- Graph of the high, average, and low errors as a percent of the average Venturi meter flow rate at 8 fps for the five flow meters.

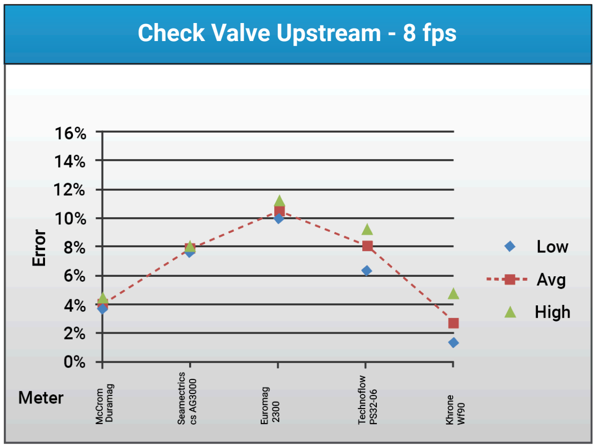

Figure 4- Graph of the high, average, and low errors as a percent of the average Venturi meter flow rate at 8 fps for the five flow meters.

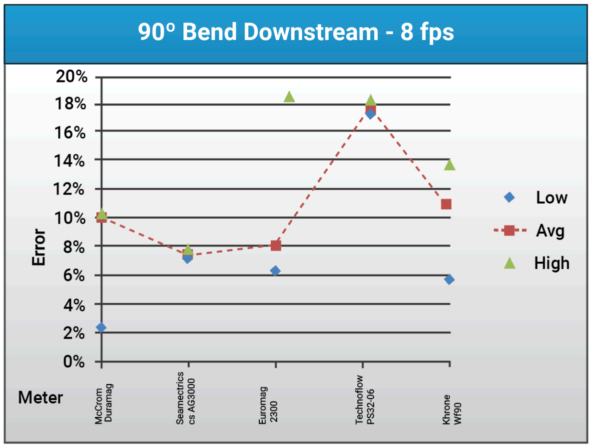

Figure 5- Graph of the high, average, and low errors as a percent of the average Venturi meter flow rate at 8 fps for the five flow meters.

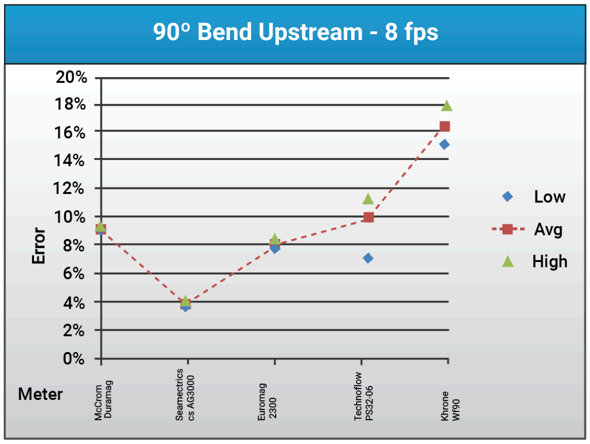

Figure 6 - Graph of the high, average, and low errors as a percent of the average Venturi meter flow rate at 8 fps for the five flow meters.

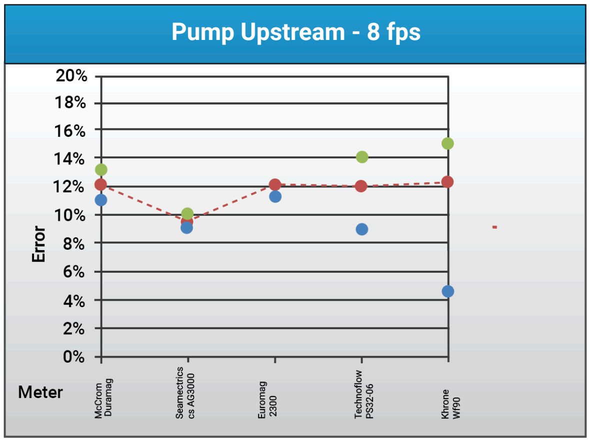

Figure 7 - Graph of the high, average, and low errors as a percent of the average Venturi meter flow rate at 8 fps for the five flow meters.

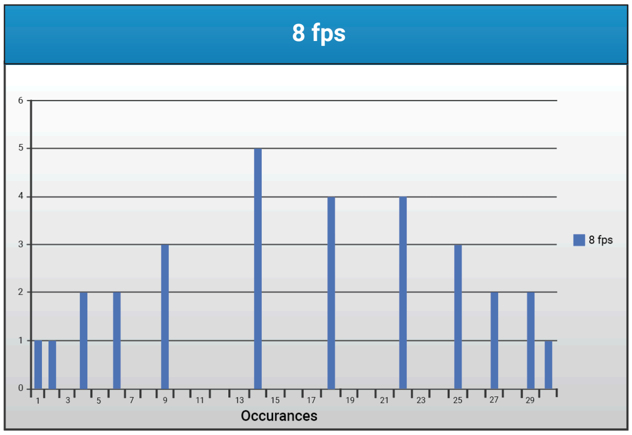

Figure 8 - Histogram of Bermad Euromag 2300 with Pump Upstream illustrating a near bell curve distribution of errors

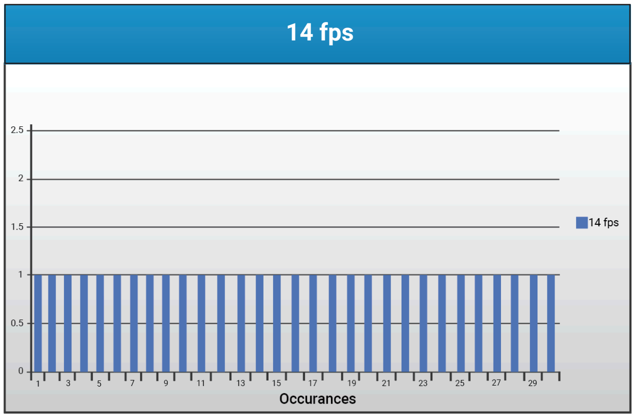

Figure 9 - Histogram of Krohne WF with Pump Upstream illustrating a uniform distribution of errors.

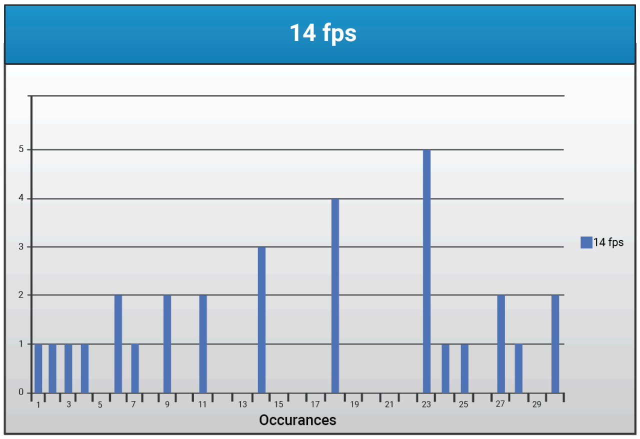

Figure 10 - Histogram of Technoflow PS32 with 90 Bend Upstream illustrating left skew (high number of lower error amounts) of the distribution of errors.

Conclusions and Recommendations

The California Water Institute (CWI) at California State University, Fresno performed an analysis of the water meters marketed in the San Joaquin Valley for irrigation water as requested by the East Kaweah Groundwater Sustainability Agency acting on behalf of the Kaweah Subbasin Groundwater Sustainability Agencies (KSB-GSAs). The analysis included a comparison of the capabilities and configurations of the water meters with criteria developed by the KSB-GSAs and CWI. The capabilities and configuration information was obtained from published documents and provided by the water meter vendors. Eight of these meters were tested in the Center for Irrigation Technology's (CIT's) Hydraulics Laboratory, an ISO 9000 certified laboratory to assess the accuracy of the meters in their standard installation. Five of the eight water meters were tested by the CIT Hydraulics Laboratory to assess the accuracy of the water meters in ten non-standard installations.

Our analysis of the testing of water meters installed in their standard configuration indicates that all of the eight water meters tested will perform within the minimal standard of accuracy of plus or minus five-percent of the actual value.

We, therefore, have no recommendation regarding the selection of a water meter based on its ability to meet the accuracy requirement as stated in their literature and as verified in the CIT Hydraulics Laboratory testing when installed in their standard configuration. One exception to this statement is the In-Situ water meter, whose standard installation requirements exceed the maximum allowed upstream straight pipe distance of five diameters.

None of the five water meters tested in the non-standard configurations performed within the accuracy standard. At all velocities that were tested. Based on the results of the five water meters that we tested in non-standard configurations, we recommend that water meters only be installed in standard configurations. The errors in the flow rates measured by the water meters when installed in non-standard installation exceeded the acceptable error limits.

CWI also analyzed telemetry units that collect water meter output and upload it to a cloud data platform. The analysis consisted of a comparison of the telemetry unit's capabilities and configurations compared with criteria developed by the KSB-GSAs and CWI. The capabilities and configuration information was obtained from published documents and completed questionnaires provided by the telemetry vendors. The ability of the telemetry units to collect and upload data to a cloud data platform was tested by CIT's Hydraulic Laboratory. CWI found that the telemetry units were either integrated into a water meter, sold as an option by some water meter vendors, or the units were sold by a third-party vendor who may also provide a cloud data platform or not. Vendors who integrated their telemetry into their water meters or provided the telemetry as an option also provided a cloud data platform. The analysis and testing revealed that all telemetry units tested performed as stated in the publications and as claimed by the vendors. Some telemetry units were easier to install, configure, and connect to a cloud data platform than others that were tested. Installation or oversight of installation of the telemetry units by factory-trained technicians is recommended.

Finally, CWI analyzed the ability of cloud data platforms to accept, store, and present data uploaded from the water meters by the telemetry units. Similar to the telemetry units, the analysis consisted of a comparison of the cloud data platform's capabilities and configurations as disclosed in publications with criteria developed by the KSB-GSAs and CWI. The information regarding the capabilities and configurations was obtained through information available from published information and provided by the cloud data platform vendors. The ability of the cloud data platforms to collect and upload data from the telemetry units was tested by the CIT's Hydraulic Laboratory. All of the platforms met the developed criteria. Therefore, we do not recommend a particular cloud data platform based on its capabilities and configurations. However, we will venture a recommendation that KSG-GSAs look closely at the third-party cloud data platforms as they are specifically developed to use Application Programming Interface (API) protocols to access data collected on the various cloud data platforms. This capability is particularly important if the KSB-GSAs will allow the groundwater users to install any of the available water meters and telemetry units because the KSG-GSAs will want to access the flow data in which they are interested on only one cloud data platform.

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