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A Low Cost Remote Monitoring Method for Determining Farmer Irrigation Practices and Water Use

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1. Introduction

Irrigated agriculture has traditionally been the backbone of the rural economy and provides nearly 70% of the worlds food supply using only 30% of planted agricultural land. Irrigated agriculture in general is a large water user that consumes roughly 80% of freshwater supplies worldwide and in the Western United States (Oad et al. 2009; Oad and Kullman, 2006). Since irrigated agriculture uses a large and visible portion of surface water in the world and the Western United States, it is often targeted for increased efficiency to free water for other uses. Due to fish and wildlife concerns, and demands from a growing urban population, the pressure to reduce consumption by irrigated agriculture increases every year. As the world population continues to grow, irrigated agriculture will also need to meet the additional food production required. The current belief is that irrigated agriculture will need to maximize the crop per drop to meet the demand in the future. The problem lies in the fact that available water supplies are currently developed and new untapped sources are limited. In order to increase production with the current amount of available water and deal with external pressure for reduced water usage, irrigated agriculture has to become more efficient in its on-farm water application and its deliveries on a whole system scale. Decision Support Systems and modernization of infrastructure can be used on a large system scale to increase the efficiency of water deliveries and have been utilized successfully in New Mexico, China, Spain and Argentina (Oad et al. 2009; Gensler et al. 2009; FAO, 2006; Gao, 1999; FAO, 1994). The problem with large infrastructure improvement projects and large scale implementation of decision support systems is that significant capital is required in addition to organizational structures that allow for such massive undertakings.

One sector where irrigated agriculture can significantly reduce water usage and stretch every drop is in on-farm water delivery. Achieving high water use efficiencies on farm requires detailed knowledge about soil moisture and water application rates to optimally manage irrigation. The problem with achieving improved efficiency is that high efficiency is generally coupled with high cost on-farm monitoring systems. Such high cost monitoring set ups are generally prohibitive to small farmers in the United States and in irrigated areas throughout the world. Additionally, the traditional methods of measuring water application require a constant presence on farm and do not allow for remote monitoring.

This chapter will focus on a low cost methodology utilized to remotely instrument eight farm fields in the Middle Rio Grande Valley. The chapter will describe in detail the instrumentation of the farm fields including soil moisture sensors and low cost flow measuring devices. The chapter will also present results regarding water usage and farmer irrigation practices that were obtained from the low cost instrumentation method. It is the hope of the author that this type of low cost monitoring network finds acceptance and contributes to improvements in water use efficiency throughout the American West and beyond, allowing irrigated agriculture to meet growing demand in the future with limited water supplies.

2. Background

The Middle Rio Grande Conservancy District (MRGCD) may be one of the oldest operating irrigation systems in North America (Gensler et al. 2009). Prior to Spanish settlement in the 1600s the area was being flood irrigated by the native Pueblo Indians. At the time of Albuquerque's founding in 1706 the ditches, that now constitute the MRGCD, were already in existence and were operating as independent acequia (tertiary canal) associations (Gensler et al. 2009). In 2010 the MRGCD operated and maintained nearly 1,500 miles of canals and drains throughout the valley in addition to nearly 200 miles of levees for flood protection. The MRGCD services irrigators from Cochiti Reservoir to the Bosque del Apache National Wildlife Refuge. An overview map of the MRGCD is displayed in Figure 1. Irrigation structures managed by the MRGCD divert water from the Rio Grande to service agricultural lands, that include both small urban landscapes and large scale production of alfalfa, corn, vegetable crops such as chili and grass pasture. The majority of the planted acreage, approximately 85%, consists of alfalfa, grass hay, and corn which can be characterized as low value crops. In the period from 1991 to 1998, USBR crop production and water utilization data indicate that the average irrigated acreage in the MRGCD, excluding pueblo lands, was 53,400 acres (21,600 ha) (Kinzli 2010). Analysis from 2003 through 2009 indicates that roughly 50,000 acres (20,200 ha) are irrigated as non-pueblo or privately owned lands and 10,000 acres (4,000 ha) are irrigated within the six Indian Pueblos (Cochiti, San Felipe, Santo Domingo, Santa Ana, Sandia, and Isleta). Agriculture in the MRGCD is a $142 million a year industry (MRGCD, 2007). Water users in the MRGCD include large farmers, community ditch associations, six Native American pueblos, independent acequia communities and urban landscape irrigators. The MRGCD supplies water to its four divisions -- Cochiti, Albuquerque, Belen and Socorro -- through Cochiti Dam and Angostura, Isleta and San Acacia diversion weirs, respectively (Oad et al. 2009; Oad et al. 2006; Oad and Kinzli, 2006). In addition to diversions, all divisions except Cochiti receive return flow from upstream divisions.

Return flows are conveyed through interior and riverside drains. From the drains, excess water is diverted into main canals in the downstream divisions for reuse or eventual return to the Rio Grande. Drains were originally designed to collect excess irrigation water and drain agricultural lands, but are currently used as interceptors of return flow and as water conveyance canals that allow for interdivisional supply.

Water in the MRGCD is delivered in hierarchical fashion; first, it is diverted from the river into a main canal, then to a secondary canal or lateral, and eventually to an acequia or small ditch. Figure 2 displays the organization of water delivery in the MRGCD. Conveyance canals in the MRGCD are primarily earthen canals but concrete lined canals exist in areas where bank stability and seepage are of special concern. After water is conveyed through laterals it is delivered to the farm turnouts with the aid of check structures in the lateral canals. Once water passes the farm turnout it is the responsibility of individual farmers to apply water and it is applied to fields using basin or furrow irrigation techniques. The overall average yearly water diversion by the MRGCD is approximately 350,000 Acre-feet (Kinzli 2010).

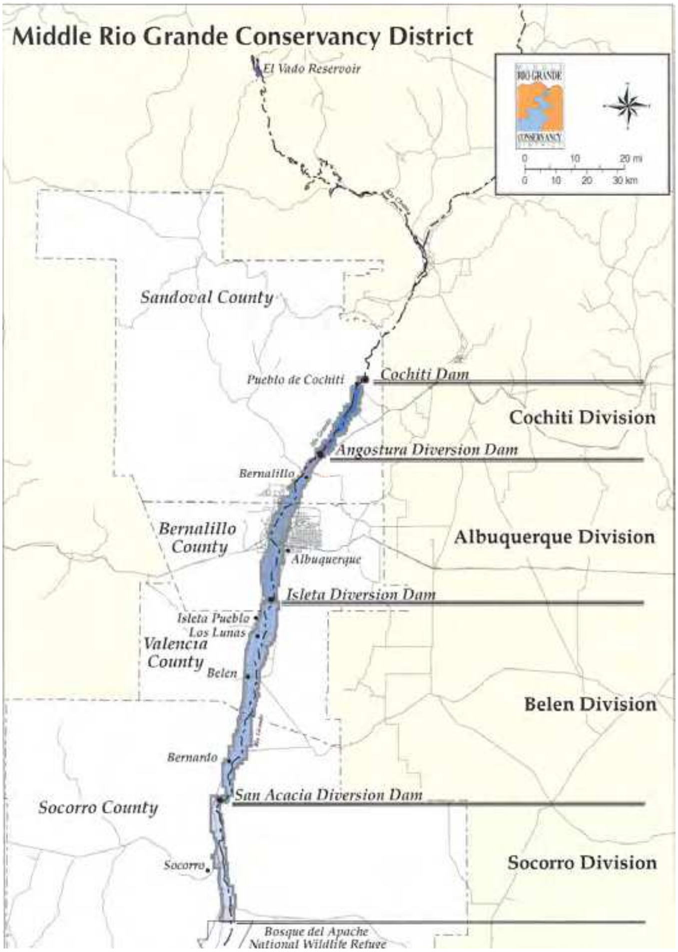


Fig. 1. Overview Map of MRGCD (MRGCD, 2007)

The MRGCD like many other conservancy districts has come under pressure to become a more efficient water user. In order to do so large scale infrastructure modernization projects have been undertaken (Gensler et al. 2009) and a decision support system has been developed and implemented (Kinzli, 2010). The one sector remaining where water saving can be realized is at the farm level by improving farmer irrigation application efficiency.

Measurements of on-farm application efficiency in the MRGCD were limited and therefore in the summer of 2008 eight fields in the MRGCD were instrumented to measure total water application and application efficiency. Figure 3 displays a map of the eight instrumented fields.

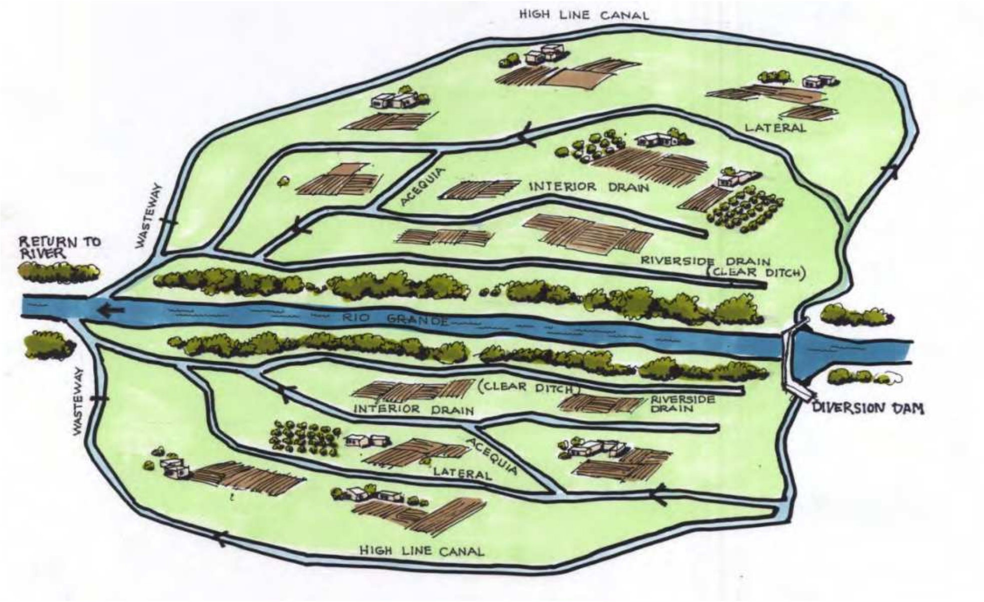


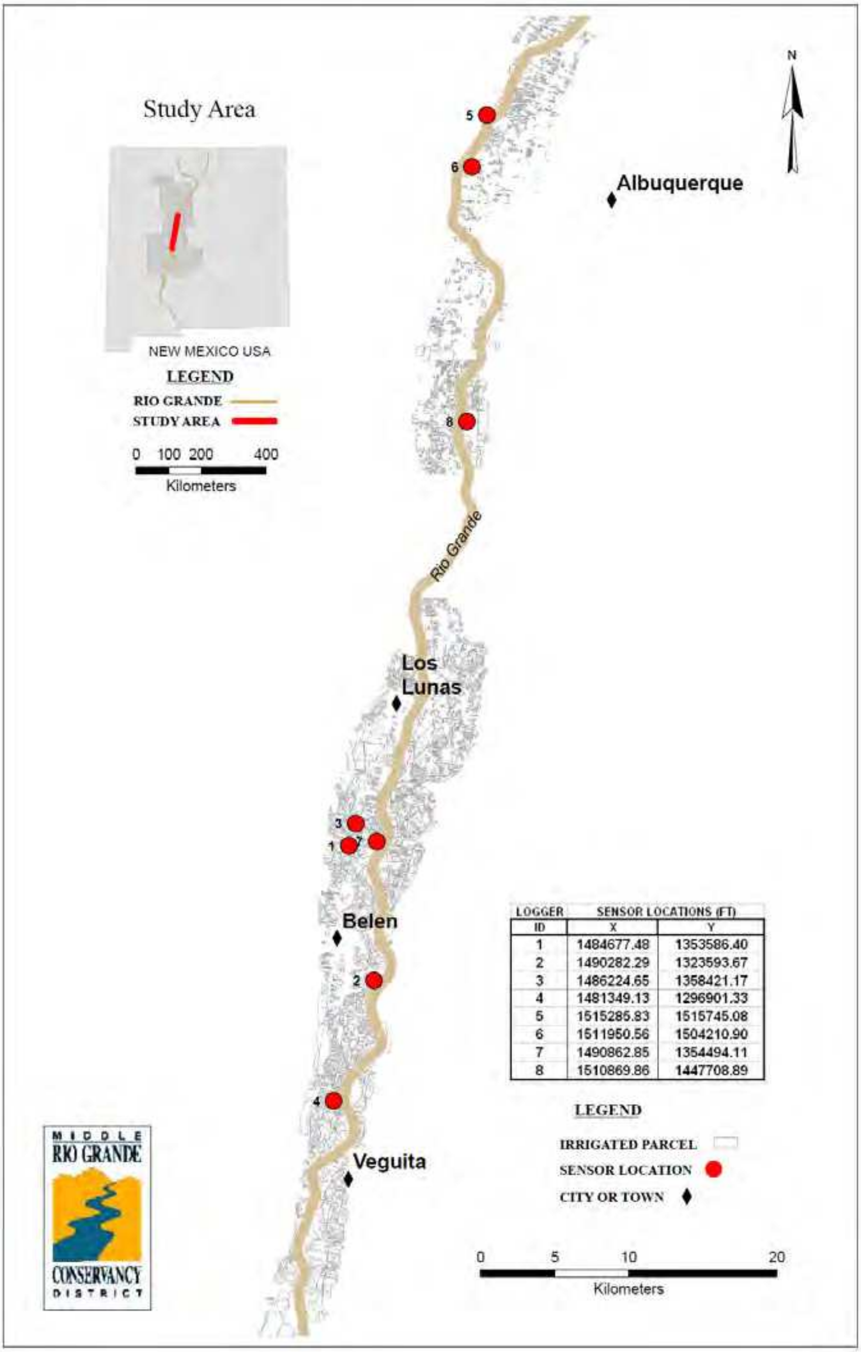
Fig. 2. Representation of MRGCD Irrigation System (Courtesy of David Gensler and MRGCD)

3. Methodology

In order to measure total water application and application efficiency it was necessary to instrument the eight fields with both a flow measurement device and instruments to measure soil moisture. Since the main crops in the MRGCD are alfalfa and grass hay 4 fields of each were chosen for monitoring. Due to the financial constraint of limited funding it was necessary to utilize a low cost setup with the total cost for each field remaining under $1200. This financial constraint would be a realistic consideration for farmers in the MRGCD as well since they produce low value crops such as alfalfa and grass hay. The use of a low cost monitoring network would also allow for application worldwide, specifically in developing countries.

3.1 Flow measurement

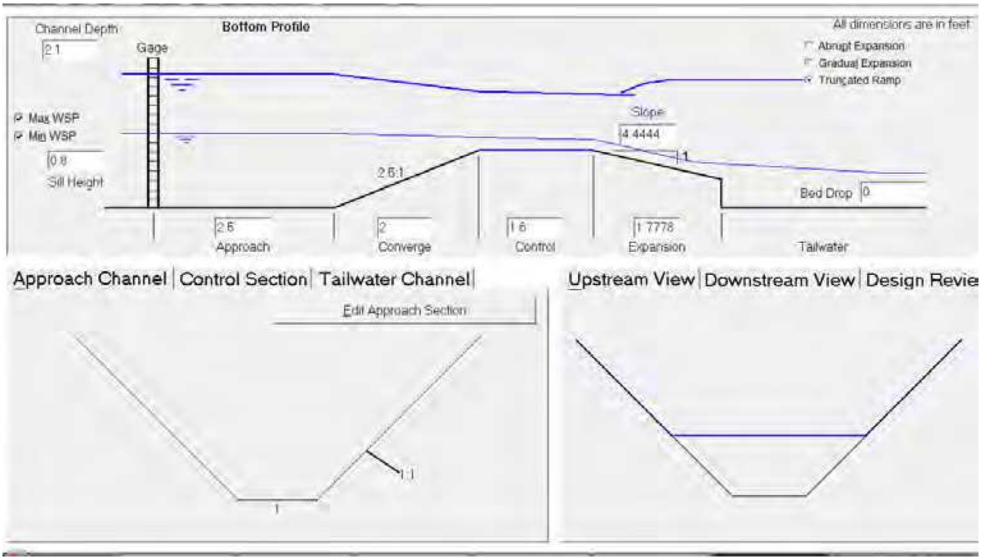
The first step in the field instrumentation was to perform a survey to determine the slope of the irrigation head-ditch, which was conducted using a laser level. The irrigation head ditches in the MRGCD are trapezoidal and have a 1 foot bottom width and a 1:1 H:V side slope. In addition to the survey, the dimensions of each head ditch were also determined. During the first irrigation event, the flow rate used for irrigation was measured using a Price



LOGGER	SENSOR LOCATIONS (FT)	
ID	X	Y
1	1484677.48	1353586.40
2	1490282.29	1323593.67
3	1486224.65	1358421.17
4	1481349.13	1296901.33
5	1515285.83	1515745.08
6	1511950.56	1504210.90
7	1490862.85	1354494.11
8	1510869.86	1447708.89

Fig. 3. Map of the Instrumented Farm Fields

Pygmy or Marsh McBirney flow meter and standard USGS measuring techniques. From the collected flow measurement and ditch data, it was possible to design a broad crested weir for flow measurement using the Unites States Bureau of Reclamation software Winflume and the Manning's flow rate equation. The software allows the user to design the appropriate flume and develops a stage-discharge equation based on the head over the crest of the weir. Figure 4 displays the flume designed for Field 3.



Channel Depth 2.1

Sill Height 0.8

Slope 4.4444

Bed Drop 0

Approach 2.5

Converge 2

Control 1.6

Expansion 1.7778

Fig. 4. Flume Designed for Measuring Field 3 (WSP = Water Surface Profile)

The broad crested weirs for each field were constructed out of concrete using cutout particle board templates as forms and cost approximately $100 each. Broad crested weirs were constructed for each of the eight fields but were utilized on seven fields. One farmer complained that the weir diminished his available flow rate, and therefore a rating curve was developed for his canal section instead of the weir. Figure 5 displays the finished broad crested weir for Field 3.

Hobo pressure transducers and data loggers ($400), manufactured by Onset Incorporated, were installed to measure the depth of water over the crest of the weir. These pressure transducers have an accuracy of 0.01 ft. Figure 6 displays a HOBO pressure transducer.

The Hobo dataloggers were installed on the side of each irrigation ditch roughly two canal widths upstream of the weir crest (Winflume design standard) using a small length of PVC pipe, clips, and concrete anchors. The section of PVC pipe was perforated multiple times with a ¼ inch drill bit to insure that water would seep into the section of PVC and allow for pressure measurement. Once the Hobo data loggers were installed in the PVC pipe a laser level was used to determine the offset between the bottom of the pressure transducer and the top of the weir crest. Figure 7 displays an installed Hobo pressure transducer.

Fig. 5. Completed Broad Crested Weir for Field 3

Fig. 6. Hobo Pressure Transducer

Fig. 7. Installed Hobo Pressure Transducer

The Hobo data loggers were set to log the absolute pressure every ten minutes. During an irrigation event, the pressure read by the Hobo included atmospheric pressure, so the atmospheric pressure from a Hobo exposed to only the atmosphere was subtracted from the reading. This resulted in a pressure reading that represented the total depth of water in the irrigation ditch. The pressure reading was converted using the conversion factor that 1 psi is the equivalent of 27.68 inches of water. Once the total depth of water in the irrigation ditch was calculated, the previously mentioned laser leveled offset of the weir crest was subtracted from the total water depth to get the depth of water over the weir crest. This value was plugged into the weir flow rate equation developed in Winflume to determine the flow passing the weir every ten minutes. Once the first irrigation event had occurred for each broad crested weir, the flow measurements calculated using the equation were compared to the initial measurement using flow meters in order to insure that the weirs were functioning properly. For each constructed weir the flow rate given by the Winflume equation was reasonable and corresponded to the measurements obtained using flow meters. The nature of this setup allowed for remote monitoring in that no on-farm presence was required during any irrigation event during the irrigation season. The Hobo pressure transducer has the capability to store an entire years worth of irrigation data and therefore data was only collected infrequently. When data was collected the Hobo optical USB cable was utilized to connect the pressure transducer to a laptop.

The total water volume in cubic feet applied during each irrigation event was obtained incrementally for every ten minute period during the irrigation event. The total volume in cubic feet was calculated by taking the flow rate in cubic feet per second every ten minutes and multiplying this value by 600 seconds. This was done for every ten minute interval during the duration of the irrigation event to obtain the total cubic feet of water applied during the event. This assumption to use a ten minute interval was validated by the fact that the water level did not fluctuate significantly during most irrigation events.

3.2 Soil moisture measurement

To improve irrigation efficiency the amount of moisture that is stored in the soil for beneficial plant use during the irrigation event and the subsequent depletion of the moisture is required. To measure the soil moisture, soil moisture probes were installed in each of the eight fields. During early 2008 before the irrigation season, soil moisture probes were installed in the eight representative fields instrumented with broad crested weirs. Electrical conductivity sensors were used instead of time domain reflectrometry (TDR) sensors due to budget constraints. TDR sensors can cost over $2000 a piece greatly, exceeding the budget available for each field. The electrical conductivity sensors used were the EC-20 ECHO probe from Decagon ($100 each). Figure 8 displays the EC-20 soil moisture probe.

Fig. 8. EC-20 ECHO Probe from Decagon Devices

Recent improvements to the ECH20 soil moisture sensor allowed for detailed measurement of soil water content (Sakaki et al. 2008). The ECH2O EC-20, which offers a low cost alternative to other capacitance type meters, (Kizito et al. 2008; Saito et al. 2008; Sakaki et al. 2008; Bandaranayake et al. 2007; Nemali et al. 2007; Plauborg et al. 2005) has been used to improve irrigation management for citrus plantations (Borhan et al. 2004). The precision of the ECH20 EC-20 is such that it can be used for greenhouse operations and to schedule field irrigation (Nemali et al. 2007). The main benefit of the ECH2O sensor is that it is one of the most inexpensive probes available and therefore can be widely used and implemented (Christensen, 2005; Luedeling et al. 2005; Riley et al. 2006). The ECH2O sensor is designed to be buried in the soil for extended periods of time and connected to a data logger such as the Em5b (Decagon Devices, Pullman WA). EC-20 sensors allow for the determination of saturation, field capacity, and wilting point, along with the redistribution pattern of soil water, and possible drainage below the root zone. This information can be used to decide the time and amount of irrigation (Bandaranayake et al. 2007).

The EC-20 probe has a flat design for single insertion and allows for continued monitoring at a user defined interval. The overall length of the sensor is 8 inches with a width of 1.2 inches and blade thickness of 0.04 inches, with a 2.4 inch sensor head length. The total sampling volume of the probe is between 7.8 and 15.6 in^3, depending on soil water content (Bandaranayake et al. 2007). The ECH2O EC-20 soil probe measures the dielectric permittivity or capacitance of the surrounding soil medium, and the final output from the sensor is either in a millivolt or raw count value that can be converted to a volumetric water content using calibration equations (Kelleners et al. 2005). The raw count is an electrical output specific to which datalogger the sensor is used with. Raw counts can easily be converted if an output in millivolts is desired. Details on the EC-20 sensor measurement principle and function are reported by the manufacturer (Decagon Devices, 2006a). Studies have shown that temperature affects on the ECH2O probes are minimal (Kizito et al. 2008; Norikane et al. 2005; Campbell, 2002) with changes of 0.0022 ft^3/ft^3 water content per degree C (Nemali et al. 2007). Problems due to soil variation and air gaps can be avoided by using the factory installation tool and developing calibration equations relevant to each soil type. Drawbacks of this sensor include water leakage into the sensor circuit in isolated cases, and damage from animals such as gophers and squirrels (Bandaranayake et al. 2007). Using the manufacturer provided equation, typical accuracy in medium textured soil is expected to be ±0.04 ft^3/ft^3 (3% average error) with soil specific equations producing results with an accuracy of ±0.02 ft^3/ft^3 (1% average error) (Decagon Devices, 2006b).

Through previous research it has been found that dielectric sensors often require site specific calibration either through field methods or laboratory analyses. Inoue et al (2008) and Topp et al (2000) found that it was necessary to perform site specific calibrations for capacitance sensors to account for salinity concerns, and Nemali et al (2007) found that it was necessary to calibrate the ECH2O sensors because output was significantly affected by the electrical conductivity of the soil. Other studies have found that site specific corrections are required for mineral, organic, and volcanic soils (Paige and Keefer, 2008; Bartoli et al. 2007; Regelado et al. 2007; Malicki et al. 1996).

Kizito et al. (2008) suggested that soil specific calibrations are important when large networks of ECH2O soil moisture sensors are deployed. Several researchers have found that soil specific calibrations are necessary for ECH20 probes across varying soil types (Sakaki et al. 2008; Mitsuishi and Mizoguchi, 2007; Fares and Polyakov, 2006; Bosch, 2004) and Saito et al (2008) found that calibration is a requirement for accurate determination of volumetric water content using the ECH2O. Based on the recommendations of these previous studies, soil specific calibrations were performed for each sensor installation using a technique described in (Kinzli, 2010). The use of EC20 ECHO sensors allowed for development of a low cost monitoring network capable of being used to schedule irrigation and therefore offer the possibility of improving water use efficiency.

The EC-20 ECHO probes installed in the eight fields were linked to Em5b data recorders ($400 each). The Em5b is a 5-channel, self-contained data recorder (Decagon, 2008). The Em5b is housed in a white UV-proof enclosure, which makes it suitable for general outdoor measurements. It uses 4 AAA-size alkaline batteries, that last 5-6 months, and has a Flash Data memory that allows for 145 days of data collection at 1 scan/hour (Decagon, 2008). All eight Em5b data loggers were set to record soil moisture every 60 minutes during the study. Figure 9 displays the Em5b data logger.

Fig. 9. Em5b-Datalogger from Decagon Devices

The EC-20 ECHO moisture probes were installed in the eight representative fields to obtain a value of soil moisture remaining before an irrigation event and to determine hourly soil moisture depletions. Each field was equipped with one sensor station, due to project budget constraints. Therefore each field represented a point measurement. This approach resulted in eight point measurements throughout the MRGCD. Lundahl (2006) showed that soil moisture measurements at one point in each field were sufficient to obtain soil moisture depletion and application efficiency in the MRGCD. The field layout used for each sensor station is displayed in Figure 10. The layout of the moisture probes was designed to eliminate data points in areas that display variable wetting front values due to distance and the points chosen provided average values for the field in question. Each sensor station consisted of two EC-20 ECHO probes (installed at 8 inches and 24 inches) so that a soil profile of up to 4 feet could be measured. Figure 11 displays the layout of a sensor station.

The Em5b data loggers were located outside of the field boundary to minimize interference with cultivation and prevent damage of the logger. A 50 ft extension cable was used to place the sensor stations out in the field to eliminate edge effects on crop ET. The 50 ft extension cable was placed in a hand dug trench out into the field at a depth of roughly 8 inches.

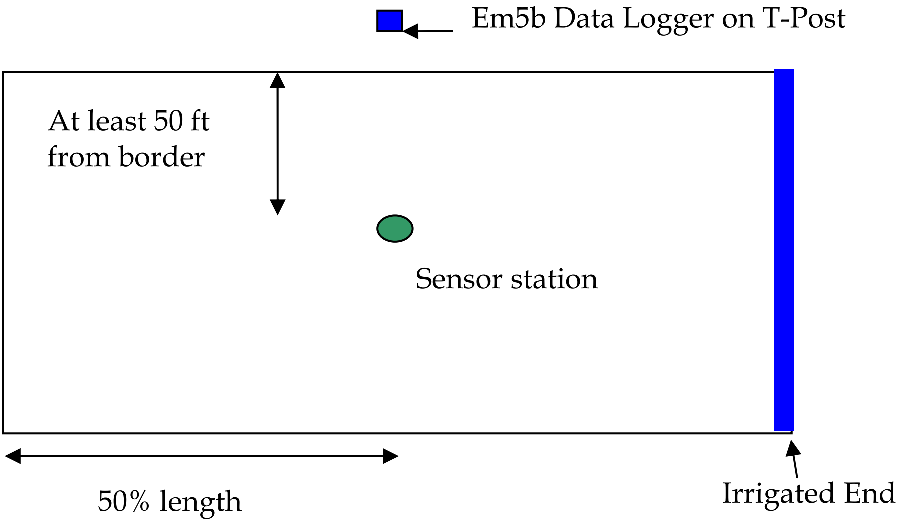


Fig. 10. Field Layout of Sensor Stations

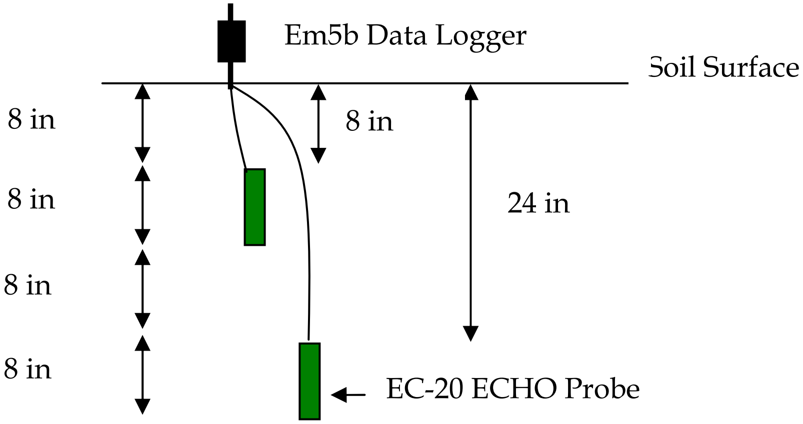


Fig. 11. Individual Layout of Sensor Stations

Once the soil moisture probes were installed, GPS points were taken at the location of the sensor station, datalogger, and the corner of the field to determine the exact irrigated acreage. From this collected data and the MRGCD aerial photography coverage, a detailed map of the flume, sensor, and datalogger location was created for each of the eight study fields. Figure 12 displays the map of Field 3.

Fig. 12. Map of Study Field 3

In order to validate that the probes were indeed functioning correctly and to develop calibration equations soil samples were taken in proximity to the installed sensor stations. A one gallon soil sample was taken for each installed sensor and analyzed at Colorado State University to determine soil type, field bulk density, pH, and electrical conductivity. Soil samples were also taken in order to determine field capacity, wilting point, and readily available moisture (RAM) for each soil type. These samples were also used to develop soil specific calibration equations for each sensor.

Using the instrumented fields it was possible to determine the on-farm application efficiency over a period of 2 years and 144 irrigation events for the eight instrumented fields. For the purpose of this analysis the on farm application efficiency was defined as the water replenished for crop use divided by the total water applied. This definition of application efficiency focuses only on water for crop growth and does not include any water used for leaching salts out of the root zone.

4. Results

In order to determine application efficiency the broad crested weirs and pressure transducers installed on the eight farm fields were used to determine the total water delivered for each irrigation event during the 2008 and 2009 irrigation seasons. Once the total water applied for an irrigation event was calculated, it was possible to calculate the depth of water applied per unit area by dividing the total volume applied by the acreage of the basin that was irrigated. This resulted in a depth of water in inches applied over the monitored field. Additionally, irrigation event number, the date, duration, and average flow rate for each irrigation event were recorded. Table 1 displays the logger ID, irrigation event, irrigation date, total water applied, and inches applied for ten irrigation events.

Logger ID	Irrigation Event	Date	Total Water Applied (ft^3)	Depth Applied (inches)
1	1	4/14/2008	157190	6.95
1	2	5/5/2008	266004	7.44
1	3	6/1/2008	325216	9.09
1	4	6/24/2008	149748	4.19
1	5	8/6/2008	150338	4.2
1	6	9/12/2008	125121	3.5
1	1	4/13/2009	112475	3.15
1	2	5/11/2009	148812	4.16
1	3	6/18/2009	173791	4.86
1	4	7/20/2009	113443	3.17

Table 1. Logger ID, Irrigation Event, Date, Total Water Applied and Depth Applied for 10 Irrigation Events

The next step in calculating the application efficiency was determining the water available for crop use that was replenished during each irrigation event. This was possible using the data collected from the installed EC-20 soil moisture sensors. The soil moisture sensor data, corrected using the developed laboratory calibration equations for each specific sensor installation, provided the volumetric soil moisture content before the irrigation event and after field capacity was reached. The difference between the volumetric water content before the irrigation event and field capacity represented the amount of water stored in the root zone for beneficial crop use. This data was recorded at both the 8 inch and 24 inch sensor location for each field for each irrigation event. To calculate the water stored in the soil for beneficial crop use in inches the 8 inch sensor was deemed to be representative of the first 16 inches of root depth for both the alfalfa and grass hay fields. The 24 inch sensor was chosen to represent the subsequent 20 inches of root depth for grass hay and the subsequent 32 inches for alfalfa. For grass hay and alfalfa this represented a 36 inch and 48 inch effective total root zone, respectively. These values were chosen based on 12 years of research conducted by Garcia et al. (2008) at the Natural Resource Conservation Service (NRCS), which was conducted in the Middle Rio Grande and Mesilla Valleys to determine the root depths that were effectively able to utilize and deplete soil moisture.

Once the effective root depth was determined, the root depth associated with each sensor and crop type was multiplied by the difference between the volumetric water content at field capacity and volumetric water content before the irrigation event took place for the 8 inch and 24 inch sensor. This yielded the water available for crop use in inches for the upper

16 inches and either lower 20 inches for grass hay or 32 inches for alfalfa. These two values were added together to give the total water in inches available for crop use applied during the irrigation event. The total water available for crop use was then divided by the total water applied to determine application efficiency. The application efficiency for all 144 irrigation events was calculated from the collected data. **Table 2** displays the results of the application efficiency analysis for 10 irrigation events.

Logger ID	Irrigation Event	Date	Depth Applied (inches)	Moisture Applied for Crop Use (inches)	Application Efficiency (%)
1	1	4/14/2008	6.95	4.64	67%
1	2	5/5/2008	7.44	1.92	26%
1	3	6/1/2008	9.09	3.36	37%
1	4	6/24/2008	4.19	2.24	53%
1	5	8/6/2008	4.2	1.76	42%
1	6	9/12/2008	3.5	2.4	69%
1	1	4/13/2009	3.15	2.56	81%
1	2	5/11/2009	4.16	2.56	62%
1	3	6/18/2009	4.86	2.56	53%
1	4	7/20/2009	3.17	1.12	35%

Table 2. Irrigation Event, Date, Depth Applied, Moisture Applied for Beneficial Crop Use and Application Efficiency for 10 Irrigation Events

The data displayed significant variability with a range in application efficiency from 8% to 100%. The mean value for all 144 irrigation events was found to be 44.4% with a standard deviation of 24.4%. The calculated mean value represent a lower application efficiency value than the 50% previously hypothesized by water managers.

To address the variability in the collected data a histogram of the collected data was created. Figure 13 displays the histogram of application efficiency.

The developed histogram displayed a nearly normal distribution about the mean value but was skewed slightly to the right due to 11 irrigation events with an application efficiency of 100%. From the developed histogram it became clear that the majority of irrigation events exhibited application efficiencies reflected by the calculated mean value.

Using the developed histogram it was also possible to calculate the probability that the application efficiency would fall within one standard deviation of the calculated mean. The probability that the application efficiency of an irrigation event would fall within one standard deviation was found to be 112 out of 144 irrigation events resulting in a probability value of 0.78. This indicates that 78% of the irrigation events were within one standard deviation of the calculated mean. Based on the analysis of the histogram and probability the revised value for application efficiency of 45% will be utilized by the MRGCD, which will allow for more precise representation of farmer practices. Several irrigation events exhibited an application efficiency of 100% and indicate possible under irrigation. Such results also point to possible measurement errors and residual moisture that is used by plants but not accounted for in calculations related to an irrigation event. One reason for possible errors could be due to the fact that only one sensor location was installed for each field due to budget constraints. Spatial variability in soil and topography that could not be measured due to a single sensor location could be the cause of uneven water distribution during the irrigation event. Differences in moisture uptake by plants due to spatial root variability could also be the cause this discrepancy.

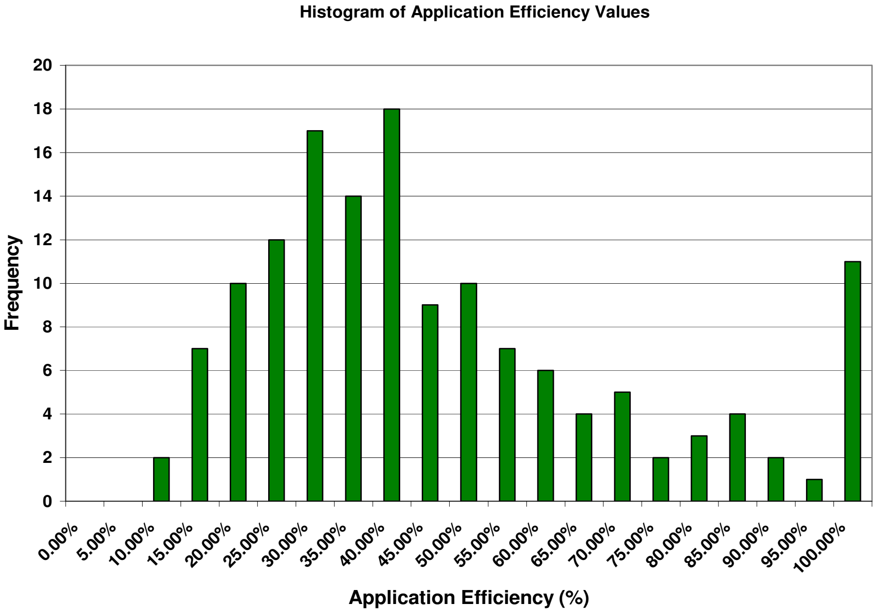


Fig. 13. Histogram of Application Efficiency

From the collected data it was also possible to refine the analysis of on farm application efficiency. First, the application efficiency was separated by crop type as analysis of the total water applied during an entire season suggested that fields with alfalfa hay would have higher application efficiency. The mean value of application efficiency for each grass field was calculated for the 2008 and 2009 irrigation seasons from all irrigation events. For 2008 the application efficiencies covered a range from 31% to 50%. For 2009 the application efficiency covered a range from 22% to 52%. The mean application efficiency of all 40 grass hay irrigation events was found to be 40.8% in 2008. The mean application efficiency of all 43 grass hay irrigation events was found to be 38.6% in 2009. Table 3 displays the average values found for each individual grass field.

The mean value of application efficiency for each alfalfa field was also calculated for the 2008 and 2009 irrigation seasons for all irrigation events. For 2008 the application efficiencies covered a range from 29% to 82%. For 2009 the application efficiency covered a range from 23% to 85%. The mean application efficiency of all 31 alfalfa hay irrigation events was found to be 50.2% in 2008. The mean application efficiency of all 30 alfalfa hay irrigation events was found to be 52.5% in 2009. Table 4 displays the average values found for each individual alfalfa field.

Logger ID	Crop Type	Application Efficiency 2008	Application Efficiency 2009
4	Grass Hay	50%	52%
5	Grass Hay	44%	41%
7	Grass Hay	33%	36%
8	Grass Hay	31%	22%

Table 3. Mean Application Efficiency for Grass Hay Fields in 2008 and 2009

Logger ID	Crop Type	Application Efficiency 2008	Application Efficiency 2009
1	Alfalfa Hay	49%	66%
2	Alfalfa Hay	29%	23%
3	Alfalfa Hay	82%	85%
6	Alfalfa Hay	45%	43%

Table 4. Mean Application Efficiency for Alfalfa Hay Fields in 2008 and 2009

The results show that the mean application efficiency for the alfalfa fields was 9.4% higher than the grass hay fields in 2008 and 13.9% higher in 2009. The temporal variation of the application efficiency numbers was also examined but no useful trends could be identified. Overall, the application efficiency numbers obtained during the study indicate that farmers in the MRGCD could improve their water management which would result in more water being available for other uses including increased production to meet the needs of our ever growing population.

5. Conclusions

As the world population continues to grow, irrigated agriculture will need to meet the additional food production required. The current belief is that irrigated agriculture will need to maximize the crop per drop to meet the demand in the future as current water supplies are already stretched thin. In order to increase production with the current amount of available water and deal with external pressure for reduced water usage, irrigated agriculture can become more efficient in its on-farm water application. Increasing on-farm application efficiency if often cost prohibitive, especially for low value crops. This chapter presented a low cost methodology utilized to remotely instrument eight farm fields in the Middle Rio Grande Valley for measurements of both applied irrigation water and soil moisture conditions. Through the instrumented fields it was possible to determine application efficiencies for 144 irrigation events over a period of 2 years. The total cost for each instrumented field was $1200 dollars and represents a cost level that most farmers in the Western United States could bear regardless of crop value.

The field instrumentation presented in this study was only used to monitor the eight fields and describe how farmers currently irrigate in the MRGCD. In order to achieve higher application efficiencies and obtain the most crop per drop the field instrumentation setup described in this chapter could be used to schedule irrigation events and precisely apply the appropriate amount of water. Knowledge of the soil moisture conditions prior to an irrigation event could be obtained from EC-20 sensor setups and an optimal application depth could be calculated. This application depth could then be precisely applied using the broad crested weirs placed in irrigation head ditches. It is the hope of the author that this type of low cost monitoring network finds acceptance and contributes to improvements in water use efficiency throughout the American West and beyond allowing irrigated agriculture to meet growing demand in the future with limited water supplies.

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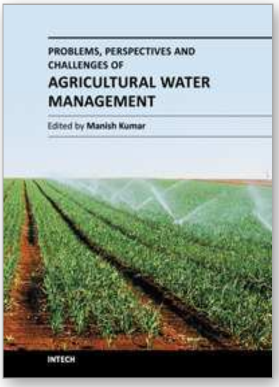

Problems, Perspectives and Challenges of Agricultural Water Management

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Food security emerged as an issue in the first decade of the 21st Century, questioning the sustainability of the human race, which is inevitably related directly to the agricultural water management that has multifaceted dimensions and requires interdisciplinary expertise in order to be dealt with. The purpose of this book is to bring together and integrate the subject matter that deals with the equity, profitability and irrigation water pricing; modelling, monitoring and assessment techniques; sustainable irrigation development and management, and strategies for irrigation water supply and conservation in a single text. The book is divided into four sections and is intended to be a comprehensive reference for students, professionals and researchers working on various aspects of agricultural water management. The book seeks its impact from the diverse nature of content revealing situations from different continents (Australia, USA, Asia, Europe and Africa). Various case studies have been discussed in the chapters to present a general scenario of the problem, perspective and challenges of irrigation water use.

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