

## IMPROVING IRRIGATION SYSTEM PERFORMANCE IN THE MIDDLE RIO GRANDE THROUGH SCHEDULED WATER DELIVERY

Kristoph-Dietrich Kinzli<sup>1</sup>  
Ramchand Oad<sup>3</sup>  
Luis Garcia<sup>5</sup>

David Patterson<sup>2</sup>  
Nabil Shafike<sup>4</sup>  
David Gensler<sup>6</sup>

### ABSTRACT

Scheduled water delivery (SWD) provides the opportunity to increase overall irrigation system performance and define legitimate water use in regions without adjudication. A well-managed program of scheduled water delivery is able to fulfill seasonal crop water requirements in a timely manner, but requires less water than on-demand water delivery. In order to successfully realize SWD in an irrigation district, several components need to be addressed and developed simultaneously.

This paper will present results of on-going research in the Middle Rio Grande Conservancy District (MRGCD) related to implementation of scheduled water delivery supported by a decision-support system (DSS) and modernization of irrigation infrastructure. A DSS developed over the last four years uses linear programming to find an optimum water delivery schedule for all canal service areas in the MRGCD irrigation system. The DSS has been developed for the entire MRGCD and a significant validation effort of input parameters and model logic has been completed.

The second component for implementing scheduled water delivery is a program of irrigation infrastructure modernization with Supervisory Control and Data Acquisition (SCADA) system. Over the past six years, the MRGCD has modernized canal infrastructure and developed a SCADA system with the focus being to improve water use efficiency.

The third component in implementing scheduled water delivery is its acceptance by all water users as a matter of district policy and practice. To gain acceptance and disseminate information regarding SWD, a public outreach program was formulated that includes providing water users information through newsletters, websites, and public meetings. It also included training related MRGCD staff in the concepts and practice of scheduled water delivery and the use of related decision-support systems.

---

<sup>1</sup> Graduate Research Assistant, Colorado State University, Fort Collins, CO; kkinzli@engr.colostate.edu

<sup>2</sup> Research Associate, Colorado State University, Fort Collins, CO; pattersd@engr.colostate.edu

<sup>3</sup> Professor, Department of Civil and Environmental Engineering Colorado State University, Fort Collins, CO; oad@engr.colostate.edu

<sup>4</sup> Hydrologist, New Mexico Interstate Stream Commission, Albuquerque, NM; nabil.shafike@state.nm.us

<sup>5</sup> Professor and Department Head, Department of Civil and Environmental Engineering Colorado State University, Fort Collins, CO; garcia@engr.colostate.edu

<sup>6</sup> Hydrologist, Middle Rio Grande Conservancy District, Albuquerque, NM; dgensler@mrgcd.com

## INTRODUCTION

Irrigated agriculture in the Western United States has traditionally been the backbone of the rural economy. The climate in the American West with low annual rainfall of 8-14 inches is not conducive to dry land farming. Topography in the West is characterized by the Rocky Mountains which accumulate significant snowfall, and the peaks of the snowmelt hydrograph are stored in reservoirs allowing for irrigation throughout the summer crop growing season. Of the total available surface water, irrigated agriculture uses roughly 80 to 90% (Oad et al. 2009; Oad and Kullman, 2006). The combined demands of agriculture, urban, and industrial sectors in the past have left little water for fish and wildlife. Since irrigated agriculture uses roughly 80 to 90% of surface water in the West, it is often targeted for decrease diversions. Due to fish and wildlife concerns and demands from a growing urban population, the pressure for flow reductions on irrigated agriculture increases every year. In order to sustain itself and deal with external pressure for reduced river diversions irrigated agriculture has to become more efficient in its water consumption. This paper focuses on research regarding improving water delivery operations, specifically scheduled water delivery, in the Middle Rio Grande irrigation system through the use of a decision support system and SCADA technology.

### Middle Rio Grande Valley

The Middle Rio Grande (MRG) Valley runs north to south through central New Mexico from Cochiti Reservoir to the headwaters of Elephant Butte Reservoir, a distance of approximately 175 miles. The valley is narrow, with the majority of water use occurring within five miles on either side of the river. The bosque, or riverside forest of cottonwood and salt cedar, is supported by waters of the Rio Grande and is surrounded by widespread irrigated farming. The Cities of Albuquerque, Rio Rancho, Belen and several smaller communities are located in and adjacent to the MRG Valley. Although the valley receives less than 10 inches of rainfall annually, it supports a rich and diverse ecosystem of fish and wildlife and is a common outdoor resource for communities in the region. Water supply available for use in the MRG Valley includes: native flow of the Rio Grande and its tributaries, allocated according to the Rio Grande Compact of 1938; San Juan-Chama (SJC) project water, obtained via a trans-mountain diversion from the Colorado River system; and groundwater. Water is fully appropriated in the MRG Valley and its utilization is limited by the Rio Grande Compact, which sets forth a schedule of deliveries of native Rio Grande water from Colorado to New Mexico and from New Mexico to Texas (Rio Grande Compact Commission, 1997), and between the United States and the Republic of Mexico. Water demand in the MRG Valley includes irrigated agriculture in the Middle Rio Grande Conservancy District (MRGCD), Pueblo prior and paramount and other currently un-adjudicated rights, and municipal and industrial consumption. In addition to these demands, there are significant consumptive uses associated with the riparian vegetation, and reservoir evaporation. There are also river flow targets associated with two federally-listed endangered species, the Rio Grande silvery minnow (*Hybognathus amarus*), and the southwestern willow fly catcher (*Empidonax traillii extimus*) (USFWS, 2003).

### **Middle Rio Grande Conservancy District**

The MRGCD was formed in 1925 in response to flooding and the deterioration of irrigation works (Shah, 2001). Water diverted by the MRGCD originates as native flow of the Rio Grande and its tributaries, including the Rio Chama. The MRGCD is able to store water in several upstream reservoirs including El Vado and Heron reservoirs. The MRGCD services irrigators from Cochiti Reservoir to the northern boundary of the Bosque del Apache National Wildlife Refuge. Irrigation facilities managed by the MRGCD divert water from the river to service agricultural lands, which include small urban parcels and large tracts that produce alfalfa, pasture, corn, and vegetable crops such as green chile, the later of which is famous throughout the Southwest. 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. Water is conveyed in the MRGCD by gravity flow through primarily earthen ditches. On-farm water management is entirely the responsibility of water users and application is typically surface (flood) irrigation, either basin or furrow. The MRGCD does not meter individual farm turnouts, and ditch-riders estimate water delivery on the basis of time required for irrigation. Therefore, the quantity of water applied to fields is not measured. The total irrigated land within the MRGCD is approximately 60,000 acres. Figure 1 displays the location of the MRGCD.

During the recent drought years, low flows combined with flow requirements for the endangered Rio Grande silvery minnow have drastically reduced available water supplies. In order to deal with reduced water availability, the MRGCD has taken a proactive approach to be a more efficient water user and service its irrigators with reduced river diversions. Towards this end, the division managers and ditch-riders are increasingly practicing scheduled water delivery, which is an effective way to fulfill demand with reduced available water.

Scheduled Water Delivery (SWD) is used in irrigation systems worldwide to improve water delivery and to support water conservation. In SWD, lateral canals receive water from the main canal by turns, allowing water use in some laterals while others are closed. In addition to this water scheduling among laterals, there can be scheduling within laterals whereby water use is distributed in turns among farm turnouts along a lateral. By distributing water among users in a systematic scheduled fashion, an irrigation district can decrease water diversions and still meet crop water use requirements.

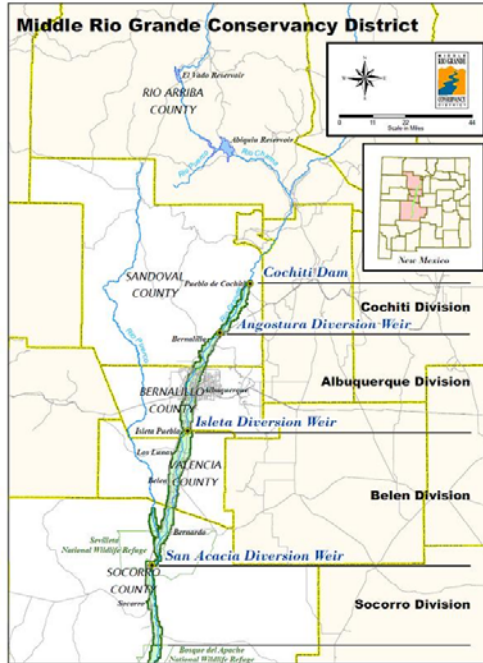


Figure 1. Middle Rio Grande Conservancy District (MRGCD)

**Decision Support Modelling of Irrigation Systems**

The New Mexico Interstate Stream Commission (NMISC) and the MRGCD have sponsored a research project with Colorado State University to develop a decision support system (DSS) to model and assist implementation of scheduled water delivery in the MRGCD’s service area. A DSS is a logical arrangement of information including engineering models, field data, Geographic Information System (GIS) and graphical user interfaces, and is used by managers to make informed decisions. In irrigation systems, a DSS can organize information about water demand in the service area and then schedule available water supplies to efficiently fulfill the demand. Figure 2 displays a conceptual view of how a DSS can be used to develop scheduled water delivery.

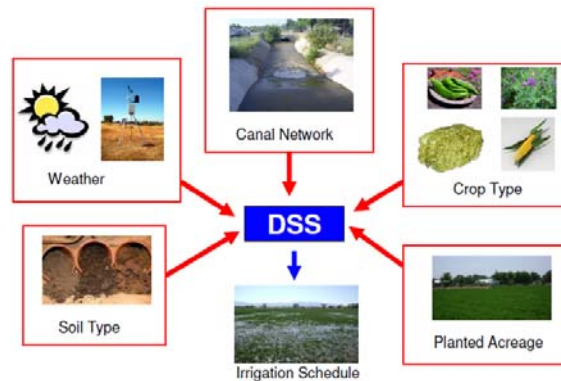


Figure 2. Conceptual View of a Generic SWD DSS

The conceptual problem addressed by a DSS for an irrigation system is how best to route water supply in a main canal to its laterals so that the required river water diversion is minimized. The desirable solution to this problem should be “demand-driven”, in the sense that it should be based on a realistic estimation of water demand. The water demand in a lateral canal service area, or for an irrigated parcel, can be predicted throughout the season through analysis of information on the irrigated area, crop type and soil characteristics. The important demand concepts are: 1) When is water supply needed to meet crop demand (Irrigation Timing), 2) How long is the water supply needed during an irrigation event (Irrigation Duration), and 3) How often must irrigation events occur for a given service area (Frequency of Irrigation).

Decision support systems have found implementation throughout the American West and are mostly used to regulate river flow. Decision support systems on the river level are linked to gauging stations and are used to administer water rights at diversions points. Although decision support systems have proved their worth in river management, few have been implemented for modeling irrigation canals and laterals (NMISC, 2006).

### **DECISION SUPPORT SYSTEM FOR THE MIDDLE RIO GRANDE**

The first component in achieving scheduled water delivery in the MRGCD is the DSS. The DSS was formulated using linear programming with the use of an objective function. A detailed description of model programming can be found in (Oad et al. 2009). Overall model structure consists of three modules that function in concert to calculate the most efficient irrigation water delivery.

#### **Model Structure**

The DSS consists of three model elements or modules: a water demand module, a supply network module, and a scheduling module. A Graphical User Interface (GUI) provides a means for linking the three elements of the DSS. This GUI is an interactive means for the user to access data and output for the system. The project GIS and databases are used to develop input for both the water demand and the supply network modules. Some of the input is directly linked through the GUI and some is handled externally in the DSS. Figure 3 displays the structure of the MRGCD DSS.

**Water Demand Module.** The water demand module of the MRGCD DSS is implemented either through the ET TOOLBOX for the Middle Rio Grande or the Integrated Decision Support Consumptive Use, or IDSCU model, a model developed over a period of years at the Colorado State University. The ET Toolbox is a web application developed by the Bureau of Reclamation that estimates real-time evapotranspiration from distributed climate stations, NexRAD precipitation data, and remotely sensed cropping patterns. Crop consumptive use is calculated using the Penman-Montieth method. The reference ET ( $ET_o$ ) is calculated using weather data from the MRGCD. Crop coefficients using growing degree days are applied to the Penman-based  $ET_o$  to obtain a consumptive use for each crop type throughout the growing season. The water demand module performs

these calculations to obtain a spatially-averaged consumptive use at the lateral service area level, using the distribution of crop types within each service area.

The crop irrigation requirement (CIR) is calculated by accounting for the effective precipitation using the Soil Conservation Service Method. The crop irrigation requirement is calculated on a daily basis, corresponding to the water needed to directly satisfy crop needs for all acres in the service area. The crop irrigation requirement for the service area is subsequently passed to the supply network module, where it is divided by an efficiency factor to obtain a lateral service area delivery requirement (LDR).

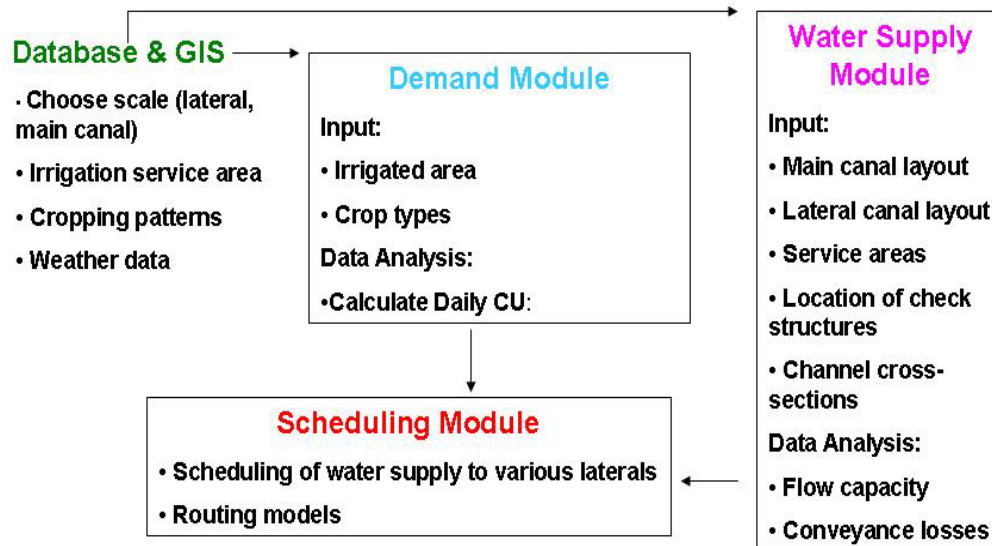


Figure 3. DSS Structure Displaying the Three Modules and Database

Based on acreages, crop types and soil types within each lateral service area, a Readily Available Moisture (RAM) is calculated. The RAM calculated in this context represents a storage capacity to be filled and depleted over several irrigation cycles during the course of the irrigation season. During each irrigation, it is expected that an amount of water equal to the RAM will be stored in soils, which is then depleted, due to crop water use.

Supply Network Module. The supply network module represents the layout of the conveyance system, its physical properties, supply to the conveyance network, and the relative location of diversions from the network to the lateral service area. The layout of the conveyance system is specified through a user-designed link-node network. Through the DSS GUI, a user can drag and drop different types of nodes such as inflows, demands and return flow nodes. The link-node network represents the connections between canals or laterals and demands for water at each service area. Figure 4 displays the supply network.

Irrigation Scheduling Module. The irrigation scheduling module can be used to plan water deliveries to meet crop demand at the lateral and at the main canal level. The module calculates and displays a schedule for the laterals on a given main canal. This schedule indicates how many laterals can be run at a time, how long each lateral should

run and how often. The module is currently set up to run on a daily time step. This module calculates the daily irrigation schedule using mass balance equations and a linear programming solver. The approach is based on the consideration that the farm soil root-zone is a reservoir for water storage, for which irrigation applications are inflows and CIR is an outflow. Figure 5 displays a calendar developed by the irrigation scheduling module.

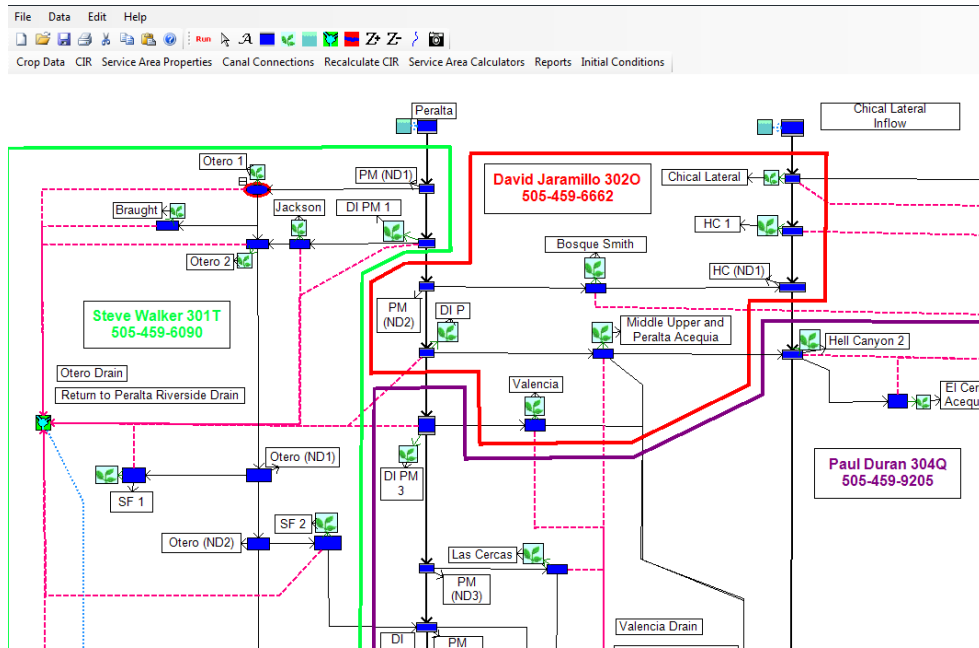


Figure 4. Representation of DSS Supply Network

May

Sun	Mon	Tues	Wed	Thur	Fri	Sat
					1 35 cfs	2 35 cfs
3 35 cfs	4 35 cfs	5 35 cfs	6 35 cfs	7 35 cfs	8 35 cfs	9 35 cfs
10 35 cfs	11 35 cfs	12 35 cfs	13 20 cfs	14 20 cfs	15 10 cfs	16 10 cfs
17 10 cfs	18 10 cfs	19 10 cfs	20 10 cfs	21	22	23
24	25	26 35 cfs	27 35 cfs	28 35 cfs	29 35 cfs	30 35 cfs
31 35 cfs						

Figure 5. Irrigation Calendar Developed Using the Scheduling Module

The DSS has undergone extensive calibration and validation and has proved to be reliable and able to create irrigation schedules based on crop demand (Oad et al. 2009).

## **SUPERVISORY CONTROL AND DATA ACQUISITION (SCADA) SYSTEM**

Along with the development of the DSS to aid in scheduled water delivery the MRGCD has been proactive in updating aging infrastructure as well as incorporating advanced technology such as SCADA (Supervisory Control and Data Acquisition) for more precise and controlled water delivery. This updated technology will allow for the control that is necessary for implementing the irrigation schedules recommended by the DSS and represents the second component necessary for achieving scheduled water delivery.

Over the past few years, the MRGCD has developed a SCADA system with the focus being to improve water use efficiency throughout the Middle Rio Grande Valley (Gensler et al. 2009). The MRGCD program of measurement and automation was built entirely in-house using inexpensive components due to budget constraints. Using traditional SCADA components as well as adaptations of technology from other industries makes the MRGCD SCADA setup unique. The developed SCADA system consists of five main components:

- Water Measurement Structures
- Automated Control Structures
- Instrumentation
- Telemetry
- Control Software

### **Water Measurement Structures**

Water measurement is the single most important component of the MRGCD's SCADA experience, since all operational decisions require sound knowledge of available water supplies and the demand throughout the system. When the MRGCD was initially constructed, considerable thought to water measurement was given. Over the years, gauging stations equipped with measurement instrumentation gradually deteriorated and quality of flow records declined.

In 1996, the MRGCD was operating only 15 gauges on 1,200 miles of canals. The following year, the MRGCD officially embarked upon its modernization program. The construction of new flow gauges was the first step in this program. New gauges were constructed at key points in the canal system, notably at diversion structures and at return flow points. Efforts were also made to improve the quality of measurements. Open channel gauging sites with no control structures gave way to site specific measuring structures. A variety of flow measurement structures were built in the MRGCD and include sharp crested weirs, broad crested weirs, adjustable weirs and Parshall flumes. Current MRGCD design standards specify that new gauges are constructed with broad-crested weirs using WINFLUME for design and calibration. Currently, MRGCD is operating 75 gauges.



### Automated Control Structures

With the advent of better data collection, it became apparent to the MRGCD that automated control was necessary. Data from gauges revealed that many operational problems occurred because canal operators could not be physically present at all times. Automation began with an experimental effort at a wasteway that had been fitted with an automated Langemann gate (Figure 6) for water measurement. The MRGCD built the prototype electronic controller and created the control software for this first automated gate, borrowing heavily from Bureau of Reclamation experience in Utah. Success and invaluable experience from the first automated structure led to installation of over 40 additional automated structures using commercial control products.

Most of the MRGCD's recent automation efforts have involved the installation of Langemann overshot gates (Aqua Systems, 2006). The majority of these can be easily retrofitted to existing structures, though some involve the construction of new check or heading structures. The Langemann Gate has the capability to maintain a constant upstream water level as a check structure or it can provide a constant flow rate to downstream users (Figure 6). The Langemann gate is equipped with solar panels to power both gate operation and telemetry units. The gates employ integrated electronic controllers built around IC Tech Radio Terminal Units (RTU's) and Aqua Systems 2000 software. Langemann gates in the MRGCD are used as checks, turnouts, spillways, and diversion structures.



Figure 6. Langemann Gate

Some existing radial gates have also been automated. Conversion involves selection of a gearbox, motor, and controller. Some in-house fabrication is involved to adapt the drive unit to the existing gate hoist shaft. Early conversion attempts used an AMI controller supplied by Aqua Systems 2000, but recently the MRGCD has used the IC Tech RTU, which can be programmed to calculate flow through automated radial gates. Though not as accurate as overshot gates, this is useful for setting target bypass flows at diversion structures for endangered species flow requirements.

### **Instrumentation**

Flow measurement and automated control must include some level of instrumentation. In the 1930's, a float in a stilling well driving a pen across a revolving strip of paper was adequate. In fact, at the beginning of modernization efforts, the MRGCD was still using 15 Stevens A-71 stage recorders. Diversions into the canal system were only known after the strip charts were collected and processed at the end of the irrigation season.

Modernization meant a device was needed to generate an electronic output that could be digitally stored or transmitted. Initially, shaft encoders were used for this purpose, providing input for electronic data loggers. Experimentation with submersible pressure sensors soon followed, and these have been adopted, although a number of shaft encoders are still in use. Recently, sonar sensors have been used satisfactorily at a number of sites. The MRGCD has learned that different situations call for specific sensor types and sensors are selected for applications where they are most appropriate.

### **Telemetry**

Data from electronic data-loggers was initially downloaded manually and proved to be only a minimal improvement over strip chart recording, though processing was much faster. To address data downloading concerns, telemetry was adopted to bring the recorded data back to MRGCD headquarters at regular intervals. The MRGCD's initial exposure to telemetry was through the addition of GOES satellite transmitters to existing electronic data loggers. This method worked, but presented limitations. Data could only be transmitted periodically, and at regularly scheduled intervals. Of greater consequence was that the GOES system, at least as used by the MRGCD, was a one-way link. Data could be received from gauging stations, but not sent back to them.

To address the rising cost of telemetry using cell phone service, experiments with FM radio telemetry were conducted. These began as a way to bring multiple stream gage sites to a central data logger, which would then be relayed via GOES to MRGCD. First attempts with FM radio were not encouraging; however a successful system was eventually developed. As this use of FM radio telemetry (licensed 450 MHz) expanded, and knowledge of radio telemetry grew, it was soon realized that data could be directly transmitted to MRGCD headquarters without using the GOES system.

The shift to FM radio produced what is one of the more unique features of the MRGCD telemetry system. The data link proved so reliable, that there was no longer a need to store data on site, and the use of data loggers was mostly discontinued, the exception being weather stations. In effect, a single desktop computer at the MRGCD headquarters has become the data-logger for the entire stream gauge and gate system, being connected to sensors in the field through the FM radio link. Three repeater sites are used to relay data up and down the length of the valley, with transmission up to 75 miles. Also, this has the benefit of being a 2-way link, so various setup and control parameters can be transmitted to devices along the canals.

The MRGCD telemetry network consists exclusively of IC Tech RTU's. Several different types of these units are used, depending on the application. The simplest units contain only a modem and radio, and transmit collected and processed weather station data from Campbell Scientific CR10X dataloggers.

The majority of the RTU's contain a modem, radio, and an input/output (I/O) board packaged into a single unit. Sensors can be connected directly to these and read remotely over the radio link. A variety of analog (4-20ma, 0-20ma, 0-5v) and digital (SDI-12, RS-485) output devices can be accommodated this way. Another type includes a programmable (RP-52 BASIC) controller. This type is used for all automatic control sites and places where unusual processing of sensor outputs such as averaging values, combining values, or timed functions, are required. At the present time, the MRGCD telemetry network gathers data from 75 stream flow gages and 18 ag-met stations, and controls 50 automated gates (Figure 7).

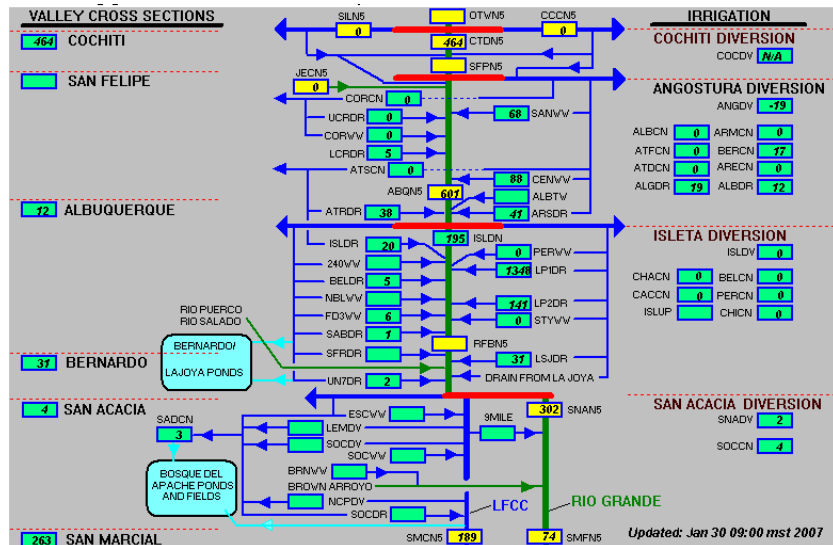


Figure 7. MRGCD Telemetry Network

**Control Software**

Measurement, automation, and telemetry components were developed simultaneously, but largely independent of one another. While each component functioned as expected, components did not exist as a harmonious whole, or what could truly be called a SCADA system. The missing component was software to tie all the processes together. There are a variety of commercially available software packages for such use and the MRGCD experimented with several. Ultimately, the MRGCD chose to purchase the commercial software package Vsystem and to employ the vendor Vista Controls to develop new features specific to the control of a canal network. Installation and setup was done by the MRGCD.

This system, known affectionately as the Supervisory Hydro-data Acquisition and Handling System (SHAHS, named after Mr. S.K. Shah), gathers data from RTU's on a regular basis. With the capability to define both timed and event driven poll routines, and

specify a virtually unlimited number of RTU's and MODBUS registers to collect, virtually any piece of information can be collected at any desired time. The Vsystem software can process data through a myriad of mathematical functions, and combine outputs from multiple stations. Vsystem also incorporates the ability to permanently store data in its own internal database, Microsoft® Structured Query Language (SQL) databases, or export data in other formats. Data can be displayed in a user-created graphical user interface (GUI) which MRGCD water operations personnel use to monitor water movement. The screens can also execute scripts to generate data, control parameters, control gate set points, and monitor alarm conditions for automated control structures. Finally, the GUI's can be used to control automated structures by transmitting new parameters, setpoints, and flowrates. With the simultaneous development of the MRGCD DSS and SCADA system, the possibility to implement scheduled water delivery based on crop demand could be realized.

### Linking DSS and SCADA

The first step was incorporating the DSS into the MRGCD SCADA System. This involved converting the DSS output into a data stream format that was compatible with the MRGCD Vsystem software. The DSS gives MRGCD operators a required irrigation delivery on a lateral level based on crop demand, as well as the timing of that irrigation. The required delivery and timing is imported into the graphical user interface (GUI) of the MRGCD SCADA system daily, so that actual deliveries along the canal system can be compared to the required deliveries. The GUI allows water managers to remotely change automated gate settings so that actual diversions closely represent water requirements. This provides better water management within the MRGCD and allows for a minimized river diversion as the required and actual diversion values converge. Figure 8 displays the MRGCD SCADA screen with actual deliveries and DSS recommendations.

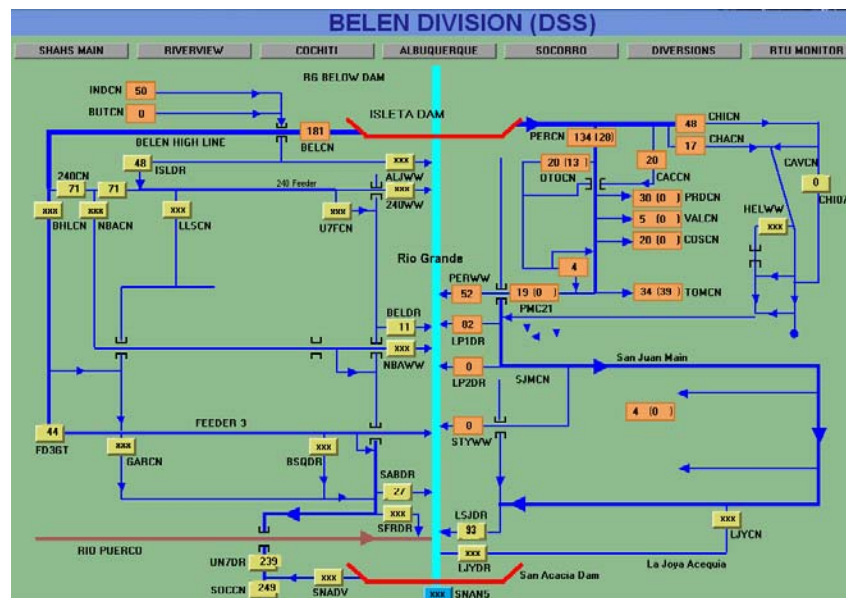


Figure 8. MRGCD SCADA Screen with Actual Deliveries and DSS Recommendations

**IMPLEMENTATON OF DSS**

The third and final component of achieving scheduled water delivery in the MRGCD was an in depth public outreach campaign. The adoption and acceptance of scheduled water delivery by the MRGCD and its water users is closely tied to understanding the principles and the benefits that this more intensive management provides. Public outreach is a timely and effective strategy for disseminating information and a necessity if water users are to accept the policy of scheduled water delivery. The program was designed to provide education and information to MRGCD water users. The information included the need to practice scheduled water delivery, that schedules are based on crop water requirements, how it will be implemented, and that it leads to fair and efficient water distribution for all concerned. Additionally, a major goal of the public outreach program was to get feedback and comments from water users and address concerns that they might have with scheduled water delivery.

There were two broad categories of information that needed to be conveyed and discussed with the MRGCD water users. The first was information related to the science, policy, and practice of scheduled water delivery as compared to the historic practice of continuous canal water delivery. The second category was the explanation of the tools, such as the DSS and SCADA, available to the MRGCD to effectively facilitate and implement scheduled water delivery.

The first step in public outreach was providing information on scheduled water delivery and the associated technology on the MRGCD website. The information provided explains the DSS and the practice of scheduled water delivery under a section of the MRGCD website that is devoted solely to the DSS and water scheduling. Figure 9 displays the links on the MRGCD homepage [www.mrgcd.com](http://www.mrgcd.com) and an article about the DSS.

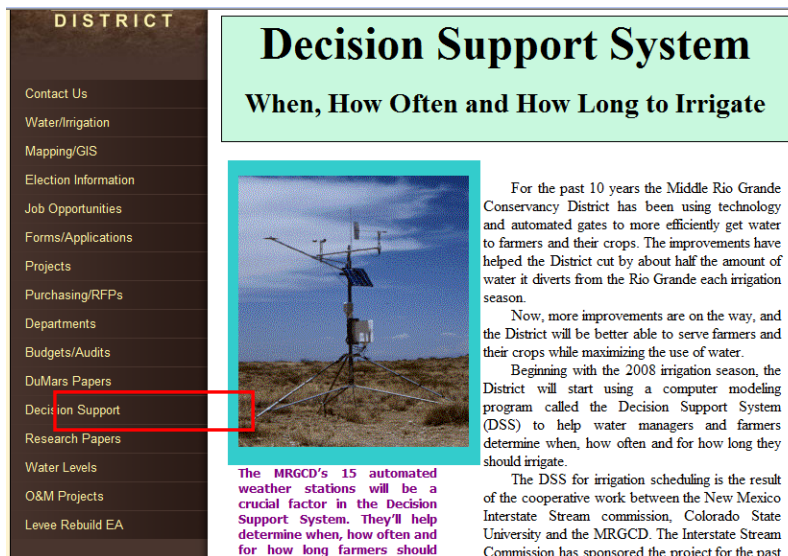


Figure 9. Article Explaining DSS on MRGCD Website

The second step of the public outreach program was including an article about scheduled water delivery in the MRGCD newsletter that gets delivered every two months. The article in the newsletter was entitled, "Computer Irrigation Scheduling Software to Remove Guesswork for Irrigators," and was delivered to over 50,000 water users, property owners, and other stakeholders in the Middle Rio Grande Valley. The article was also posted on the MRGCD website and linked to the Decision Support Section of the website. Developments regarding scheduled water delivery are periodically inserted into the newsletter to inform farmers about any changes or progress.

The third and key component of the public outreach program has been to conduct outreach meetings with water users throughout the MRGCD. Large scale public outreach meetings have been held in the Belen, Socorro, and Albuquerque Divisions. Small scale neighborhood meetings were held in the more urban sections of the Albuquerque North and South Valley to deal with the higher population density. These meetings were advertised in the MRGCD newsletter and personal invitations were sent to water users resulting in excellent turnout. Smaller meetings and presentations have also been held at the Los Poblanos Irrigation Workshop, and throughout the Belen Division. Meetings with over 100 individual farmers have also been held to clarify scheduled water delivery, the DSS, and to address concerns. These meetings provided a productive venue to educate farmers about scheduled water delivery, modernization efforts, and the DSS. The meetings also provided the opportunity to inform water users about future plans in the MRGCD. Additionally, water users were able to ask questions, voice concerns, offer valuable suggestions, and provide information critical to successfully implementing scheduled water delivery. One unexpected benefit of the outreach meetings has been that reporters have been present at several of the meetings which resulted in newspaper articles published in the Albuquerque Journal and the Valencia County News Bulletin. Three total articles have been published describing scheduled water delivery, its benefits, and the technology being used to implement scheduling.

The fourth aspect of the public outreach campaign has been to gain the support of the MRGCD Board of Directors and CEO. Presentations of scheduled water delivery and the DSS have been made to the MRGCD Board and CEO on four occasions and have been received well. The MRGCD Board understands the need for scheduled water delivery and supported the use of the DSS to develop water delivery schedules beginning in 2008. At a recent meeting the board re-emphasized their complete support of scheduled water delivery practice utilizing the DSS as an advisory tool. In tandem, the MRGCD water policy has been placed on the website in order to clarify any confusion. The policy states that water for irrigation must be scheduled with the ditch-rider and that rotational scheduling will be implemented during times of water shortage. Such political support has been invaluable in gaining water user acceptance of scheduled water delivery.

The fifth main aspect of implementing scheduled water delivery and the DSS has been the training of ditch-riders and water management personnel. For the DSS to be accepted by the MRGCD, it was necessary to have the water operations personnel running the DSS and creating water delivery schedules. The training of the ditch-riders consisted of education in regards to the scientific principles used in the DSS, a tutorial on how to

develop schedules with the DSS, and training on the use of soil moisture sensors. For the 2009 irrigation season ditch-riders were given portable Aquaterr™ soil moisture meters to ensure that water delivery schedules were not adversely affecting crop growth in their service areas.

The five steps of the public outreach campaign have resulted in positive progress towards district wide scheduled water delivery. First, MRGCD water users can easily access information about relevant issues such as irrigation water delivery and scheduling of their water supply. The public outreach program also provided a much needed opportunity for water users and managers to meet and discuss issues related to an extremely precious resource – irrigation water. Before this program, there was no structured process whereby the water users could meet as a group and discuss their concerns and questions with their water provider.

Second, the public outreach program has resulted in the limited implementation of the DSS. The DSS is currently being used to develop irrigation schedules in the form of a calendar which determines when certain lateral canals need to be running to meet crop demand. The area over which the implementation is occurring represents roughly 14% of the total irrigated acreage in the MRGCD. The calendars are allowing irrigators to plan their water use and provide for a more reliable water delivery method. Without calendars or scheduling, water deliveries were often unreliable and unpredictable. Creating schedules that address water deliveries in advance allows managers to adjust deliveries upstream accordingly.

Overall, scheduling has been successful in several aspects. The schedules have resulted in increased head in the irrigation ditches, increased reliability in water delivery, and efficiency improvements. From a management standpoint, the DSS has resulted in a much more organized protocol for delivering water by determining water delivery targets in advance, which allows managers to adjust deliveries upstream accordingly. Over time, scheduled water delivery and the MRGCD DSS will be used throughout the entire district.

## RESULTS

Using limited scheduled water delivery and infrastructural improvements, the MRGCD has been able to significantly reduce river diversions. Historically, the MRGCD diverted as much as 600,000 AF/year from the Rio Grande. Over the last 3 years, their diversions have averaged less than 350,000 AF/year. This is a significant accomplishment as the MRGCD has been able to reduce diversion to meet fish and wildlife concerns, while still providing the needed water to irrigators. Figure 10 displays the decreasing trend in total MRGCD river diversions. Currently scheduling is only practiced in a few limited areas, leaving much room for efficiency improvement.



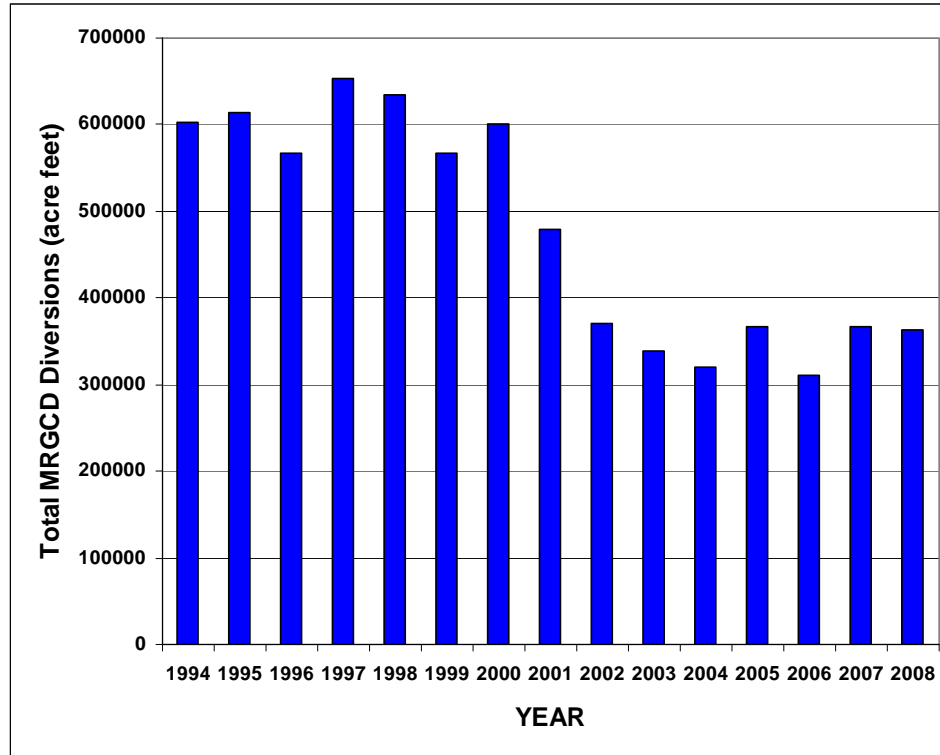


Figure 10. MRGCD River Diversions by Year

## CONCLUSIONS AND FURTHER RESEARCH

An integrated decision support system and SCADA system for the Middle Rio Grande Conservancy District has been developed that models the canal network and can compute water delivery options for optimum water delivery scheduling. The system additionally allows for local and automated controls which can be actuated at a central office. The linking of the MRGCD SCADA and the DSS provides operators with a required irrigation delivery on a lateral level based on crop demand as well as the timing of that irrigation. This provides better water management within the MRGCD and allows for a minimized river diversion as the required and actual diversion values converge. The system has also resulted in increased head in the irrigation ditches, increased reliability in water delivery, efficiency improvements, and improved protocol for anticipating future water demands. The public outreach campaign has been successful in educating water users on the principles of scheduled water delivery as well as providing much needed opportunities for water users and water managers to discuss water delivery issues.

Future plans for scheduled water delivery in the MRGCD include expanding the use of the DSS and scheduled water delivery. Plans also include further modernization efforts and continued public outreach and training programs to facilitate scheduled water delivery. Through expanded implementation of scheduled water delivery and the DSS the MRGCD will further reduce river diversions, while continuing to sustain irrigated agriculture in the Middle Rio Grande Valley.



**ACKNOWLEDGEMENTS**

The authors would like to thank Subhas Shah, the MRGCD Board of Directors, the staff of the MRGCD, the New Mexico Interstate Stream Commission, the New Mexico Office of the State Engineer, the Middle Rio Grande Endangered Species Act Collaborative Program, the National Science Foundation, the United States Army Corp of Engineers, and the United States Bureau of Reclamation. Also, the exceptional support of Jim Conley at IC Tech, Gerald Robinson and Lee Allen at Aqua Systems 2000, and Cathy Laughlin, Virginia King, and Peter Clout of Vista Control Systems is graciously recognized.

**REFERENCES**

- Aqua Systems 2000 Inc (2006). [www.aquasystems2000.com](http://www.aquasystems2000.com) Accessed 2/28/2006
- Barta, R. 2003. Improving Irrigation System Performance in the Middle Rio Grande Conservancy District. Masters Thesis. Department of Civil Engineering, Colorado State University. Fort Collins, Colorado
- DuMars, C.T. and S.C. Nunn (eds.). 1993. Working Document: Middle Rio Grande Conservancy District Water Policies Plan. Middle Rio Grande Conservancy District. Albuquerque, New Mexico.
- Gensler, D. Oad, R. and Kinzli, K. (2009). "Irrigation System Modernization: A Case Study of the Middle Rio Grande Valley." ASCE Journal of Irrigation and Drainage. 135(2): 169-176
- King, J.P., A.S. Bawazir, and T.W. Sammis. 2000. Evapotranspiration Crop Coefficients as a Function of Heat Units for Some Agricultural Crops in New Mexico. New Mexico Water Resources Research Institute. Technical Completion Report. Project No. 01-4-23955.
- New Mexico Interstate Stream Commission (NMISC); 2006 (authors Ramchand Oad, Luis Garcia, Dave Patterson and Kristoph-Dietrich Kinzli of Colorado State University, and Deborah Hathaway, Dagmar Llewellyn and Rick Young of S. S. Papadopoulos & Assoc.); *Water Management Decision-Support System for Irrigation in the Middle Rio Grande Conservancy District*; March, 2006.
- Oad, R. Garcia, L. Kinzli, K, Patterson, D and N. Shafike. (2009). "Decision Support Systems for Efficient Irrigation in the Middle Rio Grande Valley." ASCE Journal of Irrigation and Drainage. 135(2): 177-185
- Oad, Ramchand and R. Kullman (2006). Managing Irrigated Agriculture for Better River Ecosystems—A Case study of the Middle Rio Grande. Journal of Irrigation and Drainage Engineering, Vol. 132, No. 6: 579-586. American Society of Civil Engineers, Reston, VA.

Oad, R. Garcia, L. Kinzli, K-D. Patterson, D. (2006) Decision Support Systems for Efficient Irrigated Agriculture. (2006). Sustainable Irrigation Management, Technologies and Policies. WIT Transactions on Ecology and Environment. Wessex Institute of Technology, Southampton UK.

Oad, Ramchand and K. Kinzli (2006). SCADA Employed in Middle Rio Grande Valley to Help Deliver Water Efficiently. Colorado Water – Newsletter of the Water Center of Colorado State University. April 2006,

Rio Grande Compact Commission. 1997. Report of the Rio Grande Compact Commission, 1997

Shah, S.K. 2001. The Middle Rio Grande Conservancy District. Water, Watersheds, and Land use in New Mexico: Impacts of Population Growth on Natural Resources, New Mexico Bureau of Mines and Mineral Resources. Socorro, New Mexico. 123-125.

United States Fish and Wildlife Service (USFWS). 2003. Federal Register 50 CFR Part 17. Endangered and Threatened Wildlife and Plants; Designation of Critical Habitat for the Rio Grande Silvery Minnow; Final Rule. Vol. 68, No. 33. U.S. Department of Interior.

United States Department of Agriculture (USDA). 1967. Irrigation Water Requirements. Technical Release No. 21.

U.S. Department of Interior (2003). Water 2025: Preventing Crisis and Conflict in the West. U.S Bureau of Reclamation.