DECISION-SUPPORT SYSTEMS FOR EFFICIENT IRRIGATION IN THE MIDDLE RIO GRANDE

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ABSTRACT

Water is the lifeblood of the American West and the foundation of its economy, but it remains its scarcest resource. The explosive population growth in Western United States, the emerging additional need for water for environmental uses, and the national importance of the domestic food production are driving major conflicts between these competing water uses. Irrigated agriculture in particular is by far the largest water user of diverted water – 80% country wide and 90% in the Western U.S – and since it is perceived to be comparatively inefficient user, it is frequently asked to decrease its water consumption (Oad and Kullman, 2006). The case of the Middle Rio Grande illustrates the problem very well. The river is the ecological backbone of the Chihuahuan Desert region in the western United States, and supports its dynamic and diverse ecology, including the fish and wildlife habitat. The Rio Grande Silvery Minnow is federally listed as endangered species, and the irrigated agriculture in the Middle Rio Grande has come under increasing pressure to reduce its water consumption while maintaining the desired level of service to its water users. This paper will present our on-going research on options to make irrigation system operations more efficient in the Middle Rio Grande Conservancy District. Specifically, it will describe formulation and implementation of a Decision-Support System (DSS) that can assist the MRGCD managers to more efficiently plan and implement their water delivery operations, thereby reducing river diversions. Since year 2000, MRGCD has been modernizing their physical water delivery network, and the DSS will be used in tandem with SCADA software in making water delivery decisions based on real-time knowledge of available water supplies and crop water requirements. In irrigation systems, the conceptual problem addressed by the DSS is how best to route water supply in a main canal to its laterals so that the required water diversion is minimized. The MRGCD DSS uses linear programming to find an optimum water delivery schedule for canal service areas in the MRGCD irrigation system. For the past three years, the model has been validated in the field and the evaluation indicates that the model recommendations are realistic and represent ditch-rider practices.

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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 20-38 cm 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 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 to decrease diversions. Due to wildlife concerns and demands from an ever 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 in the Middle Rio Grande irrigation system through the use of a decision support system.

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 MRG Valley is displayed in Figure 1.

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; the bosque being 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 22 cm 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). Water demand in the MRG Valley includes irrigated agriculture in the Middle Rio Grande Conservancy District (MRGCD) Indian Lands, and municipal and industrial consumption. In addition to these demands, there are significant consumptive uses associated with the riparian vegetation, reservoir evaporation, and the 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).

Figure 1. Middle Rio Grande Valley (Barta, 2003)

<u>Middle Rio Grande Conservancy District.</u> 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 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 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.

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.

Decision Support Modelling of Irrigation Systems

The New Mexico Interstate Stream Commission 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, 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.

The conceptual problem addressed by a DSS for an irrigation system, then, 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: When is water supply needed to meet crop demand (Irrigation Timing), How long is the water supply needed during an irrigation event (Irrigation Duration), and How often must irrigation events occur for 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). The research presented in this paper has focused on developing, calibrating, validating and eventually implementing a decision support system capable of modeling flow on a canal and lateral level, with the overall goal of efficient irrigation water delivery.

FORMULATION OF DECISION SUPPORT SYSTEM FOR THE MIDDLE RIO GRANDE

The DSS was formulated using linear programming with the use of an objective function. Overall model structure consists of three modules that function in concert to calculate the most efficient irrigation water delivery.

Model Programming

Programming in the model was developed using an objective function to schedule water deliveries to lateral service areas. Constraints on variables within the objective function are specified and must be satisfied in determining the optimum solution. This process achieves the result that water delivery to laterals with more immediate water needs is favored, and delivery to laterals that have sufficient water in a given time step is minimized.

$$\text{Minimize } Z = MP_{D-0}\, X_{D-0} + MP_{D-1}\, X_{D-1} + MP_{D-2}\, X_{D-2} + MP_{D-3}\, X_{D-3}$$

where Z is the sum of a modified priority (MP) multiplied by amount of supply (X) from the dummy supply to each demand node. The subscripts refer to the nodal points between which flow occurs, i.e., X_{D-1} refers to flow from the Dummy supply to Check 1, and MP_{D-1} refers to the modified priority of demand to be satisfied at Check 1 from the Dummy supply node. The MP value reflects the need-based ranking system where demand nodes with lower available soil moisture are favored for irrigation. The objective function is solved in conjunction with a system of mass balance equations representing the actual water (and dummy water) delivered to demand nodes, along with other physically-based constraints. Figure 2 displays a schematic representing the model programming.

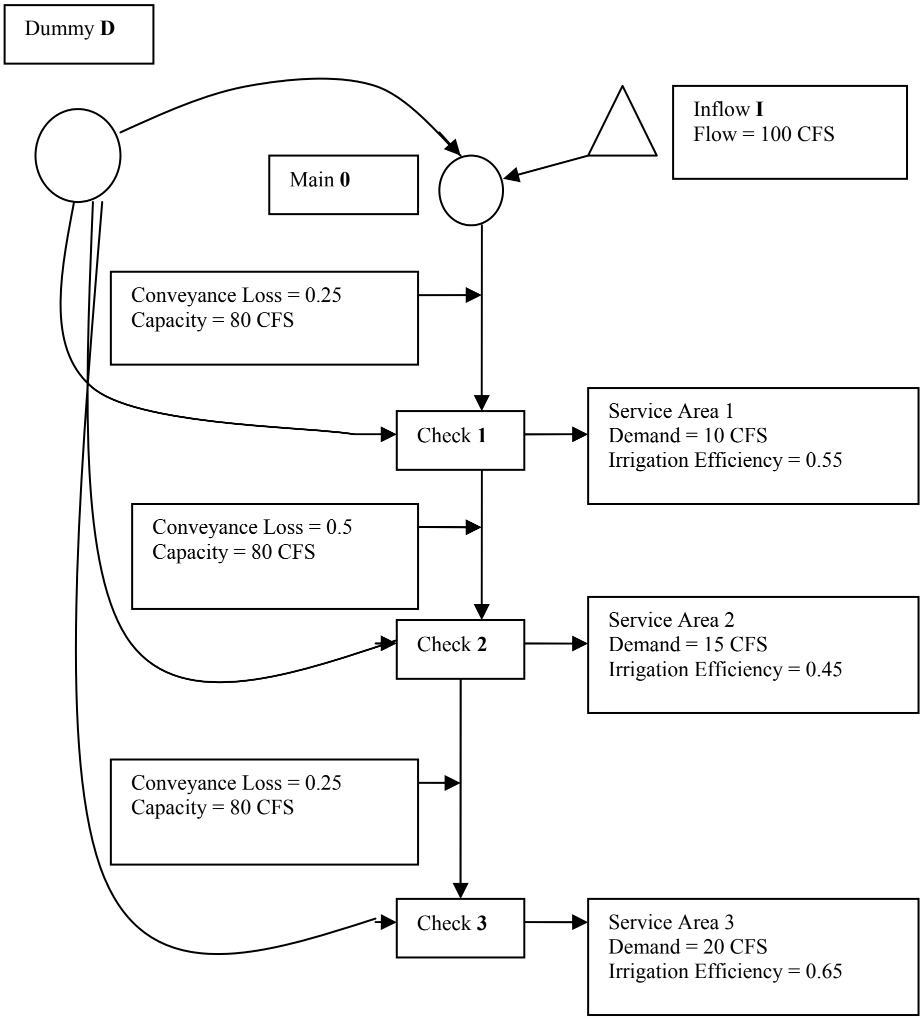

Figure 2. Schematic of Model Programming

Model Structure

The DSS consists of three elements; 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 constitutes a framework for the DSS that provides the user with the ability to access data and output for the system. The three DSS model components are termed modules. 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 this DSS version. Figure 3 displays the structure of the MRGCD DSS.

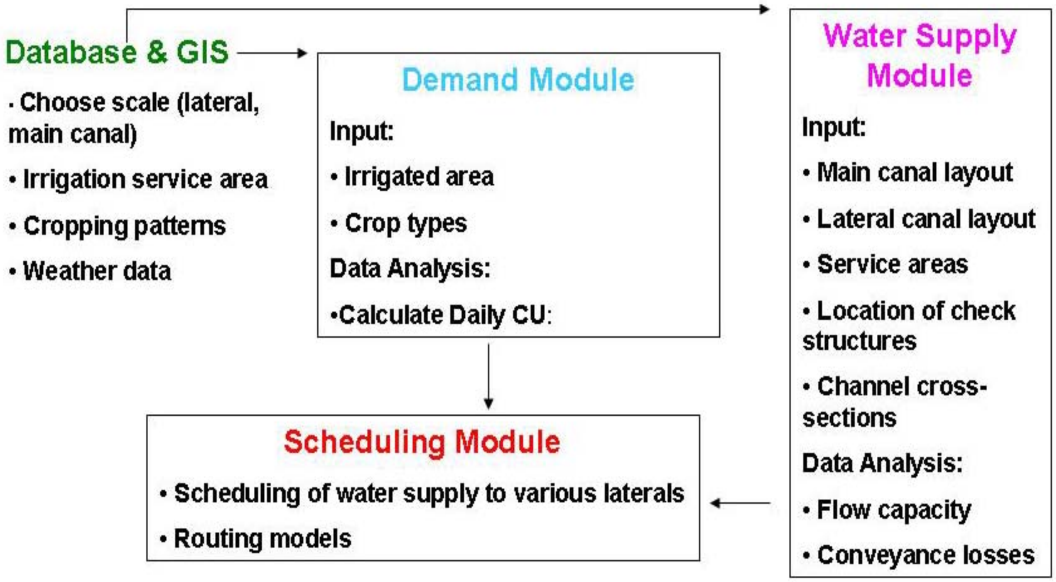

Figure 3. Model Structure Displaying the Three Modules

Water Demand Module. The water demand module of the MRGCD DSS is implemented through the Integrated Decision Support Consumptive Use, or IDSCU model, a model developed over a period of years at the Colorado State University. The IDSCU model consists of a Graphical User Interface (GUI) written in Visual C++ and program calculations implemented with FORTRAN. The IDSCU model offers numerous features and options and calculates the following: crop consumptive use (CU), crop irrigation requirement (CIR), and readily available moisture (RAM) as a capacity. The latter two variables, CIR and RAM, are subsequently used in the supply network module. Crop consumptive use is calculated using the Penman-Montieth Method. The reference ET is calculated using weather data from the MRGCD. Crop coefficients using growing degree days are applied to the Penman-based ET 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).

Based on acreages, crop types and soil types within each lateral service area, a 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 is 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.

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 the 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.

MODEL FIELD TESTING AND IMPLEMENTATION

A research collaboration between the MRGCD, the New Mexico Interstate Stream Commission and Colorado State University has supported the DSS project since 2004. During this time, calibration and field testing have been conducted to improve the performance of the DSS.

Field Data Collection and Calibration

Data files were initially developed for each main canal and its laterals by collecting the following information: cropped acreage, crop type, and soil type by lateral service area. The water holding capacity of the soil in each lateral service area was determined using GIS and SSURGO soil maps. System infrastructure data were also collected to insure accurate representation of the distribution network. Canal capacity measurements were made to represent actual canal carrying capacities in the DSS. To calibrate the model, a sensitivity analysis was performed on the main input variables. Sensitivity analysis consisted of varying one single variable while keeping all other variables constant. Using the sensitivity analysis the model input parameters were calibrated.

Field Testing

To test the model prediction capability, the model was run in operational mode using 2006 water supply, weather, and crop area data. The readily available moisture (RAM) at the beginning of the season was set at zero. The RAM at the start of a delivery schedule was also set to zero in order to utilize the entire available soil moisture. The irrigation efficiency and the return flow percentage were both set at 50%, based on the results of previous sensitivity analysis and our review of the literature. The irrigation schedule recommended by the DSS model for 2006 was compared to the actual water delivery practice of ditch-riders in 2006. The irrigation duration, irrigation frequency (time between irrigations) and irrigation flowrate during an irrigation season from the model were compared to data collected in the field over a period of three years. The field data obtained from ditch-riders consists of mean irrigation duration, mean irrigation frequency, and mean irrigation flowrate. Figures 4, 5, and 6 display the comparison of irrigation duration, irrigation frequency and irrigation flowrate for the 2006 irrigation season respectively. Table 1 displays the comparison between the DSS and actual practice for mean irrigation duration, mean irrigation frequency and mean irrigation flowrate.

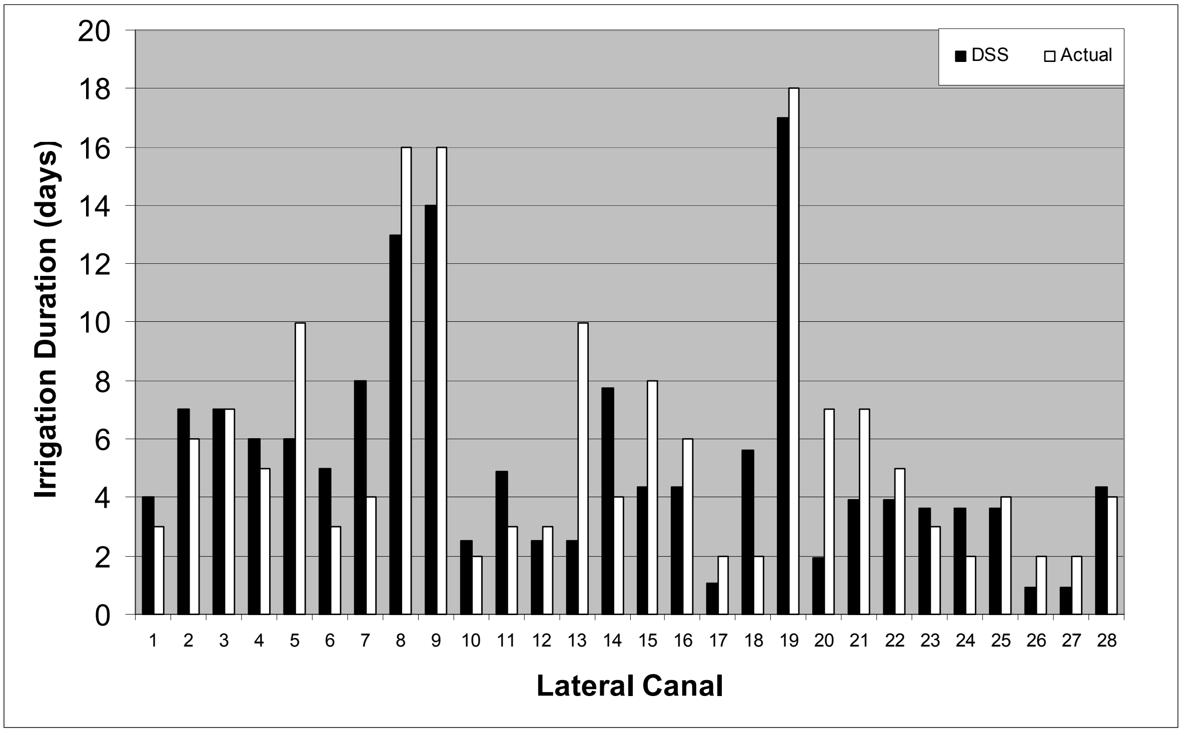

Figure 4. DSS Irrigation Duration compared to Actual Irrigation Duration for 28 Laterals in 2006

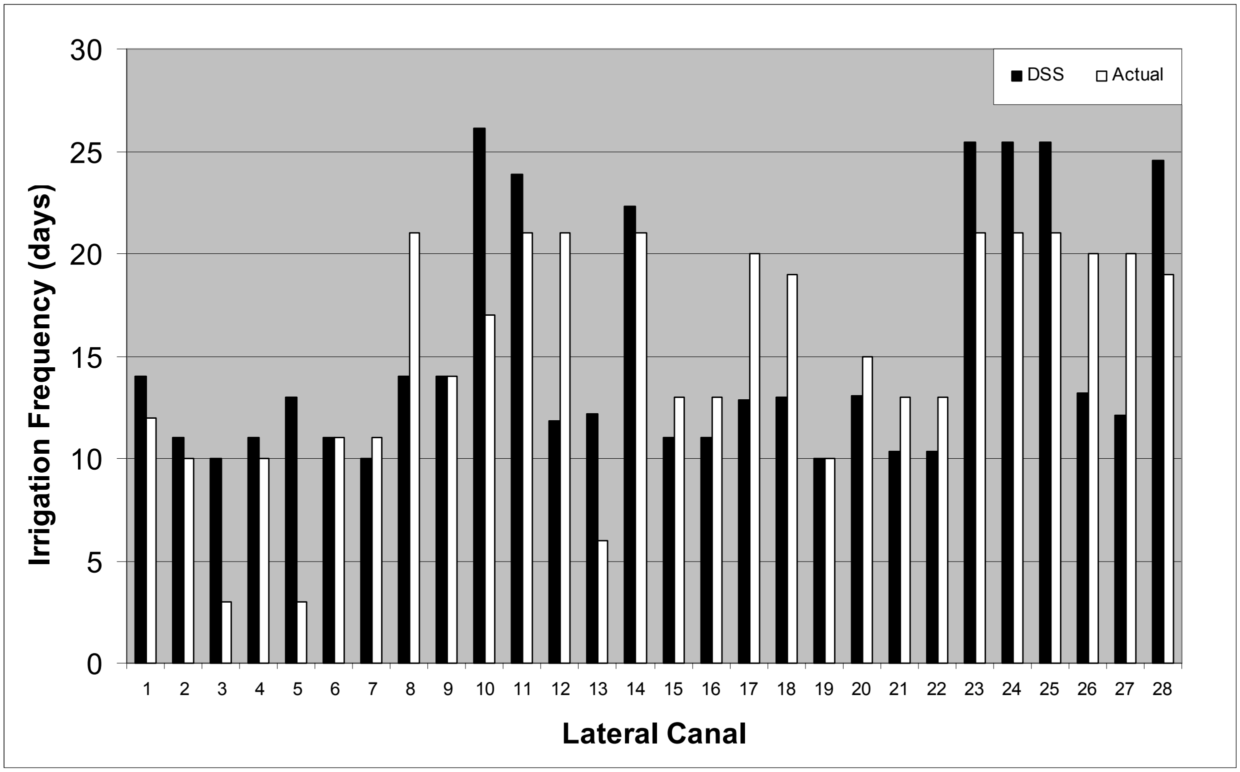

Figure 5. DSS Irrigation Frequency compared to Actual Irrigation Frequency for 28 Laterals in 2006

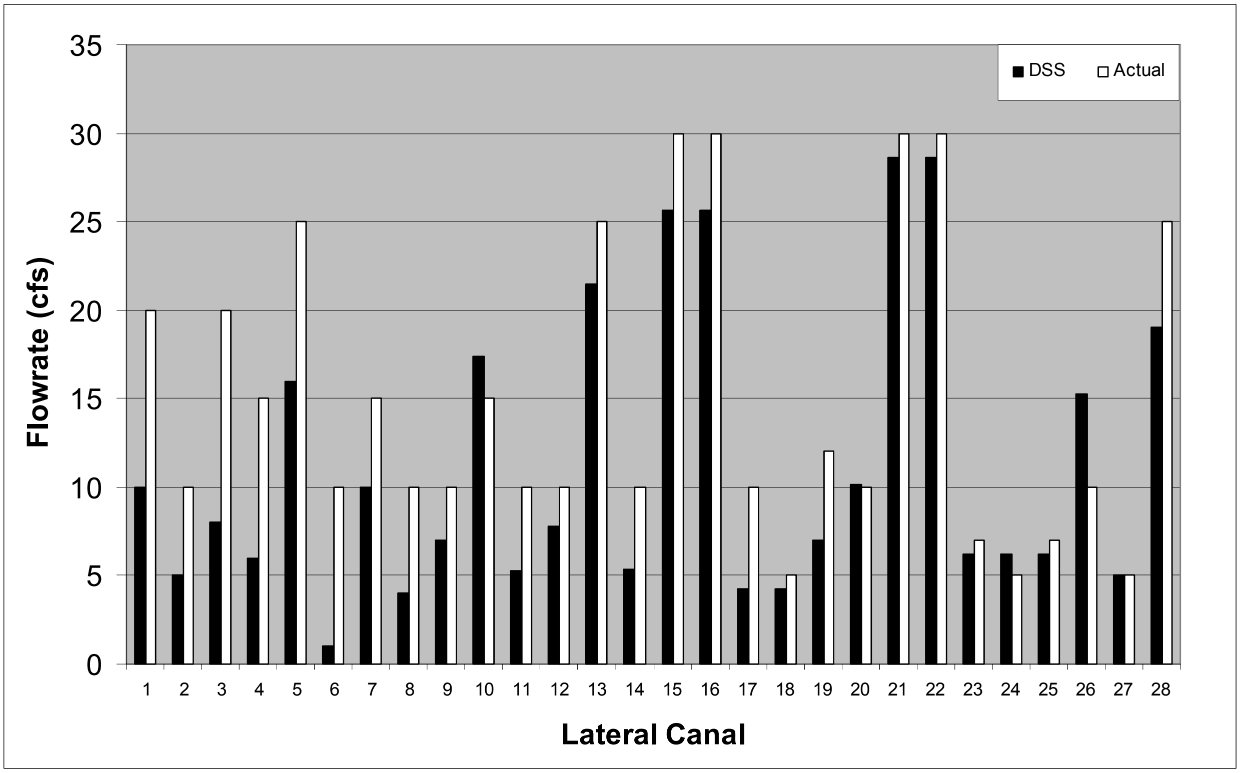

Figure 6. DSS Flowrate compared to Actual Flowrate for 28 Laterals in 2006

Table 1. Comparison between the DSS and Actual Practice for Mean Irrigation Duration, Mean Irrigation Frequency and Mean Irrigation Flowrate.

Irrigation Duration (days)

Year	Mean DSS Recommendation	Mean Ditch-rider Practice	Difference
2004 (2 Laterals)	4.41	3.50	-0.91
2005 (2 Laterals)	2.85	3.10	0.26
2006 (28 Laterals)	5.34	5.86	0.52

Irrigation Frequency (days)

Year	Mean DSS Recommendation	Mean Ditch-rider Practice	Difference
2004 (2 Laterals)	13.85	16.00	2.15
2005 (2 Laterals)	15.13	16.00	0.88
2006 (28 Laterals)	15.07	14.96	-0.10

Irrigation Flowrate (cfs)

Year	Mean DSS Recommendation	Mean Ditch-rider Practice	Difference
2004 (2 Laterals)	6.49	9.00	2.52
2005 (2 Laterals)	5.89	9.50	3.62
2006 (28 Laterals)	11.30	15.04	3.73

Irrigation duration comparison results are acceptable for most laterals but large discrepancies exist between the model and the actual practice on a significant number of laterals. This could be due to several reasons. First, the information obtained through the ditch-rider interviews is quite subjective and might not reflect the actual irrigation practice. Second, the irrigation practice used by ditch-riders could be inappropriate which is indicated by the irrigation durations being either too short or too long. The fact that the 2006 irrigation season was the first time several ditch-riders practiced scheduled water delivery could explain the difference between the optimal duration represented by the DSS and the actual duration used in practice. Ditch-riders currently do not have soil moisture probes that can be used to indicate the need for irrigation and their schedules are often arbitrary. The laterals with significant discrepancies warrant further investigation to determine if the model recommendations are reasonable or if the ditch-riders' practices need change.

DSS Model values for irrigation frequency were slightly longer than the values obtained from the ditch rider practice, and large discrepancies exist between the model and the actual practice on a significant number of laterals. The reason for this could be that in actual practice, irrigation events occur before the soil moisture (RAM) is significantly depleted. Field observations during the 2005-06 irrigation seasons show that alfalfa fields were irrigated every ten days, which is excessive and would account for the shorter irrigation frequency recorded from the field data.

Irrigation frequencies that are longer than the DSS recommendation indicate that the crops are possibly being stressed.

The actual flow rate proved to be significantly larger than the model recommendations. This is due to the fact that gauges do not exist on most canals and the flow rate given by the ditch-riders is at best an estimate. In the future, staff gages need to be installed on canals in order to develop stage-discharge relationships, or automated gates with flow meters need to replace aging lateral turnout structures.

When comparing the irrigation duration, frequency, and the required irrigation flowrate the results from the model compare well with the field data. Overall, the scheduled water delivery developed by the DSS is reasonable within the limits set forth by the MRGCD.

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 acre feet per year from the Rio Grande. Over the last 3 years, their diversions have averaged less than 350,000 acre feet per year. Figure 7 displays the decreasing trend in total MRGCD river diversions. Current schedules are not based on crop demand and rotation is only practiced in a few limited areas, leaving much room for efficiency improvement.

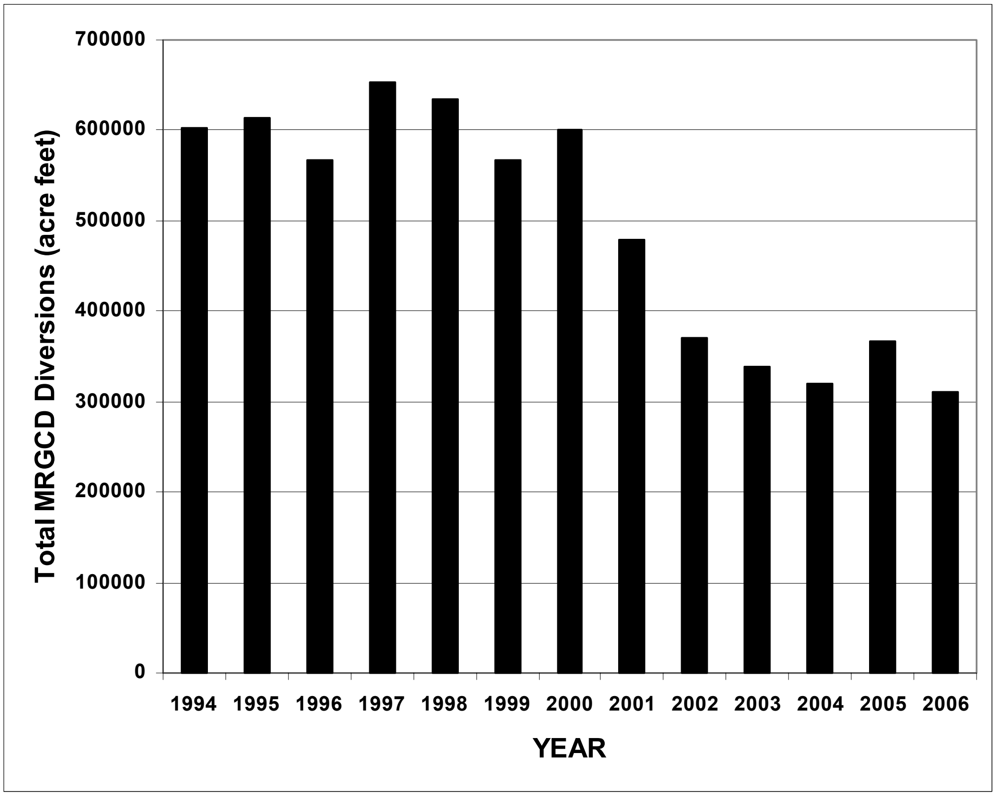

Figure 7. MRGCD River Diversions by Year

Implementation

The DSS will be implemented by being incorporated into the MRGCD Supervisory Control and Data Acquisition (SCADA) System. The DSS will give 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 will be imported into the graphical user interface (GUI) of the MRGCD SCADA system so that actual deliveries along the canal system can be compared to the required deliveries. The GUI will allow water managers to remotely change automated gate settings so that actual diversions closely represent water requirements. This will provide better water management within the MRGCD and allow for a minimized river diversion as the required and actual diversion values converge.

CONCLUSIONS AND FURTHER RESEARCH

A decision support 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 use. Using three modules, the model represents water demands, the irrigation network, and water scheduling aspects of irrigation. The model is fully capable of developing schedules for water delivery in the MRGCD and evaluation has shown that model recommendations are realistic and adequately represent ditch-rider practice.

Future work on the DSS will entail an in depth field investigation of model adequacy using soil moisture sensors and eventually the full implementation of the model. Model adequacy will be tested by closely monitoring fluctuations in RAM during a period where the schedule from the model is used exclusively. By determining whether the model effectively manages the moisture in the root zone, revisions and improvements to the model can be made. Once the field investigations are complete, the finalized model can be implemented for scheduling water deliveries throughout the entire MRGCD. Implementation will focus on incorporating the DSS into the already existing MRGCD SCADA system. By implementing the DSS for scheduling the MRCGD will further reduce river diversions and can continue to sustain irrigated agriculture in the Middle Rio Grande Valley.

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REFERENCES

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.

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. Papadopulos & Assoc.); *Water Management Decision-Support System for Irrigation in the Middle Rio Grande Conservancy District*; March, 2006.

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.

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.