New Mexico Interstate Stream Commission
FY 2003 Project Report

Water Management Decision-Support System for Middle Rio Grande Irrigation

Acknowledgements

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TABLE OF CONTENTS

List of Figures

List of Tables

List of Appendices

1.0 INTRODUCTION

This project, conducted under FY-2003 funding from the Middle Rio Grande Endangered Species Act Collaborative Program and the New Mexico Interstate Stream Commission (NMISC), develops datasets and models to support the implementation of scheduled, rotational water delivery to irrigators within the Middle Rio Grande Conservancy District (MRGCD). This work builds on MRGCD's efforts in the past several years to improve its system operations and management of its water supply. The goal of this project is to develop information and tools that will support improvements in irrigation system operations, including efficient water delivery to irrigators, while potentially facilitating the maintenance of river flows in environmentally sensitive reaches. Key elements of the work include:

- Training workshops to familiarize MRGCD management and division-level staff with the fundamentals of rotational water delivery,
- Compilation of existing data and collection of field data describing the system infrastructure and operations in the Belen Division of the MRGCD, and
- Development of a decision support system (DSS) for the Belen Division to facilitate the effective implementation of scheduled, rotational water delivery.

This work was undertaken by Colorado State University under the direction of Dr. Ramchand Oad, with assistance Dr. Luis Garcia, Director of the Integrated Decision Support Center. Additional technical and field support has been provided by the NMISC and its contractor, S.S. Papadopulos & Associates, Inc. (SSPA).

1.1 Project Overview and Justification

The MRGCD manages an irrigation system along approximately 150 river miles of the Middle Rio Grande Valley in New Mexico, between Cochiti Dam and the northern boundary of the Bosque del Apache National Wildlife Refuge. This irrigation system is a prominent user of water in the Middle Rio Grande valley. The ESA Collaborative Program, through its Water Acquisition and Management Sub-Committee (WAMs), identified a need for

"studies or projects that would lead to water and water use and/or water management efficiencies within the existing system that would benefit the species of concern".

This project was developed to address the identified need for more efficient water use and management. This is being accomplished through the development of a decision-support system (DSS) to support improvements in system management and water delivery procedures. The DSS consists of informational databases and water demand, water supply and scheduling modules. The DSS is used to explore options for implementing rotational water delivery procedures.

For the FY 2003 project, data collection and model development efforts were focused on the Belen Division. A second year project has been initiated under FY 2004 funding from the ESA Collaborative Program and the NMISC to refine this work in the Belen Division and begin data collection toward extension of the model into the downstream Socorro Division. During the second year of the project, the Belen Division models developed in the first year of the project, as described in this report, will be field-checked, tested and refined.

1.2 Report Organization

Section 2 of this report provides background information on the study area, the structure and management of the MRGCD, and the basic concepts of rotational water delivery and decision support systems. Section 3 documents the project efforts directed towards training of MRGCD staff and institutional development of rotational water delivery concepts. Section 4 describes data collection and compilation efforts undertaken to support the DSS model development in the Belen Division, for example, physical data and operational information.

Section 5 describes the conceptual and computer models developed to capture processes related to irrigation demand, water supply, and scheduling for the Belen Division. The methodology used to implement the conceptual models into a suite of integrated model programs is described; and, results illustrating the application of the DSS to schedule rotational water delivery are presented. Section 6 provides conclusions drawn from the FY03 project; and describes the field methodology planned for model refinements during the 2005 irrigation season[1].

To maintain readability of the report, detailed technical material and supporting data are organized within several appendices. These appendices include field data and documentation,

[1] Under the FY 04 project, the Belen model will be refined using 2005 field data; this effort will improve the models functionality for simulating field conditions and optimizing irrigation water scheduling.

summaries of key data sets and data reduction procedures, model development details, and preliminary model results. In addition, a Compact Disk (CD) is attached and contains electronic data compilations and model files, including input and output files for a baseline case and two example model runs.

2.0 BACKGROUND INFORMATION

2.1 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 (Figure 2.1). The valley is narrow, with the majority of water use occurring within five miles on either side of the river. The *bosque*, or the riverside forest of cottonwood and salt cedar, is supported by waters of the Rio Grande. Surrounding the bosque, there is widespread irrigated farming. The City of Albuquerque 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 resource for communities in the region.

Figure 2.1 Upper and Middle Rio Grande Valley
Source: ACOE, modified by SSPA

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. The Compact sets forth a schedule of deliveries of native Rio Grande water from Colorado to New Mexico and from New Mexico to Texas.

Water demand in the MRG Valley includes irrigated agriculture in the MRGCD and Indian Pueblos, and municipal and industrial consumption. In addition to these demands, there are significant consumptive uses associated with riparian vegetation, and wetland, river, and reservoir evaporation. Superimposed on these demands are river flow targets associated with Federally-listed endangered species.

2.2 Middle Rio Grande Water Conservancy District (MRGCD)

The MRGCD was formed in 1925 in response to flooding and the deterioration of irrigation works. In 1950, MRGCD entered into a contract with the USBR to provide financial assistance and system rehabilitation (the Middle Rio Grande Project). System improvements occurred until 1975, when MRGCD resumed operation and maintenance of the system.

In 1930, the MRGCD filed two permits with the Office of the State Engineer – 0620 and 1690 – that allow for storage of water in El Vado Reservoir, release of the water to meet irrigation demand, and diversion from the Rio Grande to irrigate lands served by the MRGCD. Water diverted by the MRGCD originates as native flow of the Rio Grande and its tributaries, including the Rio Chama. The MRGCD also has a contracted right to about 20,900 acre-feet annually from the San Juan-Chama Project. MRGCD stores water in El Vado Reservoir, which has a present storage capacity of about 180,000 acre-feet.

2.2.1 Physical System

The MRGCD services irrigators from Cochiti Reservoir to the northern boundary of the Bosque del Apache National Wildlife Refuge (Figure 2.2). 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. The diversity of users includes: six Indian pueblos, large farm parcels, community ditch associations,

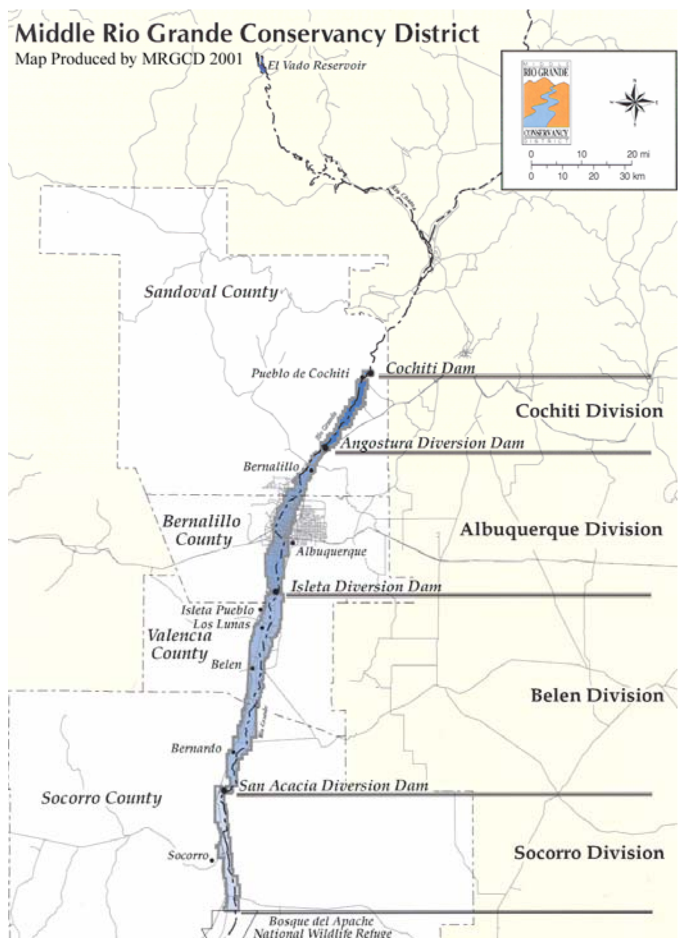

Figure 2.2 Middle Rio Grande Conservancy District

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. In addition to direct diversions at these weirs, all divisions except Cochiti receive return flow via drains from divisions upstream. Flow in drains includes intercepted seepage from the river, seepage from canals, deep percolation from applied irrigation water, and direct runoff. These flows are eventually diverted into a main canal for reuse in the MRGCD or are returned to the river. Although drains were originally constructed for purpose of collecting excess percolating water from agricultural lands to reduce water-logging problems, many now serve as interceptors of operational return flow and are used to convey interdivisional water supply.

The Cochiti Division largely serves Pueblo lands, managed by Pueblo and MRGCD ditch-riders. The Albuquerque Division services primarily small urban water users, but some large water users irrigate in the northern and southern boundaries of the division. The Belen Division is the largest division in terms of service area, and services both small and large irrigated parcels as well as Pueblo lands. The Socorro Division is the second largest in terms of service area and most of the water users cultivate large land parcels.

Water is conveyed in the MRGCD by gravity flow through primarily earthen ditches. Concrete-lined canals and pipe networks exist in few areas where bank stabilization and water seepage problems are prevalent. Water is delivered to users in a hierarchical manner: it is typically diverted from the river into a main canal, to secondary canal or lateral, and eventually into the farm ditch. After water is conveyed through laterals, it is delivered to the farm through a turnout structure, often with a check structure in the lateral canal. On-farm water management is entirely the responsibility of water users. The method of application is typically surface (flood) irrigation, either basin or furrow.

2.2.2 Organization and Water Delivery

The MRGCD delivers water to users through services and administration provided at a central office and four division offices. The central office in Albuquerque provides many administrative services, including management of service charges to water users. Each division office includes administrative, field maintenance and water operation services. A division manager and several ditch-riders manage water delivery operations in each of the four divisions. Ditch-riders are responsible for the distribution of water to users in a particular service area, and for coordination of water delivery with the ditchriders serving adjacent areas. The ditch-rider controls check structures and headgates, using local knowledge of the distribution system and irrigator needs to deliver water. Ditchriders evaluate water delivery and water use conditions through physical monitoring of canal and through communication with water users.

The MRGCD does not meter individual farm turnouts, rather, ditchriders estimate water delivery on the basis of time required for irrigation. Prior to the recent drought, to provide flexible and reliable water delivery to users on a continuous basis, MRGCD operated the main canals and laterals near full capacity, so water supply was always greater than perceived demand. This operational mode allowed water needs to be met on-demand, with few denials for water delivery requests, so users receive timely irrigations for crop needs. Operationally, this practice was more cost-effective because it required less management, planning, monitoring, and financial resources. During the recent drought years, the MRGCD has taken a proactive approach to improving its water delivery operations and its management of available water. Towards this end, the division managers and ditch-riders are increasingly practicing rotational water delivery, which is an effective way to fulfill demand with reduced available water.

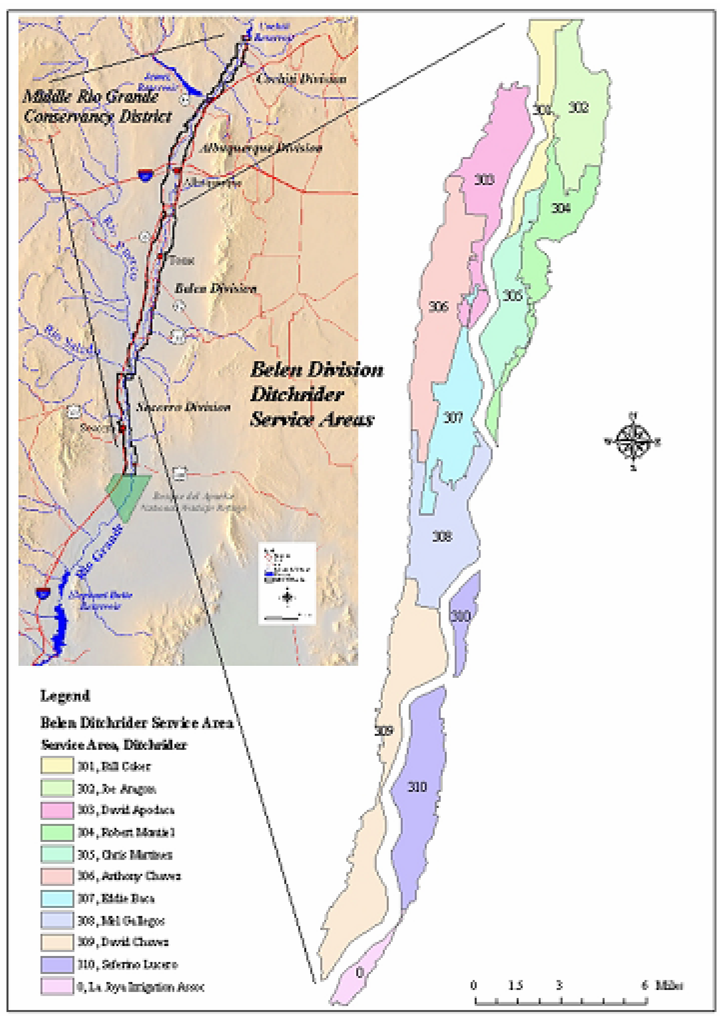

Figure 2.3 Belen Division Ditchrider Areas
Source: MRGCD, modified by SSPA

2.3 Study Area Description

At a broad level, the study area for this project includes the entire area served by the MRGCD. The FY-2003 phase of this project focused on the Belen Division, which is the largest division, in terms of service area, in the MRGCD. The Belen Division extends from the Isleta Dam south to the San Acacia Dam. The work conducted in this study relates to the non-Pueblo irrigated lands within the Belen Division served by the Peralta Main Canal, the Belen Highline Canal and the San Juan Feeder Canal. It consists of a complex network of water delivery canals that service large farm parcels, community ditches and acequias, and recently urbanized areas. For water delivery administration, the division is organized into ten ditch-rider service areas (Figure 2.3).

Water is diverted from the Isleta diversion structure on both the east and west sides of the river. Water on the west side of the river is diverted through the Belen Highline Canal, and water on the east side is diverted through the Peralta Main Canal and Chical Lateral, as well as two smaller ditches. The drainage and return flow from the Belen Division service area is captured and utilized for irrigation in the downstream Socorro Division. Water management in the Belen Division, therefore, impacts water availability in the Socorro Division.

2.4 Conceptual Description of Rotational Water Delivery

Rotational Water Delivery (RWD) is used in irrigation systems worldwide to improve water delivery and to support water conservation. In RWD, 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 rotation *among laterals*, there can be rotation *within laterals* whereby water use is distributed in turns among farm turnouts or check structures along a lateral. By distributing water among users in a systematic rotational fashion, an irrigation district can decrease water diversions and still meet crop water use requirements.

A schematic of a hypothetical rotational delivery schedule (Figure 2.4) illustrates rotation among laterals, and contrasts it with continuous water delivery. As Figure 2.4 shows, rotation among laterals is implemented by alternating points of water delivery to laterals on a regular basis. A well-managed program of rotational water delivery is able to fulfill seasonal crop water requirements in a timely manner, but requires less water than continuous water delivery.

In recent years, the MRGCD has taken a proactive approach to improving its water delivery operations and its management of available water. Towards this end, the division managers and ditch-riders are increasingly practicing rotational water delivery, which is an effective way to fulfill demand with reduced available water.

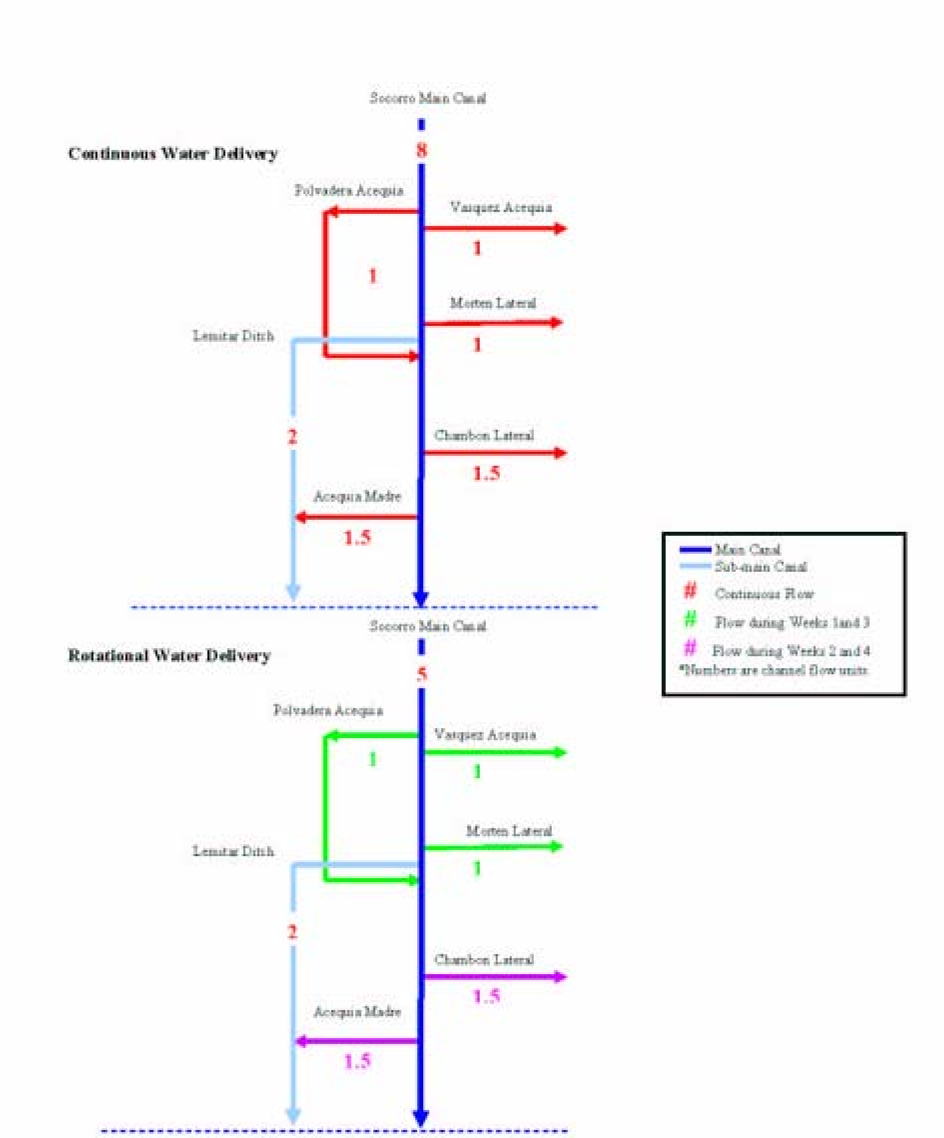

Figure 2.4 Conceptual Description of Rotational Water Delivery
Source: Barta 2003

2.5

Decision Support Modeling

In the current project, a Decision-Support System (DSS) has been formulated to model and assist implementation of rotational water delivery in the MRGCD's Belen Division. A DSS combines intellectual resources of individuals with capabilities of computers to improve the quality of decision-making. It 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 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 at 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.

A detailed description of the DSS model formulation and implementation in the Belen Division of the MRGCD is provided in Section 5 of this report.

3.0 MRGCD WORKSHOPS

The project scope of work included the task:

> "conduct training workshops to familiarize each division-level staff with the fundamentals of rotational water delivery and its implementation."

During the 2004 irrigation season, Dr. Ramchand Oad conducted two workshops with MRGCD staff. The MRGCD staff, both at the office and field level, have a central role in implementation of rotational water delivery. These workshops were therefore aimed at imparting to them a full understanding of the purpose, fundamentals, and related practical aspects of rotational water delivery. These interactions with MRGCD field staff also provided the project team with field information, which was used in the DSS model formulation, and a better understanding of the concerns of field staff concerning the implementation of RWD and DSS, which allowed the DSS to be formulated in a way that minimizes these concerns. As part of this project, Dr. Oad also gave a presentation to the Water Acquisition and Management Subcommittee (WAMs) of the ESA Collaborative program, describing the goals and methods of the project.

3.1 MRGCD Central Office Workshop

The first workshop was conducted at the central MRGCD office in Albuquerque, on May 19, 2004. It was attended by the district central office staff and the four division managers. Dr. Oad gave a presentation that included a brief history of the project work with MRGCD, leading to the recommendation of adopting rotational water delivery. He then presented fundamental concepts of rotational water delivery and provided examples of its implementation in irrigation systems around the world.

Following the presentation, participants discussed various aspects of rotational water delivery, and raised several practical concerns that they face while pursuing the implementation of rotational water delivery in the MRGCD. One recurring concern related to the presence of Pueblo lands and the effect of the variability of Pueblo water use on the availability of water for the downstream lands. The canal discharge downstream of the Pueblo lands on the Peralta Main Canal, for example, varies considerably as a result of water use in the Pueblo lands, and the ditch-riders have a difficult time planning water deliveries to users downstream.

Another commonly expressed concern was the complexity of the irrigation network and the resulting difficulty associated with determining the most effective routing of water. The drainage and return flows are especially difficult to predict and accommodate while planning for water delivery to users. Other expressed concerns included: accommodation of farmers who miss their irrigation turn; the large turnover of ditch-riders resulting in loss of experience; and the increased management cost associated with rotational water delivery.

3.2 Belen Division Workshop

The second workshop was held at the Belen Division office on June 2, 2004. It was attended by more than 50 people, including Belen division staff, all ditch-riders and several farmers. The Belen Division has a large service area, in which water delivery is managed by ten ditch-riders, two water masters and the division manager. There was discussion among these water managers of several aspects of rotational water delivery, and how best it can be implemented in MRGCD and more specifically in the Belen Division. The concerns expressed at the previous workshop, including the complexity of the system and the unpredictability of flows from the Pueblo lands, were further flushed out. In addition, concern was expressed that many ditch-riders in the division were new, and were in the process of becoming familiar with the network, the users and their demand patterns. Some more experienced ditch-riders mentioned that they already practice rotational delivery, especially in the water-short times. They also pointed out that water delivery and distribution in the Belen Division is made more complicated by the fact that presently, most water supply for the downstream Socorro Division is conveyed through the Belen Division.

Ditch-riders also mentioned that some rehabilitation of the network facilities will be necessary in order to implement RWD. Seepage losses in the canals, especially in the Belen Highline Canal, the need for better control at the check structures, and the potential benefits of consolidation of the turnouts were mentioned within this context.

3.3 WAM Subcommittee Presentation

On May 20, 2004, Dr. Oad presented an introduction to the project goals and methods to the WAM Subcommittee of the MRG ESA Collaborative Program. He presented an overview of the background studies that led to the recommendation of RWD for scheduling and managing water delivery within the MRGCD, the practice of RWD in other irrigation systems, and practical constraints. The discussion was directed at potential benefits of RWD, specifically its contribution to the objective of minimizing irrigation water diversions without adverse effect to irrigated lands.

The committee members were also interested in ways the ESA Collaborative Program could help the MRGCD successfully implement RWD. The committee members supported the development and use of decision-support models to help the MRGCD plan and manage its water delivery operations, and discussed in detail the potential formulation and application of these models. The committee members also suggested that the MRGCD provide more information to its water users related to its structural and operational improvements. The FY- 2004 project has provided funds for conducting “public outreach meetings”, with the purpose of improving communications between MRGCD and its water users.

4.0 DATA COLLECTION AND PROCESSING

Project data were collected between May and August of 2004 by CSU with assistance from the NMISC and SSPA. The objective was to collect field data and compile existing information about soils, crops, water delivery practices and related information that is needed in the development of the DSS model. Section 4.1 gives a brief overview of all data collected and Section 4.2 describes how the data were processed and analyzed for use in the DSS model.

4.1 <u>Data Collection</u>

4.1.1 GIS Coverages

GIS coverages were obtained from the MRGCD and other sources, and included the following information:

- Locations of all main and lateral canals within the district,
- Service area for each lateral;
- Service area for each ditchrider;
- Irrigated parcels within the division;
- Location of gages within the division;
- Location of roads within the division;
- Location of cities within the division;
- Location of the Rio Grande within the division;
- Division boundaries; and,
- Crop type and irrigated area, by parcel, for 2002 and 2003.

4.1.2 MRGCD Canal Profile Design Sheets

The MRGCD provided original plan and profile engineering design sheets of 27 irrigation canals and drains within the Belen Division. These plan and profile black-line drawings list the survey and plotting dates, the design discharge capacities, and the design channel slope. The information extracted from the original plan and profile sheets is provided in Appendix 4-A.

4.1.3 Valencia County Soil Mapping

Digitally formatted GIS coverage of the Valencia County soils were obtained from the National Resource Conservation Service (NRCS). The GIS coverages contain the following information:

- Soil type maps;

- Soil descriptions; and,
- Available water-holding capacities (AWC) for individual soil types.

4.1.4 Flow Data

Flow data for diversions and return flows, as well as key mid-division locations, were collected from the real-time MRGCD stream flow data website hosted by the USBR (http://www.usbr.gov/pmts/rivers/awards/Nm/rg/RioG/gage/schematic/SCHEMATICnorth.html and http://www.usbr.gov/pmts/rivers/awards/Nm/rg/RioG/gage/schematic/SCHEMATICsouth.html). (The schematics of the MRGCD Network with main diversions is shown in Appendix B). Provisional real-time stream flow data for 2003 and 2004 were downloaded from the website approximately once per week during the 2003 and 2004 irrigation seasons (March 1st through November 15th). A compilation of the downloaded data, for all of the MRGCD divisions, is provided on the attached CD.

4.1.5 Weather Data

Daily weather data for the 2003 and 2004 irrigation seasons were obtained from the USBR ET Toolbox website (USBR, 2003: http://www.usbr.gov/pmts/rivers/awards/index.html), which contains links to weather monitoring stations maintained by the MRGCD and others. The weather stations from which data were obtained are:

- Pena Blanca
- Angostura
- Candelaria Farms
- Jarales
- Boy's Ranch
- San Acacia
- Luis Lopez
- North Bosque

These data are provided on the attached CD.

4.1.6 Ditchrider Interviews

The ten ditchriders in Belen Division, who are responsible for water delivery to users, were interviewed during the 2004 irrigation season. The CSU team member interviewed each ditchrider during the course of his work day, asking questions and noting his standard operational policies, and variations to those policies for individual lateral service areas, or check structure service areas, within his jurisdiction. A list of questions developed to guide interviews is provided in Appendix 4-C.

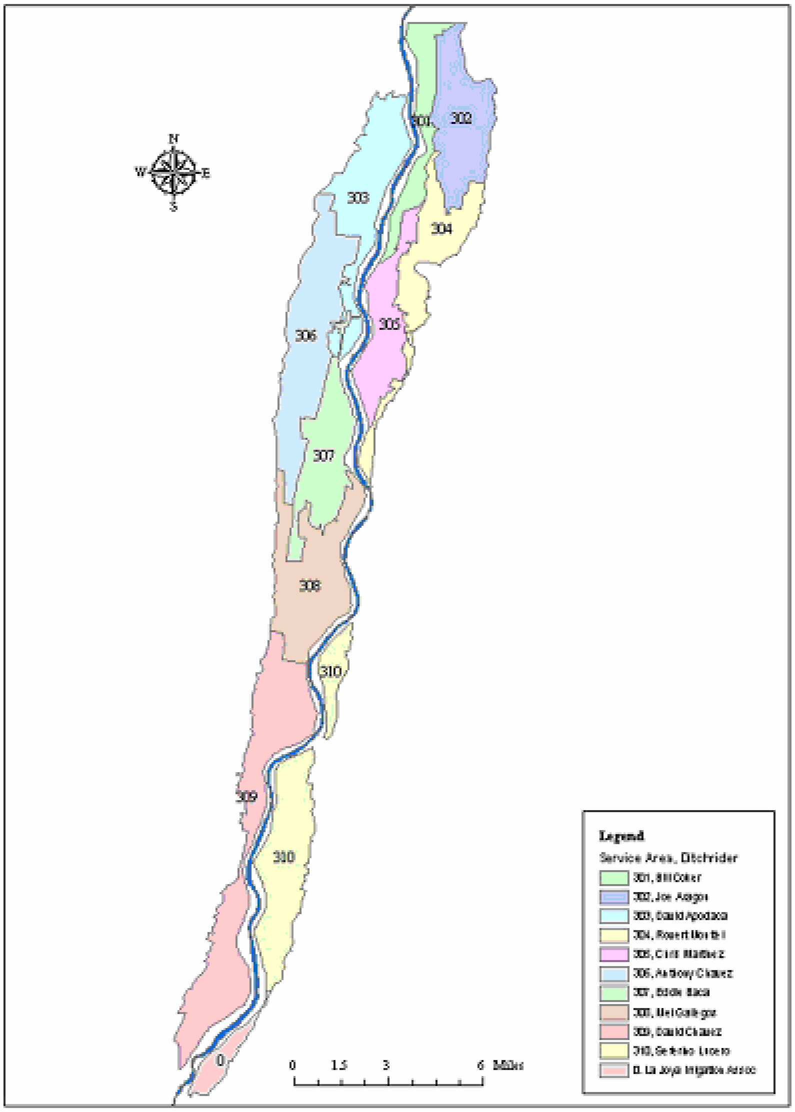

Figure 4.1. Belen Division Ditchrider Service Areas
Source: MRGCD, modified by SSPA

The service area numbers (according to the numbering scheme used by the MRGCD), names of ditchriders serving these areas, and dates on which these interviews were performed are as follows (Figure 4.1):

- Service area 301, Bill Coker, interviewed on 06/03/04;
- Service area 302, Joe Aragon Jr., interviewed on 07/07/04;

- Service area 303, David Apodaca, interviewed on 06/30/04;
- Service area 304, Robert Montiel, interviewed on 06/23/04;
- Service area 305, Chris Martinez, interviewed on 06/22/04;
- Service area 306, Anthony Chavez, interviewed on 06/02/04;
- Service area 307, Eddie Baca, interviewed on 06/15/04;
- Service area 308, Mel Gallegos, interviewed on 07/06/04;
- Service area 309, David Chavez, interviewed on 06/16/04; and
- Service area 310, Sepherino Lucero, interviewed on 07/08/04.

The information obtained from the interviews was reviewed to identify system attributes that would be important in the development of the DSS, including irrigation duration for specific service areas, the number of check structures dropped to build the hydraulic head needed to divert to a specific turnout, and any noted structural or operational problems. Notes from ditchrider interviews and the compiled operational information can be found in Appendix 4-D.

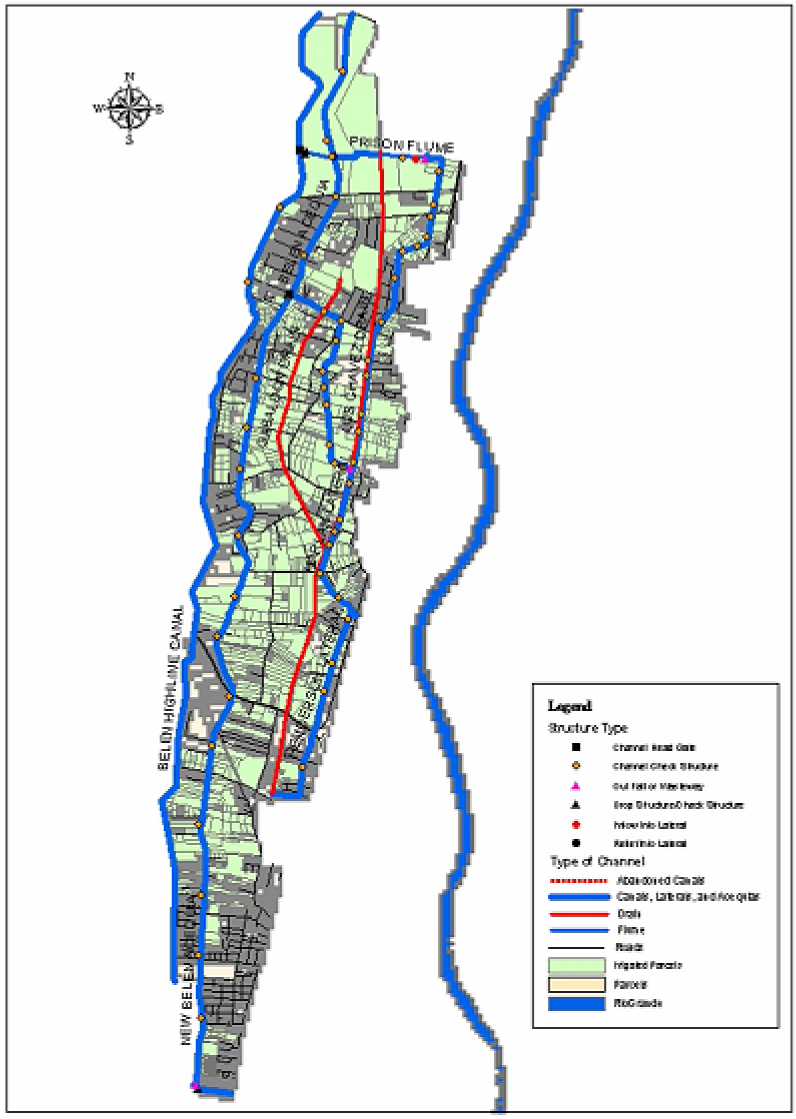

Figure 4.2. Ditchrider Area Number 306, Anothony Chavez
Source: MRGCD, modified by CSU and SSPA

4.1.7 Field Mapping of Water Control Structures

Water control structures, such as check structures, lateral turnouts and wasteway turnouts within the Belen Division were located using a hand-held GPS (Global Positioning System) unit. The following types of structures were located:

- Canal headgates;
- Lateral turnouts;
- Canal check structures;
- Canal outflows and wasteways;

- Automated flow-regulating gates; and,
- Flow metering gages.

The GPS waypoints were imported into the GIS coverage of irrigated parcels. The GPS files and a spreadsheet containing the GPS points are included on the accompanying CD.

These water control data were added to the GIS coverage for each ditchrider service area; an example ditchrider service area map presenting these features is shown on Figure 4.2. The resulting maps included:

- Total parcels and irrigated parcels within each ditch rider service area;
- Canals and drains within the service area; and,
- Location of checks, head gates, and outflows within the service area.

4.1.8 Irrigation Duration at Check Structures

Ditchriders provided information related to the typical duration of irrigation at check structures. This information was recorded on a map of the ditchrider service area such as that shown on Figure 4.3. The information received from the ditchriders is approximate, since irrigation durations were estimated rather than measured. However, this information provides a reasonable estimate that is useful in developing the preliminary DSS. All maps were scanned and are included in the CD.

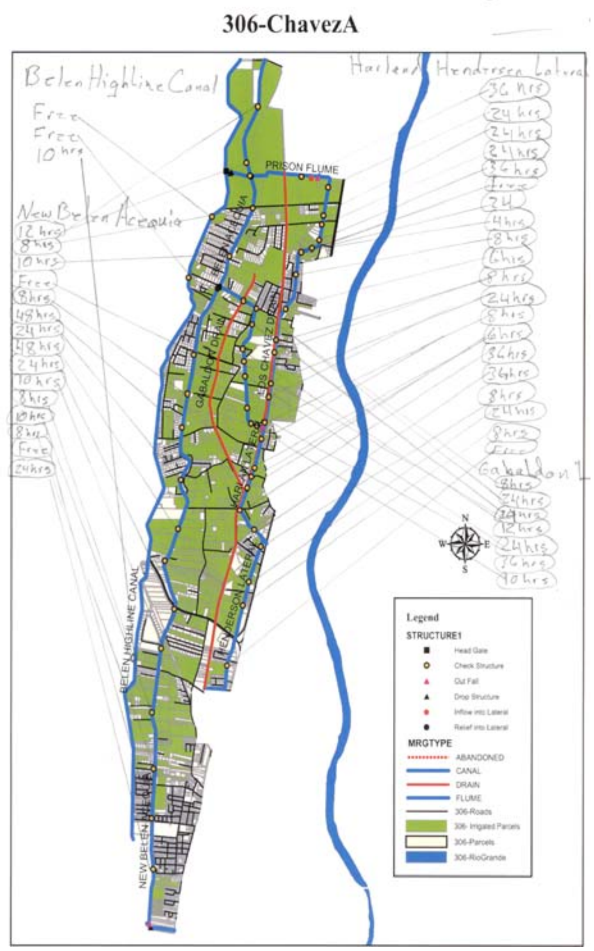

Figure 4.3. Estimates of Irrigation Time per Check Structure for Ditchrider Area 306

4.1.9 Discharge Measurements for Assessment of Seepage Losses

To provide a measure of the magnitude of the canal conveyance losses, seepage tests were performed on six lateral canals. Seepage estimates were obtained by subtracting measured downstream flow from measured upstream flow along a lateral segment, typically of at least a three-mile length, with adjustment for intervening inflows, outflows and evaporation. At each discharge measurement location, cross-sectional surveys were also conducted to provide information related to the channel geometry. Data tables summarizing the discharge and channel geometry measurements are provided in Appendix 4-E and on the attached CD.

4.2 Data Analysis

This section describes how the data collected and compiled were processed or analyzed for subsequent use in the development of the DSS.

4.2.1 Network Schematic Development

Conveyance schematics of the Peralta Main Canal system, the San Juan Main Canal System and the Belen High Line Canal System were developed using observational field notes obtained during the summer 2004, in conjunction with existing schematics, GIS coverages and aerial photos. These schematics were later used to develop the water conveyance layout, or water supply network, for the DSS.

4.2.2 Socorro County Soil Map Geo-rectification

The NRCS has not digitized the soil survey for Socorro County, which contains the lower portion of the Belen Division. Therefore, soil survey information was obtained from hard-copy maps provided in *Soil Survey of Socorro County Area, New Mexico* (USDA, 1988). The pertinent soil maps were scanned and geo-rectified for use in the project model. Digital Ortho-Quartile Quadrangle maps (USGS, 1996) were used as a reference for the geo-rectification process. The resulting GIS coverage was then linked to the soil attributes, including available water-holding capacity.

4.2.3 Irrigation System Flow Data

For development and initial trouble-shooting of the DSS, a set of irrigation supply inflow data was required for a recent irrigation season. Canal diversion data, obtained as described in Section 4.1.4, was re-formatted for export into the water supply module of the DSS. The data pertinent to the current model, which is focused on the Belen Division, can be found in electronic format on the accompanying CD. A description of how the data were processed and how missing data were interpolated can be found in Appendix 4-B.

4.2.4 Seepage Loss and Wetted Perimeter

The cross-sectional surveys performed as part of the discharge measurements described in Section 4.1.10 were used to calculate an average wetted perimeter for the Belen Division main canals (Appendix 4-F). The average wetted perimeter and discharge data were obtained for possible use in the DSS channel loss specification. Estimated canal seepage loss (Appendix 4-G) was not incorporated in the current model due to the limitation of the collected data. In the initial model development, a simpler percentage-loss approach was utilized (loss rate of 1.5 percent/mile was assumed for all canal system).

4.2.5 Irrigated Crop Acreage within Lateral Service Areas

To support the water demand calculations in the DSS, the irrigated acreages within the lateral service areas, as well as check structure service areas, were calculated from the GIS coverages of irrigated crop type and acreage provided by the MRGCD for the 2002 and 2003 irrigation seasons. The irrigated crop type and acreage were determined from the attribute tables for each selected service area.

4.2.6 Available Water-Holding Capacities of Soils

Soil property data were used to develop spatially- and depth-averaged values of available water-holding capacity (AWC) for soils in individual lateral service areas. This parameter forms the basis for the calculation of water demand for laterals in the DSS, as the AWC represents storage for applied irrigation water; and the utilization of this water by crops will impact the timing and duration of subsequent irrigations. This section describes how the spatially- and depth-averaged values for AWC for lateral service areas were determined from available data.

Using the data from USDA, 1988 (see Section 4.2.2), intrinsic available water-holding capacity (IAWC) for a given soil type was determined by averaging high and low IAWC values mapped for each soil depth range, or layer ($IAWC_{layer}$). Next, available water-holding capacity for each soil column (AWC_{column}) was calculated using a depth-weighted average approach as described in Equation 4.1.

$$AWC_{column} = \sum [(IAWC_{layer})*(Depth_{layer})]/(\text{Soil Column Depth}) \qquad \text{Equation (4.1)}$$

The depth-weighted AWC_{column} values calculated for each soil type were then used to calculate a spatially-weighted average for each lateral service area (AWC_{lat}). This was done using Equation (4.2).

$$AWC_{lat} = \Sigma[AWC_{column}*(\text{Area of soil type in a lateral service area/total service area of lateral})] \qquad \text{Eq. (4.2)}$$

5.0 DECISION-SUPPORT SYSTEM MODEL DEVELOPMENT AND PRELIMINARY TESTING

5.1 Conceptual Description and Framework

A Decision Support System (DSS) has been formulated to model and provide management support for water delivery in MRGCD's Belen Division. The DSS was designed to improve understanding of how the water supply can be best scheduled to meet the crop water demand; and specifically, to aid in the implementation of rotational water delivery practices within the Belen Division. The DSS consists of three elements:

- A *water demand model* that calculates crop consumptive use and soil moisture storage properties, aggregated by lateral service areas;
- A *supply network* that represents the layout of the conveyance system, main canal inflow, conveyance system physical properties, and the location of diversions for lateral service area; and,
- A *scheduling program* that routes water through the network to meet irrigation demand, using a mass-balance approach and based on a ranking system that depends on the existing water deficit in the root-zone.

A Graphical User Interface (GUI)[2] provides a means for linking the three elements of the DSS. This GUI constitutes a framework for the DSS that provides user with the ability to access data and output for the system. The three DSS model components are termed *modules*. A schematic of the three modules and the way that they relate within the DSS framework is shown in Figure 5.1. 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.

[2] The GUI has been developed using Visual C++.

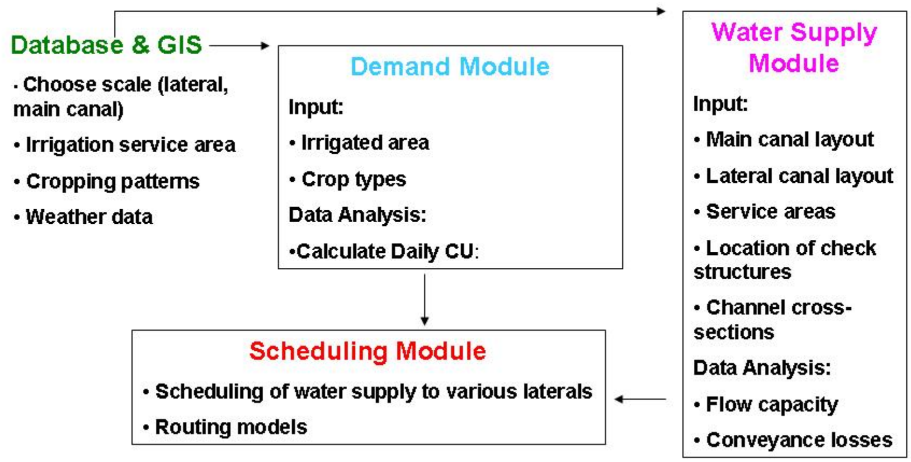

Figure 5.1: DSS Framework

The DSS is designed to run in planning or operational mode. In the planning mode, the user can input an anticipated cropping pattern for the season and other related data and the model will calculate the required main canal diversions as a function of time. In the operational mode, the user can input the available main canal flows and the model will recommend a water delivery schedule for the lateral canal service areas within the main canal that optimizes the use of the available water.

5.2 Model Structure

The three modules that comprise the MRGCD DSS are described in the following sections. These modules include the water demand module, the supply network module and the irrigation scheduling module.

5.2.1 Water Demand Module

The water demand module of the MRGCD DSS is implemented through the *Integrated Decision Support Consumptive Use*, or IDSCU, model code, developed over a period of years by Colorado State University (www.ids.colostate.edu/projects/idscu). The IDSCU model code consists of a Graphical User Interface (GUI) written in Visual C++ and program calculations implemented with FORTRAN. It offers numerous features and options, not all of which are needed or used in this application. This section describes the way the IDSCU model code is used to develop the water demand module for the MRGCD Belen Division DSS, which is used to calculate the water demand for lateral service areas.

The water demand module calculates the following:

- Crop consumptive use (CU);
- Crop consumptive irrigation requirement (CIR); and,
- Readily available moisture (RAM), as a capacity.

The latter two variables, CIR and RAM (as a capacity), are subsequently used in the supply network module. Data utilized in the water demand module, the data source, and the spatial unit for which the information is aggregated is shown on Table 5.1.

Table 5.1. Data for the Water Demand Module

Data for Water Demand Module		
Required data	**Source of data**	**Mgmt. level in irrigation system**
Service area and irrigated area	MRGCD GIS database: legal parcel delineation, lateral service area boundaries	Cumulative for lateral service areas
Cropping patterns	MRGCD data base, field observation	Cumulative for lateral service areas
Soil: Available water holding capacity (*AWC*)	USDA, 1988	Averages for lateral service areas
Weather data, Rainfall, Crop coefficients, planting/harvest dates	USBR ET Toolbox, Penman-Montieth Equation	Averages for lateral service areas
Other variables: root zone depth and management allowable depletion	ASCE Manual 70 (ASCE, 1990)	Averages for lateral service areas

5.2.1.1

Crop Consumptive Use

The Penman-Monteith (P-M) method is used to determine the crop consumptive use for the system. The P-M equation (ASCE Manual #70, 1990) takes the form:

$$ET = \frac{\left[\frac{\Delta}{\Delta + \gamma^*}(R_n - G) + \frac{\gamma}{\Delta + \gamma^*} K_1 \frac{0.622\lambda\rho}{P} \frac{1}{r_a}(e_s - e_a) \right]}{\lambda} \qquad \textbf{(1)}$$

$$\gamma^* = \gamma(1 + \frac{r_c}{r_a}) \qquad \textbf{(2)}$$

Where:

ET	: crop evapotranspiration (m/day)
R_n	: calculated net radiation at the crop surface ($MJ/m^2 \cdot day$)
G	: soil heat flux density at the soil surface ($MJ/m^2 \cdot day$)
e_s	: saturation vapor pressure at 1.5 to 2 m height (KPa), calculated for daily time as the average of saturation vapor pressure at maximum and minimum air temperature.
e_a	: mean actual vapor pressure at 1.5 to 2.5 m heights (Kpa)
Δ	: slope of saturation vapor pressure-temperature curve (Kpa/^oC)
γ	: psychrometric constant (Kpa/^oC)
r_a	: aerodynamic resistance to sensible heat and vapor transfer (air resistance) (s/m)
r_c	: surface resistance to vapor transfer (canopy resistance) (s/m)
ρ	: air density (Kg/m^3)
P	: mean atmospheric pressure at site elevation (Kpa)
K_1	: dimension coefficient ($8.64X10^4$ s/day).
λ	: latent heat of vaporization (MJ/Kg)

The weather data is obtained from the USBR ET Toolbox. Crop coefficients (FAO, 1998; ASCE Manual #70, 1990) are applied to the P-M-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.

5.2.1.2 <u>Crop Consumptive Irrigation Requirement</u>

The P-M-based consumptive use is adjusted by the demand module to obtain a consumptive irrigation requirement (CIR) for the lateral service area by accounting for effective precipitation. The effective precipitation is the fraction of total rainfall that can be stored in the soil for later use by the plant. The DSS calculations of effective precipitation accounts for the relationship between rainfall intensity and infiltration (the idea that slow soaking rains are more easily absorbed into the ground than quick downpours). The effective precipitation is calculated according to the Soil Conservation Service Method (USDA, 1967), and is subtracted from the P-M-based consumptive demand. The CIR is calculated on a daily basis, corresponding to the water needed to directly satisfy crop needs for all irrigated acres in the service area. The CIR for a lateral 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 5.2 provides a snapshot of the demand module interface for the Jackson service area. From this interface, supporting data for the calculations can be accessed, reviewed and edited. This snapshot shows the CIR (labeled as IWR, for Irrigation Water Requirement, in this figure) calculated by the demand module for the Jackson service area, by month.

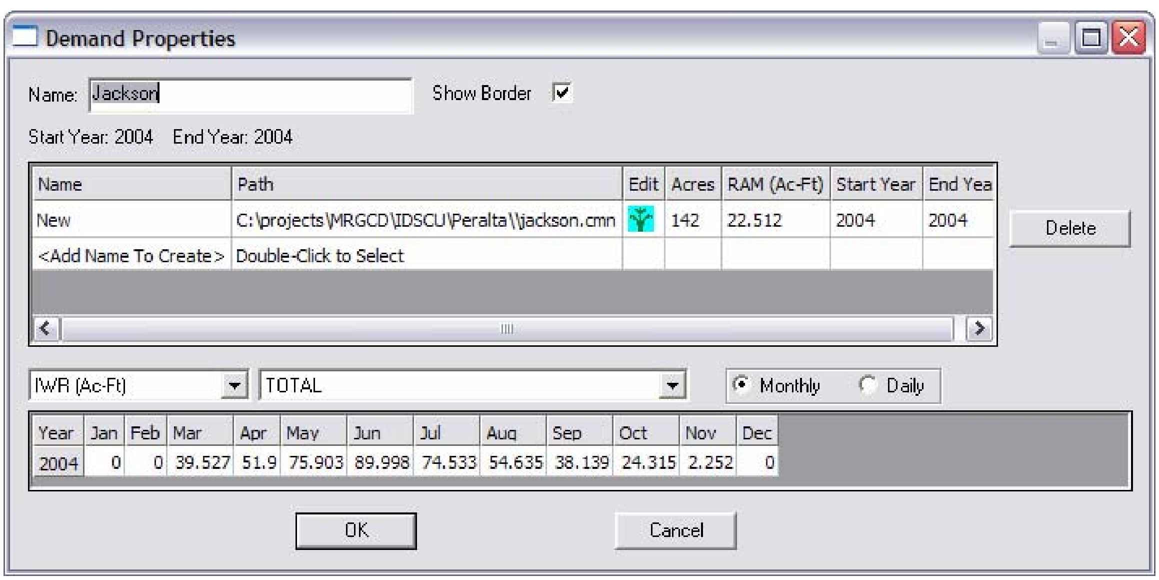

Figure 5.2. Demand Module User Interface

5.2.1.3

Readily Available Soil Moisture

To characterize the water storage capacity of soils for irrigation scheduling purposes, a parameter termed readily available moisture (RAM) is defined. This parameter reflects soil properties, root zone depth and a management risk factor. It is determined by first calculating the total available moisture (TAM), which is the available water holding capacity (AWC) for a given soil type, times the root-zone depth, defined as follows:

TAM = AWC * root-zone depth

RAM is the amount of water that the roots can remove from the soil without causing stress and equal to the TAM multiplied by a management risk factor (the factors are crop specific and range from 30% to 60%). Currently, the model is designed to schedule irrigation when 75% of the RAM is depleted (this is the management allowed depletion, or MAD; FAO, 1998; ASCE Manual #70, 1990). Both MAD and the management risk factor are user specified input.

Based on acreages, crop types and soil types within each lateral service area, a RAM is calculated. As can be seen in Figure 5.2, a RAM of 22.512 acre feet is calculated for the 142-acre Jackson service area. 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 an amount of water equal to the RAM will be stored in soils. Then, as crops utilize water, the RAM will become depleted. The daily status of RAM is important in the scheduling of water delivery, as will be discussed below.

5.2.2 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 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 reaches, inflows and demand nodes. The link-node network represents the connections between canals or laterals and demand nodes (lateral service areas). Figure 5.3 provides a view of a portion of the link-node network for the Peralta Main Canal.

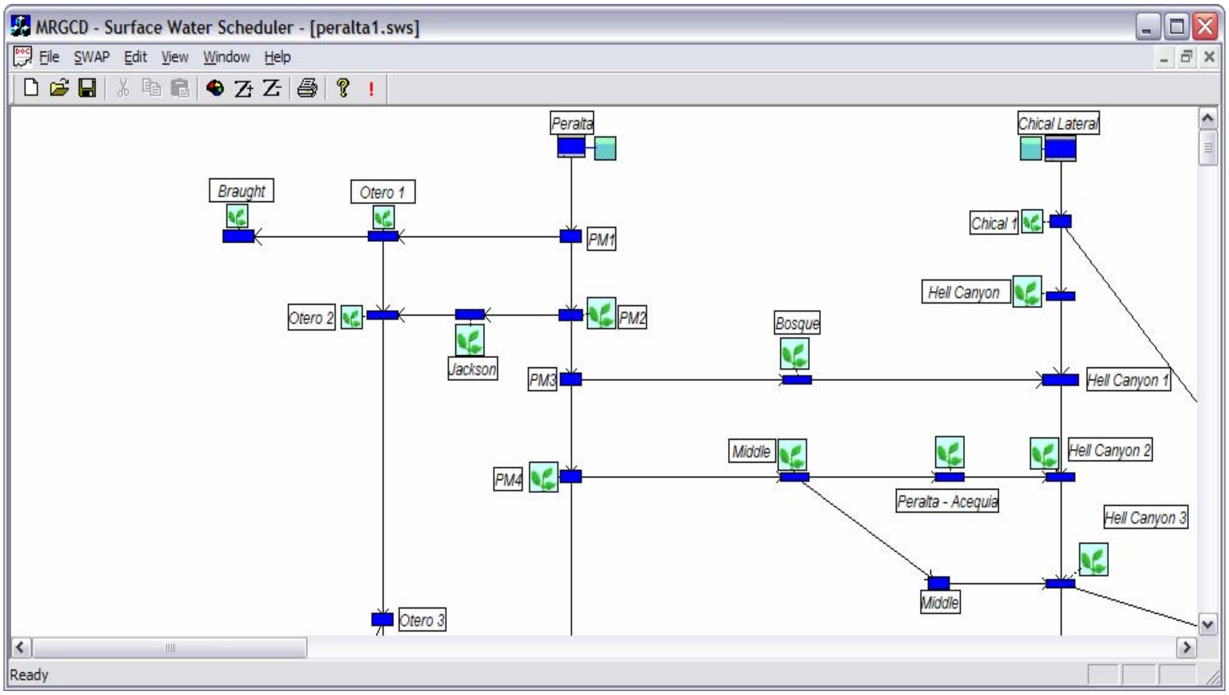

Figure 5.3. Portion of Supply Network for the Peralta Main Canal

The supply network module is a repository for supply, demand and physical information that relates to the conveyance network. The module obtains the consumptive irrigation requirement (CIR) and the RAM from the water demand module, and associates these parameters with a demand node on the supply network. An efficiency factor is applied to the CIR to account for application efficiency (on-farm efficiency) and conveyance losses within the service area (between the lateral diversion and the farm headgates). The resulting lateral delivery requirement (LDR) is similar in concept to a farm delivery requirement (FDR) but applies to a larger spatial area, a lateral service area (the service area selected as the calculation unit in the present version of the DSS). The efficiency factor can be specified by the user for each lateral service area. In the present version of the model, a factor of 0.5 is uniformly applied. This value can be refined to better represent service area characteristics in future model applications.

The user provides upstream inflow and physical characteristics for the links (canals) and diversion points to the system. Figure 5.4 shows the GUI for the inflow nodes. The inflow nodes require the user to either type the inflow values or link to an excel spreadsheet.

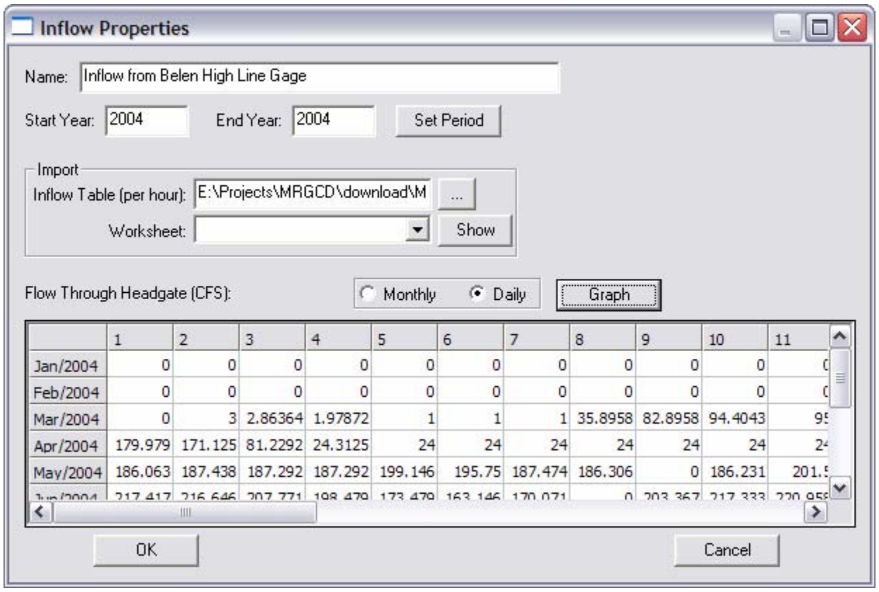

Figure 5.4. GUI for Inflow Node

Stream nodes require the user to provide information about the length of the segments, the capacity, the conveyance loss, the lateral service area efficiency factor and identification of to which "sub-system" the stream segment belongs. Sub-systems are used to preferentially rank laterals that should be irrigated together. Figure 5.5 shows the GUI for the stream nodes that is accessed from the link-node network.

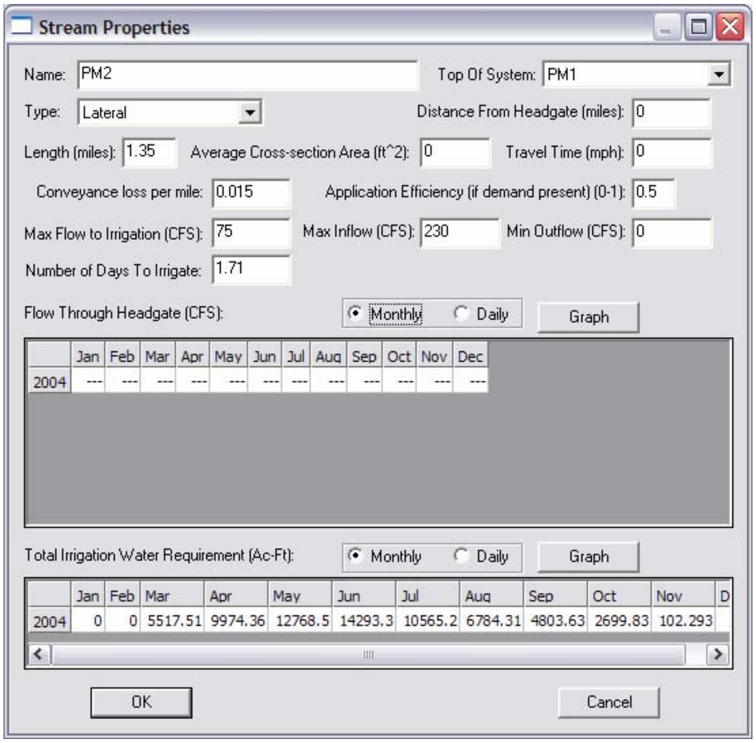

Figure 5.5. GUI for Stream Properties

Using the specified information, this module calculates a demand-based flow rate required for irrigation of the lateral service area. The flow rate is calculated as the LDR (Lateral Service Area Delivery Requirement, see Section 5.2.1.2) divided by the irrigation duration. However, if the calculated flow rate exceeds the maximum flow to irrigation (lateral capacity) specified by the user, then, the flow rate is set at the user-input lateral capacity. In either case, when irrigation occurs, as determined by the scheduling module (discussed below), the amount of water removed from the stream link and delivered to the lateral service area for the daily time step is set equal to the volume of water that would be delivered at this flow rate over a one-day period. This volume of water, or time-adjusted portion of LDR, is then reduced by the efficiency factor and added to the daily RAM for the service area. If the LDR is not fully delivered in the one-day irrigation, the irrigation may continue into subsequent days, depending on the remaining need, the need of other laterals, and the assigned ranking system in the scheduler.

5.2.3 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 rotational 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 module writes out an input file for the solver, executes the solver and reads the output of the solver. In the present model version, the irrigation scheduling module displays the results in tabular form; this information can then be viewed graphically through the supply network module.

The module uses a mass balance approach to schedule irrigation timing and duration for lateral canal service areas. The approach is based on the consideration that the farm soil root-zone is a reservoir for water storage, from which irrigation applications are inflows and CIR is an outflow.

$$RAM_{t+1} = I_{t+1} - O_{t+1} + RAM_t$$

Where :
RAM = Readily Available (soil) Moisture (see Section 5.2.1.3)
I = *Inflows*
O = Outflows
t = Time

A linear programming approach is used to calculate flows to the service areas by posing the problem as a minimum-cost flow problem. The model uses the projected number of days until the soil moisture storage is depleted in a reverse-ranking system to prioritize the need for irrigation among service areas.

Based on observations of the water delivery operations, it appears that water delivery can be changed from one set of laterals to another set within one day. As travel time appears to be less than the daily time step at the present scale of model application, time lag accounting was not included in the scheduling module.

5.3

Model Programming

This section describes the model programming for scheduling water supplies to user groups. A *linear programming* method is used to find the optimum irrigation schedule. Linear programming is a method for optimizing a quantity that is defined with a mathematical expression, or, *objective function*. Constraints on variables within the objective function are also 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. The method and its implementation in the DSS are described in greater detail below.

For illustration purposes, the scheduling problem is described using a hypothetical irrigation network. Figure 5.6 shows a simple irrigation network with a main supply canal and a number of laterals that represent crop water demand. The problem is similar to a transportation problem, where the service areas are the demand nodes and the inflows are the supply nodes. Links are created between each node where water can be routed. In a transportation problem, the supplies need to equal the demands; therefore, to ensure that the system balances, a “dummy” source node is added which can supply water to every demand node in the event the system is water short. Note that in a water-rich scenario, the dummy would not be used. The system is also set up to use less than the total amount of water available if the demands are less than the supplies.

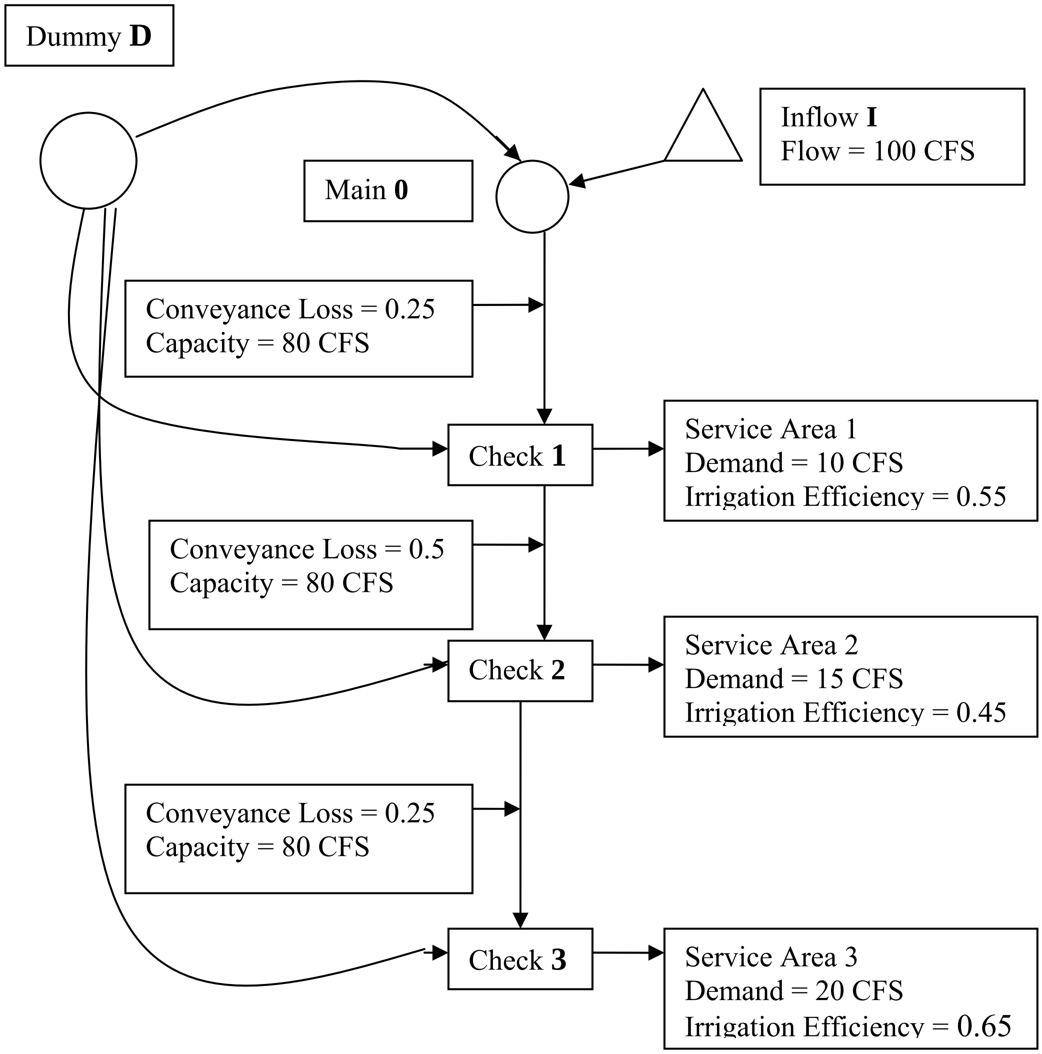

Figure 5.6. Hypothetical Irrigation Network

The scheduling problem is cast as a minimization problem for which the goal is to provide water to the nodes with the higher need for water. This is achieved through the use of a ranking system based on water need, the use of water delivery from the dummy supply and a set of constraints that capture mass balance conditions through the stream network. The objective function is:

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

where Z is the sum of a modified priority (MP) multiplied by available 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, whereby 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.

The variables in the objective function represent the links in the network between the dummy supply and the demand nodes. The coefficient of each variable represents the flow "cost" of that link. In other words, delivery of water to a node without a need for water results in a higher "cost". As further discussed below, the ranking system has been assigned such that minimization of this objective function will result in minimization of water delivery to demand nodes that already have sufficient water (RAM).

Constraints on the solution of the objective function express the mass balance relationships throughout the link-node network and the capacity limits on flow. These are expressed below. A mass-balance constraint is created for each node (including the dummy) that establishes the inflow and outflow to that node. The coefficients of the variables for each constraint (each row) are represented as a matrix, with a column for every variable in the objective function and a row for every node. Inflows are indicated by negative values, and outflows are positive values. Outflow coefficients are always one, and inflow coefficients are the conveyance loss of the connection. The objective function is subject to the following constraints:

$$
\begin{array}{llllllllll}
\mathbf{X_{I-0}} & & & & & & & & \mathbf{<=} & \mathbf{I} \\
\mathbf{-X_{I-0}} & \mathbf{+X_{0-1}} & & & \mathbf{-X_{D-0}} & & & & \mathbf{=} & \mathbf{R_0} \\
 & \mathbf{-L_1X_{0-1}} & \mathbf{+X_{1-2}} & & & \mathbf{-X_{D-1}} & & & \mathbf{=} & \mathbf{R_1} \\
 & & \mathbf{-L_2X_{1-2}} & & \mathbf{+X_{2-3}} & & \mathbf{-X_{D-2}} & & \mathbf{=} & \mathbf{R_2} \\
 & & & \mathbf{-L_3X_{2-3}} & & & & \mathbf{-X_{D-3}} & \mathbf{=} & \mathbf{R_3} \\
 & & & & & \mathbf{X_{D-1}} & \mathbf{+X_{D-2}} & \mathbf{+X_{D-3}} & \mathbf{<} & \infty
\end{array}
$$

Where

$$\mathbf{X_{0-1} <= C_{0-1}}$$
$$\mathbf{X_{1-2} <= C_{1-2}}$$
$$\mathbf{X_{2-3} <= C_{2-3}}$$

All $\mathbf{X_{i-j} >= 0}$

The variables used are:

- **I** is the total available inflow,
- $\mathbf{X_{i\text{-}j}}$ is the flow in a canal reach between points i and j,
- $\mathbf{C_{i\text{-}j}}$ is the maximum capacity of the canal reach between points i and j,
- **D** refers to a dummy supply node that is used to force the demands and supplies to balance, the subscript 0 refers to the inflow node, and subscripts 1, 2, 3, … refer to nodal points, typically located at check structures,
- $\mathbf{L_{i\text{-}j}}$ is the conveyance loss between in the canal reach between points i and j,
- **R** is the demand (water requirement) at the nodal point indicated by the subscript (can be zero if not associated with a lateral diversion point).

For example, the third row refers to activity at check **1**. There is an inflow from the headgate ($\mathbf{- L_1X_{0\text{-}1}}$) and is given a negative sign since by convention all inflows are negative. The conveyance loss is represented by the coefficient $\mathbf{L_1}$. There is an outflow to check **2** ($\mathbf{+ X_{1\text{-}2}}$) (positive sign, since by convention all outflows are positive). To ensure that the system balances, there is also an inflow from the dummy source ($\mathbf{- X_{D\text{-}1}}$). Because this node represents a demand, the solution for this row is constrained to be exactly the demand ($\mathbf{R_1}$).

If a node represented a source, then the solution for the row would be constrained to fall between zero and the inflow, which allows us to use less than the total amount of water available if the demands are less than the supplies or if at some point in the network the capacity is insufficient to route the inflow. The first row in the constraint equations represents this type of node.

A conveyance loss factor is input to the supply network module as a fractional value of flow per mile. The conveyance loss (L) to be applied in the mass balance equation, reflected in the constraints, is calculated by subtracting the fractional value from one and raising it to the number of miles of the canal segment between nodes. For example, a 3-mile reach with a 0.015 conveyance loss factor would have a loss of $1 - (.985)^3 = 0.0443$ of the instream flow to this reach.

The ranking system used to derive the modified priority (MP) values for the objective function is a two-step process, involving assignment of a priority (P) based on the irrigation need at demand nodes, and then, a modified priority that effectively reverses the ranking so that nodes with the least need are the preferred recipient for dummy water. This results in the actual available water being delivered to the demand nodes with highest irrigation needs.

First, a priority (P) is assigned to each of the demand nodes, with smaller values indicating higher need for irrigation. The priority is based on the number of days until the service area runs out of readily available moisture (RAM). If the service area is not being irrigated, 100 points are added to the priority, which forces the system to favor areas being irrigated until the RAM is full again. The concept of a subsystem was also added to give priority to remaining canals within a group on the assumption that if one of the canal service areas in the subsystem is being irrigated, it would be desirable that the remaining canal services areas in the same group be irrigated as well. If a service area is determined to be in a subsystem that is being irrigated, its priority is set to 50 plus the number of days remaining until the RAM is depleted.. This makes them higher priority than other services areas that not in a subsystem and therefore the optimization program will try to water them first.

Second, the ranking system is implemented by modifying the priorities with respect to the dummy connections, effectively reversing the priorities. Currently the modified priority (MP) for the "dummy -> node x" connection is $100,000/P_x$. For example, if the node has a priority of 105, then the priority assigned to the connection is100,000/105 or 952.38. This will force dummy water to be delivered first to the lower priority nodes, leaving real water for the high priority nodes. The modified priority (MP) values are represented by the MP variables in the objective function.

The linear programming software utilized in the DSS is a package called glpk (GNU Linear Programming Kit). The software and documentation can be downloaded from http://www.gnu.org/software/glpk/glpk.html.

5.4 Preliminary Model Test

The DSS was applied to the three main canal service areas in the Belen Division for preliminary testing. The objective was to assess the model's reasonableness using actual field data and information that were collected during the 2004 irrigation season. As a result of the model run and evaluation, we have identified some data gaps, which can be addressed in our 2005 data collection and model refinement effort.

The DSS has two modes of operation – water delivery operation mode and planning mode. The operation mode uses historical data or user-supplied values for main canal diversions to schedule the delivery of the diverted water to various lateral service areas in the most efficient way. If the available inflow is greater than is the flow needed to efficiently irrigate the system, the model will show the remaining water as excess or return flows at the bottom of the network. In the planning mode, the model calculates the demands and the minimum diversions required to meet these demands. The model does not yet operate in the planning mode. For this preliminary testing phase, the DSS model was run for the Peralta Main Canal in operation mode.

5.4.1 Example Run for Peralta Main Canal

A link-node diagram, representing the distribution network for the Peralta main canal, is shown in Figure 5.7. Each thick blue icon with grey border links to a pop-up window displaying the "stream properties" for this node, as shown on Figure 5.8.

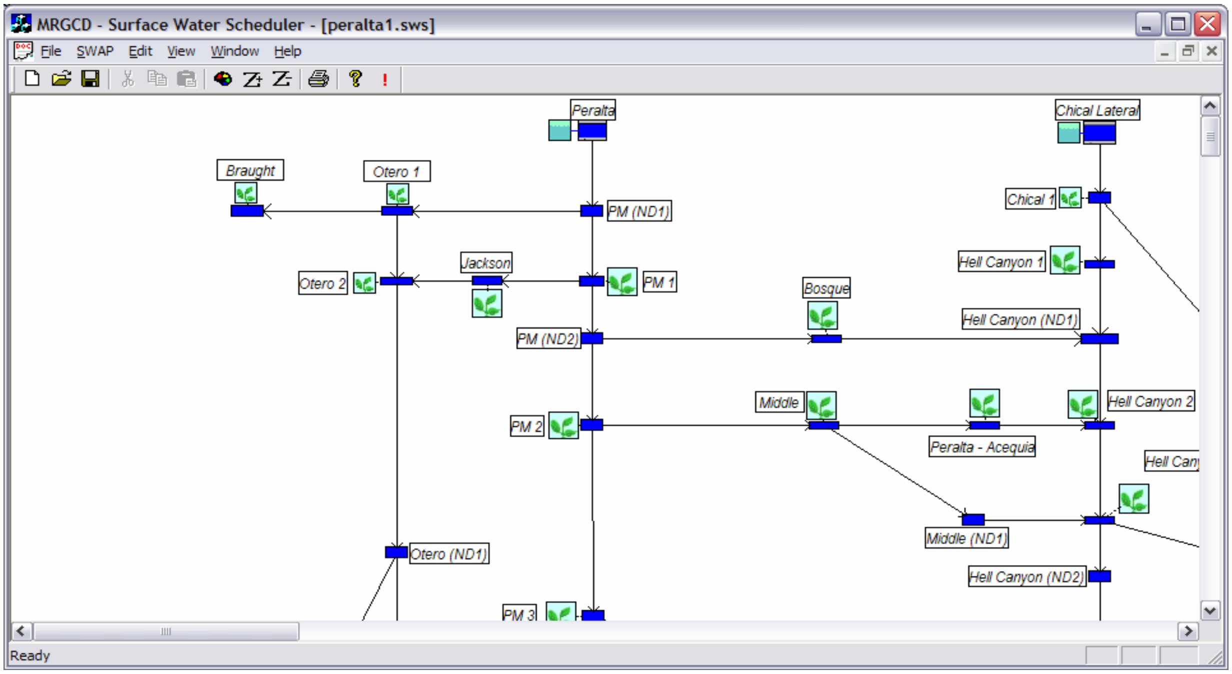

Figure 5.7. Peralta Main Canal Network

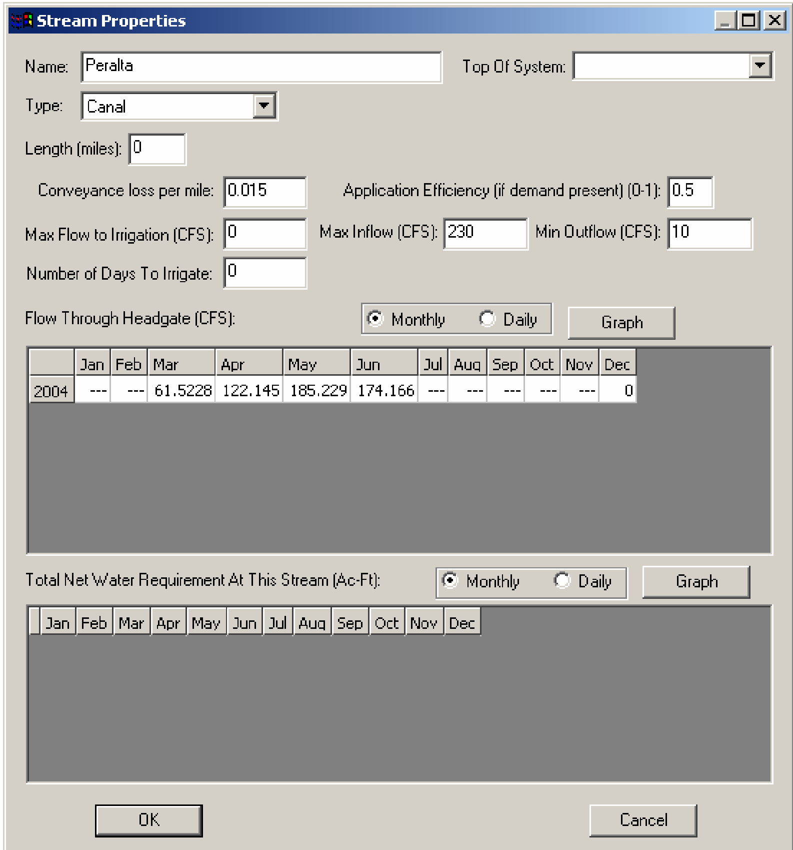

Figure 5.8. Properties of Peralta Main Canal

Similarly, each demand node is linked to a pop-up window displaying demand properties, which represent water requirements in various lateral canal service areas, as shown in Figure 5.9 for the Vallejos Lateral.

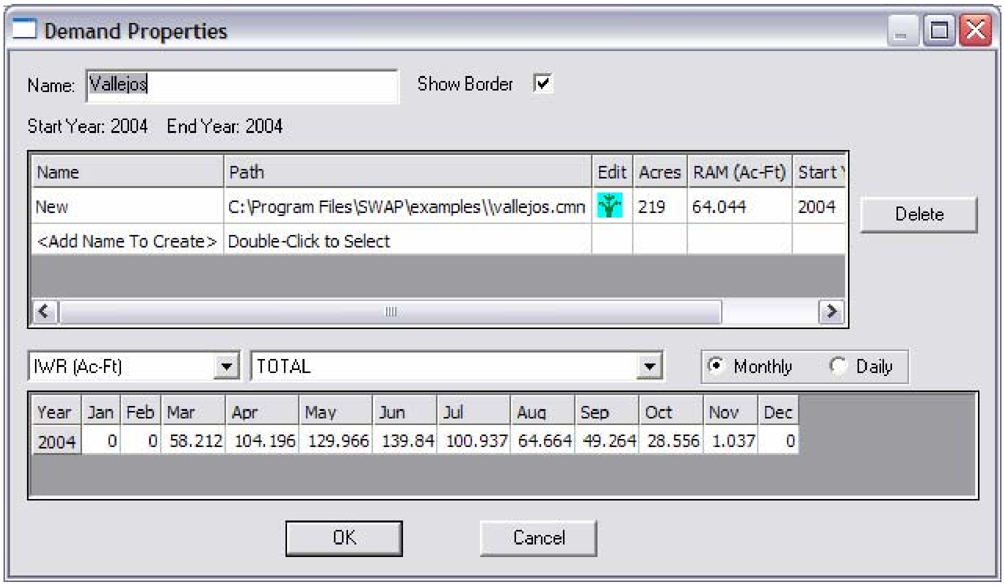

Figure 5.9. Demand Properties of an Example Lateral Canal Service Area

In this run, which is in *Operation* mode, the model uses canal diversions that were entered in the inflow properties dialog box, and optimizes the delivery of these inflows to the lateral canal service areas. The results are populated into an output table. In this table, results are displayed based on a user-selected *View Mode (*for example, RAM, flow, conveyance loss, application efficiency, number of days until RAM depleted, etc.) and the user-specified units (acre-feet, cfs, etc.). Figure 5.10 shows an example output displaying the flow for each lateral service area..

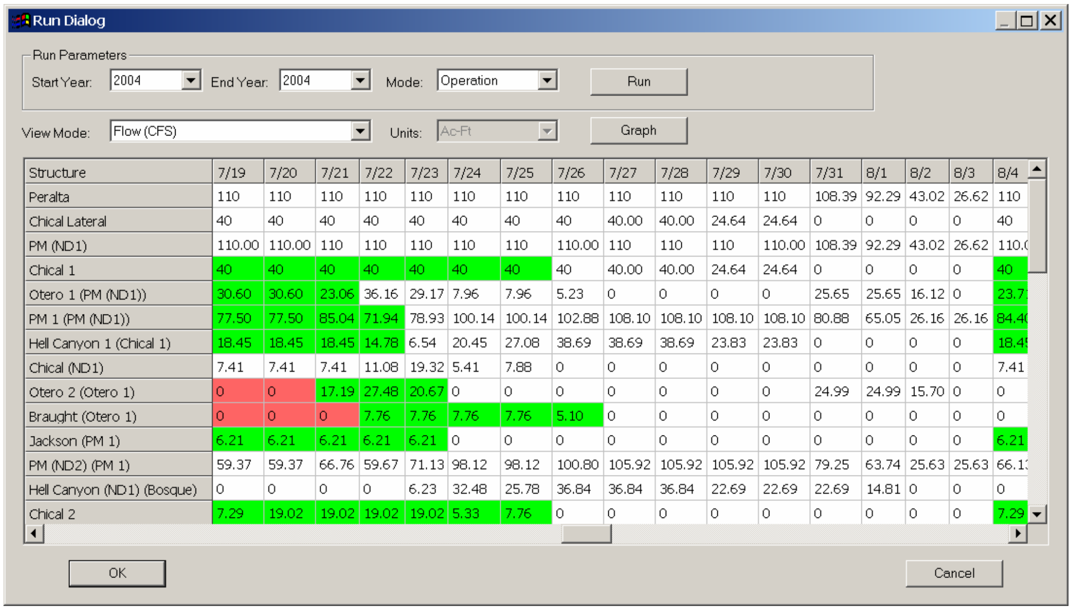

Figure 5.10. Example Results of Model Run in Operation Mode

The results show the lateral canals that are "on" during a rotation (shown in green, indicating that irrigation is taking place) and the required flows to those canals (the numbers shown in the green cells). The results also show the specified inflow into the Peralta main canal (in the upper row, adjacent to "Peralta"). The red colored cells are cells where irrigation is required. Also, red cells indicate that water is not available to satisfy this demand at that time and the model will allow more than 100 percent of the RAM to be depleted as shown in Figure 5.11. Therefore the rotation length (time between irrigations) is variable and in this run the average calculated rotation length for the Peralta main canal was 22.5 days.

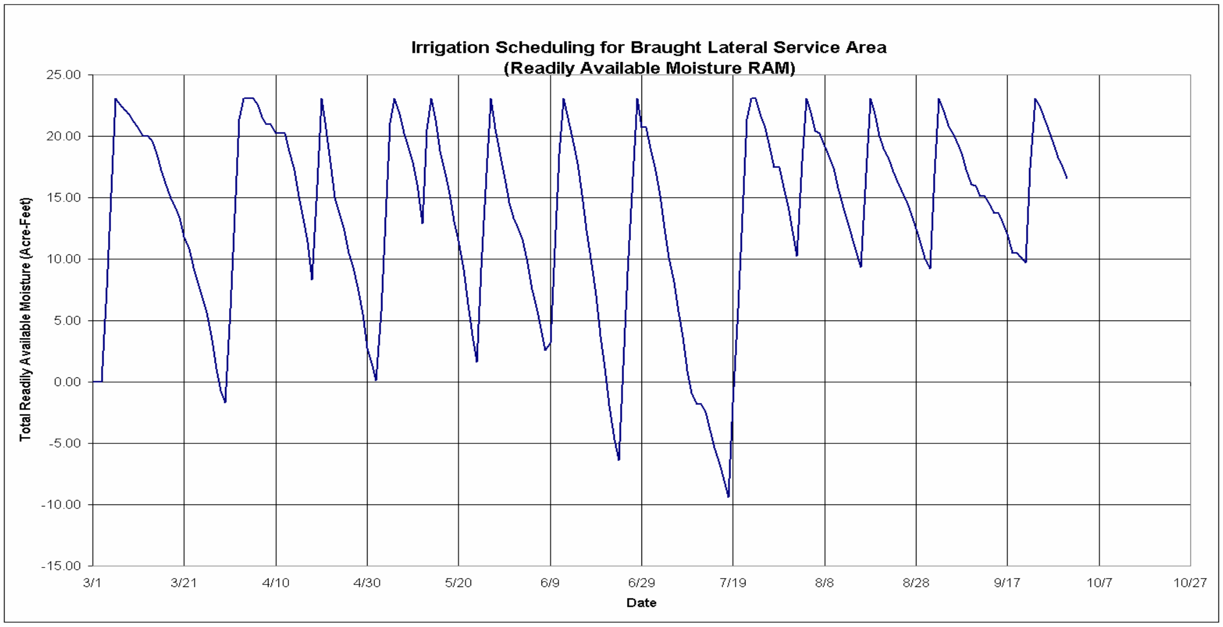

Figure 5.11. Readily Available Moisture (RAM) for Braught Lateral Service Area

Figure 5.12 shows a snapshot of the model output for July 28th, 2004. The numbers in blue are the canal flows and in parenthesis the canal loss between a node and the next downstream node (estimated values in this version of the model). The numbers in the red represent the demand that was met at that node.

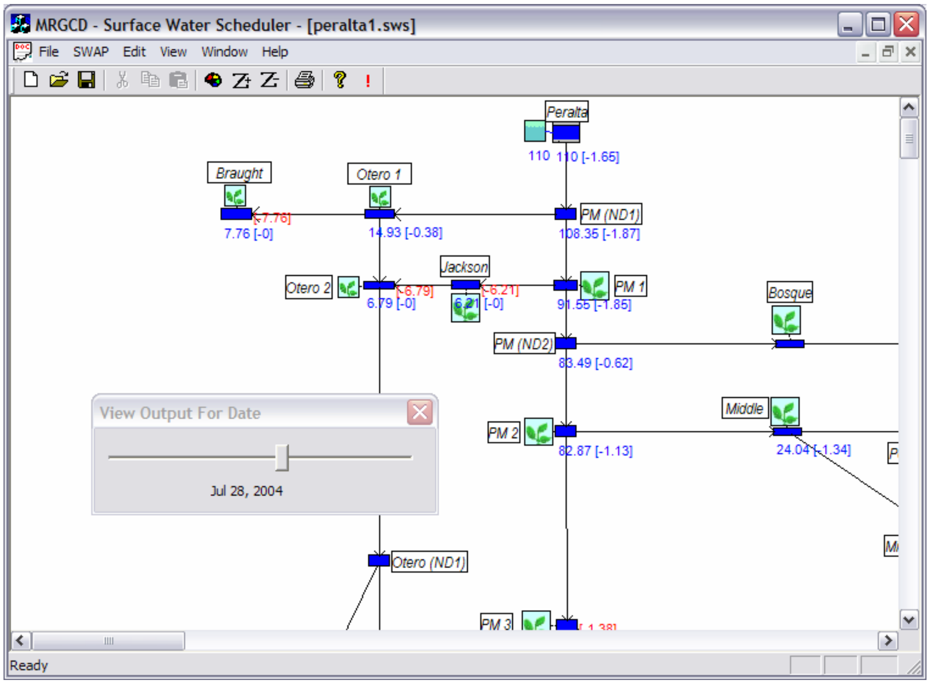

Figure 5.12. Canal Flows Required to Meet the Service Area Demand

6.0 SUMMARY AND RECOMMENDATIONS

6.1 Summary

At the completion of the first year of funding for this project, basic structuring and formulation of the DSS model is complete. The three modules – the supply network module, the demand module, and the irrigation scheduling module – are fully functional and interlinked. The linear programming runs efficiently and seems to yield water scheduling results that are reasonable. The model has been successfully run for the three main canal service areas of the Belen Division. It allocates water to various lateral canals following the principles of mass balance, and based on a ranking system that depends on the existing water deficit in the root-zone of the soils within the associated lateral service area.

The model can be run in two modes – a planning mode and an operational mode. In the planning mode, the user inputs an anticipated cropping pattern for the season and other related data and the model calculates the required main canal diversions as a function of time. In the operational mode, the user inputs the available main canal flows and the model recommends a water delivery schedule for the lateral canal service areas within the main canal command that optimizes the use of the available water.

6.2 Recommendations for FY-2004 Project: Field Assessment and Model Refinement for the Belen Division

One component of the FY-2004 project, funded by the MRG ESA Collaborative Program and the NMISC, will be the collection of field data during the 2005 irrigation season for assessment and refinement of the Belen Division model. The fundamental methodology will be to run the model in the planning mode, based on the best available information at the beginning of the season. We will then compare the results of the model with the actual water delivery operations carried out by the ditchriders. The ditchriders will be asked to fill in the logbook where they record when and where irrigation water was delivered and for how long (irrigation duration). The study will monitor irrigation duration, flow requirements for each service area, and management allowed depletion (MAD) factor, to compare the model recommendations with actual practice.

6.2.1 Irrigation Duration

During the 2004 irrigation season, ditchriders in the Belen Division provided maps summarizing their experience related to how much time it takes to irrigate service areas within their jurisdiction (see Figure 4.3). The current dataset for each of the three canal service areas consists of data from Barta, 2003 supplemented with data collected as part of this project. The current output of the model provides a water delivery schedule, and indicates irrigation duration for individual laterals.

During the 2005 irrigation season, the study will ask the ditchriders to document the actual irrigation duration times in the logbooks they will be provided by the Division Manager. These actual times will then be used to further calibrate and improve the model.

6.2.2 Canal Discharge

Another important output of the model is the required flow discharge for the laterals that are on during a particular rotation. The user can assign a maximum flow to irrigation for each lateral service area or a length of time it takes to irrigate the service area. The 2004 data sets were developed using an average duration time it took to irrigate a service area (based on ditchrider information). In actual practice, the required flow to irrigation and duration time will vary as the season progress. During the 2005 irrigation season, the study will monitor the actual duration time and related ditchrider practices and compare them to model recommendations.

6.2.3 Management Allowed Soil-Water Depletion Factor

The current datasets and DSS model trigger irrigation when the readily available soil moisture (RAM) is depleted by 75 % of its full value. The factor (75% in this case) is a user defined input, and might be conservative, since the RAM is already set as 50% of the total available water holding capacity (AWC) for the soils in the lateral service areas (see Section 5.2.1.3). The study will compare the model recommendation of irrigation timing with the actual practice. This information can then be used to calibrate the model with a more practical value for the depletion factor.

It is recommended that the study track soil moisture through the installation of moisture probes in a few sample cropped fields (say six fields in the Peralta main canal service area and six in the Belen Highline Canal service area) through the growing season. The moisture probes should be equipped with data loggers, to continuously record moisture content. The model estimation of RAM in a particular service area, and consequent irrigation-timing recommendation, can then be compared to actual soil moisture data from that service area.

6.3 Data Gaps and Recommendations for Improvement of the Belen DSS

Initial model runs and calibrations have pointed out several data gaps, as well as areas in which model refinements could significantly enhance model accuracy and effectiveness, some of which can be addressed as part of the FY-2004 project. These include:

- More accurate rainfall data: Presently, the model accounts for the contribution of local precipitation to meeting the crop water requirements. The model acquires the precipitation data from eight local weather stations, and uses the data obtained from these stations to calculate evapotranspiration. Since rainfall is highly variable spatially, incorporation of additional weather monitoring stations into the model could greatly improve the representation of effective precipitation at the lateral-service-area level. Reportedly, the MRGCD has added weather stations to its network, and the incorporation of these additional weather stations would be helpful. In additional, data could be obtained from NEXRAD (**Nex**t Generation **Rad**ar) Doppler Radar stations, and the ET Toolbox.

- Return and drainage flows: Return and drainage flows, which constitute a portion of the MRGCD's local water supply, are presently not accounted for in the model operations. MRGCD staff has installed gages at several return flow points, and this information can be used to better address the issue of return flow.

- Canal seepage losses: The model has incorporated estimates of canal seepage loss rates, but good reliable data on the loss rates in individual canals are not currently available. The 2005 data collection season should include efforts to collect such data in key canal segments.

- Canal capacity data: The canal capacity values currently incorporated into the model are the original design capacities. It is recommended that during the 2005 irrigation season, specific canal capacity measurements be made in key canals.

- Field-level idiosyncracies: The model can be enhanced through the representation of local variations in the distribution. For example:

  - What areas constitute "sub-systems" (areas that need to be irrigated sequentially)?
  - What areas cannot be irrigated at the same time?
  - What areas are in need of infrastructure improvements in order to effectively administer RWD?
  - Portrayal of root zone depth: The present version of the model uses constant root-zone depth throughout the growing season. In actuality, root-zone depth for many crops vary through the growing season. It is recommended that the FY-04 version of the model include a root-zone function to simulate these variations.

7.0 REFERENCES

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8.0 APPENDICES

Appendices 4 (A-G)

4-A	MRGCD Original Plan and Profile Design Sheets Information Spreadsheet
4-B	Stream Flow Data Information
4-C	Ditch Rider Interview Standard Questions
4-D	Ditch Rider Interviews – (A sample of interview with Anthony Chavez is provided here. All interviews are provided in the accompanying CD)
4-E	Discharge Measurement Sheet (A sample of the Belen High Line Upstream Location is provided here. For all discharge measurements data, see the accompanying CD).
4-F	Cross Section Survey Input Sheet and Graph (A sample of the Belen High Line Upstream Location is provided here. For all cross-sections survey data, see the accompanying CD).
4-G	Discharge measurements results and Analysis

Appendix 4-A

MRGCD Original Plan and Profile Design Sheets for Lateral Canals

Lateral Name	Date Plotted	Discharge Capacity (cfs)	Description of Sheet
Sabinal Lateral	2/21/1934	106.5	Plan and Profile from Sta. 0+00 to Sta. 53+83.2
Otero Lateral	7/19/1933	81	Plan and Profile from Sta. 0+00 to Sta. 52+80
Braught Lateral	2/19/51 Surveyed	N/A	Plan view of Lateral, Scale 1"=400, No Discharge Capacity
Cacique Lateral	10/17/1934	2.08	Plan and Profile from Sta. 53+00 to Sta. 78+38.5
San Juan Canal	3/19/1933	138	Plan and Profile from Sta. 7+67.2 to Sta. 53+30
Belen Grant Lateral #1	9/1/1933	35.5	Plan and Profile from Sta. 0+00 to Sta. 53+30
Belen Grant Lateral #2	9/1/1933	111.36	Plan and Profile from Sta. 0+00 to Sta. 52+80.7
Los Nutrias Lateral	10/1/1933	30.6	Plan and Profile from Sta. 0+00 to Sta. 53+00
San Juan Lateral	4/12/1934	N/A	Plan and Profile from Sta. 0+00 to Sta. 53+80, No Discharge Capacity
Belen High Line Canal	1/1/1934	775.4	Plan and Profile from Sta. 2+53.9 to Sta. 61+52.6
Huning Lateral	10/1/1933	101.22	Plan and Profile from Sta. 0+00 to Sta. 52+80
Enrique Lateral	11/1/1935	33.17	Plan and Profile from Sta. 0+00 to Sta. 60+00
Prision Farm Feeder	2/17/1940	N/A	Plan and Profile from Sta. -0+67 to 29+00, No plan view, copy was hard to read, no discharge capacity
Tafoya Lateral	7/1/1993	N/A	Plan and Profile from Sta. 0+00 to Sta. 20+00
Tome Lateral	11/9/1934	34.2	Plan and Profile from Sta. 0+00 to Sta. 12+76
Gabaldon Lateral	3/1/1937	37	Plan and Profile from Sta. 108+47.5 to Sta. 168+00
Gabaldon Lateral	3/1/1937	N/A	Plan and Profile from Sta. 168+00 to Sta. 187+36.1
Garcia Lateral #1	12/1/1933	27.9	Plan and Profile from Sta. 0+00 to Sta. 53+00
Caldwell Lateral	12/15/1947	N/A	Plan and Profile from Sta. 0+00 to Sta. 60+00
Sabinal Ditch	6/1/1934	52.5	Plan and Profile from Sta. 0+00 to Sta. 47+27.4

Jaral Lateral #1	3/1/1934	63.4	Plan and Profile from Sta. 0+00 to Sta. 51+80.7
Jaral Lateral #2	4/1/1934	30.6	Plan and Profile from Sta. 0+00 to Sta. 53+00
Abeytas Lateral #1	8/1/1933	51.2	Plan and Profile from Sta. 0+00 to Sta. 52+80
Sanchez Feeder	3/20/1938	N/A	Plan and Profile from Sta. 0+00 to Sta. 28+00
Sabinal Riverside Drain	3/31/1930	N/A	Plan and Profile from Sta. 0+00 to Sta. 44+60
Cerro Interior Drain	5/1/1933	N/A	Plan and Profile from Sta. -2+45 to Sta. 52+80
Belen Riverside Drain	7/14/1930	N/A	Plan and Profile from Sta. 0+00 to Sta. 60+00

Appendix 4-B
MRGCD Metered Streamflow Metadata

Streamflow data were collected for the model from the real-time MRGCD streamflow metering website hosted by the USBR:

http://www.usbr.gov/pmts/rivers/awards/Nm/rg/RioG/gage/schematic/SCHEMATICnorth.html
http://www.usbr.gov/pmts/rivers/awards/Nm/rg/RioG/gage/schematic/SCHEMATICsouth.html

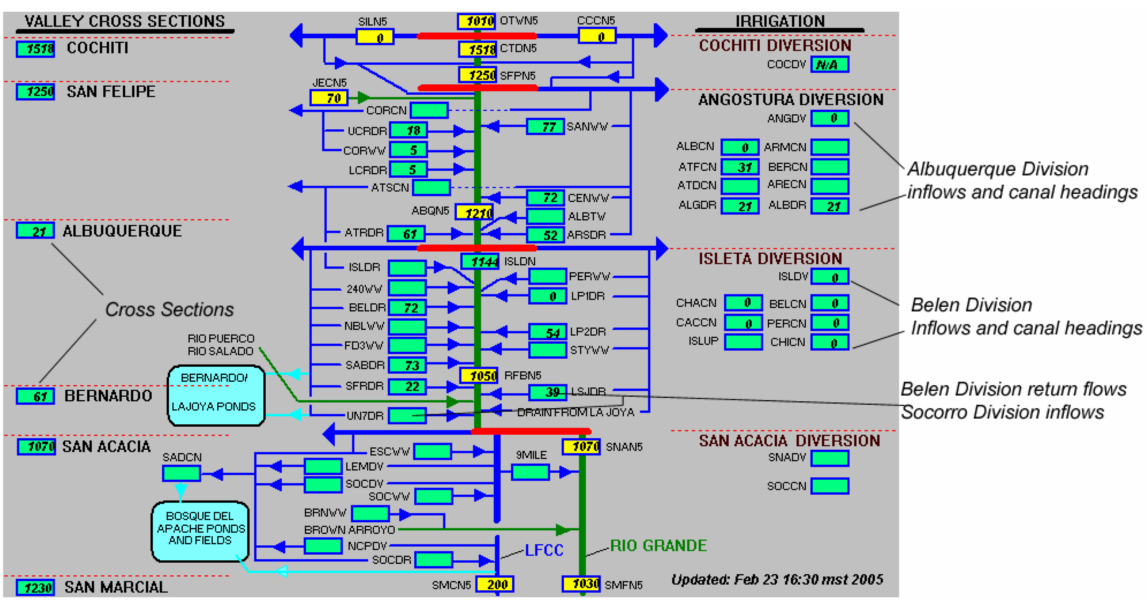
SSPA personnel downloaded provisional real-time streamflow data (2003 and 2004) from the MRGCD websites approximately once a week.

The data downloaded is subject to review and possible revision, it is provisional data, and can only be used for estimation purposes until published by the MRGCD.

The data were downloaded into the following MS Excel workbooks (see attached CD):

- Cochiti and Albuquerque Divisions
- Belen Division
- Socorro Division
- Rio Grande Gages
- Diversions
- X-Sections

The following graphic illustrates the organization of the webpage from which the gage data were downloaded:



Middle Rio Grande Conservancy District (MRGCD) Gage Schematic (Under Development)

In the figure presented above, the green boxes represent MRGCD gages and the yellow boxes represent USGS Rio Grande gages. The staff gage height data is radioed to the MRGCD central office every 30 minutes, fitted to a rating curve, and then uploaded to the webpage. The vertical green line, representing the Rio Grande begins at OTWN5 at the top of the graphic and connects the Diversions at Cochiti, Angostura, Isleta and San Acacia that are represented by the horizontal red lines. The thicker blue lines ending in arrows pointing away from the river represent the diverted flow direction, while the thinner blue lines represent the riverside drains, feeder canals, and return flows. The green boxes to the far left of the graphic post evapotranspiration calculations. For example “Albuquerque”, is the “Summary for: URGWOM Reach 4 (Cen. Ave. to Bernardo gage), Vegetation classification: IKONOS 2000 + USU 2001, ET TOOLBOX classes (ag. + rip. + open water + urb.): 59368.3 acres, (Daily URGWOM Water Use = Daily Consumptive Use Total - Rain) (USBR/MRGCD).

Individual gage information used in this report was collected and organized by SSPA for its report to the NM ISC during 2001 and 2002. (SSPA, 2002) The MRGCD provided the information for the period of record data for and the gage metering equipment.

The MRGCD uses various types of gages and controls to meter flows. For example the Lower Peralta Drain Outfall #1 collects data using a pressure transducer, with gate potentiometer and radio transmitter, the control is a Langemann Weir Gate, and is powered by a solar panel charged battery. The Belen Highline Canal, in 2001, collected data using a Sutron shaft encoder, with a float and radio transmitter; the equipment is housed in a shelter and powered by a solar panel charged battery, with the control being a earthen channel. The staff gage heights are transmitted to the MRGCD main office every 30 minutes and fitted to a rating curve to determine flow before posting to the webpage. Rating curves are developed by the MRGCD from control volumes and calibrated by streamflow measurements. In the Belen Division, the gage information posted for the total Isleta Diversion, (both east and west sides of diversion), is derived from summing the discharges of the five real-time gaged flows at the diversion (SSPA, 2002).

Table below lists the Belen gages, starting with the diversion at Isleta, the inflow to the Belen Division, and ending with the San Juan and Unit 7 Drains at the outflow of the Belen Division. The information referenced for each gage is from S.S. Papadopulos & Associates report to the New Mexico Interstate Stream Commission; *Evaluation of the Middle Rio Grande Conservancy District Irrigation and Measurement Program*; December 2002.

Gage ID	Gage Name	Data Collection	Data Transmission	Quality of Record	Period of Record	Operator
ISLDV	Isleta Diversion	Derived Gage	Calculated from other transmissions	N/A	1966	MRGCD
PERCN	Peralta Main Canal (east side of diversion) at heading of east side of irrigation system	Gage heights are collected every 30 minutes	Transmitted to MRGCD office	Good	(1974) 2001	MRGCD
CHICN	Chical Lateral (east side of diversion) at heading of east side of irrigation system	Gage heights are collected every 30 minutes	Transmitted to MRGCD office	Good	1974	MRGCD
CHACN	Chical Acequia at Heading	Gage heights are collected every 30 minutes	Transmitted to MRGCD office	Good	1974	MRGCD
CACCN	Cacique Acequia at Heading	Gage heights are collected every 30 minutes	Transmitted to MRGCD office	Fair to poor	1974	MRGCD
ISLUP	No data	No data	No data	No data	No data	MRGCD
PERWW	Peralta Main Canal Wasteway	Gage heights are collected	Transmitted to MRGCD office	Good	1999	MRGCD

		every 30 minutes				
LP1DR	Lower Peralta Drain Outfall #1	Gage heights are collected every 30 minutes	Transmitted to MRGCD office	Good	2001	MRGCD
LP2DR	Lower Peralta Drain Outfall #2	Gage heights are collected every 30 minutes	Transmitted to MRGCD office	No data	N/A	MRGCD
STYWW	Storey Wasteway	Gage heights are collected every 30 minutes	Transmitted to MRGCD office	Good	2001	MRGCD
LSJDR	Lower San Juan Riverside Drain Outfall	Gage heights are collected every 30 minutes	Transmitted to MRGCD office	Good to fair	2003	MRGCD
BELCN	Belen Highline Canal (west side of diversion) heading of west side irrigation system	Gage heights are collected every 30 minutes[3]	Transmitted to MRGCD office	Good to fair[4]	1974	MRGCD
ISLDR	Isleta Riverside Drain	Gage heights are collected every 30 minutes	Transmitted to MRGCD office	No data	No data	MRGCD
240WW	240 Wasteway	Gage heights are collected every 30 minutes	Transmitted to MRGCD office	No data	No data	MRGCD
BELDR	Belen Riverside Drain Outfall	Gage heights are collected every 30 minutes	Transmitted to MRGCD office	Good	2000	MRGCD
NBLWW	New Belen Drain Outfall	No data	No data	No data	No data	MRGCD
FD3WW	Feeder #3 Wasteway	Gage heights are collected every 30 minutes	Transmitted to MRGCD office	Good	2000	MRGCD
SABDR	Sabinal Drain Outfall	Gage heights are collected every 30 minutes	Transmitted to MRGCD office	Good	2001	MRGCD
SFRDR	San Francisco Riverside Drain Outfall	Gage heights are collected every 30 minutes	Transmitted to MRGCD office	No data	N/A	MRGCD
UN7DR	Unit #7 Drain	Gage heights are collected	Transmitted to MRGCD office	Fair to poor	No data	MRGCD

[3] Gage heights are fitted to a rating curve to determine discharge before posting to the webpage.
[4] Quality of records follows the USGS standard of accuracy: "Excellent" means that about 95% of the daily discharges are within 5% of the true value; "Good" within 10%; and "Fair" within 15%. Anything less than 'Fair' is rated "Poor". Report of the Rio Grande Compact Commission, 2003

		every 30 minutes				
RFBN5	Rio Grande Floodway near Bernardo, NM	Gage heights are collected every 30 minutes	Transmitted to MRGCD office	No data	No data	USGS

Table 3.1, source: SSPA, 2002

Appendix 4-C

Standard Ditchrider Interview Questions

- What is the ditchrider's usual daily routine?
- How does the ditchrider set up his scheduling and rotation?
- Are there any problems with scheduling and rotation?
- In general, what are the procedures used for water distribution? – is scheduling required? If so, how do the irrigators react you?
- After providing supply to the laterals, who operates the checks?
- Who decides how long a farmer can use water?
- How does he deal with out–of-rotation use?
- How does he know if a farmer is using too much water, or irrigating too often?
- Are the check structures in his service area adequate, or are more necessary?
- Have new gates or gages been installed that have lessened problems in this service area?
- Does the service area consist mainly of small-parcel weekend farms, large full-time farms, or a combination of the two?
- How often is the lateral charged or in use?
- Are there any canals or laterals that need to run full to supply users? If so, why? (Is it because of a large number of free-flow irrigators who do not schedule? Is it because it feeds an important downstream canal or lateral?)
- How does the ditchrider rotate users on the lateral?
- Do you rotate any laterals (between laterals and on a lateral)? If so how do you do it?
- Are there canals and laterals that have high loss rates that lining would fix?
- Is there groundwater use within the area – for irrigation or municipal/industrial use? Has the ditchrider noticed any effects of this groundwater pumping on his operations?
- What other special attributes does the service area have (direct flow from the diversion; variable supply from the Pueblo, problems with gophers or riparian vegetation; etc.)
- Are there any operational problems that are unique to this service area?

<u>Appendix 4-D</u>
Field Notes: Anthony Chavez, Ditchrider & Water Master, Belen Division
Date: 06/02/04

Anthony Chavez has been a ditchrider for 20 years and just recently became the water master for the Belen Division.

Service Area
Anthony's service area is located upstream on the west side. It is comprised of four main and secondary laterals. These laterals include the Belen High Line Lateral from the end of David Apodaca's service area to the beginning of Mel Gallegos' area, the New Belen Acequia from the end of David's area to the outflow, the Harlen-Henderson Lateral from the head gate to the outflow and the Gabaldon Lateral from the head gate to the outflow.

Operations
The main operational problem within Anthony's service area has to deal with ditch breaks and supervising the other ditchriders. Anthony stated that since the Belen High Line is the furthest west lateral in the division, that runoff from the west mesa ends up flowing into the lateral and causing ditch breaks. Also, since Anthony is the Water Master for the Belen Division, he has to be available to help the other ditchriders within the division if they need help, be it questions that the ditchriders can't answer themselves, or helping other ditchriders with issues dealing with the farmers and water. Anthony has no new automated gates within his service area.

Daily Operations
Anthony's day usually starts at 6AM with him starting at the top of his area and working down one lateral to check that the water pressure is good, no debris has accumulated and that nothing has been tampered with on the lateral. Once his finishes going down the lateral he then works up from the bottom of the next lateral to the top and back down again on the following lateral until his whole area has been covered. Once he is done with that, he returns phone calls he might have received, spends a few hours looking over the irrigation for the week and communicates with the farmers to let them know what will be happening. He gets a few personal hours to himself during the afternoon and then he drives his laterals again, and ends his day at 6 or 7PM. He is on call 24/7 but he stated that it isn't bad at night. Scheduling for his area is done on a 10-14 day rotation for new seed and a 21-28 day rotation for established seed. He will follow this schedule until the water supply becomes limited. From talking with other ditchriders, he was able to tell me that when the water becomes limited, the ditchrider will know when and how much water is coming his way and that he is responsible for dividing it up evenly until it runs out.

Every day, Anthony has to schedule water for the farmers so they know when they can expect it and so he knows when and where to provide the water. He stated that the farmers would usually call him when they need the water or would like the water again. He will schedule them and if the water is adequate, he will get them water when the next cycle is ready. This cycle is 7-14 days for new seed, 21-28 day for established crops. If water is not adequate, he will get it to them as soon as it becomes available. He stated that communication was very good between him and the farmers and that they usually know when they can expect to water again. He stated that his communication with the farmer usually occurs by both phone and in person depending on the situation. He likes to have new farmers communicate in person so that they know who he is and what his service area is like and how and when they can expect the water.

Delivery of the water is the next important step in getting the irrigators water. Anthony stated that the farmers operate the checks that deliver the water and that he will operate the head gates to his laterals. All the turnouts require checks but since communication is good between him and the farmers, he will let the farmers operate the checks. The Belen High Line Main Canal delivers the water within his service area.

Anthony was asked if he thought the farm turnouts were located to high or to low or if they were okay compared to the height of the lateral. He stated that most of the turnouts within his service area are good but that there are a couple that are too high because there was a larger pipe at one point and that they changed it to a smaller pipe but never lowered the pipe in the lateral, however, he couldn't tell me exactly where these farm turnouts were located. Anthony also stated that all of his farm turnouts did require checks to receive water, except for the irrigators that take water from the Belen High Line. Most of the irrigators on the Belen High Line are free flow irrigators because the Belen High Line is deep enough and the turnout structures are located deep enough that good water pressure is always present.

Once the water has arrived, the issue of demand and how long the irrigators should water is present. Anthony stated that he doesn't determine demand. He stated that the Belen Division would know how much water to expect within the season by communicating with the other divisions within the district and know how much water is being released from Cochiti Lake and how that will affect them. The farmer will call when they need the water and when his personal schedule says it's their turn; he will get the farmer the water. Anthony will let them irrigate until the farmer believes they are done. He will look at what type of crop is being grown and will usually know how much water the farmer will need for that crop. He allows the irrigators to irrigate until their fields are done. Also, the farmers will let him know how much they need at the beginning of the season but the farmers will usually exaggerate about how long they need to irrigate, but after a few times of watering, Anthony will start to notice exactly how long they are irrigating. He stated that knowing how long irrigation took is good because if a farmer goes over the average time, he can talk to them about not over watering.

Like in every irrigation system, there is a possibility of farmers taking water without scheduling. Anthony stated that if he finds that a farmer has stolen water illegally within his area, he will confront them first hand and make sure that it is only a one-time situation and won't happen again. If it does continue there might be a chance that the farmer will be fined and or his water rights taken away from him. However, Anthony says that stealing water has not happened within his area for a long time.

To help prevent the farmers from taking water illegally and having his laterals tampered with, Anthony was asked if he locks his head gates and check structures. He stated that all of his head gates and check structures are locked. He stated that he definitely makes sure that everything is locked where there are kids present or where people usually party.

Groundwater use within his area could help with ease of rotation. Anthony stated that there are personal wells within his area, but none of his farmers have used them this summer and that they usually use them in the later summer months. There wasn't enough time during the tour to find exactly where the wells were.

Some operational problem can have to do with leaking or bad check structures within his service area. Anthony stated that the checks within his service area were pretty old and that he has a couple that have wagon wheels on the side of them. However, they are adequate, they just need to be updated.

Since this project is trying to place everyone on rotation, out of rotation use can become a problem. Anthony stated that out of rotation use was not a problem in his area, the Belen High Line Main Canal is the only lateral that is not on rotation because it is constantly full. It is constantly full because it is the Main Canal for the West side of the River. However, the farmers will tell him when they want to water and he will keep them on the new seed, established crop schedule and get them their water when they need it.

Water-short years can be a big concern within the New Mexico area and when this happens, ditchrider responsibilities can increase. Anthony stated that in water short years, he fans out the water and divides it equally until the water runs out. However, when the water runs out, he performs the same tasks as if it were a typical day with water running in every canal. He drives his laterals just in case a big gush of water was to come into the laterals from rain or from somewhere else, he would be ready.

Observations by the Ditchrider

Improvements within the division can be a big concern and Anthony was asked if there were any improvements that he would like to see within his service area or the division. He stated that he would like to see all farmers get better equipment and that they should all laser level their farms because the efficient is better with laser level than without. Also, he thinks changing some of the lateral to piping or concrete lined would increase delivery of the water because seepage wouldn't occur that often. He would particularly like to see this happen on the Belen High Line Canal.

Service Area Tour

This project is going to try to place every lateral on rotation so it was important to know how the ditchrider services his laterals. Anthony stated that all his laterals except one are on a rotation basis. The only one that isn't on rotation is the Belen High Line Main Canal. This lateral isn't on rotation because it is the main canal for the west side of the river.

Belen High Line Lateral

The Belen High Line if fed directly from the diversion dam and dumps into feeder 3 waste way. This Canal is long and has 4 ditchriders on it. The canal runs continuously since it is a Main Canal and feeds the entire west side. This canal is unique in that it collects most of the runoff in rain events on the west side of the division and needs to be shut off when this occurs so flooding with not occur with in the area. This happens by opening the new automated check at the 240 waste way or closing the gate at the diversion dam. He does not rotate this lateral because it runs continuously. Most if not all of the irrigators on this Main Canal are free flowing irrigators.

New Belen Acequia

The New Belen Acequia feeds from just below the new automated gate on the 240 waste way and it drains into the New Belen Wasteway. Anthony is the second ditchrider on this lateral and his service area starts when David Apodaca's service area ends. This lateral is on a rotation basis within his area and while this is going on it flows continuously. It takes 2-3 weeks to rotate this lateral. Anthony rotates it from top to bottom. When irrigation is caught up later in the season, the Acequia is cut back to about 30% to 40% of full until the rotation needs to start again. Anthony is in charge of this lateral from Morris Road down to the waste way. It is uncertain how many checks Anthony can drop on this lateral at one time.

Harlen-Henderson Lateral

The Harlen-Henderson Lateral feeds from the Belen High Line, the New Belen Acequia and the Los Lunas Acequia and drains into the Los Chavez drain. The lateral is on a rotation basis and takes 3 weeks to complete. This rotation basis starts from the top down and when the rotation is going on, the water flows continuously, however every 3 weeks, the lateral will shut down for a couple days to a week for maintenance and until the rotation starts back up again. It is uncertain how many checks Anthony can drop on this lateral at one time.

Appendix 4-E: Discharge Measurement Sheet for Belen High Line Canal Upstream Location

Flow Measurement Field Data

Location: Belen High Line Upstream

Total Discharge (cfs): 92.28813

Start Time: 9:45

End Time: 10:45

Date: 8/11/2004

LEW: 0

REW: 17

Channel Width: 17

Beginning Staff Gage (ft.): ________

Ending Staff Gage (ft.): ________

Personnel:

	Distance (ft)	Width (ft)	Depth (ft)	Area (sqft)	60% or 80%	20%	Avg (ft/sec)	Discharge (cfs)
1	0.5	1	3.2	3.2	2.18	2.53	2.355	***7.536***
2	1.25	0.5	3.4	1.7	1.8	2.4	2.1	***3.57***
3	1.75	0.5	4	2	1.69	2.41	2.05	***4.1***
4	2.25	0.5	3.8	1.9	1.4	2.52	1.96	***3.724***
5	2.75	0.5	3.8	1.9	1.28	2.4	1.84	***3.496***
6	3.25	0.5	3.85	1.925	1.46	2.44	1.95	***3.75375***
7	3.75	0.5	3.7	1.85	1.53	2.56	2.045	***3.78325***
8	4.25	0.5	3.75	1.875	0.85	2.55	1.7	***3.1875***
9	4.75	0.5	3.8	1.9	0.17	2.43	1.3	***2.47***
10	5.25	0.5	3.6	1.8	1.61	2.54	2.075	***3.735***
11	5.75	0.5	3.6	1.8	1.62	2.45	2.035	***3.663***
12	6.25	0.5	3.5	1.75	1.71	2.46	2.085	***3.64875***
13	6.75	0.5	3.4	1.7	1.67	2.47	2.07	***3.519***
14	7.25	0.5	3.2	1.6	1.77	2.45	2.11	***3.376***
15	7.75	0.5	3.2	1.6	1.71	2.54	2.125	***3.4***
16	8.25	0.5	3.15	1.575	1.41	2.52	1.965	***3.094875***
17	8.75	0.5	3.15	1.575	1.66	2.37	2.015	***3.173625***
18	9.25	0.5	3.05	1.525	1.85	2.41	2.13	***3.24825***
19	9.75	0.5	3	1.5	1.81	2.37	2.09	***3.135***
20	10.25	0.5	3	1.5	1.88	2.3	2.09	***3.135***
21	10.75	0.5	3	1.5	1.83	2.36	2.095	***3.1425***
22	11.25	0.5	2.9	1.45	1.67	2.29	1.98	***2.871***
23	11.75	0.5	2.7	1.35	1.64	2.03	1.835	***2.47725***
24	12.25	0.5	2.5	1.25	1.76	2.07	1.915	***2.39375***
25	13	1	2.3	2.3	1.26	2	1.63	***3.749***

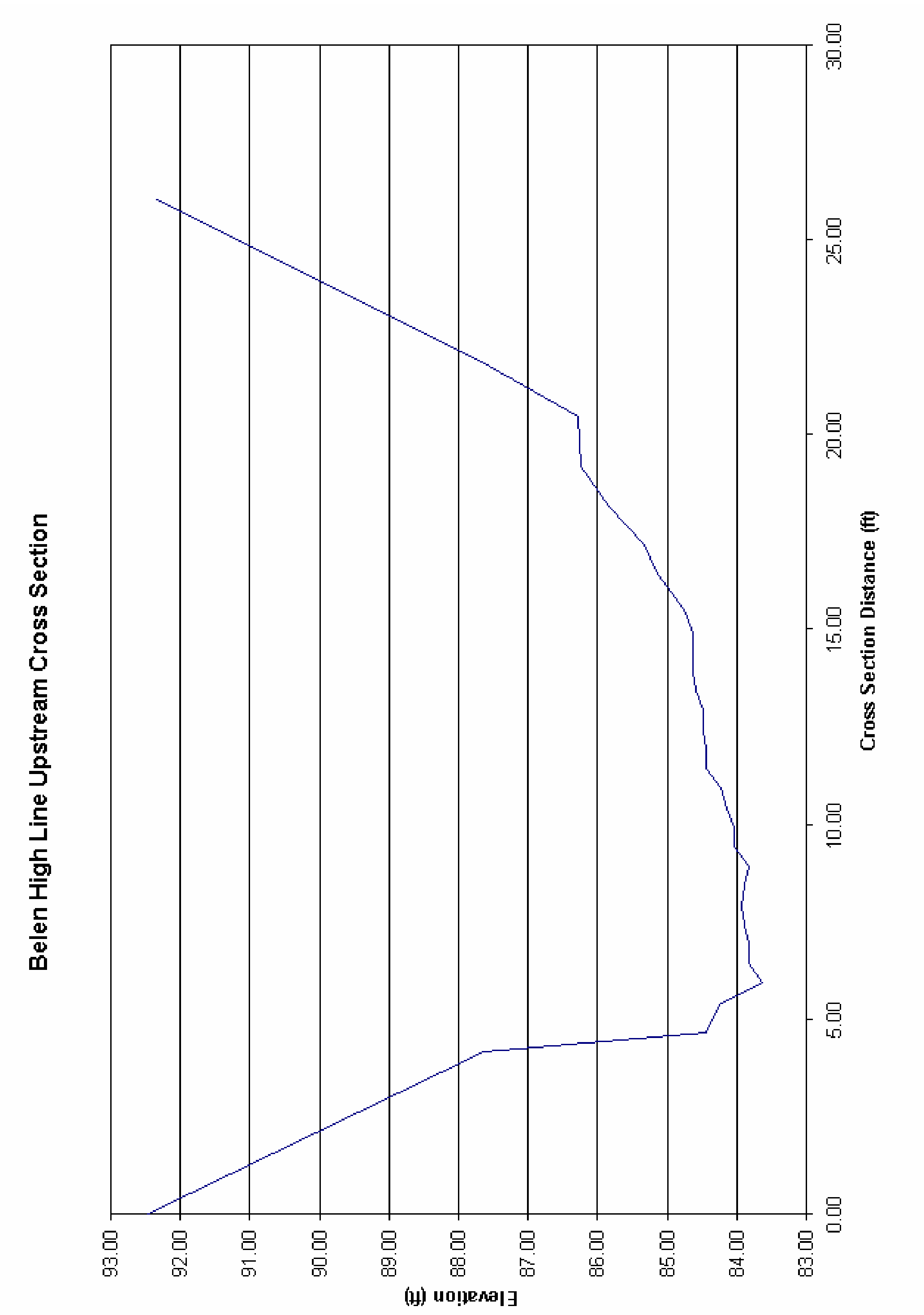
26	14	1	1.8	1.8	1.71		1.71	***3.078***
27	15	1	1.4	1.4	0.98		0.98	***1.372***
28	16.3	0.75	1.35	1.0125	0.45		0.45	0.455625
29				0			0	0
30				0			0	0
31				0			0	0
32				0			0	0
33				0			0	0
34				0			0	0
35				0			0	0
36				0			0	0
37				0			0	0
38				0			0	0
39				0			0	0
40				0			0	0
41				0			0	0
42				0			0	0
43				0			0	0
44				0			0	0
45				0			0	0
						Excel derive		**92.288125**
						5%		**4.61440625**

Appendix 4-F: **Cross Section Survey Input Sheet and Graph – Belen High Line Upstream Location**

Location: Belen High Line Main Canal Upstream
Date: 8/4/2004
Setup: Downstream on the Left Bank
Type of Survey: Cross Section Survey

Hi Stad	Low Stad	Difference	Length from Transit	Degree	Discharge Measurement Cross Section Distance	Cross Section Distance	Rod Read	Discharge Measurement Depth	Elevation	Description
7.729166667	7.40	0.33	33.33	0.00	-	0.00	7.53	-	92.47	East End of Bridge on Left Bank
12.52083333	12.22	0.30	30.21	-5.00	-	4.17	12.36	-	87.64	ter Edge Left Bank - changed deg
-	-	-	-	-	0.50	4.67	-	3.20	84.44	
-	-	-	-	-	1.25	5.42	-	3.40	84.24	
-	-	-	-	-	1.75	5.92	-	4.00	83.64	
-	-	-	-	-	2.25	6.42	-	3.80	83.84	
-	-	-	-	-	2.75	6.92	-	3.80	83.84	
-	-	-	-	-	3.25	7.42	-	3.75	83.89	
-	-	-	-	-	3.75	7.92	-	3.70	83.94	
-	-	-	-	-	4.25	8.42	-	3.75	83.89	
-	-	-	-	-	4.75	8.92	-	3.80	83.84	
-	-	-	-	-	5.25	9.42	-	3.60	84.04	
-	-	-	-	-	5.75	9.92	-	3.60	84.04	
-	-	-	-	-	6.25	10.42	-	3.50	84.14	
-	-	-	-	-	6.75	10.92	-	3.40	84.24	
-	-	-	-	-	7.25	11.42	-	3.20	84.44	
-	-	-	-	-	7.75	11.92	-	3.20	84.44	
-	-	-	-	-	8.25	12.42	-	3.15	84.49	
-	-	-	-	-	8.75	12.92	-	3.15	84.49	
-	-	-	-	-	9.25	13.42	-	3.05	84.59	
-	-	-	-	-	9.75	13.92	-	3.00	84.64	
-	-	-	-	-	10.25	14.42	-	3.00	84.64	
-	-	-	-	-	10.75	14.92	-	3.00	84.64	
-	-	-	-	-	11.25	15.42	-	2.90	84.74	
-	-	-	-	-	11.75	15.92	-	2.70	84.94	
-	-	-	-	-	12.25	16.42	-	2.50	85.14	
-	-	-	-	-	13.00	17.17	-	2.30	85.34	
-	-	-	-	-	14.00	18.17	-	1.80	85.84	
-	-	-	-	-	15.00	19.17	-	1.40	86.24	
-	-	-	-	-	16.30	20.47	-	1.35	86.29	
12.375	12.21	0.17	16.67	24.58	-	21.91	12.29	-	87.71	Water Edge Right Bank
7.71875	7.55	0.17	16.67	Point Unknown	-	26.08	7.65	-	92.35	West End of Bridge on Right Bank

Note: An arbitrary elevation of 100ft is used as transit level elevation
Note: All elevation calculations that were taken from the Discharge measurement sheet was subtracted from the Left Bank Water Edge Elevation


Belen High Line Upstream Cross Section
Elevation (ft)
93.00
92.00
91.00
90.00
89.00
88.00
87.00
86.00
85.00
84.00
83.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
Cross Section Distance (ft)

Appendix 4-G: Estimation of Canal Seepage Loss-- Discharge measurements and Analysis

Several main canals/laterals were selected for seepage analysis based on their apparent representation of a typical channel within the irrigation system. Belen Highline Canal is a major canal supplied by the Isleta Diversion and is the primary conveyance for west side irrigation in the Belen Division. Peralta Main Canal was considered, however, the numerous inflows and outflows were not accessible to measure safely. San Juan Main Canal is supplied by returns from upstream irrigation and flow diverted into the Peralta Riverside Drain. San Juan Main Canal is the main conveyance for the Belen Division's lower east side and the only other major conveyance where a stretch over one mile in length was safely accessible.

A Marsh-McBirney FLOWMATE 2000 was used to perform the discharge measurements. To determine the accuracy of the discharge data, standard USGS measuring protocol was followed, including the 5% rule. The protocol divides the width of the channel into cells, and the target measurement is that all cells measured are under or in close proximity of 5% of the total flow.

Cell width was determined by estimating the flow either by checking a posted upstream gaged flow on the internet or by taking a couple of measurements and determining a rough estimate of the flow. After estimating the flow cell width was adjusted so that the discharge in the cell was measured at less than 5% of the estimated total flow. Discharge measurements were taken in the middle width of the cells at 60% of the depth (e.g. for a depth of 1.5 feet, the sensor is set at 0.9 feet from water surface). For depths over 2.5 feet, measurements were taken at 80% and 20% of the total depth. Four and eight foot Rickly Hydrological "Top Set Wading Rods" were used to hold the flow sensor bulb and determine depths.

Total flow was calculated as the sum of the cell flows for each cross section. The table below lists the flow measurements and the gain/loss for each canal or lateral. The gain/loss was calculated using the following formula:

$$\text{Canal Seepage} = (Q_2 + D - Q_1) / L$$

Where:
Q = flow (cfs), Q_1 is the upstream measurement and Q_2 is the downstream measurement.
D = diversions (cfs)
L = distance between measurements (mile)

Canal/Lateral Gain/Loss Analysis

Location	Date	Upstream Discharge (cfs)	Downstream Discharge (cfs)	Diversion (cfs)	Distance (miles)	Gain (+) or Loss (-) (cfs/mile)
Tome Acequia	3-Aug-04	23.0	25.0	0.0	2.2	0.9
San Juan Main Canal	4-Aug-04	95.0	103.0	0.0	1.2	6.7
Belen Grant	5-Aug-04	15.0	15.0	0.0	4.2	0.0
Garcia Lateral	9-Aug-04	27.0	29.0	0.0	3.2	0.6
Los Chavez Lateral	10-Aug-04	32.0	n/a	0.0	0.0	n/a
Belen Highline Canal	11-Aug-04	92.0	70.0	19.0	9.0	-0.3

The large gain per mile in the San Juan Main Canal is partially explained by the geologic features in the reach. The earthen channel follows the contour at the base of an abrupt rise in elevation from the heading of the canal to well past the downstream measurement. The 6.7 cubic foot per mile loss calculated for the San Juan Main Canal translates to 13.3 acre-foot per mile per day gain .

The Belen Highline canal reach that was measured runs along the western side of the river, and feeds the whole flood plain on the west side. The geology of the reach measured is unconsolidated sand and gravel. The 0.333 cubic foot per mile loss calculated for the Belen Highline translates to 0.66 acre-feet per mile per day loss.

The reaches measured on the Tome Acequia, Garcia Lateral, and the Belen Grant #2 run parallel to the riverside drain and at times are within 100 feet of the drain. The close proximity to the riverside drain might explain the gain or zero loss in these reaches.

The Los Chavez Lateral discharge measurements were not completed because multiple turnouts were opened when farmers began irrigating that day. Due to time constraints, the measurements were not repeated.

The calculated gains and losses reflect the conditions on the day of the measurements and do not necessarily reflect daily conditions throughout the year. Considering that the measurements were taken during the monsoon season, conditions could vary during wetter or drier conditions.