THESIS

DECISION SUPPORT SYSTEMS FOR MANAGING EFFICIENT IRRIGATION WATER DELIVERIES – A CASE STUDY OF IRRIGATED AGRICULTURE IN THE MIDDLE RIO GRANDE

Submitted by

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ABSTRACT

DECISION SUPPORT SYSTEMS FOR MANAGING EFFICIENT IRRIGATION WATER DELIVERIES – A CASE STUDY OF IRRIGATED AGRICULTURE IN THE MIDDLE RIO GRANDE

Irrigation has been practiced for centuries in the Middle Rio Grande (MRG) Valley of New Mexico. Many of the practices governing irrigation in earlier times, both by Native Americans and by Spanish settlers, are continued into the present day.

In recent years, considerable pressure has fallen on the Middle Rio Grande Conservancy District (MRGCD) to decrease its water diversions from the Rio Grande and to allow more water to remain in the river for ecological uses. This pressure has stemmed from increasing and competing water demands and interest in the preservation of natural habitat associated with the river, especially the endangered Rio Grande silvery minnow *(Hybognathus amarus).* The MRGCD has opted to modernize its physical infrastructure and improve water delivery practices to more efficiently utilize diversions from the Rio Grande, and meet farm demands with reduced river diversions.

To reach this goal while still providing farmers with adequate supplies, the MRGCD has employed scheduled water delivery. Scheduled water delivery introduces significant management challenges that can be addressed using Decision Support

Systems (DSS). The MRGCD DSS was successfully implemented in the Peralta Main service area during the year 2009. This thesis presents a hypothetical evaluation of the implementation of the Decision Support System (DSS) as a guiding tool for farmers to improve irrigation water scheduling management in the Albuquerque Division of the MRGCD. Specifically, this research evaluates the question of whether the use of the DSS for scheduling irrigation water deliveries would result in reduced river water diversion, efficiently improve irrigation water scheduling management, and identify required infrastructure improvements while still meeting all crop water requirements.

The study verified the hypothesis that a DSS can proficiently and justifiably be utilized to manage scheduled water delivery operations in the Albuquerque Division of the MRGCD. A DSS combined with infrastructure improvement and SCADA inclusion can significantly reduce river diversion while still serving water users demands. Overall, the DSS can provide the MRGCD with a powerful tool that can be used to efficiently schedule water delivery, determine appropriate water use, improve reservoir operations and sustain irrigated agriculture in the face of future water management challenges.

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ABBREVIATED TERMS

AWHC	Available Water Holding Capacity
DSS	Decision Support System
ESACP	Endangered Species Act Collaborative Program
MRG	Middle Rio Grande
MRGCD	Middle Rio Grande Conservancy District
RAM	Readily Available Moisture
RGSM	Rio Grande Silvery Monnow
RWD	Rotational Water Delivery
RWS	Relative Water Supply
SJC	San Juan Chama
SCADA	Supervisory Control and Data Acquisition
SWD	Scheduled Water Delivery
SSPA	S.S. Papadopulos and Associates, Inc.
USACE	U.S. Army Corps of Engineers
USBR	U.S. Bureau of Reclamation
USCB	U.S. Census Bureau
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
VHGA	Van H. Gilbert Architect

CHAPTER 1. INTRODUCTION

1.1 Introduction

Irrigation has been practiced for centuries in the Middle Rio Grande (MRG) Valley of New Mexico. Many of the practices governing irrigation in earlier times, both by Native Americans and by Spanish settlers, are continued into the present day.

In recent years, considerable pressure has fallen on the Middle Rio Grande Conservancy District (MRGCD) to decrease water diversions from the Rio Grande and to allow more water to remain in the river for ecological uses. This pressure has stemmed from increasing and competing water demands and interest in the preservation of natural habitat associated with the river, especially for endangered species. The MRGCD has opted to modernize its physical infrastructure and improve water delivery practices to more efficiently utilize diversions from the Rio Grande, and meet farm demands with reduced river diversions. This thesis evaluates a Decision Support System (DSS) as a tool for farmers to manage irrigation water scheduling in the Albuquerque Division.

1.2 Problem Statement

The Rio Grande is one of the few large rivers in the American Southwest and it supports a diverse set of ecosystems as well as urban, industrial, interstate, and agricultural demands. Available water is fully allocated among users, and demand for the limited water supply continues to grow (Gensler et al., 2009; Oad et al., 2009; Oad and

Kinzli, 2006; Oad and Kullman, 2006) as the population increases and drought conditions persist in the Southwest. The native flow of the Rio Grande is limited, and cannot meet urban, industrial, interstate, ecological and agricultural demands during severe drought conditions. Competition for this limited water resource has greatly increased during the last decade and many complex issues have arisen as environmental concerns require a larger portion of available water (Kinzli and Myrick, 2009; Oad et al., 2009; Oad and Kinzli, 2006).

The MRG Valley cannot support increasing water demand and large irrigation diversions from the river limit the amount of water available in the valley. Additionally, the State of New Mexico is concerned that large irrigation diversions are unsustainable and will not support future demands. A more recent concern, brought forth by the Endangered Species Act Collaborative Program (ESACP), is that large diversions from the river have negatively impacted the river ecosystem and wildlife, specifically the endangered Rio Grande silvery minnow (RGSM).

To reach this goal while still providing farmers with adequate supplies, the MRGCD has employed scheduled water delivery through the development of the MRGCD DSS. The MRGCD DSS was successfully validated and implemented in the Peralta Main Canal during the 2009 irrigation season (Kinzli, 2010).

1.3 Hypothesis

The research premise is that the MRGCD can conserve more water and support the larger water supply concerns in the MRG Valley. Based on this premise it is hypothesized that the Albuquerque Division of the MRGCD can implement scheduled water delivery (SWD) through the use of a DSS, while decreasing the amount of diversions from the river for irrigation purposes.

The overall objective of this research was to evaluate DSS options that would enable the MRGCD to;

a) Improve irrigation water management and scheduling.
b) Maintain water delivery to the farmers.
c) Achieve reduction in river diversions.

This research does not address the complex issues concerning Endangered Species Act in the Rio Grande ecosystem. It is the opinion of the U.S. Fish and Wildlife Service (USFWS) that irrigated agriculture in the MRG Valley diverts excessive water from the river and eventually influences the survival of the RGSM and Southwest willow flycatcher (USFWS, 2003b). This research acknowledges the importance of a healthy river ecosystem and approaches it from the view point that improved irrigation scheduling will result in reduction of river diversions from the Rio Grande River. This could help improve the health of the river ecosystem.

1.4 Objectives and Scope

The overall objective of the research presented in this thesis was to evaluate a hypothetical application of the DSS in irrigation water scheduling as a guiding tool for farmers in the Albuquerque Division for the 2009 irrigation season. The goal of the research was to validate the effectiveness of the DSS in predicting diversions from the river, while meeting the requirements of the farmers.

The overall objectives of this research were to hypothetically evaluate the question whether the use of MRGCD DSS, in the Albuquerque Division, for scheduling irrigation water deliveries would:

- Result in reduced river water diversion?
- Identify required infrastructure improvement?
- Efficiently improve irrigation water scheduling management, and
- Identify required infrastructure improvements while still meeting all crop water requirements.

The analyses were done for the Albuquerque Division of the MRGCD, and diversion data for the year 2009 were utilized.

Irrigation systems can meet user demand and reduce water supply diverted by improving the physical irrigation system and by adopting improved water management practices. This research emphasizes improving the management of irrigation scheduling by the application of a DSS. This research is concerned with improving the current performance of irrigation scheduling in the Albuquerque Division. Also, this research does not address MRGCD's entitlement to water use under state law.

A significant amount of water diverted from the Rio Grande River by the MRGCD is returned further downstream, where it is diverted for use in other areas. If irrigation scheduling is improved, the river diversion will be reduced, and the timing of irrigation return flows will also change. The resultant change on the downstream water use and the resulting impact in the river ecosystem were not addressed in this research.

The MRGCD provides irrigation services to six Native American pueblos. Pueblo irrigators are recognized as having senior water rights and operate separately from

MRGCD management. This research did not address river diversions for pueblo irrigators nor did it attempt to schedule water delivery in the six Native American pueblos.

1.5 Approach

A main research priority was to understand the MRGCD's current water operation procedures, especially in the Albuquerque Division. The first step was to conduct extensive interviews with ditch-riders and MRGCD technical staff. This procedure involved the "riding" of the canals, laterals and ditches within the ditch-riders service area.   A related step in understanding the current MRGCD procedure was to identify the infrastructure presently in use, identify any potential improvements necessary for irrigation water scheduling in the Albuquerque Division, and to understand the basic logistics followed in allocating irrigation water to the users. The final step was to compare the DSS recommended diversions and actual diversions, and explore the correlation between the two.

1.6 Framework

The research framework is guided by the scheduled water delivery concept (SWD), which is used in irrigation systems worldwide, to improve water delivery and to support water conservation. In SWD (Figure 1.1), a main canal receives water from river diversions and feeds lateral canals according to their need for water, allowing water use in some laterals while others are closed. In addition to water scheduling among laterals, there can be scheduling within laterals whereby water use is distributed among farm turnouts or check structures along a lateral. By distributing water among users in a systematic fashion based on crop demand (as opposed to continuous delivery), an irrigation district can decrease water diversions and still meet crop water use requirements.

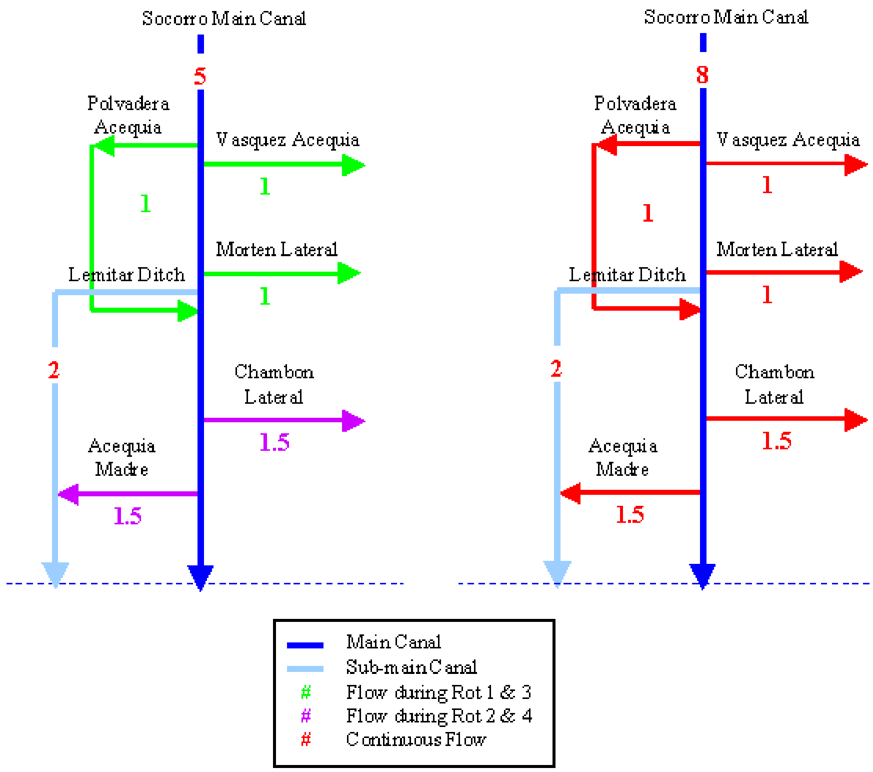

Figure 1.1 Schematic Showing Scheduled Water Delivery (Barta, 2003)

Previous research by Barta (now Kullman) (Oad and Kullman, 2006; Barta, 2003) examined operational procedures that would reduce river diversions in the Middle Rio Grande Valley. Kullman found that scheduled water delivery in the MRGCD could theoretically reduce river diversions by up to 40% (Oad and Kullman, 2006).

CHAPTER 2. BACKGROUND

This chapter provides background on water supply and demand in the MRG Valley. The purpose is to develop a general understanding of water supply and demand, and how water is allocated among various users in the MRG Valley as water allocation and use in the MRG are a complex subject.

2.1 Description of the Middle Rio Grande Valley

The MRG Valley (Figure 2.1) runs north to south through central New Mexico from Cochiti Reservoir to the headwaters of Elephant Butte Reservoir, a distance of approximately 175 miles. The valley is narrow, with the majority of water use occurring within five miles on either side of the river. The bosque (Spanish for forest) of native cottonwood (Populus fremontii) and non-native salt cedar (Tamarix ramosissima) is supported by waters of the Rio Grande. Surrounding the bosque is widespread irrigated farming. From an aerial viewpoint, the river valley appears as a meandering ribbon of green in contrast to the surrounding semi-arid desert (Barta, 2003). 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 (DuMars and Nunn, 1993).

Water has been considered an important resource to the MRG, even prior to Spanish settlement in the late 1500's. Indian pueblos in the region today still express its importance in the practice of their culture and maintenance of traditions (Becker, 2001). As a desert region that continues to grow in population, the MRG Valley is under constant pressure to provide for increasing water needs.

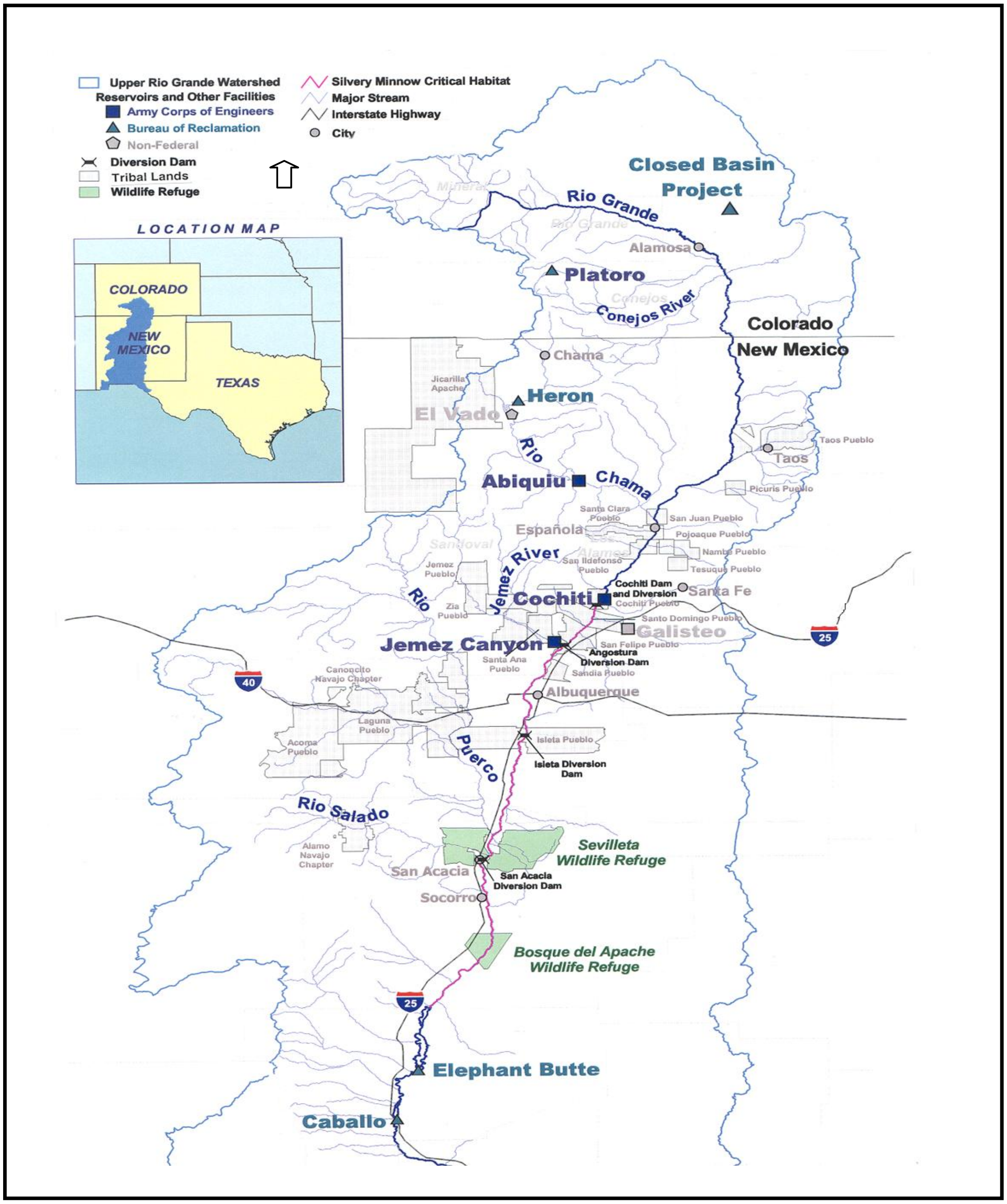

Figure 2.1 The Middle Rio Grande Valley (MRGCD, 2003)

2.2 Water Supply

Regional water supply includes native surface water, groundwater and a trans-mountain diversion. As there are very few reservoirs within the MRG Valley, regional water supply is regulated through reservoirs owned by various agencies in the Upper Rio

Grande Valley, which include the U.S. Army Corps of Engineers (USACE), U.S. Bureau of Reclamation (USBR), and the MRGCD.

Native Flow

The Rio Grande originates in southwest Colorado's San Juan Mountain Range, and flows south through the center of New Mexico eventually turning east to form the border between the state of Texas and Mexico. The major tributaries of the Rio Grande are the Conejos River in Colorado, the Chama, Jemez, Rio Puerco and Rio Salado Rivers in New Mexico, and the Pecos River in Texas. The Rio Grande empties into the Gulf of Mexico at Boca Chica Beach, Texas (Google Earth, 2006). The Rio Grande Basin within the lower part of Colorado and within New Mexico south to Elephant Butte can be seen in Figure 2.1.

Water in the MRG Valley is fully appropriated and depletion of surface water is limited by the Rio Grande Compact of 1938. Set forth in the Compact is a schedule of deliveries of native Rio Grande water from Colorado to New Mexico, and then on to Texas. New Mexico's required delivery to Texas is determined using gauged flow on the Rio Grande at Otowi Bridge near San Ildefonso Pueblo, and water deliveries to Texas occur at Elephant Butte Reservoir. Water obligation to Texas is measured on a sliding scale and is a percentage of the flow passing Otowi Bridge. For example, in an average year when 1,100,000 ac-ft (1,345,850,000 m^3) of water passes Otowi Bridge, approximately 393,000 ac-ft (480,835,500 m^3) of the 1,100,000 ac-ft (1,345,850,000 m^3) is available for use in the MRG Valley (Rio Grande Compact Commission, 1997). According to the sliding scale, the maximum amount of native flow available for use in the MRG Valley is 405,000 ac-ft/year (495,517,500 m^3/year) (Rio Grande Compact Commission, 1997).

Groundwater

Groundwater supply in the region is currently derived from stream-connected aquifers. In the vicinity of Albuquerque, the former stream-connected aquifer has been disconnected from the river as a result of pumping, estimated to be 191,844,800 m^3/yr (SSPA, 2000). Compared to stream-connected aquifers in which pumping impacts on the river are relatively immediate, this disconnect has created further delay in the time for pumping impacts to be observed in the river. Because groundwater withdrawals ultimately result in river depletions and because river flows are considered fully appropriated, groundwater does not represent an additional supply (SSPA, 2000).

Trans-Mountain Diversion

The USBR began diverting water from tributaries of the San Juan River in the Colorado River Basin in 1971, through the San Juan Chama Project (SJC). The SJC consists of a system of diversion structures and tunnels that allow trans-mountain movement of water from the San Juan River Basin to the Rio Grande Basin. The project takes water from three upper tributaries of the San Juan River, namely the Navajo, Little Navajo, and Blanco Rivers (USBR, 2005), and delivers water through a system of siphons and tunnels that converge at a point on the Navajo River. From there the water is transported to the Rio Grande Basin via the 12.8 mile long, 950 cfs capacity Azotea Tunnel (USBR, 2005). The water enters the Rio Grande Basin through Azotea and Willow Creeks and flows downstream to be stored in Heron Reservoir. The project was designed by the USBR and was completed in 1971. The SJC Project provided an average of 75, 844 ac-ft/yr (92, 795, 135m^3/yr) from 1990 to 1998 to the MRG Valley (SSPA, 2000). The primary purpose of the diversion is to supplement the supply for the municipal, agricultural and industrial water users in the MRG Valley (USBR, 2005). From the average annual diversion of the SJC Project, the Middle Rio Grande Conservancy District (MRGCD) can withdraw 20,900 ac-ft for agricultural use (USBR, 2005).

2.3 Water Demand

Water demand in the MRG Valley is comprised of multiple users which include: (1) the Rio Grande Compact, (2) urban and industrial users, (3) Endangered Species Act, and (4) the MRGCD. With water being fully allocated, the four main users compete for limited water resources as the population in the MRG Valley expands. Consumptive uses from vegetation along 175 miles of the MRG and water evaporation from the river's surface add an additional demand to an already fully allocated water resource. Complete allocation and consumptive use along the river have led to water disputes, which are exacerbated during drought conditions.

Rio Grande Compact

Annual yield from the Rio Grande is allocated annually among states insuring an equitable apportionment for use (Barta, 2003) and water depletions in the MRG Valley are limited by the State of New Mexico to ensure that Rio Grande Compact obligations to New Mexico, Colorado, and Texas are met. The Rio Grande Compact uses credits and debits to allocate water rights to the three states and limits the amount of debit or under-delivery of water to downstream states. Colorado can acquire a debit of up to 100,000 ac-ft to New Mexico and New Mexico can accrue a debit of up to 200,000 ac-ft to Texas (Rio Grande Compact Commission, 1997).

The portion of the Rio Grande under New Mexico jurisdiction starts at the Colorado-New Mexico line and ends at Elephant Butte Reservoir (Figure 2.1). The difference between the amount of water passing through Otowi Bridge and the amount necessary to pass through the Elephant Butte Dam, plus change in water supply between these two points, is the amount of surface water available for depletion in the MRG Valley (SSPA, 2000). Under normal flow conditions the Rio Grande Compact allocates 400,000 ac-ft for use in the MRG Valley.

Recent persistent drought conditions in the MRG Valley and demands associated with the RGSM have reduced stored water available for both irrigation and meeting New Mexico's compact obligations to Texas (Kinzli, 2010). Under low water conditions, Article VII of the Rio Grande Compact prohibits water storage in reservoirs above Elephant Butte Reservoir that were constructed after 1929 (Barta, 2003). In practice, Article VII prohibits storage of Rio Grande water for use in the MRG Valley until the allocated delivery to Texas in Elephant Butte Reservoir reaches 400,000 ac-ft.

Urban and Industrial

In 2000, there were approximately 690,000 inhabitants in the MRG Valley (USGS, 2002). Of those, 445,000 (65%) lived in the greater Albuquerque area (USCB, 2000). There has been a steady increase in population growth in the MRG Valley since the 1950's. Development in the area has been supported by the San Juan Chama Project and increased groundwater pumping in the vicinity of Albuquerque (Barta, 2003). In 2009 the Albuquerque water treatment plant completed an inflatable diversion dam and began to use SJC project water that was previously available for other entities, and the utilization of this water exacerbated the already complex and intricate delivery of water throughout the valley (Kinzli, 2010). A shift from rural to urban and industrial use has also increased groundwater demand in the region (Hansen and Gorbach, 1997). Unfortunately, since the only water source for Albuquerque is the SJC project and groundwater, the aquifer depletion rates continue to exceed recharge rates (Earp et al., 1998). Although groundwater supports current urban and industrial demand, it is not a sustainable option for the future if population growth continues.

Endangered Species Act

The Rio Grande silvery minnow (RGSM, Figure 2.2) is one of seven species in the genus *Hybognathus* found in the United States (Bestgen and Propst, 1996). It is believed that the RGSM existed on the Rio Grande upstream of Cochiti Reservoir, in the downstream reaches of the Chama and Jemez Rivers and throughout the Middle and Lower Rio Grande Valleys to the Gulf of Mexico (Wilber, 2001). The RGSM is small for the genus *Hybognathus* and rarely exceeds a total length of 3.5 inches (Bestgen and Platania, 1991). The RGSM is so named because the sides and back appear silver to olive in color (Bestgen and Propst, 1996). Historically, the RGSM thrived in 2,465 miles of rivers in New Mexico and Texas (Kinzli and Myrick, 2009). Extirpated from over 95 percent of its historic range, existing populations of the RGSM are found only in the MRG Valley (USFWS, 2003c).

Figure 2.2 Rio Grande Silvery Minnow (*Hybognathus* *Amarus*) (Kinzli, 2010)

The USBR and the USACE, in consultation with the USFWS have developed water operations and river maintenance procedures using biological assessments that are critical to the survival and recovery of the RGSM (USFWS, 2003a; USFWS 2003b). These procedures include timing of flow requirements to help initiate spawning, implementing minimum flow requirements along the Rio Grande, and realizing habitat improvements to help with the survival of the RGSM (USFWS, 2003b). The biological assessments led to the designation of critical habitat for the RGSM in March 2003. The critical habitat designation forces federal agencies, the State of New Mexico and the MRGCD to take actions that will ensure the survival of the RGSM (Gallea, 2005). The area designated as critical habitat includes the entire Rio Grande from Cochiti Dam to Elephant Butte Reservoir, and encompasses the MRGCD.

To aid in the recovery of the RGSM the Albuquerque Bernalillo County Water Utility Authority has developed a rearing and breeding facility at the Albuquerque Biological Park, with the goal of rearing 50,000 young fish per year (VHGA, 2006). The facility is designed to produce 50,000 minnows a year with 25,000 minnows to be returned to the river and 25,000 to be retained for future captive spawning (VHGA, 2006). An additional naturalized refugium was completed in the town of Los Lunas (Figure 2.3) in 2008 and became operational during the summer of 2009 (Kinzli, 2010). The Los Lunas refugium is a cutting edge rearing facility designed to mimic the flood cycles found in the historic Rio Grande (Tave et al., 2008), and contains habitat features preferred by the RGSM such as shallow sandy shelves, eddies, backwaters, and off-channel pools (Haggerty et al. 2008). It also contains natural substrate and native bank vegetation, which will be flooded to induce RGSM spawning (Tave et al., 2008). The overall goal of the refugium is to produce RGSM for augmentation in a natural setting (Tave et al., 2008).

Figure 2.3 Los Lunas Naturalized RGSM Refugium (Kinzli, 2010)

2.4 Middle Rio Grande Water Conservancy District

The MRGCD may be one of the oldest operating irrigation systems in North America (Gensler et al., 2009). Prior to Spanish settlement in the 1600s the area was being flood irrigated by the native Pueblo Indians (Kinzli, 2010). At the time of Albuquerque’s founding in 1706, the ditches that now constitute the MRGCD were already in existence and were operating as independent acequia (tertiary canal) associations (Gensler et al. 2009). These acequias consisted of farmer groups that maintained individual irrigation canals, and the acequia system was introduced to the MRG Valley by Spanish settlers. In acequia communities, each farmer was responsible for maintaining a certain length of canal and would in return receive irrigation water. The use of irrigation water was managed by an elected mayordomo (ditch-rider or water master) (Gensler et al., 2009).

Irrigated agriculture in the MRG Valley reached its greatest extent in the 1880s. In the early 1920s, an overabundance of seepage from the Rio Grande combined with excessive irrigation flooding and resulted in water logging throughout the MRG Valley; swamps, seeps, and salinization of agricultural lands were the result (Kinzli, 2010). In 1925, the State of New Mexico passed the Conservancy Act, which allowed for the creation of the MRGCD, which was accomplished by combining 79 independent acequia associations into a single entity (Gensler et al., 2009; Shah, 2001). Over the next twenty years the MRGCD provided benefits of irrigation, drainage, and flood control; however, by the late 1940s, the MRGCD was financially unstable and further rehabilitation of structures was required. In 1950, the MRGCD established a 50-year contract termed the Middle Rio Grande Project with the USBR to provide financial assistance, system rehabilitation, and system improvement (Kinzli, 2010). System improvements and oversight from the USBR continued until 1975 when the MRGCD resumed operation and maintenance of the system. Currently the MRGCD operates and maintains nearly 1,500 miles of canals and drains throughout the valley in addition to nearly 200 miles of levees for flood protection (Kinzli, 2010).

Water use in the MRG Valley has not been adjudicated but the MRGCD holds various water rights and permits for irrigation (Oad and Kullman, 2006). Some users in the MRGCD hold vested water rights (surface rights) claimed by land owners who irrigated prior to 1907 (SSPA, 2002). Most water users in the MRGCD receive water through state permits held by the MRGCD. The permits allow the MRGCD to irrigate a maximum of 123,000 acres although only 70,000 acres are actually irrigated (MRGCD, 2007). This acreage includes roughly 10,000 acres irrigated by pueblo farmers (Kinzli, 2010). The MRGCD charges water users an annual service charge per acre to operate and maintain the irrigation system. For example, since 2000 the MRGCD is charging $28 per acre per year for the right to irrigate land within the district (Barta, 2003).

Physical Description

The MRGCD (Figure 2.4) services irrigators from Cochiti Reservoir in the north to the Bosque del Apache National Wildlife Refuge in the south. Irrigation structures managed by the MRGCD divert water from the Rio Grande to service agricultural lands that include both small urban landscapes and large scale production of alfalfa, corn, vegetable crops such as chili and grass pasture (Kinzli, 2010). The majority of the planted acreage, approximately 85%, consists of alfalfa, grass hay, and corn. In the period from 1991 to 1998, USBR crop production and water utilization data indicate that the average irrigated acreage in the MRGCD, excluding pueblo lands, was 53,400 acres (21,600 ha) (SSPA, 2002). Analysis from 2003 through 2009 indicates that roughly 50,000 acres (20,200 ha) are irrigated as non-pueblo or privately owned lands and 10,000 acres (4,000 ha) are irrigated within the six Indian Pueblos (Cochiti, San Felipe, Santo Domingo, Santa Ana, Sandia, and Isleta) (Kinzli, 2010). Agriculture in the MRGCD is a $142 million a year industry (MRGCD, 2007). Water users in the MRGCD include large farmers, community ditch associations, six Native American pueblos, independent acequia communities and urban landscape irrigators. The MRGCD supplies water to its four divisions -- Cochiti, Albuquerque, Belen and Socorro -- through Cochiti Dam and Angostura, Isleta and San Acacia diversion weirs, respectively (Oad et al. 2009; Oad et al. 2006; Oad and Kinzli, 2006). In addition to diversions, all divisions except Cochiti receive return flow from upstream divisions.

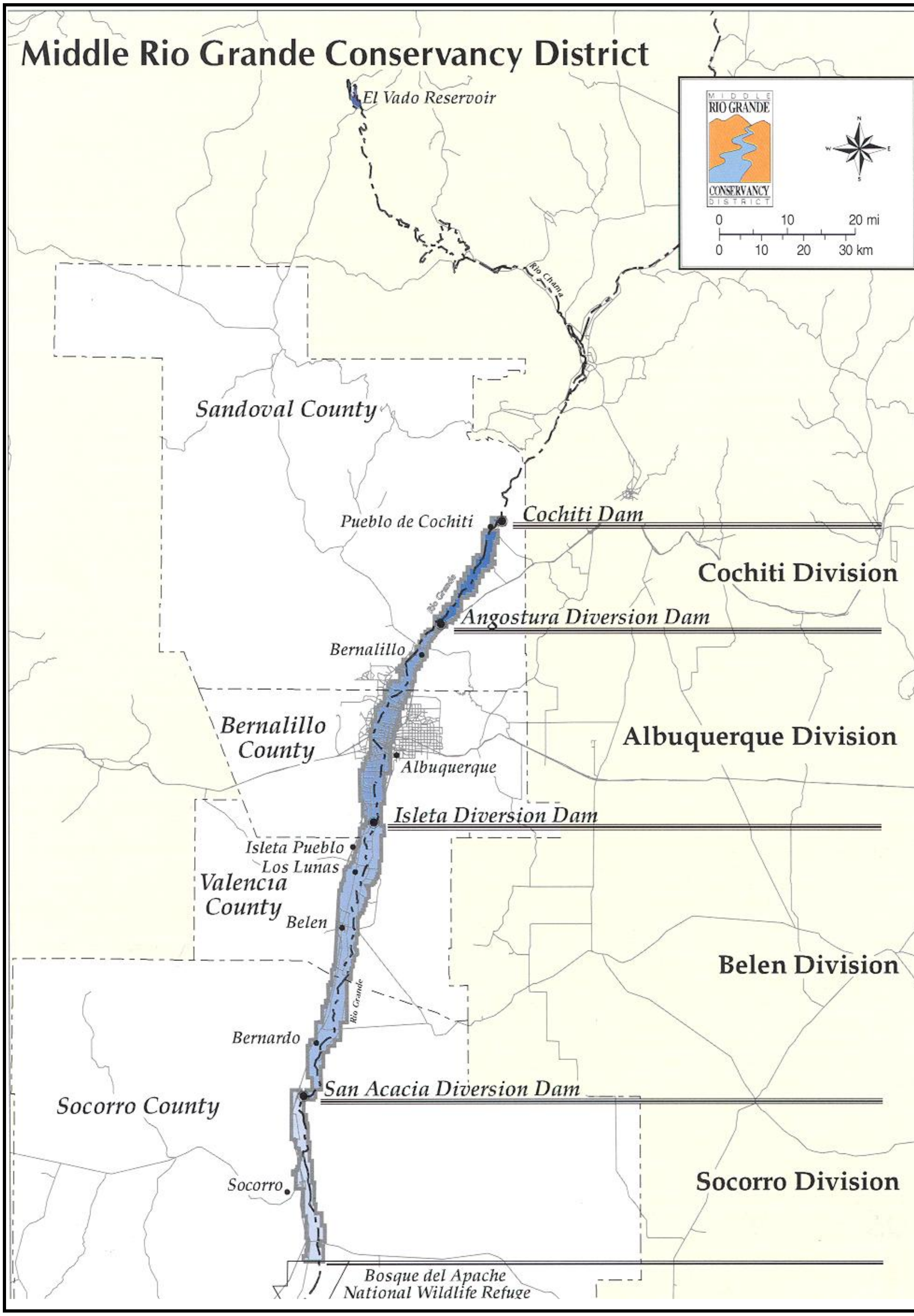

Figure 2.4 Overview Map of MRGCD (MRGCD, 2009)

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

During the later part of the irrigation season, the MRGCD operates using released storage water from the high mountain reservoirs of El Vado, Heron, and Abiquiu. Water stored in these reservoirs consists of snowmelt runoff captured during the early summer months and water from the San Juan-Chama trans-mountain diversion. These reservoirs are located 98 river miles upstream and water delivery is associated with a significant time lag, which can approach seven days to reach the southern portion of the district.

The Cochiti Division consists primarily of Native American pueblo land. The pueblo and non-pueblo lands in the Cochiti Division are managed by four MRGCD ditch-riders. The non-pueblo lands in the Cochiti Division represent 723 acres. The Albuquerque Division services many small urban irrigators, but also provides irrigation water to pueblo irrigators at the northern and southern boundaries of the division. The Albuquerque Division is managed by one water master and 12 ditch-riders to oversee the complex irrigation scheme, and totals 6,480 acres. The Belen Division is the largest in terms of overall service area with a total irrigated area of 28,500 acres. Irrigation in the Belen Division is comprised of large farms, pueblo irrigators, and urban water users. In Belen the MRGCD employs one water master and 12 ditch-riders. The Socorro Division consists of mostly large parcel irrigators with a total irrigated acreage of 12,000 acres. Water distribution in Socorro is straightforward when compared to the Albuquerque and

Belen Divisions, and is managed by one water master and four ditch-riders (Kinzli, 2010). Water availability in Socorro can become problematic since the division depends on return flows from upstream users.

Organization and Water Delivery

Water in the MRGCD is delivered to users through management and administration provided at a central office and four divisional offices. The central office in Albuquerque provides oversight of the four divisional offices and assesses service charges for water use. Each division office includes administrative, field and equipment maintenance, and water operations personnel. Water operations in each division are managed by a division manger, a water master, and ditch-riders in each division. The division managers oversee all aspects of the division, and water masters coordinate ditch-rider operations. Ditch-riders are responsible for managing water delivery in a particular service area, typically servicing between 250 and 900 irrigators. Check structures and head gates are controlled by ditch-riders to deliver irrigation water in their service area to meet user demand. Water delivery and water use conditions are monitored by ditch-riders through the physical riding of ditches and through communication with water users. Ditch-riders generally cover all of the ditches in their service area twice a day and are on call 24 hours a day to deal with emergencies and water disputes, in addition to daily operations.

Water in the MRGCD is delivered in hierarchical fashion (Figure 2.5); first, it is diverted from the river into a main canal, then to a secondary canal or lateral, and eventually to an acequia or small ditch (Kinzli, 2010). Conveyance canals in the

MRGCD are primarily earthen canals but concrete lined canals exist in areas where bank stability and seepage are of special concern. After water is conveyed through laterals it is delivered to farm turnouts with the aid of check structures in the lateral canals. Once water passes farm turnout it is the responsibility of individual farmers to apply water and it is applied to fields using basin or furrow irrigation techniques.

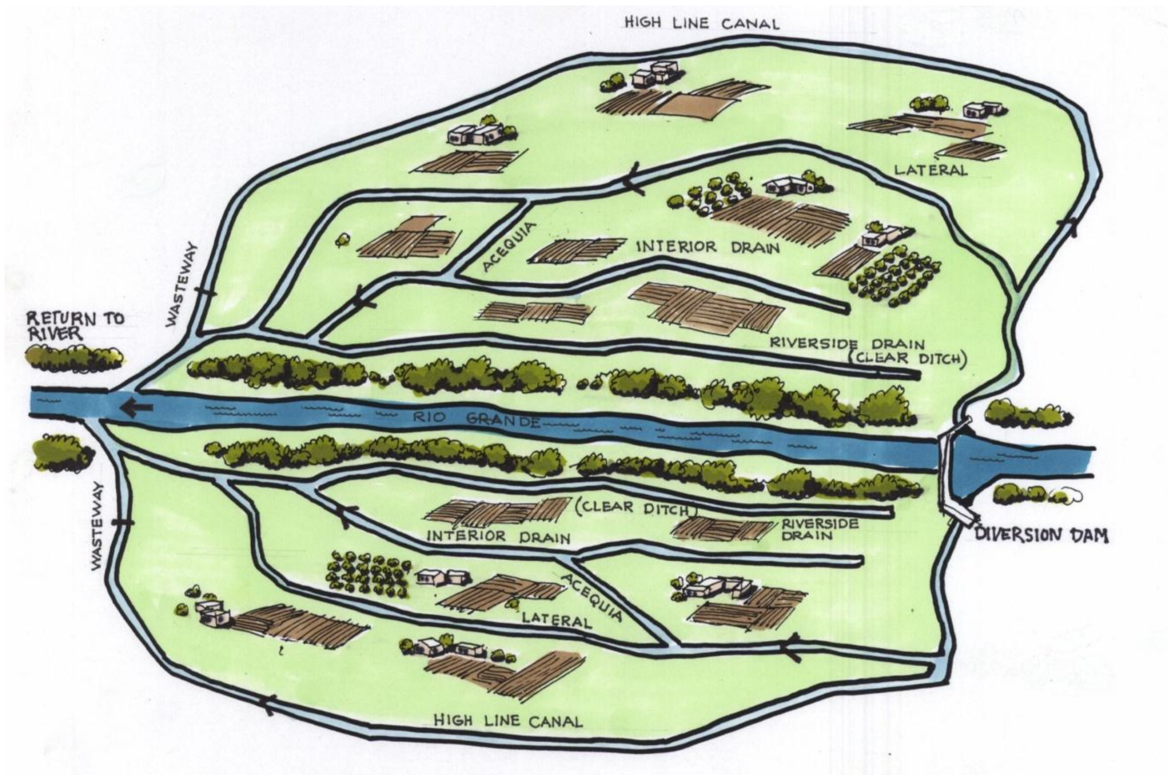

Figure 2.5 Representation of MRGCD Irrigation System (Kinzli, 2010).

Water delivery in the MRGCD is not metered at individual farm turnouts. To determine water delivery the ditch-riders estimate the time required for irrigation. The historic practice in the MRGCD was to operate main canals and laterals as full as possible throughout the entire irrigation season. This practice provided for flexible and reliable water delivery with minimal managerial and financial ramifications, also known as on-demand water delivery (Kinzli, 2010). On-demand or continuous water delivery however resulted in large diversions from the Rio Grande. During the recent drought years, the MRGCD has voluntarily reduced river diversions by switching to scheduled water delivery. The drawback to this approach is the increased managerial involvement and the overall cost of water delivery. To aid with the operational and managerial challenges posed by scheduled water delivery, the MRGCD has been working with Colorado State University to develop and implement a Decision Support System (DSS) to aid in facilitating scheduled water delivery. Additionally, the MRGCD has begun to replace aging water delivery infrastructure with automated control gates that make accurate measurements for scheduled water allocation and delivery.

Definition of Water Rights

The MRGCD holds water rights and permits for irrigation, and most irrigators receive water through state permits held by the MRGCD. Also, the MRGCD holds water permits for storage in El Vado Reservoir with the New Mexico Office of the State Engineer, for total irrigation of 123,267 ac (49,885 ha). Of this total, 53,926 ac (21,823 ha) predated the establishment of the MRGCD. There are concerns regarding MRGCD water use in relationship to state water rights. This research only addressed water rights in MRGCD to the extent that they pertain to the research objectives, as it is believed that water diversions can be minimized. Since 2000 the MRGCD has committed to taking a proactive approach to conserving water so more water is available for alternative societal needs.

According to the MRGCD, their operational practice: a) is economically efficient and allows management to keep water assessment low, b) allows for flexible and reliable irrigation delivery, c) supports an ecosystem by keeping the *bosque* green, d) contributes to recharge of the Albuquerque aquifer, and e) provides a source of recreation and way of life for people in the MRG Valley (DuMars and Nunn, 1993).

The most common management objectives of an irrigation system are adequacy of water delivery in relation to crop consumption use, equity of water distribution and dependability of water supply (Oad and Sampath, 1995). The MRGCD provides flexible and reliable delivery through on-demand scheduling. The approach to managing water delivery so that supply is greater than demand is economically and socially effective, as it requires less management, reduces cost, and ensures equitable delivery among users (Barta, 2003).

Additionally the MRGCD is also keeping the *bosque* green, important because the *bosque* is a communal property in the MRG Valley. The MRGCD has created a unique habitat and ecosystem within the irrigation system itself. In addition to providing water for irrigation, the MRGCD supports a riparian environment and way of life for people in the valley. These benefits should not be dismissed; rather continuation of proper management of this relationship that exists between the irrigated landscape and river landscape should be emphasized.

Several studies have recommended options for improving performance in MRGCD (Goulg, 1996; Frizell et al., 1996; Hernandez, 1997; SSPA, 2002). These studies have not evaluated in detail options for reducing irrigation diversions. The

MRGCD has committed to improved water allocation management practice in the valley through the implementation of the MRGCD DSS. In 2009 the MRGCD implemented the DSS as a management tool for irrigation water scheduling in the Peralta Main Canal. This research is evaluating the hypothetical implementation of a DSS in the Albuquerque Division.

CHAPTER 3. LITERATURE REVIEW

Important concepts of this research are water delivery patterns and DSS. The conceptual framework that is discussed in this chapter includes the ecology of irrigation (Corward, 1980), the relative water supply concept (Oad and Levine, 1985; Oad and Podmore, 1989), and DSS (Kinzli, 2010).

3.1 The Ecology of Irrigation

The ecology of irrigation is the response that irrigation institutions and organizations make to the physical and natural habitants in which they occur; and the notion that changes in relative water supply available in a system and rearrangements in the physical system have important implications for the organization of social relations (Corward, 1980).

Attempts to improve performance or modernize irrigation systems have taken place with radical departures from traditional practice (Levine, 1980; Corward, 1980; Sagardoy et al., 1986). Improvements have been made from the perspective of increasing efficiency in water use, mechanics of operation and system cost (Barta, 2003). There are attempts to understand or improve operation within an existing system.

When operational or physical improvements are made to an irrigation system, methods of operation and whether these methods are achieved through the physical system must be considered (Barta, 2003). This approach has been emphasized for some time by international development agencies, and has more recently evolved in domestic attempts to modernize irrigation systems (Corward, 1980; Levine, 1980; Stringam et al., 1999; Rogers, 1999; Wilson and Lucero, 1997).

3.2 Relative Water Supply

The concept of Relative Water Supply (RWS, shown graphically in Figure 3.1) relates available water supply, demand for water use, and the management intensity in an irrigation system (Oad and Podmore, 1989). In general, this concept relates changes in water supply availability relative to demand to the level of management intensity and control.

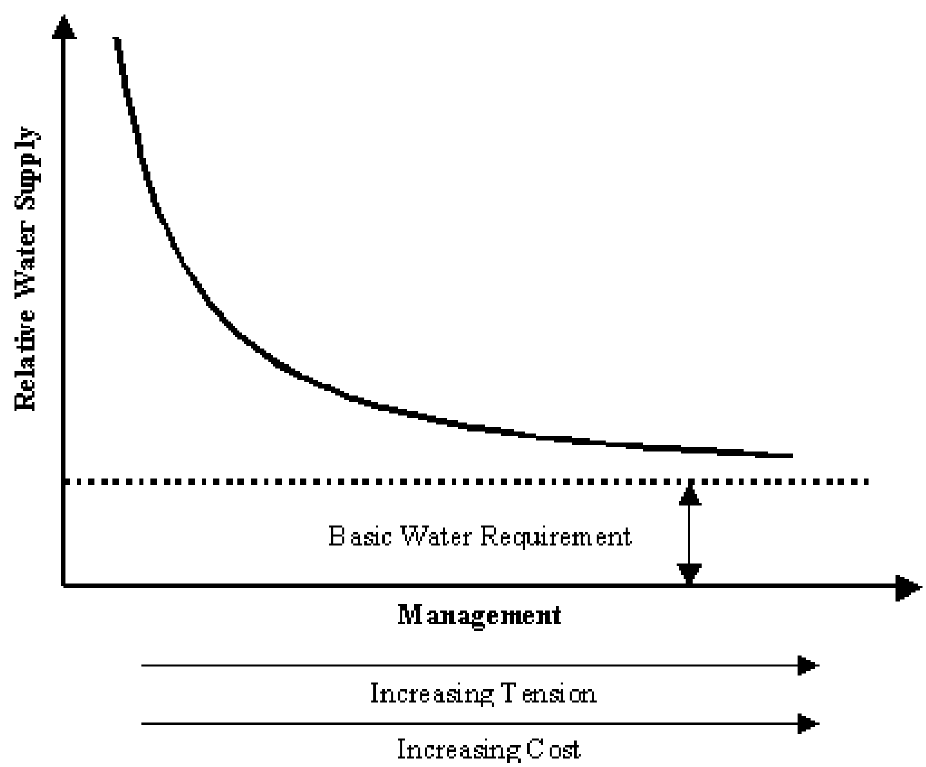

Figure 3.1 Relative Water Supply Concept (Barta, 2003)

A mathematical expression of RWS (Oad and Levine, 1985) can be defined as:

$$RWS = \frac{WaterSupply}{DemandforWater} = \frac{IrrigationDeliveries + Rain}{Evapotranspiration + DeepPercolation \,\&\, Seepage}$$

The RWS can be calculated on any unit of an irrigation system including a farm, an irrigation service canal, or an entire irrigation district (Kinzli, 2010). In an irrigation system the decrease of water delivery and rainfall result in a lower RWS. A lower RWS results in tighter and more stringent management requirements to equitably distribute water to users. Tighter management in an irrigation system consequently leads to an overall higher cost of water delivery.

RWS is similar to the supply and demand concept associated with capitalism. If supply exceeds demand, cost goes down and competition decreases. As demand exceeds supply, cost increases significantly and competition for the limited resource is exacerbated. RWS has been used to explain how management intensity changes according to variable water supply conditions. Oad and Podmore (1989) found that irrigation systems in Central Java, Indonesia, manage the cost of operation according to changes in water supply. During the wet season when RWS is high, water flows in irrigation canals continuously, farmers can irrigate at their own leisure, and management costs are low. During the dry season RWS decreases significantly and the management required for equitable water distribution increases, resulting in a higher cost of water delivery.

In the MRGCD historical water distribution consisted of running canals and laterals near capacity. This provided for a high RWS that allowed for low intensity management and low cost. To lower the RWS, and improve water use efficiency, the MRGCD has opted to use scheduled water delivery for water distribution (Kinzli, 2010; Oad et al., 2005; Oad et al., 2006). With a lower RWS, the management and cost of water delivery have increased. In order to equitably distribute the water supply under low RWS, the MRGCD has opted to develop and implement the DSS to assist with increased management intensity needs (Kinzli, 2010).

3.3 Scheduled Water Delivery

Scheduled Water Delivery (SWD) is used in irrigation systems worldwide to improve water delivery and to support water conservation. When SWD is used, lateral canals receive water from the main canal according to their need for water, allowing water use in some laterals while others are closed. In addition to this water scheduling among laterals, there can be scheduling within laterals whereby water use is distributed in turns among farm turnouts or check structures along a lateral. By distributing water among users in a systematic fashion based on crop demand, an irrigation district can decrease water diversions and still meet crop water use requirements. A well-managed program of scheduled water delivery is able to fulfill seasonal crop water requirements in a timely manner, but generally requires less water than continuous water delivery.

3.4 Decision Support System

Decision support systems (DSS) have found implementation throughout the American West and are mostly used to regulate river flow. A DSS combines intellectual resources of individuals with the capabilities of computers to improve the quality of decision-making. DSS on the river level are linked to gauging stations and are used to administer water rights at diversion points. DSS used in irrigation systems make informed decisions about how best to route water through the canal delivery system to optimize satisfaction of crop water requirements while minimizing river water diversions. A DSS is a logical arrangement of information including engineering models, field data, GIS and graphical user interfaces, and is used by managers to make informed decisions (Kinzli, 2010). 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 the DSS for an irrigation system is how best to route water supply in a main canal to its laterals so that all existing crop water demand in the main canal service area is satisfied while the required river water diversion is minimized. The desirable solution to this problem is "demand-driven" in the sense that it should be based on a realistic estimation of water demand. The water demand in a lateral canal service area, or for an irrigated parcel, can be predicted throughout the season through analysis of information on the irrigated area, crop type and soil characteristics. Important demand concepts include:

- Irrigation timing: When is water supply needed to meet crop demand?
- Irrigation duration: How long is the water supply needed during an irrigation event?
- Time between irrigations: How frequent must irrigation events occur for given cropped service area?

The MRGCD DSS was developed using these concepts as well as historical and GIS data, and combined into three new DSS elements or modules (Figure 3.2):

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

A Graphical User Interface (GUI) links the three modules of the DSS, and allows users to access data and output for the system. Figure 3.3 displays a conceptual view of how a DSS can be used to develop scheduled water delivery. 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, while some is handled externally. Detailed descriptions of the DSS model formulation and related data sets for the MRGCD main canals are provided in previous annual reports (Oad et al., 2005; Oad et al., 2006), and are also published in a refereed journal article (Oad et al., 2009).

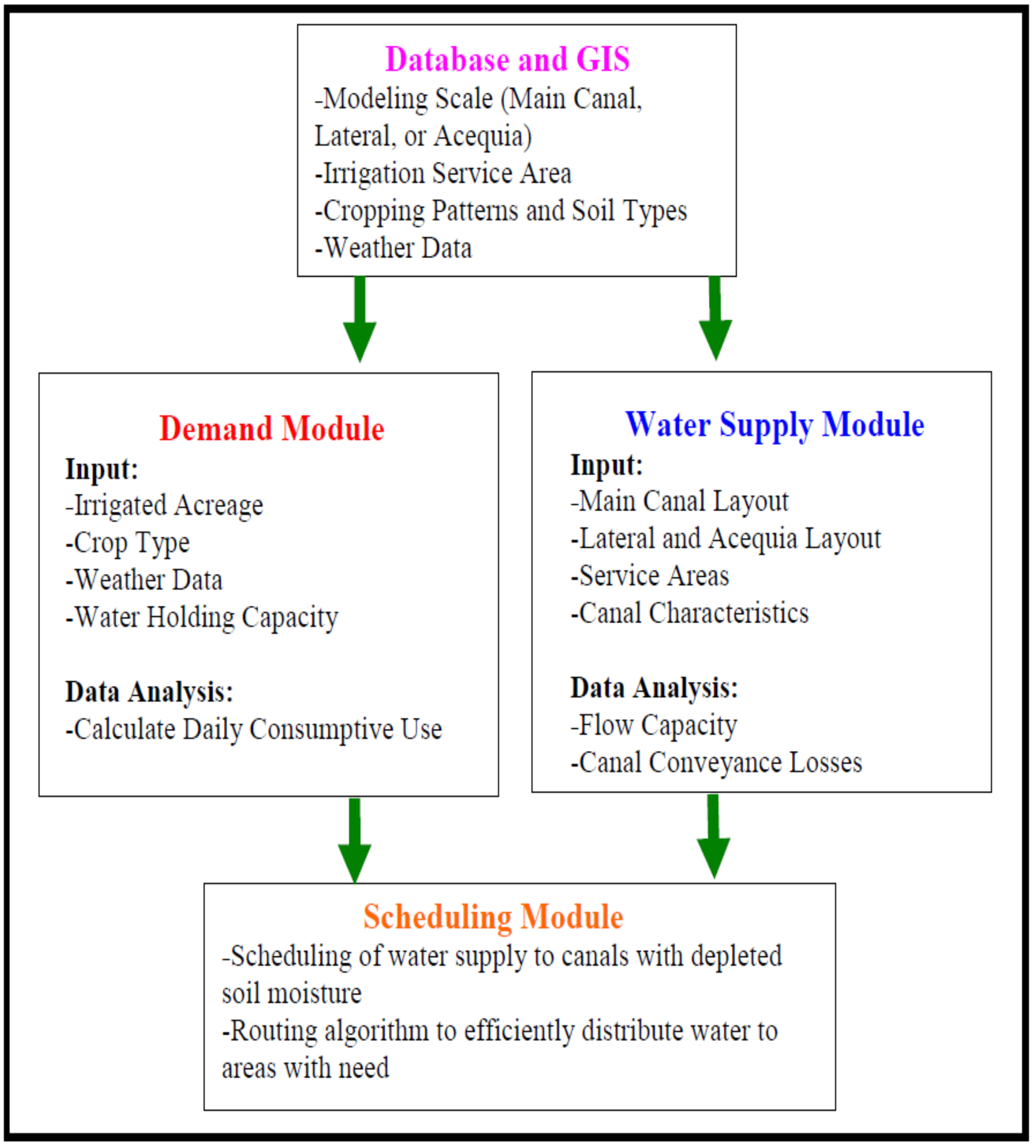

Figure 3.2 Schematic of the DSS Model Structure (Kinzli, 2010)

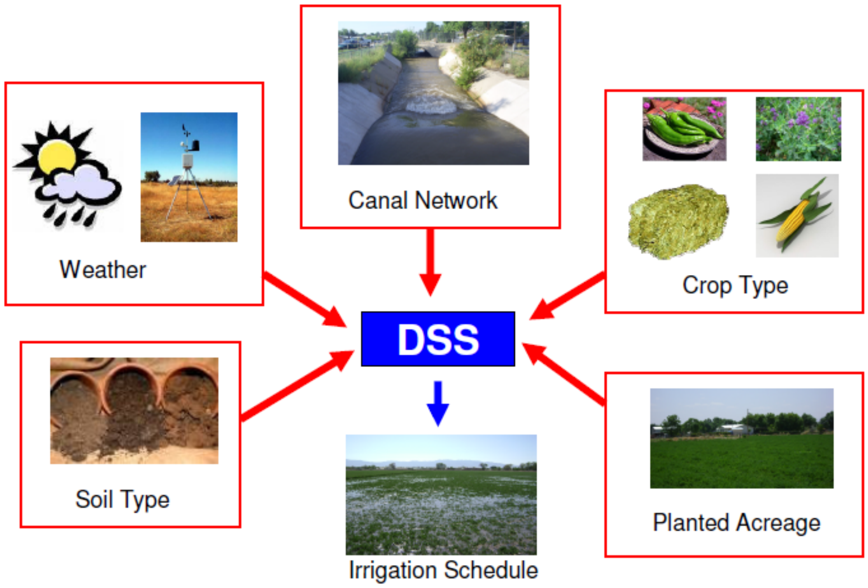

Figure 3.3 Conceptual View of a DSS used to Develop Irrigation Schedules (Kinzli, 2010)

DSS models are management tools that can assist in making informed decisions. However, they cannot entirely mimic a complex enterprise such as irrigated agriculture since human judgment is always important. For example, the DSS model developed through this project can schedule irrigations to lateral canal service areas but not to the individual farm holdings within the service areas. The farmers' groups will still need to work with the ditch rider to schedule irrigations within their lateral canal service area. Another limitation is that the model computes a crop water requirement for the entire lateral canal service area considering an average cropping pattern for the service area. The resulting irrigation schedule will therefore be adequate for major crops such as alfalfa and corn but not suitable for vegetable crops. Special consideration will be needed for vegetable crops and other management events such as alfalfa cuttings.

CHAPTER 4. WATER DELIVERY AND DISTRIBUTION AMONG WATER USERS

The research objective was to study and analyze irrigation scheduling and water delivery procedures, in the Albuquerque Division of the MRGCD, and specifically, to analyze whether the use of DSS scheduled irrigations would result in reduced river water diversions. This review was prompted as a continuation of the implementation of scheduled water delivery, assisted by the MRGCD DSS, in the Belen Division. Before further use of the DSS, it was considered prudent to review the existing policy and practice related to irrigation water scheduling and delivery to the MRGCD water users. This chapter provides significant insight into irrigation practices in the Albuquerque Division, including analysis of ditch-riders' interviews, review of MRGCD water delivery policy, and documentation of the actual practice of water delivery and distribution.

4.1 Interviews with Ditch-Riders and MRGCD Staff

Intensive interviews and on-the-job observations were conducted with all ditch-riders in the Albuquerque Division during the 2010 irrigation season. The primary purpose was to determine the actual water delivery practice and other standard operational practices including the degree to which scheduled water delivery was practiced. Some quantitative data were also obtained from these interviews including the irrigation duration, the average flow required for irrigation and the time between irrigation events for each lateral service area. Information on ditches where scheduled water delivery was practiced (non-pueblo land) are displayed in Table 4.1. Scheduled water delivery scheduling for all the lateral canals is shown in Appendix B. Operational data obtained from interviews included the irrigation duration, the average flow required for irrigation and the time between irrigation events for each lateral service area. Other standard operational practice including the degree to which scheduled water delivery was practiced was also documented. The capacity of the canals in each ditch-rider area was also determined during the interviews where there are water measuring devices.

Table 4.1 Scheduled Water Delivery Practice in the Albuquerque Division

Lateral Name	No. of Days Ditch is Running per Week	Flow-rates (cfs)
Alameda Lateral	7 days a week	17
Albuquerque Main Canal	7 days a week	130
Arenal Main Canal	7 days a week	75
Atrisco Feeder	7 days a week	40 - 90
Barr Main Canal	7 days a week	50
Bernalillo Acequia	5 days and shut off for 9 days	29
Bennett Lateral	3 days or when needed	10
Corrales Main Canal	7 days a week	45 - 50
Griegos Lateral	7 days a week	40 - 75
Gun Club Lateral	7 days a week	13 -26
Rogers Lateral	7 days a week	5
Sandia Acequia	7 days a week	22 - 25
Williams Lateral	7 days a week	30 - 35

As a matter of MRGCD policy, all ditch riders are required to practice scheduled water delivery 2002. The degree to which the ditch-riders have been able to actually follow this policy directive varies through the division. Initially there was some apprehension, both from irrigators and ditch-riders, but every year has seen an increase in the acceptance and cooperation for scheduled water delivery.

4.2 Description of Research Area

The Albuquerque Division (Figure 4.1) is the third largest division in terms of service area in MRGCD, and delivers water to about 7,000 acres (Belen and Socorro being the number one and two in terms of service area, respectively). The Albuquerque Division extends from the Angostura Dam in the north to the Isleta Dam in the south. The work conducted in this study relates to all non-Pueblo irrigated lands within the Albuquerque Division served by the Albuquerque Main Canal, the Corrales Main Canal, the Arenal Main Canal and the Barr Main Canal. It consists of a complex and intricate network of water delivery canals that service small farm parcels, community ditches and urban areas. The average size for an irrigated parcel in the Albuquerque Division is 2.2 acres, which are mostly residential lawns, gardens, and pastures for horses. Other crops include grass hay, alfalfa, orchards, and chili. Most of the farmers are growing crops for home use; that is, for family consumption and for animal fodder. For water delivery administration, the Albuquerque division is organized into 12 ditch-rider service areas. Water is diverted from the Angostura diversion structure on the east side of the river. The two main canals served on the east side of the river are the Albuquerque Main Canal (Figure 4.2) and the Barr Main Canal. Water for the west side of the river is supplied by the Atrisco and Corrales Siphons from the Albuquerque Main Canal. The Corrales siphon supplies the Corrales Main Canal and the Atrisco siphon supplies the Arenal Main Canal. The drainage and return flow from the Albuquerque Division service area is captured and utilized for irrigation in the downstream Belen Division.

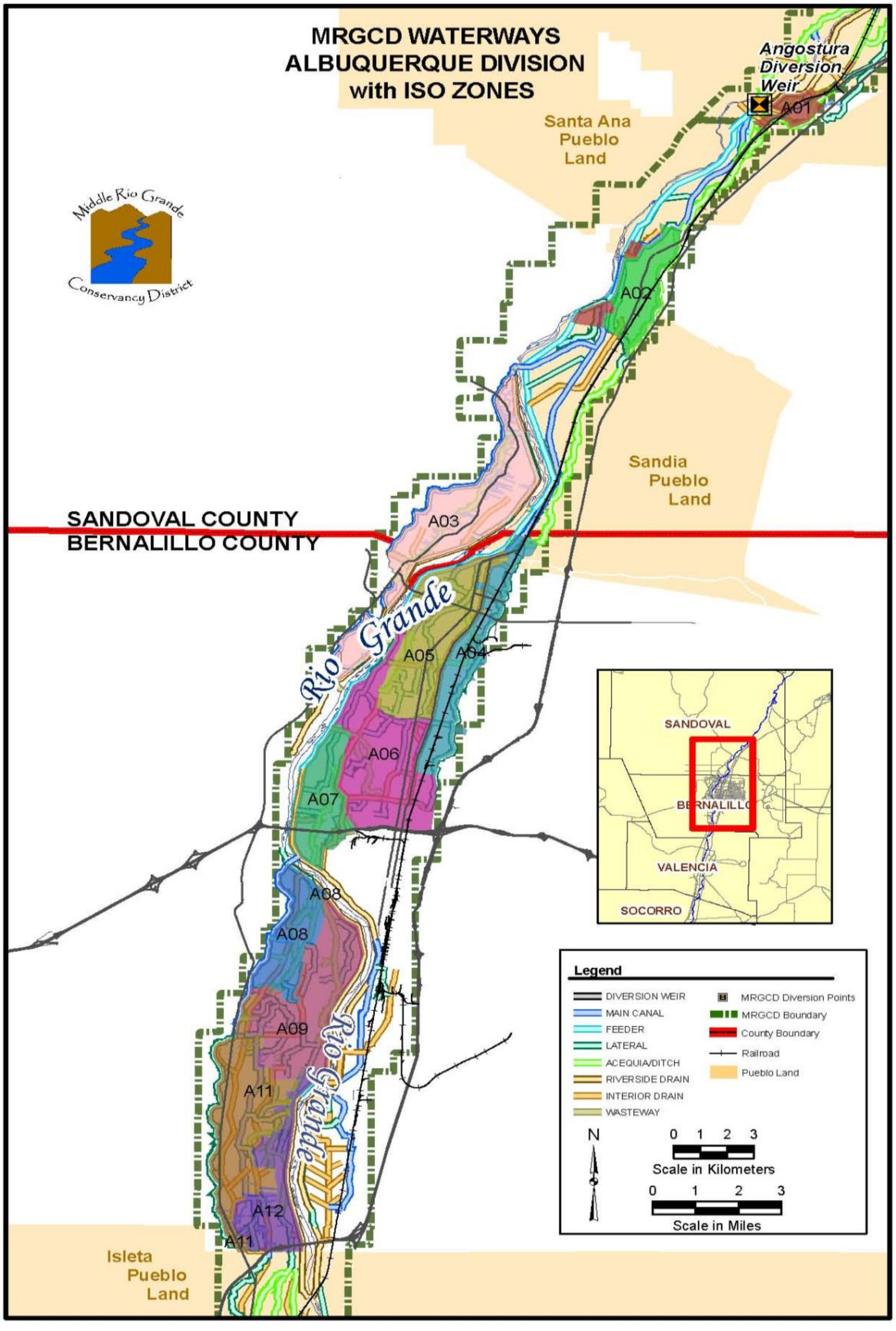

Figure 4.1 MRGCD Albuquerque Division Displaying the Ditch-rider Service Area (MRGCD, 2010)

Figure 4.2 Albuquerque Main Canal Heading at Angostura Dam

4.3 MRGCD Water Delivery Policy

The MRGCD holds water rights and permits for irrigation on behalf of its water users, and most irrigators receive water through the State permits held by the MRGCD. Since water rights are not adjudicated, the amount of water delivery is not measured at the farm level. Below is a summary of MRGCD water delivery policy, accessed from the MRGCD website *(www.MRGCD.com) on 9/23/2010*.

Water Distribution

The MRGCD water allocation and distribution policy states that water available to the District will be delivered to the Divisions in proportion to the amount of land served, if possible, and to lands within each Division in similar manner. Native

Americans land under cultivation at the present time are considered to have the first right to irrigation water.

The ditch-rider holds a critically important position in the execution of this policy and is expected to maintain close contact with water users at all times. There should be no partiality in the distribution of water regardless of personal feelings, race, creed, relationship, political, or social standing or previous grievances. The scheduling of water for irrigators shall be from 7:00 a.m. to 8:00 p.m. and the water user has to forward a request to the ditch-rider 48 hours in advance to an irrigation requirement. In case a ditch-rider is not available, the irrigator may call the appropriate Division office for assistance.

The water distribution policy further states that there will be no water delivered to water users who are delinquent in the payment of the District Assessments. Currently farmers are required to pay $28 per 3 ac-ft per year (Barta, 2003). In the public interest of efficient water distribution and use, the ditch-rider is not obligated to deliver water to silt-laden and weed-clogged community canals, farm channels and laterals, which the farmers are required to keep clean.

For water users' welfare, water will be delivered to main canals at the upper end of each division and will be supplied progressively toward the lower end of the division. Irrigation has to be completed in each area before transferring the water to another area, provided inter-division water rationing and rotation are not required. Also, in a similar manner, irrigation deliveries will commence at the upper end of each lateral, and each farm served by the lateral will be irrigated progressively downstream upon request from the water users. No further irrigation deliveries will be made except with the express permission of the ditch-rider.

During a period of water shortage, the distribution policy directs the water users to irrigate both day and night on a seven day schedule to utilize all available supplies. Failure to do so will be construed to indicate no further need for water. It is the responsibility of the ditch-riders to advise in advance, if possible, water users who work outside their farms as to when water is scheduled for delivery to their farm so that they can make arrangements for the required labor.

The water distribution policy also states that water users will be permitted to open their turnouts and operate checks only at times specifically approved by the ditch-riders. The water user is expected to notify the ditch-rider as far in advance as possible of his need for water, and the ditch-rider will advise the water user as far in advance as possible when the water will be available.

Each ditch-rider is expected to keep a record, or log book for the purpose of showing water use within each lateral service area. The record should contain water users in proper sequence on each canal, the date irrigation was started and shut off, and whether irrigation was all completed. Notes shall be made of any special cases of delivery or use of water. Any individual user violations will be promptly reported to the Division Manager, and each such report will be noted in the log book. A complete set of Policies and Procedures of the MRGCD is included in the Appendix section.

4.4 Actual Practice of Water Delivery and Distribution

This description of water delivery operations was developed through interviews, field visits and observation, and review of documents relevant to MRGCD operations. Field visits and interviews were conducted over a period of two months (August and September) during the summer of 2010, and involved intensive interaction with ditch-riders and other MRGCD personnel. Twelve ditch-riders and several other MRGCD personnel, including Division Hydrologist, water-masters and field supervisors from the Albuquerque Division were interviewed.

Field observations consisted of a detailed tour of each ditch-rider area and an informal discussion concerning operations, infrastructure, and on-farm water use within the ditch-rider service area. These discussions were informal in the sense that although a general set of interview questions were kept in mind, interviews were open to the specific concerns and characteristics of each ditch-rider area.

Ditch-riders are responsible for the distribution of water to irrigators within their service areas. The ditch-rider evaluates water delivery and water use conditions through physical monitoring, or “riding”, the ditches, canals, drains, and wasteways within their designated service area and through communication with irrigators. The ditch-rider controls check structures and head gates, using local knowledge of the distribution system and the irrigator’s needs to deliver available water within the service area. Ditch-riders control water delivery manually and do not meter individual farm turnouts (although they do estimate water delivery based on time required for irrigation).

4.5 Water Scheduling

Water delivery patterns used by the ditch-riders include aspects of both on-demand delivery and delivery rotation. Ditch-riders are responsible for the distribution of water to irrigators within their service areas. The ditch-rider evaluates water delivery and water use conditions through physical monitoring, or "riding", the ditches, canals, drains, and wasteways within their designated service area and through communication with irrigators. When scheduling irrigation water to a service area, the ditch-rider first establishes contact with the farmers. The purpose is to establish relationships with water users, including their location along the laterals and the crops they farm. This is essential to the ditch-riders since there is not much formal orientation or on-the-job training organized by the MRGCD management, and the ditch riders would otherwise not know the situation related to water demand within their service area. The practice also helps the ditch-rider to understand the network of canals and ditches in their service area. Farmers call the ditch-riders for water scheduling 48 hours before water is required. Ditch-riders typically use one or more of the following criteria to deny or accept a water delivery request:

- Number of irrigators scheduled for requested time
- Number and/or size of turnouts open at requested time
- An understanding of additional ditch-rider service area demand
- An intuitive sense of the water volume and head in the delivery system

The operational and physical nature of the canal or lateral used for water delivery also plays a role in the scheduling procedure used. It takes between two to three years for a new ditch-rider to completely know and understand their service area.

The “rule of thumb” the ditch-riders use for scheduling irrigations is that field crops including hay, grass, alfalfa, and corn require irrigation once every two weeks, the vegetable crops need to be irrigated once every week. Based on this understanding the ditch-riders group the farmers into “irrigation blocks” starting from the upstream end of the lateral and proceeding downstream. The “irrigation block” closer to the lateral heading irrigates first and then the next block in line is allowed to irrigate. This process repeats until all the farmers further down along the lateral canal get a chance to irrigate. The ditch-rider has to patrol the ditches to ensure that every farmer who is scheduled to irrigate has enough flow and duration and that the scheduling turns are properly adhered to by all water users.

Over the years, the ditch-riders and the farmers have been able to develop an understanding as to when the water users are to receive water for irrigation and for how long. Many of the farmers, especially those growing alfalfa, grass, and orchards do not need to call the ditch-rider for water scheduling because of management consistency and good relationships with the ditch-riders. However the ditch-rider still has to patrol the irrigation events so to be sure that everything is operating correctly.

4.6 Operation of Check Structures

On average each ditch rider is responsible for water delivery and distribution in about six lateral canal service areas and the total length of all irrigation canals to be patrolled is more than 15 miles. This scenario presents a big challenge to the ditch-rider to be able to operate more than one check structure (Figure 4.3) at a given time when the farmers need to irrigate. The ditch-rider operates some of the key check structures and the rest are operated by the farmers. This is done based on the ditch-rider's discretion, and they must keep informed of such operations.

Figure 4.3 A Typical Check Structure in an Open Position

The ditch-riders also operate the automated heading gates that divert water from the main canal to the lateral canals. Not all ditch-riders are engaged in the operation of lateral canal heading gates since many laterals originate in the service of one ditch rider but may flow through more than one ditch rider service area. This results in the ditch-riders at the downstream end of the canal relying on the ditch-riders at the upstream end of the canal. It is therefore very important that the ditch riders communicate with each other, and they do so quite frequently. For example, if the upstream ditch rider makes some adjustments to the flow at the heading, he will alert all other ditch riders on the canal.   The ditch-rider making flow changes at the heading will do so based on instructions received from the MRGCD Hydrologist on a daily basis as to how much water should be released at the headings. During this research it was observed that there was no proper irrigation scheduling in the south western part of the Albuquerque Division. This has resulted in minimal flow received at the tail end of the laterals.

4.7 Monitoring of Irrigation Canals and Drainage Ditches

Each ditch-rider does at least three inspections of the canals and ditches in their service areas per day, seven days a week. They are relatively independent, scheduling rounds according to the time that works best for the ditch-rider and the water users. This is necessary for the ditch-rider to clear any debris in the ditches and to ensure that water flows without any hindrances. The ditch rider watch also helps to deter any unauthorized water diversions from the canals or some farmers cutting others who are already scheduled for irrigation. Many people with lands located next to the canals tend to illegally take water by pumping from the canals. If a person is caught cutting off other farmers or irrigating outside the schedule, then the ditch rider would warn the person and in extreme cases may decide to lock the farm turnout.

In addition to the responsibilities of water delivery and system monitoring, a ditch-rider is responsible for collecting a significant amount of data in ditch-rider logs as per the policies and procedures of the MRGCD. Ditch-rider log books contain a page for each land parcel irrigated in a ditch-rider service area. These ditch-rider logs give the District office a written record of irrigator water delivery and use. The data are critical field checks for lands reported irrigated and the assessments charged to water users. The ditch-rider logs also serve to support the on-going GIS mapping within the MRGCD, and a way to monitor and grade ditch-riders' performance. With such information, the District office has been able to match irrigated parcels with a particular water delivery structure in a GIS interface. Although a significant amount of data is collected in the ditch-rider logs, there are many inaccuracies. Such as, the sizing of farmers' plots and the number of farmers permitted to utilize the water.

4.8 Maintenance of Canals/Ditches

The MRGCD also conducts other activities necessary to ensure adequate water operations, including maintenance of the conveyance and drainage system (excluding private community ditches). Ditch-riders are expected to keep the ditches clear of any debris or branches during mowing of the ditches, or during any maintenance activities being carried out within their service areas. During the study, it was observed there is inadequate communication between the division office and the ditch riders. Often, it was observed that a ditch rider did not have the prior knowledge of mowing operations scheduled in his service area, and came to know of the activity only while patrolling the service area.

Some ditches are concrete lined in some areas due to the collapse of the walls because of the sandy soils. The poor quality of the maintenance work has resulted in narrowing the canal widths and affecting the slope. This anomaly causes the canal to overtop at some points along its length which in turn results in the canal breaking and affecting the water scheduling.

Almost all small ditches have not been dredged for a long time due to the inaccessible conditions they are in. The service road on their levee has a limited width such that machinery cannot access it. Dredging priority is always given to main canals and drainage ditches. This results in no dredging for lateral canals which has a negative impact on the flows. Most of the farm fields have not been laser leveled for years. This results in farmers taking longer time to finish their irrigation, which in turn adversely affects other farmers. In one instance, it takes 15 hours for one farmer to irrigate 2.5 acres. Normally it takes one hour to irrigate one acre.

4.9 Flow Measurement Devices

Most of the lateral canals in the Albuquerque Division do not have flow measuring stations, but the main canals do (Table 4.2). These include the Albuquerque Main Canal, Arenal Main, Barr Main, Corrales Main and Atrisco Main Canal which are key headings in the Albuquerque Division canal network. Flow measurement devices are imported in monitoring diversions and farm delivery for evaluation of water rights issues. The flows diverted from the river into the main canals are entirely at the instructions of the District Hydrologist (David Gensler). The absence of gauging stations in lateral canals poses a great challenge to the ditch riders since they don't know how much water is available for them to meet water user's requirements. As such, the ditch riders have devised various crude strategies of marking out the ditches with paint marks. This helps them to determine whether the flow is adequate or not. On the gated checks, they have devised a system of counting the number of turns needed on the opening wheel to estimate whether the flow is adequate or not. This has resulted in more time spent by the ditch riders in trying to figure out a working combination for their service areas.

Table 4.2 List of Canals and Laterals with Flow Measuring Devices

Lateral Name	Number of Flow Measuring Devices
Albuquerque Main Canal	3
Arenal	3
Gun Club	1
Pajarito	1
Griegos	1
Duranes	1
Atrisco Ditch	1
Armijo Ditch	1
Chamisal	1
Corrales	1
Sandia Acequia	1
Alameda Lateral	1
Barr Main	1

Flow measurement devices are strategically positioned throughout the Albuquerque Division. However, there is a need for more flow measurement locations to assist the MRGCD to be able to:

- Maximize system efficiency or otherwise improve operations
- Match supply to demand more precisely
- Efficiently implement Decision Support System

4.10 Summary of Findings Related to Water Delivery Practice

While administrative and field maintenance operations are important components of the MRGCD service, emphasis in this study was placed on the water operation services provided by ditch-riders. Ditch riders are responsible for the water delivery and its distribution among irrigators within their service areas. The ditch-rider evaluates water delivery and water use conditions through physical monitoring or "riding" the canals, drains, and wasteways within their designated service area and through communication with irrigators.

The job of a ditch-rider is very demanding. During the irrigation season (March 1 through October 31), ditch-riders are required to be on call at all times, and are accessible via pager, cell phone, and CB radio in their MRGCD trucks. In fact, many MRGCD ditch-riders reside, and sometimes irrigate, within their service areas. Ditch-riders also attend to emergencies including ditch breaks, ditch clogs, leaky gopher holes, and drastic alterations in water levels. Perhaps the biggest concerns for ditch-riders are the monsoon rains that occur mid-summer in New Mexico. During such events, arroyos (natural floodways) running perpendicular to MRGCD canals bring unwanted sediment and water; often overflowing and breaking ditch banks. Because such rains occur frequently and unexpectedly, ditch-riders must be available at all times to make necessary changes in the conveyance system (such as opening wasteways).

The ditch-rider controls check structures and head gates and uses local knowledge of the distribution system to deliver available water to irrigators. There is no structured way for the ditch riders to know what crop water requirements are, and they are oblivious to flow discharges due to lack of measurement in most canals. Ditch-riders control water delivery manually and do not meter individual farm turnouts (although they do estimate water delivery amount based on time required for irrigation). The evidence clearly suggests a need for a more organized water management system to help improve delivery allocation and measurement, as currently it is primarily based on crude and inaccurate methods.

CHAPTER 5. VALIDATION OF MRGCD DSS IN THE ALBUQUERQUE DIVISION

This chapter describes hypothetical analysis of the MRGCD DSS model in the Albuquerque Division during the 2009 irrigation season. The DSS was validated and implemented in the Peralta Main Canal during the 2009 irrigation season; detailed description of the implementation can be found in Kinzli, 2010. This chapter also identifies physical improvements that will make the MRGCD system more efficient, and also analyzes the DSS schematic network for the Albuquerque Division. Finally, this chapter also describes the benefits that MRGCD will realize through the implementation of DSS in the valley.

5.1 Comparison of DSS Diversions and Actual Diversions

Since automated Langemann gates were installed on some of the main canals in the Albuquerque Division, it was possible to compare the actual water deliveries to the deliveries suggested by the DSS. Data from three main canals for the 2009 irrigation season were used for the comparison. The comparison of the diversion on the Albuquerque Main Canal, Corrales Main Canal and the Atrisco Siphon were conducted using the Nash-Sutcliffe modeling efficiency statistic.

The MRGCD DSS can be run under two different modes namely the operations mode and the planning mode. Mode refers to how surface water is supplied. In operations mode, the water that can be supplied to the system is determined by actual canal diversions. In planning mode, surface inflows are limited only by the capacity of each canal and water deliveries are calculated to meet all crop demand. The DSS results used in this analysis were obtained by running the DSS model in planning mode for the year 2009.

Nash-Sutcliffe modeling efficiency statistic

To compare the actual measured data and the DSS recommended data it was decided that the Nash-Sutcliffe modeling efficiency statistic analysis be used. The Nash-Sutcliffe model evaluation statistic has been widely used to validate various moisture accounting models (McCuen et al. 2006; Downer and Ogden 2004; Birikundavyi et al. 2002); and it was first used to compare hydrologic models (Nash and Sutcliffe, 1970). This method can also be used to describe the predictive accuracy of models as long as there is observed data to compare the model results to. For example, Nash–Sutcliffe efficiencies have been reported in scientific literature for model simulations of discharge, and water quality constituents such as sediment, nitrogen, and phosphorus loadings (Nash and Sutcliffe, 1970). The Nash-Sutcliffe modeling efficiency statistic is also recommended by ASCE (ASCE, 1993) for evaluation of moisture accounting models. The Nash-Sutcliffe model efficiency statistic is defined in the mathematical equation below;

$$E = 1 - \frac{\sum_{t=1}^{T} \left(Q_o^t - Q_m^t\right)^2}{\sum_{t=1}^{T} \left(Q_o^t - \overline{Q_o}\right)^2} \tag{1}$$

In this equation Q_o is an observed measurement, Q_m is the model predicted value, $\underline{Q_o}$ is the mean actual measurement and Q_o^t is the actual measurement at time *t*. Nash–Sutcliffe efficiencies can range from −∞ to 1. An efficiency of one ($E = 1$) corresponds to a perfect match of modeled values to the observed data. An efficiency of zero ($E = 0$) indicates that the model predictions are as accurate as the mean of the observed data. An efficiency less than zero ($E < 0$) occurs when the observed mean is a better predictor than the model or, in other words, when the residual variance (described by the nominator in the expression above), is larger than the data variance (described by the denominator). Essentially, the closer the Nash-Sutcliffe model efficiency is to one, the more accurate the model (Moriasi et al. 2007; Nash and Sutcliffe, 1970).

5.2 Comparison of Diversion Data

The 2009 irrigation season data were used for doing statistical analysis of comparing DSS recommended diversions and the actual diversions in the Albuquerque Main Canal. The Albuquerque Main Canal (Figure 5.1) diverts water from the Angostura Dam and in turn feeds the entire lateral canal network in the Albuquerque Division; hence it was used to do the comparison analysis. The Corrales Main Canal (Figure 5.2) supports the north western side of the Albuquerque division and is fed from the Albuquerque Main canal through a siphon. The Atrisco Feeder supports the south western part of the Albuquerque Division by feeding the Arenal Main Canal (Figure 5.3) through the Arenal siphon.

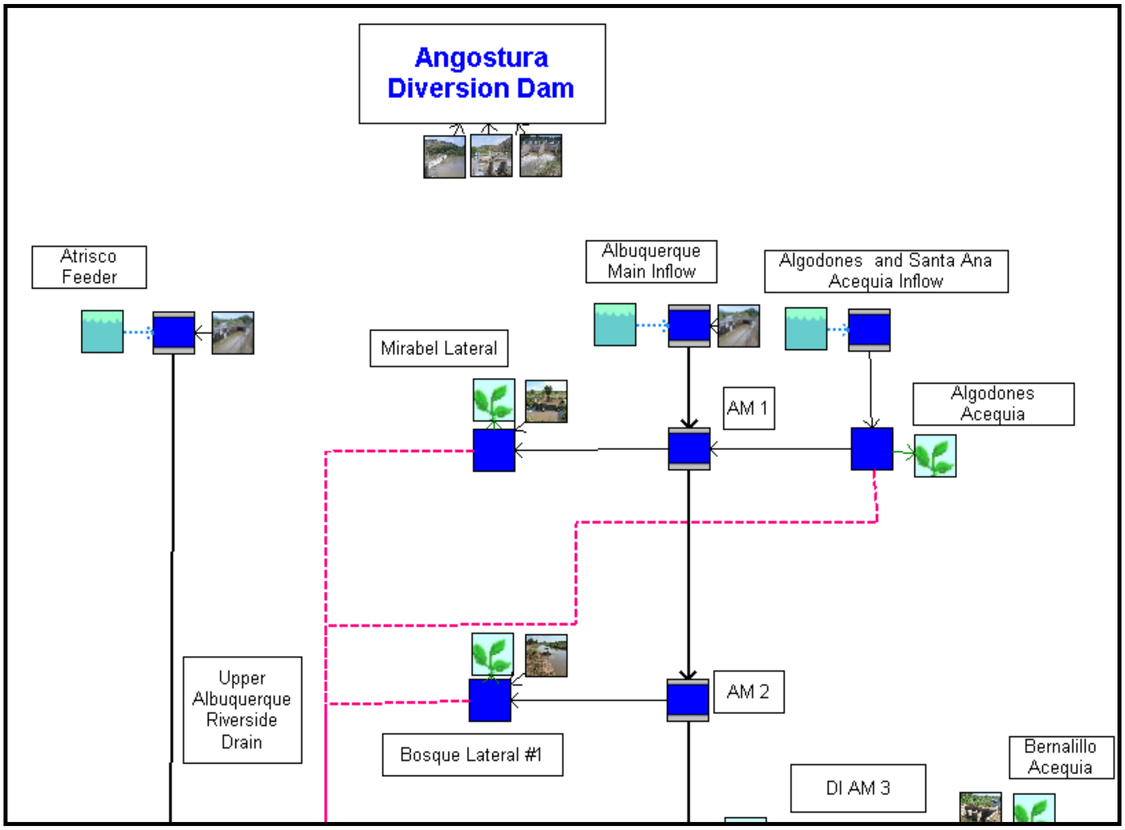

Figure 5.1 DSS Interface Showing the Albuquerque Main Canal Heading.

Through the use of the installed flow measuring gate at the heading and SCADA telemetry it was possible to record the flow rate being delivered to the Albuquerque Main Canal every thirty minutes during the 2009 irrigation season. Daily values were used for the analysis. These values were compared to the flow rate values suggested by the DSS water delivery calendars to assess the benefit of the DSS.

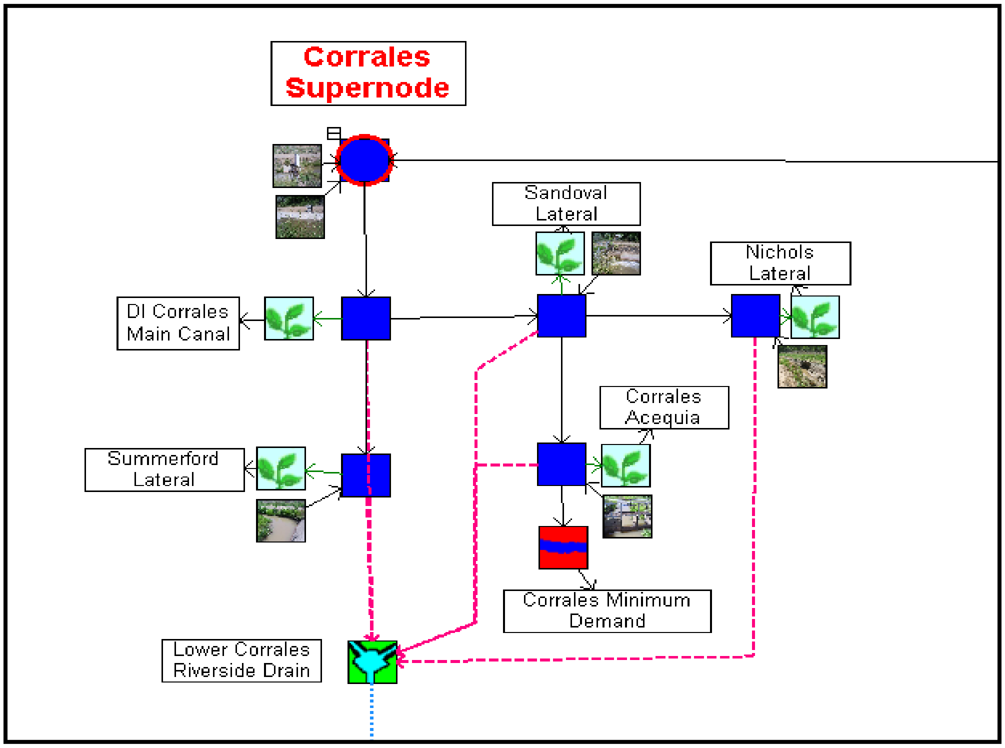

Figure 5.2 DSS Interface Showing the Corrales Main Canal Heading.

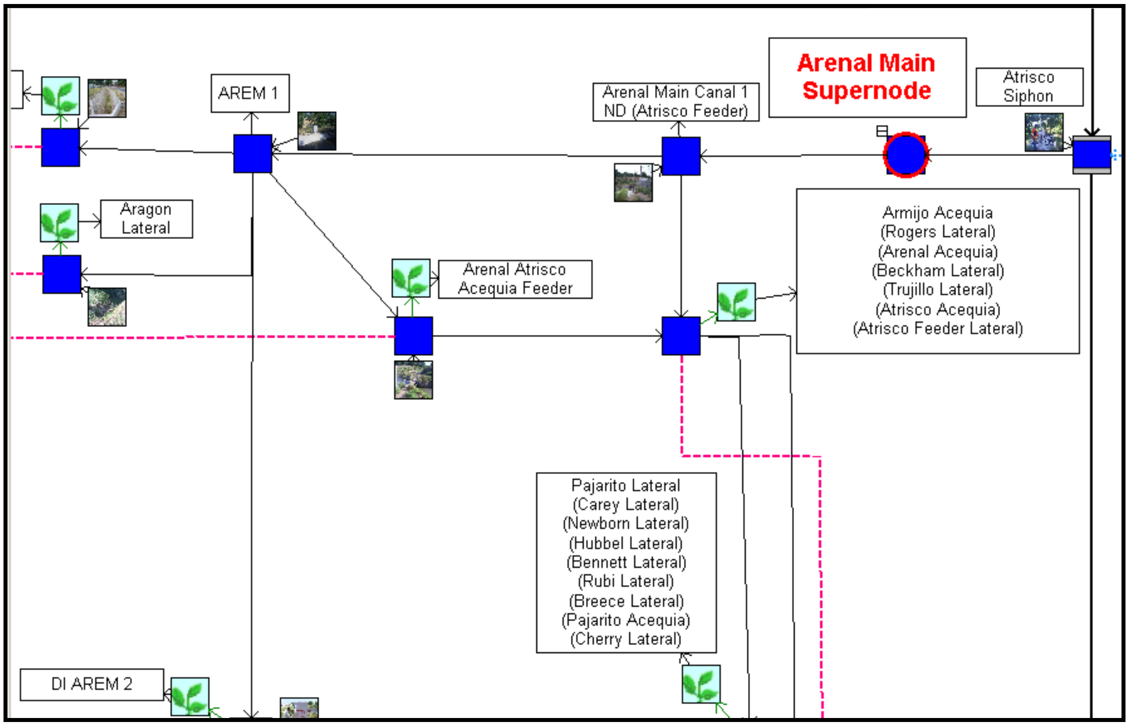

Figure 5.3 DSS Interface Showing the Arenal Main Canal Heading.

5.2.1 Albuquerque Main Canal

The first comparison that was analyzed for the Albuquerque Main Canal diversion was the daily value of flow rate in ac-ft. The daily flow rate values for actual diversions showed significant variability and the DSS diversion numbers showed a constant maximum predicted value and very little variation on minimum flow predictions. This is due to the settings on the DSS inflow node to incorporate flow fluctuations in the canal. Figure 5.4 displays the daily flow rate suggested by the DSS and the actual flow rate for 2009.

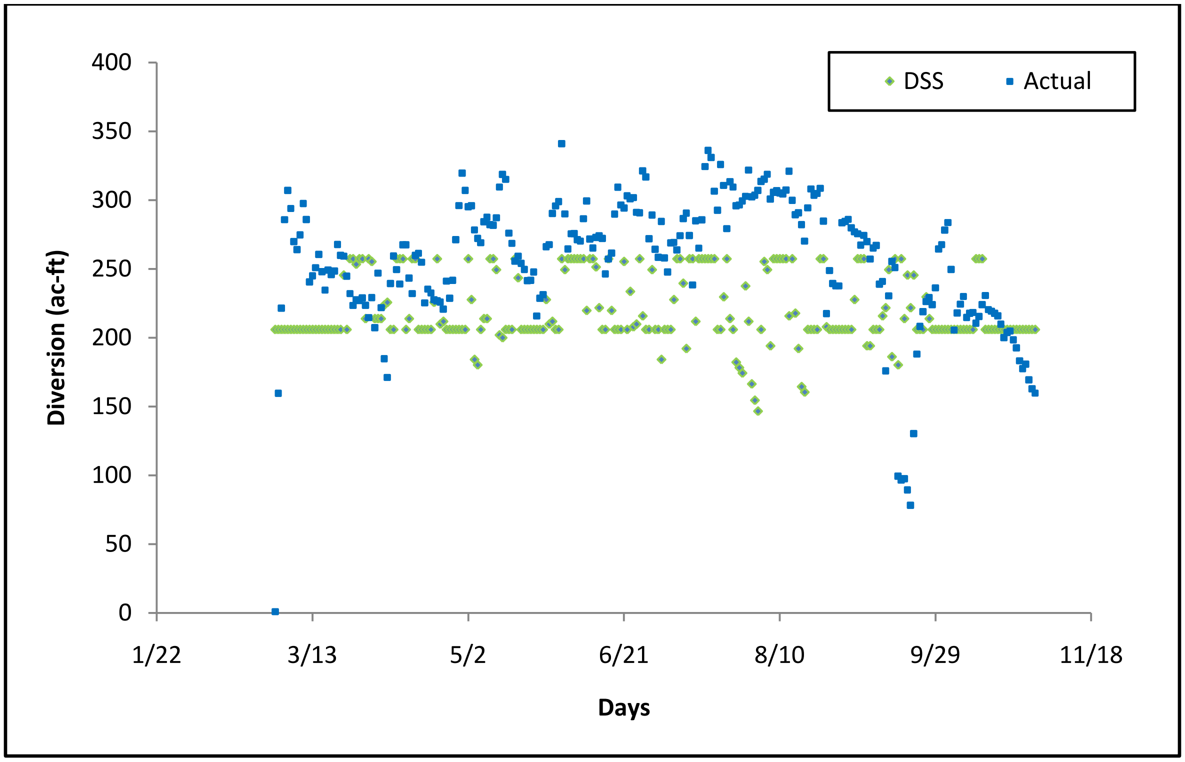

Figure 5.4 DSS Daily Flow Recommendations and Actual Flow Rate for the Albuquerque Main Canal in 2009.

To analyze the variability in the daily flow rate values for the Albuquerque Main Canal the Nash-Sutcliffe modeling efficiency statistic was calculated. The Nash-Sutcliffe value for the fit between the modeled DSS daily flow rate and the actual daily flow rate was found to be -0.80 (Table 5.1). This indicates that on a daily basis the DSS had minimal agreement with the actual practice. However, the Nash-Sutcliff value for cumulative daily DSS flow rate was 0.90. The Nash-Sutcliff value for monthly analysis was -1.19, which again indicates minimal agreement on this aspect. This indicates that on a daily cumulative analysis the DSS had a reasonable agreement with the actual practice. The minimal agreement indicates a need in farming improvements practiced in the Albuquerque Division.

Table 5.1 Nash Sutcliffe Analysis for the Albuquerque Main Canal.

Canal	Nash-Sutcliffe Modeling Efficiency (Daily)	Nash-Sutcliffe Modeling Efficiency (Cumulative Daily)	Nash-Sutcliffe Modeling Efficiency (Monthly)
Albuquerque Main Canal	-0.80	0.90	-1.19

For further analysis the data was compared using monthly recommendations, Figure 5.5 shows actual monthly diversions and DSS monthly recommendations. The Nash-Sutcliffe value for the fit between the modeled DSS monthly flow rate and the actual monthly flow rate was found to be -1.19. Both the DSS and the actual monthly diversions showed a bell curve shape characteristic of a canal that is used to supply water for crop demand. The actual diversion numbers on a monthly basis were higher than the DSS suggested value in every month except September where the variation difference was 1.0% (Table 5.2).

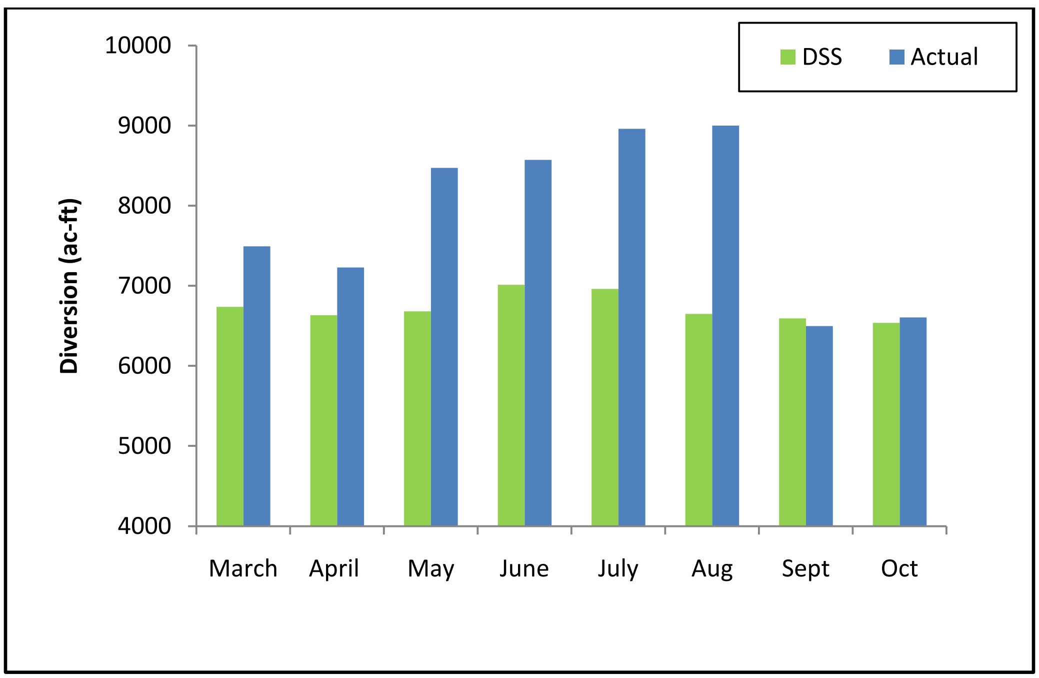

Figure 5.5 Actual Monthly Diversions and DSS recommendations in the Albuquerque Main Canal

Table 5.2 Comparison of Monthly DSS Diversions and Actual Diversions

Albuquerque Main Canal		
Date	**DSS (Ac-ft)**	**Actual (Ac-ft)**
March	6,736	7,492
April	6,635	7,228
May	6,683	8,473
June	7,013	8,572
July	6,962	8,961
Aug	6,649	8,998
Sept	6,591	6,499
Oct	6,538	6,605

The monthly comparison indicates higher actual diversions between 1.0 and 26%, with the highest diversion being in the month of August. The DSS diversion predictions were higher during the month of September by 1.4%. The monthly diversions indicate some agreement between the DSS and the actual practice.

The mean monthly difference between the actual diversions and the DSS recommended diversions was found to be 1,127 ac-ft. This indicates that on average the MRGCD Hydrologist and the ditch-riders could match the recommended diversions within 1,127 ac-ft on a monthly basis. This is another indication which shows some degree of agreement between the DSS and actual diversions.

The annual diversions for the Albuquerque Main Canal were also compared to the DSS recommendations (Figure 5.6). The DSS recommended yearly diversion for the Albuquerque Main Canal in 2009 was 53,807 ac-ft. The actual diversion for the Albuquerque Main Canal was 62, 828 ac-ft. The yearly difference between actual diversions and the DSS predicted diversions on the Albuquerque Main Canal was 9, 021ac-ft, which is 14% more than the DSS recommendations.

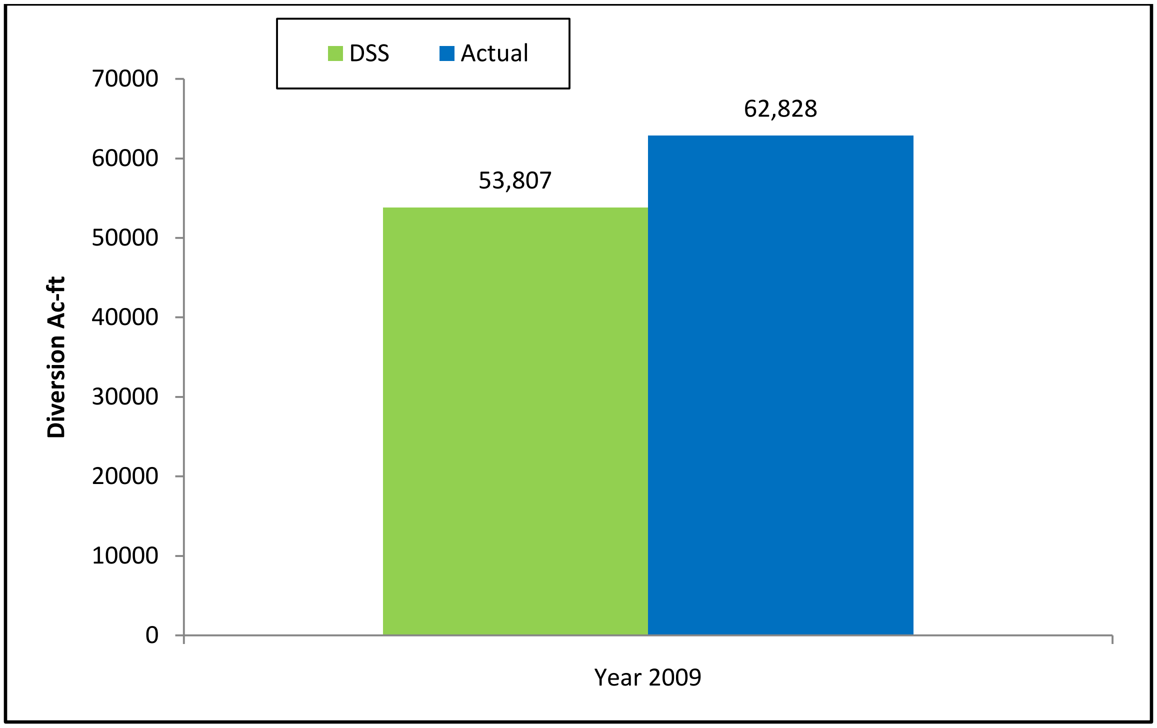

Figure 5.6 Comparison of Yearly DSS Recommended Diversions and Actual Diversions in Albuquerque Main Canal in 2009

The daily cumulative actual diversions and daily DSS recommended values for the Albuquerque Main Canal were also analyzed to determine how well the diversions suggested by the DSS were followed as the season progressed (Figure 5.7). For the Albuquerque Main Canal the actual cumulative diversions were slightly higher than the DSS recommendations, indicating that the required amount of water on a cumulative basis was supplied throughout the season and that water users would not have been negatively impacted by the utilization of the DSS. The Nash-Sutcliffe value for the cumulative DSS modeling efficiency was 0.90 indicating that throughout the season the DSS recommendations had a reasonable agreement with the actual practice currently used.

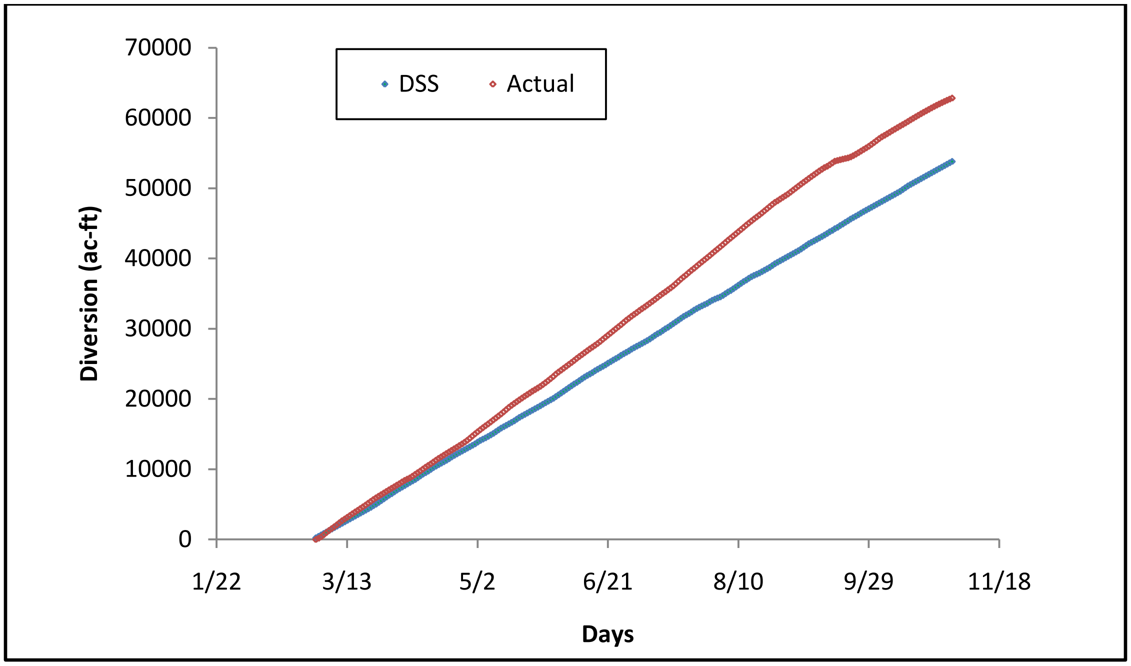

Figure 5.7 Comparison of DSS Cumulative Flow and Actual Cumulative Flow in the Albuquerque Main Canal in 2009.

The correlation between the daily cumulative DSS recommended flow and the daily cumulative actual flow utilized during the 2009 irrigation season for the Albuquerque Canal was also examined (Figure 5.8). The correlation coefficient was calculated to be $R^2 = 0.99$ which indicates that the actual cumulative daily flow and DSS recommended flow were highly correlated. Plotting the DSS cumulative flow against the actual cumulative flow indicated that the correlation was skewed slightly higher than the ideal fit line, indicating that actual diversions were slightly higher than the DSS suggested diversions.

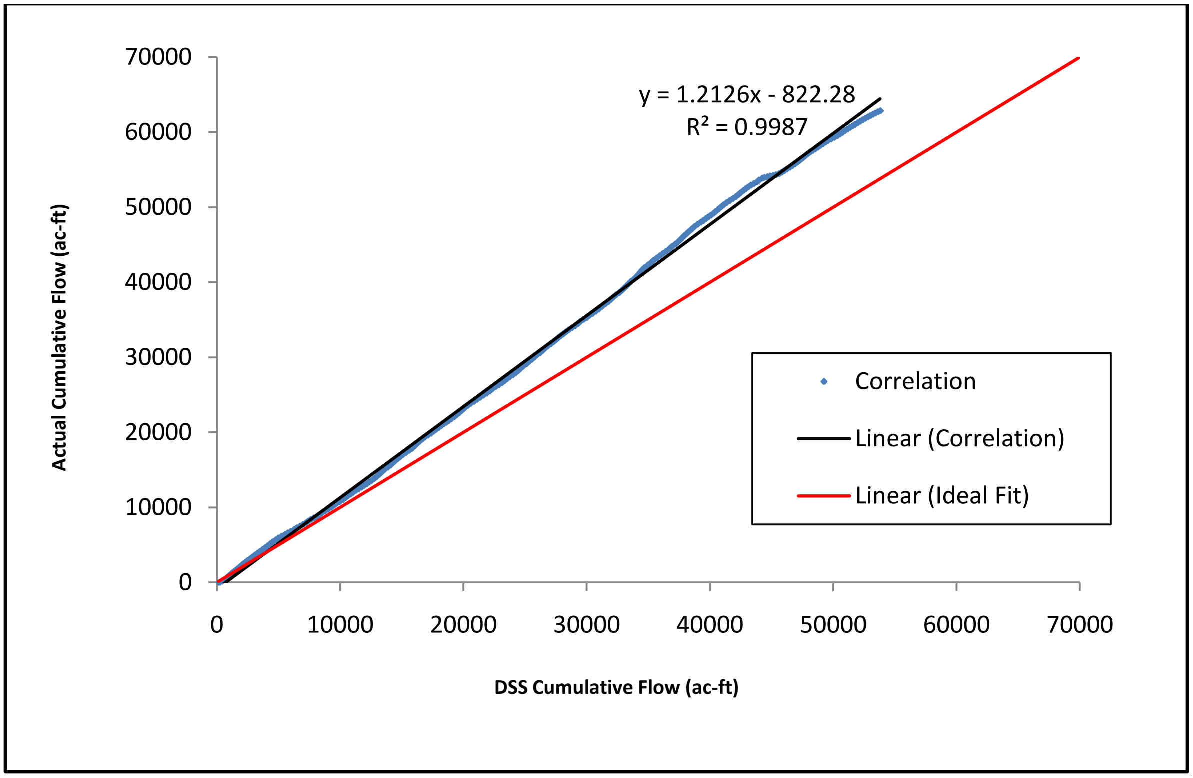

Figure 5.8 Daily Cumulative DSS Recommended Diversions Compared to Daily Cumulative Actual Diversions in Albuquerque Main Canal.

5.2.2 Arenal Main Canal

Daily flow diversion rates for the Arenal Main Canal were also analyzed in ac-ft. The daily flow rate values for actual diversions showed higher minimum values and higher maximum vales compared to the DSS recommendations (Figure 5.9). The DSS recommended diversions numbers showed significant variability throughout the irrigation season.

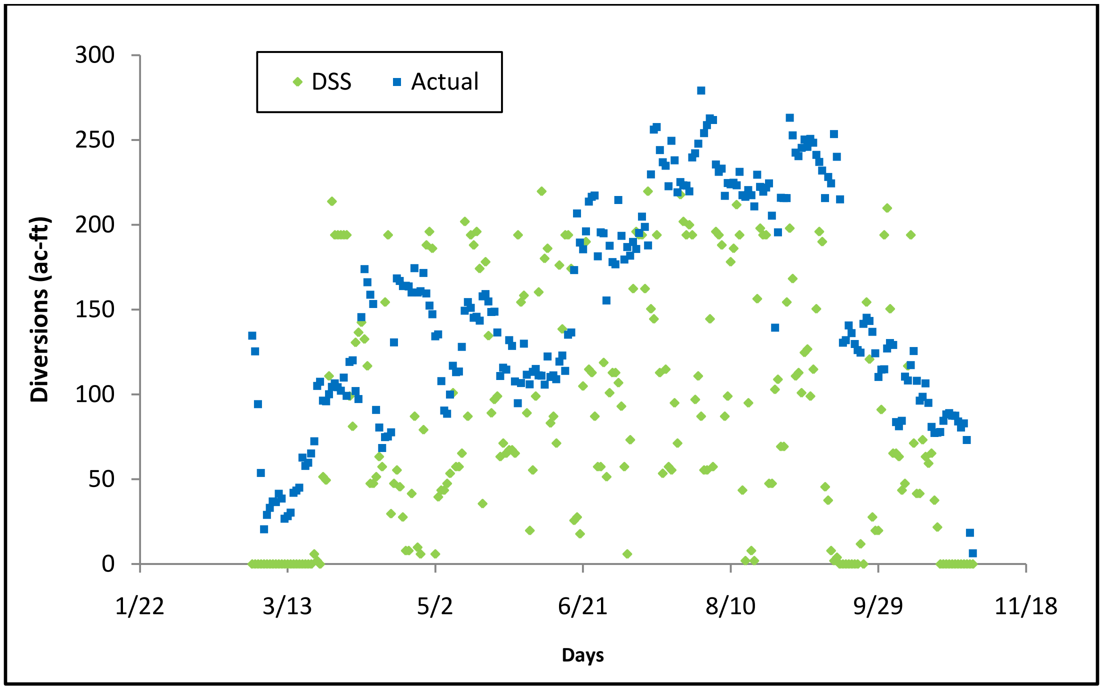

Figure 5.9 Comparison of Daily Actual and Daily DSS Recommended Diversions in the Arenal Main Canal.

To analyze the variability in the daily flow rate values for the Arenal Main Canal the Nash-Sutcliffe modeling efficiency statistic was calculated. The Nash-Sutcliffe value for the fit between the modeled DSS daily flow rate and the actual daily flow rate was found to be -1.33 (Table 5.3). This indicates that on a daily basis the DSS had minimal agreement with the actual practice, indicating more water usage in the Albuquerque Division. The Nash-Sutcliffe value for cumulative daily DSS flow rate was 0.57. The Nash-Sutcliffe value for monthly analysis was -0.79, which again indicates minimal agreement on this aspect. This indicates that on a daily cumulative analysis the DSS had some agreement with the actual practice.

Table 5.3 Nash Sutcliffe Analysis for the Arenal Main Canal.

Canal	Nash-Sutcliffe Modeling Efficiency (Daily)	Nash-Sutcliffe Modeling Efficiency (Cumulative Daily)	Nash-Sutcliffe Modeling Efficiency (Monthly)
Arenal Main Canal	-1.33	0.57	-0.79

For further analysis the data was compared using monthly recommendations, Figure 5.10 shows actual monthly diversions and DSS monthly recommendations. The Nash-Sutcliffe value for the fit between the modeled DSS monthly flow rate and the actual monthly flow rate was found to be -0.79. Both the DSS and the actual monthly diversions showed a bell curve shape characteristic of a canal that is used to supply water for crop demand. The actual diversion numbers on a monthly basis were significantly higher than the DSS recommendations for the entire 2009 irrigation season.

The monthly comparison indicates higher actual diversions between ranges of 21.5% to 66.9%, with the highest diversion being in the July through September period (Table 5.4). The monthly diversions indicate that the DSS recommendations are drastically low compared to the actual practice. The mean monthly difference between the actual diversions and the DSS recommended diversions was found to be 1,923 ac-ft. This indicates that on average the MRGCD Hydrologist and the ditch-riders could match the recommended diversions within 1,923 ac-ft on a monthly basis which shows very minimal agreement between the DSS recommendations and actual diversions.

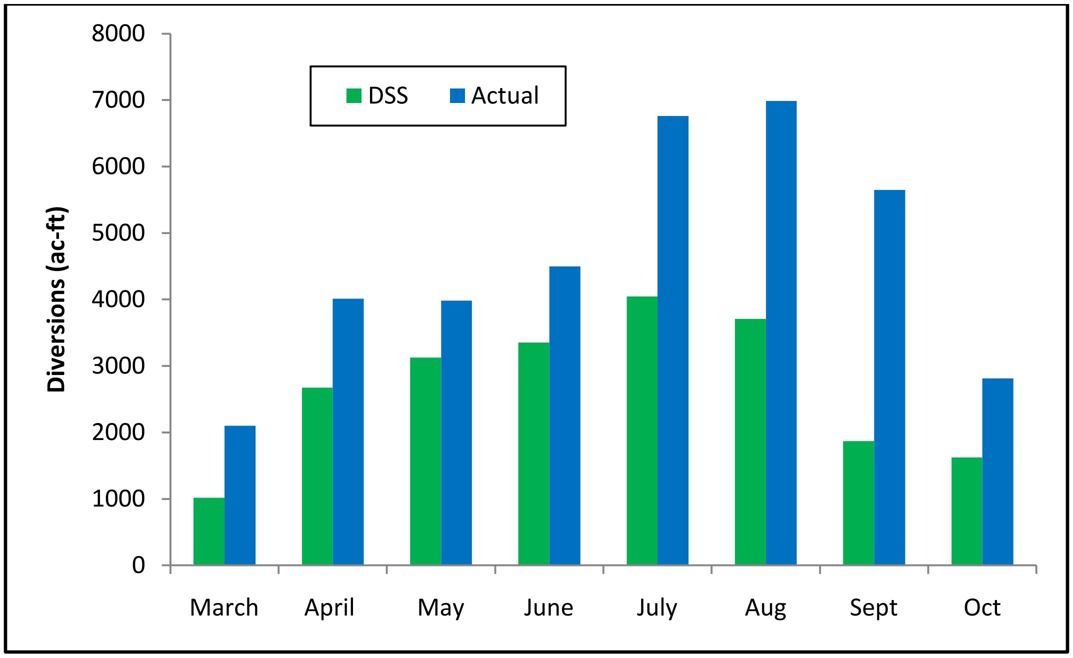

Figure 5.10 Monthly DSS Recommended Diversions and Actual Diversions in the Arenal Main Canal in Year 2009

Table 5.4 Comparison of Monthly DSS Diversions and Actual Diversions

Arenal Main Canal		
Date	**DSS (Ac-ft)**	**Actual (Ac-ft)**
March	1,016	2,101
April	2,673	4,010
May	3,124	3,981
June	3,354	4,498
July	4,043	6,762
Aug	3,707	6,986
Sept	1,869	5,647
Oct	1,626	2,812

During the period of July through September the mean actual diversion was 6,465 ac-ft. The DSS recommendations were notably in minimal agreement with the actual diversions during this period. This significant difference during the month of July through September is due to the farming practices done during this period. During this period the water users collude with the ditch-riders in using more water since it is the driest part of the irrigation season.

The annual diversions for the Arenal Main Canal were also compared to the DSS recommendations (Figure 5.11). The DSS recommended yearly diversion for the Arenal Main Canal in 2009 was 20,705 ac-ft, and the actual diversions were 36,797 ac-ft. The difference in diversions is almost double the DSS recommendation, which is an indication of more water used because of poor management. The yearly difference between actual diversions and the DSS recommended diversions on the Arenal Main Canal was 26, 604ac-ft, which is 43% more than the DSS recommendations.

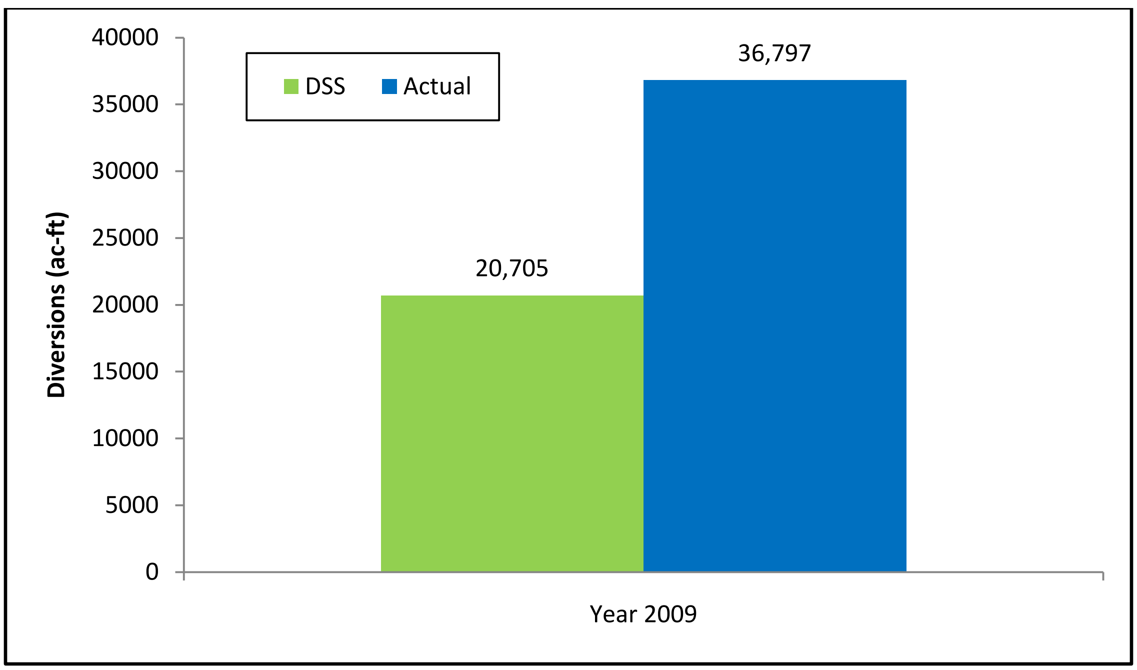

Figure 5.11 Comparison of Yearly DSS Recommended Diversions and Actual Diversions in the Arenal Main Canal in Year 2009

The daily cumulative actual diversions and daily DSS recommended values for the Arenal Main Canal were also analyzed to determine how well the diversions suggested by the DSS were followed as the season progressed (Figure 5.12). For the Arenal Main Canal the actual cumulative diversions were significantly higher than the DSS recommendations. This is another indication of the poor irrigation water management practiced in this service area. The Nash-Sutcliffe value for the cumulative DSS modeling efficiency was 0.57 indicating that throughout the season the DSS recommendations had a minimal agreement with the actual practice.

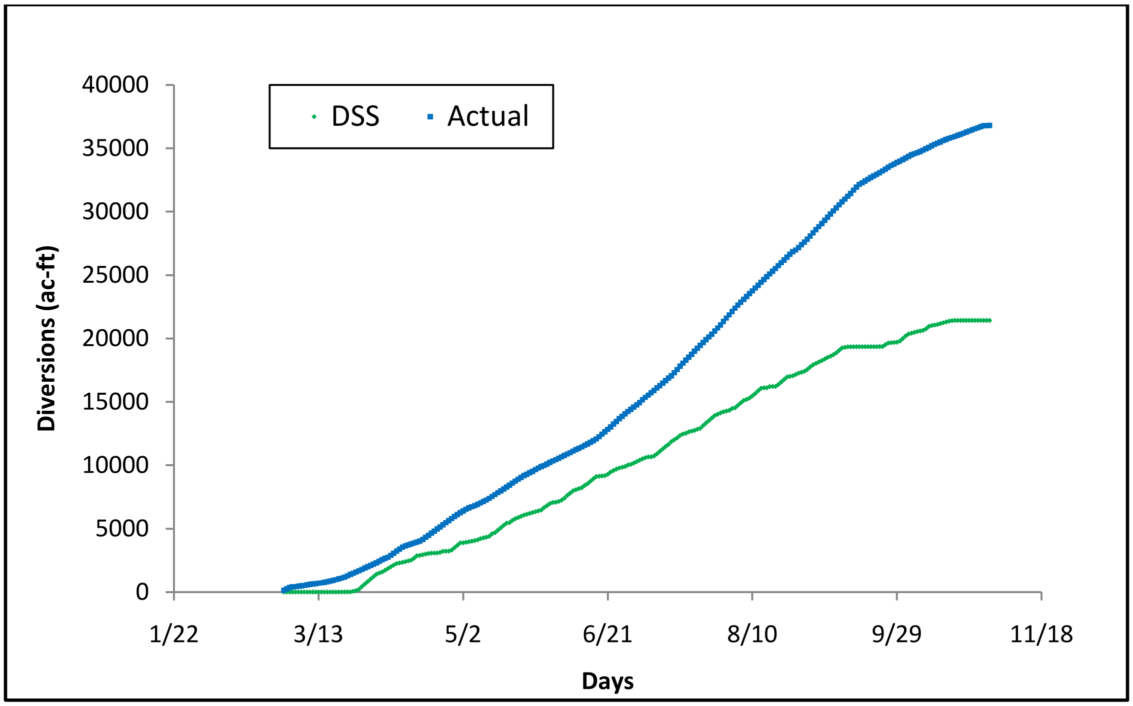

Figure 5.12 Comparison of DSS Daily Cumulative recommendations and Actual Daily Cumulative Diversions in the Arenal Main Canal in Year 2009.

This is an indication that the MRGCD is diverting more water from the river due to bad irrigation scheduling practiced within the Arenal Main Canal service area.

The correlation between the daily cumulative DSS recommended flows and the daily cumulative actual flows utilized during the 2009 irrigation season for the Arenal

Main Canal was also examined (Figure 5.13). The correlation coefficient was calculated to be $R^2 = 0.98$ which indicates that the actual cumulative daily flow and the DSS recommended flow were highly correlated. Plotting the DSS cumulative flow against the actual cumulative flow indicated that the correlation was skewed extensively higher than the ideal fit line, indicating that actual diversions were much higher than the DSS recommended diversions.

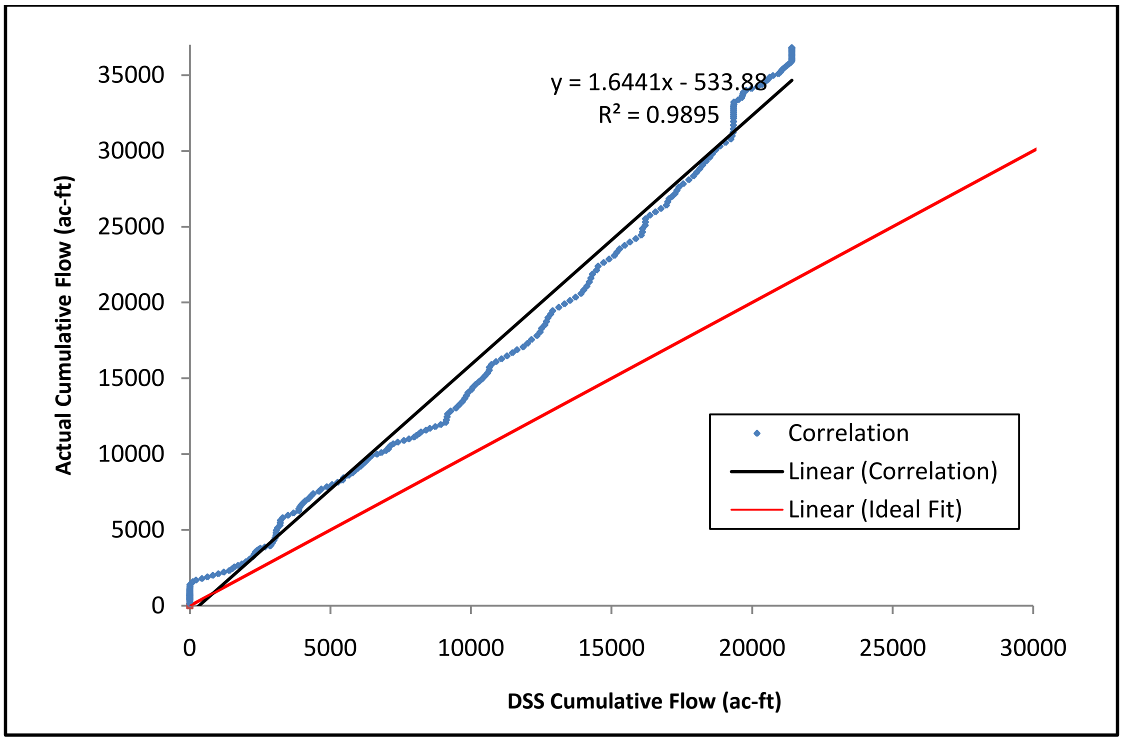

Figure 5.13 Comparison of DSS Cumulative Flow and Actual Cumulative Flow.

5.2.3 Corrales Main Canal

Daily flow rates data for the Corrales Main Canal diversion were also analyzed in ac-ft. The daily flow rate values for actual diversions showed a bell shaped pattern throughout the irrigation season. The DSS diversion numbers (Figure 5.14) showed more variability throughout the irrigation season. However, the DSS recommendations indicated a constant daily average diversion value for the entire irrigation season. This is because of the DSS settings which were done to cater for the constant flow fluctuations in the canal.

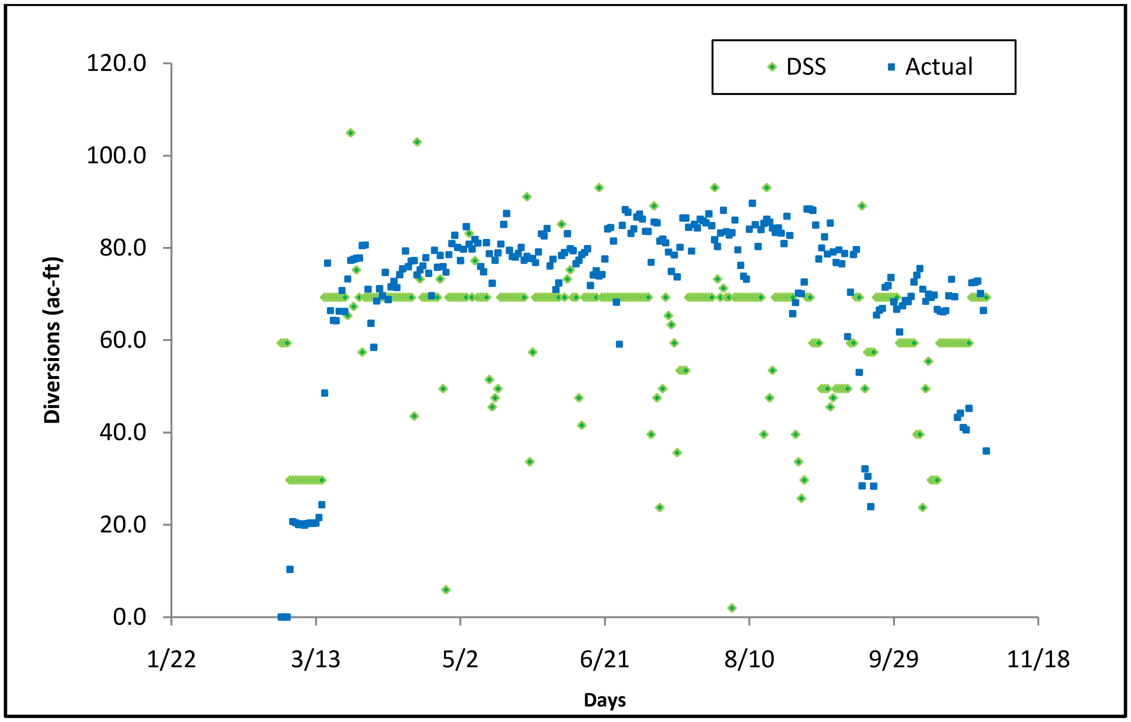

Figure 5.14 Daily Actual Diversions and DSS Recommended Diversions in the Corrales Main Canal

To analyze the variability in the daily flow rate values for the Corrales Main Canal the Nash-Sutcliffe modeling efficiency statistic was calculated. The Nash-Sutcliffe value for the fit between the modeled DSS daily flow rate and the actual daily flow rate was found to be -0.34 (Table 5.5). This indicates that on a daily basis the DSS had minimal agreement with the actual practice. However, the Nash-Sutcliff value for cumulative daily DSS flow rate was 0.94. The Nash-Sutcliff value for monthly analysis was -1.12, which again indicates minimal agreement on this aspect. This indicates that using daily cumulative analysis the DSS had reasonable agreement with the actual practice.

Table 5.5 Nash-Sutcliffe Analysis for Corrales Main Canal in Year 2009.

Canal	**Nash-Sutcliffe Modeling Efficiency (Daily)**	**Nash-Sutcliffe Modeling Efficiency (Cumulative Daily)**	**Nash-Sutcliffe Modeling Efficiency (Monthly)**
Corrales Main Canal	-0.34	0.94	-0.12

For further analysis the data was compared using monthly recommendations, Figure 5.15 shows actual monthly diversions and DSS monthly recommendations in the Corrales Main Canal. The Nash-Sutcliffe value for the fit between the modeled DSS monthly flow rate and the actual monthly flow rate was found to be -1.12. Both the DSS and the actual monthly diversions showed a bell curve shape characteristic of a canal that is used to supply water for crop demand. The actual diversion numbers on a monthly basis were higher than the DSS suggested value in every month except for March where the DSS recommendations where higher by 289 ac-ft (17%) (Table 5.6).

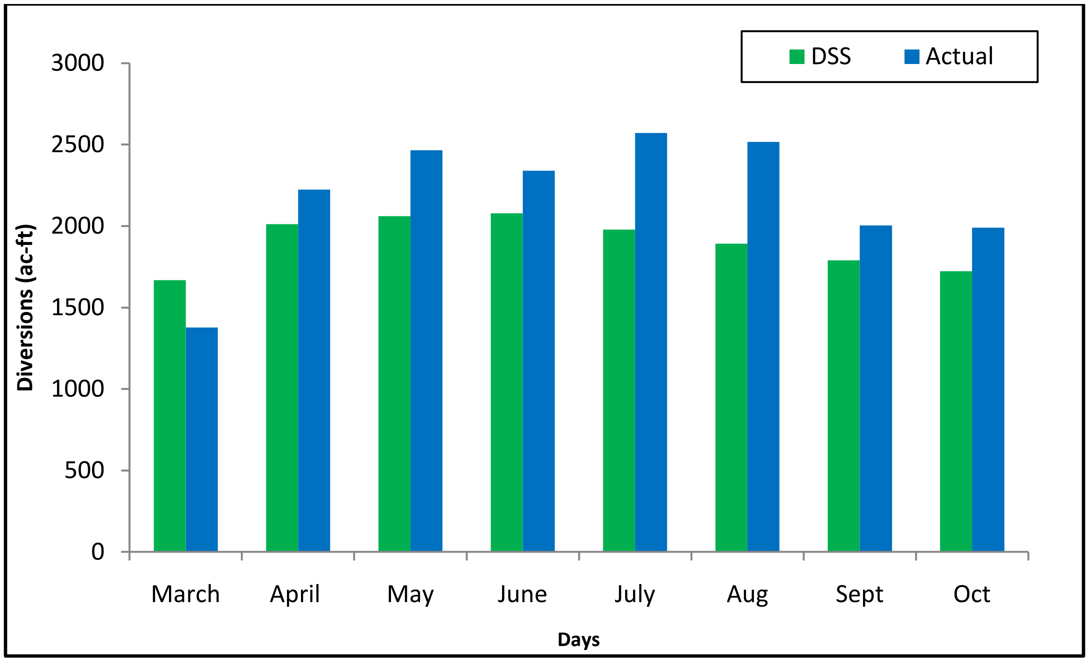

Figure 5.15 Monthly DSS Recommended Diversions and Actual Diversions for the Corrales Main Canal

Table 5.6 Comparison of Monthly Diversions for the Corrales Main Canal

Corrales Main Canal		
Date	**DSS (Ac-ft)**	**Actual (Ac-ft)**
March	1,667	1,378
April	2,012	2,224
May	2,061	2,465
June	2,079	2,340
July	1,978	2,572
Aug	1,891	2,516
Sept	1,790	2,005
Oct	1,723	1,989

The monthly comparison indicates higher actual diversions between ranges of 1.1 to 24.8%, with the highest diversions being in July through August period. During this period, the actual diversions where 2,572ac-ft and 2,516ac-ft, respectively; compared 1,978ac-ft and 1,981ac-ft recommended by the DSS.

The mean monthly difference between the actual diversions and the DSS recommended diversions was found to be 358 ac-ft. This indicates that on average the MRGCD Hydrologist and the ditch-riders could match the recommended diversions within 358 ac-ft on a monthly basis. This is another indication which shows a reasonable agreement between the DSS and actual diversions.

The annual diversions for the Corrales Main Canal were also compared to the DSS recommendations (Figure 5.16). The DSS recommended yearly diversion for the Corrales Main Canal in 2009 was 15,200ac-ft. The actual diversion for the Corrales Main Canal was 17, 489ac-ft. The yearly difference between actual diversions and the DSS recommended diversions on the Albuquerque Main Canal was 2,289ac-ft, which is 13% more than the DSS recommendations.

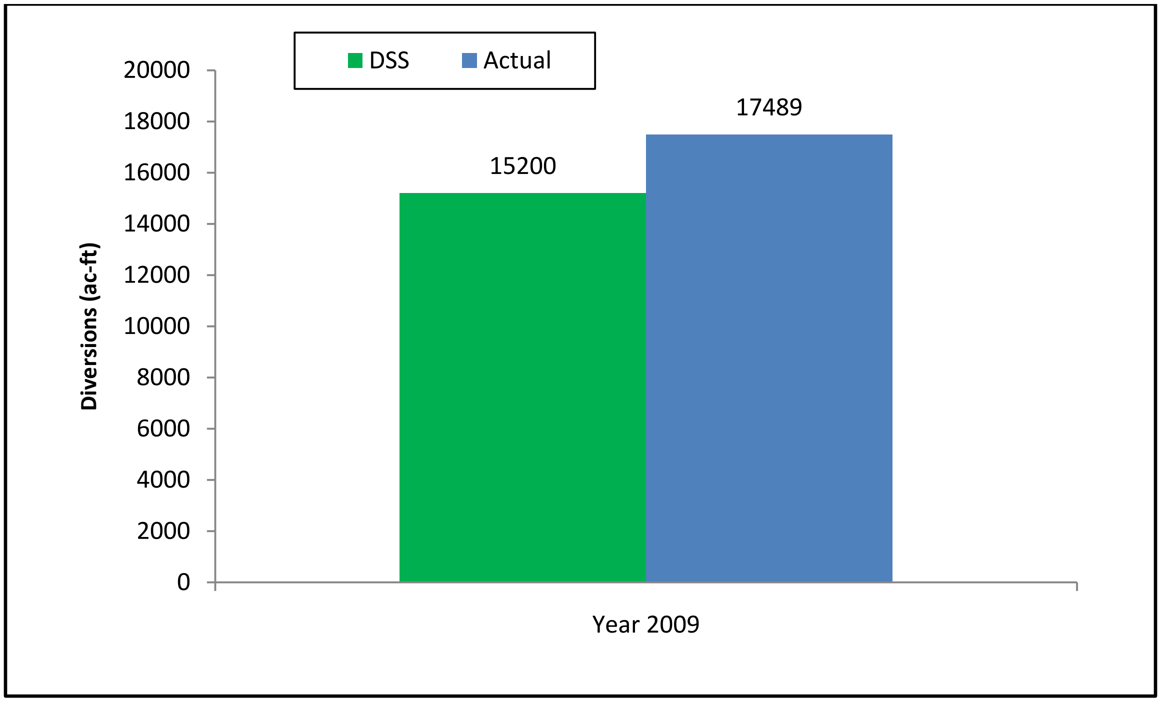

Figure 5.16 Comparison of Yearly Diversions in the Corrales Main Canal

The daily cumulative actual diversions and daily DSS recommended values for the Corrales Main Canal were also analyzed to determine how well the diversions suggested by the DSS were followed as the season progressed (Figure **5**.17). For the Corrales Main Canal the actual cumulative diversions were lower than the DSS recommendations during the first month of the irrigation season. However, the actual diversions were eventually higher than the DSS recommendations as the season progressed. This indicates that the required amount of water on a cumulative basis was supplied throughout the season and that water users would not have been negatively impacted by the utilization of the DSS. The Nash-Sutcliffe value for the cumulative DSS modeling efficiency was 0.94 indicating that throughout the season the DSS recommendations had a reasonable agreement with the actual practice currently used.

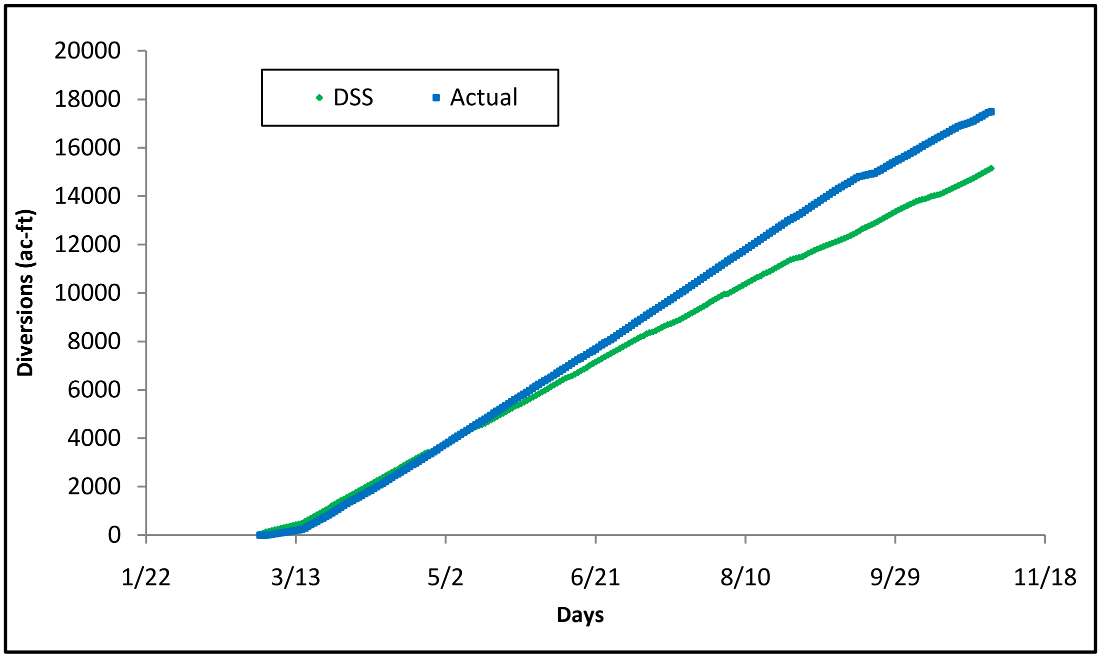

Figure 5.17 Comparison of Daily Cumulative Diversions in the Corrales Main Canal

The correlation between the daily cumulative DSS recommended flow and the daily cumulative actual flow utilized during the 2009 irrigation season for the Corrales Main Canal was also examined (Figure 5.18). The correlation coefficient was calculated to be $R^2 = 0.99$ which indicates that the actual cumulative daily flow and DSS recommended flow were highly correlated. Plotting the DSS cumulative flow against the actual cumulative flow indicated that the correlation was skewed lower than the ideal fit line for the first month of the irrigation season, indicating that the DSS recommendations were higher than the actual diversions. As the season progressed the correlation was skewed higher than the ideal fit line, indicating that actual diversions were higher than the DSS suggested diversions.

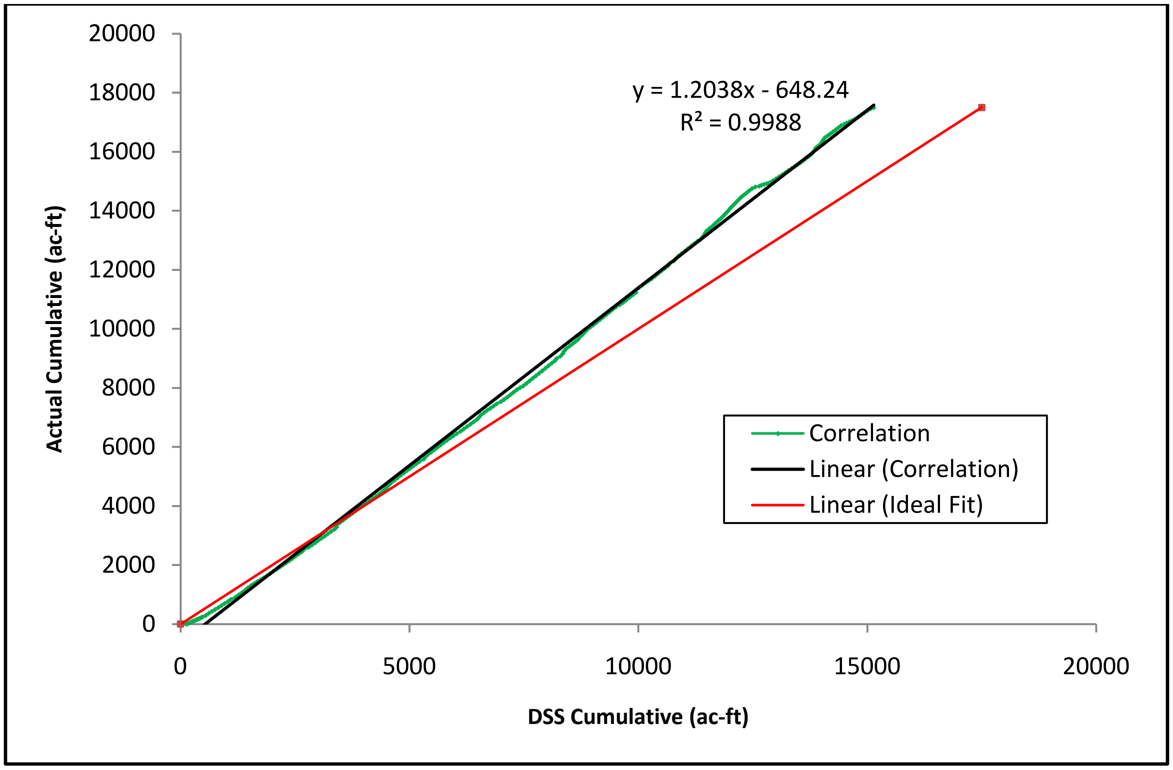

Figure 5.18 Comparison of DSS Daily Cumulative and Actual Daily Cumulative in the Corrales Main Canal

5.3 MRGCD DSS Schematic Analysis

Analysis of the water supply network module was also carried out. This is one of the DSS elements representing the layout of the canal system, conveyance system physical properties, and the relative location of diversions for each lateral service area. The analysis was deemed important since the DSS produces irrigation water schedules using calendars for each lateral based on the input data in the DSS modules namely, Scheduling Module, Demand Module and Water Supply Module (Figure 3.2). Also it was necessary to ascertain drastic diversions difference in the Arenal Main Canal. The schematic network interface represents the actual canal network on the ground.

The analysis indicated that some lateral canals and acequias, in the DSS network schematic, are grouped together as one lateral. The DSS schematic network, in the southwestern part of Albuquerque division, shows the Armijo Acequia demand node (Figure 5.19) representing six lateral canals and acequias; namely, the Rogers, the Beckham, the Trujilo, the Atrisco Feeder laterals and the Arenal and the Atrisco Acequias.

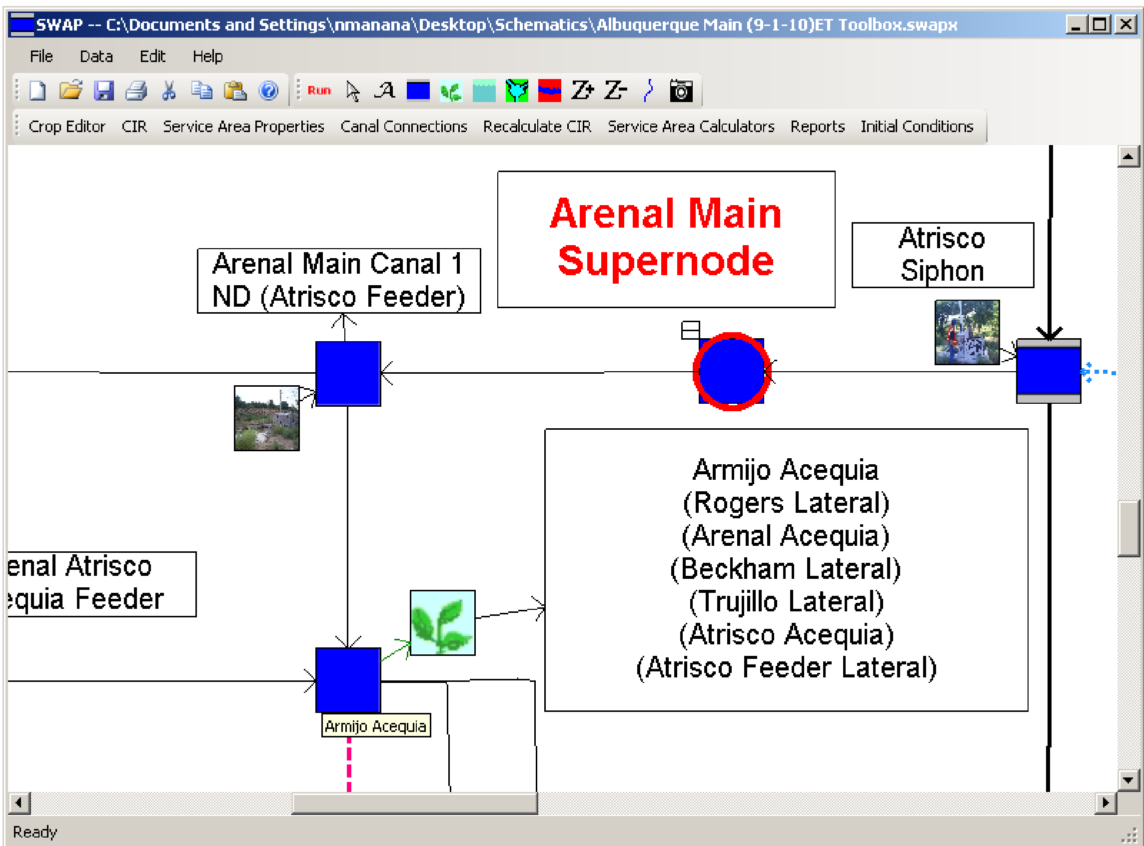

Figure 5.19 Albuquerque DSS Network Schematic Showing the Armijo Acequia.

Similarly, the Pajarito Lateral demand node (Figure 5.20) represents the following lateral canals and acequias: the Carey, the Newborn, the Hubbel, the Rubi, the Breece, the Cherry lateral canals and the Pajarito Acequia. To scrutinize the validity of setup analysis of the schematic showed that the soils type, the available holding capacity (AWHC), and the acreage data were properly represented in the schematic. However, the canal conveyance losses data, through seepage, were not well represented. Canal conveyance data were only entered for the Pajarito Lateral and the Armijo Acequia.

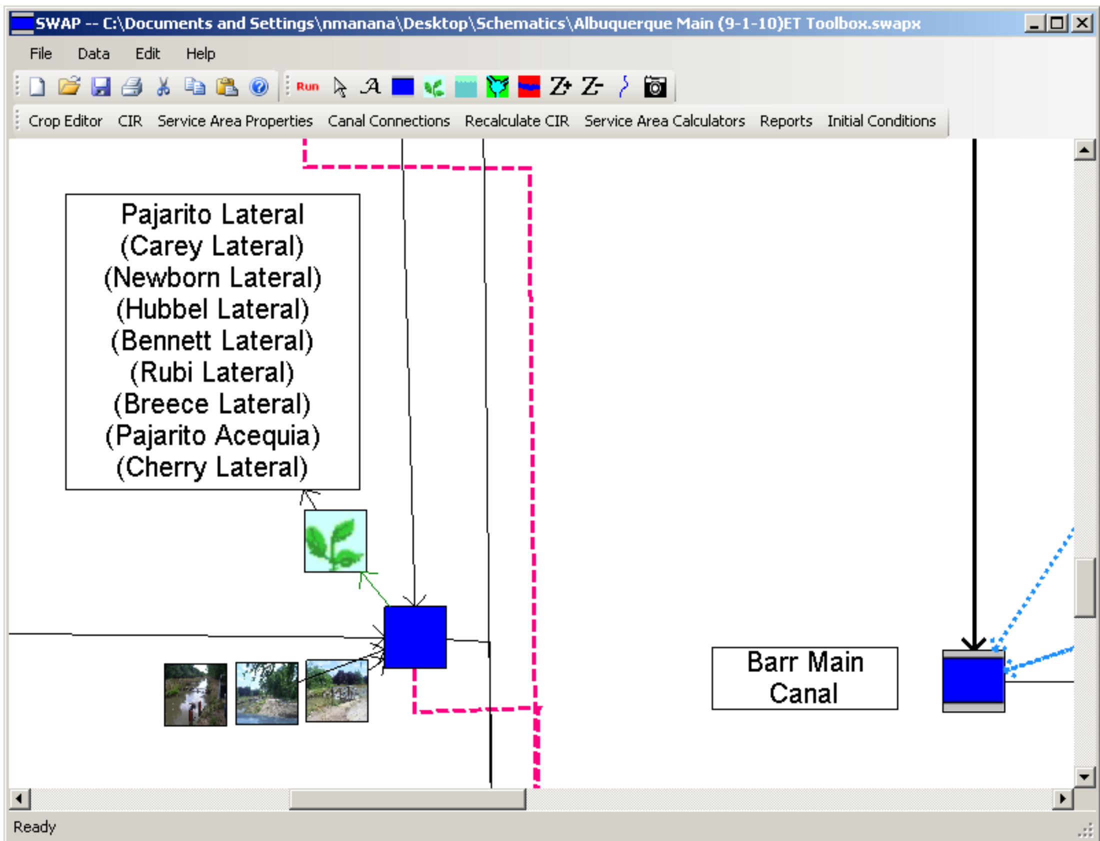

Figure 5.20 Albuquerque DSS Network Schematic Showing the Pajarito Lateral

Input data in terms of conveyance losses for a total of 14 lateral canals and acequias in the water supply network nodes of the DSS had no canal lengths data. A canal conveyance study for the MRGCD (Kinzli, 2010) indicated that lateral canals and acequias had higher conveyance loses compared to main canals. The average conveyance loses on the acequias and lateral canals is 3.2% loss per mile, and for the main canals is 1.2% loss per mile.

This anomaly was corrected by entering the missing data for all lateral canals and acequias represented by the Pajarito Lateral and the Armijo Acequia. After the correction and re-running of the DSS the results indicated that there was very little effect this caused on the model predictions. In fact the difference was insignificant.

Upon further investigation, it was discovered that due to the complicated nature of the Albuquerque Division canal network, the concepts of super-nodes and aggregated nodes were employed to develop a more user friendly network schematic. Aggregated nodes are the combination of multiple small irrigation canals that feed off one another and are in the same general vicinity. The nature of the small canals running through highly urbanized areas created the problem that the schematic became convoluted and unintelligible. In addition, most of the small laterals irrigate less than 30 acres. Among the aggregated nodes used are the Armijo Acequia and the Pajarito Lateral. The aggregated information includes the acreage, weather, and soil water holding capacity data. Using aggregated nodes it was possible to simplify the schematic and make it more user friendly without losing any functionality or short changing farmers on small irrigation canals.

Other factors which could have a negative effect on the DSS functionality in the Albuquerque division, especially the south western part, include the following;

- Some lateral canals are constantly kept running, even when not in use, to compensate for high conveyance losses.

- Some farmers with large acreage are non-cooperative to the ditch-riders in following issued irrigation schedules. They create and follow their own irrigation pattern and the administration turns a blind eye on such practices even when reported.
- The Native Americans water demands are not predictable. They demand water anytime they need and this cannot be accommodated in the DSS.
- There is no accountability on the amount of water diverted, drained or wasted from the lateral canals. Wasting water is necessary in controlling flows in the laterals canals to avoid canal breaks.
- In most cases the ditch-riders don't have an idea as to how much flow they have in the lateral canals since there are no water measuring devices. This could result in higher river diversions.
- Some ditch-riders are not as vigilant in their duties such that they allow farmers to operate check structures and farm headings without their (ditch-rider) consent.

The *bosque* or the riverside forest of cottonwood, willows, russian olive and salt cedar, is supported by the shallow groundwater system that is connected to the Rio Grande and surrounded by the widespread irrigated farming that diverts water directly from the Rio Grande. Some irrigation water is used up by the *bosque* and this water usage is not incorporated in the DSS.

To correct this anomaly of farming practices a more intense level of management in the MRGCD is required if water is to be conserved and adequately delivered to water users. There should be awareness campaign of proper farming practices to the water user.

CHAPTER 6. DISCUSSIONS AND RECOMENDATIONS

6.1 Discussions

For all the three main canals evaluated (Albuquerque, Arenal and Corrales) the actual diversions were higher than the diversions suggested by the DSS. As the season progressed, the actual diversion numbers more closely matched the DSS recommended diversions except for the Arenal Main Canal. The difference in the yearly diversions, in Ac-ft, varied among the three canals (Figure 6.1).

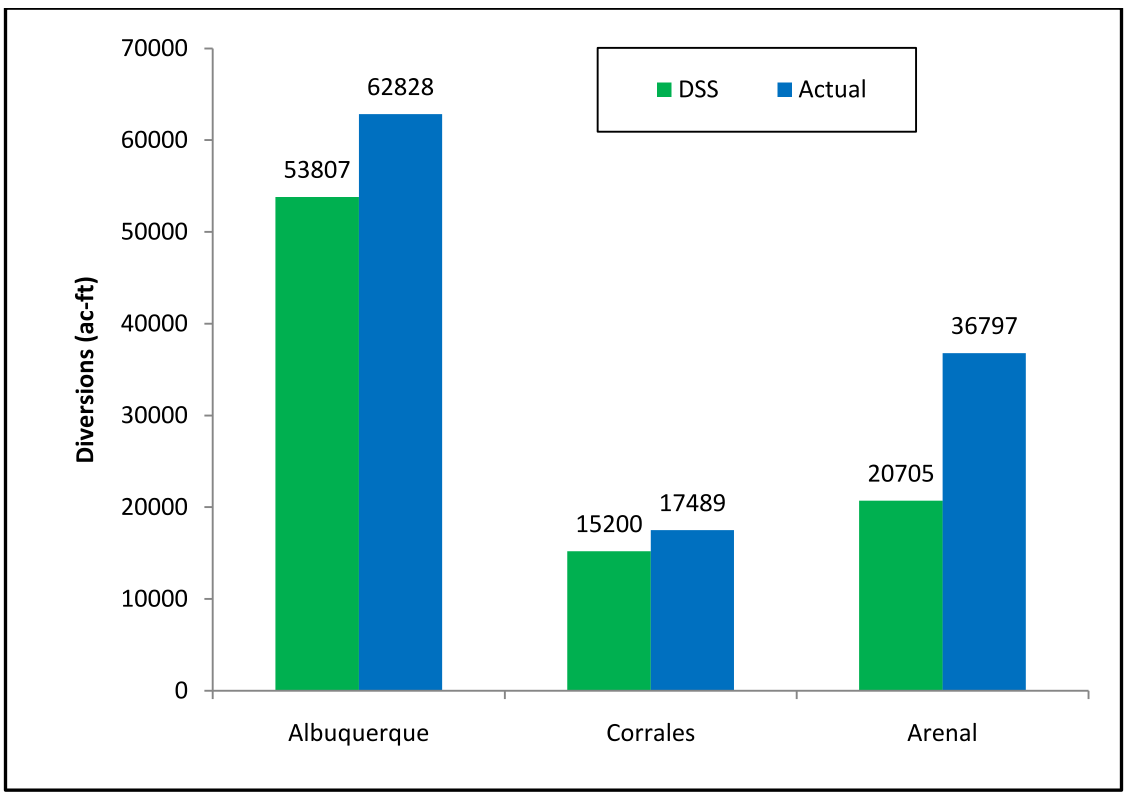

Figure 6.1 Yearly Diversions in the Albuquerque, Corrales and Arenal Main Canals in 2009.

The analysis indicates that the DSS recommendations and actual diversions are highly correlated on a cumulative basis but not on a daily or monthly basis. The minimum and maximum values (Figure 5.4), or repeating values (Figure 5.14) recommended by the DSS are not representative of what actually occurred in 2009. This indicates that the MRGCD needs to improve in irrigation water scheduling practices in order to meet their objectives. The study indicates that there is a potential in cutting down river diversions, and also improvements in irrigation water scheduling management in terms of delivery efficiency and monitoring skills.

The study indicates that the difference in actual diversions and the DSS recommendations for the Albuquerque Main Canal was 9,021ac-ft (14%) and 2,289 ac-ft (13%) for the Corrales Main Canal (Table 6.1). Though the Arenal Main Canal proved to have a large difference of 43% in the diversion values (16, 092 ac-ft) between the actual and the DSS recommendation, there is still much room for efficient improvement in irrigation scheduled water management through farm practice improvements. The mean annual diversions value for the three canals was 9,134 ac-ft.

Table 6.1 Annual Diversions Comparison of the Three Canals

Canal	**DSS (ac-ft)**	**Actual (ac-ft)**
Albuquerque Main Canal	53,807	62,828
Corrales Main Canal	15,200	17,489
Arenal Main Canal	20,705	36,797

Scheduled water delivery assisted by the DSS has the potential to provide adequate irrigation water scheduling and improve MRGCD personnel management skills, while concurrently minimizing excess river water diversions. The MRGCD can realize significant yearly reductions in water diversion. The study indicated that the Albuquerque and the Corrales main canals diversions could be reduced by 13% and 14%, respectively. The DSS recommendations for the Arenal main canal indicated a reduction of 43%. This high reduction value clearly indicates higher irregular farming practices in the Arenal Main Canal service area, like running lateral canals nonstop to incorporate conveyance loses. .

6.2 DSS Improvement

It must be recognized that DSS models are management tools that can assist in making informed decisions, and have some limitations. They cannot entirely mimic a complex enterprise such as irrigated agriculture, and as such human judgment is always important. Another limitation is that the model computes a crop water requirement for the whole lateral canal service area considering an average cropping pattern for the service area. The farmers' groups will still need to work with the ditch-rider to schedule irrigations within their lateral canal service area. For example, the DSS model developed for the MRGCD can schedule irrigations to lateral canal service areas but not to the individual farm holdings within the service areas. The resulting irrigation schedule will therefore be adequate for major crops such as alfalfa and corn but not suitable for vegetable crops. Special consideration will be needed for vegetable crops and after events including alfalfa cuttings and irrigation thereafter.

Also, DSS is not accounting for farming practices such as cutting and bailing, the planting of new fields, pueblo irrigators utilizing water without advance notice, and farmers' not utilizing water when it was available, the *bosque* demand, and the dilapidated condition of the infrastructure.

The DSS does not take into consideration the Native American Pueblos water demands. The pueblos are considered as ancient water users and have first priority when it comes to water allocation. They are not expected to forward a water request to ditch-riders at least 48 hrs prior like all other water users.

6.3 Infrastructure Improvements

Physical canals in the lateral network should be improved or rehabilitated for better delivery efficiency and measurement. The maintenance services on the laterals also need to be improved for more effective irrigation water scheduling practices. A properly maintained lateral network can reduce the risk of ditch breaks, clogging of laterals and drastic alterations in water levels due to accumulating silt and debris.

There is a desperate need to increase flow measuring locations within the lateral network. To effectively convey water through laterals to delivery at farms, it is necessary for the MRGCD to have an understanding of the quantity and location of water supply. At a minimum, flow should be metered at every lateral head gate and on several locations along the main canals. Such improvements on the infrastructure will provide the ditch-riders with real-time data, through the SCADA link. The ditch-riders will have a better understanding of the supply conditions in their service areas as well as be able to predict conditions through observation of upstream measurement gauges. Metering provides a better understanding of supply availability and location for purpose of managing water diversions to meet demand requirements. With real-time data available it will be possible for MRGCD personnel to make immediate decisions based on given supply conditions.

6.4 Increases in Management Intensity

The DSS will require a more intense level of management in the MRGCD if water delivery is to be adequately supplied to individual water users. More intense management will require an increase in operational cost, more labor resources and increases in labor input. Increases in management intensity should include training the ditch-riders on crop water requirements, basic hydraulics, and operations of an irrigation system. The ditch-riders must understand the DSS and have proper policy guidelines to support the decisions they make.

To realize this achievement, additional automated gates and flow measurement devices should be installed throughout the lateral network. The success of a DSS will depend on the ability of the MRGCD to institutionalize all aspects of the decision-making process. Not only do management personnel need an understanding of the DSS, they also must have the capacity to upgrade the system for its long term viability. Significant training of ditch-riders would be a necessity, in order to provide the ditch-riders with a better quantitative understanding of supply and demand in each service area. MRGCD ditch-riders have to understand the DSS and have proper policy guidelines to support the decisions they make. Overall, the DSS will require better organization and control of water supply, water demand and operational management in the MRGCD. Such implementations will certainly increase costs for the MRGCD but result in more efficient water allocation. The end benefits will of course supersede the implementation costs.

6.5 Future Objectives

Future implementation of the MRGCD DSS is essential for the MRG Valley to fulfill the desired goals. However, the implementations could be more costly since there will be a lot of infrastructure improvements required. This includes acquiring of required software, training of personnel and awareness campaign to the water users. A future direction would be to implement an irrigation advisory service to assist the MRGCD in enhancing its technical capabilities. Several other questions regarding accretion in agricultural drains and return flow patterns from applied irrigation water are poorly understood and would provide water managers with useful information and shed light on groundwater and surface water interactions in the Middle Rio Grande Valley.

CHAPTER 7. CONCLUSIONS

The hypothetical application of the MRGCD DSS in the Albuquerque Division has demonstrated that a decision support system can accurately calculate water delivery schedules for the Albuquerque Division in the MRGCD. The MRGCD DSS can be a good solution in irrigation water scheduling management provided it is properly implemented.

Scheduled water delivery implemented through the use of DSS coupled with infrastructure improvement and SCADA incorporation has various benefits for the MRGCD. The main benefit being that the DSS could provide a more efficient tool to properly manage water for scheduled irrigation. It could also assist in predicting projected water use, satisfying and maintaining economical agriculture in the MRG valley. Finally, it could help maintain reliable reservoir operations by the MRGCD Hydrologist.

The study supported the hypothesis that a DSS can proficiently and justifiably be utilized to manage scheduled water delivery operations in the Albuquerque Division. A DSS combined with infrastructure improvement and SCADA inclusion can significantly reduce river diversion while still serving water users demands.

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APPENDICES

APPENDIX A: Policies and Procedures of the Middle Rio Grande Conservancy District

(RULES AND POLICIES ESTABLISHED BY THE MIDDLE RIO GRANDE CONSERVANCY DISTRICTAND U.S. BUREAU OF RECLAMATION DEPARTMENT OF INTERIOR) Revised 04/05/07 JB

1. WATER DISTRIBUTION

a) Water that is available to the District will be delivered among Divisions in proportion with the amount of land served, so far as it is possible to do so, and to lands within each Division in like manner. Indian Lands under cultivation at the present time are considered to have first right to the water.

b) No water will be delivered to water users who are delinquent in the payment of Conservancy District Assessments.

c) In the interest of water user's welfare and efficient water distribution, DITCH RIDER/ISO will not be required to deliver water to silt-laden and weed-clogged community ditches, field ditches and laterals.

d) Water will be delivered to ditches at the upper end of each division and will be supplied progressively toward the lower end of the division. Irrigation will be completed in each area before transferring the water to another area, provided inter-division water rationing and rotation are not required.

e) In a similar manner, irrigation deliveries will commence at the upper end of each ditch, and each tract served by the ditch will be irrigated progressively downstream upon request from the water users. No irrigation deliveries will be made except with the express permission of the DITCH RIDER/ISO.

f) During the period of water shortage, it is essential that water users irrigate both day and night on a seven day schedule to utilize available supplies. Failure to do so will be construed to indicate no further need for water.

g) Water users who work outside their farms will, if possible be advised in advance as to when water is scheduled for delivery to their farm so that they can make arrangements for labor that may be required.

h) Water users will be permitted to open their turnouts and operate checks only at times specifically approved by the DITCH RIDER/ISO. The water user shall notify the DITCH RIDER/ISO as far in advance as possible of his need for water, and the DITCH RIDER/ISO will advise the water user as far in advance as possible when the water will be available.

i) Each DITCH RIDER/ISO will keep a record in a District issued Log Book for the purpose of showing water use by ditches. The record will show water users in proper sequence on each ditch, the date water was started and shut off, and whether irrigation was completed. Notes shall be made of any special cases of delivery or use of water. Each violation will be promptly reported to the Division Manager, and each such report will be noted in the record book.

j) The DITCH RIDER/ISO holds a key position and will at all times maintain close contact with the farmer or water user. There shall be no partiality shown in distribution of water regardless of personal feelings, race, creed, relationship, political, or social standing or previous grievances.

k) Scheduling of water for irrigators shall be from 7:00 a.m. to 8:00 p.m. In case a Ditch Rider/ISO is not available the irrigator may call appropriate Division office for assistance.

l) The Ditch Rider/ISO and / or superiors are duly constituted representatives of the District and are in charge of operation and maintenance of District works, and shall report any violations of the above rules and regulations.

m) Water pumped from drains during water shortage seasons is subject to the same regulations of distribution as irrigation water distributed through the regular irrigation canal distribution system.

n) As of February 25, 1964, the issuance of licenses permitting pumping of water from Conservancy drains is discontinued, except in cases where it is not physically financially feasible for water to be obtained from any other source. Any license using water in accord with permit issued prior to this date is required to conform to all rules and regulations herein set forth, and the license of any violator there of shall be revoked.

2. INSTALLATION AND REPLACEMENT OF FARM TURNOUT STRUCTURES

a) Farm turnouts will be installed on the basis of one turnout per ownership or farm unit up to 40 acres in size. Where the ownership exceeds 40 acres, additional turnouts may be provided for each additional 40 acres or increment thereof. Additional turnouts may also be installed where the topography of the land makes it impractical to irrigate all of the land from one turnout. Such additional turnouts may be installed only after a careful engineering study has been made. The cost for turnout and its installation shall be borne by the irrigator.

b) Additional turnouts will not be installed to serve subdivisions of existing ownerships. The sub- divider will be required to provide for irrigation deliveries to all subdivisions of holdings through head ditches located outside of rights of way owned by the Conservancy District or the United States. The District’s obligation shall end at the original point of diversion previously provided for serving the original tract.

c) Installation and replacement of farm turnouts will be done in compliance with project design criteria.

d) Where it is practical to do so, water users in the general vicinity of a turnout will be served their water supply through the use of existing water distribution boxes, which were established at the time of the original construction of the district works and/or rehabilitation by the Federal Government.

e) The Water User shall reimburse the District for an installation of a new turnout or relocation of an existing turnout if approved by the District.

3. MAINTENANCE, REPLACEMENT AND CONSTRUCTION OF CANAL, LATERAL, LEVEE AND DRAIN CROSSINGS

a) Maintenance and replacement of all crossings structures on state, county, or city roads or streets is the responsibility of the agency maintaining the road or street.

b) Crossing structures which were constructed by the Conservancy District of the Bureau of Reclamation to facilitate operation and maintenance work and located at points other than the intersections with state, county, or city roads and streets, will be maintained by the District

c) Bridges constructed by the District because of severance of ownership will be maintained and/or replaced as necessary by the District so long as the ownership continues to be severed. If all of the land of one side of the ditch is sold, the severance will no longer exist. Maintenance or replacement of a crossing constructed by the District because of severance which no longer exists will no longer be the responsibility of the Conservancy District. In instances where the District has maintenance responsibility on bridge crossings as requirements demand, the District will up-date these crossings either by revamping the bridge or by the installation of a pipe to meet the load requirements of today's activities.

d) Crossings structures at private roads must be maintained and replaced as necessary by the individual using the crossing. Bridge or culvert designs must be specifically approved in advance by the District and the Bureau.

e) No crossing may be constructed without prior written approval of the Conservancy District and the Bureau of Reclamation. Such approval shall be in the form of a license. Licenses for construction of new crossings will be issued only after the responsibility for maintenance has been clearly established.

f) A license for the construction of a crossing over District facilities may be granted in event of definite inconvenience or hardship imposed by severance or as a result of District or Bureau construction, real estate transactions or developments which result in loss of access detrimental to land use through no fault of the applicant.

g) Requests for licenses to construct new crossings must be submitted in writing to the Chief Engineer of the Conservancy District. No construction will be permitted until controlling elevations have been established or checked in the field by a representative of either the District or the Bureau.

4. CONSTRUCTION OF CROSS FENCES

a) No fences may be constructed or maintained across rights of way of the District or the United States unless specifically authorized in writing by the District.

5. FENCES PARALLELING RIGHTS OF WAY OF THE UNITED STATES OR DISTRICT

a) Upon request, the Bureau or the District may field inspect the location of the rights-of-way line, established by the owner’s surveyor so that parallel fences may be constructed on that line. No parallel fences may be constructed upon rights or way of the United States or the District.

6. FIELD HEAD DITCHES

a) Field head ditches will not be permitted upon rights of way owned by the United States or the District. It shall be the land owner's responsibility to remove any such existing ditches from rights of way of the District or the Bureau of Reclamation upon notice.

7. OTHER ENCROACHMENTS AND TRESPASSES ON RIGHTS OF WAY OF THE UNITED STATES OR DISTRICT

a) It is the duty of every employee of both the District and the Bureau to report to his/her superior what may appear or definitely be any encroachment or trespass of any kind upon rights of way of the United States or the District. Failure to do so will be considered grounds for disciplinary action.

8. USE OF OPERATION AND MAINTENANCE OF ROADS BY THE PUBLIC

a) The roads adjacent to the canals, laterals, levees, and drains are essential for efficient and economical operation and maintenance. Any unauthorized use shall be discontinued. The cooperation of City, County, State and Federal law enforcement officers will be solicited to aid in achieving this goal.

9. DUMPING TRASH ON RIGHTS OF WAY OWNED BY THE BUREAU OF RECLAMATION OR THE CONSERVANCY DISTRICT

a) Employees of the District or the Bureau are required to report the description of the vehicle, license number, name of driver, if available, time and place of any observed unlawful dumping of trash or debris on the rights of way of the District or the United States. Failure to do so will be considered grounds for disciplinary action.

10. CONTAMINATION OF WATER IN DITCHES OWNED BY THE UNITED STATES OR THE CONSERVANCY DISTRICT

a) It shall be the duty of every employee to advise the public as to regulations concerning contamination of waters conveyed by canals, laterals and drains as may be required, and to promptly report violations to his superior.

<u>APPENDIX B</u>: Ditch-Rider Water Delivery Practice in Albuquerque Division

Lateral Name	No. of Days Ditch is Running per Week	Flow-rates (cfs)
Alameda Lateral	7 days a week	17
Alameda Wasteway	1 day	
Albuquerque Main Canal	7 days a week	130
Allison Lateral	7 days every other week	
Archibeque Lateral	7 days every other week	
Aragon Lateral	7 days every other week	
Arenal Acequia	7 days a week	
Arenal Main Canal	7 days a week	75
Atrisco Feeder	7 days a week	40 - 90
Armijo Acequia	7 days a week	
Atrisco Acequia	7 days a week	
Atrisco Lateral	7 days a week	
Barr Main Canal	7 days a week	50
Bernalillo Acequia	5 days and shut off for 9 days	29
Beckham Lateral	7 days every other week	
Bennett Lateral	3 days or when needed	10
Bosque Lateral #1	7 days a week	
Bosque Lateral #2	7 days a week	
Breece Lateral	Weekends	
Carey Lateral	1 day when needed	
Chamisal Lateral	7 days a week	
Cherry Lateral	7 days a week	
Corrales Acequia	7 days a week	
Corrales Main Canal	7 days a week	45 - 50
Cramer Lateral	7 days every other week	
Deramedera Acequia	7 days a week	
Durand Lateral	7 days a week	
Duranes Lateral	7 days a week	
Foraker Lateral	7 days a week	
Gallegos Lateral	7 days a week	
Garcia Lateral	1 day every other week	

Lateral Name	**No. of Days Ditch is Running per Week**	**Flow-rates (cfs)**
Griegos Acequia	7 days a week	
Griegos Lateral	7 days a week	40 - 75
Gun Club Lateral	7 days a week	13 -26
Hackman Lateral	7 days a week	
Hale Lateral	1 day when needed	
Harwood lateral	7 days a week	
Hubbel Lateral	7 days a week	
Koogler Lateral	7 days a week	
Kramer Lateral	7 days every other week	
Lane Lateral	7 days a week	
Los Padillas Acequia	7 days a week	
Menaul Lateral	7 days a week	
Mercantile Lateral	7 days a week	
Newborn Lateral	1 day when needed	
Nichols Lateral	7 days a week	
Old Albuqerque Lateral	7 days a week	
Pajarito Acequia	7 days a week	
Pajarito Lateral	7 days a week	
Phelan Lateral	7 days every other week	
Pierce Lateral	7 days every other week	
Placitas Lateral #1	7 days a week	
Placitas Lateral #2	7 days a week	
Rice Lateral	7 days a week	
Rogers Lateral	7 days a week	5
Rubi Lateral	Weekends	
San Jose Lateral	7 days every other week	
Sandia Acequia	7 days a week	22 - 25
Sandoval Lateral	7 days a week	
Summerford Lateral	7 days every other week	
Trujillo Lateral	7 days every other week	
Wenk Lateral	7 days every other week	
Williams Lateral	7 days a week	30 - 35
Zearing Lateral	7 days a week	