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Final Report

On-Farm Irrigation Efficiency Evaluation of Representative Irrigation Sites within the Middle Rio Grande Conservancy District

Prepared for the
Water Acquisition and Management Subcommittee

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Analyses of Conveyance Optimization and On-Farm Efficiencies of Representative Irrigation Sites in the Middle Rio Grande Conservancy District

for the

Middle Rio Grande Endangered Species Act Collaborative Program

Water Acquisition and Management Subcommittee

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EXECUTIVE SUMMARY

This study of on-farm irrigation efficiency within the Middle Rio Grande Conservancy District (MRGCD) was conducted as part of the Middle Rio Grande Endangered Species Act (ESA) Collaborative Program by URS Group, Inc. (URS) and New Mexico State University (NMSU) under direction of the Water Acquisition and Management Subcommittee. This report is one of a two-part study and addresses the on-farm irrigation efficiency evaluation among farms within the MRCGD. The second volume addresses the seepage analysis of the Belen Highline Canal within the Belen Division of the MRGCD. The on-farm irrigation efficiency evaluation was conducted by URS with NMSU, while the conveyance seepage study was conducted by URS. Both studies were conducted between fall 2003 and spring 2005.

As a direct consequence of listing the Rio Grande Silvery Minnow and the Southwestern Willow Flycatcher as endangered species under the ESA, the work of the multi-agency ESA Collaborative Program is intended to address critical habitat issues for these species within the Middle Rio Grande Valley. Enforcement of the ESA for these species has resulted in the development of the U.S. Fish and Wildlife Service's (USFWS's) 2003 Biological Opinion and endangered species recovery plans for these two species, requiring maintenance of minimum flows along certain reaches of the Middle Rio Grande that are deemed critical for species survival. Because irrigated agriculture accounts for a large portion of surface water withdrawals from the Middle Rio Grande, operation of the MRGCD has fallen under close scrutiny by water managers and the public. As a major portion of water diverted from the Rio Grande by the MRGCD is delivered to farms within the irrigation district, off-farm conveyance efficiency and on-farm irrigation efficiency have also received a great deal of interest by water managers and the public. Although studies have been conducted within the MRGCD focusing on off-farm conveyance efficiency and surface-groundwater interactions, there is relatively little existing information regarding on-farm irrigation efficiency among farms within the MRGCD. However, the value of this water use efficiency information, in both off-farm and on-farm settings, cannot be overstated. Accurate seepage loss data for specific reaches of individual canals can be used to identify areas where capital improvements are necessary to limit undesirable seepage loss and improve delivery of adequate head to irrigator turnouts for improved on-farm irrigation efficiency. Likewise, in an effort to limit undesirable on-farm water losses, accurate on-farm irrigation efficiency data can be used to determine the potential for system-wide on-farm irrigation efficiency improvements and the means to institute these improvements based on evaluation of various on-farm water conservation measures and the current extent to which they are employed among farms within the MRGCD. Ultimately, conveyance and on-farm irrigation efficiency data are critical for implementation of water resource management changes that will result in improved conveyance and on-farm irrigation efficiency within the MRGCD. In addition to the many ancillary benefits afforded to individual irrigators and the MRGCD as a whole, improved efficiency within the MRGCD could allow for reduced diversions from the Rio Grande and more available water to be managed for endangered species recovery. It is important, however, that water managers recognize the complex relationships between surface and groundwater in the area of the Middle Rio Grande, and the potential for adverse impacts from increased off-farm conveyance and on-farm irrigation efficiency and reduced agricultural diversions from the Rio Grande. Specifically, increases in on-farm irrigation efficiency over relatively large areas within the MRGCD would likely result reduced deep percolation, which could have adverse impacts to shallow aquifers and riparian habitat which those aquifers support. Furthermore, depending on the reach of the river and time of year, loss of shallow and deep aquifer recharge resulting from increased on-farm irrigation and off-farm conveyance efficiency, as well as from reduced overall river diversions, could reduce river recharge from groundwater/bank storage and adversely impact flows in the Rio Grande.

Based on the hypothesis that increasing on-farm irrigation efficiency within the MRCGD could allow for lower Rio Grande diversion requirements for irrigation and consequently provide for more water to be managed for species recovery, this research was undertaken to evaluate on-farm irrigation efficiency within the MRGCD and to identify opportunities to improve irrigation efficiency. The specific objectives of the research were to: 1) review relevant literature; 2) perform field studies at multiple farms within the MRGCD with varying levels of on-farm water conservation measures; 3) conduct an agency survey and personnel interviews to estimate on-farm irrigation efficiency and the extent of conservation measures employed throughout the MRGCD; 4) estimate the potential for system-wide irrigation efficiency improvements and subsequent reduction in water loss upon MRGCD-wide implementation of on-farm conservation measures; and 5) develop recommendations for implementation of on-farm irrigation efficiency improvements.

Twelve irrigation efficiency studies were performed on six fields on five farms located within the MRGCD, including: 1) the Indian Hills Farm in San Acacia; 2) the David Wade Farm in San Antonio; 3) the Dennis Harris Farm in San Antonio; 4) the Candelaria Farm in Albuquerque; and 5) the Hubble-Oxbow Farm in Albuquerque. Among the study fields, significant differences in irrigation performance parameters and on-farm water use correlated reasonably well with the different levels of on-farm conservation measures employed at each study field. Generally, those fields that employed higher levels of on-farm conservation measures had higher on-farm irrigation efficiency, and visa versa. According to the different ranges of on-farm irrigation efficiency observed at each study field, three primary irrigation efficiency groups emerged from the study group: high-efficiency fields used between 0.5 and 0.6 acre-feet/acre (ac-ft/ac) for each irrigation event; intermediate-efficiency fields used between 0.6 and 0.8 ac-ft/ac; and low-irrigation efficiency fields used between 0.8 and 1.9 ac-ft/ac. Based on interviews of Natural Resource Conservation Service (NRCS) agents, the relative proportion of total irrigated acreage with high-, intermediate-, and low-irrigation efficiency was 3.5 percent, 66.5 percent and 30 percent, respectively, within Bernalillo/Sandoval Counties; 5, 65, and 30 percent, respectively, within Valencia County; and 25, 70, and 5 percent, respectively, within Socorro County.

Using on-farm irrigation efficiency results observed among the irrigation efficiency groups and NRCS agent's estimates of the relative proportion of these groups within the MRGCD, a volume estimate of current MRGCD on-farm water use was developed, which is comparable to volume estimates of water delivered by MRGCD to farms reported elsewhere. In addition, estimates of potential reduction in MRGCD on-farm water use were developed for two scenarios which considered irrigation efficiency improvement among all irrigated acreage within the MRGCD upon further implementation of on-farm conservation measures. Based on these findings, improving on-farm irrigation efficiency from current conditions by laser leveling all irrigated acreage and concrete lining all on-farm conveyances could yield a reduction in on-farm water use of approximately 8 to 29 percent in Bernalillo/Sandoval and Valencia Counties. Improving on-farm irrigation efficiency from current conditions by laser leveling all irrigated acreage, concrete lining all on-farm conveyances, instituting NRCS irrigation water management (IWM) plans, and employing additional operational practices that further limit on-farm water use could yield a reduction in on-farm water use of approximately 24 to 47 percent in Bernalillo/Sandoval and Valencia Counties and 15 to 25 percent in Socorro County.

Future refinement of input parameters will improve confidence in estimations of potential on-farm irrigation efficiency improvement within the MRGCD. Investing additional resources to improve these estimates and broaden the scope of research in the area of on-farm irrigation efficiency is important because additional information is needed for critical water management decisions that affect stakeholders within the Middle Rio Grande Valley. At a time when irrigated agriculture is in a decline and when urban development is rapidly expanding within the Middle Rio Grande Valley, a better account of how water resources are used and how beneficial use can be maximized will be necessary to balance future human and natural resource needs.

To refine estimates of on-farm irrigation efficiency within the MRGCD, it is recommended that the following occur:

- Develop a database so that on-farm irrigation efficiency data and on-farm conservation improvement information can be retrieved for later analysis
- Conduct a field survey to verify the extent of conservation measures employed among farms within the MRGCD, including a broad spectrum of farm sizes and crops;
- Conduct a field survey to determine the magnitude and number of irrigation events per irrigated acreage among within the MRGCD, including review of ditch rider logs;
- Conduct additional on-farm irrigation efficiency evaluations within the MRGCD, including a broad spectrum of farm sizes and crops, to further refine range of on-farm water use values among the primary efficiency groups;
- Conduct a quantitative analysis of water conservation effectiveness of various on-farm conservation measures in the MRGCD, including those not evaluated as part of this study (e.g., drip and sprinkler irrigation systems).

To promote increases in on-farm irrigation efficiency among all farms within the MRGCD the following actions are recommended:

- The "low hanging fruit" in improvement of irrigation efficiencies is the matching of applied water to pre-irrigation deficits. Different soils and relationship to groundwater make generalizations about fixed rotations and applied depths impossible; to maximize irrigation performance, growers must match applied water to deficits on a field-by-field, irrigation-by-irrigation basis. It is recommended that in addition to encouraging the use of on-farm conservation measures, those agencies responsible for technical assistance should focus efforts on training farmers to match applied water to pre-irrigation deficits.

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ABBREVIATIONS AND ACRONYMS

ac-ft/ac	acre-foot (feet) per acre
AE	application efficiency
AELQ	application efficiency of the low quarter
ASAE	American Society of Agricultural Engineering
cfs	cubic foot (feet) per second
CIR	Consumptive Irrigation Requirement
CU	Christiansen Uniformity
DPP	deep percolation percentage
DU	distribution uniformity
EBID	Elephant Butte Irrigation District
ESA	Endangered Species Act
ET	evapotranspiration
FSA	Farm Service Agency
IE	irrigation efficiency
ISC	New Mexico Interstate Stream Commission
IWM	Irrigation Water Management
LUTA	land use trend analysis
MAD	management allowed deficit
MRG	Middle Rio Grande
MRGB	Middle Rio Grande Basin
MRGCD	Middle Rio Grande Conservancy District
NASS	National Agriculture Statistics Service
NCIR	net consumptive irrigation requirement
NMAS	New Mexico Agricultural Statistics
NMOSE	New Mexico Office of the State Engineer
NMSE	New Mexico State University
NRCS	National Resource Conservation Service
RE	requirement efficiency
RP	runoff percentage
SMD	soil moisture deficit
SP	storage percentage
SSPA	S.S. Papadopulos & Associates, Inc.
URS	URS Group, Inc.
USDA	U.S. Department of Agriculture
USFWS	U.S. Fish and Wildlife Service
WAM	Water Acquisition and Management Subcommittee of the Middle Rio Grande ESA Collaborative Program

DEFINITIONS

Application efficiency (AE): The ratio of the average depth of irrigation water infiltrated and stored in the root zone to the average depth of irrigation water applied, expressed as a percent.

Application efficiency of the low quarter (AELQ): The ratio of the average low-quarter depth of irrigation water infiltrated and stored in the root zone to the average depth of irrigation water applied, expressed as a percent.

Available water (capacity): The amount of soil moisture in chemical forms accessible to plant roots or compounds likely to be convertible to such forms during the growing season.

Christiansen's uniformity coefficient (CU): The average depth of irrigation water infiltrated minus the average absolute deviation from this depth, all divided by the average depth infiltrated.

Deep percolation percentage (DPP): The ratio of the average depth of irrigated water infiltrated and drained out of the root zone to the average depth of the irrigation water applied, expressed as a percent.

Deficit Irrigation: Occurs when applied irrigation is less than the crop requirement, causing the crop to rely on soil storage for its needs.

Distribution uniformity (DU): The ratio of the average low-quarter depth of irrigation water infiltrated to the average depth of irrigation water infiltrated, expressed as a percent.

Field capacity: The content of water, on a mass or volume basis, remaining in a soil two or three days after having been wetted with water and after free drainage is negligible.

Irrigation efficiency (IE): The ratio of the average depth of irrigation water, which is beneficially used to the average depth of irrigation water applied, expressed as a percent. Beneficial uses include satisfying the soil moisture deficit and any leaching required to remove salts from the root zone.

Management allowed deficit (MAD): The desired soil moisture deficit at the time of irrigation.

Requirement efficiency (RE): The ratio of the volume of water stored in the root zone to the pre-irrigation soil moisture deficit, expressed as a percent.

Runoff percentage (RP): The ratio of the equivalent depth of irrigation water running off the field to the depth of irrigation water applied, expressed as a percent.

Soil moisture deficit (SMD): The depth of water required to bring a specific depth of soil to field capacity at a particular time.

Storage percentage (SP): The ratio of the average depth of irrigation water infiltrated and stored in the root zone to the soil moisture deficit, expressed as a percent.

SECTION 1. INTRODUCTION

1.1 Background

Among all natural resources, water has arguably played the most important role in shaping the history and character of the American West. For instance, within the relatively dry southwestern region of the United States, many laws and cultural traditions related to property, resource rights, and commerce owe their evolution in part to the great value people have placed on water. Given the increasing demands upon this region's water resources for agriculture, advancing urbanization, industry, as well as a variety of other uses, water and its availability will certainly continue to play a pivotal role in determining the future of development in the southwest. In the Rio Grande Valley of New Mexico, water use often takes place at or beyond the margins of supply, such that the impacts of a single season of below average precipitation, whether in the headwaters or further downstream, frequently result in reduced river flow, impaired wildlife habitat, and hardship for irrigators. Viewed from a long-term perspective, the persistent reoccurrence of below-average precipitation and the resulting multi-year drought has forced critical examination of current water resource management practices. The intent of this examination is to balance water supply with Rio Grande ecosystem requirements and population demand, now and for future generations.

Under the Endangered Species Act (ESA), the Rio Grande Silvery Minnow and the Southwestern Willow Flycatcher are currently listed as endangered species within the Middle Rio Grande ecosystem, allowing for their protection under the law. Enforcement of the ESA for these species has resulted in development of the U.S. Fish and Wildlife Service’s (USFWS’s) 2003 Biological Opinion for these two species, requiring maintenance of minimum flows along certain reaches of the Middle Rio Grande deemed critical for species survival (USFWS, 2003). Irrigated agriculture accounts for 80 percent of surface water withdrawals from the Rio Grande Basin (Wilson et al., 2003) and 37 percent of river depletions within the Rio Grande Valley (S.S. Papadopulos & Associates, Inc. [SSPA], 2002). As a consequence, agricultural institutions, individual irrigators, and agencies involved in management of agricultural water have fallen under close scrutiny. Much of this focus centered on the Middle Rio Grande Conservancy

District (MRGCD), which is directly responsible for a vast majority of the river diversion, conveyance, and delivery of agricultural water within the Middle Rio Grande Valley. Regional water managers hope to increase water availability for critical water management decisions by reducing undesirable water loss resulting from inefficiency within the MRCGD. Specifically, by improving MRGCD efficiency, water managers hope to reduce river diversions without adversely impacting agriculture, thereby allowing more water to remain in the Rio Grande or in storage upstream so that river flows can be managed according to requirements of the endangered species.

Table 1-1. Agricultural Withdrawals within New Mexico and Rio Grande Basin, as a Percent of Total Withdrawals

	Surface Water (%)	Groundwater (%)	Total (%)
New Mexico	77.7	74.2	76.1
Rio Grande Basin	80.2	51.3	71.2

Reference: Wilson et al., 2003.

Previous assumptions have suggested that over the course of an irrigation season, approximately 7.2 acre-feet are diverted for each acre of irrigated land served by the MRGCD, with the intention of delivering approximately 3.0 acre-feet/acre of water to the irrigator's turnout. However, timing, scheduling, and a host of other variables probably cause more than this amount to potentially be available to many irrigators. The remaining 4.2 acre-feet of water that is not delivered to an irrigator can be, in part, required "push water" for sufficient head within canals which is subsequently returned to the river, lost to evapotranspiration, or lost to seepage. In addition, on-farm consumptive use, including Consumptive Irrigation Requirement (CIR) and that portion of the application which was lost to direct evaporation (claimed by MRCGD to be approximately 2.1 acre-feet per average irrigated acre within the MRGCD), is often less than the three acre-feet intended for delivery by the MRGCD (Gensler, 2006). Consequently, some portion of water delivered to irrigators is subject to loss through evaporation, seepage, and runoff (Gensler, 2005). In contrast to these earlier assumptions, the MRGCD acre-feet diversions per acre over the last three irrigation seasons (2004, 2005, and 2006) has been between 5.2 and 5.9 acre-feet per acre (Gensler, 2006).

The subject of the MRGCD system inefficiency has been the focus of several recent studies, including those commissioned by the New Mexico Office of the State Engineer (NMOSE). A 2002 study of the MRGCD concluded that the MRGCD diverts on average between 8 and 12 acre-feet per acre of irrigated land, while the Elephant Butte Irrigation District (EBID) diverted on average approximately 6 acre-feet per acre of irrigated land (Gaume, 2002). It should be noted that MRGCD disputes these findings and the comparison to the EBID, which is a very different system (Gensler, 2006). The combined losses from conveyance systems and irrigated land within the Rio Grande Valley were estimated to be as high as 50 percent in 1995 (Wilson, 1997). Off-farm conveyance loss in canals and laterals in New Mexico were estimated in 1999 at 734,050 acre-feet, or about 40 percent of the total surface water withdrawals for irrigation, while off-farm conveyance loss for the MRGCD was estimated at 52 percent. In contrast, conveyance loss for the EBID was estimated to be 35 percent (Wilson et al., 2003).

Although studies have been conducted within the MRGCD focusing on off-farm conveyance efficiency and surface-groundwater interactions, there is relatively little existing information regarding on-farm irrigation efficiency among farms within the MRGCD. However, the value of this water use efficiency information, in both off-farm and on-farm settings, cannot be overstated. Accurate seepage loss data for specific reaches of individual canals can be used to identify areas where capital improvements are necessary to limit seepage loss and improve delivery of adequate head to irrigator turnouts for improved on-farm irrigation efficiency. Likewise, accurate on-farm irrigation efficiency data can be used to determine the potential for system-wide on-farm irrigation efficiency improvements and the means to institute these improvements based on evaluation of various on-farm water conservation measures and the current extent to which they are employed among farms within the MRGCD. Ultimately, conveyance and on-farm irrigation efficiency data are critical for implementation of water resource management changes that will result in improved conveyance and on-farm irrigation efficiency within the MRGCD. In addition to the many ancillary benefits afforded to individual irrigators (e.g., increased productivity) and the MRGCD as a whole, improved efficiency within the MRGCD could allow for reduced diversions from the Rio Grande and more available water to be managed for endangered species recovery. It is important, however, that water managers recognize the complex relationships between surface and groundwater in the area of the Middle Rio Grande, and the potential for adverse impacts from increased on-farm irrigation and off-farm conveyance efficiency and reduced agricultural diversions from the Rio Grande. As Oad and King (2005) pointed out, the losses from a riparian irrigation system such as the MRGCD are not losses at all; the canal seepage and deep percolation, which are the target of efficiency improvement measures, are the primary source of recharge for the shallow alluvial aquifer in the MRGCD, and the shallow aquifer supplies diverse aquatic, terrestrial, and avian habitat with water. Significantly reducing seepage and deep percolation will have adverse effects on drain flows and the vigor of the bosque that covers much of the Middle Rio Grande. Furthermore, depending on the reach of the river and time of year, loss of shallow and deep aquifer recharge resulting from increased on-farm irrigation and off-farm conveyance efficiency, as well as from reduced overall river diversions, could reduce river recharge from groundwater/bank storage and adversely impact flows in the Rio Grande. Therefore, in light of the complex surface-groundwater relationship in the Middle Rio Grande Valley, it is important for water managers to focus on-farm irrigation efficiency efforts on reducing non-beneficial water losses, such as over-application of irrigation water resulting from poorly leveled fields or inadequate field layout, which cause non-uniform irrigation application and increased irrigation times.

This report comprises the first volume of a two-part study; this report addresses the on-farm irrigation efficiency evaluation among farms within the MRCGD. The second volume addresses the seepage analysis of the Belen Highline Canal within the Belen Division of the MRGCD. The on-farm irrigation efficiency evaluation was conducted by URS with NMSU, while the conveyance seepage study was conducted by URS. Both studies were conducted between fall 2003 and spring 2005.

1.2 Project Objectives

The project was undertaken to evaluate on-farm irrigation efficiency within the MRGCD and to develop specific recommendations to improve irrigation efficiency throughout the MRGCD. The objectives of the evaluation of on-farm irrigation efficiency were to: 1) review relevant literature; 2) perform field studies at multiple farms within the MRGCD with varying levels of on-farm water conservation measures; 3) conduct an agency survey and personnel interviews to estimate on-farm irrigation efficiency and the extent of conservation measures employed throughout the MRGCD; 4) estimate the potential for system-wide irrigation efficiency improvements and subsequent reduction in water loss upon MRGCD-wide implementation of on-farm conservation measures; and 5) develop recommendations for implementation of on-farm irrigation efficiency improvements. Recommendations for on-farm irrigation efficiency improvements within MRGCD focus on specific actions for agencies and the MRGCD. These recommended actions, including further research, are intended to provide the MRGCD and all irrigators within the MRGCD with necessary resources that will result in MRGCD-wide irrigation efficiency improvements and subsequent water conservation benefiting endangered species within the Middle Rio Grande.

1.3 Project Approach

This project involved the following tasks:

- Compilation and review of published data and reports
- Compilation and review of unpublished data and reports
- Interview of agency and MRGCD personnel
- Interview of irrigators and tribal representatives
- Evaluation of on-farm irrigation efficiency
- Analysis of on-farm irrigation efficiency results
- Analysis of literature/report data and agency survey results
- Development of recommendations for implementation of irrigation efficiency improvements

The project team consisted of Dale Lyons, soil scientist, and Dr. Steve Geiger, hydrologist, of URS; Jimmy Moreno, a graduate student in agricultural engineering; and Dr. J. Phillip King, agricultural engineer, of NMSU. This work was also accomplished through the assistance and cooperation of David Gensler of the MRGCD; Corrine Brooks, Rudy Garcia, Arlin Ricke, Danny Thomas, Darrel Reasoner, and Santiago Misquez, all district conservationists with the Natural Resource Conservation Service (NRCS); John Sorel, Pueblo of Isleta hydrologist; and the staff at the City of Albuquerque's Open Space Division. Sincere appreciation is also extended to the irrigators who participated in the on-farm irrigation efficiency evaluations. In addition to their project support by allowing investigators to observe their operations, the study benefited greatly from their experience and input. These irrigators include: Scott Rasband of the Candelaria Farm (Albuquerque, NM); Leo Rizzo of the Hubble-Oxbow Farm (Albuquerque, NM); Gordon

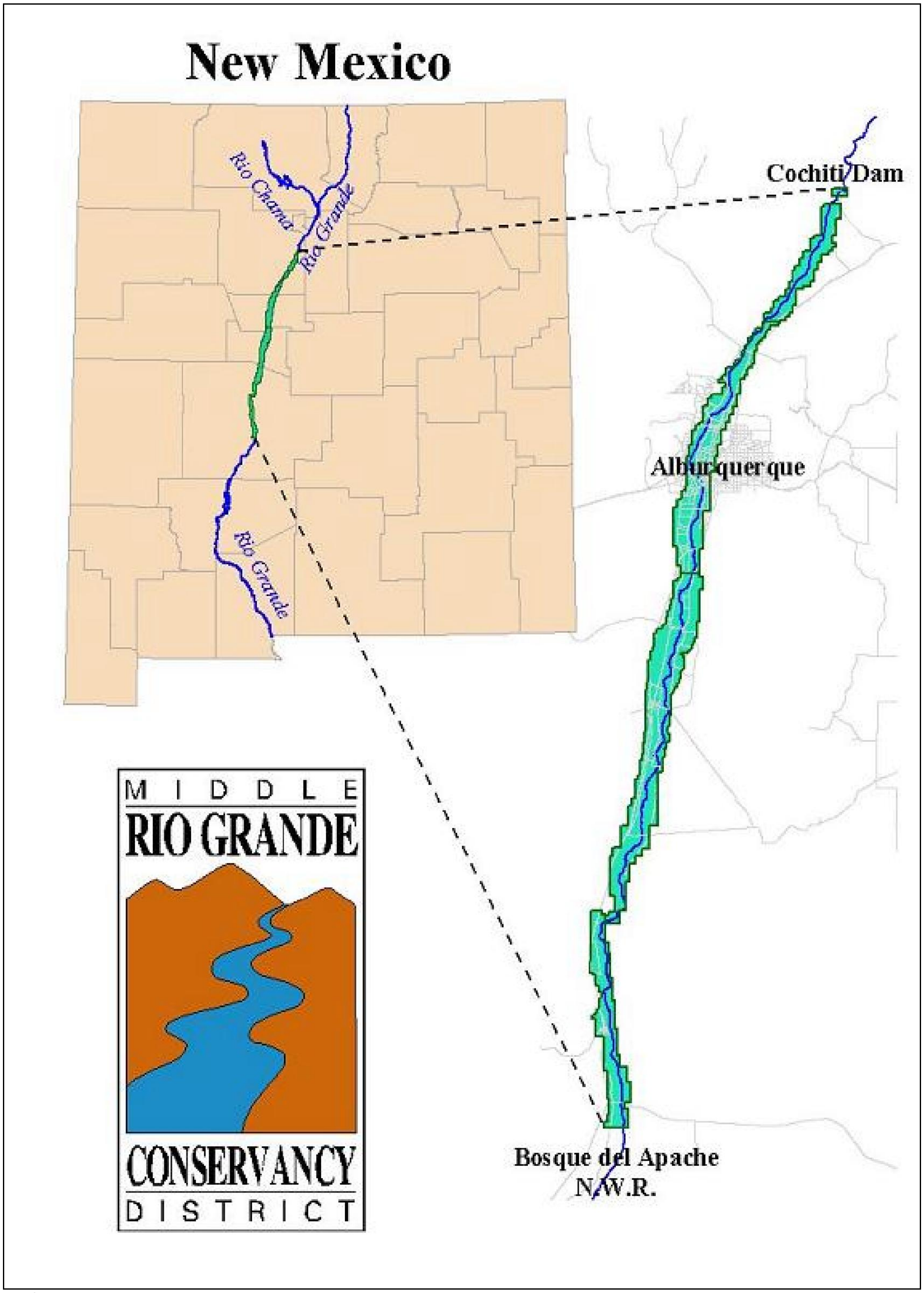
Herkenhoff of Indian Hill Farms (San Acacia, NM); Dennis Harris of the Harris Farm (San Antonio, NM); and David Wade of the Wade Farm (San Antonio, NM).

1.4 Project Location

The Middle Rio Grande Basin (MRGB) is located in north-central New Mexico and consists of the surface water drainage area from Otowi Bridge above Cochiti Reservoir to the Bosque del Apache National Wildlife Refuge and Elephant Butte Reservoir, a distance of approximately 175 miles (SSPA, 2002). The area of the MRGB is approximately 3,060 square miles (Bartolino and Cole, 2002). The main flows supplying MRGB include the Rio Grande River, its tributaries, and imported water from the San Juan River. Figure 1-1 illustrates the MRGB in relation to the region.

The MRGCD, a political subdivision of the State of New Mexico, was created in 1923 to providing flood control, drainage, and irrigation for the Middle Rio Grande Valley in New Mexico. The MRGCD extends from Cochiti Dam in the north to San Marcial at the upstream end of the Elephant Butte Reservoir in the south (downstream of the Bosque del Apache National Wildlife Refuge). The conservancy district is located in Sandoval, Bernalillo, Valencia, and Socorro Counties, within the Middle Rio Grande Valley. The MRGCD is long and narrow, consisting of a number of strips of land from one to seven miles wide, through which the river meanders from one side of the historic floodplain to the other, forming a series of natural units or divisions (Burkholder, 1928). The MRGCD has four separate operational divisions, from north to south: the Cochiti Division, the Albuquerque Division, the Belen Division, and the Socorro Division (Figure 1-2). The MRGCD claims water rights to irrigate 123,267 acres with 2.1 acre-feet of water per year, for a total consumptive use of 258,861 ac-ft/year (Bartolino and Cole, 2002). As stated above, on-farm consumptive use, including Consumptive Irrigation Requirement (CIR) and that portion of the application which was lost to direct evaporation (claimed by MRCGD to be approximately 2.1 acre-feet per average irrigated acre within the MRGCD), is often less than the three acre-feet intended for delivery by the MRGCD (Gensler, 2006).

The MRGCD holds water permits with the New Mexico Office of the State Engineer for storage in El-Vado Reservoir and irrigation of 123,267 acres. Of this total, 53,926 acres predated the establishment of the MRGCD, 26,859 acres MRGCD claimed in its 1930 survey but did not irrigate due to high groundwater tables and 42,482 acres MRGCD intended to develop and render irrigable. The USBR Crop Production and Water Utilization Data (1991–1998) indicate that MRGCD irrigates about 54,500 acres, but MRGCD claims irrigation of approximately 63,000 acres including the Pueblo lands (Oad and King, 2005). The approximate crop and fallow agricultural acres among the respective counties encompassing the MRGCD are 8,008 acres in Sandoval County, 9,292 acres in Bernalillo County, 28,460 acres in Valencia County, and 17,892 acres in Socorro County. The approximate crop and fallow agricultural acres among the four MRGCD divisions are 4,130 acres in the Cochiti Division, 13,107 acres in the Albuquerque Division, 34,492 acres in the Belen Division, and 11,923 acres in the Socorro Division (SSPA, 2002).



Reference: MRGCD, 2005.

Figure 1-1. Extent of the Middle Rio Grande Conservancy District along the Rio Grande

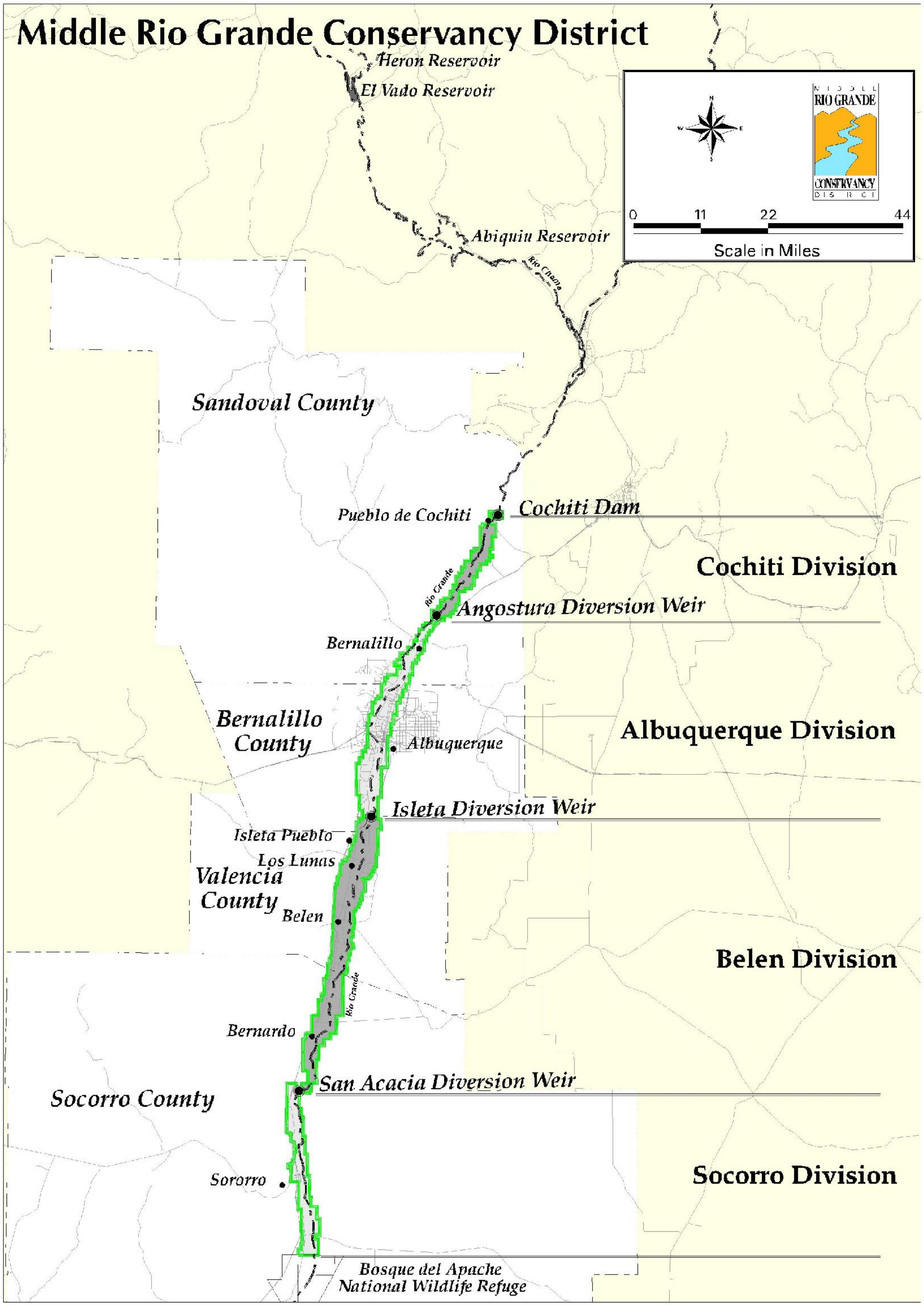
The MRGCD permits with the Office of the State Engineer (0620 and 1690 – filed in 1930) allow for storage of water in El Vado reservoir, release of the water to meet irrigation demand, and diversion from the Rio Grande to irrigate the lands served by MRGCD. Water diverted by MRGCD originates as native flow of the Rio Grande and its tributaries, including the Rio Chama. The MRGCD has a contracted right to about 20,900 acre-feet annually from the San Juan-Chama Project that diverts water from the Colorado River. The MRGCD stores water upstream in El-Vado reservoir, which has a present storage capacity of about 180,000 acre-feet (Oad and King, 2005).

From Cochiti Reservoir to the Bosque del Apache National Wildlife Refuge, the MRGCD manages nearly 1,200 miles of irrigation facilities (e.g. conveyance canals and drains) to divert water from the river to service agricultural land. Irrigated lands include small-scale urban landscapes as well as large-scale production of alfalfa, pasture, corn and vegetable crops. The diversity of users includes six Indian pueblos, community ditch associations, large-scale farmers, independent acequia communities and urban landscape irrigators. The MRGCD supplies water to its four divisions, Cochiti, Albuquerque, Belen and Socorro, through Cochiti, Angostura, Isleta and San Acacia diversion structures, respectively. In addition to direct diversions at these structures, all divisions except Cochiti receive return flow from divisions above. These return flows are conveyed through riverside drains and are eventually diverted into a main canal for reuse in the MRGCD or are returned to the river. Although drains were originally constructed for the purpose of collecting excess water from the agricultural lands, many now serve as interceptors of return flow and provide a source of interdivisional water supply. The Cochiti Division is primarily Pueblo lands, which are managed by the Pueblos' own ditch riders. MRGCD has few ditch riders in the Cochiti Division for managing the non-Pueblo lands. The Albuquerque Division services primarily small-scale urban water users, but some large-scale and Pueblo water users irrigate in the northern and southern boundaries of the division. The Belen Division is the largest division in terms of service area, and irrigates small-scale, large-scale, and Pueblo water users. The Socorro Division is relatively small but serves entirely large-scale water users.

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

The MRGCD delivers water to users through services and administration provided at a central office and four division offices. The central office provides many administrative services, including management of service charges to water users. Each division office includes administrative, field maintenance and water operation services. A division manager and several ditch-riders manage water delivery operations in each of the four divisions. Ditch-riders are responsible for the distribution of water to users in a particular service area. The ditch-rider controls check structures and head gates, using local knowledge of the distribution system and irrigator requirements to deliver water. Ditch-riders evaluate water delivery and water use conditions through physical monitoring, or “riding,” of ditches and laterals and through communication with water users.

The MRGCD does not meter individual farm turnouts, rather they estimate water delivery on the basis of time required for irrigation. In the past, the MRGCD operated the main canals and laterals on a continuous basis. More recently (since 2001), the MRGCD has adopted water-saving measures such as rotational water delivery, whereby it is able to meet the same user demand with reduced river water diversions (Oad and King, 2005).



Reference: MRGCD, 2004.

Figure 1-2. MRGCD Boundaries

SECTION 2. LITERATURE REVIEW

2.1 Background

Relatively few individual case studies of irrigation efficiency have been conducted within the Middle Rio Grande Valley. Because these case studies have been relatively limited in scope, comparatively little data are available that indicate general levels of water application efficiencies achieved by farmers within the Middle Rio Grande Valley (Hulsman, 1983). Furthermore, past research conducted within the Middle Rio Grande Valley has not attempted to evaluate differences in irrigation efficiencies between farms where conservation measures are employed and farms where conservation measures are either deficient or absent. The NRCS routinely conducts irrigation efficiency analyses on farms that are considered for FSA assistance and cost-share improvements for on-farm conservation measures such as laser leveling of fields and concrete lining of ditches, then conducts follow-up analyses after these measures are implemented to determine the improvement and water savings. However, access to the results of these NRCS analyses is limited because the NRCS keeps these results in individual files for each farm, often accompanying the cost-share financial information. As a result, analytical information from farms assisted by the NRCS is not tabulated for comparison nor is it readily obtainable from the agency. Furthermore, it is unlikely that NRCS data can be used to draw broad conclusions about irrigation efficiency within the MRGCD because farms assisted by the NRCS and FSA tend to have fewer conservations measures instituted and generally represent the lower end of the irrigation efficiency spectrum and because agency priorities and eligibility for technical assistance and financial assistance varies by County.

The term *efficiency* is one of the most used and abused terms in discussions of irrigation and water conservation (King and Maitland, 2003). “Efficiency” is used to present a measure of performance of an irrigation system, but unless it is specifically defined, the term is ambiguous and misleading. Definitions of terms used to designate or evaluate the efficiency with which irrigation water is applied by a given system vary widely within the past literature (Merriam and Keller, 1978). As a result, simple comparison of “efficiencies” can lead to false conclusions. To avoid ambiguity and confusion in reviewing previous research, it imperative to clearly define all parameters labeled as "efficiency" and to use caution when comparing data from previous studies—especially those from different sources.

2.2 Estimation of Irrigation Efficiency

As part of estimations of irrigation efficiency that have been conducted throughout the western United States, including New Mexico, efficiency values have been proposed for efficient and well-maintained fields. Doneen and Westcot (1984) employ the term "water application efficiency" when discussing irrigation efficiency, and define the term as follows:

$$E_a = E_t / I_d$$

Where:

$E_a = \textit{water application efficiency}$

$\mathrm{E_t} = \textit{evapotranspiration}\,\text{(depth)}$

$I_d = \textit{irrigation water at the farm gate}\,\text{(depth)}$

Accounting for evapotranspiration (ET) in an efficiency evaluation is the most accurate means of measuring an irrigation system's true water usage performance. However, accurate evapotranspiration data are not easily obtained, and use of evapotranspiration in evaluating irrigation efficiency is problematic unless evapotranspiration is known for a particular crop in a particular field at a particular time. Doneen and Westcot (1984) note that ideal efficiencies percentages are on the order of 60 to 70 percent, assuming good control of the irrigation stream, a properly leveled field, and a shaped irrigation basin system. Although transpiration is typically low in the beginning of the season, peaks during the summer months when the crops are fully grown with full canopy, and falls again during senescence, irrigators commonly apply the same amount of water throughout the season. For purposes of estimation of irrigation efficiency, Doneen and Westcot used an average evapotranspiration value for the entire irrigation season to derive the overall efficiency range of 60 to 75 percent. As a consequence, it is possible that irrigation efficiencies estimated using this approach could be higher during the periods of full growth and when irrigators do not over apply water. Because water applied is measured at the farm gate, or turnout, this approach to estimating irrigation efficiency also takes into account the on-farm conveyance losses.

Merriam and Keller (1978) estimated that a well-designed and properly operated irrigation system would have an estimated irrigation efficiency of 60 to 85 percent. The authors use the term "application efficiency of low quarter" when discussing irrigation efficiency, which is defined by the NRCS (1997) as the ratio of the average of the lowest one-fourth of measurements of irrigation water infiltrated to the average depth of water applied. Merriam and Keller used the following formula to calculate application efficiency of low quarter:

$$AELQ = D_{low} / D_{app}$$

Where:

$AELQ = \textit{application efficiency of low quarter}$

$D_{low} = \textit{average low quarter depth of water stored in root zone}$

$D_{app} = \textit{average depth of water applied}$

This approach to estimating irrigation efficiency is based on the relatively well understood relationship between actual water applied and stored water in the root zone. This approach can be particularly useful because these parameters can be readily measured in the field during an evaluation.

Wilson et al. (2003) estimated on-farm irrigation efficiencies and off-farm conveyance efficiencies for several locations in New Mexico. Although this study presented a definition for irrigation efficiencies, termed "on-farm irrigation efficiency," there was no mention of how values for formula parameters were obtained for the study locations. This study's definition of irrigation efficiency differs from that of the Merriam and Keller (1978) study by using water diverted at the farm gate rather than actual water applied, thereby taking into account, at least in part, on-farm conveyance losses.

$$E_f = D_{low} / D_{div}$$

Where:

$E_f = \textit{on farm irrigation efficiency}$

$D_{low} = \textit{average low quarter depth of water stored in root zone}$

$D_{div} = \textit{average depth of water diverted at farm headgate}$

Table 2-1 summarizes the irrigation efficiency results from the Wilson et al. (2003) study. The values reported are only for irrigation systems watered with surface water.

Table 2-1. Estimated Irrigation and Conveyance Efficiencies in NM

River Basin	Locality	On-Farm Irrigation Efficiency (%)	Off-Farm Conveyance Efficiency (%)
Rio Grande	MRGCD	48-50	48
Rio Grande	Elephant Butte Irrig. Dist.	60-85	55-65
Rio Grande	Rio Chama	50	60
Pecos	Rio Hondo	55-65	70
Pecos	Roswell	60	75
Pecos	Fort Sumner Irrig. Dist.	27	76
Pecos	Carlsbad Irrig. Dist.	60	69

Reference: Wilson et al., 2003.

2.3 Irrigation Efficiency Studies

Hulsman (1983) conducted sixteen on-farm closed border, surface irrigation system evaluations in Doña Ana County, New Mexico. The crops evaluated included alfalfa, barley, chile, cotton, cucumber, lettuce, onions, pecans, and wheat. Variations in individual crop efficiencies from one to 233 percent and seasonal efficiencies from 23 to 125 percent were reported. The seasonal efficiencies of alfalfa were calculated to be 64 and 81 percent in 1980 and 1981, respectively. Hulsman employed a consumptive use model for the evaluation of irrigation efficiency in this study, which is presented below.

$$E_i = \left(ET + LF - P + \Delta S\right)/W_i$$

Where:

E_i = *irrigation efficiency*

ET = *evapotranspiration (depth)*

LF = *leaching fraction* (*assumed zero for this study*)

P = *precipitation (depth)*

ΔS = *change in soil moisture (depth)*

W_i = *applied irrigation (depth)*

Based on this model, irrigation efficiency results greater than 100 percent are possible due to changes in soil moisture storage. According to the author, efficiencies in excess of 100 percent are the result of under-irrigations, also known as deficit irrigation, which occurs when applied irrigation is less than the crop requirement, causing the crop to rely on soil storage for its needs. Although this model provides a useful insight into mechanisms of crop water usage and efficiency, due to the nature and complexity of the model's input parameters, comparison with other efficiency data is problematic. In addition, irrigation efficiencies in excess of 100 percent make it difficult to estimate the actual efficiency of an irrigation system.

Sammis (1980) conducted an irrigation scheduling and efficiency study on a farm located in the Mesilla Valley in southern New Mexico. The study farm contained an elaborate surface distribution system consisting of lined and unlined ditches as well as five irrigation wells to supplement surface irrigation water. The crops grown on the farm were wheat, tomatoes, cotton, lettuce, peppers, chile, grain, sorghum, and alfalfa. Irrigation efficiency was calculated using the consumptive use model presented below.

$$E_i = C_u / (I_a + P)$$

Where:

E_i = *irrigation efficiency*

C_u = *consumptive use*

I_a = *irrigation applied*

P = *precipitation*

Among all fields included in this study irrigated with surface and groundwater, irrigation efficiency was reported to have ranged from 35 to 92.9 percent, and irrigation efficiency of alfalfa varied from 76 to 93 percent. Table 2-2 summarizes irrigation efficiency results from his study. Consumptive use was not determined for the specific crops and fields in this study; rather consumptive use input values for the above model were based known crop coefficients or consumptive use at other locations.

Table 2-2. Irrigation Efficiencies for Mesilla Valley Farm

Crop	Irrigation Efficiency (%)
Alfalfa	76-92.9
Cotton	48-91.3
Lettuce	39.8
Peppers	55.4-64.8
Tomatoes	35-61
Wheat	50-54.5

Reference: Sammis, 1980.

Cortez (1999) conducted an evaluation of irrigation efficiency and nitrogen leaching in the Mesilla Valley, southern New Mexico. The study was conducted at 20 sites on 5 cooperating farms. Among these farms, soil characteristics differed, and the study included various crop types including chile, alfalfa, cabbage, lettuce, onion, corn, cotton, and pecan. To evaluate irrigation efficiency at the study sites, researches measured the differences in chloride concentrations between the applied irrigation water and percolating water below the root zone. Using this method, the irrigation efficiency was calculated as follows:

$$IE = (1 - LF)$$
$$LF = (Et * Cli * 10^{-6} - Clc)/(Et * Clp * 10^{-6} - Clc)$$

where:

$IE =$ *irrigation efficiency*

$LF =$ leaching fraction

$Et =$ seasonal evapotranspiration (kg/ha)

$Cli =$ chloride concentration in the irrigation water (mg/l)

$Clp =$ chloride concentration in percolation water below crop root zone (mg/l)

$Clc =$ chloride uptake by crop (kg/ha)

$10^{-6} =$ *conversion* factor

This method assumes that a steady-state condition exists within the root zone and root zone water storage is constant over time. Although near-steady-state conditions in the root zone may be present in some areas with high groundwater, or on fields where light irrigation is frequently applied, these agricultural conditions are not common in southern New Mexico. This method also assumes that soil anion exchange reactions during the evaluation don't result in significant changes in the soil solution Cl- balance. However, Cl- reactions between soil and irrigation water resulting in changes in the Cl- balance are common during irrigation (Stewart 1978). Reported irrigation efficiency values for this study are relatively high, suggesting that deficit irrigation may have occurred. In addition, irrigation efficiency values are only calculated for a single point in a field and do not take into account on-farm conveyance or water application distribution. Irrigation efficiency results from this study are summarized in Table 2-3.

Table 2-3. Irrigation Efficiency of Mesilla Valley Farms, NM, Chloride Method

Farm	Site	Crop	Irrigation Efficiency (%)
A	1	Alfalfa	87-95
	2	Cotton	91
	3	Cotton	88-93
	4	Cotton	91-96
B	1	Pecan	93-94
	2	Pecan	79-86
	3	Corn	97
	4	Corn	97
C	1	Cotton, Cotton, Corn	92, 97, and 96
	2	Cotton, Cotton, Lettuce	96, 94, and 87
	3	Corn, Cotton	93 and 95
	4	Alfalfa	94-98
D	1	Cotton	94-96
	2	Chile, Lettuce, Corn	94, 89, and 94
	3	Alfalfa, Cotton	96 and 97
	4	Cotton, Chile, Alfalfa	92, 91, and 96
E	1	Cotton	87-93
	2	Chile, Onion, Lettuce	85, 96, and 86
	3	Chile, Onion, Cabbage	83, 84, and 88
	4	Alfalfa	92-97

Reference: Cortez 1999.

Another irrigation efficiency study employing the chloride method was conducted 2001 by Al-Katheeri. Ten fields in the Mesilla and Rincon Valleys of New Mexico were evaluated as part of this study. Crops grown on these study fields included chile, alfalfa and pecan. As with the Cortez study conducted in 1999, which also employed the chloride method, irrigation efficiency results were relatively high, suggesting deficit irrigation occurred. The results from this study are summarized in the Table 2-4.

Table 2-4. Irrigation Efficiency for Mesilla and Rincon Valley Farms, NM, Chloride Method

Field	Site	Crop	Irrigation Efficiency (%)
A	1	Chile	89.7
	2	Chile	95.9
	3	Chile	96.3
B1	1	Alfalfa	93
	2	Alfalfa	91.7
	3	Alfalfa	93.1
B2	1	Alfalfa	79.1
	2	Alfalfa	78
	3	Alfalfa	87.3
C	1	Alfalfa	90.7
	2	Alfalfa	83.6
	3	Alfalfa	83.2
D1	1	Pecan	97.8
D2	1	Pecan	98.2
D3	1	Pecan	96.5
D4	1	Pecan	91.5
D5	1	Pecan	97.1
D6	1	Pecan	96.7

Reference: Al-Katheeri, 2001.

As previously noted, the NRCS routinely conducts irrigation efficiency evaluations at farms considered by FSA for financial assistance and on-farm conservation improvements. Agencies operating in each county, including NRCS, FSA, and SWCD, prioritize agricultural assistance needs every year, and some agencies set minimum acreage requirements, which vary by county, while others agencies don't. In general, assistance is based on the level on-farm irrigation efficiency, where those farms with low efficiency rank higher that those with higher efficiency, regardless of farm size. Priorities for the types of assistance also vary by county. For example, currently in Bernalillo County the NRCS has no minimum acreage requirement and drip irrigation and center pivot projects rank higher than laser leveling or ditch lining projects. Cost share ratios also vary by county, but the NRCS generally provides greater levels of assistance for poor, minority, or new farmers (Ricke, 2006). It should also be noted that a significant portion of on-farm conservation measures, including concrete-lined ditches, laser leveled fields, and high-flow turnouts, within the MRGCD have be implemented without NRCS, FSA, or other agency assistance, and have been completed by individual farmers.

The method of irrigation efficiency evaluation employed by the NRCS, described in the NRCS National Engineering Handbook (1997), takes into account irrigation applied at the field turnout and pre-irrigation soil moisture content and the resultant irrigation requirement in calculation of irrigation efficiency (i.e., irrigation efficiency is the ratio of the average depth of irrigation water beneficially used to the average depth applied, expressed as a percentage). NRCS irrigation efficiency results from evaluations conducted during summer 2004 included three farms located in Bernalillo County and five farms located in Sandoval County. Evaluations were conducted on one field at each farm, and field crops included alfalfa and planted alfalfa pasture. Irrigation efficiency results at the three farms in Bernalillo County were 8.3, 27, and 21 percent, while irrigation efficiency results at the five farms in Sandoval County were 1.4, 5.8, 22, 8.2, and 11.2 percent (NRCS, 2004).

The relatively low-irrigation efficiencies observed by the NRCS are likely not representative of average on-farm irrigation efficiency in the MRGCD because farms that the agency provides technical and financial assistance are generally selected for assistance based on their lack of adequate conservation measures and apparent low on-farm irrigation efficiency. Low on-farm irrigation efficiencies at these farms may have a number of causes, including lack of coordination with ditch riders and failure to maintain adequate head in canals, low head in turnouts caused by excess border width and opening of multiple turnouts, lack of field leveling, discontinuous borders, and excess seepage in on-farm conveyances. In addition, low efficiencies at these locations may in part be attributed to high soil moisture deficit prior to irrigation efficiency evaluations. Although results from these NRCS evaluations may not be representative of average on-farm irrigation efficiency within the MRGCD, they do provide insight into the range of on-farm irrigation efficiency within the MRGCD.

SECTION 3. METHODOLOGY

3.1 On-Farm Irrigation Efficiency Evaluation

3.1.1 Field Selection

Twelve irrigation efficiency studies were performed on six fields on five farms located within the MRGCD. American Society of Agricultural Engineering Standard EP419 (ASAE, 1990) was used as a guideline for the irrigation efficiency evaluations. Although the ASAE Standard EP419 was developed for evaluation of furrow irrigation systems, the procedure was modified to allow for evaluation of basin irrigation systems, which is the type of system used in the six fields evaluated in this study and most commonly used among farms within the MRGCD. In addition, slight modifications of the evaluation procedure were applied to individual fields depending on logistic and site-specific constraints. Depending upon the objectives of a particular evaluation and the resources available, some procedures were simplified or omitted.

To compare irrigation efficiency among farms within the MRGCD that had implemented varying levels of on-farm conservation measures, including those without on-farm conservation measures, five study fields were selected with laser leveled fields and various field layouts and varying irrigation turnout configurations, while another field was selected because laser leveling had not been conducted and on-farm conveyances were unlined. Prior to beginning the on-farm irrigation efficiency evaluations, specific operational practices at each farm that affect on-farm irrigation efficiency were unknown and were documented over the course of the study. In selecting the agricultural field representative of overall farm efficiency performance at each farm location, consideration was also given to irrigator input and factors such as variability in field size, soil and hydraulic properties, and general water application practices.

3.1.2 Field Layout

Following field selection, field-specific information was collected, including dimensions and slope characteristics of the field, number and dimensions of columns bound by borders, and number and size of turnouts. Then, based on the size of the field, a number of irrigation water advance stations were established and their locations were marked within each field using stakes or flags. In general, more advance stations within a field results in greater accuracy in recording irrigation advance, but only a limited number of advance stations can practically be monitored during the evaluation. Therefore, a reasonable effort by study personnel was assumed when selecting the number and spacing of irrigation advance stations for each field. The resulting advance station grid within each field reflected the field dimensions, as grid spacing does not have to be the same dimension in both directions. For example, if the field is narrow and long, adjustments to the directional spacing of the grid can be made to accommodate the layout. Due to field dimension irregularities, inaccuracies can result from calculating field area by using only the width and length dimensions of each field. To avoid this problem, the area of each field was determined using the grid layout. The slope of the field, if any, was determined using surveying instruments. Any apparent irregularities or discontinuities in slope within each field are noted in the results section of this report.

3.1.3 Soil Sampling and Characterization

Soil samples were collected from all fields where irrigation efficiency evaluations were conducted. Soil samples were taken at two to four locations within each field, depending on the size of the field, from 6-, 18-, and 30-inch depths, within 24 hours prior to the irrigation evaluation. Each soil sample was of sufficient volume to fill a two-inch-diameter by two-inch-tall soil core sleeve, which was stored in a watertight sample container. The purpose of the sampling was to obtain the pre-irrigation moisture content as well to verify the texture reported in the SCS (NRCS) Soil Survey Reports for the area of the particular farm. Following collection, soil samples were placed in the watertight sample container for transport, and then later analyzed in the laboratory. To estimate the water holding capacity of these soils, laboratory analysis was conducted to determine soil particle size fractions and textural classification using the USDA classification system as well as soil textural classification.

Soil water holding capacity for each soil sample was estimated based on soil textural class as described in the NRCS Soil Surveys. One exception was the near surface soil horizon of the San Acacia South Field, comprised largely of clay. NRCS soil survey data indicated an available water capacity of 0.09- to 0.11-inch/inch, implying a field capacity of 18 to 22 percent. However, moisture samples taken 24 hours after irrigation showed moisture contents of about 45 percent. While drainage was probably still occurring, this suggests a much higher field capacity than that indicated by the NRCS. A field capacity of 35 percent was assumed for the upper soil layer at this site, and the calculations and results presented here reflect that assumption.

The soil moisture deficit was determined for each soil sampling location. The soil moisture deficit is the amount water that needs to be applied to replenish the root zone to field capacity. The soil moisture deficit was determined by multiplying the root zone depth by the difference between the field capacity of the soils and the actual soil moisture. If the actual soil moisture was greater than field capacity, the deficit was taken to be zero. If multiple layers were present in the root zone, soil deficit was determined for each layer, and then summed over the entire root zone profile.

The infiltration characteristics of soil at each study field were determined using the cylinder infiltration method, which is appropriate for flood irrigation systems. This method consists of a metal cylinder 18 inches (45 centimeters) in diameter and 14 inches (36 centimeters) in length, which was pressed or driven into the soil, being careful to avoid soil disturbance, at representative locations within each field. Infiltration was measured by ponding water inside the cylinder and measuring the rate that the free surface falls, or by measuring the rate that water was added to maintain a constant ponded depth. This procedure was continued until minimal change was observed in infiltration or water application rate. Throughout this procedure, the ponded depth applied in the cylinder did not exceed the expected ponding depth of normal irrigation, nor was the soil within the cylinder exposed to air. Because residual soil water content affects infiltration characteristics, infiltration tests were conducted shortly before irrigation occurred.

Following infiltration tests, the resulting data were fit to an empirical infiltration equation most commonly used for irrigation, as specified by ASAE Standard EP419: the Modified Kostiakov equation, defined as follows.

$$d = at^b + ct$$

Where:

$$d = \text{cumulative depth}$$
$$t = \text{infiltration opportunity time}$$
$$a, b = \text{ empirical fitting paramters}$$
$$c = \text{infiltration rate as } t \rightarrow \infty$$

3.1.4 Irrigation Evaluation

3.1.4.1 Inflow and Runoff

During the irrigation evaluation, irrigation inflow to each study field was measured periodically, especially while the inflow rate was changing. The location of the measured flow at each field was near the entrance to each basin or furrow to be sure that the measured flow reflected the actual flow rate applied to the field. For irrigation evaluations performed for this study, an Ott-type (A) current meter was used to determine flow rate. The number of point velocity measurements for a single cross-section depends on the depth and width of the measured canal or channel section. The conveyance canals at the study farms were relatively small in size, and only one horizontal measurement was taken using the current meter. For on-farm conveyance canals with depths greater than 2 feet, current meter measurements for the vertical profile were taken at 0.2 and 0.8 of the total depth from the water surface, while for conveyance depths less than two feet, flow measurements for the vertical profile were taken at 0.6 of the total depth from the water surface. Cross-sectional area for each conveyance canal was determined using the current meter rod and measuring tape.

To account for unused irrigation water in the form of runoff that occurred during the evaluation, sheet flow runoff was either measured once confined to a channel using small berms or measured once runoff collected in existing downslope channels.

3.1.4.2 Irrigation Advance and Recession

Advance time is a key input parameter to the irrigation performance calculations. Measuring advance and recession of applied irrigation water is necessary to determine the intake opportunity time for the advance stations. Intake opportunity time, the difference in time between advance and recession time for a given station, is the amount of time available for water to infiltrate into the soil. Advance time begins when water inflow begins at the head a field, and continues until water reaches the end of the field. Although irrigation advance time can be estimated by employing power function calculations based on field infiltration characteristics, advance times for each irrigation evaluation conducted for this study were measured in the field during the course of each evaluation.

Recession of irrigation water is simply the disappearance of water on a field, from the beginning to the end of a field following irrigation application and irrigation advance. Although recession can be objectively measured in furrow irrigation systems, recession is more difficult to determine in basin irrigation systems due to the large increase in number of stations and inherent subjectivity of making recession measurements. Specifically, recession measurement in basin systems is exceedingly difficult to make if recession is rapid and multiple points are recessing at similar times. As with irrigation advance time, irrigation recession time can be estimated by calculation based on measured infiltration characteristics of an evaluated field, provided that the study field has minimal gradation and ponding of water. Because the gradation range of all six fields evaluated for this study was negligible, recession time was estimated by calculation for each irrigation evaluation. Because recession time estimates were based on infiltration characteristics at each study location, the resulting recession time estimates used in calculation of performance parameters provided no new information and are not presented in this report.

For each irrigation evaluation conducted as part of this study, individual advance curves that illustrate the advance progression were developed. During each irrigation event, the advance of irrigation water was closely followed and advance time was recorded for each station, as well as irrigation start time and cutoff time. Relevant operational procedures and adjustments were also noted for each irrigation event conducted, including canal water levels, turnout opening, canal leakage, basin separation, runoff, etc. In some cases, irrigation advance across a field did not progress normally as a result of water from one column migrating laterally to an adjacent column, thereby inundating column grid points ahead of the irrigation advance water. In those cases, it was impossible to determine exactly when the irrigation advance arrived at the grid points as water had already contacted the point. Therefore, the time that water arrived at each point within each column was simply recorded. Irrigation advance results were plotted as individual points with distance (ft) on the x-axis and time (min) on the y-axis, following ASAE Standard Engineering Practice ASAE EP 419. Though grid point data within each column are not linked temporally, a line was then fitted along these points to form an advance curve for each column within a field. In those instances where grid points were wetted prior to the arrival of the main irrigation advance within a column, the slope of the plotted advance curve becomes negative. Advance curve deviations from a positive slope serve to illustrate the occurrence and magnitude of non-uniform irrigation advance within study fields.

3.1.4.3 Irrigation Performance Parameters

All irrigation performance parameters for each study field were calculated based on the data obtained during each irrigation evaluation. The first irrigation performance parameter calculated was irrigation application efficiency. Using infiltration opportunity time data and field infiltration characteristics, the depth and infiltrated volume of irrigation water were calculated. Based on depth and volume of irrigation water, application efficiency was determined for each field using the following equation:

$$
\begin{aligned}
&AE = RZ / V_a \\
&\textit{Where:} \\
&AE = \textit{application efficiency} \\
&RZ = \textit{volume of water stored in root zone} \\
&V_a = \textit{volume of water applied}
\end{aligned}
$$

In circumstances where irrigation does not replenish the root zone, the above volumetric equation will result in an application efficiency of 100 percent, which certainly does not imply a perfect irrigation. Because deficit irrigation is common, another performance parameter is necessary to better characterize the performance of an irrigation system. To obtain critical information regarding a field’s SMD, the requirement efficiency performance parameter is necessary. Requirement efficiency is calculated using the following equation:

$$
\begin{aligned}
&RE = RZ / SMD \\
&\textit{Where:} \\
&RE = \textit{requirement efficiency} \\
&RZ = \textit{volume of water stored in root zone} \\
&SMD = \textit{preirrigation soil moisture deficit}
\end{aligned}
$$

The requirement efficiency performance parameter rates an irrigation system's performance with respect to replenishing the soil moisture deficit in the field. Requirement efficiency is always 100 percent when a field has been over-irrigated because the SMD is totally replenished. In these cases, the application efficiency performance parameter will indicate the amount of water over-applied. Likewise, in the case of under-irrigation, the application efficiency will be 100 percent, though the requirement efficiency will indicate a deficit remaining in the root zone.

The volume of water stored in the root zone was determined by measuring the amount of water infiltrated at a single grid point. This was accomplished by using the infiltration equation to determine the depth of water infiltrated at each grid point, accounting for advance time at each grid point, multiplying by the area around each grid point, then extrapolating to the entire field area to determine the total volume (RZ). Since the amount of time fluctuated (differences in advance time) between grid points and infiltration characteristics changed between parts of the field, differences occurred in the infiltrated depth. If the infiltrated amount was greater than the deficit required to replenish the root zone, infiltrated water below the root zone was lost to deep percolation.

Two other performance parameters important in determining the performance of an irrigation system are the deep percolation percentage and the runoff percentage. These parameters are described in the following formulae:

$$DPP = V_P / V_a$$

Where:

$$DPP = deep\ percolation\ percentage$$
$$V_P = volume\ of\ water\ percolating\ below\ root\ zone$$
$$V_a = volume\ of\ water\ applied$$

$$RP = V_R / V_a$$
$$RP = runoff\ percentage$$
$$V_R = volume\ of\ runoff\ water$$
$$V_a = volume\ of\ water\ applied$$

The deep percolation percentage parameter describes how much water percolates below the root zone and becomes unavailable to the crop, while the runoff percentage parameter indicates how much water has run off the system. Because water is either stored in the root zone, deep percolates, or runs off a field, the sum of application efficiency, deep percolation percentage, and runoff percentage is 100 percent.

Although the above performance parameters give insight into how efficient an irrigation system is functioning and whether water is deep percolating or running off, they do not describe the spatial distribution of water on the field. To evaluate the distribution of irrigation water within an irrigation system, two performance parameters are employed: Christiansen's uniformity coefficient and distribution uniformity (ASAE, 1990). Both performance parameters evaluate irrigation distribution, and both are employed for confirmation of results. These performance parameters are defined in the following equations:

$$CU = 1 - \frac{\sum A_i \left| d_i - d_{avg} \right|}{\sum A_i d_i}$$

$Where:$

$CU = Christiansen's\ uniformity\ coefficient$

$A_i = area\ of\ polygon$

$d_i = water\ depth\ of\ polygon$

$d_{avg} = average\ water\ depth\ applied\ on\ field$

$$DU = d_{lq} / d_{avg}$$

$Where:$

$DU = distribution\ uniformity$

$d_{lq} = average\ depth\ of\ low\ quarter\ of\ field$

In the above formula, distribution uniformity of lower quarter is defined as the ratio of the average of the lowest one-fourth of measurements of irrigation water infiltrated (or applied) to the average depth of (the total) irrigation water infiltrated (applied) (ASAE, 1998).

All irrigation system performance parameters for this study were calculated using an iterative approach to the volume balance method: opportunity times, applied water volumes, and infiltration characteristics were assigned to points within the grid layout for each field. As such, recession time for each irrigation event was iteratively solved and solutions were obtained for all inputs necessary to compute the performance parameters for each field. The resulting performance parameters provide a comprehensive description of performance for each of the six irrigation systems studied, which then can be used to compare the irrigation systems as well as evaluate possibilities for irrigation efficiency improvement.

In addition to the irrigation performance parameters above, an irrigation application was also calculated for each irrigation run at each field, which represents the approximate total volume of water diverted from the MRGCD canal per acre of irrigated field. For all the study fields except the Hubble-Oxbow Field, the irrigation application was calculated based on the total field inflow volume in acre feet (inflow rate [cubic feet/second (cfs)] and time period) per acre of irrigated field. Though the irrigation flow rate was measured at the head of the field, this flow was assumed to reflect actual diversion flow rates as the on-farm conveyances at all study locations, except at the Hubble-Oxbow Field, were concrete-lined. In the case of the Hubble-Oxbow Field, on-farm conveyances were earthen ditches and leakage was evident during the evaluation. As a result, the actual diversion flow was recorded at this study farm at the MRGCD canal. Consequently, at the Hubble-Oxbow Field, the irrigation application was calculated based on these measurements at the diversion point.

3.2 Agency Survey and Interviews

Investigators began interviewing NRCS personnel in fall 2003 to obtain estimates of the extent of conservation measures among farms within the MRGCD. There has been no comprehensive study of conservation measures within the MRGCD, and agricultural statistics compiled by the U.S. Department of Agriculture (USDA) in the Census of Agriculture do not focus directly on the type, extent, or effectiveness of conservation measures. Therefore, the NRCS agents responsible for the four counties encompassing the MRGCD were contacted because of their familiarity with the status of farms within the MRGCD and their extensive experience assisting farmers with implementation of conservation measures. Initial meetings with the NRCS agents involved site visits by investigators and extensive interviews discussing on-farm conservation measures within their respective counties. Following these interviews, the first of two surveys was submitted to each NRCS agent representing a county encompassing some portion of the MRGCD. It is important to note that survey responses obtained from NRCS agents were based on the agent’s personal opinion and secondary data sources regarding conditions within the MRGCD, and were not based on NRCS agency records. The following NRCS agents were interviewed and responded to the first survey:

- Corinne Brooks, Bernalillo and Sandoval Counties
- Danny Thomas, Valencia County
- Darrel Reasoner, Socorro County

Following compilation of results from the first survey submitted to the above NRCS agents, a second survey was submitted to the NRCS county offices in spring 2005. The second survey included confirmatory questions and additional questions regarding the status of conservation measures employed within the MRGCD. In the intervening period between the two surveys, NRCS personnel changes at two county offices resulted in different NRCS agents responding to the second survey for Valencia and Socorro Counties. The NRCS agents to whom the second survey was submitted include:

- Corinne Brooks, Bernalillo and Sandoval Counties
- Rudy Garcia, Valencia County
- Santiago Misquez, Socorro County

Because NRCS agent responses were in text and numeric formats, the information was compiled into a spreadsheet as received, then converted to a uniform numeric response format. For example, because the first survey instructed NRCS agents to answer as either percents or acres, either response was recorded on the working spreadsheet, then converted to a uniform response. In other cases, NRCS agents provided responses in terms of a range rather than one value. As a result, these ranges are included in the results summary table (Table 4-19). It is also important to note that, because both Bernalillo and Sandoval Counties were administered in the Albuquerque NRCS office by Corrine Brooks, responses for these counties were combined for both Bernalillo and Sandoval Counties. In addition, during the second survey, NRCS agents were asked to review responses by other county NRCS representatives provided in the first survey, and if any comments or corrections were made, this information was also included in the working spreadsheet. Although the second survey was submitted to all three county offices, the second survey questions were only responded to by Santiago Misquez of the Socorro NRCS office, and comments were made regarding responses to the first survey only by Rudy Garcia of the Valencia County NRCS office and by Santiago Misquez of the Socorro NRCS office. In those cases where one agent's response was different from another's, then a range of values was entered as the final response. Some of the information requested of the NRCS agents was later deemed not relevant and subsequently not used in the study. The summary of results from the NRCS survey only includes information pertinent to the study.

Recognizing that Tribal agricultural land accounts for a significant amount of water use and agricultural production within the MRGCD, investigators contacted representatives from all tribes located within the Middle Rio Grande Basin, as well as the Bureau of Indian Affairs, Southern Pueblo Agency Office in an effort to obtain information regarding the status of on-farm conservation measures on Indian land. However, the contacted tribes either did not respond to the initial inquiry or stated that they were unwilling to participate in this study of on-farm irrigation efficiency. These tribes included Cochiti Pueblo, Santa Domingo Pueblo, San Felipe Pueblo, Santa Ana Pueblo, Sandia Pueblo, and Isleta Pueblo.

To obtain another perspective on conservation measures within the MRGCD, the USDA 2002 Census of Agriculture was reviewed. The USDA's 2002 Census of Agriculture (USDA, 2004) summarized data by county, and agriculture outside of the MRGCD boundaries are in included in the census data. However, because a large majority of each county's irrigated agriculture lies within the MRGCD, census data regarding irrigated agriculture was deemed representative of the MRGCD. Although the census information did not provide direct data regarding on-farm conservation, some deductions could be made about trends in agriculture and possibly conservation measures from the data, including relative levels of irrigated acreage and crop type as it has changed since the preceding USDA census surveys in 1997. The National Agriculture Statistics Service (NASS) is responsible for conducting the USDA Census of Agriculture as well as the NM Agricultural Statistics (NMAS). Data collection for the 5-year Census of Agriculture and the annual NMAS reports involve multiple surveys, and the surveys and questionnaires for each of the two reports are separate and not combined. The NASS surveys and questionnaires are submitted to every known producer/farmer in the state, and the return rate for the Census of Agriculture and the NMAS range from 60 to 85 percent, though this range doesn't indicate the percent completion for the various survey/questionnaires forms (Nelson, 2006).

3.3 Estimate of MRGCD-Wide Irrigation Efficiency Improvement

To obtain an estimate of MRCGD-wide irrigation efficiency improvement upon implementation of conservation measures for all irrigated acres within the MRGCD, the irrigation efficiency results from the field studies were used to determine the relative differences in irrigation efficiency between fields where on-farm conservation measures are employed and fields where no conservation measures are employed. Evaluation of these results yielded a range of efficiency for groups of study fields that appear to represent high-, intermediate-, and low-irrigation efficiency. Fields within each of these three groups were then evaluated to determine if efficiency results correlated with relative levels of on-farm conservation measures employed at these fields. It was determined that study fields with higher irrigation efficiency correlated with increased use of on-farm conservation measures, and visa versa. Once the on-farm irrigation efficiency range was established for each of the three efficiency groups, irrigation performance parameters and irrigation applications derived from the on-farm irrigation efficiency investigations were used in conjunction with the NRCS estimates of irrigation efficiency and relative distribution of primary efficiency groups within the MRGCD to determine the potential reduction in agricultural water use upon increased implementation of conservation measures among farms within the MRGCD.

There were four basic input parameters controlling the annual MRGCD on-farm water use estimate derived as part of this study: 1) total irrigated acreage; 2) number of irrigation events per acre per year; 3) water application depth per acre per event (irrigation efficiency); and 4) the relative fractions of irrigation efficiency groups among all irrigated acreage. To compare estimates of total annual volume of water delivered to MRGCD farmers derived in this study to estimates reported by others, separate calculations used lower input values for total irrigated acreage and the number of irrigation events per acre per year.

SECTION 4. RESULTS

4.1 On-Farm Irrigation Efficiency Evaluation

4.1.1 San Acacia North Field

The San Acacia North Field is an alfalfa field located in the Indian Hills Farm, owned by Gordon Herkenhoff, in San Acacia, New Mexico (Figure 4-1). The field is approximately 425 feet wide by 1,300 feet long, with a total acreage of approximately 13 acres. The field has conservation measures in place, including maintenance of laser leveling and concrete-lined on-farm supply canals, suggesting that opportunities exist to obtain relatively high irrigation efficiencies at this field. According to the irrigator, the field was laser leveled in 1998 or 1999, and the slope of the field was approximately 0.17 ft/100 ft. The survey conducted in the field by investigators found that the field had a slope of approximately 0.08 percent. In order to survey the field layout, field grid points were established using pin flags. A total of six columns and 84 grid nodes were used for the first irrigation run of the San Acacia North Field (conducted on August 8, 2003), while four columns and 52 grid points were used for the second irrigation run (conducted on March 17, 2004). Appendix 1 contains pictures of the San Acacia North Field as well as field activities conducted at this location.

Although four locations within the San Acacia North Field were initially selected for infiltration analysis based on conversations with the irrigator, results from only two locations are included in the study because the other two locations were outside of the irrigated basin. Figure 4-2 shows results for the two infiltration tests located on the San Acacia North Field, as well as fitted infiltration based on the Modified Kostiakov infiltration equation. The initial infiltration rate at both locations is significantly higher than later in the test, which is consistent with normal intake properties of soil.

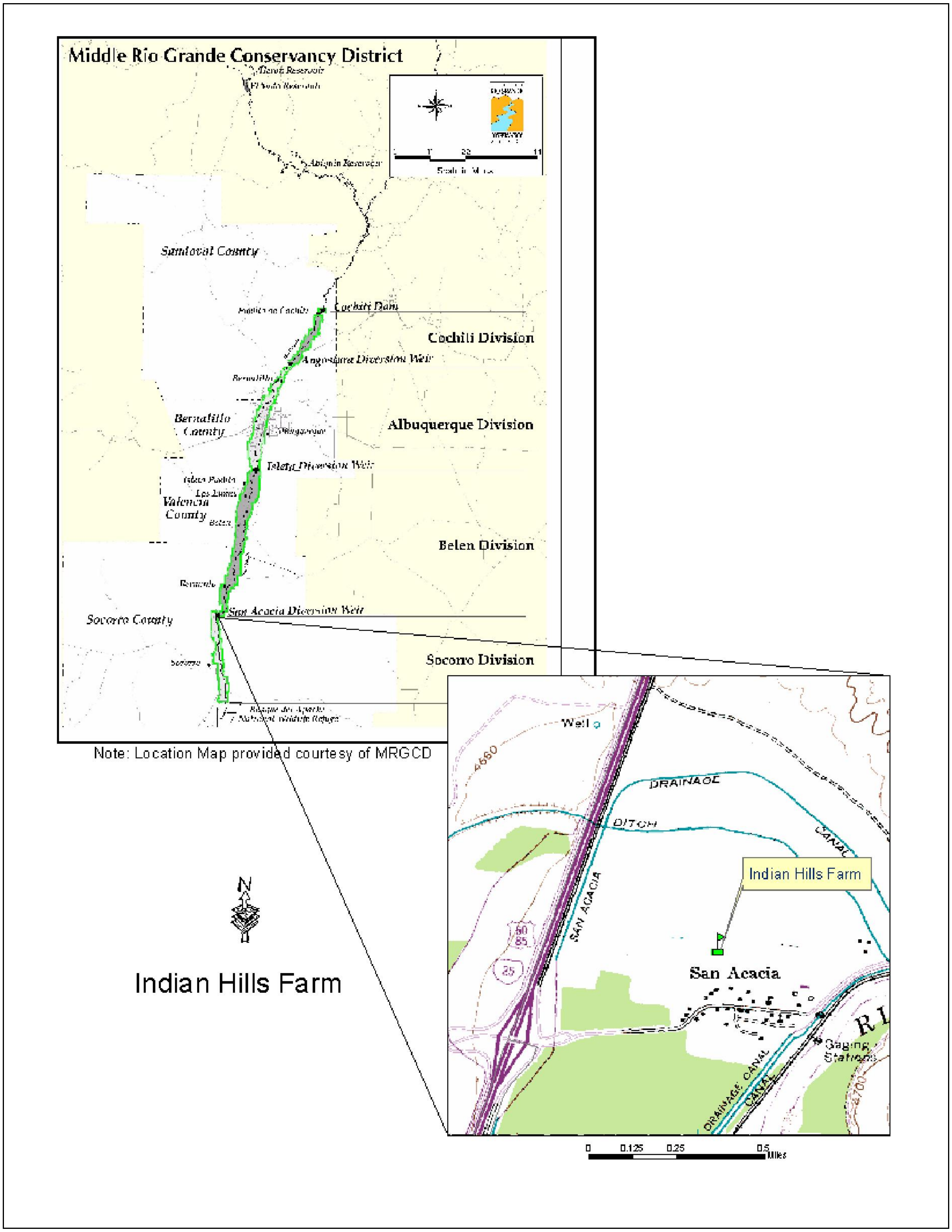


Figure 4-1. Location of Indian Hills Farm (San Acacia North and South Fields)

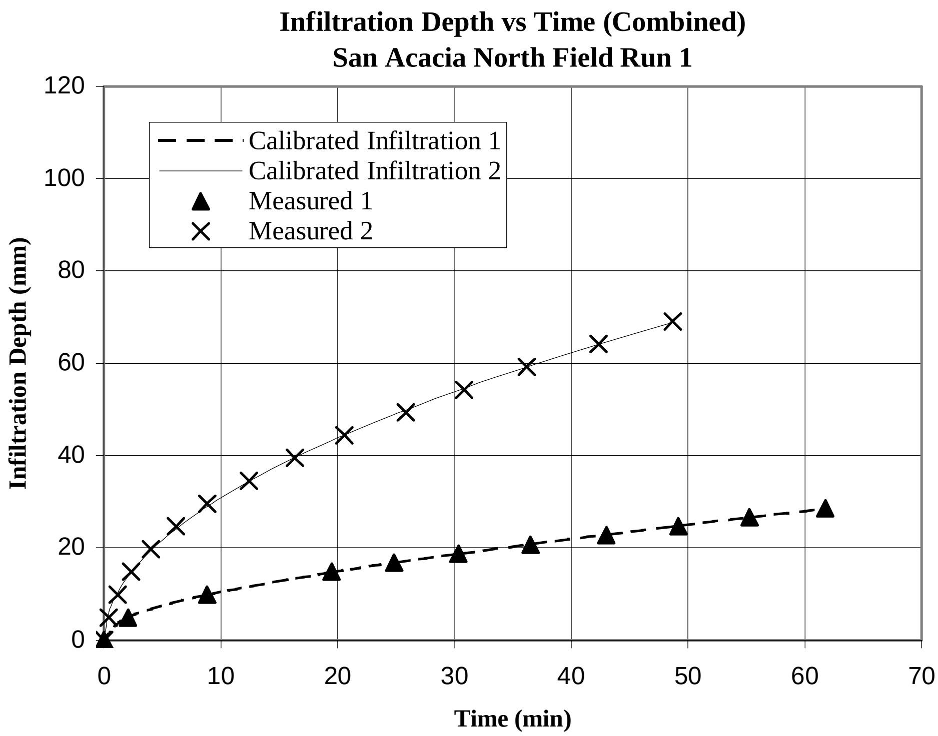


Figure 4-2. Infiltration Characteristics for San Acacia North Field Run 1

Some of the variation between infiltration test results was due to desiccation cracks located within the study field. Although care was taken to avoid the cracks, complete avoidance was impossible due to the relatively high amount of cracking within the field. The desiccation cracks act as water pathways, which influence the infiltration characteristics of the soil. Consequently, results from vertical infiltration tests may be exaggerated due to vertical and horizontal water movement through soil cracks. In order to determine whether soil desiccation cracks influenced the infiltration tests, resulting infiltration characteristics were compared to the NRCS Soil Survey Reports for significant differences, of which none were found.

In addition to the infiltration tests, three soil samples were collected at locations where infiltration tests were conducted, from 6-, 18-, and 30-inch depths. Following sample collection, pre-irrigation moisture content was determined for each soil sample using the gravimetric method. Soil texture for each soil sample was determined in the field, then compared to NRCS Soil Survey Reports for confirmation and to determine the type and properties of each of the soils. Figure 4-3 shows the moisture content for the samples collected at the San Acacia North Field.

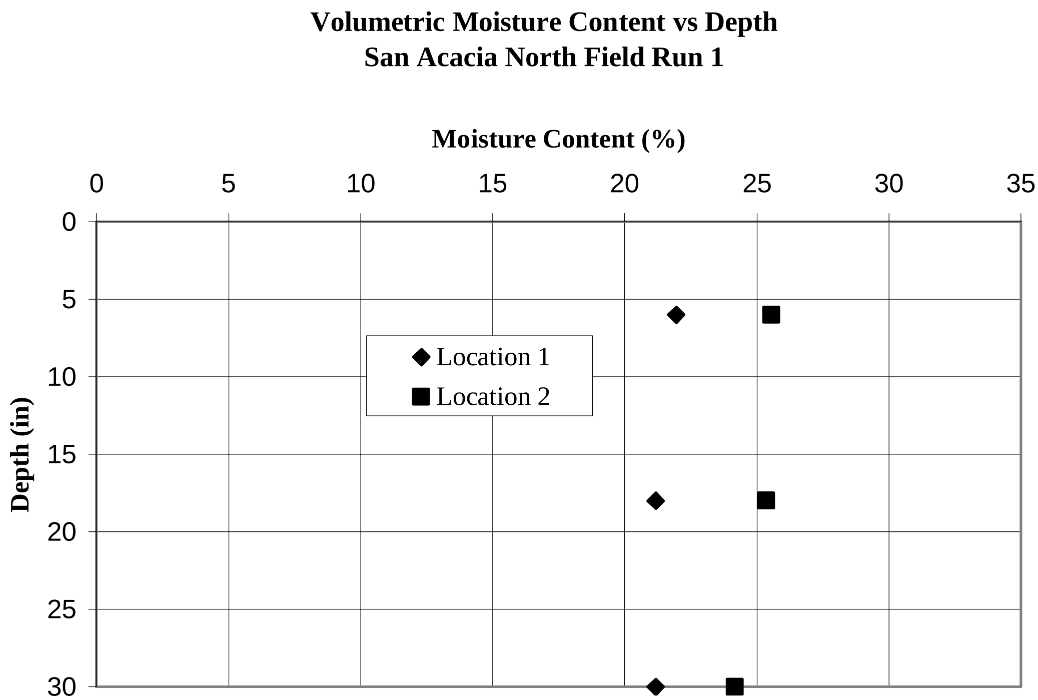


Figure 4-3. Pre-Irrigation Moisture Content for San Acacia North Field Run 1

The soil moisture content analysis of these samples indicated relatively uniform moisture content for each profile and between sample locations. Moisture content at Location 1 was approximately 22 percent by volume at a 6-inch depth and decreased only slightly deeper in the soil profile. This result was also observed at Location 2, where near surface water content was approximately 25 percent, and decreased only slightly deeper in the soil profile. Soil samples were collected and infiltration tests were conducted within 24 hours of the pending irrigation to approximate the conditions at the time of irrigation.

Infiltration tests and soil sampling were also performed for the second irrigation run on the San Acacia North Field (Figure 4-4). In contrast to the first irrigation run, the infiltration rate at Location 1 was greater, while the infiltration rate at Location 2 was lower.

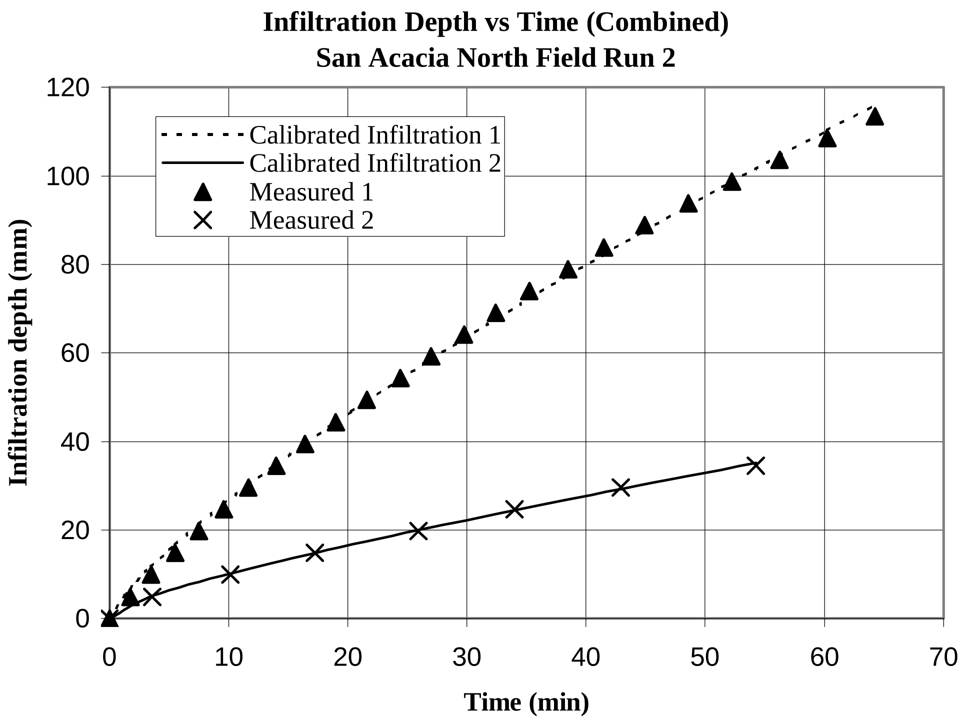


Figure 4-4. Infiltration Characteristics for San Acacia North Field Run 2

As shown on Figure 4-5, pre-irrigation soil moisture content at both locations at the San Acacia North Field was considerably different than before the first irrigation run. At Location 1, the moisture content was approximately 24 percent by volume at a 6-inch depth, and increased to 32 percent at a depth of 30 inches in the soil profile. At Location 2, the near-surface-water content was approximately 18 percent, increased to 23 percent at 18 inches, and decreased to 13 percent at 30 inches in the soil profile.

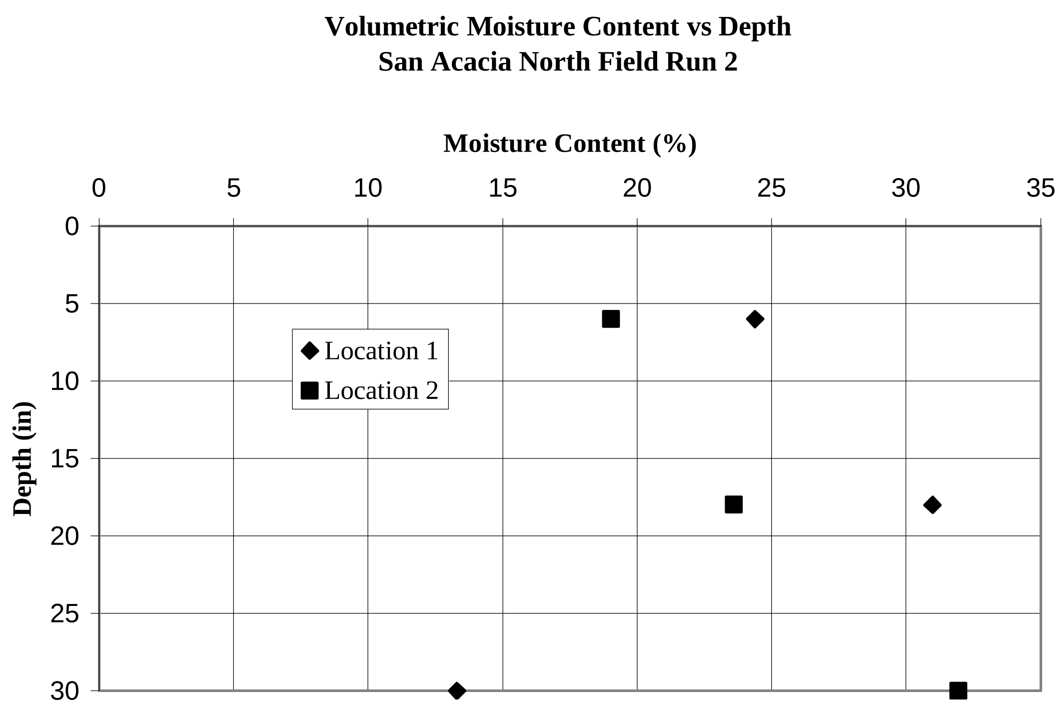


Figure 4-5. Pre-Irrigation Moisture Content for San Acacia North Field Run 2

Soil textures were compared to the NRCS Soil Survey Reports to determine properties of the soils, summarized in Table 4-1. Textural characteristics of each soil varied according to depth, with clay loam accumulation near the surface and higher content of fine sand in deeper horizons. Changes in soil texture at varying depths in large part controlled soil physical properties and, consequently, infiltration characteristics at each location.

Table 4-1. Soil Classification and Characteristics for the San Acacia North Field

Field Classification			NRCS Soil Survey			
Sample Location	**Sample Depth (in.)**	**Field Description**	**Layer (in.)**	**Available Water Content (in./in.)**	**Permeability (in./hr)**	**USDA Classification**
1	6	Brown Clay (Loamy)	0-8	0.15-0.17	0.2-0.6	Clay Loam
	18	Silty Loam	8-23	0.15-0.17	0.6-2.0	Silt Loam
	30	Light Brown Fine Sand	23-60	0.05-0.07	6-20	Fine Sand
2	6	Brown Clay (Loamy)	0-8	0.15-0.17	0.2-0.6	Clay Loam
	18	Sandy Loam	8-23	0.15-0.17	0.6-2.0	Silt Loam
	30	Fine Sand	23-60	0.05-0.07	6-20	Fine Sand

The San Acacia North Field was supplied irrigation water from the Alamillo Canal, an unlined earthen conveyance canal operated by the MRGCD. Water from the Alamillo Canal is diverted into an on-farm concrete-lined canal through an 18-inch circular gate piped under the Alamillo earthen bank. Once in the concrete-lined canal, the alfalfa field is irrigated directly using four 10-inch turnouts. The head level in the Alamillo Canal was observed to be higher during the first irrigation run as compared to the second irrigation run. During the course of the irrigation events, several parameters were measured including start time, inflow, advance time, and cutoff time. Average inflow for the first irrigation run was 14.8 cfs, while average inflow for the second irrigation run was 15.8 cfs. Advance time was measured for each grid point surveyed during the pre-irrigation field layout. Figure 4-6 shows the advance time for the first irrigation run of the San Acacia North Field. A typical advance time curve should have certain characteristics: the advance should initially be relatively rapid, then slow down as the irrigation water progresses along the length of the field. As illustrated on Figure 4-5, the observed advance curves exhibit these characteristics, although other site-specific factors controlling advance time may also be evident. Advance times for Columns 1-3 and Columns 4-6 were observed to be closely similar. As indicated by negative slopes along the Column 4 advance curves, several grid points in Column 4 were inundated ahead of the irrigation advance in this column by water escaped from adjacent columns.

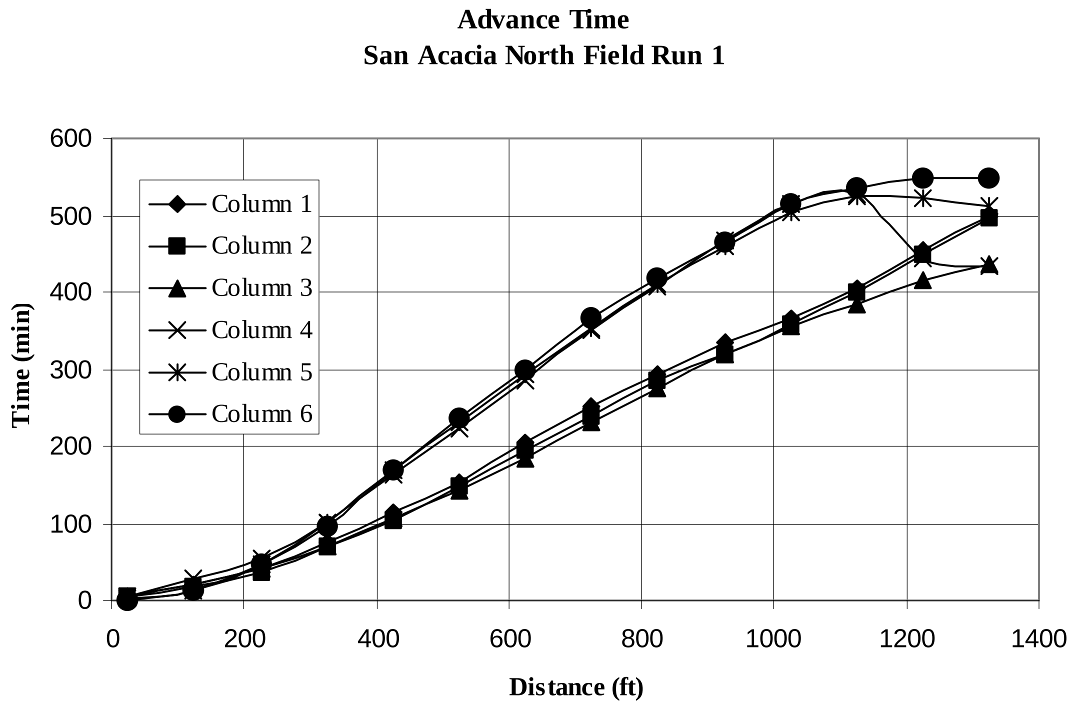


Figure 4-6. Advance Time Curves for San Acacia North Field Run 1

Figure 4-7 shows the advance curves for the second irrigation run of the San Acacia North Field. The grid points were redistributed for the second irrigation run to obtain a uniform area distribution for the nodes. As a result, 4 columns were used for the flag layout. Columns 1 and 2 were located on the western sub-basin, and Columns 3 and 4 were located on the eastern sub-basin. The advance curves for the second irrigation run show a more uniform advance than the first irrigation run.

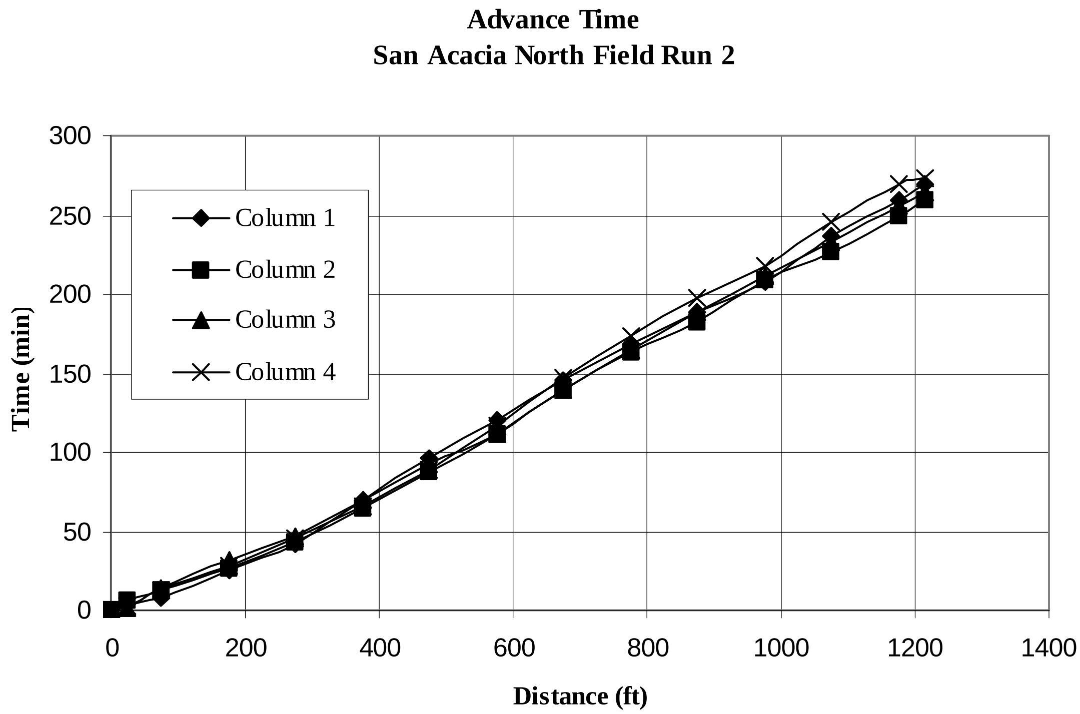


Figure 4-7. Advance Time Curves for San Acacia North Field Run 2

In addition to changes in advance curves between the first and second irrigation runs, total advance time was also significantly different between runs. Specifically, advance time for the second irrigation run was five hours shorter that that observed in the first irrigation run (4 and 9 hours, respectively).

Using the soil analysis and current meter data, soil deficits and inflows were determined for the San Acacia North Field. Table 4-2 presents a summary of these results. Calculated areas for the irrigation runs were slightly different for each irrigation run conducted within the same field due to inherent measurement errors in flagging/surveying the field as well as integration errors in calculating the area.

Table 4-2. Soil Deficit and Inflow Parameters for the San Acacia North Field

Irrigation Run	Area (acres)	Soil Deficit (in.)	Inflow (ft^3)	Inflow (ac-ft)	Average Depth (in.)	AE (%)	RE (%)
1	13.0	4.7-7.1	501,477	11.51	11.4	51.6	100
2	12.6	3.2-9.2	230,700	5.30	5.4	96.8	84.0

The resulting irrigation performance parameters were calculated for the San Acacia North Field and are presented in Table 4-13. These performance parameters indicate significant differences between the first and second irrigation runs. Specifically, the application efficiency was lower in the first irrigation run (51.6 percent) compared to the second irrigation run (96.8 percent), while requirement efficiency was higher in the first irrigation run (100 percent) compared to the second irrigation run (84.0 percent), suggesting the field was over watered in the first irrigation run and deficit-irrigated in the second. The differenced between the two irrigation events are also be evident in irrigation uniformity coefficients for the two irrigation runs. Specifically, the Christiansen's uniformity and distribution uniformity for the first irrigation run were 90.5 percent and 80.9 percent, respectively, while for the second irrigation run they were 79.9 percent and 63.0 percent, respectively.

4.1.2 San Acacia South Field

San Acacia South Field is an alfalfa field located at the Indian Hills Farm, owned by Gordon Herkenhoff, in San Acacia, New Mexico. The field is approximately 325 feet wide by 750 feet long, with a total acreage of approximately five acres. The South field was rehabilitated from salt cedar overgrowth and is now a productive alfalfa field. According to the irrigator, the field was laser leveled in 2003, and the soil was predominately sandy with intermixed clay layers. According to the irrigator, the slope of the field was approximately 0.05 ft/100 ft. The survey conducted in the field by study investigators indicated that the field slope was 0.05 percent. A total of 6 columns and 45 grid nodes were used for the first and second irrigation runs of the South Field. Because the San Acacia Drain bisects the southwestern side of the field, the field is not rectangular, and the resulting column lengths decrease from Column 1 to Column 6. Appendix 2 contains photographs of the San Acacia South Field. The first irrigation run at this study field was conducted on March 18, 2004, and the second irrigation run was conducted on August 29, 2004.

For the first irrigation run infiltration characteristics were measured at one location on the San Acacia South Field. Based on the size of the South Field, 2 infiltration tests were initially planned, but due to a change in irrigator watering schedule, only one infiltration test was completed because of time constraints. Figure 4-8 presents results for the infiltration test at San

Acacia South Field. On Figure 4-8, infiltration data are compared with fitted infiltration data generated by the Modified Kostiakov equation.

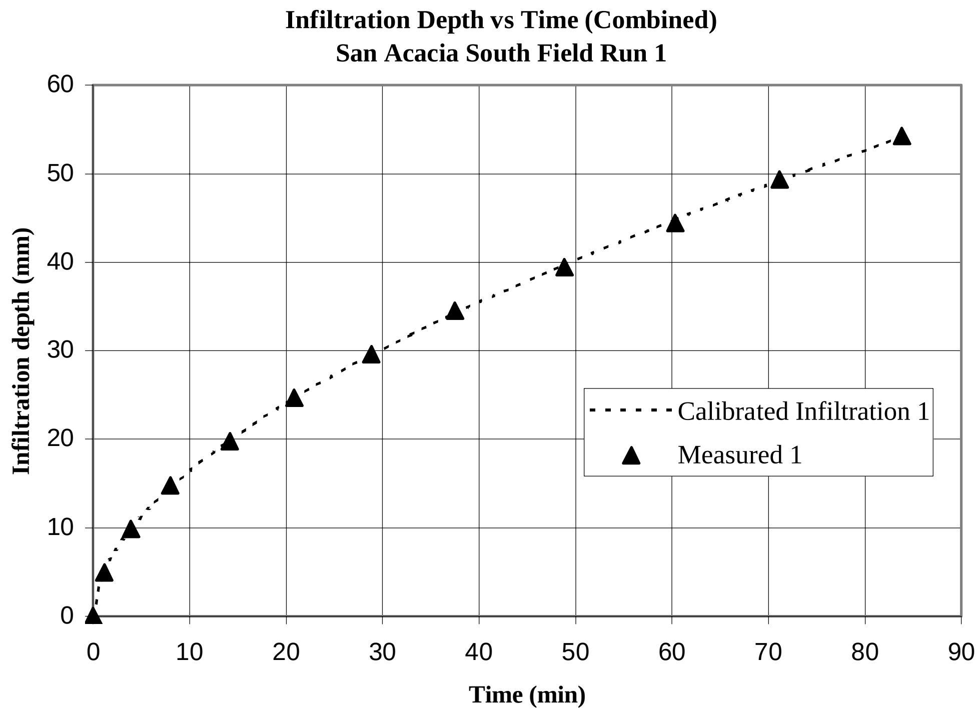


Figure 4-8. Infiltration Characteristics for San Acacia South Field Run 1

Like the San Acadia North Field, desiccation cracks were evident at the San Acacia South Field. Although care was taken to avoid cracks when selecting the location for the infiltration test, complete avoidance was impossible due to the relatively high amount of cracking in the soil within this field.

In addition to the infiltration test, soil samples were collected at two locations originally intended for infiltration analyses, from 6-, 18-, and 30-inch depths. Following sample collection, pre-irrigation moisture contents were determined for each of the samples using the gravimetric method. The textures of the soil samples were also compared to the NRCS Soil Survey Reports to determine the type and properties of each of the soils. Figure 4-9 illustrates the change in moisture content with depth prior to the first irrigation run of samples collected at the South Field.

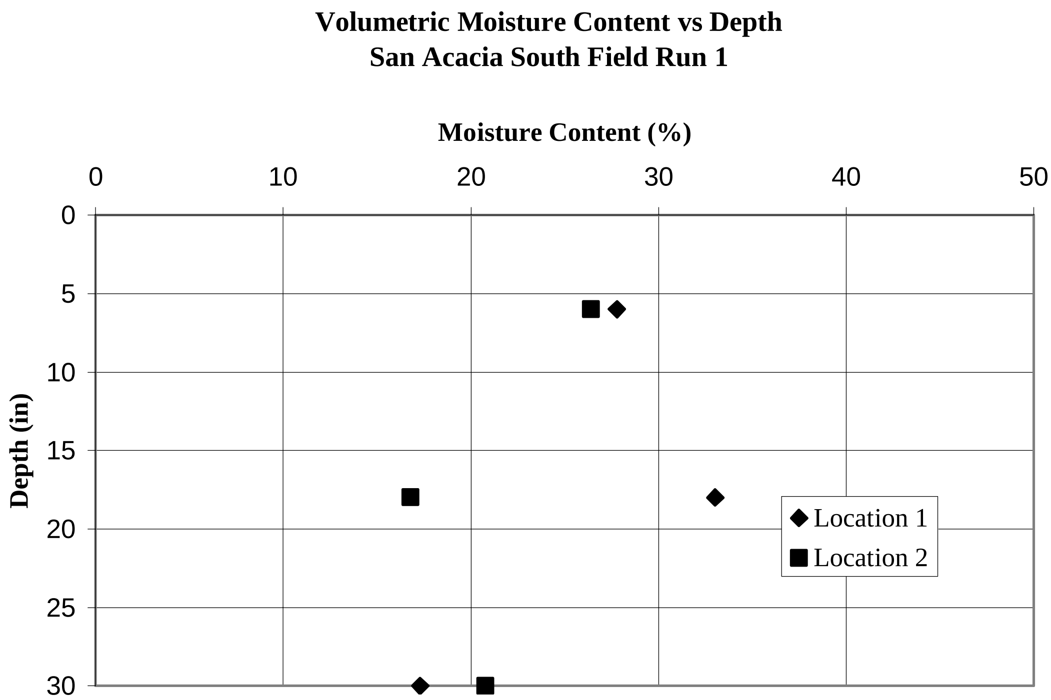


Figure 4-9. Pre-Irrigation Moisture Content for San Acacia South Field Run 1

Soil moisture content analysis of these samples indicated non-uniform soil moisture conditions for the soil profiles. Specifically, moisture content was approximately the same (28 percent) at a depth of 6 inches at both locations, while at the 18-inch depth soil moisture increased at Location 1 and decreased at Location 2. At a 30-inch depth within the soil profile, the moisture contents were similar for both locations 1 and 2 (18 to 21 percent, respectively).

Infiltration tests were conducted and soil samples were collected for the second irrigation run on San Acacia South Field. Figure 4-10 illustrates the infiltration results for the second irrigation run on San Acacia South Field.

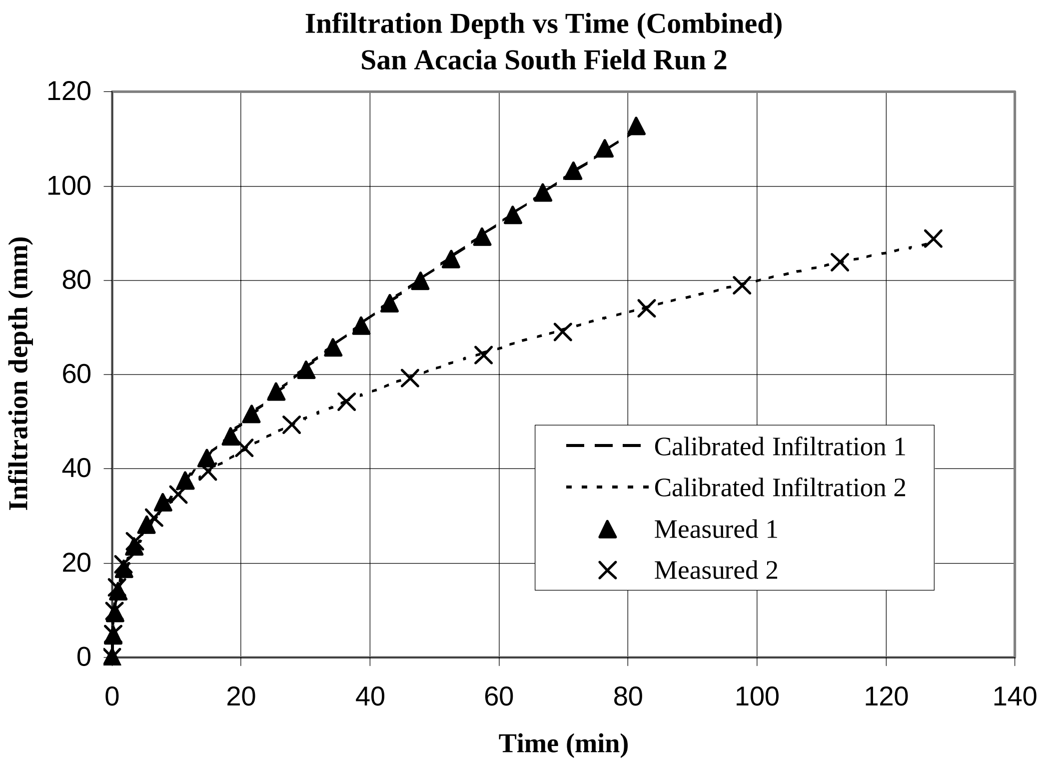


Figure 4-10. Infiltration Characteristics for San Acacia South Field Run 2

Figure 4-11 shows the moisture content for both infiltration test locations prior to second irrigation run at San Acacia South Field. The moisture content profiles prior to the second irrigation run were similar to results observed prior to the first irrigation run, with the exception of moisture content at the 30-inch depth at Location 1 being significantly higher in the second irrigation run (31 percent) as compared to the first irrigation run (22 percent) at this location, possibly due to interaction with shallow groundwater.

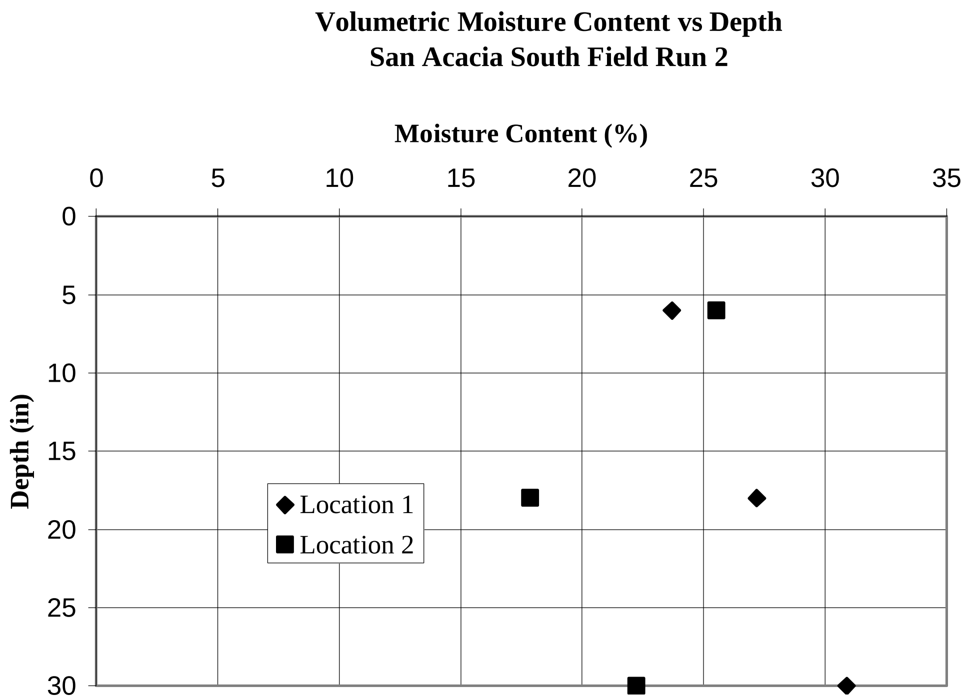


Figure 4-11. Pre-Irrigation Moisture Content for San Acacia South Field Run 2

Soil textures from samples collected at Locations 1 and 2 were also compared to data in the NRCS Soil Survey Reports for this area to determine soil properties, summarized in Table 4-3. The textural characteristics of the soil can be seen to change with depth, beginning with clay accumulation at the surface, then increasing amounts of fine sand with depth.

Table 4-3. Soil Classification and Characteristics for San Acacia South Field

Field Classification			NRCS Soil Survey			
Sample	**Sample Depth (in.)**	**Field Description**	**Layer (in.)**	**Available Water Content (in./in.)**	**Permeability (in./hr)**	**USDA Classification**
Location 1	6	Brown Clay (Organics)	0-18	0.09-0.11	<0.6	Clay
	18	Transition Light Brown Fine Sand	18-60	0.03-0.08	6-20	Fine Sand/ Loamy Sand
	30	Light Brown Fine Sand				
Location 2	6	Brown Clay (Organics)	0-18	0.09-0.11	<0.6	Clay
	18	Transition Light Brown Fine Sand	18-60	0.03-0.08	6-20	Fine Sand/ Loamy Sand
	30	Light Brown Fine Sand				

San Acacia South Field is supplied by MRGCD's Socorro Main Canal, which is an earthen-lined canal. Water is diverted from the Socorro Main Canal to an on-farm concrete-lined canal through a 24-inch circular gate. From the concrete-lined canal, the alfalfa field was irrigated directly using eight circular 10-inch turnouts. The start time, inflow, advance time, and cutoff time were all noted for San Acacia South Field. The advance time was measured for each grid point, as illustrated on Figure 4-12. The advance curves indicate a uniform advance for the first irrigation run at San Acacia South Field. The advance rate was observed to increase at the end of Columns 2 through 4. As described above, the field is not rectangular, resulting in shorter column lengths from Column 1 to Column 6. As a result, this is reflected in different advance curve lengths for each column.

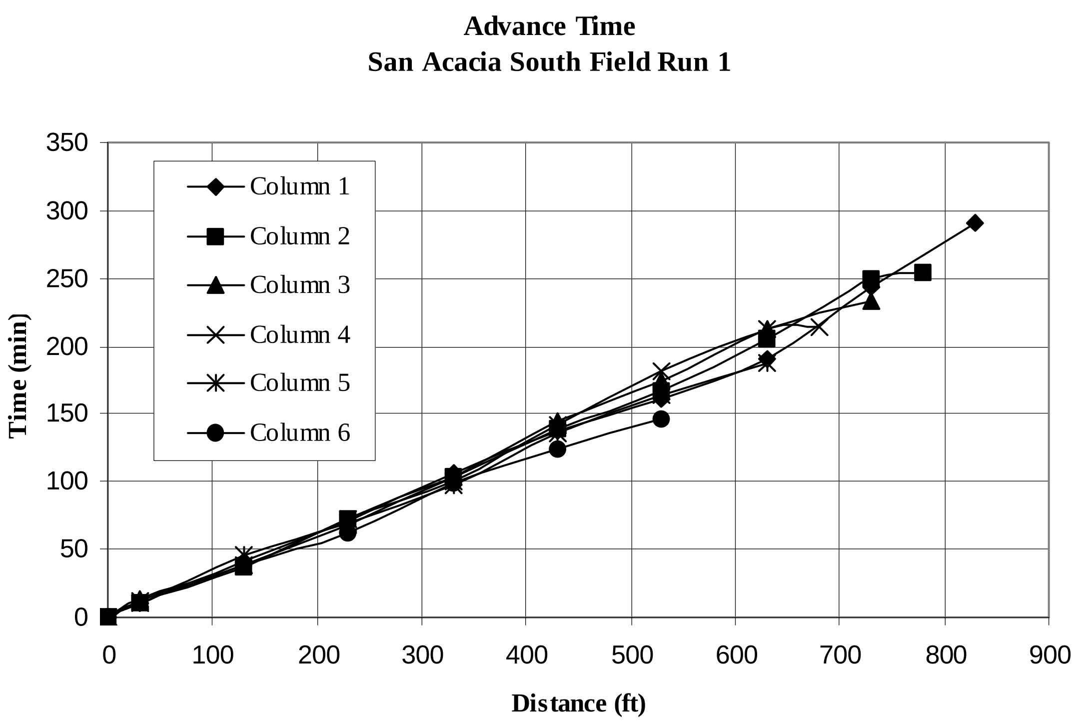


Figure 4-12. Advance Time Curves for San Acacia South Field Run 1

Figure 4-13 shows the advance curves for the second irrigation run of San Acacia South Field. The advance curves for the second irrigation run show a similar uniform advance as observed in the first irrigation run. As in the first irrigation run, an increase in advance rate for Columns 2 through 4 near the end of the irrigation run is evident. The total advance time for the first irrigation run was just under 5 hours, while advance time was over 8 hours for the second irrigation run.

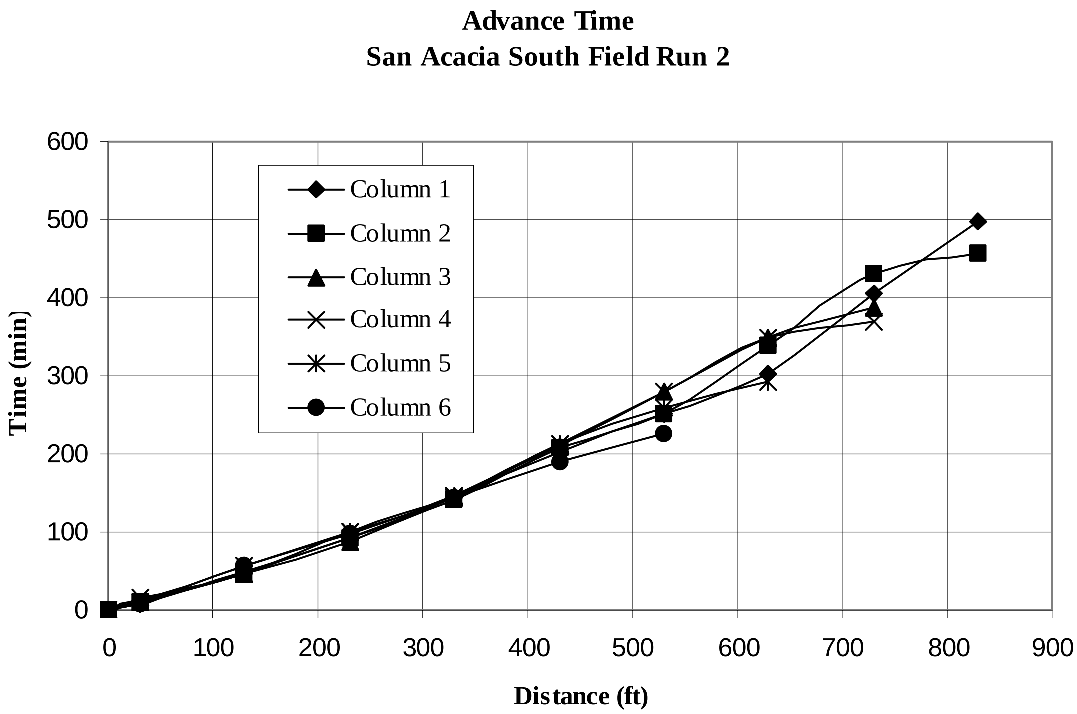


Figure 4-13. Advance Time Curves for San Acacia South Field Run 2

Table 4-4 summarizes the soil deficit and inflow results for San Acacia South Field.

Table 4-4. Soil Deficit and Inflow Parameters for San Acacia South Field

Irrigation Run	Area (acres)	Soil Deficit (in.)	Inflow (ft^3)	Inflow (ac-ft)	Average Depth (in.)	AE (%)	RE (%)
1	5.05	1.3-1.5	165,825	3.81	9.1	15.7	100
2	5.14	1.7-2.0	160,749	3.69	8.6	21.7	100

Tables 4-4 and 4-13 present irrigation performance parameters calculated for San Acacia South Field. Both irrigation runs show a very small pre-irrigation deficit, which is dependent on the assumed field capacity. For this site, a field capacity of 35 percent was assumed for the upper soil horizon, which was comprised largely of clay. This site was challenging, as the desiccation cracks on the surface and plant turgor indicated that irrigation was necessary, but the field evaluation suggested that a much more shallow irrigation would have been appropriate. Shallow groundwater interaction is likely complicating this evaluation. The requirement efficiency for both irrigation runs was 100 percent, and that fact, coupled with the low application efficiency values, suggests that the field was over watered in both cases.

4.1.3 Wade Field

Wade Field, farmed by David Wade, is an alfalfa field located on the Wade Farm in San Antonio, New Mexico. Wade Field is located directly west of Harris Farm and the Harris study field across the county road (Figure 4-14). The field is approximately 550 feet wide by 500 feet long, with a total area of approximately seven acres. Wade Field was laser leveled in 2003, prior to the irrigation efficiency study. A total of six columns and 63 grid nodes were used for the first and second irrigation run of the Wade Field. Appendix 3 contains photographs of the Wade Field. The first irrigation run at this study field was conducted on May 31, 2004, and the second irrigation run was conducted on August 31, 2004.

Prior to the first irrigation run, infiltration characteristics were measured at four locations at the Wade Field. Figure 4-15 shows the results for the infiltration tests, as well as fitted data generated by the Modified Kostiakov equation. Infiltration analyses at Locations 1 and 2 demonstrated very similar results, while infiltration analyses at Locations 3 and 4 were similar.

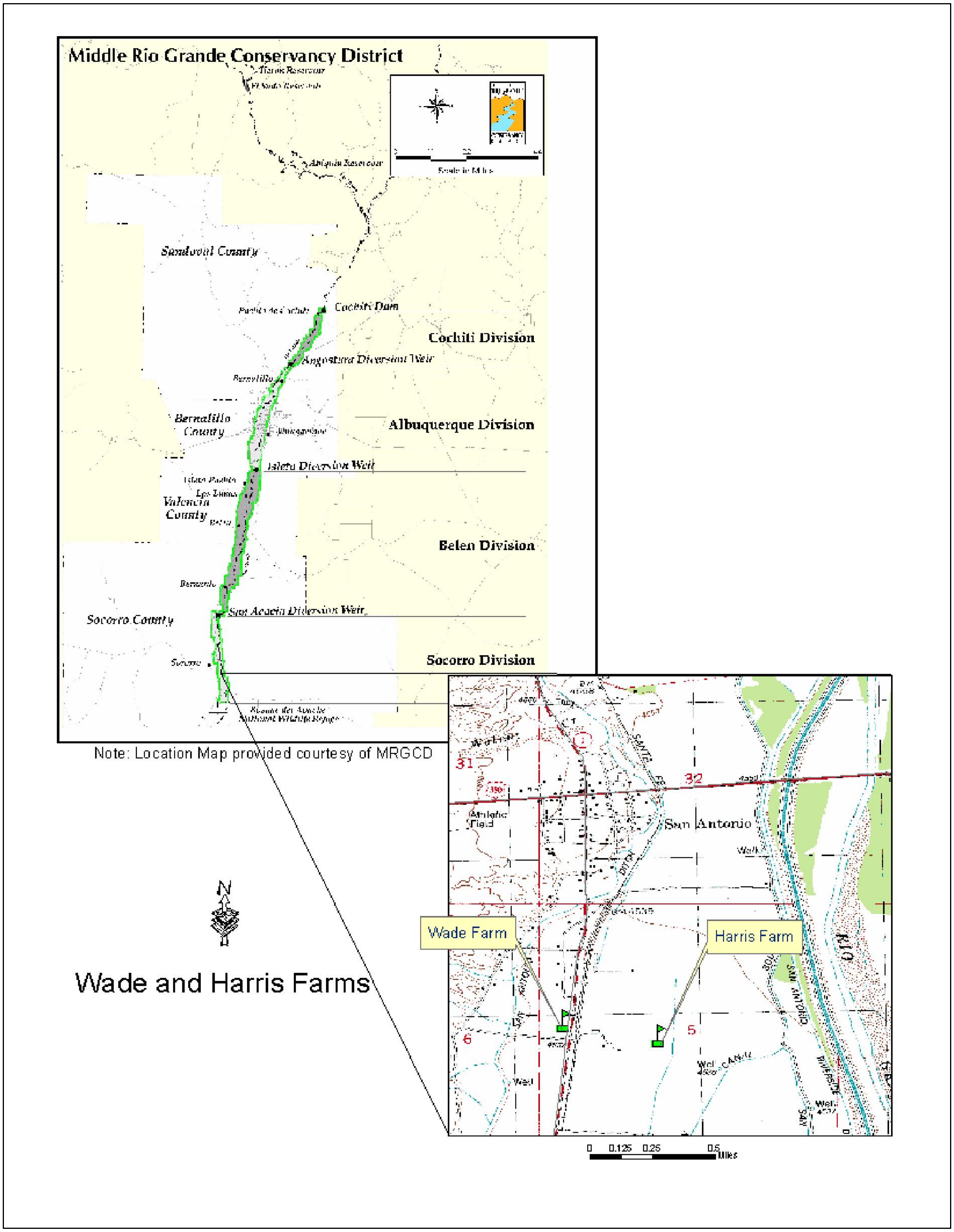


Figure 4-14. Location of Wade Farm and Harris Farm

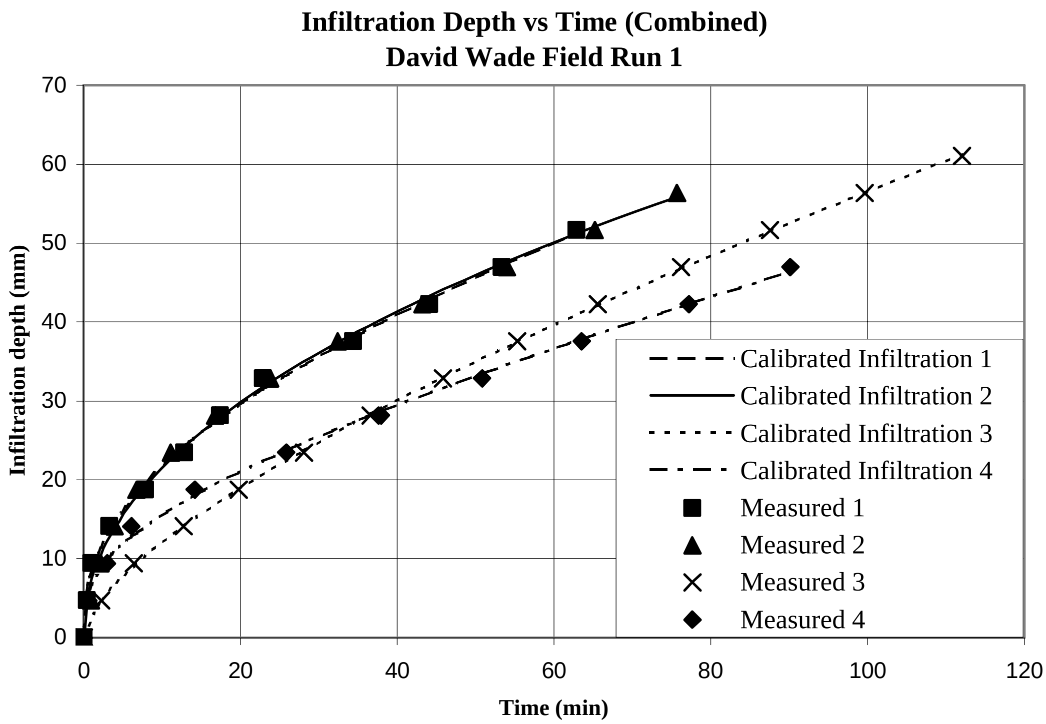


Figure 4-15. Infiltration Characteristics for Wade Field Run 1

Soil desiccation cracks were present at Wade Field, though not as extensive as those observed at the San Acacia fields. Soil samples were collected at four locations from 6-, 18-, and 30-inch depths, and all were similar in texture. The pre-irrigation moisture content was determined for each of the samples. The textures of the soil samples were also compared to the NRCS Soil Survey Reports for this area to determine the type and properties of each of the soils.

Figure 4-16 shows the volumetric moisture content for sample collected prior to the first irrigation run at Wade Field.

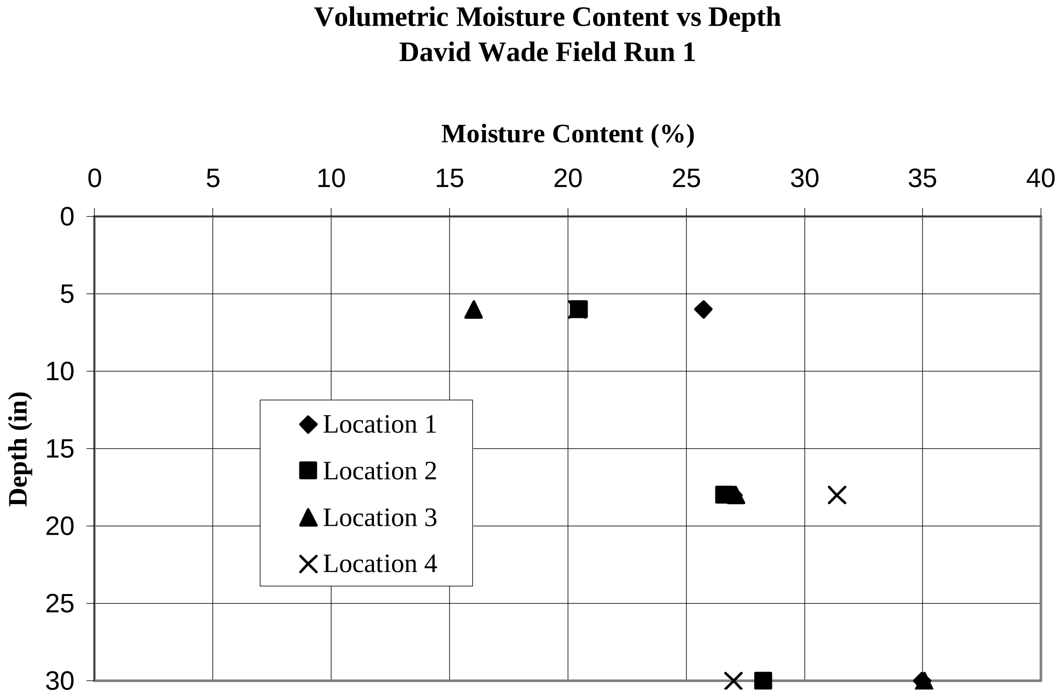


Figure 4-16. Pre-Irrigation Moisture Content for Wade Field Run 1

The moisture content analysis revealed differences between sample locations at various depths. The 6-inch depth moisture content ranged from about 16 to 26 percent. At an 18-inch depth, the soil moisture was relatively similar (27 percent) for Locations 1 through 3 and slightly higher (32 percent) for Location 4. Locations 1 and 3 had similar moisture contents (35 percent) at 30 inches, and Locations 2 and 4 had similar moisture contents (27 to 28 percent) as well. A general trend of increasing moisture content with depth was indicated by these results. As with San Acacia South Field, the pre-irrigation deficit was small, and all in the upper soil layer. Shallow groundwater interaction may have been a significant factor at this site as well.

Infiltration tests were not performed prior to the second irrigation run at Wade Field. The MRGCD ditch rider delivered irrigation water to Mr. Wade on short notice, resulting in limited time for investigators to gather preliminary data. Despite not being able to conduct infiltration tests, soil samples were collected prior to the second irrigation run on the Wade Field. Figure 4-17 shows the moisture content profiles prior to the second irrigation run at Wade Field. Although the moisture content prior to the second irrigation run was similar to that observed prior to the first irrigation run, there were slight differences. Specifically, at the 30-inch depth at

Location 4, moisture content was relatively low prior to the first irrigation run, whereas it was significantly higher prior to the second irrigation run. Presumably, this is due to moisture retention at this depth from the first irrigation. Also, soil moisture profiles were more uniform prior to the second irrigation run as compared to before the first irrigation run.

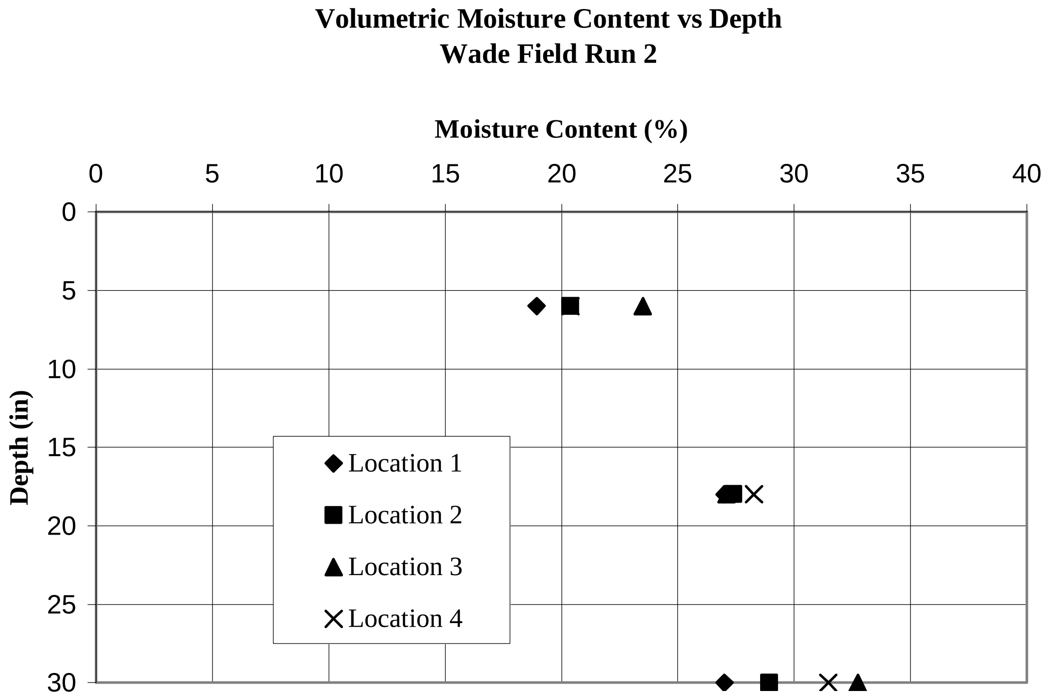


Figure 4-17. Pre-Irrigation Moisture Content for Wade Field Run 2

Table 4-5 summarizes the properties of the soil samples collected from Wade Field. The textural characteristics of the soil change with depth slightly, starting with clay loam at the surface, then loam and silty loam predominates with depth.

Table 4-5. Soil Classification and Characteristics for Wade Field

Field Classification			NRCS Soil Survey			
Sample Locations	**Sample Depth (in.)**	**Field Description**	**Layer (in.)**	**Available Water Content (in./in.)**	**Permeability (in./hr)**	**USDA Classification**
1 & 2	6	Brown Clay Loam	0-18	0.15-0.18	0.2-0.6	Clay Loam
	18	Light Brown Silty Loam	18-60	0.12-0.14	0.2-0.6	Loam
	30	Light Brown Silty Loam				
3 & 4	6	Brown Clay Loam	0-18	0.15-0.18	0.2-0.6	Clay Loam
	18	Brown Loam (Gravel Fragments)	18-60	0.12-0.14	0.2-0.6	Loam
	30	Brown Clay				

Wade Field was supplied irrigation water from the San Antonio Ditch, which is an earthen-lined conveyance canal. The check structure for the inlet supply was located approximately 2,000 feet downstream of the first supply gate and 2,600 feet downstream of the second supply gate. The water exits the supply gates directly into the Wade Field, utilizing two, 24-inch circular gates. The start time, inflow, advance time, and cutoff time were all noted for the field test. The advance time was measured for each grid point and is shown on Figure 4-18. The advance curves showed a uniform advance for the first 130-150 feet of Wade Field, with the exception of Column 4, after which the advance rate generally decreased (especially in Columns 5 and 6) and there was significant non-uniformity in advance for all columns thereafter. At a distance of about 200 feet, the advance rate began to increase again in all columns for the duration of the irrigation.

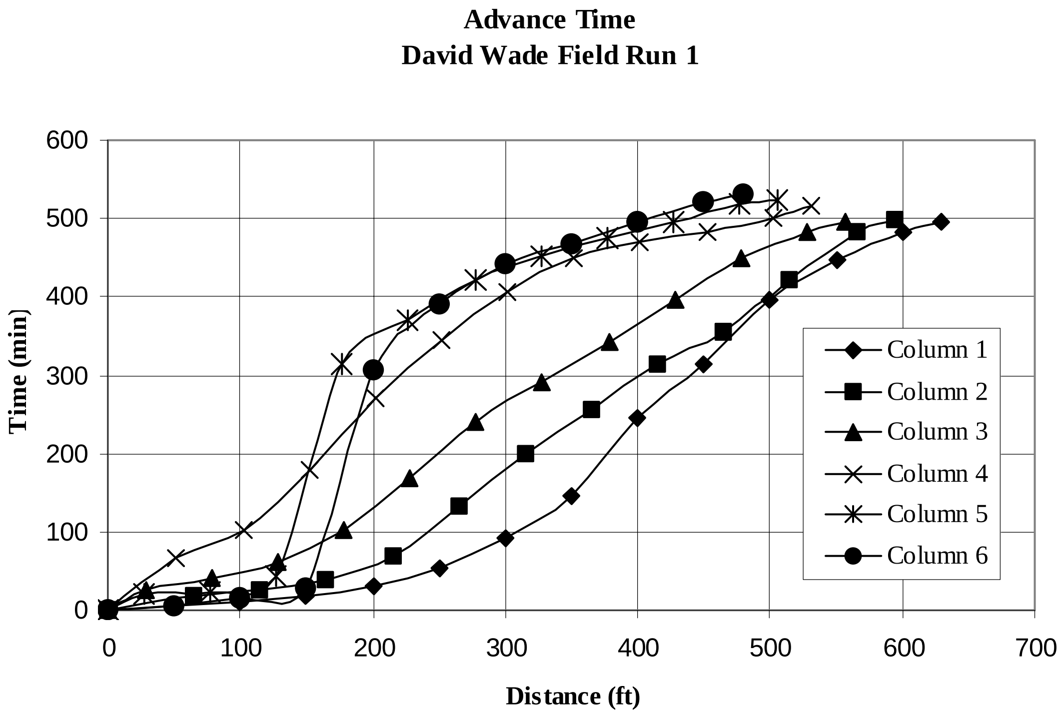


Figure 4-18. Advance Time Curves for Wade Field Run 1

Figure 4-19 shows the advance curves for the second irrigation run of Wade Field. The advance curves for the second irrigation run show a more uniform advance than that observed during the first irrigation run. The total advance time for the first irrigation run took just under nine hours, and took just over three hours for the second irrigation run.

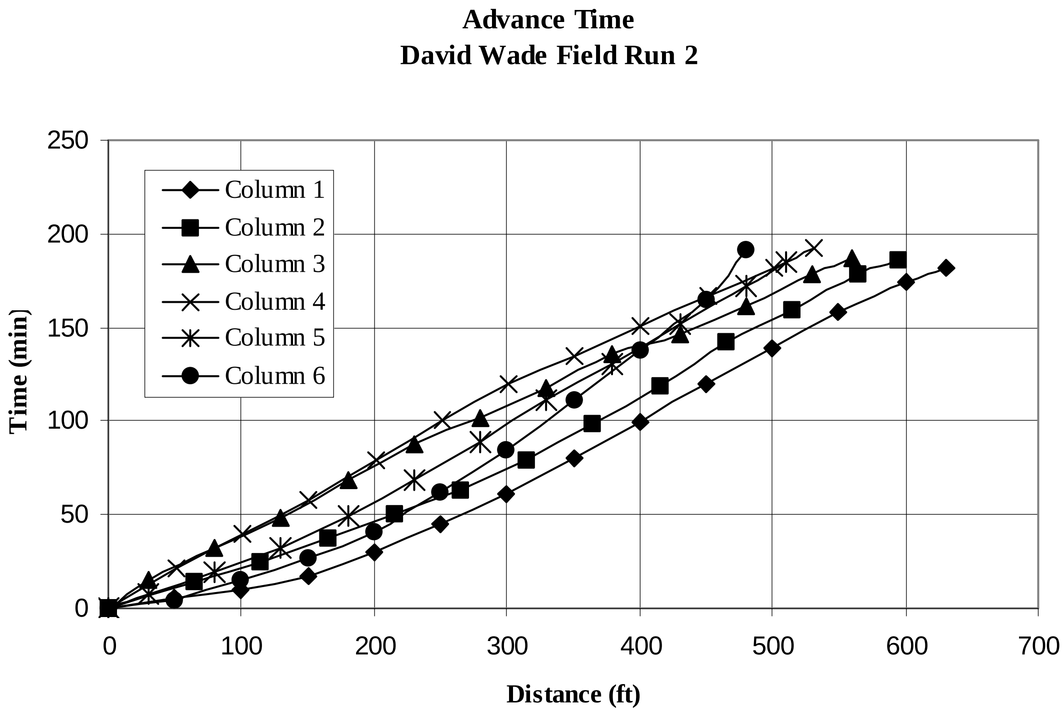


Figure 4-19. Advance Time Curves for Wade Field Run 2

Table 4-6 summarizes the soil deficit and inflow results for Wade Field.

Table 4-6. Soil Deficit and Inflow Parameters for Wade Field

Irrigation Run	Area (ac)	Soil Deficit (in.)	Inflow (ft^3)	Inflow (ac-ft)	Average Depth (in.)	AE (%)	RE (%)
1	7.24	9.90	311,785	7.16	11.86	18.7	100
2	7.26	9.90	207,179	4.76	7.86	29.9	100

During the first irrigation run at Wade Field, the inflow rate decreased substantially for a period of approximately 3 hours. During this three-hour interval, there was no irrigation flow in one of the field inlets. Figure 4-20 shows the combined inflow rate for the two inlets of the Wade Field. The flow decreases from 18.3 cfs at the start time, to a minimum of 6.2 cfs, and then increases to 21.5 cfs at cutoff time.

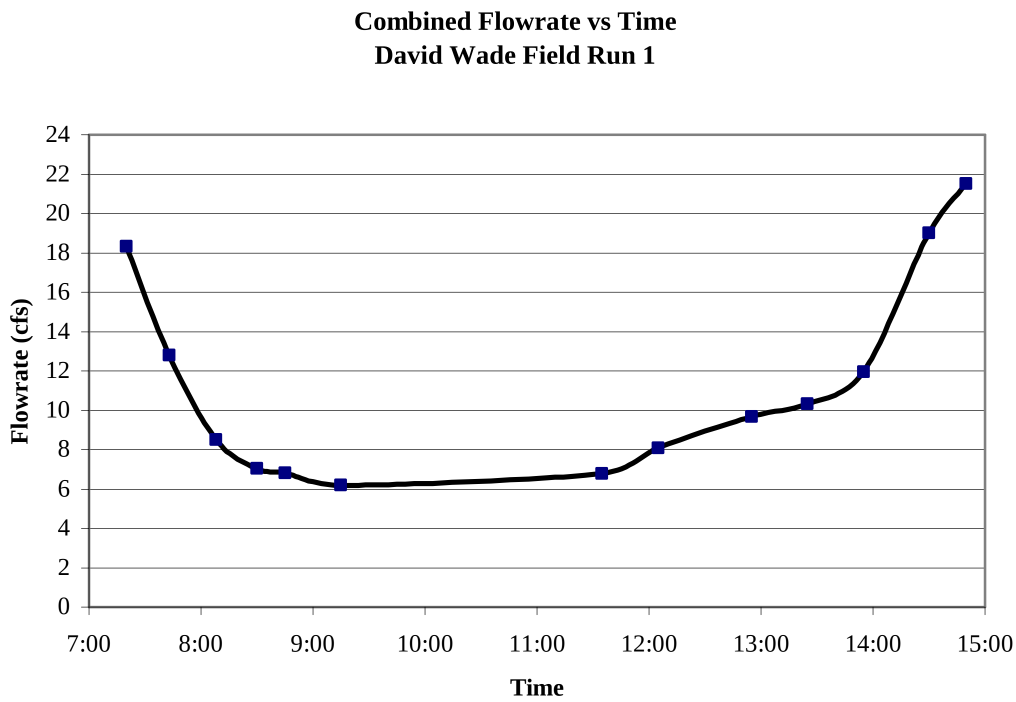


Figure 4-20. Combined Inflow Rate of Wade Field Run 1

Tables 4-6 and 4-13 present irrigation performance parameters were calculated for Wade Field. Differences can be seen in the irrigation performance parameters of Wade Field. The requirement efficiency and application efficiency for the first irrigation run at Wade Field was calculated to be 100 percent and 18.7 percent, respectively. The requirement efficiency and application efficiency for the second irrigation run at Wade Field were calculated to be 100 percent and 29.9 percent, respectively. This suggests a small pre-irrigation deficit and over watering during both runs, while the variable of head in the main canal extended advance time, further reducing uniformity. The Christiansen's Uniformity and distribution uniformity for the first irrigation run at Wade Field was calculated to be 86.5 percent and 80.0 percent, respectively. Christiansen's Uniformity and distribution uniformity for the second irrigation run of Wade Field was calculated to be 93.0 percent and 88.4 percent, respectively.

4.1.4 Harris Field

Harris Field is an alfalfa field located on the Harris Farm, owned by Dennis Harris, in San Antonio, New Mexico. Harris Farm is east of the Wade Field, directly across the county road. Harris field is approximately 900 feet wide by 650 feet long with a total acreage of approximately 14 acres. Harris Field was previously laser leveled in 2000. The survey conducted in the field by study investigators indicated that the field slope was approximately 0.075 percent. A total of nine columns and 62 grid nodes were used for the first and second irrigation runs of Harris Field. T he first irrigation run at this study field was conducted on March 17, 2004, and the second irrigation run was conducted on June 21, 2004. Appendix 4 contains pictures of Harris Field during the non-irrigation season.

Prior to the first irrigation run, infiltration characteristics were measured at four locations on the Harris Field (Figure 4-17). Figure 4-21 shows infiltration tests 1 and 4 displaying similar infiltration characteristics to each other, while infiltration characteristics observed at locations 2 and 3 were more varied. Harris Field had little presence of desiccation cracks.

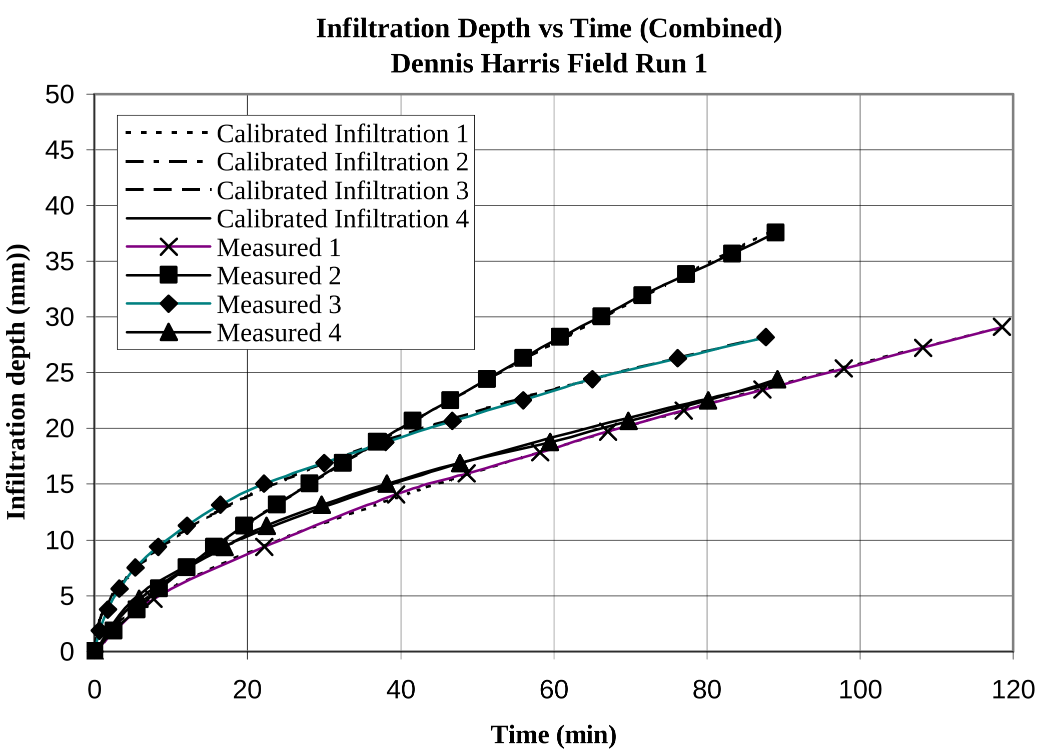


Figure 4-21. Infiltration Characteristics for Harris Field Run 1

Soil samples collected at the four locations, from 6-, 18-, and 30-inch depths, proved to be relatively different in texture. Following collection, the pre-irrigation moisture content was determined for each sample. In addition, soil textures for each sample were compared to the NRCS Soil Survey Reports to determine the type and properties of each of the soils. Figure 4-22 illustrates the volumetric moisture content of soil samples collected prior to the first irrigation run at Harris Field. Soil moisture content analysis revealed non-uniform results between sampling locations, and within each profile. While moisture content among all samples collected from the 6-inch depth were grouped between 20 and 25 percent, moisture contents varied more widely at 18 inches and 30 inches, possibly a result of differing soil types at these locations.

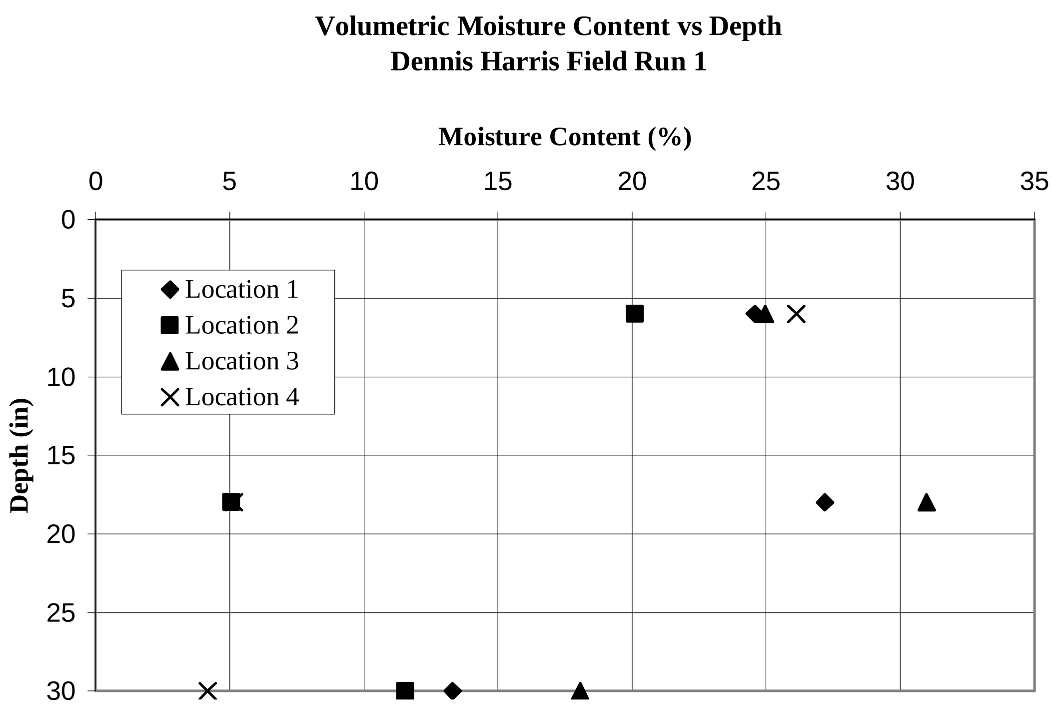


Figure 4-22. Pre-Irrigation Moisture Content for Harris Field Run 1

Two infiltration tests were performed prior to the second irrigation run at Harris Field. Figure 4-23 presents the results for these two infiltration tests, which are similar to those observed during the first irrigation run.

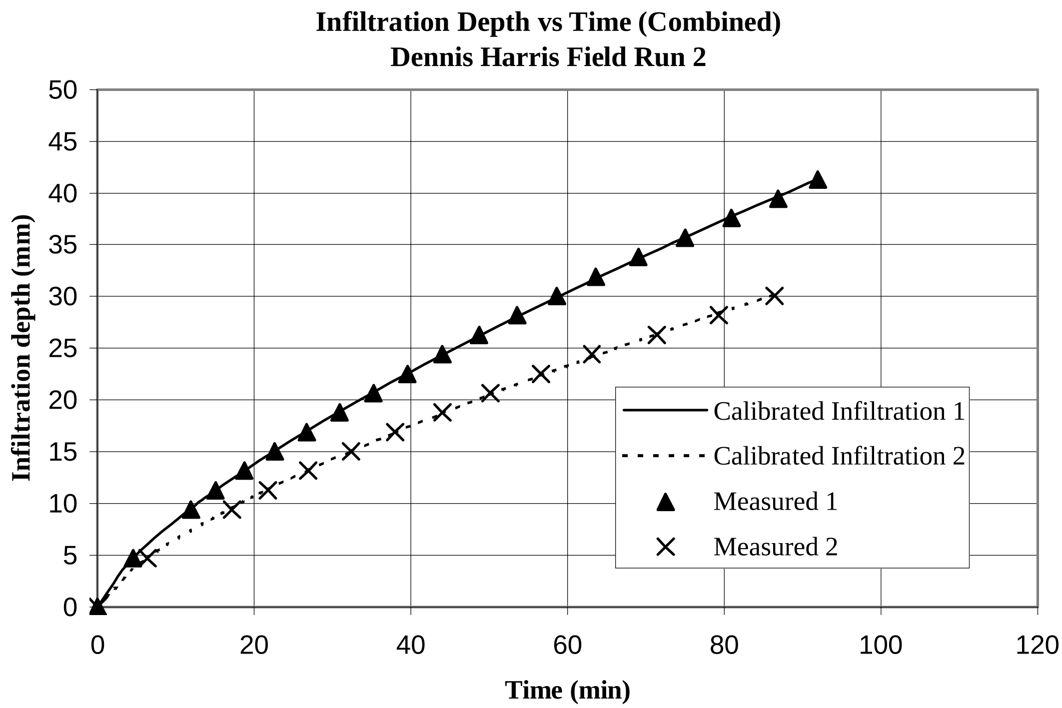


Figure 4-23. Infiltration Characteristics for Harris Field Run 2

Figure 4-24 illustrates the moisture content profiles for soil samples collected prior to the second irrigation run of Harris Field. The moisture content profiles for the second irrigation run were similar to those observed before the first irrigation run. The moisture profiles follow the same trend as those observed before the first irrigation run, except that moisture contents were slightly lower. For instance, the 6-inch depth shows a range of about 18 to 23 percent compared to 20 to 26 percent for the first irrigation run.

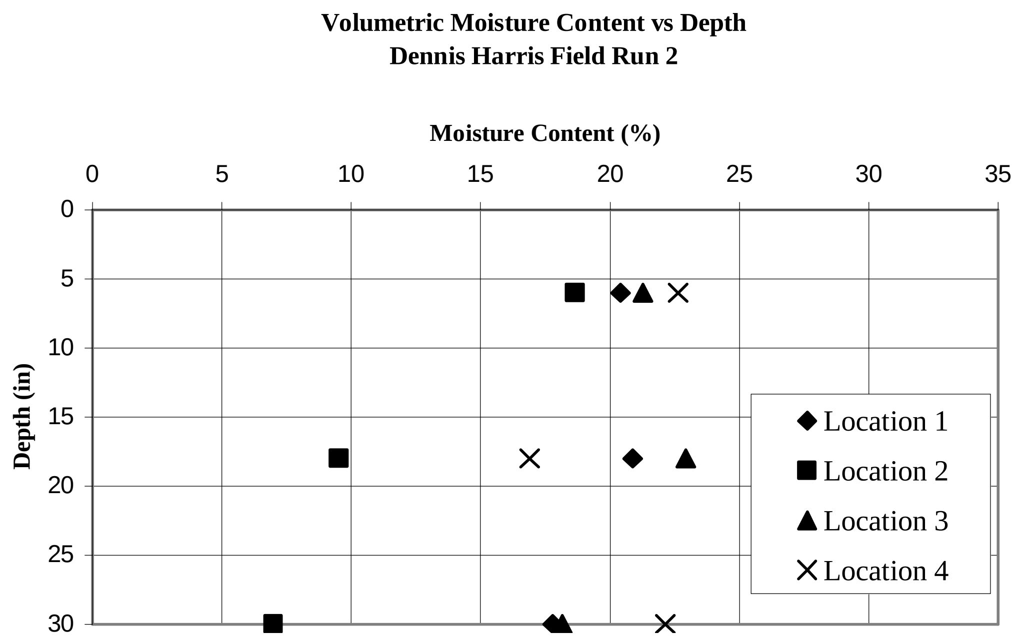


Figure 4-24. Pre-Irrigation Moisture Content for Harris Field Run 2

Table 4-7 summarizes the properties of soil samples collected at Harris Field. As noted above, soil textural characteristics varied significantly with depth. For Locations 1 and 3, the near-surface soil was a clay loam, transitioned to a sandy loam, and finally to a fine sand. At Locations 2 and 4, the surface soil was a clay loam, then abruptly transitioned to sand.

Table 4-7. Soil Classification and Characteristics for Harris Field

Field Classification			NRCS Soil Survey			
Sample Locations	**Sample Depth (in.)**	**Field Description**	**Layer (in.)**	**Available Water Content (in./in.)**	**Permeability (in./hr)**	**USDA Classification**
1 & 3	6	Brown Clay Loam	0-8	0.13-0.15	0.2-0.6	Clay Loam
	18	Light Brown Silty Loam	8-23	0.11-0.13	0.6-2.0	Sandy Loam
	30	Silty Sand	23-60	0.05-0.07	6.0-20	Fine Sand
2 & 4	6	Brown Clay Loam	0-15	0.13-0.15	<0.06	Clay Loam
	18	Med. Sand	15-60	0.03-0.08	6.0-20	Fine Sand/ Sand
	30	Med. Sand				

Irrigation water is conveyed to Harris Field by the Socorro Main Canal, which is an earthen conveyance canal. Socorro Main Canal supplies water to an on-farm, concrete-lined canal with a 30-inch circular gate. The concrete-lined canal then supplies the study field with fifteen 10-inch circular turnouts.

The advance time for the first irrigation run at Harris Field is shown on Figure 4-25. The advance curves illustrate a relatively uniform advance for Harris Field. The last advance station in Column 1 shows an increase in advance time compared to the other end points, likely due to a change in field slope in this area.

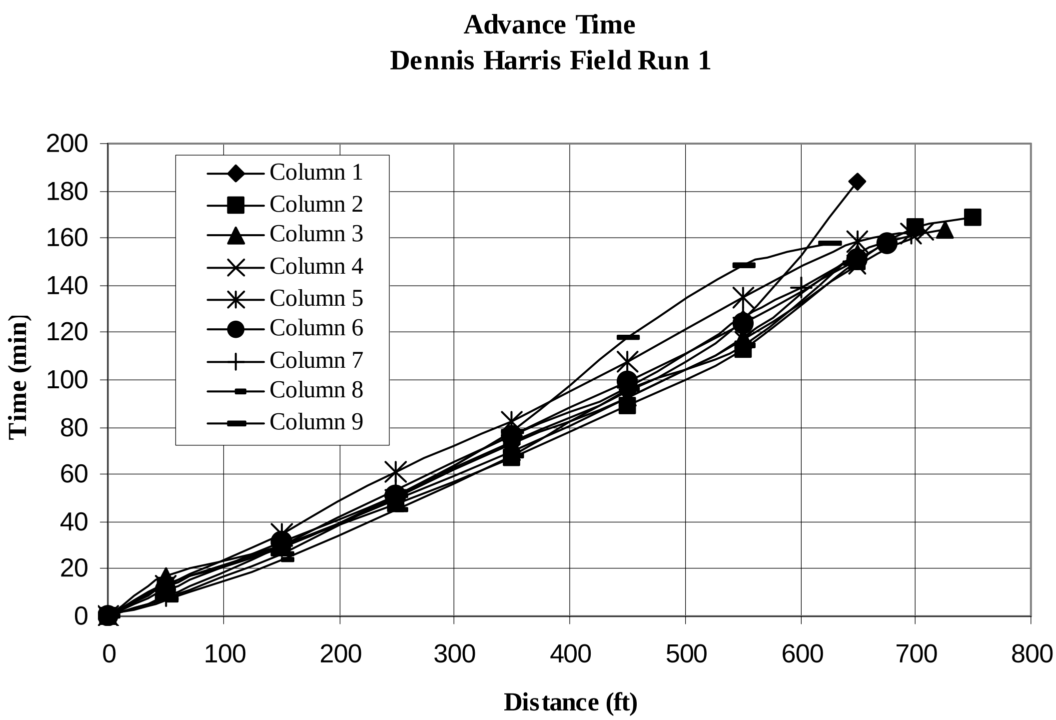


Figure 4-25. Advance Time Curves for Harris Field Run 1

Figure 4-26 shows the advance curves for the second irrigation run at the Harris Field. As observed in the first irrigation run, the advance curves for the second irrigation run show a uniform advance. However, the second irrigation run at Harris Field shows a more typical power function advance than the first irrigation run. The total advance time for the first irrigation run was just over 3 hours, while advance for the second irrigation was 5 hours. In contrast, irrigation duration for the first and second irrigation runs was 3.32 hours and 3.28 hours, respectively.

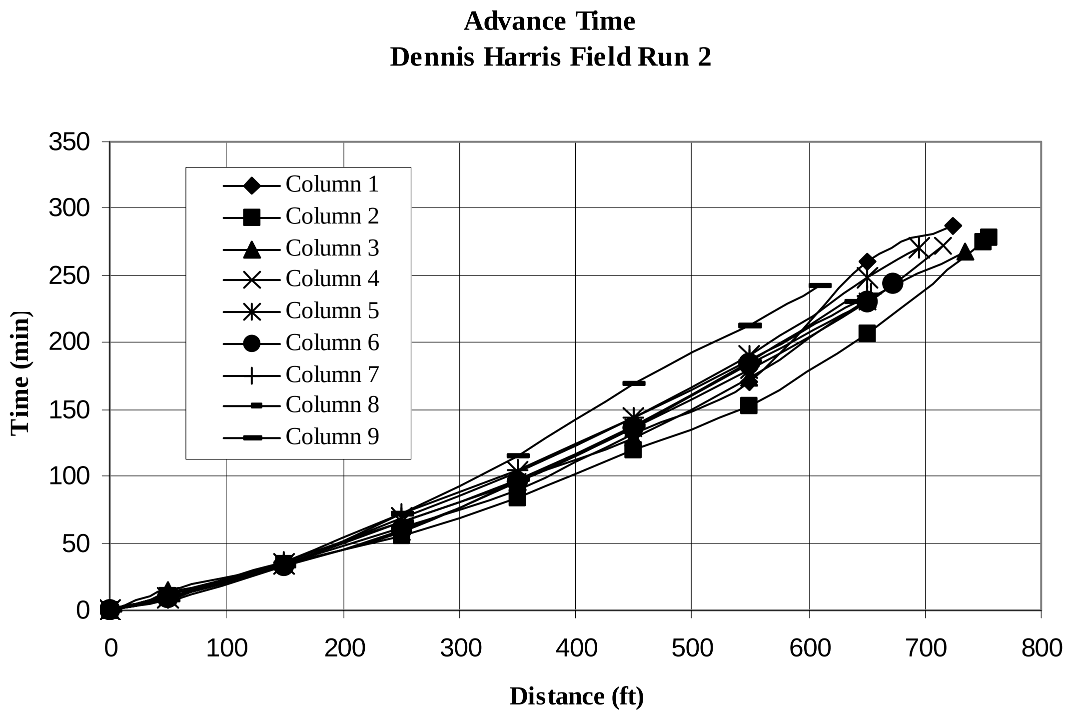


Figure 4-26. Advance Time Curves for Harris Field Run 2

Table 4-8 summarizes the soil deficit and inflow results for both irrigation runs at Harris Field. The total inflow for the second irrigation run was significantly higher than the first inflow.

Table 4-8. Soil Deficit and Inflow Parameters for Harris Field

Irrigation Run	Area (acres)	Soil Deficit (in.)	Inflow (ft^3)	Inflow (ac-ft)	Average Depth (in.)	AE (%)	RE (%)
1	13.91	0.3-6.8	265,687	6.10	5.03	53.1	100
2	13.96	1.0-5.4	340,871	7.83	6.62	33.5	100

Tables 4-8 and 4-13 present irrigation performance parameters that were calculated for Harris Field. The soil moisture deficit was highly variable in both irrigations, but the averages were similar (2.2 for the first run, 2.3 for the second. Both irrigations showed excess application, but the highly irregular pre-irrigation deficit may require over-irrigating part of the field to fully irrigate those with the higher deficit. The primary reason for the differences in deficits across the field is the variability in soil texture.

4.1.5 Candelaria Field

Candelaria Field is located on Candelaria Farm, in Albuquerque, New Mexico (Figure 4-27). The farm is owned by the City of Albuquerque Open Space Division and leased to Scott Rasband for contract farming. Candelaria Field is an alfalfa field that was last laser leveled in 2002. The laser-leveled field is approximately 200 feet wide by 600 feet long, with a total area of approximately 3.5 acres. Based upon interviews with the farmer, two basins were initially thought to be within the irrigated area and would be irrigated at the same time. Once field surveying and preliminary tests had been accomplished, the irrigator informed the investigators that he would irrigate only one basin at a time. This resulted in only two columns of advance stations being placed on each of the basins. Although the investigators intended to conduct separate irrigation efficiency evaluations on both of the surveyed basins, this was impossible due to water escaping the first basin into the nearby basin. Since the volume of water that escaped was unknown, an accurate measure of irrigation parameters would not have been possible. The first irrigation run at this study field was conducted on July 21, 2004, and the second irrigation run was conducted on August 15, 2004. Appendix 5 contains pictures of Candelaria Field.

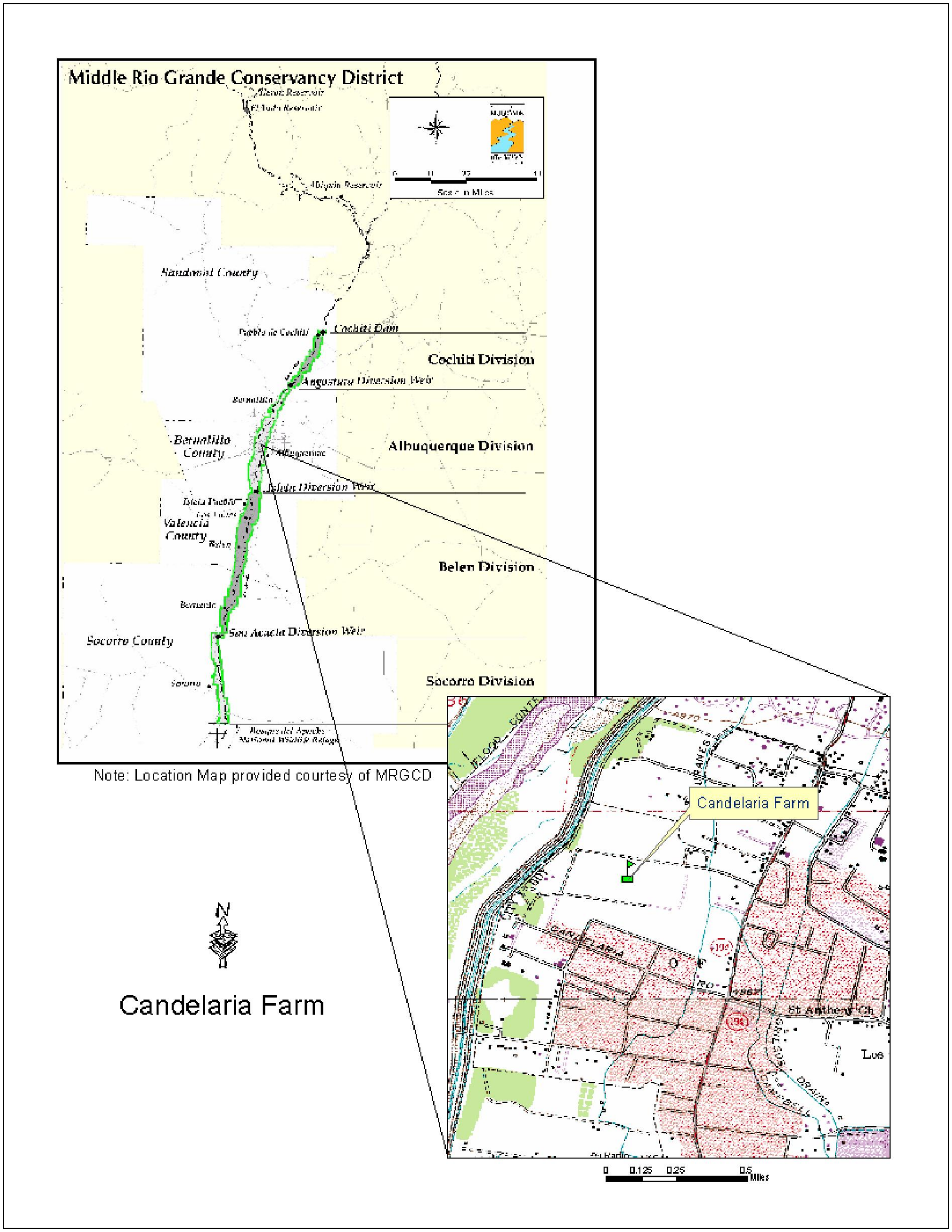


Figure 4-27. Location of Candelaria Farm

Infiltration characterization was measured at two locations on Candelaria Field and the results of these analyses are illustrated on Figure 4-28. The infiltration characteristics were significantly different at each of these two locations. At Location 1, relatively slow infiltration was observed, while infiltration at Location 2 was relatively rapid. The Candelaria Field contained a large number of desiccation cracks on its surface and avoidance of such discontinuities proved very difficult for the infiltration tests. These cracks likely increased the infiltration rate observed in the second infiltration test.

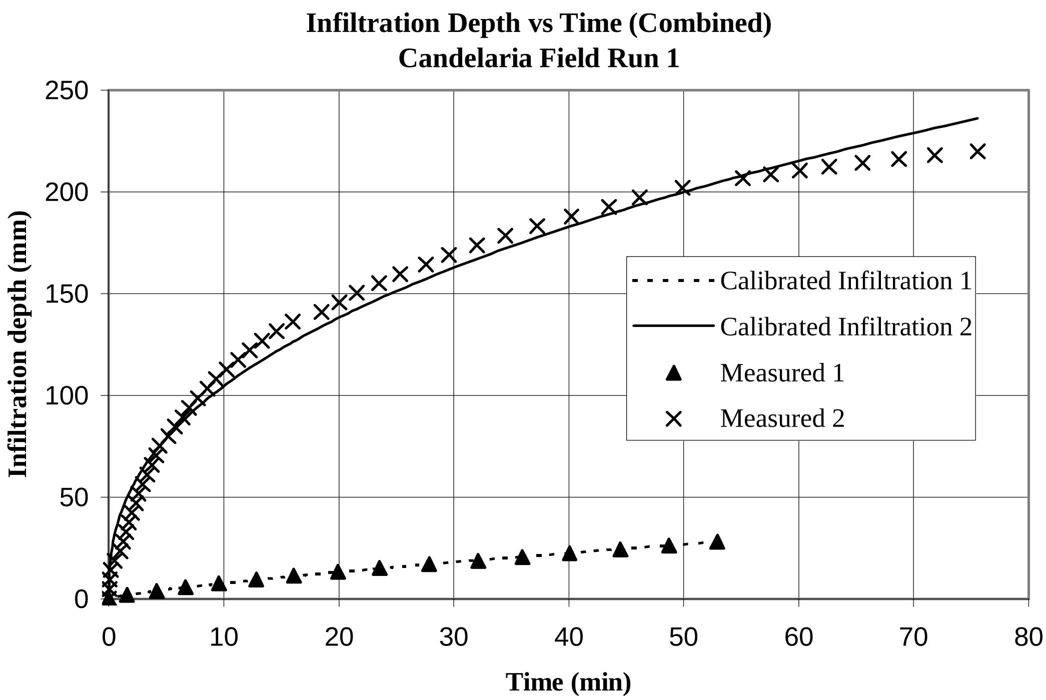


Figure 4-28. Infiltration Characteristics for Candelaria Field Run 1

Soil samples collected at the same locations as the two infiltration tests, at 6-, 18-, and 30-inch depths, were similar in texture to each other. Pre-irrigation moisture content was determined for each of the collected soil samples. Soil textures of the soil samples were also compared to the NRCS Soil Survey Reports to determine the type and properties of each of the soils. Figure 4-29 illustrates the volumetric moisture content of soil collected prior to the first irrigation at Candelaria Field.

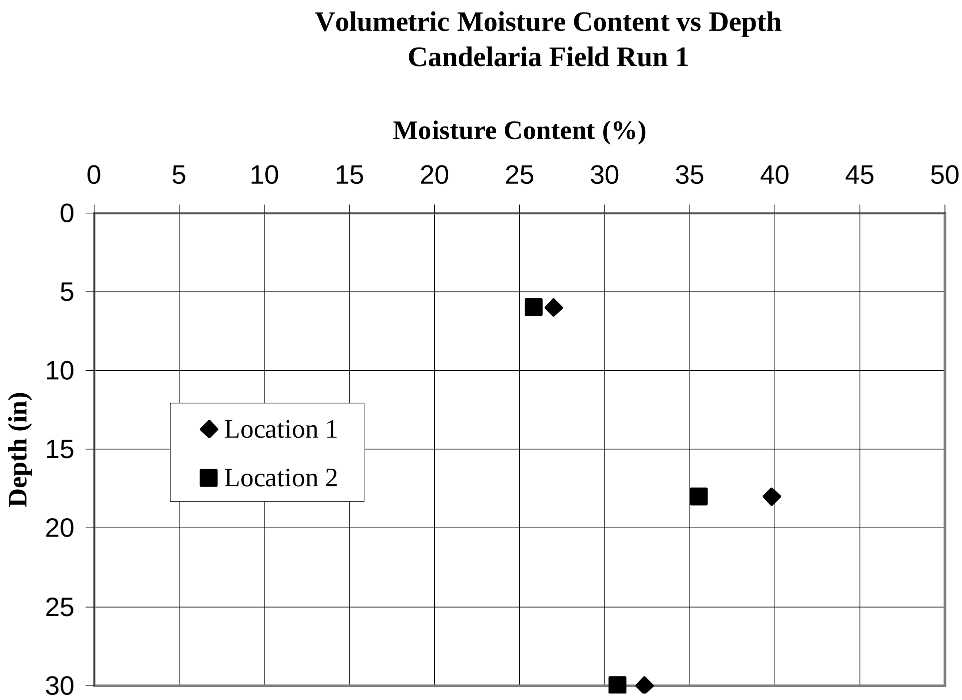


Figure 4-29. Pre-Irrigation Moisture Content for Candelaria Field Run 1

The moisture content analyses revealed very similar results for each of the sample locations, with slight variation within each soil profile. The 6-inch depth moisture content for the both profiles is about 26 percent, while at the 18-inch depth, the moisture increases to about 35 to 40 percent; the moisture content then drops to about 32 percent at a 30-inch depth.

Unfortunately, no infiltration tests could be performed for the second irrigation run at the Candelaria Field. Irrigator schedule changes resulted in a limited amount of time to perform pre-irrigation data collection. Results from the moisture content analysis of soil samples collected at the Candelaria Field prior to the second irrigation run are presented on Figure 4-30. As was observed prior to the first irrigation run, the moisture content profiles at each sample location are similar to each other at the 6- and 18-inch depths. However, at the 30-inch depth, the moisture contents vary significantly between the two locations. Between irrigation runs, the moisture profiles appear to vary significantly, with a general decrease in water content at 18 inches before the second irrigation run at both locations.

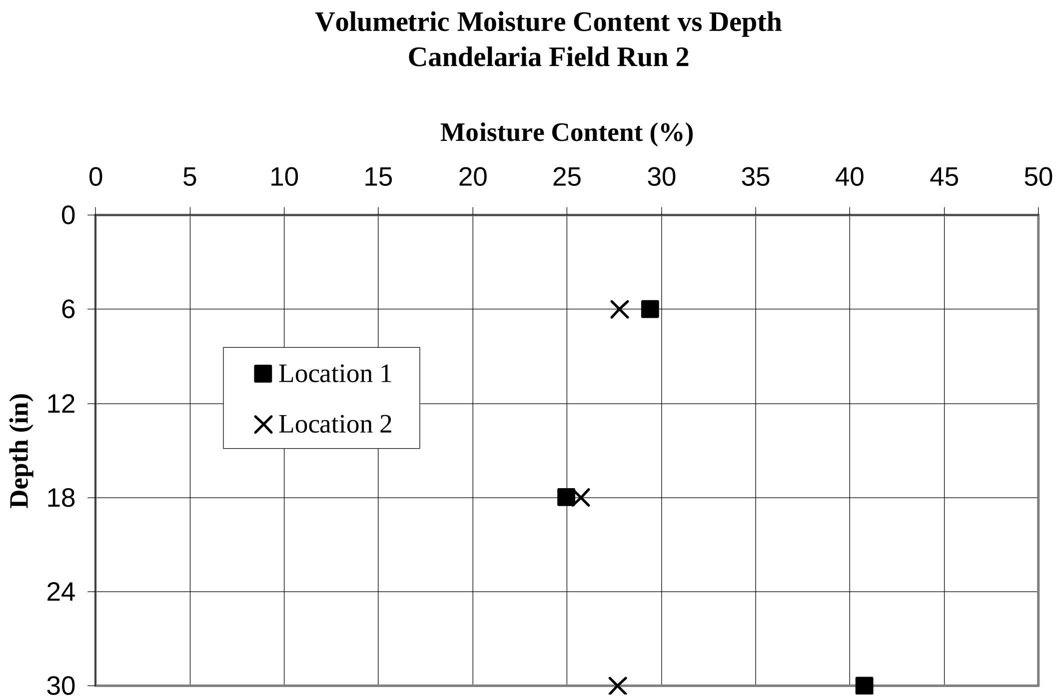


Figure 4-30. Pre-Irrigation Moisture Content for Candelaria Field Run 2

Table 4-9 summarizes the properties of the soil samples collected at Candelaria Field. The textural characteristics of the soil change slightly with depth, beginning with clay loam near the surface, then transitioning to a silty loam deeper in the profile. There are no significant changes in permeability for the soil layers in the profile.

Table 4-9. Soil Classification and Characteristics for Candelaria Field

Field Classification			NRCS Soil Survey			
Sample Locations	**Sample Depth (in.)**	**Field Description**	**Layer (in.)**	**Available Water Content (in./in.)**	**Permeability (in./hr)**	**USDA Classification**
1 & 2	6	Brown Clay Loam	0-6	0.16-0.20	0.2-0.6	Clay Loam/Loam
	18	Light Silty Loam	8-23	0.19-0.21	0.2-0.6	Silt Loam
	30	Light Silty Loam	23-60	0.19-0.21	0.2-0.6	Silt Loam

Candelaria Field is supplied by the Duranes Canal, an earthen supply canal that supplies water to an on-farm, concrete-lined canal with a 24-inch circular gate. The lined canal then supplies the study field with two, 10-inch-diameter turnouts. Figure 4-31 illustrates the advance time for the first irrigation run at Candelaria Field. The advance curves indicate a relatively uniform advance for Candelaria Field, although the advance curves deviate from each other toward the end of the field. This result is typical for advance curves in a basin system.

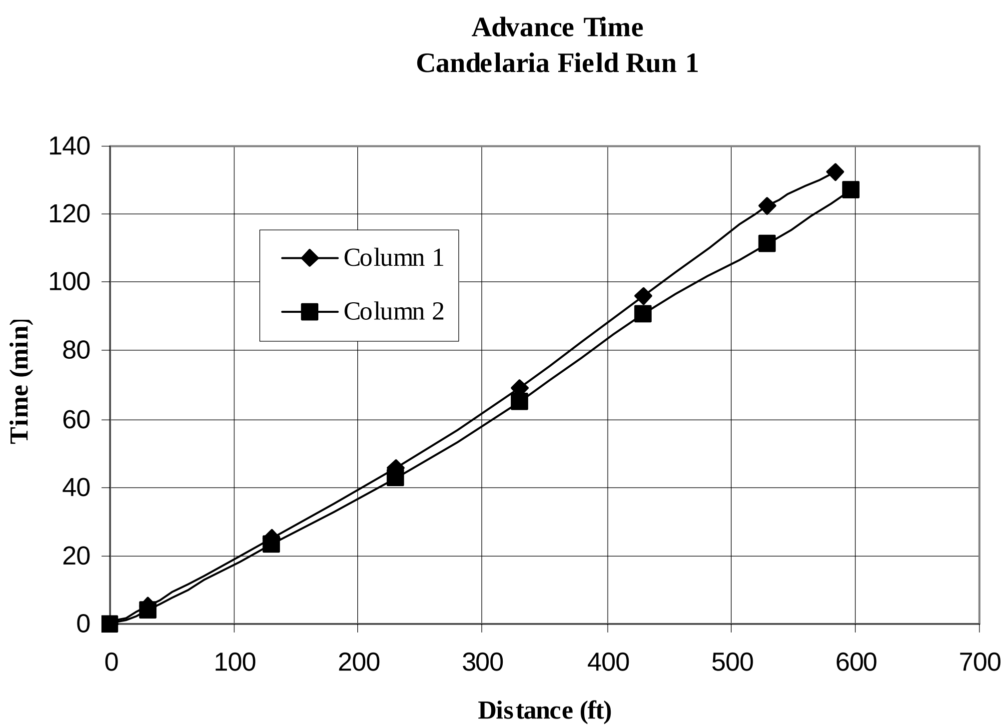


Figure 4-31. Advance Time Curves for Candelaria Field Run 1

Figure 4-32 illustrates the advance curves for the second irrigation run at Candelaria Field. As observed in the first irrigation run, the advance curves for the second irrigation run show a uniform advance. The total advance time for both irrigation runs was just over two hours.

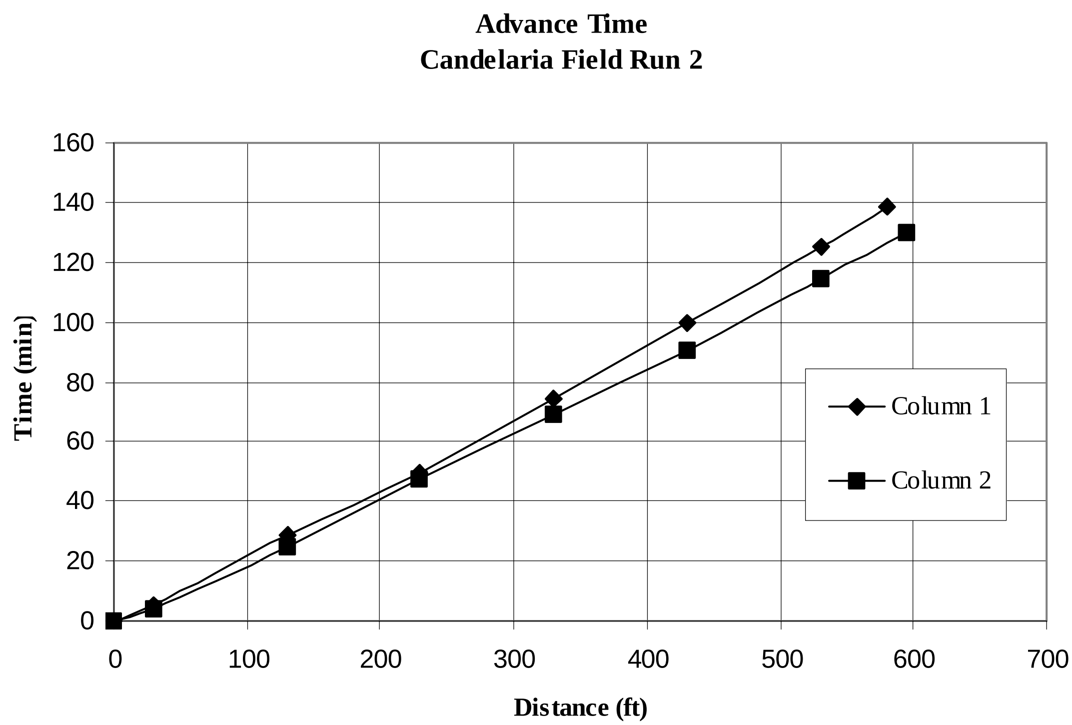


Figure 4-32. Advance Time Curves for Candelaria Field Run 2

Table 4-10 summarizes the soil deficit and inflow results for the Candelaria Field irrigation runs. Notably, the total inflow for the second irrigation run is slightly higher than the first inflow.

Table 4-10. Soil Deficit and Inflow Parameters for Candelaria Field

Irrigation Run	Area (acres)	Soil Deficit (in.)	Inflow (ft^3)	Inflow (ac-ft)	Average Depth (in.)	AE (%)	RE (%)
1	3.53	4.5-6.0	84,401	1.94	6.59	79.6	100
2	3.51	2.8-8.8	92,280	2.12	7.24	80.2	100

Tables 4-10 and 4-13 present irrigation performance parameters that were calculated for Candelaria Field. This site demonstrates the upper end of achievable application efficiency for a full irrigation. Not only does it have the advantage of a low intake surface soil layer, it is also a relatively small field with high inflow and a well-timed cutoff.

4.1.6 Hubble-Oxbow Field

Hubble-Oxbow Field is an alfalfa/sorghum field located on the Hubble-Oxbow Farm in Albuquerque, New Mexico (Figure 4-33), owned by the City of Albuquerque Open Space Division, and leased to Leo Rizzo for contract farming. The field is approximately 135 feet wide and 850 feet long, with a total area of approximately 2.5 acres. Prior to the study, Hubble-Oxbow Field had not been leveled within recent memory, according to the irrigator and City of Albuquerque Open Space Division personnel. A total of five columns and 47 grid nodes were used for the first and second irrigation runs at Hubble-Oxbow Field. The first irrigation run at this study field was conducted on June 7, 2004, and the second irrigation run was conducted on August 23, 2004. Appendix 6 contains pictures of the Hubble-Oxbow Field.

Prior to the first irrigation run, infiltration characteristics were measured at two locations on the Hubble-Oxbow Field. Figure 4-34 illustrates the results for these infiltration tests. The infiltration rate at Location 1 was significantly slower than at Location 2.

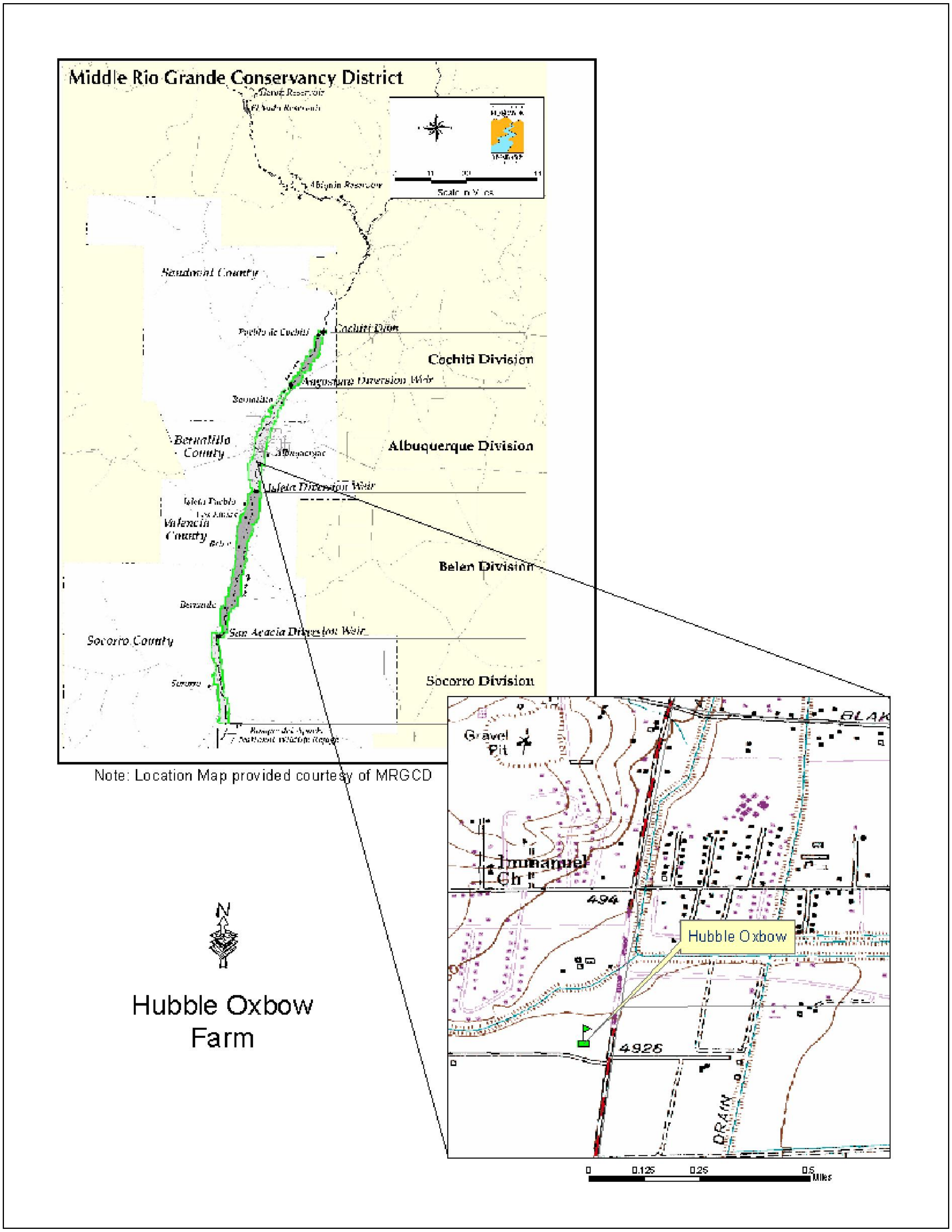


Figure 4-33. Location of Hubble-Oxbow Farm

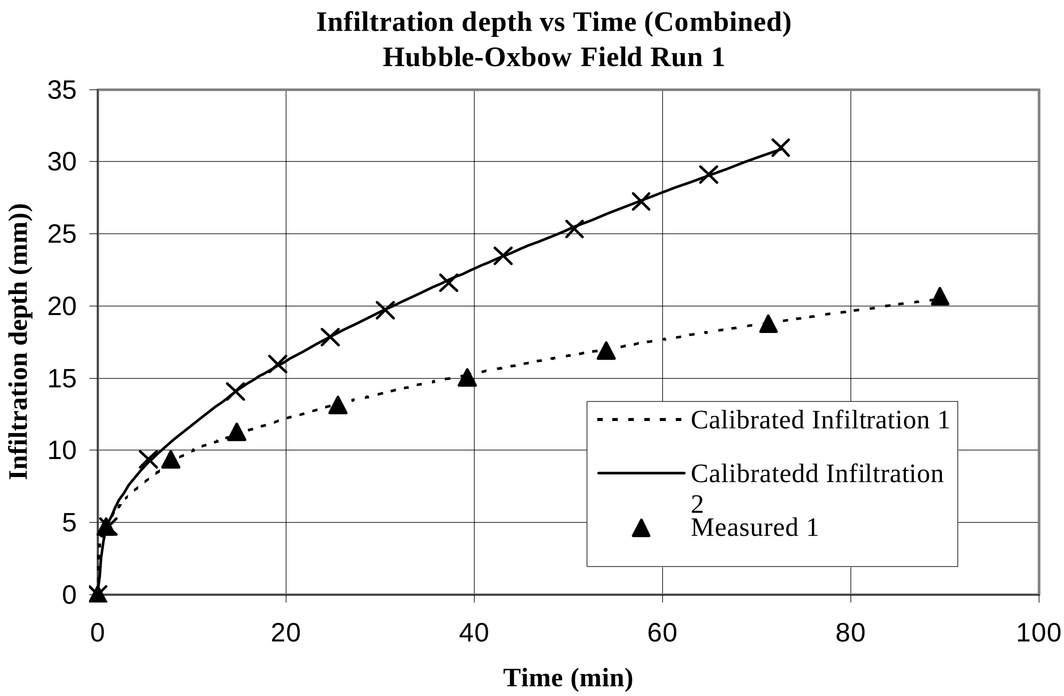


Figure 4-34. Infiltration Characteristics for Hubble-Oxbow Field Run 1

The pre-irrigation volumetric moisture content was determined for soil samples collected from 6-, 18-, and 30-inch depths at each of the two sample locations. The textures of the soil samples were also compared to the NRCS Soil Survey Reports to determine the type and properties of each of the soils. Figure 4-35 shows the volumetric moisture content for soil samples collected prior to the first irrigation run at Hubble-Oxbow Field. The moisture content results indicated slightly different results for the two soil profiles. At both locations the moisture content was approximately the same at the 6- and 18-inch depths, but at 30 inches, the moisture content increased from about 19 percent to about 26 percent at Location 1, while at Location 2 moisture content decreased from about 21 percent to about 10 percent.

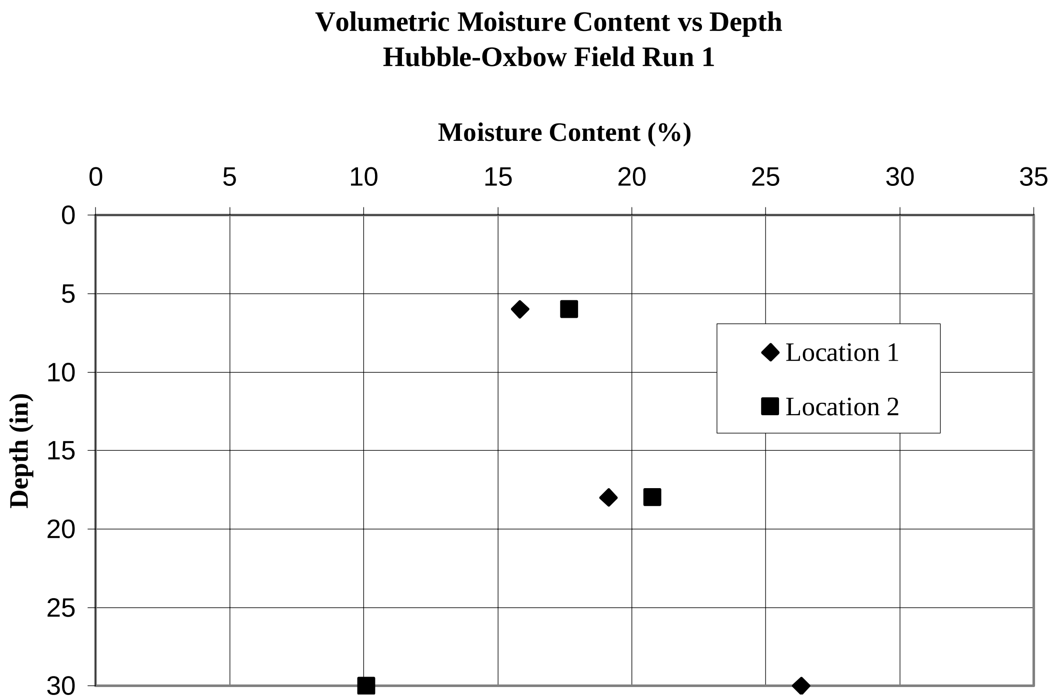


Figure 4-35. Pre-Irrigation Moisture Content for Hubble-Oxbow Field Run 1

Infiltration tests and moisture content analysis also were performed for the second irrigation run at the Hubble-Oxbow Field. Figure 4-36 illustrates the infiltration results for the second irrigation run at Hubble-Oxbow Field, which were significantly different from the results observed during the first irrigation run at this location. As for other fields in the study, the presence of numerous desiccation cracks caused problems in obtaining accurate vertical infiltration rates for the Hubble-Oxbow Field.

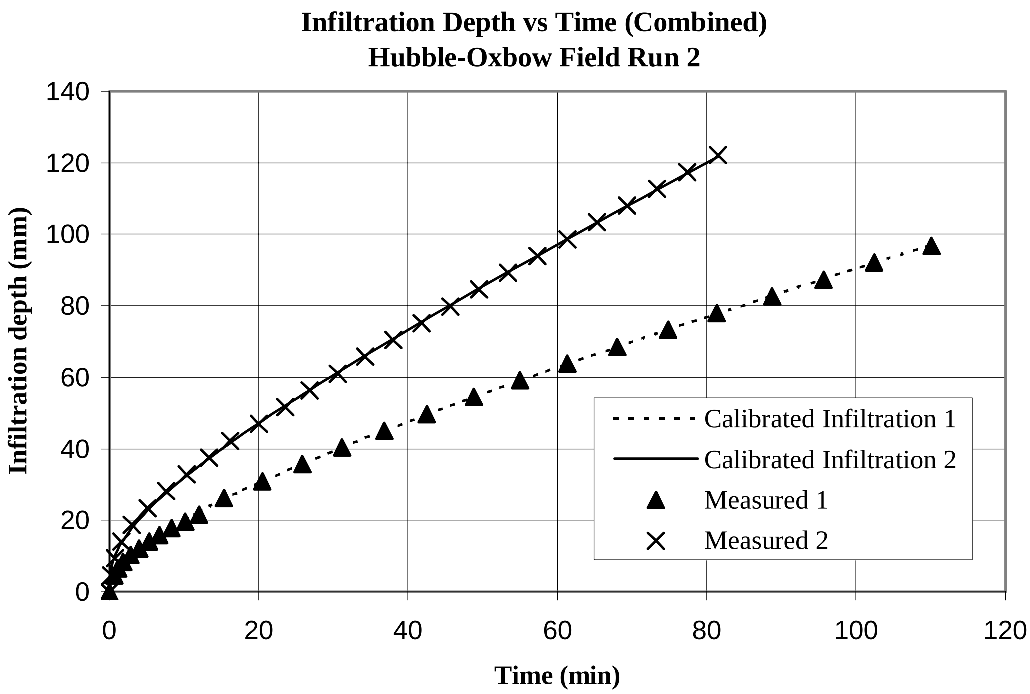


Figure 4-36. Infiltration Characteristics for Hubble-Oxbow Field Run 2

Figure 4-37 shows the moisture content for both locations prior to the second irrigation run at Hubble-Oxbow Field. The moisture content for the second irrigation run was similar to the first irrigation run. In general, moisture contents at almost all depths in both locations were slightly lower prior to the second irrigation run as compared to the first irrigation run.

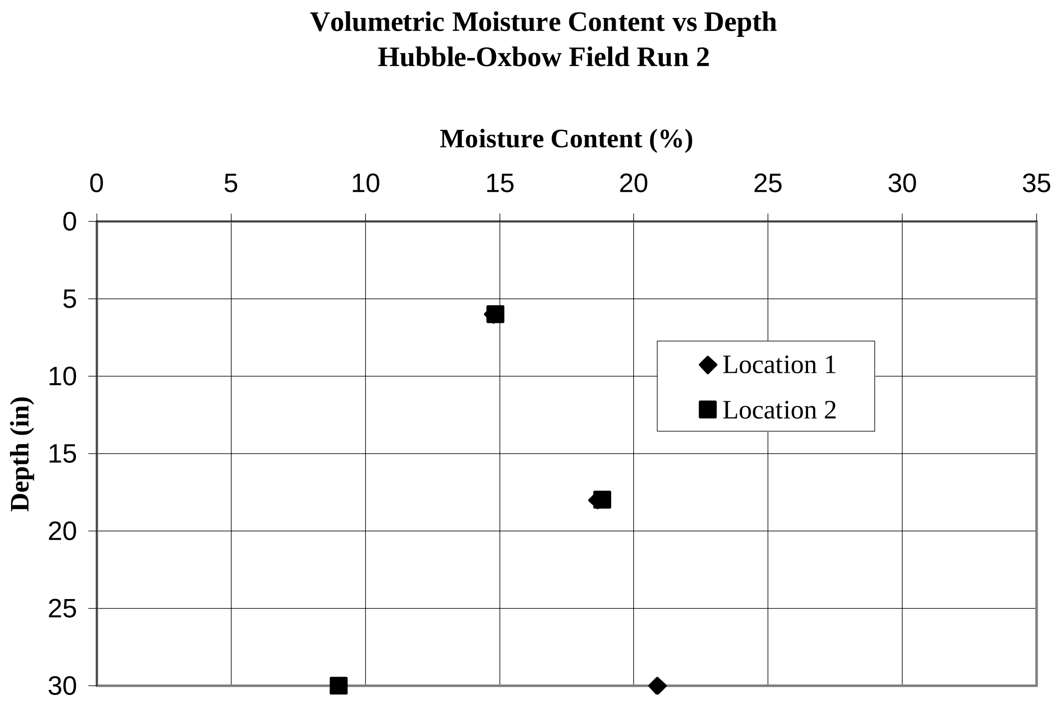


Figure 4-37. Pre-Irrigation Moisture Content for Hubble-Oxbow Field Run 2

Table 4-11 summarizes the soil textures among soil samples collected from Hubble-Oxbow Field. Soil textures from this location were compared to the NRCS Soil Survey Reports to determine properties of the soils. The textural characteristics of the soil were observed to change with depth, beginning with a sandy loam containing some organic matter near the surface, to a sandy loam with little organic matter, then to sand.

Table 4-11. Soil Classification and Characteristics for Hubble-Oxbow Field

Field Classification			NRCS Soil Survey			
Sample Location	Sample Depth (in.)	Field Description	Layer (in.)	Available Water Content (in./in.)	Permeability (in./hr)	USDA Classification
1	6	Brown Sandy Loam	0-8	0.19-0.21	0.2-0.6	Silt Loam
	18	Light Brown Sandy Loam	8-24	0.19-0.21	0.2-0.6	Clay Loam
	30	Sandy Silt	24-60	0.05-0.07	6-20	Sand
2	6	Brown Sandy Loam	0-18	0.19-0.21	0.2-0.6	Silt Loam
	18	Light Brown Sandy Loam	18-24	0.19-0.21	0.2-0.6	Clay Loam
	30	Sand	24-60	0.05-0.07	6-20	Sand

Hubble-Oxbow Field is supplied by the Gun Club Canal, which is a small earth lined lateral. Initially, the Gun Club Canal supplies an on-farm, concrete-lined canal from a 24-inch circular gate. Once in the concrete-lined canal, the water is supplied to multiple earthen- lined canals. From the earthen-lined canals, the field was supplied directly using three, 12-inch-diameter turnouts.

Advance time was measured for each grid point and is illustrated on Figure 4-38. Generally, the advance curves indicate a non-uniform advance for the first irrigation run of Hubble-Oxbow Field, although Columns 1 through 3 show a more uniform advance than Columns 4 and 5. As well, Columns 1 through 3 also show a higher advance rate compared to the other two columns. Hubble-Oxbow Field was divided into two basins and both were irrigated at the same time. Columns 1 through 3 were located in the western basin, and Columns 4 and 5 were located in the eastern basin. Of the three supply turnouts, two were located on the western basin and one was located on the eastern basin. As indicated by negative slopes along the advance curves, several grid points in Columns 4 and 5 were inundated ahead of the irrigation advance in these columns by water that had escaped from adjacent columns.

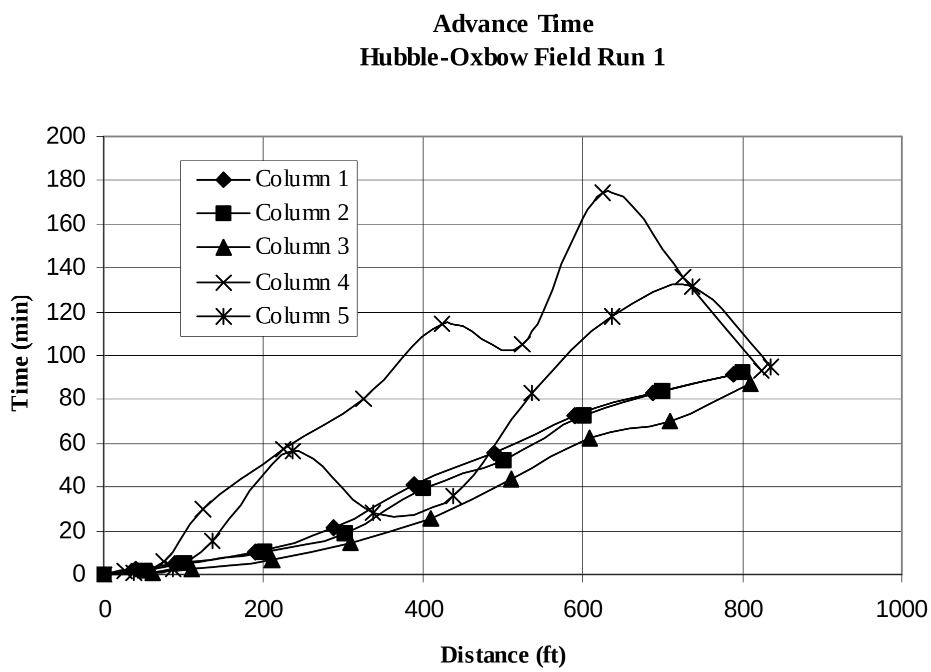


Figure 4-38. Advance Time Curves for Hubble-Oxbow Field Run 1

Figure 4-39 shows the advance curves for the second irrigation run of Hubble-Oxbow Field. The advance curves for the second irrigation run show a similar advance as the first irrigation run. There was no separation at the end of the basins. The total advance time for the first irrigation run was just under three hours, while advance time for the second irrigation run was just under four hours. As in the first irrigation run, several grid points in Columns 4 and 5 were inundated ahead of the irrigation advance in these columns by water flowing laterally from adjacent columns.

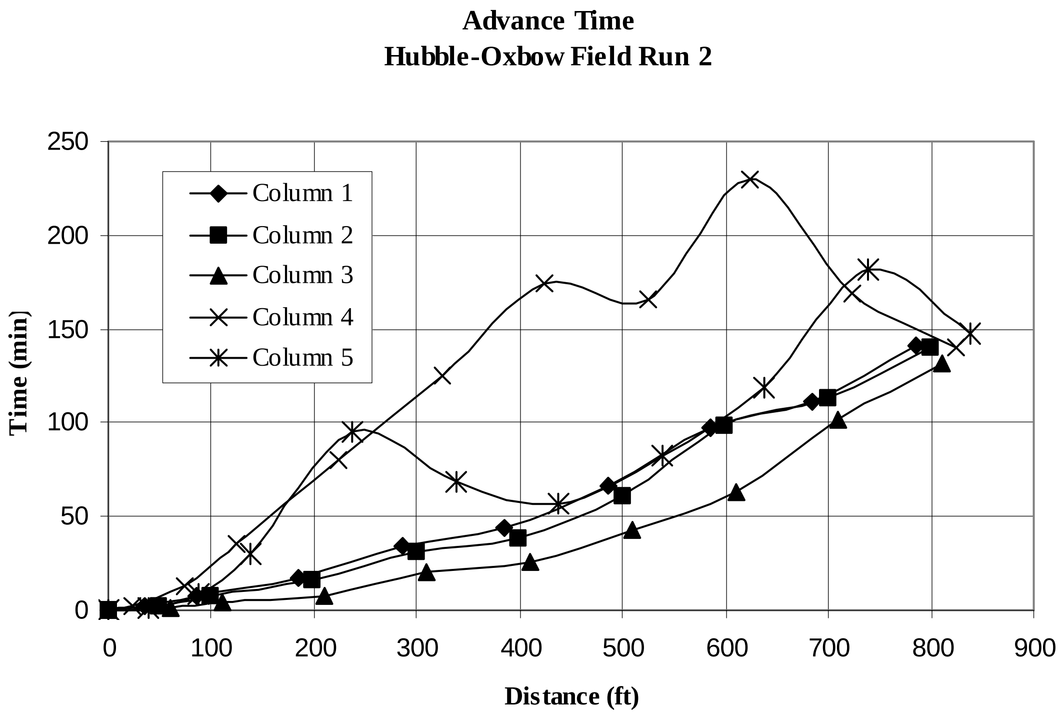


Figure 4-39. Advance Time Curves for Hubble-Oxbow Field Run 2

Table 4-12 summarizes the soil deficit and inflow results for Hubble-Oxbow Field. Since the Hubble-Oxbow Field was directly supplied irrigation water by an earthen canal, the flow rate was measured at the farm head gate to determine water loss between the head gate and field turnout. The flow rate at the farm head gate was measured to be 14.6 cfs for the first irrigation run. Two fields were being irrigated at the same time during the first irrigation run. One of the fields was the study field, while the other field was located at the opposite end of the farm. The flow rate measured for the study field during the first irrigation run was approximately 3.9 cfs, while inflow rate for the other field was approximately 3.5 cfs. Notably, the on-farm conveyance canal was observed to be leaking somewhat during the first irrigation run. This results in 51 percent conveyance efficiency for the Hubble-Oxbow Field during the first irrigation run (i.e., approximately 49 percent of the total water diverted from the Gun Club Lateral Canal was lost to on-farm conveyance leakage and seepage). Assuming a canal diversion period of 3.28 hours—a very conservative estimate of the actual period of time water was diverted on-farm from the Gun Club Lateral Canal—the total volume of water diverted on-farm during the first irrigation run was approximately 3.96 ac-ft. As mentioned above, the study field and another field there were being irrigated during the first irrigation run, and the respective field inflow rates were 3.9 and 3.5 cfs, respectively. Based on these inflow rates, we can assume that 52 percent of the water diverted from the Gun Club Lateral Canal to the Hubble-Oxbow Farm was intended for the study field. In terms of volume of water diverted from the Gun club Lateral Canal to on-farm conveyance per irrigated area of the study field (2.56 acres), this results in approximately 0.8 ac-ft/acre for the first irrigation run at the Hubble-Oxbow Field.

Table 4-12. Soil Deficit and Inflow Parameters for Hubble-Oxbow Field

Irrigation Run	Area (acres)	Soil Deficit (in.)	Inflow (ft^3)	Inflow (ac-ft)	Average Depth (in.)	AE (%)	RE (%)
1	2.56	5.3-6.1	46,529	1.07	5.01	87.4	77.1
2	2.58	5.4-7.2	48,191	1.10	5.15	92.7	75.5

Only the study field was irrigated during the second irrigation run, but significant on-farm conveyance leakage was occurring during the irrigation event (more leakage than was observed in the first irrigation run). During the second irrigation, the inflow at the farm head gate was measured to be 14.2 cfs, while the average inflow rate at the study field was 3.2 cfs, resulting in 23 percent conveyance efficiency for the second irrigation run of the Hubble Field (i.e., 78 percent of diverted water was lost to on-farm conveyance seepage and leakage). Assuming a canal diversion period of 4.22 hours—a very conservative estimate of the actual period of time water was diverted on-farm from the Gun Club Lateral Canal—the total volume of water diverted on-farm during the second irrigation run was approximately 4.95 ac-ft. In terms of volume of water diverted on-farm per irrigated area (2.58 acres), this results in approximately 1.92 ac-ft/acre for the second irrigation run at the Hubble-Oxbow Field.

Tables 4-12 and 4-13 present irrigation performance parameters that were calculated for Hubble-Oxbow Field. As indicated by the performance parameters for both irrigation runs, the two runs were quite similar in terms of pre-irrigation deficit, application efficiency, and requirement efficiency. The high application efficiency (in spite of the irregular advance) results from deficit irrigation and a comparatively large pre-irrigation deficit. The low uniformities reflect the effect of the irregular advance. Full irrigation on this field would likely result in a significantly reduced application efficiency. The irrigator appears to have good control of applied volume, as the average applied depth in both cases was approximately five inches.

4.1.7 Performance Parameter Results

Table 4-13 summarizes the irrigation performance parameters for the 12 irrigation efficiency evaluations conducted as part of this study, and these results will be referred to throughout the following discussion section. Application efficiencies at the study fields ranged from 15.7 percent to 96.8 percent, and requirement efficiencies ranged from 75.5 to 100 percent. Among the study fields, deep percolation percentage ranged from 7.3 to 84.3 percent. Runoff percentage, only calculated for Harris Field where runoff occurred during the study, was 4.3 percent and 1.6 percent for the first and second irrigation runs at this location, respectively. Among the study fields, Christiansen's uniformity and distribution uniformity ranged from 59.7 to 95.4 percent and 53.9 to 92.1 percent, respectively.

Table 4-13. Irrigation Performance Parameters for Study Fields within the MRGCD

Location/Run	AE (%)	RE (%)	DPP (%)	RP (%)	C.U. (%)	DU (%)	Average d_r (in.)	$\bar{d}$ (in.)
San Acacia North/1	51.6	100.0	48.4	0.0	90.5	80.9	5.9	11.4
San Acacia North/2	96.8	84.0	21.6	0.0	79.9	63.0	6.2	5.4
San Acacia South/1	15.7	100.0	84.3	0.0	95.4	92.1	1.4	9.1
San Acacia South/2	21.7	100.0	78.3	0.0	91.4	84.7	1.9	8.6
Wade/1	18.7	100.0	81.3	0.0	85.6	80.0	2.2	11.9
Wade/2	29.9	100.0	70.1	0.0	93.0	88.4	2.3	7.8
Harris/1	53.1	100.0	42.5	4.3	62.7	60.6	2.8	5.0
Harris/2	33.5	100.0	64.9	1.6	60.0	55.2	2.3	6.6
Candelaria/1	79.6	100.0	20.4	0.0	94.7	90.0	5.2	6.6
Candelaria/2	80.2	100.0	19.8	0.0	95.3	89.5	5.8	7.2
Hubble-Oxbow/1	87.4	77.1	12.6	0.0	59.7	53.9	5.7	5.0
Hubble-Oxbow/2	92.7	75.5	7.3	0.0	59.7	54.0	6.3	5.2

NOTES: Columns are Application Efficiency (AE), Requirement Efficiency (RE), Deep Percolation Percentage (DPP), Runoff percentage (RP), Christiansen Uniformity (CU), Distribution Uniformity (DU), Average Pre-Irrigation Deficit (d_r), and Average Applied Depth ($\bar{d}$).

Table 4-14 summarizes the field and inflow characteristics for all the efficiency evaluations conducted as part of this study. Among the study fields, average inflow rate during irrigation, combining all turnouts, ranged from 3.2 cfs to 31.9 cfs. Duration of the irrigation period at each study field (from irrigation start to cutoff), ranged from 1.7 hours to 9.4 hours. The total volume of irrigation inflow at study fields ranged from 1.07 ac-ft to 11.51 ac-ft.

Table 4-14. Field and Inflow Characteristics for Study Fields within the MRGCD

Location/Run	Area (ac)	No. of Turnouts	Size of Turnouts (in.)	Average Inflow Rate (cfs)	Irrigation Duration (hrs)	Total Inflow (ac-ft)	Irrigation Application (ac-ft/ac)
N. San Acacia R1	12.97	4	10	14.8	9.42	11.51	0.89
N. San Acacia R2	12.60	4*	10	15.8	4.07	5.30	0.42
S. San Acacia R1	5.05	8	10	12.4	3.92	3.81	0.76
S. San Acacia R2	5.14	8	10	7.3	6.13	3.69	0.72
Wade R1	7.24	2	24	9.6	9.07	7.16	0.99
Wade R2	7.26	2	24	17.7	3.25	4.73	0.65
Harris R1	13.91	15	10	31.9	3.32	6.10	0.43
Harris R2	13.96	15	10	28.8	3.28	7.83	0.56
Candelaria R1	3.53	2	10	13.5	1.73	1.94	0.54
Candelaria R2	3.51	2	10	12.1	2.17	2.12	0.60
Hubble-Oxbow R1	2.56	3	12	3.9	3.28	1.07	0.80
Hubble-Oxbow R2	2.58	3	12	3.2	4.22	1.11	1.92

NOTE: * = Two were partially closed.

From these results, it appears that the single management measure that would have the largest effect on application efficiency would be to determine the cutoff time to better match the total inflow to the soil moisture deficit, particularly where the deeper root zone is moist. It should be noted that first irrigations are often less efficient than subsequent irrigations because of rougher soil conditions and intentional deep percolation, intended to fully wet the root zone and provide leaching.

Land (laser) leveling is a proven water conservation method, and the performance of leveled fields relative to unleveled fields is compelling. The potential for substantial gains through leveling is somewhat limited by the fact that it is such an attractive practice that most large farmers leveled their fields long ago, and maintain them with touch-up leveling every two to five years. Fields that have not been leveled certainly stand to benefit in terms of irrigation efficiency, and regular maintenance is necessary.

Maintaining a consistent and high inflow rate would have helped the performance of some of the irrigations observed here. By providing a high inflow, a more rapid advance is achieved, producing more uniform infiltration of irrigation water. The quickest and most efficient way to deliver water to multiple turnouts is to give a few turnouts at a time as high a flow as can be managed, make the delivery, and rotate through all turnouts needing water. This requires coordination and cooperation among irrigators and ditch riders, but the potential performance benefits are significant.

4.2 Results of NRCS Agent Survey and Interviews

Table 4-15 summarizes results from the NRCS survey and interviews conducted in 2003 and in 2005 regarding the status of on-farm irrigation efficiency conservation measures employed within the MRGCD.

A comparison of county irrigated acreage data from the USDA 2002 Census of Agriculture (summarized in Table 4-16) with irrigated acreage within each county estimated by NRCS agents to have been irrigated within the last three years (2000 to 2003) reveals significant differences: the total irrigated acreage reported in the 2002 Census of Agriculture was 45,004 acres and the total irrigated acres estimated by the NRCS agents was 60,000 acres. Because the Middle Rio Grande Valley has experienced a general decline in irrigated agriculture from 1997 to 2002 as indicated by the USDA Census of Agriculture data (USDA, 2004), it is not likely that the differences between census data and the NRCS agent's estimates are explained by increases in irrigated acreage since 2002. A more plausible explanation for the discrepancy is that the lower USDA Census of Agriculture may underestimate total irrigated acreage among the four counties encompassing the MRGCD as a consequence of the return rate to NASS surveys and questionnaires being between 60 to 85 percent (Nelson, 2006), while the NRCS agents' estimates are similar to what MRGCD reported in 2005: approximately 62,000 acres irrigated, including pueblo lands, which was derived from tallying records from MRGCD ditchriders on the properties which were serviced. The MRGCD reported acreage fit well with the land use trend analysis (LUTA) and more recent IKONOS imagery. MRGCD currently estimates 73,000 acres serviced, with approximately 63,000 being irrigated in any particular year, and approximately 10,000 being fallow or otherwise idle for one or more years (Gensler, 2006).

Table 4-15. Results from 2003 Survey (and 2005 Follow-Up Comments) of NRCS Agents for Counties Encompassing the MRGCD

New Mexico County NRCS Agent(s)	Bernalillo & Sandoval Corinne Brooks		Valencia Danny Thomas & Rudy Garcia		Socorro Darrel Reasoner & Santiago Misquez	
	Acres	%	Acres	%	Acres	%
Total irrigated acreage in county farmed within last 3 years	22,000		17,000		21,000	
Total irrigated acreage in county benefiting from some conservation measure	15,400	70	6,800-11,900	40-70	19,950	95
Total irrigated acreage in county benefiting from only field laser leveling	11,000	50	1,500	9	14,000-15,000	67-71
Total irrigated acreage in county benefiting from only lined ditches	2,200	10	1,200	7	6,000	29
Total irrigated acreage in county benefiting from only piping	2,200	10	300	2	500	2
Total irrigated acreage in county benefiting from a combination of field laser leveling and ditch lining or piping	15,400	70	5,000-11,900	29-70	4,000-6,500	19-31
Total irrigated acreage in county benefiting from implementation of water management plan/program	500-1,000	2-5	850-3,400	5-20	4,000-6,500	19-31
Total irrigated acreage in county that is being irrigated using drip irrigation	300	1	100	<1	300	1
Total irrigated acreage in county that is being irrigated using above ground sprinklers (center pivot, side roll, or lay-down)	50	<1	300	2	0-10	<1
Irrigation efficiency (%) with no conservation measures		25		21		25-30
Irrigation efficiency (%) with only field laser leveling		45		33		35-40
Irrigation efficiency (%) with only ditch lining or piping		40		29		40
Irrigation efficiency (%) with field laser leveling and ditch lining or piping		60		50		40
Irrigation efficiency (%) with Irrigation Water Management Plan/Program (including optimum combination of above conservation measures)		80		30-65		40-75
Irrigation efficiency (%) with drip systems		90		85		75
Irrigation efficiency (%) with aboveground sprinklers		65		70		NA
Percentage of water conservation measures implemented with NRCS/FSA assistance		75		50-75		75
Total acreage irrigated using groundwater as water source	1500		400		900-2,000	

Table 4-16. USDA 2002 Census of Agriculture Irrigated Acreage Data

	Counties Encompassing the MRGCD		
	Bernalillo & Sandoval	**Valencia**	**Socorro**
Irrigated land (acres)	18,545	14,086	12,373
Harvested cropland (acres)	9,220	8,798	9,113
Pastureland and other (acres)	9,325	5,288	3,260
Total irrigated acreage for all counties	45,004		

Reference: USDA, 2004, Table 10.

Other estimates of irrigated acreage within the MRGCD are summarized in the 2002 SSPA report, including those from USBR crop census records, compilations prepared by NMSU, and more recent sources including LUTA conducted by the USBR from 1992 to 1994, and a satellite imagery-based vegetation classification survey conducted by the MRGCD and the ISC in 2001 (SSPA, 2002). Although the reported quantities vary between 52,000 and 63,000 acres, these values are not directly comparable because they include/exclude different parameters (e.g., acreage outside MRGCD, fallow and/or idle acres, Tribal acres, and acres for specific crops). Because the USBR Crop Census Reports (1956–1998) include the primary parameters of interest (acres irrigated and fallow or idle lands within the MRGCD), the average irrigated acreage value, excluding fallow or idle lands, from 1991–1998 (53,355 acres) was considered representative and used in this study to develop estimates of potential irrigation efficiency improvement within the MRGCD. Because the USBR Crop Census Reports present a single irrigated acreage value for the entire MRGCD, and not acreages by county, the 1991 to 1998 USBR Crop Census Report irrigated acreage value was scaled for each of the four counties encompassing the MRGCD using irrigated acreage data for each county based on the revised LUTA dataset (SSPA, 2002), yielding an approximate irrigated acreage for Bernalillo, Sandoval, Valencia, and Socorro Counties.

According to estimates made by the Bernalillo and Sandoval County NRCS agent, approximately 70 percent of all irrigated acreage benefits from some form of on-farm conservation measure, which is the same percentage for irrigated land benefiting from a combination of conservation measures. This suggests that if conservation measures are used at all, they are used in combination (e.g., laser leveled fields and concrete line on-farm conveyance canals).

In contrast, estimates of the extent of conservation measure for Socorro County suggest the opposite may be true. Specifically, it was estimated that 95 percent of all irrigated acreage benefits from some form of conservation measure, 67 to 71 percent of all irrigated acreage employed laser leveling as the only conservation measure, and only 19 to 31 percent of all irrigated land benefited from some combination of conservation measures. In the follow-up survey, the Socorro County NRCS agent confirmed that of all irrigated land, 95 percent had been laser leveled. While there is some discrepancy, these results suggests that in most cases laser leveling was the only conservation measure employed, and that a combination of conservation measures was employed only about 19 to 31 percent of the time.

The estimates of the total extent of conservation measures employed within Valencia County were somewhat similar to those estimated for Bernalillo/Sandoval counties. The NRCS agents for Valencia County estimated that between 40 to 70 percent of all irrigated acreage benefited from some form of conservation measure, resulting in about 30 to 60 percent of all irrigated acreage not benefiting from conservation measures. According to NRCS agents, 5 to 20 percent of all irrigated acreage benefits from a combination of Irrigation Water Management (IWM) Plan and laser leveled fields and concrete–lined, on-farm conveyances and/or piping. The ranges of these estimates for Valencia County were larger than for the other counties included in the study.

NRCS defines IWM as determining and controlling the rate, amount, and timing of irrigation water in a planned and efficient manner. As part of IWM, elements of soil and crop type, precipitation, soil moisture and irrigation methods are considered, in addition to other factors such as cultural operations and environmental factors that affect irrigation efficiency. For this purpose, the NRCS has standardized aspects of the method and developed specific tools to be used by the irrigator to accomplish IWM for individual farm operations. IWM is applicable for any farm operation suitable for irrigation that has water supply in sufficient quantity and quality.

The following questions and responses comprised this study's second NRCS survey conducted in spring 2005. Results from the second NRCS survey expand on and confirm information obtained in the first NRCS survey, specifically the first and second questions regarding the extent of on-farm conservation measures within the study area.

Second Survey Submitted to NRCS Agents, February 2005

(Response only received from Socorro County NRCS Office)

Question: *Among irrigated acres benefiting from a combination of on-farm conservation measures, which conservation measures are used in combination with others and on what portion of this irrigated land are they used?*
Response: Among 6,500 irrigated acres within Socorro County benefiting from some combination of conservation measures, 95% has been laser leveled, 92% are supplied irrigation water from concrete-lined canals, and 8% are supplied irrigation though irrigation pipe.

Question: *What percentage of all irrigated land has been laser leveled?*
Response: Within Socorro County, 95% has been laser leveled.

Question: *What is the estimated irrigation efficiency among farms that employ a combination of water conservation measures?*
Response: Within Socorro County, 40-50% efficiency or 2 acres/hour.

Question: *Among water conservation measures most commonly used within your county by farms within the MRGCD, which conservation measures are most effective from a cost/capitol investment standpoint?*
Response: Laser leveling of fields > concrete lining of on-farm conveyance canals > irrigation piping > water control structures (increase capacity/number of turnouts or change placement of turnouts).

Question: *For farmers in your county within the MRGCD, what are the biggest obstacles to implementation of on-farm conservation measures?*
Response: Expense/capitol investment > time > motivation.

Question*: What would be the most effective way to remove obstacles that prevent implementation of on-farm conservation measures among farms within the MRGCD?*
Response: Increase the Farm Bill (EQUIP) const share percentage, increase on-farm technical assistance with farmers (i.e. spend more time discussing benefits of improvements with farmers).

Question: *Upon full implementation of on-farm conservation measures among farms within the MRGCD in your county, what would be the overall improvement in on-farm irrigation efficiency?*
Response: Approximately 25% increase in efficiency in Socorro County.

Question: *Estimate the extent to which canal head loss affects on-farm irrigation efficiency within your county. What is the frequency and extent of this problem in your county?*
Response: This problem occurs in times of water shortage with the system, and has occurred consistently over the last five years. An estimate of the negative impact of canal head loss on irrigation efficiency is about 25%.

Question: *What would be the most effective solution to the problem of canal head loss (e.g. structural improvements to maintain canal head, irrigation scheduling improvements, other)?* Response: Having MRGCD focus all available water into one main lateral at a time, scheduling on-farm delivery of water based on water management plan (i.e., soil moisture conditions, consumptive use requirements, and system efficiency).

4.3 Estimate of MRGCD-Wide Irrigation Efficiency Improvement

Following compilation of NRCS estimates summarized in Table 4-15, the results were reviewed to determine the relative proportion of the primary irrigation efficiency groups (high-, intermediate-, and low-irrigation efficiency) within each county. Primarily based on two questions from the first NRCS survey, investigators estimated the relative proportion of the three irrigation efficiency groups among farms within each county encompassing the MRGCD. Based on NRCS estimates of the total irrigated acreage in the respective counties benefiting from some conservation measure, proportion of the low- and intermediate-irrigation efficiency groups were developed using the following logic: irrigated acreage benefiting from at least some form of on-farm conservation measure were in the intermediate- and high-irrigation efficiency range, while the remaining portion that did not benefit from some form of on-farm conservation measure were in the low-irrigation efficiency group. The portion of irrigated acreage in the high efficiency range was then determined from NRCS estimates of irrigated acres benefiting from an IWM Plan (including the optimum combination of on-farm conservation measures), while the remaining portion was determined to be the intermediate-irrigation efficiency group. The intermediate-irrigation efficiency group portion was then compared for consistency to NRCS estimates of irrigated acreage benefiting from both laser leveling and concrete line on-farm conveyances (deemed to yield an intermediate level of irrigation efficiency).

In the case of Valencia and Socorro Counties, one NRCS agent responded to the first survey while another commented on original responses and provided additional estimates, resulting in a range of percentages estimates. To reconcile the relatively large range of percentage estimates for Valencia County, investigators conducted a follow-up interview with Valencia County NRCS agent Rudy Garcia on June 16, 2005. Based on this conversation, it is likely that preliminary response to the first survey regarding the relative proportion of irrigated acreage benefiting from some form of conservation measure (e.g., laser leveled field or concrete-lined on-farm conveyance) was underestimated. This preliminary response (only 40 percent) suggested that 60 percent of irrigated acreage in Valencia County did not benefit from any form of conservation measure. However, according to Valencia County NRCS agent Rudy Garcia, the actual percentage of irrigated acreage in Valencia County benefiting from some form of conservation measure is closer to approximately 70 percent, suggesting that only about 30 percent of irrigated acreage did not benefit from any form of conservation measure. Furthermore, Rudy Garcia indicated that the actual percentage of irrigated acreage in Valencia County benefiting from IWM Plans/Programs and an optimal combination of on-farm conservation measures was approximately 5 percent. Because these revised NRCS estimates were more in line with estimates from other NRCS agents in Bernalillo/Sandoval Counties and Socorro Counties, these revised estimates for Valencia County were used in subsequent calculations of irrigation efficiency for Valencia County.

In the case of the NRCS estimates for all counties included in the study, there was an overlap in percentage responses resulting in over 100 percent for all three efficiency groups. In order to normalize the estimates, the low- and high-efficiency portions were left unchanged and the intermediate portion was adjusted so that the percentage total for the three groups was 100 percent. In some cases, for Bernalillo/Sandoval and Socorro Counties, the NRCS agents responded with a range of values rather than one value. For these counties, the range was averaged, yielding one value (per county per efficiency group) for use in later calculations.

Table 4-17 summarizes relative efficiency group portions developed in this study based on the NRCS responses to this study's surveys.

Table 4-17. Relative Proportion of Irrigation Efficiency Groups by County

Irrigation Efficiency Group	**Bernalillo and Sandoval Counties**		**Valencia County**		**Socorro County**	
	Original	Adjusted	Original	Adjusted	Original	Adjusted
	(%)	(%)	(%)	(%)	(%)	(%)
High	2-5	3.5	5-20	5	19-31	25
Intermediate	70	66.5	40-70	65	95	70
Low	30	30	30-60	30	5	5
Total		100		100		100

Once the percentages of irrigation efficiency groups were established for each county, the derived MRGCD irrigated acreage values for each county (based on USBR Crop Census Reports and LUTA datasets) were used to calculate the current irrigated acreage among each efficiency group within each county, which were then multiplied by the irrigation application for each efficiency group [ac x (ac-ft/ac)] to yield total acre-feet of water used on farms within each efficiency group per irrigation event by county. Because the irrigation application for each efficiency group were a range of values, subsequent calculations involving the ratios resulted in a range of results.

To determine the total volume of water (ac-ft) used on-farm among each irrigation efficiency group for each county by year, the-per-irrigation-event volumes were multiplied by an estimated number of irrigation events per year for a typical field in each county. Under optimum growing conditions, farmers can expect five alfalfa cuttings per year, which typically require two irrigation events prior to each cutting, providing there is no supplemental water from precipitation (Herkenhoff, 2005). A subject matter expert from the MRG ESA Collaborative Program Water Acquisition and Management Subcommittee suggested that in the MRGCD there are typically seven irrigations per season: two irrigations before first cut, one irrigation before the 2nd cut, two irrigations before the 3rd cut, one before the 4th cut, and one final irrigation regardless of whether there is opportunity for a 5th “clipping”. Also, because of mid-summer water shortage, farmers may not be able to complete a second irrigation before 3rd cut (WAM, 2006).

Another factor affecting the estimate of total irrigation events per year for irrigated acreage within each county is the crop distribution variability throughout the MRGCD. For instance, the distribution of alfalfa production in the Albuquerque basin (from Cochiti Dam downstream to San Acacia) ranged between 30.1 and 61.9 percent (45.9 percent average), while the two next largest crop distributions were planted pasture (17.3 to 45.0 percent, 26.1 percent average) and vegetables/field (2.9 to 30.8 percent, 13.4 percent average) (USBR, 1995). Based on CIR values reported in Wilson et al. (2003), the average CIR for Bernalillo, Sandoval, Socorro, and Valencia Counties for all crops is approximately 2.18 feet. Oad and King (2005) estimated the CIR of alfalfa in the MRGCD to be 2.57 feet, while pasture is likely lower, on the order of 2 feet CIR. The CIR of vegetables and field crops vary widely depending on type and management level.

To account for other crops with lower irrigation requirements being grown on irrigated land within the MRGCD, irrigated land that is not irrigated for whatever reason, and precipitation during the growing season, the estimated number of irrigation events per irrigated field per year was assumed to be six irrigations for each county.

Once the current total volume of on-farm water use per efficiency group per year was calculated for each county based on the current proportion of the efficiency groups within each county, total on-farm water use was calculated for each county based on two scenarios: 100 percent of irrigated acreage being intermediate on-farm irrigation efficiency; and 2) 100 percent of irrigated acreage being high on-farm irrigation efficiency. Table 4-18 summarizes the results from irrigation efficiency estimates for the MRGCD.

Following these calculations, reductions in water use from current levels to those calculated under scenario one and two were determined, as well as percentage efficiency increase under each scenario. Negative values represent a reduction in water use (ac-ft) from the present level to a future level based on the above scenarios where on-farm irrigation efficiency is increased. These results are summarized in Table 4-19.

For comparison of estimates of total annual volume of water delivered to MRGCD farmers, Table 4-20 summarizes this study’s estimate reported as a range and estimates reported by MRGCD and SSPA (SSPA, 2002).

Table 4-18. Summary of On-Farm Irrigation Efficiency Estimates for the MRGCD

			Counties Encompassing the MRGCD		
			Bernalillo/Sandoval	**Valencia**	**Socorro**
		Irrigated acres	14,501	23,855	14,998
		Irrigation events/yr	7	7	7
Irrigation Efficiency Group	**Irrigation Application (range)***		**Proportion of Efficiency Groups in County**		
	(ac-ft/ac)		(%)	(%)	(%)
High	0.5 to 0.6		3.5	5	25
Intermediate	0.6 to 0.8		66.5	65	70
Low	0.8 to 1.0		30	30	5
Irrigation Efficiency Group	**Irrigation Application**		**Irrigated Acres by Group in County**		
	(ac-ft/ac)		(ac)	(ac)	(ac)
High	0.5 to 0.6		507	1,193	3,750
Intermediate	0.6 to 0.8		9,643	15,506	10,499
Low	0.8 to 1.0		4,350	7,157	750
Irrigation Efficiency Group	**Irrigation Application**		**Current On-Farm Water Use by Group in County (range of values per county)***		
	(ac-ft/ac)		(ac-ft)	(ac-ft)	(ac-ft)
High	0.5 to 0.6		253 to 304*	596 to 716	1,875 to 2,250
Intermediate	0.6 to 0.8		5,786 to 7,715	9,303 to 12,405	6,299 to 8,399
Low	0.8 to 1.0		3,480 to 8,266	5,725 to 13,597	600 to 1,425
		Sum (ac-ft)	9,520 to 16,286	15,625 to 26,718	8,774 to 12,073
		Total ac-ft/yr	57,123 to 97,714	93,750 to 160,306	52,643 to 72,441
Irrigation Efficiency Group	**Irrigation Application**		**Potential On-Farm Water Use if all Irrigated Acreage in County is Intermediate Efficiency**		
	(ac-ft/ac)		(ac-ft)	(ac-ft)	(ac-ft)
Intermediate	0.6 to 0.8		8,701 to 11,602	14,313 to 19,084	8,999 to 11,998
		Total ac-ft/yr	52,207 to 69,609	85,878 to 114,504	53,993 to 71,991
Irrigation Efficiency Group	**Irrigation Application**		**Potential On-Farm Water Use if all Irrigated Acreage in County is High Efficiency**		
	(ac-ft/ac)		(ac-ft)	(ac-ft)	(ac-ft)
High	0.5 to 0.6		7,251 to 8,701	11,928 to 14,313	7,499 to 8,999
		Total ac-ft/yr	43,506 to 52,207	71,565 to 85,878	44,994 to 53,993

NOTE: * The range of values for irrigation application (ac-ft/ac) observed among the study fields yields a range of values for on-farm water use (ac-ft).

Table 4-19. Summary and Analysis of Results from the MRGCD On-Farm Irrigation Efficiency Estimates

<table>
<tr><th colspan="4">Counties Encompassing the MRGCD</th></tr>
<tr><th></th><th>Bernalillo/Sandoval</th><th>Valencia</th><th>Socorro</th></tr>
<tr><th colspan="4">Change in County Water Use, Current Efficiency to 100% Intermediate Efficiency
(range of values per county)</th></tr>
<tr><td>(ac-ft/yr)</td><td>-4,916 to –28,1059</td><td>-7,872 to –45,802</td><td>1,350 to -450</td></tr>
<tr><td>(%)</td><td>9 to 29</td><td>8 to 29</td><td>-3 to 1</td></tr>
<tr><th colspan="4">Change in MRGCD Water Use, Current Efficiency to 100% Intermediate Efficiency
(range of values per MRGCD)</th></tr>
<tr><td colspan="2">(ac-ft/yr)</td><td colspan="2">-11,438 to –74,356</td></tr>
<tr><th colspan="4">Change in County Water Use, Current Efficiency to 100% High Efficiency
(range of values per county)</th></tr>
<tr><td>(ac-ft/yr)</td><td>-13,617 to –45,507</td><td>-22,185 to –74,428</td><td>-7,649 to –18,448</td></tr>
<tr><td>(%)</td><td>24 to 47</td><td>24 to 46</td><td>15 to 25</td></tr>
<tr><th colspan="4">Change in MRGCD Water Use, Current Efficiency to 100% High Efficiency
(range of values per MRGCD)</th></tr>
<tr><td colspan="2">(ac-ft/yr)</td><td colspan="2">-43,451 to –138,382</td></tr>
</table>

Table 4-20. Comparison of Estimates of Total Annual Volume of Water Delivered to MRGCD Farmers

<table>
<tr><th colspan="2">Total MRGCD On-Farm Water Use (sum of results for all counties), under Current Water Use Efficiency (Table 4-18). Input parameters summarized in Table 4-18.</th></tr>
<tr><td>(ac-ft/yr)</td><td>237,436 to 385,537</td></tr>
<tr><th colspan="2">Total Annual Water Volume Delivered to MRGCD in 1999 (SSPA, 2002)</th></tr>
<tr><td>(ac-ft/yr)</td><td>195,589</td></tr>
<tr><th colspan="2">Average Total Annual Water Volume Delivered to MRGCD 1976-1999 (USBR data as summarized in SSPA, 2002)</th></tr>
<tr><td>(ac-ft/yr)</td><td>174,374*</td></tr>
</table>

*This number is based on MRGCD's 3 ac-ft/yr delivery goal. As noted in Section 1.1, MRGCD likely delivers in excess of this amount (Gensler, 2006).

SECTION 5. DISCUSSION

5.1 On-Farm Irrigation Efficiency Evaluation

5.1.1 San Acacia North Field

Because soil moisture content tended to be higher at the 18-inch depth at San Acacia North Field, especially after the first irrigation event and prior to the second irrigation event, moisture content results at this location largely may be a function of soil texture and organic matter, and resultant retention at this depth. Lower soil moisture content near the surface and at the 30-inch depth may be in response to evapotranspiration and infiltration, respectively.

As illustrated on Figure 4-6, the advance curves of Columns 1 through 3 and Columns 4 and 5 were closely similar to each other. This grouping of results is due to the proximity of the columns to each other: Columns 1 through 3 are located on the western basin of San Acacia North Field, and Columns 4 through 6 are located on the eastern basin of San Acacia North Field. These sub-basins were distinct except at the head and tail sections of San Acacia North Field, where the sub-basins were not distinct. Because the field is separated into two distinct basins, irrigation water within the field can be expected to advance at different rates within each sub-basin. Differing advance rates were evident in the study field as Columns 1 through 3 advanced more quickly than Columns 4 through 6 (the west basin advance took 6 hours to reach 1,000 feet, while the east basin advance took 8.5 hours to reach 1,000 feet). This was likely due the western basin receiving a higher irrigation inflow rate than the eastern basin. Although each basin was supplied from the same canal (Alamillo), and each basin was supplied by two turnouts, the turnouts for the western basin were located closer to the check in the lined canal, resulting in higher head near these turnouts. Furthermore, because of the higher inflow rate into the western basin, advancing flow approached the tail end of the western basin much more quickly than that of the eastern basin. Upon reaching the tail end of the western basin, the water was able to move across into the eastern basin due to the lack of border and begin inundating the grid points at the tail end of the eastern basin. As previously explained, the time at which water arrives at each grid point within a column is recorded, whether the water is part of the column's irrigation advance or escape water from another column, which may occur prior to the column's irrigation advance.

In contrast to the first irrigation run at this field, the advance curves observed in the second irrigation run were much more uniform, likely due to manipulation of the turnouts for the western basin during the second irrigation run. The irrigator partially closed the turnouts in the western basin to reduce the flow, thereby obtaining a similar flow rate to that of the eastern basin turnouts. As a result, a much more uniform advance was observed between the two sub-basins for the second irrigation run.

The difference in advance time between the first and second irrigation run at the San Acacia North Field (9 hours and 4.5 hours, respectively) may in part have been due to increased average irrigation inflow rate in the second irrigation run as compared to that of the first irrigation run. Although the increase in inflow rate between the first and second irrigation runs was relatively small, the resulting differences in inflow volumes were dramatic (11.51 acre-feet and 5.3 ac-ft, respectively). This difference in volume suggests that a large portion of water deep percolated during the first irrigation run because of differing advance rates within the sub-basins. Therefore, while manipulation of turnouts to achieve more uniform advances within the sub-basins may have increased the advance rate for the second irrigation run, the overall increase in inflow rate during the second irrigation run may have influenced the shorter advance time to a more significant degree.

Due to these differences in inflow rates and volumes between the two irrigation runs and their subsequent impact on advance within the two sub-basins, performance parameters for the two irrigation runs were significantly different as well. For instance, lower Christiansen's and distribution uniformity was observed in the second irrigation run at San Acacia North Field as compared to the first irrigation run. Although advance time for the second irrigation run was quicker and more uniform, the uniformity coefficients were calculated to be lower because of the smaller volume of water applied to the field in the second irrigation run. In the first irrigation run, the higher volume of water applied offsets the difference in water distribution on the field and increases the overall irrigation uniformity. The larger volume of water applied in the first irrigation run is also reflected in the deep percolation percentage, which was 26.8 percent higher in the first irrigation run as compared to the second irrigation run (48.4 percent and 21.6 percent. respectively).

Requirement efficiency in San Acacia North Field was 16 percent lower in the second irrigation run as compared to the first irrigation run (84 percent and 100 percent, respectively). In the case of the first irrigation run, the crop root zone was replenished entirely as reflected by the 100 percent requirement efficiency, and the extent to which water was applied in excess of root zone is indicated by the deep percolation percentage. The requirement efficiency value of 84 percent represents the percentage of irrigation water that replenished the root zone during the irrigation event. In contrast, application efficiency was 45.2 percent lower in the first irrigation run as compared to the second irrigation run (51.6 percent and 96.8 percent, respectively), largely due to the increased inflow rate and faster advance time for the second run. While there is a proportional relationship between application efficiency and requirement efficiency by virtue of their calculation, from a practical standpoint, higher application efficiency results in more significant water savings than a reduction in requirement efficiency. In this instance, the 45.2 percent higher application efficiency correlating to the 16 percent lower requirement efficiency between the first and second irrigation runs at San Acacia North Field resulted in 54 percent less water used in the second irrigation run.

Because the San Acacia North Field has conservation measures in place, including maintenance of laser leveling; concrete–lined, on-farm supply canals; and low-intake soils, opportunities exist to obtain relatively high irrigation efficiencies at this location. Although the main limitation to improving irrigation efficiency at this location is the relatively long advance length of the field (approximately 1,300 feet), reducing the advance length would prove difficult at this location due to infrastructure constraints. Reducing advance time can also be achieved at this location by decreasing basin width or number of basins irrigated, thus increasing application efficiency. If the irrigator chose to reduce basin width and irrigate fewer basins at a time, the number of field turnouts may have to be increased and/or turnouts may have to be modified or replaced to handle inflow from the supply canal to adequately irrigate each basin. However, as the field is divided into smaller basins, more time is required of the irrigator to manage irrigation of each basin, which would likely be irrigated individually, possibly resulting in a longer period to complete irrigation of the entire field. In addition, structural changes to the supply canal may also be required to accommodate irrigation of smaller basins. Therefore, the irrigator must weigh the potential benefit of irrigation efficiency and resulting water savings with the additional amount of effort and capitol investment required to attain increased irrigation efficiency.

5.1.2 San Acacia South Field

Although the total volume of inflow was relatively similar between the first and second irrigation runs (3.81 and 3.69 ac-ft, respectively), duration of the first irrigation run was significantly shorter than duration of the second irrigation run (3.92 and 6.13 hours, respectively). Likewise, the total advance time of the first irrigation run was shorter than the second irrigation run (approximately 5 and 8.3 hours, respectively). The longer advance time for the second irrigation run was largely result of head loss in the Socorro Main Canal during irrigation that resulted in reduced average inflow rate (12.4 cfs under normal canal head conditions during the first irrigation run and 7.3 cfs under reduced canal head conditions during the second irrigation run). The difference between the irrigation duration (start of inflow to cutoff) and advance time for both irrigation runs was due to the shutoff of irrigation inflow before the advance reached the end of the field, allowing the head of water on the field to distribute across the remaining portion of the field.

The low-application efficiencies for the San Acacia South runs appear to be the result of running water too long. The uniformities are relatively high, but the small pre-irrigation deficits (1.4 inches for the first run, 1.9 inches for the second run) and the average depth of applied water (9.1 and 8.6 inches, respectively) do not match. Fortunately, adjusting the cutoff time is one of the easiest improvements to make.

5.1.3 Wade Field

For the first irrigation run at Wade Field, irrigation advance was relatively uniform for the first 150 feet between all columns except Column 4, which was located in the center of the field. Because the field's two inlets were closest to Columns 1 and 2, and 5 and 6, and Column 4 was furthest away from either inlet, the advance was delayed for the center portion of the field, resulting in a longer overall advance time for the entire field. Although when irrigation began, canal head was sufficient for adequate irrigation advance within the field, soon thereafter the canal head began to drop and irrigation inflow significantly decreased, resulting in non-uniform advance for an extended period. Approximately two hours later, the canal head began to rise and field inflow returned to normal, after which irrigation advanced with relatively uniformity (Figure 4-18). Based on an interview with the ditch rider of MRGCD, the drop in canal head was the result of an upstream irrigator using water out of rotation. Although the frequency and magnitude of canal head loss affecting this study field is unknown, and beyond the scope of this report, these results illustrate how canal head loss can decrease irrigation application efficiency in the MRGCD.

As a result of sufficient canal head during the entire second irrigation run, inflow rate was relatively constant (average of 17.7 cfs) and the irrigation advance was more uniform and took less time as compared to the first irrigation run. Although advance uniformity and total advance time was dramatically improved in the second irrigation run, and 34 percent less water was used in the second irrigation run as compared to the first irrigation run, advance uniformity and advance rate at this field was still relatively low compared to other well-maintained laser-leveled fields. This was largely due to the field having only two inlets for water application, causing the outer columns of the field to advance faster than the center column of the field.

There are several ways that on-farm irrigation efficiency can be improved at the Wade Field. The first priority should be to determine pre-irrigation deficit in the root zone, and adjust the cutoff time to match the applied water to the deficit. Another improvement would be to divert flow from one or both of the turnouts into a new, lined on-farm canal, from which numerous smaller turnouts could supply water to the field, instead of irrigating the field from two large turnouts near each upstream corner of the field as is done currently. Although this approach will involve capital expanse and increase operational complexity, the improved advance distribution and reduced irrigation time will result in reduced total water use. Of course, this outcome is dependent on sufficient canal head, which is beyond the control of the individual irrigator. The MRGCD check structure for Wade Field is located a considerable distance downstream from the two inlets (approximately 2,000 feet and 2,600 feet), which limits head level at the turnouts and consequently reduces flow at the turnouts. Constructing a new check structure closer to the turnouts would result in less turnout flow rate fluctuation during low canal head periods and could lead to increased application efficiencies at Wade Field.

5.1.4 Harris Field

For the first irrigation run at Harris Field, irrigation advance was very uniform, with the exception of the last grid point at the end of Column 1, which appeared to be at a higher elevation. The relatively uniform advance was largely due to the number and capacity of turnouts, which yielded a high inflow rate for the field. In addition, the high turnout flow was made possible by a large, 30-inch-diameter gate supplying the lined canal. The total average inflow for the first irrigation run was approximately 31.9 cfs, which was substantially higher than inflows of other study fields. Given the size of the study field (13.9 acres), irrigation was accomplished relatively quickly, again, largely due to the high inflow rate. Because the inflow was cutoff before water reached the end of the field, allowing the on-field head of water to move to the end, the total advance time for the first irrigation run was approximately three hours, while the application time was 3.32 hours.

Although irrigation also advanced uniformly during the second irrigation run, the general shape of the second irrigation run advance curves, in contrast to advance curves of the first irrigation run, indicates that there were significant differences in terms of efficiency outcome. Specifically, advance curves for the first irrigation run were near linear, while the advance curves for the second irrigation were near-power function advance curves, which may be a result of higher inflow rates during the first irrigation run. The rate of advance remained relatively constant in the first irrigation run because the higher inflow rate masked the effect of infiltration in areas where irrigation water had already advanced across the field. This infiltration typically causes the advance rate to slow toward the end of the field as seen in the second irrigation run, but the additional inflow water in the first irrigation run provided sufficient head to keep the advance relatively constant across the field.

A combination of factors resulted in the significantly longer irrigation application time for the second irrigation run as compared to the first (approximately five hours and three hours, respectively). One factor was the slightly higher irrigation inflow during the first irrigation run as compared the second, which manifested in a faster advance rate across the field for the first irrigation run. Another factor was underestimation of irrigation advance rate during the second irrigation run by the irrigator, which resulted in over application of water to the end of the field and runoff. Although runoff was observed during both irrigation runs, the longer period of time free water was present on the field surface during the second irrigation run resulted in a higher deep percolation percentage for the second irrigation run. In addition, the faster advance rate observed during the first irrigation run, as compared to the second, may also explain the slightly higher runoff observed for the first irrigation run as a result of increased water momentum and less opportunity for infiltration in the first irrigation run, as compared to the second. Harris Field was the only field where runoff was measured during this study, and where a runoff percentage was calculated. At the tail end of the field a pipe coupled with a gate allowed the irrigator to remove excess water from the field, which was then emptied into the Elmendorf Drain. This draining system prevented anaerobic conditions from developing from extended ponding conditions resulting from an over-application of water on the field. The reduction in runoff percentage between the first and second irrigation run resulted from a better estimate of the cutoff time by the irrigator.

The difference in inflow rate between the two irrigation runs was due to lower canal head during the second irrigation run resulting from two fields being watered at Harris Farm at the same time. Although the pre-irrigation canal head was higher prior to the second irrigation run as compared to before the first irrigation run, once multiple fields were being irrigated simultaneously, the canal head dropped below a sufficient level to adequately irrigate either of the two fields. Because of the lower inflow rate and longer advance time for the second irrigation run, approximately 22 percent more total water volume was used in the second irrigation run as compared to the first.

The lower inflow rate and longer advance and application time observed during the second irrigation run, as compared to the first, was also reflected in a decrease in application efficiency (53.1 percent for the first irrigation run and 33.5 percent for the second), while the requirement efficiency for both runs was 100 percent. In addition, uniformities also decreased from the first irrigation run to the second at Harris Field as a result of the longer total advance time: Christiansen's uniformity decreased from 63 to 60 percent and the distribution uniformity decreased from 61 to 55 percent.

These levels of uniformities, for both irrigation runs, were relatively low for a field where such uniform advances between columns were observed. This is likely due to differing soil textures and soil moisture status within the relatively large field. The relatively low application efficiencies at Harris Field may also be due to the low water holding capacity of the soils at this location. In general, the thin upper soil horizon at Harris Field was a clay loam underlain by a medium textured sand, which has poor water retention properties. As a consequence of the rapid infiltration characteristics of this soil, application efficiency is relatively low for this study field. Furthermore, varying thickness of the clay loam surface horizon may cause surface sealing and limit irrigation advance uniformity on the field. In part, this clay surface horizon is deposited with suspended sediment in successive irrigation applications. Incorporation of organic matter and limited tillage at this field may improve infiltration characteristics/soil uniformity and irrigation efficiency at this study field.

In addition to soil amendments that may improve infiltration characteristics, another way to improve irrigation efficiency at Harris Field is to decrease the field size. By decreasing field size, soil heterogeneity is also decreased, resulting in more uniform irrigation advance and improved irrigation efficiency. On fields with coarse textured soils, high inflow rates should be utilized over short periods of time in order to minimize the total volumetric inflow and reducing large infiltration volumes at the head of the field. As in other study locations, the recommendations for improved irrigation efficiency require additional capital expenditure, operation time and complexity, and sufficient head in supply canals.

5.1.5 Candelaria Field

The advance curves of the first irrigation run at Candelaria Field illustrate a relatively uniform and rapid advance. This was largely due to the high flow rate applied compared to the size of the field. Though the advance time was somewhat longer for the second irrigation run, the advance curves, similar to the first irrigation run, illustrate a relatively uniform advance. The longer advance time for the second irrigation run relative to the first irrigation run was due to a lower inflow rate for the second irrigation run (13.5 cfs for the first irrigation run and 12.1 cfs for the second irrigation run). This inflow rate during the first irrigation run was the highest the irrigator had ever attained at Candelaria Field. At one point towards the end of the irrigation, the turnout flow had to be reduced slightly to prevent overflowing of the lined ditch, which the irrigator indicated had never been necessary before. According to the irrigator, the second irrigation inflow rate was more indicative of the normal flow for the field.

For the first and second irrigation runs at Candelaria Field, requirement efficiency was calculated to be 100 percent. The alfalfa crop at Candelaria Field was under a 14- to 16-day irrigation rotation schedule. This rotation and associated deficit level, coupled with soils with high plant available water capacity, meant that deficit irrigation conditions were avoided at this location. The high application efficiency (100 percent) was due to the high inflow rates relative to the small field size and the proper amount of water applied to the field to replenish the root zone. Uniformities were also relatively high at this location for both irrigation runs, largely due to small field size, adequate leveling of field, and uniform soil texture.

Generally, this farm operates at the upper end of efficiency for farms within the MRGCD, and for surface irrigation systems in general. In large part, this is due to a large amount of capital investment for various types of conservation measures including concrete-lined ditches, laser leveled fields, and high-flow turnouts. Because this farm has been used for experimentation in the past, this farm could be used to experiment with different crops and other forms of irrigation such as drip irrigation and side roll sprinklers in an effort to obtain higher irrigation efficiency. This field provides a demonstration of the achievable efficiency in the MRGCD.

5.1.6 Hubble-Oxbow Field

The irrigation advance for the first irrigation run at Hubble-Oxbow Field was relatively non-uniform between the columns, as illustrated by the advance curves. While advance curves for Columns 1 through 3 were somewhat closely grouped from start to finish, the rate of irrigation advance within Columns 4 and 5 fluctuated dramatically during the experiment. This result is attributed to the presence of two basins within the Hubble-Oxbow Field, which were irrigated at the same time. Columns 1 through 3 were located on the western basin, and Columns 4 and 5 were located on the eastern basin. Of the three inlets, two were located on the western basin, while one was located in the eastern basin. The more uniform irrigation advance within Columns 1 through 3 resulted from a higher average inflow rate into the western basin from the two turnouts (combined rate of 3.1 cfs), while relatively low average inflow rate from the one turnout into the eastern basin (0.8 cfs) caused a slower irrigation advance within Columns 4 and 5 (total average inflow rate for all three turnouts was 3.9 cfs). The dramatic fluctuations in advance rate at Hubble-Oxbow Field, especially in Columns 4 and 5, were due to the unevenness of the field, resulting in poor distribution and pooling in some areas. This was evident from the low irrigation uniformities at this study field: Christiansen's uniformity was just under 60 percent, while distribution uniformity was 54 percent for both irrigation runs. According to the irrigator, Hubble-Oxbow Field had not been leveled within the last 5 years, and had probably never been laser leveled.

The irrigation advance for the second irrigation run, as illustrated by the advance curves, was similar to the irrigation advance observed in the first irrigation run, although the total advance time was significantly longer for the second irrigation run as a result of lower average inflow rate (3.2 cfs) as compared to the first irrigation run (3.9 cfs). An increase in canal leakage was evident during the second irrigation run and is likely the reason for a lower average inflow rate.

As previously mentioned in Section 4.1.6, the on-farm conveyance canal leaked significant amounts of water during the irrigation runs at Hubble-Oxbow Field. The low conveyance efficiencies calculated for the first and second irrigation runs at the Hubble-Oxbow Field (51 percent and 22 percent, respectively) indicate the severity of the problem at this farm. Although on-farm conveyance loss included seepage loss and some leakage into the study field, based on the volume of water observed leaking from the conveyance canal into other areas on the farm, it was clear the latter-mentioned form of loss comprised the majority of on-farm conveyance loss.

Hubble-Oxbow Field had high application efficiencies for the first and second irrigation runs as a result of deficit irrigation conditions (87 percent and 93 percent, respectively). Requirement efficiencies for the first and second irrigation runs (77 percent and 75 percent, respectively) emphasize the degree of soil water deficit that existed following deficit irrigation at the Hubble-Oxbow Field. Hubble-Oxbow Field was under a 30-day rotation irrigation schedule during the 2004 irrigation season. This relatively long duration between irrigation events allowed for significant soil drying resulting in significant crop stress.

There are many opportunities to improve on-farm irrigation efficiency at the Hubble-Oxbow Farm by implementing conservation measures including laser-leveling the field to obtain a uniform advance across the field, concrete lining of on-farm conveyance canals to prevent leakage and seepage loss, installation of additional high-flow turnouts, reconfiguration of the field to reduce advance length, and perhaps construction of a supply canal check structure to raise hydraulic head. The small size of the current basins coupled with these conservation measures will have a substantial impact on irrigation efficiency at Hubble-Oxbow Field.

5.1.7 Comparative Analysis of Irrigation Efficiency among Study Fields

Due to the complexity of on-farm systems and the multitude of site-specific factors that control on-farm irrigation efficiency, no single irrigation performance parameter presented in this report conclusively evaluates irrigation efficiency. Rather, each performance parameter portrays an aspect of on-farm irrigation efficiency and has to be considered along with other performance parameters and site-specific characteristics to make semi-quantitative assessments about irrigation efficiency. Although performance parameters outlined in ASAE Standard Practice EP419 were developed for evaluation of irrigation performance as it relates to agricultural production, the effectiveness of on-farm water conservation measures is implicit within these parameters as on-farm water conservation, in part, controls overall on-farm irrigation efficiency. The most important judgment, based largely on site-specific knowledge, which was made in assessment of on-farm irrigation efficiency at the study locations, was estimating to what degree on-farm conservation measures control on-farm irrigation efficiency.

Varied combinations of conservation measures, including laser leveled fields, concrete–lined, on-farm conveyances, greater number and capacity of turnout gates relative to irrigated area, and irrigation of relatively small basins (i.e., limited length and width of field) were employed at all of the study fields, with the exception of Hubble-Oxbow Field. The function of each conservation measure varied at each location, depending on its current condition and the degree to which the irrigator utilized each conservation measure through operation. For example, deposition of suspended sediment from irrigation water onto a field changes the slope uniformity and consequently impacts irrigation efficiency over time. Therefore, without periodic maintenance through re-leveling, effectiveness of the on-farm conservation measure is reduced over time. To assist in assessing the relative effectiveness of the various conservation measures employed, investigators collected pertinent information regarding the status of conservation measures and operational details related to conservation at each study location.

The following summarizes the status of principle conservation measures at each of the six study locations. Additional field information is summarized in Table 4-14:

- The San Acacia North Field was last laser leveled in 1998 or 1999, and irrigated from a concrete-lined, on-farm conveyance canal through four 10-inch turnouts.
- The San Acacia South Field was last laser leveled in 2003, and was supplied irrigation water from a concrete-lined, on-farm conveyance through eight 10-inch turnouts.
- The Wade Field had been recently laser leveled in 2003 prior to the study, and irrigation water was applied directly to the field from the earthen-lined San Antonio Ditch through two, 24-inch turnouts.
- The Harris Field was last laser leveled in 2000, and was supplied irrigation water from a concrete-lined on-farm conveyance through 15, 10-inch turnouts.
- The Candelaria Field was last laser leveled in 2002, and was irrigated from a concrete-lined, on-farm conveyance through two, 10-inch turnouts.
- Among the study fields, Hubble-Oxbow Field was the only study field where laser leveling had not been done. In addition, only a short section of on-farm conveyance canal below the Gun Club Lateral was concrete-lined, while the remaining longer sections of on-farm conveyance canals were earth lined at this study field. From three earthen-lined canals, Hubble-Oxbow Field was supplied irrigation water from three, 12-inch turnouts.

Hubble-Oxbow Farm was the only study location where irrigation water was conveyed on-farm to the study field through a series of earthen ditches. Because of this, diverted flow from the Gun Club Lateral Canal to Hubble-Oxbow Farm was measured near the diversion point in addition to measuring the field inflow rate. Because all other study locations had concrete-lined ditches conveying on-farm diverted irrigation water to study fields, only the field inflow rates were measured, assuming that seepage was negligible in these concrete-lined on-farm conveyances. The ratio of total volume of water diverted on-farm relative to irrigated acreage at Hubble-Oxbow Farm was 0.8 ac-ft/ac for the first irrigation run and 1.92 ac-ft/ac for the second irrigation run, while the ratio of total volume of water diverted on-farm relative to irrigated acreage at the five other study locations, including both first and second irrigation runs, ranged between 0.42 and 0.99 ac-ft/ac. By comparison, these ratios suggest that, in the absence of on-farm, concrete-lined conveyances, water loss resulting from ditch leakage and seepage can as much as double the amount of water diverted for irrigation. Doubtless, the amount of water diverted would be much higher were sufficient water diverted to replenish soil moisture deficit for crops at this location. Although Hubble-Oxbow Farm probably represents a segment of farms within the MRGCD with very poor on-farm conveyance efficiency, these results are useful for estimating the range of on-farm conveyance efficiency among farms within the MRGCD that lack concrete-lined conveyances.

As with conveyance efficiency, irrigation efficiency at Hubble-Oxbow Field was significantly below the level measured at the other study locations. Although several study fields were determined to be irrigated under deficit conditions, none did so to the extent observed at the Hubble-Oxbow Field. Specifically, because of poor field layout, poor field inflow system configuration, and relatively unleveled field surface, Hubble-Oxbow Field had the lowest requirement efficiency and the poorest irrigation uniformity as compared to other study fields.

Deficit irrigation conditions at Hubble-Oxbow Field were indicated by relatively low-requirement efficiencies and very low levels of deep percolation percentage. Although deficit irrigation conditions might be thought to result in reduced on-farm water use and subsequent reduction of on-farm water loss, in many cases deficit irrigation may indicate the opposite is true. For example, because Hubble-Oxbow Field was relatively unleveled and irrigation uniformities were very low, and because field layout and inflow configuration was poor, more irrigation water was applied to the field than would have been applied if the field was properly laser leveled and had proper layout, etc. Furthermore, because deficit irrigation can result in soil moisture deficit and subsequent plant stress, the frequency of irrigation may be increased to obtain crop growth goals; again, resulting in more on-farm water use.

Based on the study results, Candelaria Field may represent the upper-end of irrigation efficiency, at least for basin irrigation agriculture within the MRGCD. In contrast to Hubble-Oxbow Farm, Candelaria Farm has implemented conservation measures such as lined canals, small irrigated basins, and laser leveling. Presumably as a result of these conservation measures, irrigation uniformities and application/requirement efficiencies were relatively high at Candelaria Field as compared to other study farms, especially the Hubble-Oxbow Field. Further indicating that excess irrigation water was not applied, the deep percolation percentage and undesirable water loss at this location was very low, even with higher irrigation frequency due to more intensive farming at this location.

In summary, study fields with relatively high overall on-farm irrigation efficiency had water diversion per irrigated area ratios of approximately 0.54 to 0.6 ac-ft/ac; fields with intermediate on-farm irrigation efficiency had ratios of 0.6 to 0.8 ac-ft/ac; and fields with relatively low irrigation efficiency had ratios from 0.8 to 1.9 ac-ft/ac. The field with relatively high on-farm irrigation efficiency had conservation measures in place and operational practices that encouraged water conservation and limited undesirable water loss; those fields with intermediate on-farm irrigation efficiency had conservation measures in place to varying degrees and some operational practices were employed that encouraged water conservation and that limited undesirable water loss; the field with relatively low on-farm irrigation efficiency had no conservation measures in place and no specific operational practices that encouraged water conservation or that limited undesirable water loss.

5.2 Agency Survey and Interviews

According to the NRCS agent's estimates, on-farm conservation measures are more widely used within Bernalillo, Sandoval, and Socorro Counties, while the majority of irrigated acreage in Valencia County does not benefit from on-farm conservation measures. The lower percentage of on-farm conservation measure use in Valencia County as compared to the other counties may be explained by the smaller average farm size in Valencia County (514 acres) (USDA, 2004). The relatively smaller farm size in Valencia County may prohibit capital investment for implementation of on-farm conservation measures.

The NRCS agent's estimates of irrigation efficiency under different conditions were relatively similar between counties. Irrigation efficiency where no conservation measures are employed for all counties was estimated to be between 21and 30 percent. As discussed in the introduction of this study, efficiency concepts vary widely, but it is assumed that the NRCS agents consider on-farm irrigation efficiency as the ratio of the amount water diverted from the canal to the amount required by crops. In comparison to the one study field that employed no conservation measure, Hubble-Oxbow Field had requirement efficiencies ranging from 75.5 to 77.1 percent, which was based on the amount of water applied to the field, not diverted from the MRGCD canal. If we consider the amount of on-farm conveyance loss due to seepage and leakage at this study location, overall on-farm irrigation efficiency would be much lower, perhaps as low as the NRCS agent's estimates for acreage without conservation measures. NRCS agent's estimates of on-farm irrigation efficiency among irrigated acreage that benefits from the combination of laser leveled fields and concrete-lined on-farm conveyances ranged from 40 to 60 percent, which was somewhat low compared to requirement and application efficiencies of the study fields where these combinations of on-farm conservation measures were employed (San Acacia North and South Fields, Harris Field, and Candelaria Field). Similarly, irrigation efficiencies estimated by NRCS agents for irrigated acreage benefiting from the IWM Plans and optimum combination of conservation measures were relatively low compared to study fields that exhibited higher irrigation efficiency (i.e. Candelaria Field). One explanation for the relatively low on-farm irrigation efficiency estimates by the NRCS agents is that irrigation efficiency evaluations conducted by the NRCS, with which the agents are most familiar, are typically conducted on farms that have poor on-farm irrigation efficiency, and therefore, qualify for agency assistance.

Only one NRCS agent in Socorro County responded to the second survey. However, based on conversations with irrigators and other NRCS agents during the course of study, the responses given by the Socorro County NRCS agent in the second survey generally echoed sentiments of the agricultural community within the MRGCD. For instance, it was generally thought that significant increases in irrigation efficiency could be realized upon further implementation of on-farm conservation measures and improved operational practices. Lack of capital investment was generally perceived as the most significant limitation to implementation of on-farm conservation measures, and increasing Federal assistance was cited as the easiest way to address this problem. In addition, off-farm canal head loss was frequently reported to cause lower on-farm irrigation efficiency (estimated to reduce on-farm irrigation efficiency by 25 percent in Socorro County). This problem generally was thought to be caused by poor operation of the canal system by the MRGCD, and that the problem could be solved by changes in MRGCD operational practices and various structural improvements to the canals themselves.

5.3 Estimate of On-Farm Irrigation Efficiency within MRGCD

This study's estimate of annual on-farm water use within the MRGCD (from 203,516 to 330,460 ac-ft) is somewhat higher than values reported elsewhere for total agricultural diversions and on-farm delivery. Shomaker (2000) estimated that 1995 agricultural withdrawals for Valencia County were just under 200,000 ac-ft, while withdrawals for Bernalillo and Sandoval Counties were each approximately 60,000 ac-ft. The SSPA (2002) study reported that the volume of water delivered to farms within the MRGCD was 195,589 ac-ft in 1999, and the average volume delivered to farms was 174,374 ac-ft (including years 1976 to 1999). However, as previously noted, MRGCD likely delivers in excess of 174,374 ac-ft to farms within the MRGCD over the course of an irrigations season (Gensler, 2006).

In this study, there are four basic input parameters controlling the estimate of annual on-farm water use within the MRGCD: 1) total irrigated acreage; 2) number of irrigation events per acre per year; 3) water application depth per acre per event (irrigation efficiency); and 4) the relative fractions of irrigation efficiency groups among all irrigated acreage. Although improving the accuracy of the input parameters will narrow the range of the estimated potential for improvement of on-farm efficiency and estimated on-farm water use within the MRGCD, obtaining more accurate input data is anticipated to involve significant effort. For instance, accurate irrigated acreage data on any given year may be accomplished through extensive field survey or water delivery accounting beyond what is currently done, but irrigated acreage could at some point also be accurately estimated using remote sensing technology which is able to distinguish between different types of land use. Improved data for on-farm water use among representative farms within the MRGCD, including application depths and the number of irrigation events per year, can only be obtained through additional evaluation of on-farm irrigation efficiency, which requires coordination with irrigators and extensive fieldwork. It should be stressed that each of the six fields evaluated in this study had unique combinations of soils, topography, inflow characteristics, management, and subsurface hydrology. Even the differences between first and subsequent irrigations on a given field often differ substantially. The lessons learned from the fieldwork provide a limited quantitative data set, but the qualitative lessons are many, including the fact that there is no such thing as a representative irrigation event or irrigator in the MRGCD.

The estimated potential for increased on-farm efficiency upon further implementation of conservation measures is based on the on-farm water use estimates, which are both derived fundamentally from the range of on-farm efficiency evaluation results observed as part of this study and from the NRCS agent’s estimates of the relative proportion of efficiency groups within each county. According to this methodology, the potential increase in on-farm irrigation efficiency on a percentage basis is independent from changes in total irrigated acreage and the assumed number of irrigation events per year, but is dependent of the relative proportion and irrigation applications of the three irrigation efficiency groups. Based on these results, the greatest potential for increased on-farm irrigation efficiency, on a percentage basis, lies in Valencia County. Furthermore, based on the relative amount of irrigated acreage in Valencia County, the potential to limit undesirable water loss and reduce river diversion by increasing irrigation efficiency among farms in Valencia County is higher than for the other counties. However, because average farm size in Valencia County is smaller in comparison to the other counties, improving irrigation efficiency in this county may prove more difficult and expensive on a per acre basis.

Based on these findings, improving on-farm irrigation efficiency from current conditions by laser leveling all irrigated acreage and concrete lining all on-farm conveyances would yield a reduction in on-farm water use of approximately eight to 29 percent in Bernalillo/Sandoval and Valencia Counties. Improving on-farm irrigation efficiency from current conditions by laser leveling all irrigated acreage, concrete lining all on-farm conveyances, instituting NRCS IWM plans, and employing additional operational practices that further limit on-farm water use would yield a reduction in on-farm water use of approximately 24 to 47 percent in Bernalillo/Sandoval and Valencia Counties and 15 to 25 percent in Socorro County.

It is important to note that without parallel improvements to the MRGCD off-farm conveyance system, improvements in on-farm irrigation efficiency and reduction of undesirable on-farm water loss within the MGRCD will not necessarily allow for lower agricultural diversion from the Rio Grande. In fact, maintaining current levels of on-farm irrigation efficiency in most cases requires operating off-farm conveyances at their current head levels. Moreover, on-farm irrigation efficiency in many cases can be improved by increasing head in off-farm conveyances in order to increase field inflow and irrigation advance rates, thereby lowering on-farm water use. Therefore, in addition to improving on-farm irrigation efficiency among farms within the MRGCD, it is necessary for the MRGCD to improve off-farm conveyance efficiency though structural and operational improvements in efforts to reduce river diversions. These structural improvements must focus on raising canal head by construction of canal controls and reducing seepage and evapotranspiration loss through canal lining. Concurrently, MRGCD operational changes in management of off-farm conveyances must focus on irrigation scheduling and rotation, MRGCD-irrigator coordination, and flow measurement.

Because increases in off farm conveyance and on-farm irrigation efficiency over relatively large areas within the MRGCD have the potential to significantly reduce deep percolation and subsequent shallow aquifer recharge, as well as negatively impact riparian habitat and post-irrigation season river flows, it is important that water managers carefully consider adverse impacts of increasing on-farm irrigation efficiency and focus future efforts on eliminating non-beneficial water loss within the MRGCD.

SECTION 6. CONCLUSION

6.1 Future Research Needs and Final Recommendations

At the conclusion of this research, it is clear that future refinement of input parameters will improve confidence in estimations of irrigation efficiency improvement within the MRGCD upon further implementation of on-farm conservation measures. Investing additional resources in improving these estimates, and broadening the scope of research in the area of on-farm irrigation efficiency are important because information is needed for critical water management decisions affecting endangered species and stakeholders within the Middle Rio Grande Valley. At a time when irrigated agriculture is in decline and urban areas are rapidly expanding within the Middle Rio Grande Valley, better accounting of how water resources are used in on-farm settings will be necessary to balance human and natural resource needs in the future.

To refine estimates of on-farm irrigation efficiency within the MRGCD, it is recommended that the following occur:

- Develop a database so that on-farm irrigation efficiency data and on-farm conservation improvement information can be retrieved for later analysis
- Conduct a field survey to verify the extent of conservation measures employed among farms within the MRGCD, including a broad spectrum of farm sizes and crops;
- Conduct a field survey to determine the magnitude and number of irrigation events per irrigated acreage among within the MRGCD, including review of ditch rider logs;
- Conduct additional on-farm irrigation efficiency evaluations within the MRGCD, including a broad spectrum of farm sizes and crops, to further refine range of on-farm water use values among the primary efficiency groups;
- Conduct a quantitative analysis of water conservation effectiveness of various on-farm conservation measures in the MRGCD, including those not evaluated as part of this study (e.g., drip and sprinkler irrigation systems).

To promote increases in on-farm irrigation efficiency among all farms within the MRGCD the following actions are recommended:

- The “low hanging fruit” in improvement of irrigation efficiencies is the matching of applied water to pre-irrigation deficits. Different soils and relationship to groundwater make generalizations about fixed rotations and applied depths impossible; to maximize irrigation performance, growers must match applied water to deficits on a field by field, irrigation by irrigation basis. It is recommended that in addition to encouraging the use of on-farm conservation measures, those agencies responsible for technical assistance should focus efforts on training farmers to match applied water to pre-irrigation deficits.

SECTION 7. REFERENCES

Al-Katheeri, Naser S., 2001. *Using Chloride Technique to Estimate Irrigation Efficiency*, Civil Engineering Masters Thesis, New Mexico State University, Las Cruces, NM.

ASAE (American Society of Agricultural Engineers), 1990. *Evaluation of Furrow Irrigation Systems*, ASAE Surface Irrigation Committee, ASAE Standard EP419.

ASAE (American Society of Agricultural Engineers), 1998. *Soil and Water Terminology*, ASAE S526.1 MAR95, ASAE St. Joseph, MI 49085-9659 USA.

Bartolino, James R., and James C. Cole, 2002. *Ground-Water Resources of the Middle Rio Grande*: Circular 1222, U.S. Geological Survey (USGS).

Burkholder, Joseph, L., 1928. Report to the Chief Engineer, Submitting a Plan for the Flood Control, Drainage and Irrigation of the Middle Rio Grande Conservancy District, Volume I of III, MRGCD.

Cortez, Jose Roberto Deras, 1999. *Evaluation of Irrigation Efficiency and Nitrogen Leaching in Southern New Mexico*, Civil Engineering Masters Thesis, New Mexico State University, Las Cruces, NM.

Doneen, L. D., and D. W. Westcot, 1984. *Irrigation Practice and Water Management*: FAO Irrigation and Drainage Paper, Food and Agriculture Organization of the United Nations.

Garcia, Rudy, June 16, 2005. Personal communication with Valencia County NRCS Agent.

Gaume, Norm, 2002. *Report Preface, New Mexico Interstate Stream Commission, December 23, 2002*. Preface to S.S. Papadopulos and Associates, Inc. December 2002 report,. Evaluation of the Middle Rio Grande Conservancy District Irrigation System and Measurement Program, Boulder, CO.

Gensler, David, March 15, 2005. Personal Communication, Middle Rio Grande Conservancy District, 3/15/05.

Gensler, David, October 5, 2006. Comments to Draft Report, Middle Rio Grande Conservancy District, 10/5/05.

Herkenhoff, Gordon, June 8, 2005. Personal Communication, Indian Hills Farm, San Acacia, NM.

Hulsman, Robert B., 1983. *Irrigation Evaluations and Improvements in New Mexico to Conserve Water and Energy*: WRRI Report No. 174, New Mexico Water Resources Research Institute, New Mexico State University, Las Cruces, NM.

King, J. Phillip, and Julie Maitland, 2003. *Water for River Restoration: Potential for Collaboration between Agricultural and Environmental Water Users in the Rio Grande*

Project Area, report prepared for Chihuahuan Desert Program, World Wildlife Fund (WWF).

Merriam, John L., and Jack Keller, 1978. *Farm Irrigation System Evaluation: A Guide for Management*, Agricultural and Irrigation Engineering Department, Utah State University.

Nelson, D.C., April 24, 2006. Personal communication with D.C. Nelson of the National Agricultural Statistics Service (NASS).

NRCS (Natural Resource Conservation Service), 1997. "National Irrigation Guide, National Engineering Handbook, Part 652, Irrigation Guide, September 1997, Washington, DC.

NRCS (Natural Resource Conservation Service), 2004. Irrigation Efficiency Evaluations conducted by District Conservationist Rudy Garcia, Bernalillo County District Office.

Oad, Ramchand, and J. Phillip King, 2005. Irrigation Forbearance Feasibility Study in the Middle Rio Grande Conservancy District, MBK International, LLC, July 2005, Los Cruces, NM.

Ricke, Arlen, April 27, 2006. Personal communication with MRCS District Conservationist Arlen Ricke.

SSPA (S.S. Papadopulos & Associates, Inc.), 2002. *Evaluation of the Middle Rio Grande Conservancy District Irrigation System and Measurement Program*. Vol. 1, Main Text, prepared for the New Mexico Interstate Stream Commission, December 2002, Boulder, CO.

Sammis, Theodore W., 1980. *Demonstration of Irrigation Return Flow Water Quality in the Mesilla Valley, New Mexico*: WRRI Report No. 117, New Mexico Water Resources Research Institute, New Mexico State University, Las Cruces. NM.

Shomaker, J., 2000. *Historical and Current Water Use in the Middle Rio Grande Region*. Shomaker and Associates & Pioneerwest, Albuquerque, NM, prepared for the Middle Rio Grande Council of Governments.

Stewart, B. A., 1978. Critique of "An approach to measuring leaching of nitrate from freely drained irrigated fields," in D. R. Nielsen and J. G. MacDonald, *Nitrogen in the Environment*, Vol. 1, Nitrogen behavior in field soil, Academic Press.

USBR (U.S. Bureau of Reclamation), 1989-1998. *USBR Form 7-2045: Crop Production and Water Utilization Data*, Albuquerque Area Office.

USBR (U.S. Bureau of Reclamation), 1995. Middle Rio Grande Water Assessment Technical Memorandum, Estimates of Consumptive Use Requirements for Irrigated Agriculture and Riparian Vegetation, Denver Technical Service Center and Upper Colorado Region, Albuquerque Area Office.

USBR (U.S. Bureau of Reclamation), 1997. *Middle Rio Grande Water Assessment, Final Report*, Chapter 3 - Effects of Changing Land Use on the Aquifer and Water Supply, Albuquerque Area Office, U.S. Department of Agriculture (USDA), 1991, National

Engineering Handbook: Part 623, Section 15: Irrigation, U.S. Department of Agriculture, Soil Conservation Service.

USDA (U.S. Department of Agriculture), 1997. *National Engineering Handbook*: Part 652: Irrigation Guide, U.S. Department of Agriculture, Natural Resource Conservation Service.

USDA (U.S. Department of Agriculture), 2004. *2002 Census of Agriculture*. New Mexico and County Data, Volume 1, June 2004, www.usda.gov/census/census02/.

USDOI (U.S. Department of Interior), 2001. *Water Measurement Manual*, Bureau of Reclamation Water Resources Technical Publication, in cooperation with the U.S. Department of Agriculture.

USFWS (U.S. Fish and Wildlife Service), 1999. *Rio Grande Silvery Minnow Recovery Plan*: Albuquerque, U.S. Fish and Wildlife Service.

USFWS (U.S. Fish and Wildlife Service), 2002. *Southwestern Willow Flycatcher Recovery Plan*, Albuquerque, New Mexico.

USFWS (U.S. Fish and Wildlife Service), 2003. Memorandum: Biological and Conference Opinions on the Effects of Actions Associated with the Programmatic Biological Assessment of Bureau of Reclamation's Water and River Maintenance Operations, Army Corps of Engineer's Flood Control Operation, and Related Non-Federal Actions on the Middle Rio Grande, New Mexico, USFWS Regional Director, March 17, 2003, Albuquerque, NM.

WAM (Water Acquisition and Management Subcommittee of the Middle Rio Grande ESA Collaborative Program), 2006. WAM Comments to URS/NMSU MRGCD On-Farm Efficiency Study Draft Report.

Wilson, Brian C., 1997. Water Use by Categories in New Mexico Counties and River Basins and Irrigated Acreage in 1995: New Mexico State Engineer Office, Technical Report 49.

Wilson et al. (Wilson, Brian C., Anthony A. Lucero, John T. Romero, and Patrick J. Romero), 2003. *Water Use by Categories in New Mexico Counties and River Basins and Irrigated Acreage in 2000*: New Mexico State Engineer Office Technical Report 51.

APPENDIX 1

SAN ACACIA NORTH FIELD PICTURES

Alamillo Supply Canal

Field Layout

10-Inch Infiltrometer

Soil Sampling

Field Turnout

Field Inflow

APPENDIX 2

SAN ACACIA SOUTH FIELD PICTURES

Socorro Main Canal

Field Layout

Canal Turnout

Field Inflow

APPENDIX 3

WADE FIELD PICTURES

Field Layout

Infiltration Tests

Field Inflow

Field Turnout

A.Ott. Velocity Meter for Inflow

APPENDIX 4

HARRIS FIELD PICTURES

Socorro Main Canal

South View of Field

Canal Turnout

APPENDIX 5

CANDELARIA FIELD PICTURES

Field Layout

Infiltration Tests

Field Turnout

Soil Sampling

APPENDIX 6

HUBBLE-OXBOW FIELD PICTURES

Field Layout

Field Turnout

Lack of Laser Leveling in Field

Supply Canal

APPENDIX 7

EXAMPLES OF HEAD LOSS IN CANALS

Low Inflow Resulting from Drop in Canal Head (Wade Field)

Low Canal Head (San Antonio Ditch)

Low Canal Head (San Antonio Ditch)

Low Canal Head (Socorro Main Canal)

San Acacia South Field Supply Canal (arrow indicates high water mark)

APPENDIX 8
EXAMPLES OF CANAL LEAKAGE

Gun Club Lateral Turnout
(water flow should advance left)

Hubble-Oxbow Field
(supply canal developed breech)

Hubble-Oxbow Field
(supply canal is on bottom-right corner)

Hubble-Oxbow Field
(water shown is leakage on field that was not being irrigated at the time)