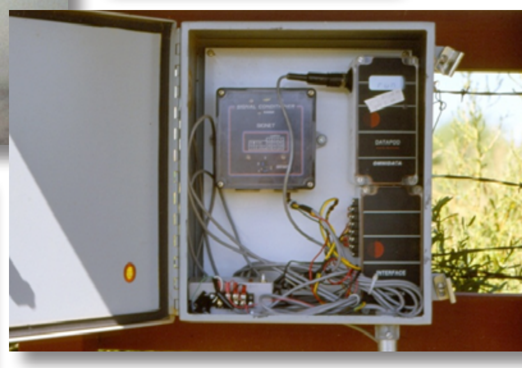
Prepared in cooperation with the Bureau of Reclamation and Colorado River Basin Salinity Control Forum

Analysis of Historic Agricultural Irrigation Data from the Natural Resources Conservation Service Monitoring and Evaluation for Grand Valley, Lower Gunnison Basin, and McElmo Creek Basin, Western Colorado, 1985 to 2003



Open-File Report 2014–1261

U.S. Department of the Interior
U.S. Geological Survey

Front cover: Top left, typical weather station measuring wind run, solar radiation, maximum-minimum temperatures, relative humidity, and precipitation; top right, pressure transducer to measure air pressure. Middle left, Datapod and housing box; middle right, Datapod, interface, and signal conditioner for a magnetic induction pipeline flow sensor. Bottom right, typical inflow installation with a stilling well and float potentiometer.

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By John W. Mayo

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U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia: 2015

Suggested citation:
Mayo, J.W., 2015, Analysis of historic agricultural irrigation data from the Natural Resources Conservation Service monitoring and evaluation for Grand Valley, Lower Gunnison Basin, and McElmo Creek Basin, western Colorado, 1985 to 2003: U.S. Geological Survey Open-File Report 2014–1261, 176 p., *http://dx.doi.org/10.3133/ofr20141261.*

ISSN 2331-1258 (online)

Acknowledgments

While the USGS study found discrepancies in some of the results of the NRCS evaluation, the author of the USGS study respectfully recognizes the work performed by the NRCS staff to complete such a complex and long-running effort of field data collection and data analysis. The number of site-years evaluated over three salinity control units, with each site often requiring daily visits, would be very difficult to replicate today. Given the time frame that the evaluation was begun (early 1980s), electronic data collection instruments and office computer technologies were then in their infancy. The analysis software for the NRCS evaluation was hand coded in the Basic programming language and run on an early Tandy home computer. If errors in definitions in the analysis software occurred at the beginning of the evaluation, it would have been difficult to recognize those errors, and even more difficult to have the software modified later. The pioneering efforts by the staff of the NRCS evaluation to overcome many technical obstacles along the way led to the successful completion of a complex and worthwhile project. Overall, the results of the NRCS evaluation have been accurate and consistent and have provided real value to the salinity control activities in the Colorado River Basin.

Thanks are extended to Frank Riggle, NRCS, former Assistant State Conservationist for Water Resources (retired), NRCS, Denver, Colo. The original project was envisioned by Frank, and without his frequent consultation, this report would not have been possible. Thanks also to Travis James, Colorado River Basin Salinity Coordinator, NRCS, Salt Lake City, Utah; Jason Peel, Irrigation Water Management Specialist, NRCS, Denver, Colo.; Bob Rayer, Soil Survey Project Leader, NRCS, Grand Junction, Colo.; Denis Reich, former Water Resource Specialist, CSU Extension Service, Grand Junction, Colo.; Dr. Calvin Pearson, Agronomist, CSU Western Colorado Research Station, Grand Junction, Colo.; Dr. Horst Caspari, Viticulturist, CSU Western Colorado Research Station, Grand Junction, Colo.; Tom Trout, Research Leader, USDA–Agricultural Research Service, Fort Collins, Colo.; Dick Bartholomay, CSU Extension Service (retired), Grand Junction, Colo.; Dr. Lorenz Sutherland, former Conservation Agronomist (retired), NRCS, La Junta, Colo., and John Sottilare, Bureau of Reclamation, Grand Junction, Colo.

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Conversion Factors and Datum

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch	2.54	centimeter (cm)
foot (ft)	0.3048	Meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	0.4047	square kilometer (km^2)
	Flow rate	
gallons per minute (gal/min)	0.0022	cubic feet per second

Altitude as used in this report refers to distance above mean sea level.

Analysis of Historic Agricultural Irrigation Data from the Natural Resources Conservation Service Monitoring and Evaluation for Grand Valley, Lower Gunnison Basin, and McElmo Creek Basin, Western Colorado, 1985 to 2003

By John W. Mayo

Abstract

The Natural Resources Conservation Service (NRCS) Monitoring and Evaluation (NRCS evaluation) for three salinity control units in western Colorado (Grand Valley, Lower Gunnison, and McElmo Creek) from 1985 to 2003 was a response to the Colorado River Basin Salinity Control Act (Public Law 93–320, July 24, 1974) and its amendments. The NRCS evaluated the effects on seasonal irrigation efficiency and deep percolation of irrigation water of various on-farm irrigation system improvements in the three salinity control units, and reported the results in a series of internal NRCS annual reports. Because of the large amount of effort and expense that went into the NRCS evaluation and the importance of the data to help quantify the changes to deep percolation, the NRCS has determined that having the evaluation results made public through a characterization and analysis of the results by the U.S. Geological Survey (USGS) could be of use to a wider audience of water managers and the general public. In 2011, the USGS, in cooperation with the Bureau of Reclamation and the Colorado River Basin Salinity Control Forum, began a study to evaluate the NRCS evaluation data to (1) document the methods of the evaluation, and (2) analyze and summarize the data collected during the evaluation. USGS scientists examined over 1,800 pages of NRCS evaluation annual reports, characterized the field methods of the evaluation, and rated the quality of the 292 site-years of data using criteria of completeness and internal consistency: in all, 268 records were usable, and 225 of the usable site-year records were of exceptional quality. USGS created a set of summary statistics and charts for the NRCS evaluation results. An order of technology improvement for the irrigation system types monitored in the NRCS evaluation was devised to rank the irrigation system types.

It was found that as irrigation systems improve in technology, deep percolation (DP) of irrigation water decreases and seasonal irrigation efficiency (SIE) increases. The variance of DP decreases as irrigation system technology improves, while variance of SIE did not change with improvement order. When DP was plotted against SIE, a fitted curve showed that DP decreases at a steep rate as SIE increases from about 10 to 35 percent; for values of SIE above 35 percent, DP decreases more slowly. This has implications for the funding of irrigation improvement projects by NRCS. USGS created soil moisture balance (SMB) spreadsheet models for 12 Grand Valley Unit sites for a detailed examination of the NRCS results at those sites. In achieving a fit of SMB model results to NRCS results, several types of potential discrepancies were found. USGS explored possible sources of quantifiable and nonquantifiable discrepancies in the NRCS evaluation methodology and results. Mean season-total crop consumptive use of irrigation water for all Grand Valley Unit NRCS evaluation sites was found to be about 10 percent lower than 1988 Colorado Irrigation Guide published values for the Grand Valley. Mean annual Grand Valley weather station precipitation from 1985 to 1995 was 7.2 inches, while NRCS reported mean annual precipitation for the same period was only 3.8 inches. To explore these discrepancies, sensitivity tests were performed on the SMB models by (1) changing weather station data sources, (2) using crop evapotranspiration stress correction or not, and (3) raising reference evapotranspiration to increase crop consumptive use to meet 1988 Colorado Irrigation Guide published values. There were no meaningful changes in SMB model results for either flood or sprinkler and microspray sites for variations of weather station precipitation data sources, for use of evapotranspiration stress correction or not, or for setting reference evapotranspiration at 100 percent of NRCS reported values. However, increasing reference evapotranspiration by 10 percent yielded possibly meaningful changes in SMB model DP and SIE for flood irrigation sites. For flood irrigation sites at 110 percent of reference evapotranspiration, mean DP decreased by 12.5 relative percent (2.5 inches) and mean SIE increased by 2.4 relative percent. For sprinkler and microspray irrigation systems at 110 percent reference evapotranspiration, DP and SIE changes were judged not to be meaningful because of the very low mean reported DP of 1.1 inches for these sites. These changes suggest that the use of NRCS evaluation results as part of baseline calculations of salt loading may have underestimated salt load savings achieved from improvements in irrigation technology

over the years. With these possible exceptions, results of the NRCS evaluation were found by USGS to be as accurate as could have been achieved at the time in such a complex, long-running data collection effort. Water managers will have to determine if suggested changes in NRCS evaluation DP and SIE results for flood irrigation sites warrant any recalibration of baseline salt loading calculations.

Introduction

The increasing salinity levels in water delivered to Mexico and the Lower Colorado River Basin states in the early 1970s created concern about economic damages to downstream water users, resulting in the enactment of the Colorado River Basin Salinity Control Act (Salinity Control Act). The primary purpose of the Salinity Control Act was "to authorize the construction, operation, and maintenance of certain works in the Colorado River Basin to control the salinity of water delivered to users in the United States and Mexico" (Public Law 93-320, June 24, 1974). The Salinity Control Act was amended in October 1984 through Public Law 98-569 to include language further directing agencies on their salinity control activities. Salinity control projects were initiated in Colorado starting with the Grand Valley Unit in 1979, the Lower Gunnison Basin Unit in 1988, and the McElmo Creek Unit in 1989.

In anticipation of the pending 1984 amendments to the Salinity Control Act, the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) initiated a program in 1982 to make a variety of irrigation improvements to reduce on-farm deep percolation (DP) and irrigation ditch seepage as part of the effort to reduce the salt load potential to the Colorado River. The NRCS irrigation improvement work included piping or lining irrigation ditches, improving the on-farm irrigation systems, and providing irrigation management assistance to landowners.

On-farm DP is excess irrigation water applied to the crop which infiltrates the soil below the crop root zone and enters the groundwater, whereas on-farm ditch seepage is water lost from irrigation water delivery ditches into the groundwater. Both DP and ditch seepage contribute to salt loading by dissolving the naturally-occurring salt in the soils which underlie the three salinity control units (Kenney and others, 2009) and ultimately transporting that dissolved salt to the Colorado River.

In 1982, the NRCS also identified the need to establish an irrigation monitoring and evaluation program (NRCS evaluation) for the Grand Valley Unit to assess the effects of irrigation improvements on deep percolation and ditch seepage. As a result, the NRCS developed the "Monitoring and Evaluation Plan, Colorado River Basin Salinity Control Program for Grand Valley Unit, Colorado and Uinta Basin Unit, Utah, July 1982" (U.S. Department of Agriculture, 1982). The NRCS evaluation was a long-term monitoring plan which described uniform guidelines and procedures to (1) assess the effectiveness of the NRCS program to reduce salt loading to the Colorado River, (2) identify the economic costs and benefits of the on-farm improvements in irrigation system technology and management, and (3) provide a significant study of the wetlands affected by the irrigation improvement projects and the NRCS-installed wildlife habitat improvement projects to determine and track the wildlife habitat lost and replaced (U.S. Department of Agriculture, 1982). Salt loading in the rivers was not directly measured or estimated in the NRCS evaluation. This monitoring and evaluation plan was later extended to the Lower Gunnison Basin Unit in 1992 and the McElmo Creek Unit in 1993.

The NRCS evaluation gathered a total of 292 site-years of irrigation application data between 1985 and 2003 at landowner sites in the three salinity control units. The evaluation sites were diverse in terms of crop types, acreage, soil types, and irrigation system types. The results of the evaluation were recorded by NRCS in internal annual reports beginning in 1985, which were shared with the Colorado River Basin Salinity Control Forum (Forum). The Forum was formed in 1973 by the Colorado River Basin States (Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming) to address the increasing salinity concentration in the Lower Colorado River and its impact on water users (Colorado River Basin Salinity Control Forum, 2013).

In recent years, the NRCS realized a need, in working with the Forum, to perform a more formal analysis of the NRCS evaluation data for use by Colorado River Basin water managers in other agencies and groups. In 2011, the U.S. Geological Survey (USGS), in cooperation with the Bureau of Reclamation and the Colorado River Basin Salinity Control Forum, began a study to evaluate the NRCS evaluation data to (1) document the methods of the evaluation, and (2) analyze and summarize the data collected during the evaluation. The NRCS agreed to gather the existing physical documents from the evaluation, transfer the raw site data to Microsoft Excel spreadsheets, and assist the USGS in understanding the dataset. The term "NRCS evaluation" is used throughout this report to refer to the NRCS monitoring and evaluation study, and the term "USGS study" refers to the USGS analysis of the NRCS evaluation.

Purpose and Scope of the USGS Study

The purpose of this report is to explain how and why the data were collected during the NRCS evaluation and to provide a published analysis for outside users to access and understand the results of the NRCS evaluation. NRCS has requested that records from the evaluation not be included in the final report. To protect the privacy of the landowners who participated in the NRCS evaluation, all references to personal information have been removed by NRCS from the evaluation data made available to the USGS study. The Forum's primary interest in the NRCS evaluation data was to improve the management of salt loading in the Colorado River; therefore, neither the on-farm economic analysis nor the wildlife habitat study results are included in the USGS study. The methodology used by the NRCS evaluation is reviewed and the site data are summarized in tables and charts from a variety of statistical perspectives. In addition, daily soil moisture balance (SMB) calculations are presented for 12 representative sites as spreadsheet-based models (SMB models) to test the per-irrigation event data reported in the NRCS evaluation.

Description of NRCS Evaluation Salinity Control Units

Irrigation practices in the Grand Valley Unit, the Lower Gunnison Unit, and the McElmo Creek Unit (fig. 1) were evaluated by the NRCS in western Colorado. Table 1 contains a summary of characteristics for the three evaluation salinity control units.

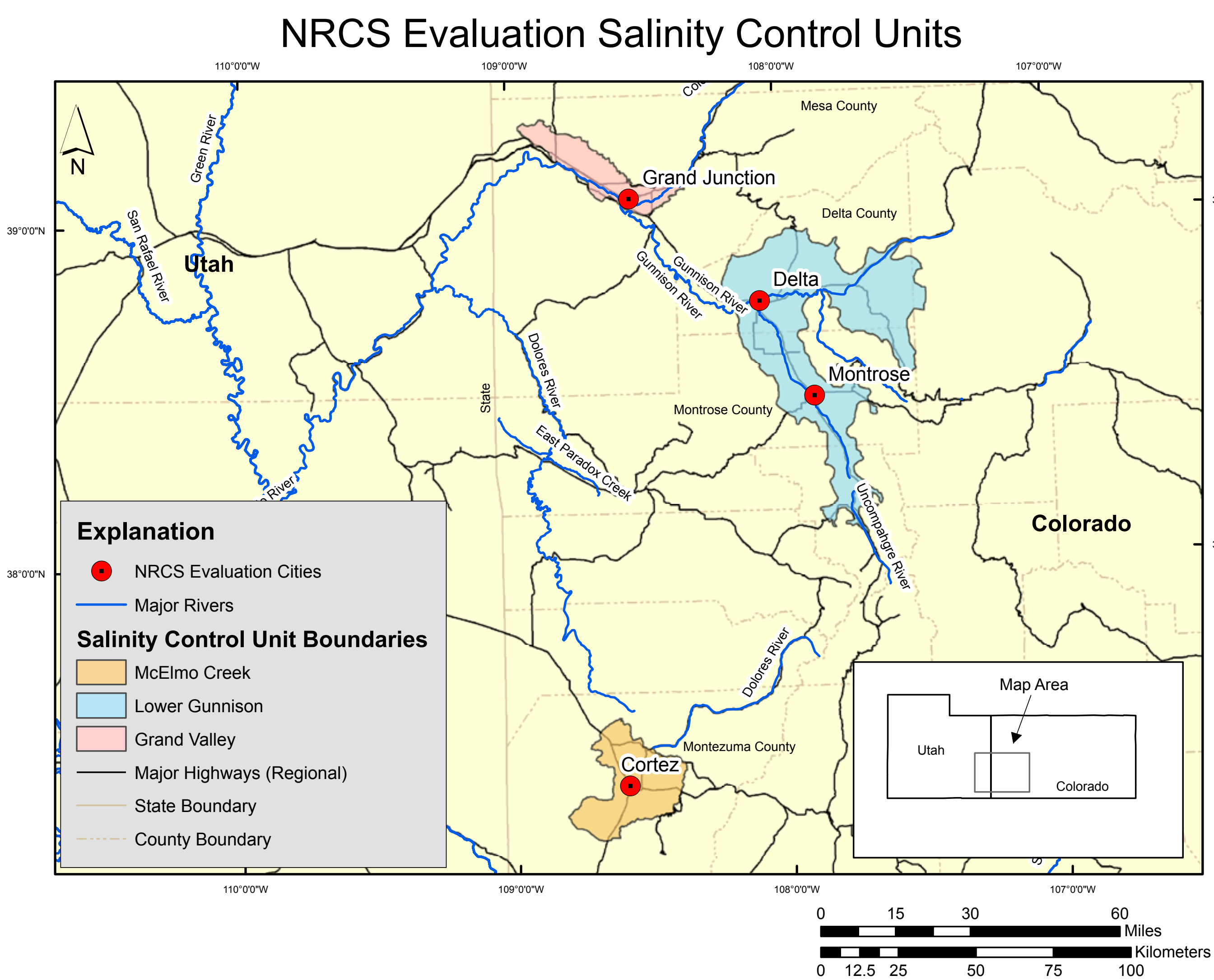


Figure 1. Natural Resources Conservation Service evaluation salinity control units in western Colorado.

Table 1. Characteristics of Grand Valley, Lower Gunnison, and McElmo Creek salinity control units.

[Unit, salinity control unit; GIS, geographic information system; %, percent]

Characteristic	Grand Valley Unit	Lower Gunnison Unit	McElmo Creek Unit	Source of Data by Unit
Total acres in unit	121,125	624,210	185,469	GIS calculations, Frank Riggle, Natural Resources Conservation Service, written commun., May 2, 2013
Total irrigated acres in unit	61,000	175,000	34,000	All irrigated lands, Colorado Water Conservation Board, Division of Water Resources, Colorado's Decision Support System, 2013
Main source(s) of irrigation water	Colorado River	Gunnison River and Uncompahgre River	Dolores River	U.S. Department of Agriculture, 1986–2003
Estimated length of canals and laterals (miles)	200 canal & 500 lateral	128 canal & 438 lateral	117 canal & 225 Lateral	John Sottilare, Bureau of Reclamation, Grand Junction field office; written commun., May 6, 2013
Annual precipitation- 2010 (inches)	11.00	8.71	15.50	U.S. Department of Commerce, 2013
Annual irrigation water diversion to unit (acre-feet per year)	1,550,000	519,000	105,200	John Sottilare, Bureau of Reclamation, Grand Junction field office; written commun., May 6, 2013
Total salt load contributed by unit (tons per year)	580,000	1,300,000	194,684	Frank Riggle, Natural Resources Conservation Service, written commun., May 3, 2013
Agricultural salt load contributed by unit (tons per year)	537,000	840,000	154,009	Frank Riggle, Natural Resources Conservation Service, written commun., May 3, 2013
Median farm size (acres)	16	440 (Delta County), 46 (Montrose County)	57	National Agricultural Statistics Service, U.S. Department of Agriculture, 2009
Mean field size (acres)	8.3	32.7	23.9	Colorado Water Conservation Board, 2013 (Grand Valley Unit), National Agricultural Statistics Service, 2009 (Lower Gunnison and McElmo Creek Units)
Predominant type of irrigation system	89.1% improved flood, 7.5% sprinkler, 3.4% microspray & drip	86.5% Improved flood, 11.4% sprinkler, 2.1% microspray & drip	67.6% sprinkler, 32.2% improved flood, 0.2% microspray & drip	U.S. Department of Agriculture, 2012
Predominant crops	Alfalfa, pasture grass, hay, corn, apples, peaches, grapes, pears	Alfalfa, pasture grass, hay, corn, dry beans, apples, peaches, grapes, pears	Alfalfa, pasture grass, hay, wheat, fruit	National Agricultural Statistics Service, 2009 (Grand Valley Unit), Delta County Development Inc., 2013 (Lower Gunnison Unit), Magnan and Seidl, 2004 (McElmo Creek Unit)
Mean altitude (feet above sea level)	4,700	5,000	6,400	U.S. Department of Agriculture, 1986–2003
County	Mesa	Delta, Montrose	Montezuma	U.S. Department of Agriculture, 1986–2003
Principal cities	Grand Junction, Fruita, Palisade	Delta, Montrose	Cortez	U.S. Department of Agriculture, 1986–2003

USGS Study Methods

Interviews with NRCS Evaluation Staff

Interviews were conducted with current and retired NRCS staff who participated in the NRCS evaluation. These interviews provided insight into how the field data collection was accomplished and how the collected data were analyzed. The original raw data records of the NRCS evaluation were not retained after the completion of the project, so many details of how the evaluation was conducted are unavailable today. A partial reconstruction of the evaluation procedures and analytical methods was possible from personal recollection of the NRCS evaluation staff, primarily Frank Riggle, retired (formerly Assistant State Conservationist for Water Resources, USDA-NRCS, Colorado), who helped initiate the NRCS evaluation project in 1984. A series of presentations and discussions was given by USGS for various staff from NRCS to elicit feedback at several stages of the USGS study. This was helpful in refining the USGS study analysis methods, particularly for the soil moisture balance models.

NRCS Printed Documentation

More than 1,800 pages of printed NRCS evaluation annual reports and documentation were collected by NRCS staff and made available to the USGS. This documentation included all of the annual monitoring and evaluation reports for the three salinity control units, as well as documents that described the creation of the project. For analysis purposes, specific irrigation data from the NRCS Monitoring and Evaluation (M&E) reports were entered into two Microsoft Excel spreadsheets, one for season total results and one for individual irrigation event results. These documents were also scanned to an Adobe Acrobat PDF file (Adobe Systems, Inc., 2013) for archiving. To protect the privacy of the landowners who participated in the NRCS evaluation, all references to personal information have been removed by NRCS from the evaluation data made available to the USGS for this study. The USGS is not able to provide access to the redacted NRCS evaluation data. Independent researchers should apply directly to NRCS for access to these datasets: (1) the NRCS evaluation annual and irrigation event data by site in spreadsheet form, (2) the USGS study analysis and SMB spreadsheets, and (3) an Adobe Acrobat PDF file containing the redacted scanned NRCS evaluation annual reports plus supporting documents. See appendix 1 for information on requesting these datasets from NRCS.

Characterization of NRCS Evaluation Field Methods

The NRCS evaluation field data collection methods were described and analyzed by the USGS study from information gathered in personal interviews, printed documentation, and written recollection of early field methods by one of the initial investigators of the NRCS evaluation (Frank Riggle, Natural Resources Conservation Service (NRCS) retired, written commun., June 27, 2011).

Analysis of the NRCS Evaluation Dataset

The NRCS and the USGS jointly developed the evaluation raw data spreadsheets for analysis. This dataset was reviewed by NRCS and USGS to rate the quality of the various site-year records, based on the criteria of completeness of the records and of internal consistency of the record data. Of the 292 total site-year records in the NRCS evaluation annual reports, this review led to the elimination of 24 site-year records, leaving 268 usable site-year records. A further qualification of the 268 usable site-year records yielded 225 gold standard records that were deemed to be most reliable in terms of completeness and internal consistency. Both the usable and gold standard site-year record sets were analyzed by the USGS using the statistical package S+ (Tibco Software, Inc., 1988–2008) and included summary statistics, scatter plots, histograms, box plots, ranked multiple comparison statistics using Tukey's method, geographic information system (GIS) site maps created in ArcMap (Environmental Systems Research, Inc., 1999–2010), and SMB Microsoft Excel spreadsheet models (Microsoft Corporation, 2010) for a selected set of sites.

NRCS Evaluation Methods

Irrigated sites were selected to represent the variety of crops and irrigation system types common in the evaluation units. The NRCS monitoring was designed to capture changes to the net soil water balance from a variety of irrigation system improvements. The sample set needed to be (1) large enough to cover the range in irrigation system types, crops, soils, and geography typical in the salinity control units, and (2) collected over a long enough span of time to capture a range in annual conditions and to capture changes over time. It should be emphasized that the NRCS monitoring and evaluation was not designed to create a statistically significant dataset. Sites were selected to cover the range in conditions and depended on identifying landowners willing to cooperate in the study. The number of sites sampled each year and the number of sites sampled in total were predominantly driven by financial constraints and available staff.

NRCS Data Collection Procedures

Each irrigation event was to be recorded throughout the irrigation season for each site. From the NRCS Monitoring and Evaluation Plan, 1984, "Data will be collected to determine the amount of irrigation water infiltrated into the soil." "For each site on-farm water budgets will be prepared for each irrigation event, starting with pre-plant or start of growing season until crop harvest. The most significant output from the water budget is deep percolation." The proposed water budget was defined as "… deep percolation equals the amount of inflow plus rainfall prior to or during the irrigation event, less surface runoff and the net irrigation requirement [expressed as the amount of water needed to bring the soils profile to field capacity]" (U.S. Department of Agriculture, 1982). The NRCS in Colorado elected to use newly developed automated water measurement and digital recording equipment to capture more complete irrigation event data for each site for the full irrigation season.

Basic characteristics recorded at the start of the irrigation season for each site included the type of irrigation system, length of field run (feet), field slope (percent), field size (acres), soil type, crop type, planting and harvest dates, specific soil type, and soil water holding capacity. Periodic site data collected during the irrigation season included daily precipitation amount, irrigation event dates and durations, and water inflow to the field and outflow from the field during irrigation events. The initial soil water balance was estimated at the beginning of the season and was also calculated using the water balance method at the start and finish of each irrigation event. Reference or potential evapotranspiration (ET_p) was calculated daily using data collected from two NRCS-operated weather stations. Crop evapotranspiration (ET_c) was estimated using a time-dependent crop coefficient (K_c). The original NRCS Monitoring and Evaluation Reports used the abbreviation ET_r for potential or reference evapotranspiration, and ET_a for actual or crop time-dependent evapotranspiration. The abbreviations ET_r and ET_p, therefore, represent the same potential ET values, and ET_a and ET_c represent the same crop ET values. Throughout this report ET_p and ET_c will be used as they represent current usage.

The climate data collected from the NRCS weather stations to determine daily ET_p included maximum and minimum temperature, relative humidity, wind run, solar radiation, and precipitation. The weather stations were typical Campbell Scientific instruments available in the 1980s. The Grand Valley Unit had two NRCS weather stations, the Lower Gunnison Unit had two weather stations, and the McElmo Creek Unit is assumed to have had one weather station (no record or site map is available). Daily ET_p was calculated from the climate data using the Modified Penman equation for alfalfa (Grand Valley Annual Report, 1985, *in* U.S. Department of Agriculture, 1986–2003). Initially the climate data were electronically transmitted from weather stations in each evaluation unit through the NRCS Snow Survey and Water Supply Forecasting Program (SNOTEL Network). The decision was made in 1985 to instead transmit the data through a radio-telemetry system due to a variety of technical problems associated with using the SNOTEL Network.

Precipitation was measured at the two centrally located weather stations and also by rain gages at individual sites. Precipitation results for each site were published in annual reports for each salinity control unit. Daily ET_p and weather data were not included in the printed annual reports.

NRCS Soil Moisture and Crop Evapotranspiration Determination

Each soil type has a specific water holding capacity or field capacity (FC), which is the maximum amount of moisture that the soil can hold at a saturated equilibrium condition (Veihmeyer and Hendrickson, 1949). Field capacity for the initial soil types at the initial NRCS evaluation sites was determined empirically using a pressure plate technique in the U.S. Department of the Interior Bureau of Reclamation (Reclamation) laboratory facilities in Grand Junction, Colorado (Frank Riggle, NRCS, written commun., February 13, 2013). The water in the soil root zone has a lower practical limit called the wilting point (WP), below which irreversible damage to the plants occurs. Available water in the root zone is thus equal to FC minus WP. In irrigation management, it is typically assumed that 50 percent of the available water is readily available to the plant. When the water in the root zone falls below the readily available level, the crop is said to be stressed (U.S. Department of Agriculture, 1997).

Each crop type (corn, wheat, grapes, among others) has a specific evapotranspiration crop coefficient curve (K_c), which is a time-dependent multiplier that varies with the growth stage of the crop (Allen and others, 1998). The ET_p multiplied by the appropriate value of K_c determines the ET_c for the crop stage based on the number of days from planting. Further adjustment of ET_c was made by the NRCS for crop stress, although the method used was not documented in the annual reports. When the root zone water falls below the readily available level, crop stress suppresses the plant's ability to transpire, which reduces the effective ET_c. Today, crop stress is usually modeled as a linear multiplier for ET_c which decreases from 1 to 0 as soil moisture declines from the not readily available level to the wilting point (Allen and others, 1998).

Soil water deficit (SWD) is the amount of water required to refill the crop root zone to bring the current soil moisture conditions up to FC for the given soil type. In 1985 and 1986, season-beginning (initial) soil moisture was determined by gravimetric analysis of soil samples (Frank Riggle, NRCS, written commun., February 13, 2013). For subsequent years, the gravimetric initial field SWD determination, if performed, was not reported. It was most likely determined at the beginning of the irrigation season by a hand estimate in the field. The 1990 Grand Valley Unit annual report states “All sites were probed before the start of the irrigation season to estimate soil moisture deficit before irrigation” (Grand Valley Annual Report, 1990, U.S. Department of Agriculture, 1986–2003).

The SWD at the start of the first irrigation event of the season was calculated using the initial SWD, adding any daily precipitation, and subtracting the stress-corrected daily ET_c from the season start date to the start date of the first irrigation. Subsequent values of start-of-irrigation SWD were determined by taking the SWD at the end of the previous irrigation, adding daily precipitation, and subtracting daily stress-corrected ET_c from the end date of the previous irrigation event to the start date of the subsequent irrigation event. The SWD at the end of each event was calculated as the event beginning SWD minus the infiltrated depth of water. If the infiltrated depth exceeded the beginning SWD, then the excess was declared to be DP. There is no documentation of lab tests being used to determine the ending SWD.

The net amount of irrigation water applied to the crop in an irrigation event is calculated as

$$\text{Infiltrated Depth} = \text{Irrigation Inflow} - \text{Irrigation Outflow} \quad (1)$$

where

Infiltrated depth is the total net irrigation water, in inches, the field receives during the irrigation event,

Irrigation inflow is the total irrigation water, in inches, entering or applied to the field during the irrigation event, and

Irrigation outflow is the total irrigation water, in inches, that exits the field as runoff (“tail water”).

When the total infiltrated depth exceeds the SWD for a particular irrigation event, the excess water is assumed to enter the soil below the root zone as DP. This is a concern because it may eventually discharge to nearby rivers, carrying with it a load of salt and other minerals that have been leached from the soil. DP for the NRCS evaluation was calculated as

$$DP = \text{Infiltrated Depth} - \text{Beginning SWD} \quad (2)$$

where

DP is deep percolation in inches of water,

Infiltrated Depth is the net irrigation water in inches applied during the irrigation event, and

Beginning SWD is the soil water deficit in inches existing at the start of the irrigation event.

This definition of DP by the NRCS evaluation is incomplete, as there is no inclusion of precipitation or crop evapotranspiration in the definition. Because the NRCS records clearly indicate that the effects of precipitation and crop evapotranspiration were taken into account when calculating DP for the evaluation sites, it must be assumed that this definition of DP (eq. 2) was simply in error when it was first written in the NRCS annual reports, and that the error was apparently propagated to later reports.

NRCS Equipment

The NRCS made the decision to purchase newly developed automated sensors and digital recorders to reduce the staffing needs and odd hours required to obtain a complete full-season irrigation dataset. Equipment names are for informational purposes only and do not constitute any type of product or other endorsement (table 2).

The decision was made in 1984 to start monitoring with sensors and recorders to equip 20 field sites in the Grand Valley Unit, and to establish two remote automated weather stations to obtain the climate data to calculate crop evapotranspiration and collect general precipitation information. In addition, manually read rain gages at each evaluation site were used to adjust the precipitation to represent more local conditions. The automated sensors and digital recorders arrived in early 1984 and were tested to understand their calibration, performance, and installation requirements. It was decided that the 20 sets of irrigation flow measurement equipment were sufficient to install 16 sites and to retain four complete sets of replacement equipment for use during the irrigation season, due to performance concerns with the newly developed installation configurations of using the flow sensors combined with digital reorders (Grand Valley Annual Report, 1985, *in* U.S. Department of Agriculture, 1986–2003).

The equipment purchased was relatively new technology and had not been extensively used for irrigation flow measurements. The 1984 irrigation season was used primarily as an installation period and provided a good learning experience in the use of automated flow recording equipment.

The sensors were run through a variety of tests to ensure performance and to design the best installation configurations. Much of the equipment had not been used for an irrigation monitoring field installation and the recorders needed moisture and climate protection. A variety of equipment boxes were adapted to provide needed security and climate protection (Grand Valley Annual Report, 1985, *in* U.S. Department of Agriculture, 1986–2003).

Table 2. Typical equipment purchased for Natural Resources Conservation Service evaluation.

Manufacturer	Product	Model Number
Omnidata International	Datapod	DP211
Omnidata International	Datapod	DP112
Omnidata International	Datapod	DP219
Omnidata International	Interface	301
Omnidata International	Easy Logger	EL824-GC
Omnidata International	Polycorder	516GE-64-A
Drexelbrook	Linear strip gauge	700-701-015
Drexelbrook	Signal conditioner	(unknown)
Robinson-Halpern	Pressure transducer	152BP015DG35
Wescor, Inc.	Pressure transducer	(Unknown)
Signet	Mighty-Mag flow sensor	MK565
(manufacturer unknown)	Soil moisture blocks (Gypsum)	(unknown)
Wescor, Inc.	Datapod DPX Series	DPX-WL-01(3)
Scientific Engineering, Inc.	Repeater	(Unknown)
Tandy Corporation	Computer	Tandy 2000
Campbell Scientific	Weather station	(unknown)

Figures 2 through 11 illustrate various field installations of monitoring equipment used in the NRCS evaluation.

Figure 2. Photograph of a linear strip gage installed in an existing concrete weir.

Figure 3. Photograph of a typical installed broad-crested weir with a linear strip gage.

Figure 4. Photograph of a typical inflow installation with a stilling well and float potentiometer.

Figure 5. Photograph of a typical weather station measuring wind run, solar radiation, maximum-minimum temperatures, relative humidity, and precipitation.

Figure 6. Photograph of a typical outflow installation with pressure transducer.

Figure 7. Photograph of a Datapod and housing box.

Figure 8. Photograph of a Datapod, interface, and signal conditioner for a magnetic induction pipeline flow sensor.

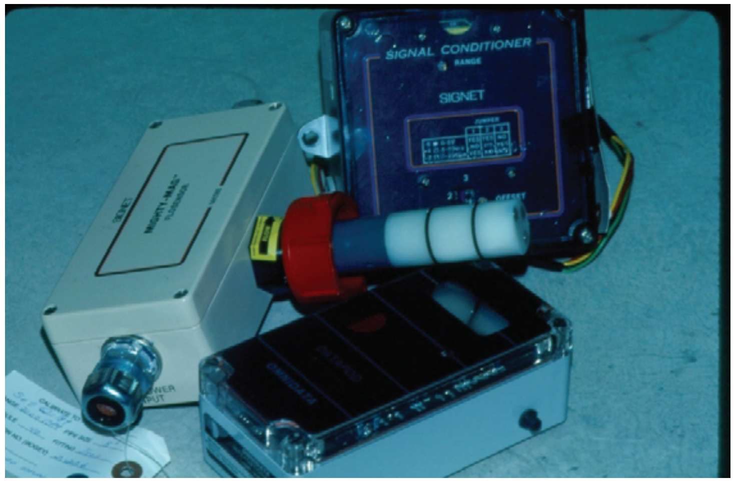


Figure 9. Photograph of a magnetic induction flow sensor with signal conditioner and Datapod recorder.

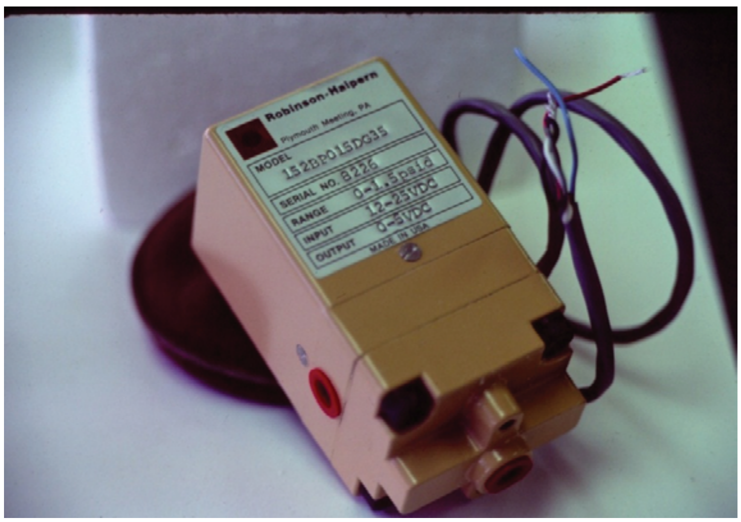


Figure 10. Photograph of a pressure transducer to measure air pressure.

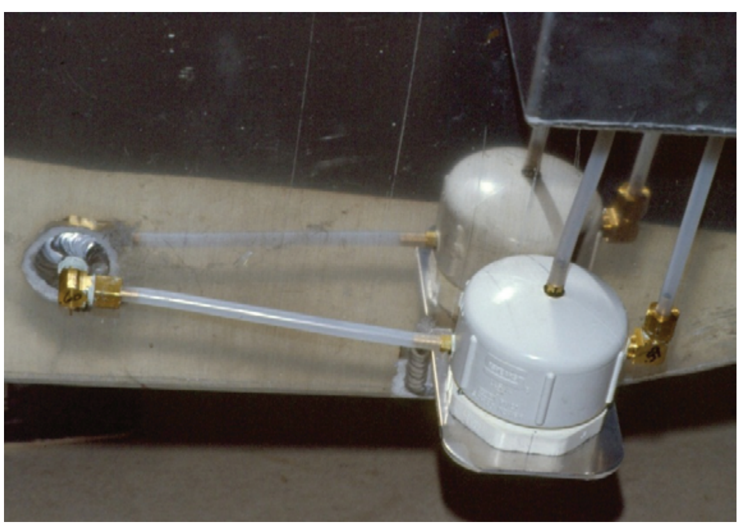


Figure 11. Photograph of a closed cell to generate air pressure for the pressure transducer designed by Tom Trout, USDA-Agricultural Research Service, Kimberly, Idaho.

NRCS Field Procedures

To capture the net water on and off each site, the inflow was measured at the point where the water entered the head of the field and the outflow was measured at the point where all the runoff (tail) water left the end of the field. Thus, the calculated DP amounts include any head ditch and tail water ditch seepage in addition to water infiltrated in the field furrows.

The first four field sites in the Grand Valley Unit were installed in the spring of 1984 to test the field data collection equipment and installation. Although the automated data collection equipment provided the sampling frequency to collect a complete dataset, field staff were required to visit each site often enough to ensure the equipment and installation was functioning properly. Sediment in weirs, failed batteries, overheated recorders, wet electrical connections, debris, sensor drift, and other performance problems frequently compromised the data collection. During the first season, each site was visited at least once every day, particularly during the irrigation events, to ensure a complete and reliable dataset. In 1984, partial data were collected on the initial four sites but the dataset was not complete enough to be used in generating an annual summary report. Based on the lessons learned from installing the first 4 sites, 12 additional sites were installed during the 1984 irrigation season in preparation for the 1985 irrigation season.

During the 1984 irrigation field season, it was determined that repairing the data collection equipment in the field was not practical, and resulted in lost data when it occurred during an irrigation event. The NRCS evaluation team decided to install 16 total sites and have 4 complete sets of replacement equipment. To have sufficient staff to cover the 16 sites distributed throughout the Grand Valley, 2 individuals were assigned for each to visit 8 sites per day during irrigation events. They carried two complete sets of sensors, recorders, and spare batteries. If a sensor or recorder was not working properly, a new one was installed immediately and the questionable equipment unit was returned from the field for repair or calibration. Although complete failures only occurred occasionally, having a ready replacement reduced the loss of irrigation event data.

The 1985 Grand Valley Unit irrigation data were reviewed by NRCS State Office and NRCS West National Technology staff for collection method, completeness, and accuracy. The staff determined that the data represented a complete and accurate set of field data and were as good as could be collected. Their technical review also supported the need for each site to be visited periodically to ensure the weirs were functioning, the sensors were clear and calibrated correctly, and the recorders were operating properly. For the field data collected by the NRCS from 1985 through 1995, each site was visited and maintained every 2 to 3 days during the field season, and equipment was calibrated and checked every day during the irrigation events (Grand Valley Annual Report, 1989, *in* U.S. Department of Agriculture, 1986–2003).

NRCS Dataset

The NRCS collected data from 1985 through 2002 in the Grand Valley Unit, 1991 through 2003 in the Lower Gunnison Unit, and for 1993 in the McElmo Creek Unit. These data represent full season and complete irrigation data for the sites sampled. The number of irrigation events and the total water balance reflect the typical performance for all irrigation events through a full season.

Tables 3 through 5 show data content summaries of the various annual reports for each of the three evaluation units. The site counts shown are the total number of sites, the number of site-year records usable in the USGS analysis, and the number of gold standard site-year records. It can be seen that the reports between 1985 and 1996 have the largest number of evaluation sites, and that most of the reports included a sufficient level of detail to be usable. Individual irrigation events were reported for most of those years, and ET_c and precipitation records were shown.

Table 3. Natural Resources Conservation Service evaluation annual report summary for the Grand Valley Unit, 1985 to 2003.

[ET_c, crop evapotranspiration; NA, not applicable; good map detail, roads and rivers shown; fair map detail, a few physical features shown; poor, no physical features shown]

Grand Valley Unit										
Year	Total Sites	Usable Site Records	Gold Standard Site Records	Annual Report	Site Map in Annual Report	Site Numbers on Map	Map Detail Level	Precipitation Data by Site	ET_c Data by Site	Irrigation Event Data by Site
1985	16	14	14	Yes	No	NA	NA	Yes	Yes	Yes
1986	16	15	15	Yes	Yes	No	Good	Yes	Yes	Yes
1987	16	16	16	Yes	No	NA	NA	Yes	Yes	Yes
1988	18	18	18	Yes	Yes	No	Good	Yes	Yes	Yes

Table 3. Natural Resources Conservation Service evaluation annual report summary for the Grand Valley Unit, 1985 to 2003.—Continued

[ET_c, crop evapotranspiration; NA, not applicable; good map detail, roads and rivers shown; fair map detail, a few physical features shown; poor, no physical features shown]

Grand Valley Unit										
Year	Total Sites	Usable Site Records	Gold Standard Site Records	Annual Report	Site Map in Annual Report	Site Numbers on Map	Map Detail Level	Precipitation Data by Site	ET_c Data by Site	Irrigation Event Data by Site
1989	19	19	19	Yes	Yes	Yes	Good	Yes	Yes	Yes
1990	25	25	25	Yes	Yes	Yes	Poor	Yes	Yes	Yes
1991	23	23	23	Yes	Yes	Yes	Poor	Yes	Yes	Yes
1992	24	24	24	Yes	Yes	Yes	Fair	Yes	Yes	Yes
1993	21	22	22	Yes	Yes	Yes	Poor	Yes	Yes	Yes
1994	12	12	12	Yes	Yes	Yes	Poor	Yes	Yes	No
1995	8	8	8	Yes	Yes	Yes	Poor	Yes	Yes	No
1996	0	0	0	NA	NA	NA	NA	NA	NA	NA
1997	0	0	0	NA	NA	NA	NA	NA	NA	NA
1998	0	0	0	Yes[1]	Yes	Yes[2]	Poor	NA	NA	NA
1999	11	4	0	Yes	No	NA	NA	No	No	Yes
2000	7	7	0	Yes	No	NA	NA	No	No	Yes
2001	3	2	0	Yes	No	NA	NA	No	No	Yes
2002	5	2	0	Yes	No	NA	NA	No	No	Yes
2003	0	0	0	NA	NA	NA	NA	NA	NA	NA
Total sites	224	211	196	NA	NA	NA	NA	NA	NA	NA

[1]Grand Valley 1998 annual report contains site summary from 1985 to 1995.

[2]Grand Valley 1998 annual report site map shows 1995 sites.

Table 4. Natural Resources Conservation Service evaluation annual report summary for the Lower Gunnison Unit, 1990 to 2003.

[ET_p, crop evapotranspiration; NA, not applicable; good map detail, roads and rivers shown; fair map detail, a few physical features shown; poor, no physical features shown]

Lower Gunnison Unit										
Year	Site Count	Usable Site Records	Gold Standard Site Records	Annual Report	Site Map in Annual Report	Site Numbers on Map	Map Detail Level	Precipitation Data by Site	ET_c Data by Site	Irrigation Event Data by Site
1990	0	0	0	Yes	Yes	Yes[1]	Good	NA	NA	NA
1991	3	3	0	Yes	No	NA	NA	Yes	No	No
1992	5	3	3	Yes	No	NA	NA	Yes	Yes	Yes
1993	7	7	7	Yes	Yes	Yes	Fair	Yes	Yes	Yes
1994	6	6	6	Yes	Yes	Yes	Fair	Yes	Yes	No
1995	6	6	6	Yes	Yes	Yes	Fair	Yes	Yes	Yes
1996	4	2	1	Yes	Yes	Yes	Fair	Yes	Yes	Yes
1997	0	0	0	NA	NA	NA	NA	NA	NA	NA
1998	0	0	0	NA	NA	NA	NA	NA	NA	NA
1999	5	5	0	yes[2]	No	NA	NA	No	No	Yes

Table 4. Natural Resources Conservation Service evaluation annual report summary for the Lower Gunnison Unit, 1990 to 2003.—Continued

[ET_p, crop evapotranspiration; NA, not applicable; good map detail, roads and rivers shown; fair map detail, a few physical features shown; poor, no physical features shown]

Lower Gunnison Unit										
Year	Site Count	Usable Site Records	Gold Standard Site Records	Annual Report	Site Map in Annual Report	Site Numbers on Map	Map Detail Level	Precipitation Data by Site	ET_c Data by Site	Irrigation Event Data by Site
2000	13	13	0	Yes	No	NA	NA	No	No	Yes
2001	7	3	0	Yes	No	NA	NA	No	No	Yes
2002	2	1	0	Yes	No	NA	NA	No	No	Yes
2003	4	2	0	Yes	No	NA	NA	No	No	Yes
Totals	62	51	23	NA	NA	NA	NA	NA	NA	NA

[1]No site data were published in Lower Gunnison annual report for 1990, but site map shows two sites.

[2]Lower Gunnison annual report for 1999 is shown in Grand Valley 1999 annual report.

Table 5. Natural Resources Conservation Service evaluation annual report summary for the McElmo Creek Unit, 1993.

[ET_c, crop evapotranspiration; blank cells, not applicable]

McElmo Creek Unit										
Year	Site Count	Usable Site Records	Gold Standard Site Records	Annual Report	Site Map in Annual Report	Site Numbers on Map	Map Detail Level	Precipitation Data by Site	ET_c Data by Site	Irrigation Event Data by Site
1993	6	6	6	Yes	No			Yes	Yes	Yes

No Grand Valley Unit sites were monitored during 1996 through 1998, and no Lower Gunnison Unit sites were monitored during 1997 and 1998. Starting in 1999 and continuing through 2003, data collection and analysis was managed by the Colorado State University Cooperative Extension (CSU Extension) program rather than the NRCS local field staff. There were a small number of Grand Valley Unit sites monitored during this period, with more focus placed on the Lower Gunnison Unit. The field methods for the 1999 through 2003 period are not as well documented, but the same field equipment was used as in the earlier evaluations, and data collection techniques were assumed to have been generally consistent with the earlier methods.

A review of the post-1996 evaluation data for the Grand Valley and Lower Gunnison Units indicates that many of the sites appear to have partial data and may or may not have captured every irrigation event through the full season. The CSU monitoring was done with limited staff and limited equipment covering both the Grand Valley and Lower Gunnison Units. The lack of available field staff and limited equipment resulted in partial datasets and is not necessarily a complete and reliable set of full season irrigation data.

Because of the questionable reliability of post-1996 data, the subset of data from 1985 to 1996 for the Grand Valley and Lower Gunnison Units is considered the most complete and consistent set of data, and is referred to by the NRCS as the gold standard data (Frank Riggle, NRCS, oral commun., June 27, 2012). This terminology is therefore also used in this report. Determination of data quality is discussed in detail in the section “Site-Year Record Quality Determination.”

The site map columns in tables 3 through 5 indicate that many annual reports up to 1998 include site maps with the site numbers shown and have a level of detail in the base map that allows for general geospatial location of the sites using GIS methods. In particular, the inclusion of roads and highways enhances the ability to locate the sites. After 1998, none of the annual reports include site maps. Some of the maps do not include site numbers or have little or no detail in the base map, which makes it impossible to georeference the sites to actual features (roads) in GIS. The GIS site maps are shown in the section titled “Creation of NRCS Evaluation Site Maps.”

USGS Study Findings on NRCS Evaluation

NRCS Annual Reports

The NRCS evaluation was originally intended for program support and to direct the NRCS as to where and how to best make irrigation improvements for salinity control. The evaluation was not done to support research other than directing the agency's salinity control work. The original paper reports were filed in the NRCS field offices for each evaluation unit. Because the original data files for the NRCS evaluation were not retained after the end of the evaluation, the paper annual reports represent the remaining documentation of the irrigation monitoring. For the USGS study, the NRCS was able to recover the paper reports from multiple field offices. The collected irrigation monitoring data are shown in all of the annual reports as season-total values for each site. For some evaluation years, and for some of the evaluation units, the paper reports also include the original per-event irrigation data. If an annual report only shows season-total summary information but does not include the individual irrigation event records, the individual event data were not found and is considered to be no longer available.

The annual reports always included the irrigation season summary data for each site monitored, and for some years the annual reports also included individual irrigation event data for each site. Data for each site and for each irrigation season included the following items:

- Site identification number
- Irrigation system type
- Crop type
- Field size (acres)
- Number of irrigations
- Irrigation water inflow (inches of water)
- Irrigation water outflow (inches of water)
- Infiltrated depth (inches of water)
- Precipitation (inches of water)
- ET_c (inches of water)
- Deep percolation (inches of water)
- Seasonal application efficiency (percent)

For the years when individual irrigation events were also reported, each site report also includes these data per site:

- Irrigation event number
- Irrigation start date
- Irrigation event duration (hours)
- Advance time – the length of time it takes for irrigation water to flow from the top to the bottom of a field when using flood irrigation (hours)
- Duration of each irrigation set (hours),
- Mean infiltration per event (inches of water)
- Number of furrows
- Mean furrow flow (gallons of water per minute)
- Inflow and outflow (inches of water)
- Soil water deficit (SWD) before the irrigation event (inches of water)
- Infiltrated depth at the end of the irrigation event (inches of water)

- Precipitation (inches of water)
- SWD after the irrigation event (inches of water)
- Total ET_c (inches)
- Deep percolation (inches)
- Irrigation application efficiency (percent)

NRCS Methods

The USGS study was able to generally characterize the field methods of the NRCS evaluation. Due to the long time span of the NRCS evaluation (19 years) and personnel changes after the suspension of evaluations from 1997 through 1998 in all three evaluation units, there were changes in the field methods over time that were not fully documented. Because the primary records of the evaluation were not retained, many of these differences cannot be ascertained with certainty. Implications for the issues noted in this section are discussed in the later section “Potential Discrepancies in Results between SMB Models and NRCS Evaluation.”

The use of instruments to measure the field inflow and outflow are judged to be sufficiently accurate. The NRCS evaluation relied on calculated soil moisture values at the start and end of each irrigation event rather than a laboratory measurement of soil moisture at those times. If consistent and documented laboratory testing had been done, a degree of “ground truthing” would have been available to check the accuracy of the SMB calculations.

Many individual irrigation event records are flagged in the results tables with the comment “Corrections have been applied to data,” but the specific nature of these corrections was not documented. For some of the individual irrigation event records, the internal soil moisture accounting does not add up mathematically, and no explanation is given for this inaccuracy. For the records starting in 1999, no ET_c or precipitation was documented in the NRCS evaluation reports for any of the sites, and no internal consistency checks could be made for the soil moisture accounting. In addition, the start of season soil moisture values were not documented in the NRCS evaluation reports for any of the sites over the years.

In addition, it was noted in 1990 that other factors could also influence the ET_c soil water balance with actual soil water deficits: “In 1990, the water budget program was updated to more accurately estimate deep percolation for annual crops. In the past, deep percolation for the first irrigation and or pre-irrigation was considered to be any amount in excess of that required to fill the first foot of soil, and the full root profile was not taken into account. With this method, deep percolation estimates were higher than they should be. The updated program takes the full rooting profile into consideration. All the previous data from 1986 to 1989 have been re-processed using the updated program to get a better estimate of deep percolation, soil moisture, and ET_a” (Grand Valley Annual Report, 1990, *in* U.S. Department of Agriculture, 1986–2003).

The reprocessed data for the previous years are not provided in the 1990 annual report, unfortunately, so there is no way to estimate the magnitude of the changes that the reprocessing may have caused. A data summary table published in the 1995 Grand Valley Unit annual report for all Grand Valley sites from 1985 through 1995 shows site data values that are identical to those published in each original annual report (Grand Valley Annual Report, 1995, *in* U.S. Department of Agriculture, 1986–2003).

Another omission in data reporting was the failure to record the harvest (“cutting”) dates for alfalfa crops at any of the sites. These cutting dates had to be inferred from the SMB models created for the USGS study.

An original NRCS evaluation document that was used as a data processing and software operation manual by the NRCS evaluation staff was located (Frank Riggle, NRCS retired, written communication, 2014) and is reproduced in appendix 2. This document provides rich detail on how the NRCS evaluation staff analyzed the site field data.

Statistical Analysis of the NRCS Dataset

Temporal Analysis of NRCS Sites

Temporal analysis refers to repeated observations of a set of variables over time. In this case, the consecutive years of evaluation at the same evaluation site can be examined for changes in principal variables such as DP and SIE. Table 6 shows years of site evaluations by site number in the Grand Valley Unit. Note that after 1995, site numbers were re-used at new locations different from their 1985–1995 locations. The longest use of a site was for nine consecutive years. It is likely that different crops could have been grown at the same site over succeeding years, and that improvements in irrigation system technology were made at the same site over time. Some Grand Valley Unit sites were paired for comparison purposes.

At the time of the NRCS evaluation, a new irrigation technology using surge valves was of interest to the NRCS (Grand Valley Annual Reports, 1990 and 1991, *in* U.S. Department of Agriculture, 1986–2003) as a way to increase SIE and reduce DP. To measure the potential benefit from using surge valves, some evaluation sites (five in 1991, five in 1992, and two in 1993), were split into two parts, with standard PGP (pipeline gated pipe) technology used on one part, and PGS (pipeline gated surge) technology on the other part.

Table 7 shows the years of site evaluations by site number for the Lower Gunnison Unit. Again, after 1996, the site numbers were re-used for different locations. There is no table for the McElmo Creek Unit, as the only year of evaluation for the six McElmo Creek sites (site numbers 21, 22, 23, 25, 26, and 27) was 1993.

Table 6. Years of site evaluations by site number for the Grand Valley Unit, western Colorado.

[*, site numbers were reused for different locations after 1995;.gap between 1995 and 1999 indicates that no sites were monitored during those years]

	Gold Standard Evaluation Years											Nongold Standard Evaluation Years			
Site Number	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1999 ***	**2000 ***	**2001 ***	**2002 ***
1															X
2															X
3															
10	X	X	X												
11	X	X	X	X	X	X	X								
12	X	X	X	X	X	X									
13	X	X					X	X	X						
14	X	X	X	X	X										
15	X	X	X	X	X	X	X	X							
16	X	X	X	X	X	X	X	X	X						
17	X	X	X	X	X	X	X								
18	X	X	X	X	X	X	X								
19	X	X	X												
20	X	X													
21	X	X	X	X	X	X	X	X		X	X				
22	X														
23	X	X													
24	X	X	X												
25	X												X	X	
26		X	X	X	X	X	X	X	X				X		
27		X	X	X	X	X						X	X	X	
28			X	X	X							X	X		
29			X	X	X	X						X			
30			X	X	X	X	X	X	X			X			
31					X	X	X	X	X	X		X			
32				X	X	X	X	X	X	X	X	X	X		
33				X	X	X	X	X	X					X	
34												X			
35				X	X							X			
36				X	X	X	X	X	X			X			
37				X	X	X	X	X	X	X		X	X		
38															

Table 6. Years of site evaluations by site number for the Grand Valley Unit, western Colorado.—Continued

[*, site numbers were reused for different locations after 1995.]

	Gold Standard Evaluation Years											Nongold Standard Evaluation Years			
Site number	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1999 ***	**2000 ***	**2001 ***	**2002 ***
39						X	X	X	X				X		
40															
41						X	X	X							
42						X									
43						X	X	X							
44						X	X	X							
45						X		X							
46						X	X	X							
47						X	X	X	X	X					
48						X									
49							X	X							
50							X								
51							X	X	X						
52															
53								X	X	X					
54								X	X	X					
55								X	X	X					
56								X	X						
57									X	X	X				
58									X	X					
59									X						
60									X	X					
61									X	X					
62											X				
63											X				
64											X				
65											X				
66											X				
858												X			
WF1															X
WF2															X

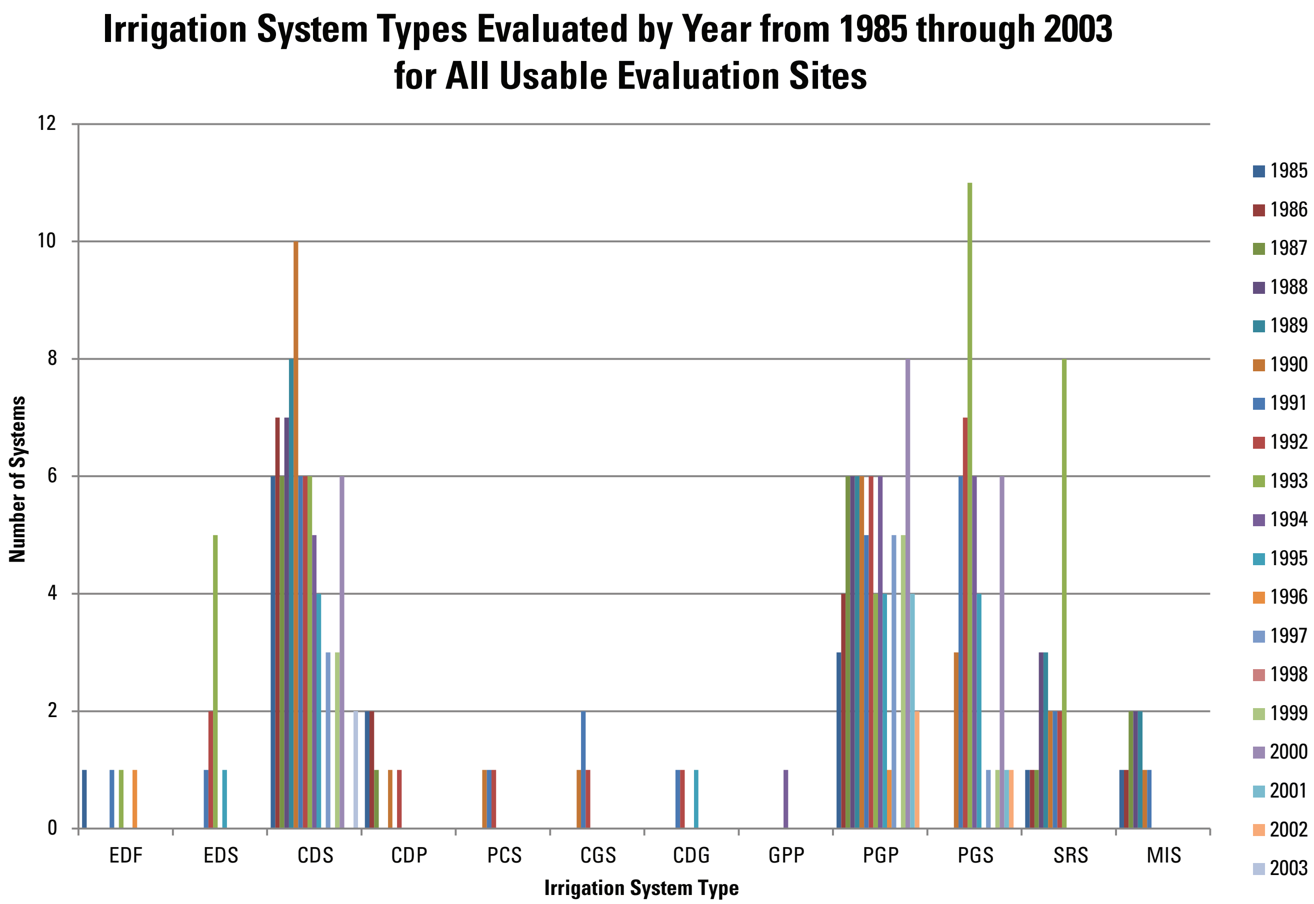
Table 7. Years of site evaluations by site number for the Lower Gunnison Unit, western Colorado.

[*, site numbers were reused for different locations after 1996.]

	Gold Standard Evaluation Years						Nongold Standard Evaluation Years				
Site Number	1991	1992	1993	1994	1995	1996	1999 *	2000 *	2001 *	2002 *	2003 *
1										X	X
2											
2b										X	X
3											X
4											X
10	X	X	X								
11											
12											
13											
14											
15											
16											
17	X	X	X	X							
18	X	X	X	X	X	X					
19	X	X	X								
20	X	X	X	X	X	X					
21			X								
22			X	X							
23				X	X						
24				X	X			X	X		
25					X						
26					X		X				
26a								X			
27						X	X				
28						X			X		
29						X		X			
30							X				
31								X			
32							X				
33								X			
33a-1								X			
33a-2								X			
34								X	X		
34a											
35							X		X		
36											
36a								X			
36b								X			
36c								X	X		
37											
38								X	X		
127								X	X		

Types of Irrigation Systems and Crops Evaluated by Year

Figure 12 shows a bar chart of irrigation system types which were monitored by evaluation year. The site counts are for all usable site records in all three evaluation units. Figure 12 shows that the preponderance of system types evaluated were concrete ditch to siphon tube (CDS), pipeline gated pipe (PGP), pipeline to gated surge (PGS), and side-roll sprinkler (SRS).



Explanation

EDF	Earth Ditch to Feeder Ditch
EDS	Earth Ditch to Siphon Tubes
CDS	Concrete Ditch to Siphon Tubes
CDP	Concrete Ditch Ported
PCS	Ported Concrete Ditch to Surge
CGS	Concrete Ditch to Gated Pipe Surge
CDG	Concrete Ditch to Gated Pipe
GPP	Gated Pipe
PGP	Pipeline to Gated Pipe
PGS	Pipeline to Gated Pipe Surge
SRS	Side-roll Sprinkler
MIS	Microspray

Figure 12. Irrigation systems monitored by evaluation year and irrigation system type from 1985 to 2003 for all usable site records in the Grand Valley, Lower Gunnison, and McElmo Creek Units.

Figure 13 shows the DP at Grand Valley Unit site 15 for 8 consecutive years, with a crop change but no change in irrigation technology. A concrete ditch to siphon tube system (CDS) was used. The crop changed from alfalfa to corn. Figure 13 shows that DP is generally higher for a corn crop than for alfalfa, primarily due to the need to irrigate the corn crop during the early plant stages when the actual net plant water extraction is still relatively low due to the small plant size and limited root zone (Frank Riggle, NRCS, written commun., May 3, 2013).

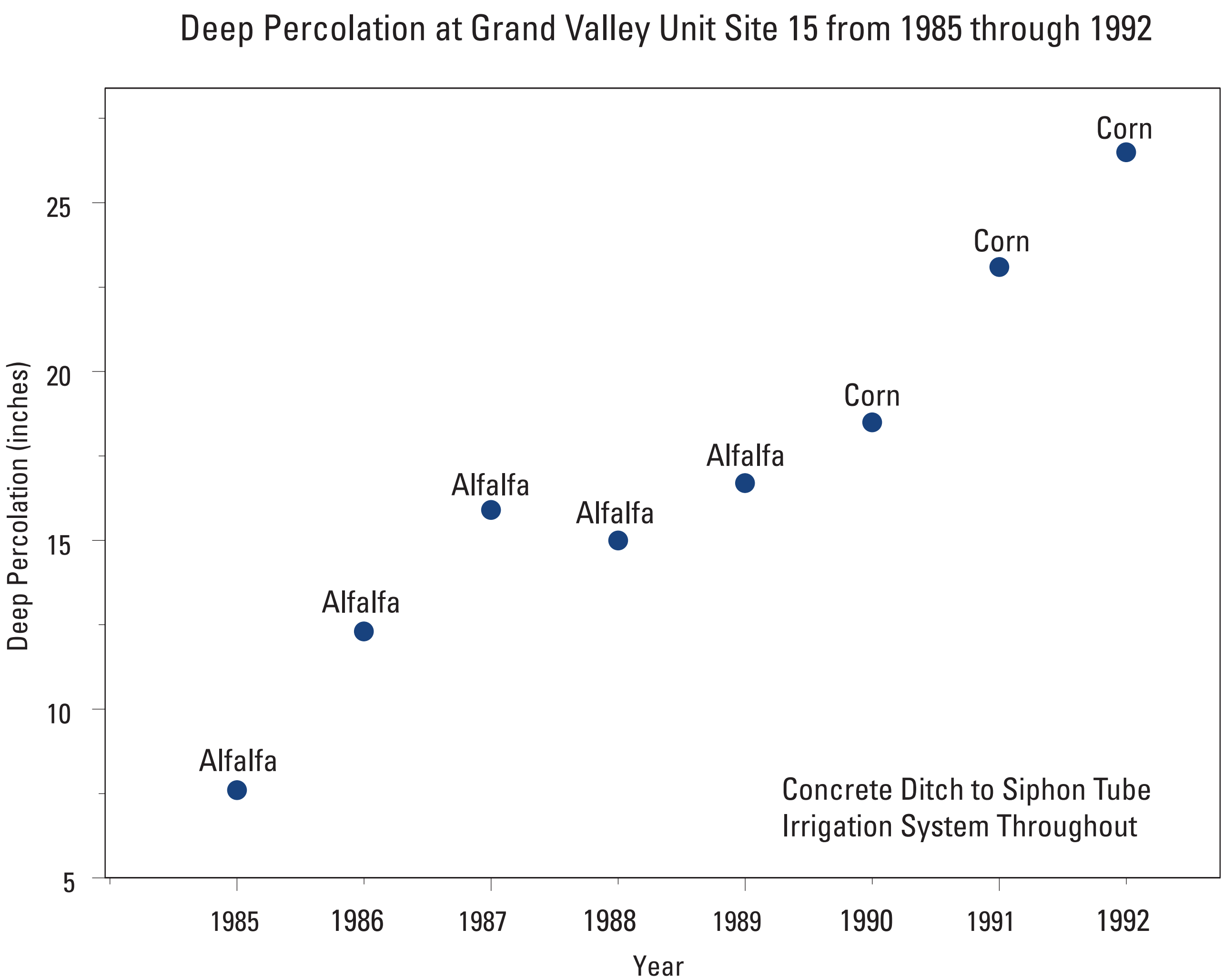


Figure 13. Deep percolation at Grand Valley Unit site 15 from 1985 through 1992 with constant irrigation type and varying crop types.

Figure 14 shows seasonal irrigation efficiency for Grand Valley Unit site 21 from 1985 through 1995. During this period, the crop changed from corn to grain to alfalfa, while the irrigation technology was upgraded from concrete ditch to siphon tube (CDS), to gated pipe (GPP), and finally to pipeline to gated surge (PGS). It can be seen that efficiency was roughly constant for CDS and GPP technology but increased after the establishment of the alfalfa crop and with the change to PGS technology in 1991. Establishment of an alfalfa crop requires extra irrigation for plant development (Frank Riggle, NRCS, written commun., May 3, 2013).

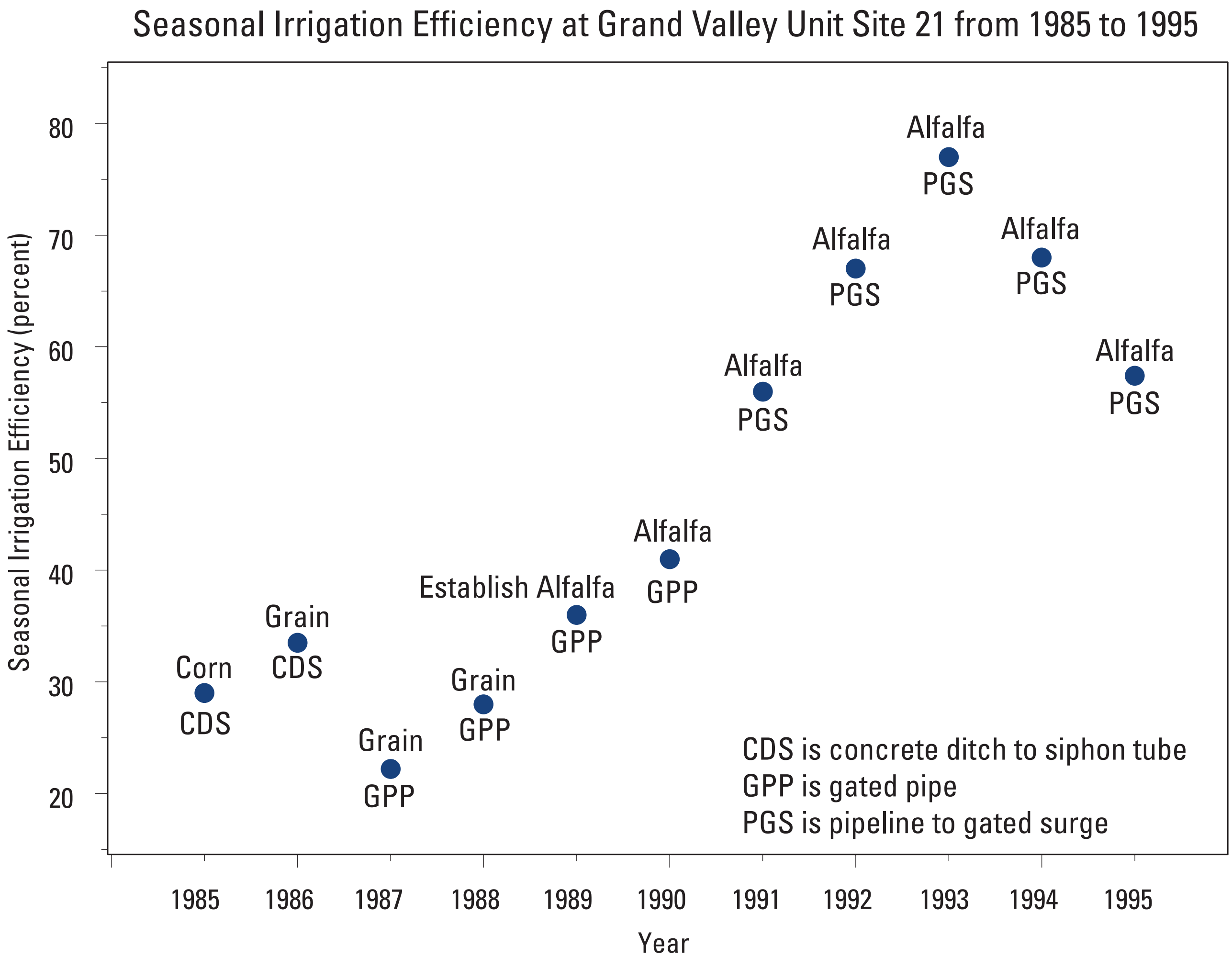


Figure 14. Seasonal irrigation efficiency at Grand Valley Unit site 21 from 1985 through 1995 with varying crop types and irrigation methods.

Creation of NRCS Evaluation Site Maps

It was possible to create a GIS map of all of the evaluation sites in the Grand Valley Unit from 1985 to 1995 from site maps in the Grand Valley Unit annual reports, and also from manual mapping from memory of the site locations by several former NRCS evaluation staff (Frank Riggle, NRCS, written commun., June 27, 2011) (fig. 15). Not all sites in the Lower Gunnison River Unit could be mapped, because the site locations were not included in some of the annual reports for that area (fig. 16). No site location data were reported for the McElmo Unit; therefore, no site map could be created. A geospatial analysis of possible variations in irrigation technology type, DP, or irrigation efficiency by location was not attempted in the UGSG study due to the complexity of requiring a separate analysis map for each evaluation year.

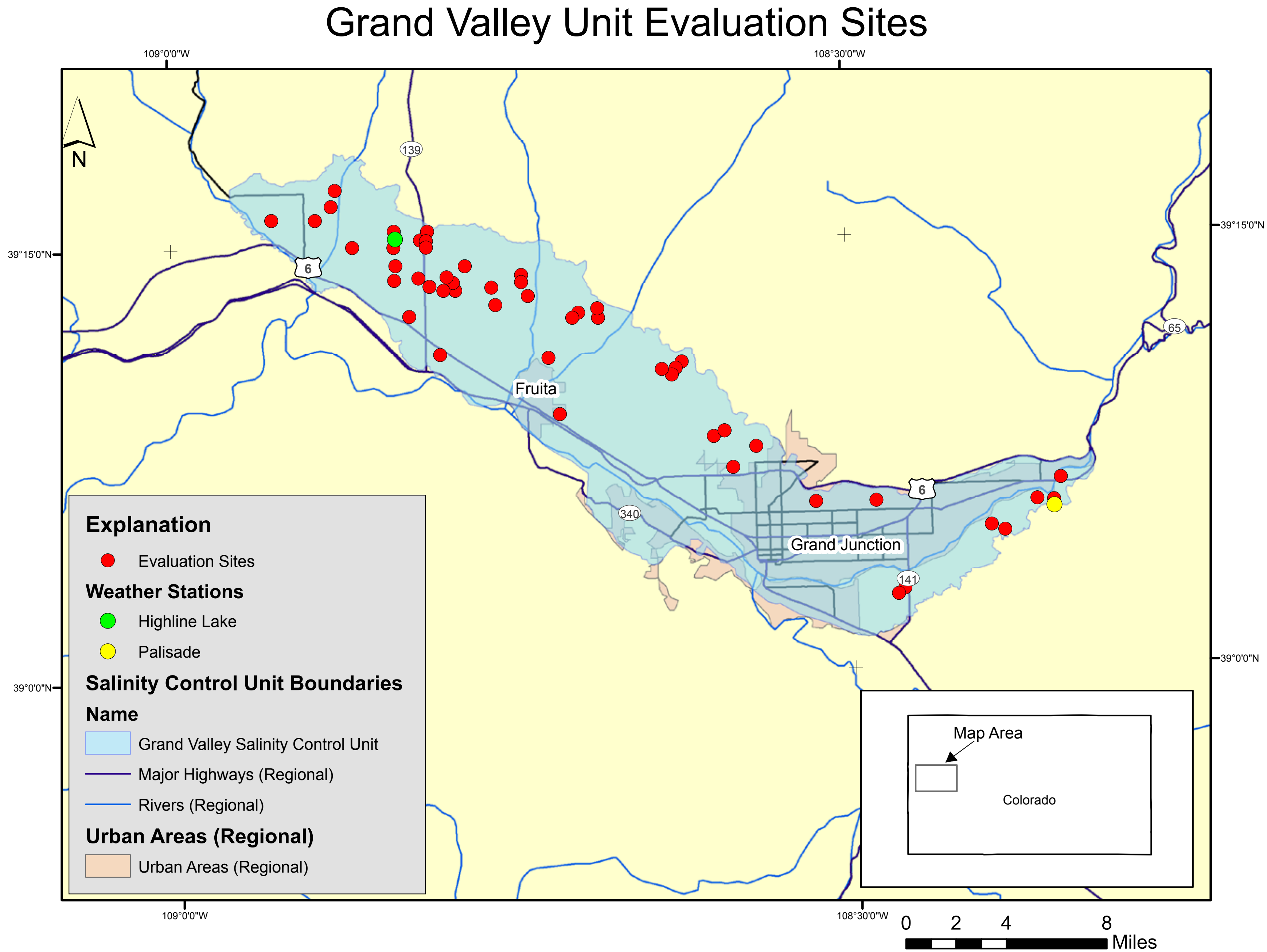


Figure 15. Map of all Natural Resources Conservation Service evaluation site locations in the Grand Valley Unit, western Colorado.

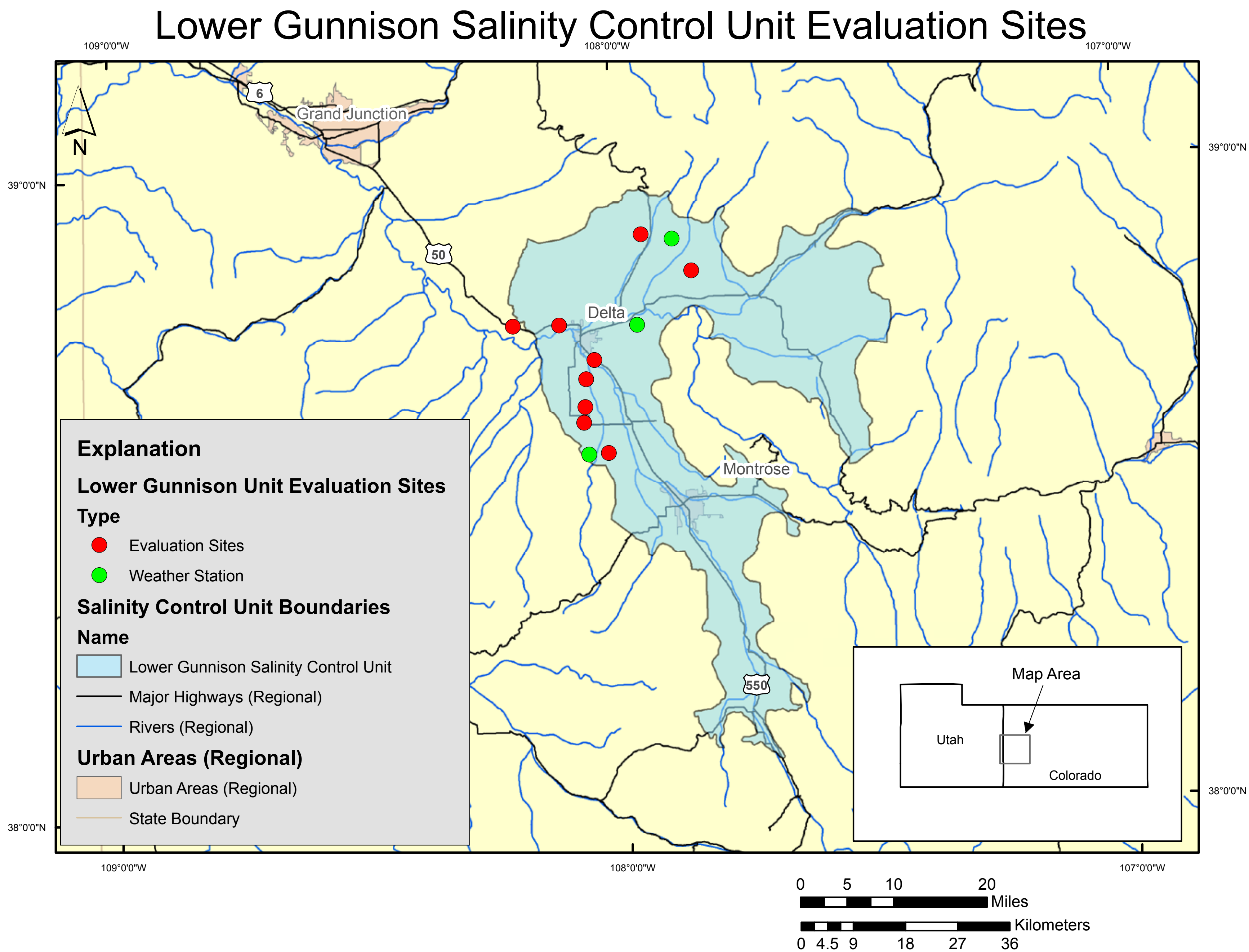


Figure 16. Map of reported Natural Resources Conservation Service evaluation site locations in the Lower Gunnison Unit, western Colorado.

Irrigation System Improvement Order

The various irrigation system types fall into a natural order of increasing level of technical sophistication (table 8). The order shown in table 8 was determined by NRCS staff for the USGS study analysis. The NRCS combined some of the 13 original evaluation system types in creating this "improvement order" of 9 levels, based on close similarity in subtypes. One system type, cablegation, was excluded from the analysis at the request of NRCS. Cablegation was highly experimental at the time of the NRCS evaluation and was only present at site 13 in the Grand Valley Unit in 1985 and 1986. NRCS judged the results from those two records as unreliable.

As the irrigation system technology level increases, irrigation efficiency is expected to improve, and DP is expected to decrease. Measuring the changes in irrigation efficiency and DP as a result of improvement levels of irrigation system sophistication was one of the most important goals of the NRCS evaluation, and these results will be discussed in detail in the USGS study statistical analysis sections.

Table 8. Irrigation system types in order of improvement.

[NRCS, Natural Resources Conservation Service]

Improvement Level	Combined System Type Codes	Original NRCS Evaluation System Type Codes	System Type Code / (Original System Type Codes)
1	EDF	EDF	Earth Ditch to Feeder ditch
2	EDS	EDS	Earth Ditch to Siphon tube
3	CDV	CDS, CDP, CDG	Concrete ditch to various distribution methods: concrete ditch to siphon tube; concrete ditch ported; and concrete ditch to gated pipe
4	PCS	PCS	Ported concrete ditch to surge
5	CGS	CGS	Concrete ditch to gated pipe surge
6	GPP	GPP, PGP	Gated pipe, pipeline to gated pipe
7	PGS	PGS	Pipeline to gated surge
8	SRS	SRS	Side-roll sprinkler
9	MIS	MIS	Microspray

Soil Physical and Chemical Properties

The NRCS evaluation recorded a soil type for each site. These soil types have been modified over the years since the evaluation by the NRCS. Typically older soil type classifications are being combined into broader classifications. The current soil classifications are mapped by the NRCS at their Web Soil Survey site (U.S. Department of Agriculture, 2013); however, the NRCS does not publish a cross-reference of the changes being made from older classifications to current classifications. The Grand Junction NRCS office has a full-time soil scientist who manually cross-referenced the changes in the NRCS evaluation soil type names. All 23 of the soil types reported by the NRCS evaluation have changed their names since the evaluation. Table 9 shows the original soil types, the current soil type, and a soil type code created for the USGS study to identify the soil type. The inclusion of soil slope ranges is part of the formal description of the soil type. Differences in slope may affect the hydrologic behavior of the soil type.

Table 9. Original Natural Resources Conservation Service (NRCS) evaluation soil types, the equivalent current soil type name, and a soil type code created for the USGS study for all NRCS evaluation soil types (Bob Rayer, NRCS, Grand Junction, written commun., September 2011).

[Percent ranges in current soil type column are soil slope ranges; %, percent]

Original NRCS Evaluation Soil Type	Current Soil Type	USGS Study Soil Type Code
Agua Fria Clay Loam	Agua Fria clay Loam 1–6%	AgFCL
Avalon Fine Silty Loam	Avalon sandy loam, gravelly substratum, 2–5%	AvSL
Billings Silty Clay Loam	Sagers silty clay Loam 0–2%	SaSCL
Christianburg Silty Clay Loam	Mesa clay loam 0–2%	MeCL
Fruita Clay Loam	Fruita clay loam 0–2%	FrCL
Fruita Very Fine Sandy Loam	Fruitland fine sandy loam 0–2%	FrFSL
Fruitland Fine Sandy Loam	Fruitland fine sandy loam 0–2%	FrFSL
Genola Clay Loam	Turley clay loam, 0–2%	TuCL
Hanksville Silty Clay Loam	Killpack silty clay, 2–5%	KiSC
Mesa Clay Loam	Mesa clay loam 0–2%	MeCL
Mesa Gravelly Clay Loam	Mesa gravelly clay loam 5–12%	MeGCL
Mikim Clay Loam	Mikim clay loam 1–3%	MiCL
Notal Silty Clay Loam	Mesa clay loam 0–2%	MeCL
Panitchen Loam	Barx—Panitchen complex, 3–12%	BarPanComp
Persayo Silty Clay Loam	Persayo silty clay loam 0–2%	PeSCL
Ravola Clay Loam	Turley clay loam, 0–2%	TuCL
Ravola Fine Sandy Loam	Sagerlite loam, 0–2%	SaL-0-2
Ravola Loam	Sagerlite loam, 0–2%	SaL-0-2
Ravola Sandy Loam	Sagerlite loam, 0–2%	SaL-0-2
Ravola Very Fine Sandy Loam	Sagerlite Loam 2-5%	SaL-2-5
Shear Silty Clay	Montrose-Delta Complex 0–2%	MonDelComp
Stutzman Silty Clay	Stutzman silty clay 0-2%	StSC
Youngston Fine Sandy Loam	Turley clay loam, 0-2%	TuCL

The physical and chemical properties of these soil types were retrieved from the Soil Data Mart website (U.S. Department of Agriculture, 2012). Table 10 lists the soil physical and chemical properties retrieved for the USGS study. Each soil type is represented by a column of soil which is typically divided into one to four horizons. A soil horizon is a layer parallel to the soil surface whose physical characteristics differ from the layers above and below (U.S. Department of Agriculture, 2013). Because of the complexity of utilizing all soil horizons in an analysis, the USGS study limited the analysis to the first soil horizon, which has a depth ranging from 2 to 16 inches depending on the soil type. This is the layer that is exposed to the surface and potentially has the most influence on irrigation water uptake. These first horizon properties were then linked to each site record to enable analysis of site characteristics by soil physical and chemical properties. The results of a multiple comparison test analysis (Helsel and Hirsch, 2002) did not identify any specific physical or chemical property that correlated in a statistically significant way (p-value less than 0.05) with SIE, DP, and irrigation water infiltrated depth of the evaluation sites. While there were statistically significant differences found in SIE, DP, and irrigation water infiltrated depth by soil type in the multiple comparison tests, the individual physical and chemical properties of the different soil types did not explain these differences.

Table 10. Soil physical and chemical properties retrieved for Natural Resources Conservation Service evaluation soil types.

[Mmhos per centimeter, milli-mhos per centimeter, a measure of electrical conductivity]

Layer	Property Type	Soil Properties	Range of Values	Units
1st Horizon	Physical	Horizon depth		Inches
1st Horizon	Physical	Sand		Percent
1st Horizon	Physical	Silt		Percent
1st Horizon	Physical	Clay		Percent
1st Horizon	Physical	Hydraulic conductivity	Minimum, maximum, and mean	Micrometers per second
1st 24 inches	Physical	Hydraulic conductivity	Minimum 24 inches	Micrometers per second
1st Horizon	Physical	Water capacity	Minimum, maximum, and mean	Inches per inch
1st Horizon	Physical	Linear extensibility	Minimum, maximum, and mean	Percent
1st Horizon	Physical	Organic matter	Minimum, maximum, and mean	Percent
1st Horizon	Chemical	pH	Minimum, maximum, and mean	
1st Horizon	Chemical	Salinity	Minimum, maximum, and mean	Mmhos per centimeter

Site-Year Record Quality Determination

A “site-year record” contains the data for one site for one irrigation season of evaluation. Because one site was often evaluated for multiple years, the site-year differentiates the different records for a site. For a site-year record to be judged complete, the record must have all the primary soil moisture balance input and output fields present: inflow, outflow, infiltrated depth, ET_c, and DP. Further, a complete record has an internal SIE calculation for the cumulative season values of these five variables, which is mathematically consistent. The soil moisture balance for each irrigation event reported by the NRCS evaluation apparently was not required to balance exactly to zero. Checks of this balance in the USGS study showed imbalances of several tenths of an inch of water for some irrigation events, and more in a few cases. These imbalances were most likely due to the corrections applied to many of the records without explanation; hence, the imbalances cannot be strictly accounted for.

To evaluate the site records over the course of the NRCS evaluation, the quality criteria used were (1) reasonable starting and ending irrigation dates, (2) reasonable frequency of irrigation events for the area, (3) reasonable number of irrigations for the area, (4) no obvious data omissions or arithmetic errors in the data, and (5) no reported notes of data collection problems or substantial amount of missed data. Based on these quality criteria, site-year records were classified for this analysis by the author and NRCS (Frank Riggle, NRCS, written commun., June 27, 2011) as (1) gold standard, (2) usable nongold standard, or (3) not-usable. Using these criteria, and also any information available in the annual report narratives, the usable records from the evaluation years 1985 through 1996 were determined to best meet the criteria for accuracy and completeness. These were the evaluation years with the most consistent and best staffed field data collection procedures and analysis practices. The usable records for the years from 1985 to 1996 are therefore referred to in this report as the gold standard records. Gold standard records are those Grand Valley, Lower Gunnison, and McElmo Creek sites that were evaluated between 1985 and 1996 that have complete records with no missing values and for which the data values were internally consistent. Gold standard sites were not required to have individual irrigation event data, but 86 percent did have this information. Usable nongold standard sites were those which were evaluated after 1996 that had complete records which were internally consistent. Ninety-three percent of nongold standard sites had individual irrigation event data. The analyses in this report use the gold standard records, all usable records, or both sets.

Not-usable records were those with incomplete or inconsistent data values, used cablegation, had no soil type listed, or had trees as the crop type. Table 11 shows the number of gold standard, usable, and not-usable records by evaluation unit. Gold standard records represented 84.0 percent of all usable records and 78.4 percent of all evaluation records. Usable gold standard and nongold standard records represented 91.8 percent of all evaluation records.

Table 11. Number of usable and not usable site-year records by evaluation unit.

Site-Year Record Quality	Grand Valley	Lower Gunnison	McElmo Creek	Total Site-Year Records
Total records of all types	224	62	6	292
Gold standard usable	196	23	6	225
Nongold standard usable	15	28	0	43
Total usable records	211	51	6	268
Not-usable (cablegation)	2	0	0	2
Not-usable (incomplete or internally inconsistent data)	11	7	0	18
Not-usable (no soil type given)	0	1	0	1
Not-usable (crop type is trees)	0	3	0	3
Total not usable	13	11	0	24

Summary Statistics and Charts of NRCS Evaluation

Summary statistics were created by the USGS study for NRCS evaluation site variables such as crop type, field acreage, years of evaluation, irrigation system type, ET_c, DP, and irrigation efficiency. Summary statistics were grouped by (1) all evaluation sites for all Units, (2) all sites in each evaluation basin, (3) crop type, (4) soil type, and (5) irrigation system type.

Depending on the analysis being performed, the USGS study utilized different sets of the evaluation data. For summary statistics, the complete span of usable site data from 1985 through 2003 is included (with non-usable site records removed). In addition, some summary statistics and charts use the gold standard subset of data. Finally, some statistics and charts also break out the statistics for each of the evaluation units. Appendix 3 contains tables of summary statistics for all usable records and for all nongold standard records.

Table 12 shows examples of discrete or grouped variable summary statistics for all gold standard site records; table 13 shows the discrete variable summary statistics for all Grand Valley Unit gold standard evaluation site records, table 14 shows the discrete variable summary statistics for all Lower Gunnison Unit gold standard sites; and table 15 shows the discrete variable summary statistics for the McElmo Creek Unit gold standard site records collected in 1993. Table 16 shows examples of continuous variable summary statistics for all gold standard site records between 1985 and 1996; table 17 shows the continuous variable summary statistics for all Grand Valley Unit gold standard evaluation site records between 1985 and 1995; table 18 shows the continuous variable summary statistics for all Lower Gunnison Unit gold standard site records between 1991 and 1996; and table 19 shows the continuous variable summary statistics for all McElmo Creek Unit gold standard site records collected in 1993. Table 20 shows annual mean results by evaluation unit and year for all reported NRCS evaluation site records, and table 21 shows the same results for all gold standard site records.

Table 12. Discrete variable summary statistics for all gold standard site records collected between 1985 and 1996 in the Natural Resources Conservation Service evaluation.

[EDF, earth ditch to feeder tube; EDS, earth ditch to siphon tube; CDV, concrete ditch to various distribution methods; PCS, ported concrete ditch to surge; CGS, concrete ditch to gated pipe surge; GPP, gated pipe; PGS, pipeline to gated surge; SRS, side-roll sprinkler; MIS, microspray; GV, Grand Valley Unit; LG, Lower Gunnison Unit; ME, McElmo Creek Unit.]

Number of Usable Site-Year Records by Evaluation Unit	Number of Site-Year Records with Irrigation Event Data	Number of Site-Year Records by Irrigation System Type Codes	Number of Site-Year Records by Crop Type	Number of Site-Year Records by Irrigation System Type	Number of Site-Year Records by Irrigation Flow Type	Number of Site-Year Records by Irrigation Distribution Type
GV: 196	No: 32	EDF: 2	Alfalfa: 73	Flood: 192	Feeder ditch: 2	Concrete ditch: 88
LG: 23	Yes: 193	EDS: 8	Beans: 12	Microspray: 10	Gated pipe: 60	Ditch: 1
ME: 6		CDV: 81	Corn: 55	Sprinkler: 23	Gated pipe surge: 41	Earth ditch: 10
		PCS: 3	Fall grain: 25		Ported: 7	Pipeline: 126
		CGS: 4	Grain: 2		Ported surge: 3	
		GPP: 57	Grapes: 10		Side-roll: 23	
		PGS: 37	Onions: 6		Siphon tube: 79	

Table 12. Discrete variable summary statistics for all gold standard site records collected between 1985 and 1996 in the Natural Resources Conservation Service evaluation.—Continued

[EDF, earth ditch to feeder tube; EDS, earth ditch to siphon tube; CDV, concrete ditch to various distribution methods; PCS, ported concrete ditch to surge; CGS, concrete ditch to gated pipe surge; GPP, gated pipe; PGS, pipeline to gated surge; SRS, side-roll sprinkler; MIS, microspray; GV, Grand Valley Unit; LG, Lower Gunnison Unit; ME, McElmo Creek Unit.]

Number of Usable Site-Year Records by Evaluation Unit	Number of Site-Year Records with Irrigation Event Data	Number of Site-Year Records by Irrigation System Type Codes	Number of Site-Year Records by Crop Type	Number of Site-Year Records by Irrigation System Type	Number of Site-Year Records by Irrigation Flow Type	Number of Site-Year Records by Irrigation Distribution Type
		SRS: 23	Orchard: 36		Spray: 10	
		MIS: 10	Pasture: 2			
			Spring grain: 1			
			Vegetable: 3			

Table 13. Discrete variable summary statistics for only Grand Valley Unit gold standard site records collected between 1985 and 1995 in the Natural Resources Conservation Service evaluation.

[CDG, concrete ditch to gated pipe; CDP, concrete ditch ported; CDS, concrete ditch to siphon tube; CGS, concrete ditch to gated pipe surge; EDF, earth ditch to feeder tube; EDS, earth ditch to siphon tube; GPP, gated pipe; MIS, microspray; PCS, ported concrete ditch to surge; PGP, pipeline to gated pipe; PGS, pipeline to gated surge; SRS, side-roll sprinkler; GV, Grand Valley Unit.]

Number of Usable Site-Year Records by Evaluation Unit	Number of Site-Year Records with Irrigation Event Data	Number of Site-Year Records by Irrigation System Type Codes	Number of Site-Year Records by Crop Type	Number of Site-Year Records by Irrigation System Type	Number of Site-Year Records by Irrigation Flow Type	Number of Site-Year Records by Irrigation Distribution Type
GV: 196	No: 23	CDG: 3	Alfalfa:67	Flood:169	Feeder ditch: 1	Concrete ditch: 86
	Yes: 173	CDP: 7	Beans: 9	Micro: 10	Gated pipe:50	Ditch: 1
		CDS:69	Corn:46	Sprinkler: 17	Gated pipe surge:34	Earth ditch: 6
		CGS: 4	Fall grain:25		Ported: 7	Pipeline:103
		EDF: 1	Grain: 1		Ported surge: 3	
		EDS: 5	Grapes:10		Side-roll:17	
		GPP: 1	Onions: 3		Siphon tube:74	
		MIS:10	Orchard:31		Spray:10	
		PCS: 3	Pasture: 2			
		PGP:46	Spring grain: 1			
		PGS:30	Vegetable: 1			
		SRS:17				

Table 14. Discrete variable summary statistics for only Lower Gunnison Unit gold standard site records collected between 1991 and 1996 in the Natural Resources Conservation Service evaluation.

[CDS, concrete ditch to siphon tube; EDF, earth ditch to feeder tube; EDS, earth ditch to siphon tube; PGP, pipeline to gated pipe; PGS, pipeline to gated surge; LG, Lower Gunnison Unit]

Number of Usable Site-Year Records by Evaluation Unit	Number of Site-Year Records with Irrigation Event Data	Number of Site-Year Records by Irrigation System Type Codes	Number of Site-Year Records by Crop Type	Number of Site-Year Records by Irrigation System Type	Number of Site-Year Records by Irrigation Flow Type	Number of Site-Year Records by Irrigation Distribution Type
LG: 23	No: 9	CDS: 2	Beans:3	Flood: 23	Feeder ditch: 1	Concrete ditch: 2
	Yes: 14	EDF: 1	Corn:9		Gated pipe: 10	Earth ditch: 4
		EDS: 3	Grain:1		Gated pipe surge: 7	Pipeline: 17
		PGP:10	Onions:3		Siphon tube: 5	
		PGS: 7	Orchard:5			
			Vegetable:2			

Table 15. Discrete variable summary statistics for only McElmo Creek Unit gold standard site records collected in 1993 in the Natural Resources Conservation Service evaluation.

[SRS, side-roll sprinkler; ME, McElmo Creek Unit.]

Number of Usable Site-Year Records by Evaluation Unit	Number of Site-Year Records with Irrigation Event Data	Number of Site-Year Records by Irrigation System Type Codes	Number of Site-Year Records by Crop Type	Number of Site-Year Records by Irrigation System Type	Number of Site-Year Records by Irrigation Flow Type	Number of Site-Year Records by Irrigation Distribution Type
ME: 6	Yes: 6	SRS: 6	Alfalfa: 6	Sprinkler: 6	Side-roll: 6	Pipeline: 6

Table 16. Continuous variable summary statistics for all gold standard site records collected between 1985 and 1996 in Natural Resources Conservation Service evaluation.

[All water quantities are in inches; N, number of records; NA, not applicable; Std Dev, standard deviation]

Statistic	Field Size	Number of Irrigation Events	Irrigation Water Inflow	Irrigation Water Outflow	Infiltrated Irrigation Water Depth	Precipitation	Evapo-transpiration	Deep Percolation	Irrigation Efficiency
Minimum	1.4	2.0	11.4	0	3.7	0.4	2.2	0	14.0
1st Quartile	7.0	6.0	39.6	8.5	27.2	2.2	20.3	4.3	33.0
Mean	20.7	7.8	55.8	16.9	38.9	3.5	26.0	15.1	47.4
Median	15.0	7.0	52.5	15.0	37.5	2.9	25.2	12.9	44.0
3d Quartile	26.0	9.0	70.2	22.8	48.8	4.3	33.3	21.3	60.8
Maximum	327.3	22.0	123	80.1	87.9	11.8	41.3	70.7	97.8
Total N	226	226	226	226	226	226	226	226	226
NA	0	0	0	0	0	0	0	0	0
Std Dev	27.5	3.4	22.0	12.1	15.3	2.3	8.1	13.4	18.5

Table 17. Continuous variable summary statistics for Grand Valley Unit gold standard site records collected between 1985 and 1995 in Natural Resources Conservation Service evaluation.

[All water quantities are in inches; N, number of records; NA, not applicable; Std Dev, standard deviation]

Statistic	Field Size	Number of Irrigation Events	Irrigation Water Inflow	Irrigation Water Outflow	Infiltrated Irrigation Water Depth	Precipitation	Evapo-transpiration	Deep Percolation	Irrigation Efficiency
Minimum	1.4	2.0	11.4	0.0	3.7	0.4	2.2	0.0	18.0
1st Quartile	8.1	6.0	40.2	8.6	27.8	2.20	20.8	4.5	34.0
Mean	18.7	7.6	55.4	15.8	39.6	3.6	26.8	14.9	48.5
Median	15.0	7.0	52.3	15.1	37.7	2.9	27.0	12.8	45.5
3d Quartile	26.0	8.0	69.4	21.1	49.4	4.4	34.0	21.1	61.0
Maximum	54.0	22.0	102.7	42.6	77.6	11.8	41.3	60.4	97.8
Total N	196	196	196	196	196	196	196	196	196
NA	0	0	0	0	0	0.	0	0	0
Std Dev	13.7	3.2	19.9	9.2	14.6	2.3	8.2	12.7	17.8

Table 18. Continuous variable summary statistics for Lower Gunnison Unit gold standard site records collected between 1991 and 1996 in Natural Resources Conservation Service evaluation.

[All water quantities are in inches; N, number of records; NA, not applicable; Std Dev, standard deviation]

Statistic	Field Size	Number of Irrigation Events	Irrigation Water Inflow	Irrigation Water Outflow	Infiltrated Irrigation Water Depth	Precipitation	Evapo-transpiration	Deep Percolation	Irrigation Efficiency
Minimum	3.0	4.0	16.7	5.3	7.3	1.0	13.4	0.0	14.0
1st Quartile	3.0	5.0	44.0	10.2	23.6	2.2	18.4	6.0	26.5
Mean	9.3	8.0	66.8	28.3	38.5	3.3	21.1	20.2	31.3
Median	7.0	8.0	66.2	19.1	38.3	3.0	21.5	16.4	29.0
3d Quartile	15.5	11.0	91.2	41.3	47.9	3.8	24.0	25.3	39.0
Maximum	23.0	17.0	123.0	80.1	87.9	6.8	29.1	70.7	55.0
Total N	23	23	23	23	23	23	23	23	23
NA	0	0	0	0	0	0	0	0	0
Std Dev	7.5	3.4	31.4	23.1	19.1	1.6	4.4	17.4	10.0

Table 19. Continuous variable summary statistics for McElmo Creek Unit gold standard site records collected during 1993 in Natural Resources Conservation Service evaluation.

[All water quantities are in inches; Abbreviations: N, number of records; NA, not applicable; Std Dev, standard deviation]

Statistic	Field Size	Number of Irrigation Events	Irrigation Water Inflow	Irrigation Water Outflow	Infiltrated Irrigation Water Depth	Precipitation	Evapo-transpiration	Deep Percolation	Irrigation Efficiency
Minimum	48.4	12.0	14.1	3.0	11.1	2.0	19.8	0.0	74.9
1st Quartile	60.0	13.5	15.6	3.2	12.5	2.0	20.1	0.0	78.8
Mean	130.5	14.8	23.0	4.6	18.4	2.2	21.7	0.3	78.8
Median	94.0	15.0	23.2	4.7	18.6	2.1	21.0	0.0	79.3
3d Quartile	151.5	15.7	29.5	5.9	23.6	2.3	23.0	0.2	80.0
Maximum	327.3	18.0	32.7	6.5	26.2	2.4	24.8	1.7	80.2
Total N	6	6	6	6	6	6	6	6	6
NA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Std Dev	105.9	2.1	8.2	1.6	6.6	0.2	2.1	0.7	2.0

Table 20. Annual mean results by Unit and year for all reported Natural Resources Conservation Service evaluation site records.

[GV, Grand Valley Unit; LG, Lower Gunnison Unit; ME, McElmo Creek Unit; ET_c, crop evapotranspiration; %, percent]

Evaluation Unit	Year	Site Count (Total/ Year)	Mean Field Size (Acres)	Mean Number of Irrigations	Mean Inflow (Inches)	Mean Outflow (Inches)	Mean Infiltrated Depth (Inches)	Mean Precipitation (Inches)	Mean ET_c (Inches)	Mean Deep Percolation (Inches)	Mean Seasonal Irrigation Efficiency (Percent)
GV	1985	16	20.4	7.6	63.1	16.8	46.3	7.8	24.3	27.7	29.4%
GV	1986	16	20.5	7.4	55.3	18.6	36.8	8.1	29.9	13.4	42.2%
GV	1987	16	19.4	6.6	53.5	16.1	37.4	4.3	30.1	12.6	46.3%
GV	1988	18	20.8	9.4	54.3	13.6	40.7	3.9	28.4	14.7	47.8%
GV	1989	19	20.7	8.9	52.9	14.4	38.5	2.7	27.5	12.4	49.2%
GV	1990	25	14.9	8.4	61.3	18.6	42.7	1.7	25.4	17.0	42.0%
GV	1991	23	15.2	7.2	56.4	14.9	41.5	2.2	26.6	15.9	45.3%
GV	1992	23	16.2	6.8	57.0	13.8	43.2	2.7	27.9	17.4	45.3%
GV	1993	22	17.1	7.4	51.9	15.1	36.8	3.4	27.0	11.8	48.3%
GV	1994	12	21.0	8.4	67.1	17.8	49.3	2.4	29.5	19.0	45.1%
GV	1995	8	29.8	4.4	42.2	16.6	25.6	2.2	12.9	11.9	32.5%
GV	1999	10	22.6	4.8	33.9	13.4	25.8	n/a	n/a	8.4	35.7%
GV	2000	7	19.1	8.0	56.3	13.7	42.6	n/a	n/a	14.0	50.7%
GV	2001	3	37.0	7.0	81.2	17.0	62.5	n/a	n/a	26.0	47.1%
GV	2002	2	18.2	7.5	48.0	15.6	32.4	n/a	n/a	5.5	56.0%
LG	1991	3	24.7	6.3	22.7	11.6	11.1	n/a	n/a	13.9	12.2%
LG	1992	3	13.0	7.7	69.5	39.5	30.0	n/a	n/a	12.6	25.1%
LG	1993	7	11.9	5.4	62.7	26.5	36.3	n/a	n/a	20.6	25.0%
LG	1994	6	7.8	9.5	69.6	27.3	42.3	n/a	n/a	20.4	31.5%
LG	1995	6	7.0	9.8	61.8	21.7	40.1	n/a	n/a	23.2	27.3%
LG	1996	4	5.9	5.3	78.7	29.2	49.4	n/a	n/a	29.8	25.0%

Table 20. Annual mean results by Unit and year for all reported Natural Resources Conservation Service evaluation site records.—Continued

[GV, Grand Valley Unit; LG, Lower Gunnison Unit; ME, McElmo Creek Unit; ET_c, crop evapotranspiration; %, percent]

Evaluation Unit	Year	Site Count (Total/Year)	Mean Field Size (Acres)	Mean Number of Irrigations	Mean Inflow (Inches)	Mean Outflow (Inches)	Mean Infiltrated Depth (Inches)	Mean Precipitation (Inches)	Mean ET_c (Inches)	Mean Deep Percolation (Inches)	Mean Seasonal Irrigation Efficiency (Percent)
LG	1999	5	20.4	6.5	52.1	16.2	36.1	n/a	n/a	11.1	47.6%
LG	2000	14	13.9	6.5	57.7	19.1	38.6	n/a	n/a	12.9	44.5%
LG	2001	7	18.7	5.8	45.2	10.4	33.4	n/a	n/a	13.7	46.8%
LG	2002	2	17.0	5.5	62.3	28.1	34.2	n/a	n/a	9.7	39.4%
LG	2003	3	14.3	6.0	60.5	25.5	34.9	n/a	n/a	6.4	47.3%
ME	1993	6	130.5	14.8	23.0	4.6	18.4	n/a	n/a	0.3	78.5%
GV means		14.7	20.8	7.3	55.6	15.7	40.1	3.8	26.3	15.2	44.4%
LG means		5.5	14.1	6.8	58.4	23.2	35.1	n/a	n/a	15.8	33.2%
All means		10.6	22.1	7.4	55.6	18.3	37.3	3.8	26.3	14.9	40.3%

Table 21. Annual Mean results by unit and year for gold standard Natural Resources Conservation Service evaluation site records.

[GV, Grand Valley Unit; LG, Lower Gunnison Unit; ME, McElmo Creek Unit; ET_c, crop evapotranspiration, %, percent]

Evaluation Unit	Year	Site Count (Total/Year)	Mean Field Size (Acres)	Mean Number of Irrigations	Mean Inflow (Inches)	Mean Outflow (Inches)	Mean Infiltrated Depth (Inches)	Mean Precipitation (Inches)	Mean ET_c (Inches)	Mean Deep Percolation (Inches)	Mean Seasonal Irrigation Efficiency (Percent)
GV	1985	14	21.5	7.4	54.1	16.3	37.8	7.6	23.8	19.8	33.3%
GV	1986	15	21.2	7.3	52.9	18.0	35.0	8.3	30.2	11.5	44.3%
GV	1987	16	19.4	6.6	53.5	16.1	37.4	4.3	30.1	12.6	46.3%
GV	1988	18	20.8	9.4	54.3	13.6	40.7	3.9	28.4	14.7	47.8%
GV	1989	19	20.7	8.9	52.9	14.4	38.5	2.7	27.5	12.4	49.2%
GV	1990	25	14.9	8.4	61.3	18.6	42.7	1.7	25.4	17.0	42.0%
GV	1991	23	15.2	7.2	56.4	14.9	41.5	2.2	26.6	15.9	45.3%
GV	1992	24	15.9	6.8	56.4	14.2	42.2	2.7	27.5	16.7	45.1%
GV	1993	22	17.1	7.4	51.9	15.1	36.8	3.4	27.0	11.8	48.3%
GV	1994	12	21.0	8.4	67.1	17.8	49.3	2.4	29.5	19.0	45.1%
GV	1995	8	29.8	4.4	42.2	16.6	25.6	2.2	12.9	11.9	32.5%
LG	1992	3	13.0	7.7	69.5	39.5	30.0	4.2	20.7	12.6	25.1%
LG	1993	7	11.9	5.4	62.7	26.5	36.3	1.9	18.8	20.6	25.0%
LG	1994	6	7.8	9.5	69.6	27.3	42.3	2.6	23.5	20.4	31.5%
LG	1995	6	7.0	9.8	61.8	21.7	40.1	5.1	20.3	23.2	27.3%
ME	1993	6	130.5	14.8	23.0	4.6	18.4	2.2	21.7	0.3	78.5%
GV means		17.8	19.8	7.5	54.8	16.0	38.9	3.8	26.3	14.9	43.8%
LG means		5.5	9.9	8.1	65.9	28.7	37.2	n/a	n/a	19.2	27.3%
All means		14.0	24.2	8.1	55.6	18.4	37.2	3.6	24.6	15.0	39.8%

The NRCS evaluation dataset was graphically characterized using frequency charts (figs. 17-20), scatter plots (figs. 21-22), and box plots (figs. 23-26) of the primary continuous variables (ET_c, irrigation efficiency, DP, water infiltrated depth, and irrigation event duration). These variables were grouped into discrete categories of evaluation area, irrigation system in improvement order, SIE, season total DP, and event days.

For some characterizations, two charts are shown: (1) for all usable site records, and (2) for all gold standard site records. In addition, the data for some charts are broken out into Grand Valley, Lower Gunnison, and McElmo Creek Units.

Frequency Charts

Figure 17 shows that the Grand Valley and Lower Gunnison Units are similar in the distribution of irrigation system types, with concrete ditch (CDV) and gated pipe (GPP) the predominant types. McElmo Creek's six sites were all side-roll sprinkler (SRS) types.

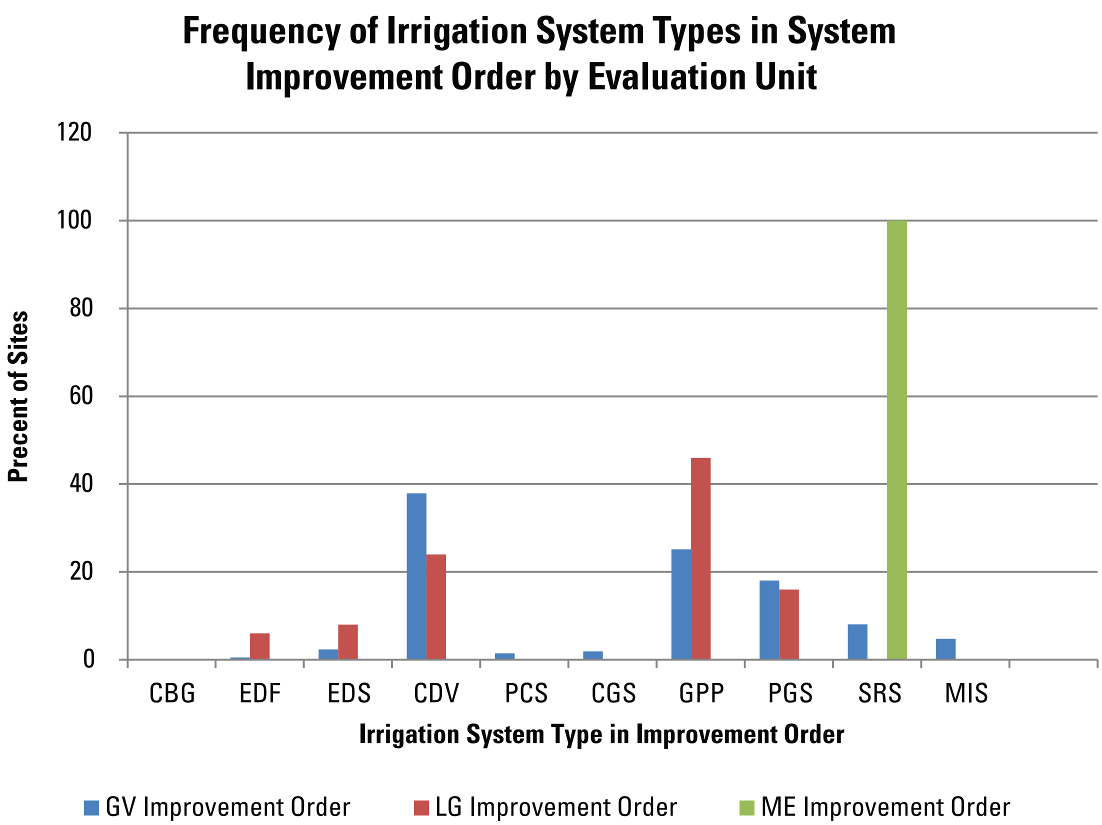


Figure 17. Frequency chart of irrigation system types by system improvement order[1] for all usable sites in Grand Valley (GV), Lower Gunnison (LG), and McElmo Creek (ME) Units. [[1]CBG, cablegation; EDF, earth ditch to feeder tube; EDS, earth ditch to siphon tube; CDV, concrete ditch to various distribution methods; PCS, ported concrete ditch to surge; CGS, concrete ditch to gated pipe surge; GPP, gated pipe; PGS, pipeline to gated surge; SRS, side-roll sprinkler; MIS, microspray.]

Figure 18 shows that SIE was mostly distributed from 30 to 80 percent for the Grand Valley Unit, from mostly 20 to 70 percent for the Lower Gunnison Unit, and from 80 to 90 percent for the McElmo Creek Unit. The high McElmo Creek efficiencies are due to the use of side-roll sprinklers.

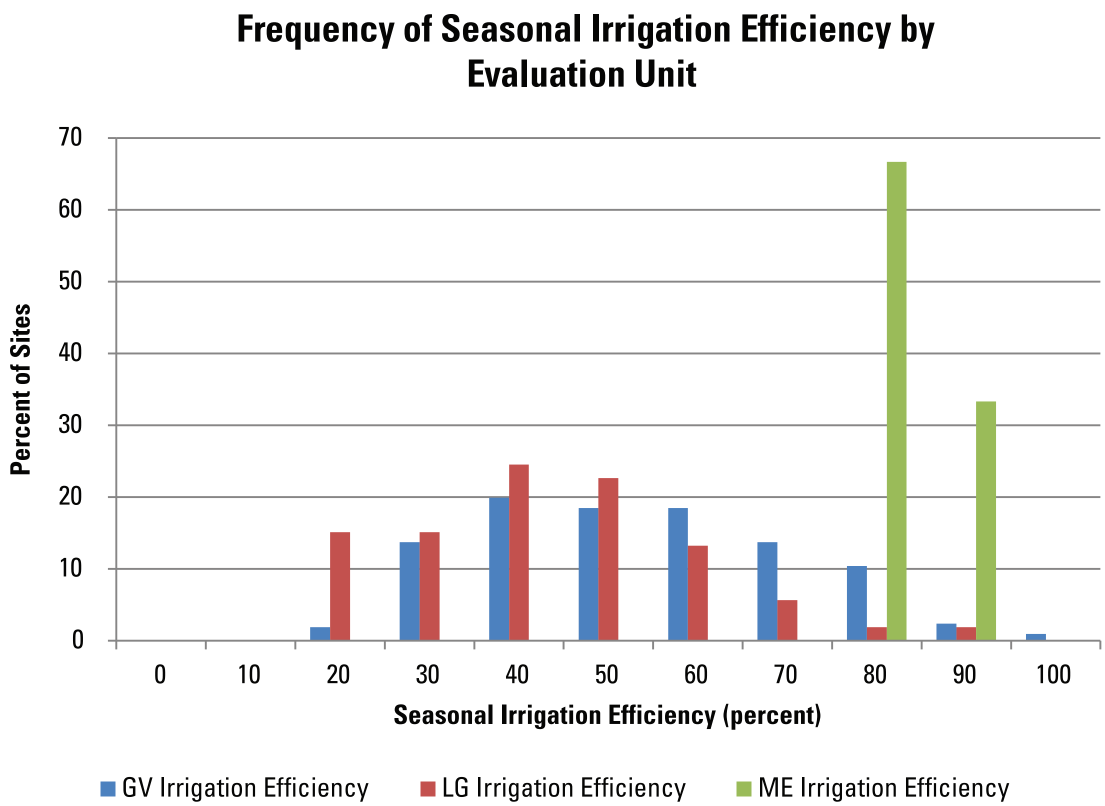


Figure 18. Frequency chart of seasonal irrigation efficiency for all usable sites in Grand Valley (GV), Lower Gunnison (LG), and McElmo Creek (ME) Units.

Figure 19 shows that generally DP was distributed from 0 to about 25 inches for the Grand Valley Unit, roughly the same for the Lower Gunnison Unit, and not above 5 inches for the McElmo Creek Unit.

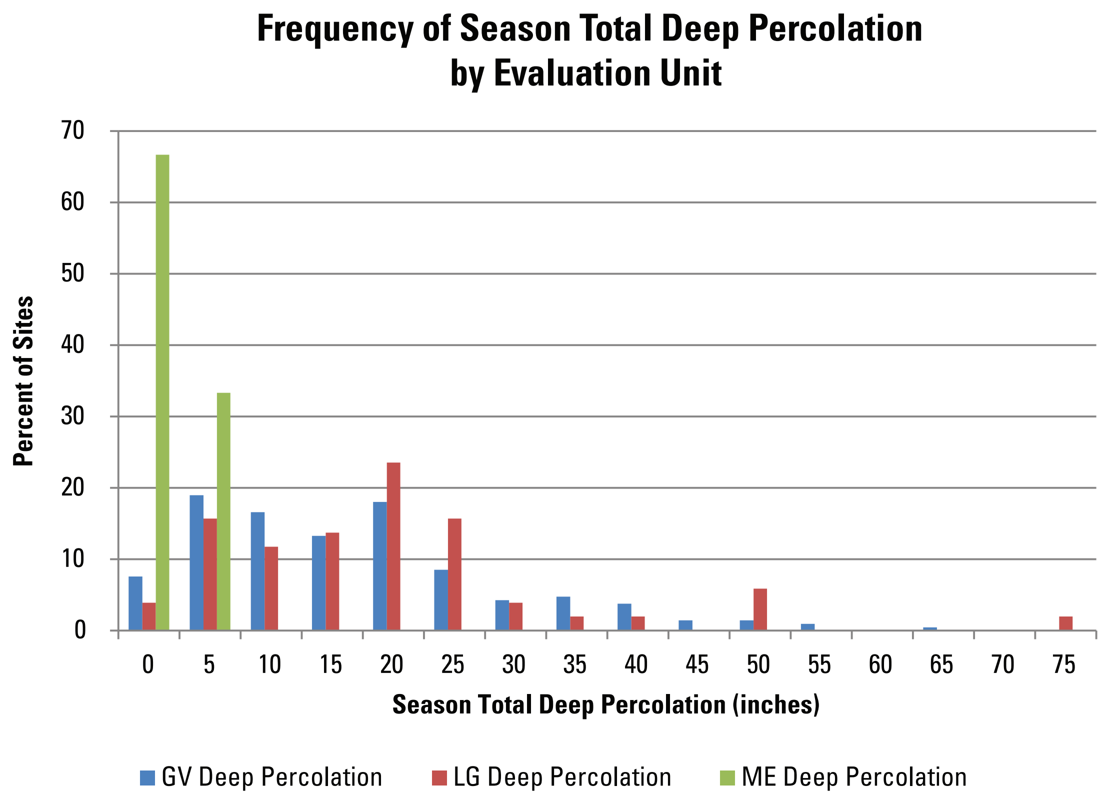


Figure 19. Frequency chart of deep percolation for all usable sites in Grand Valley (GV), Lower Gunnison (LG), and McElmo Creek (ME) Units.

Figure 20 shows the frequency distribution of irrigation event durations for all usable sites. Most irrigation events ranged from 1 to 9 days in duration. Eight percent of the events exceeded 10 days, with three single outliers at 20, 24, and 27 days in duration (these single events are barely visible on chart). The peak at 2 days is for flood irrigated sites in the Grand Valley Unit, with no particular crop type predominating. The later peak at 9 days is due primarily to flood irrigation of alfalfa sites in the Grand Valley Unit. Most of the 10 day and longer events are for side-roll sprinkler sites in the Grand Valley Unit. The three outliers are (1) 20 days for concrete ditch to siphon tube irrigation of fall grain in the Grand Valley Unit; (2) 24 days for pipeline to gated pipe irrigation of fall grain in the Grand Valley Unit; and (3) 27 days for side-roll sprinkler irrigation of alfalfa in the McElmo Creek Unit.

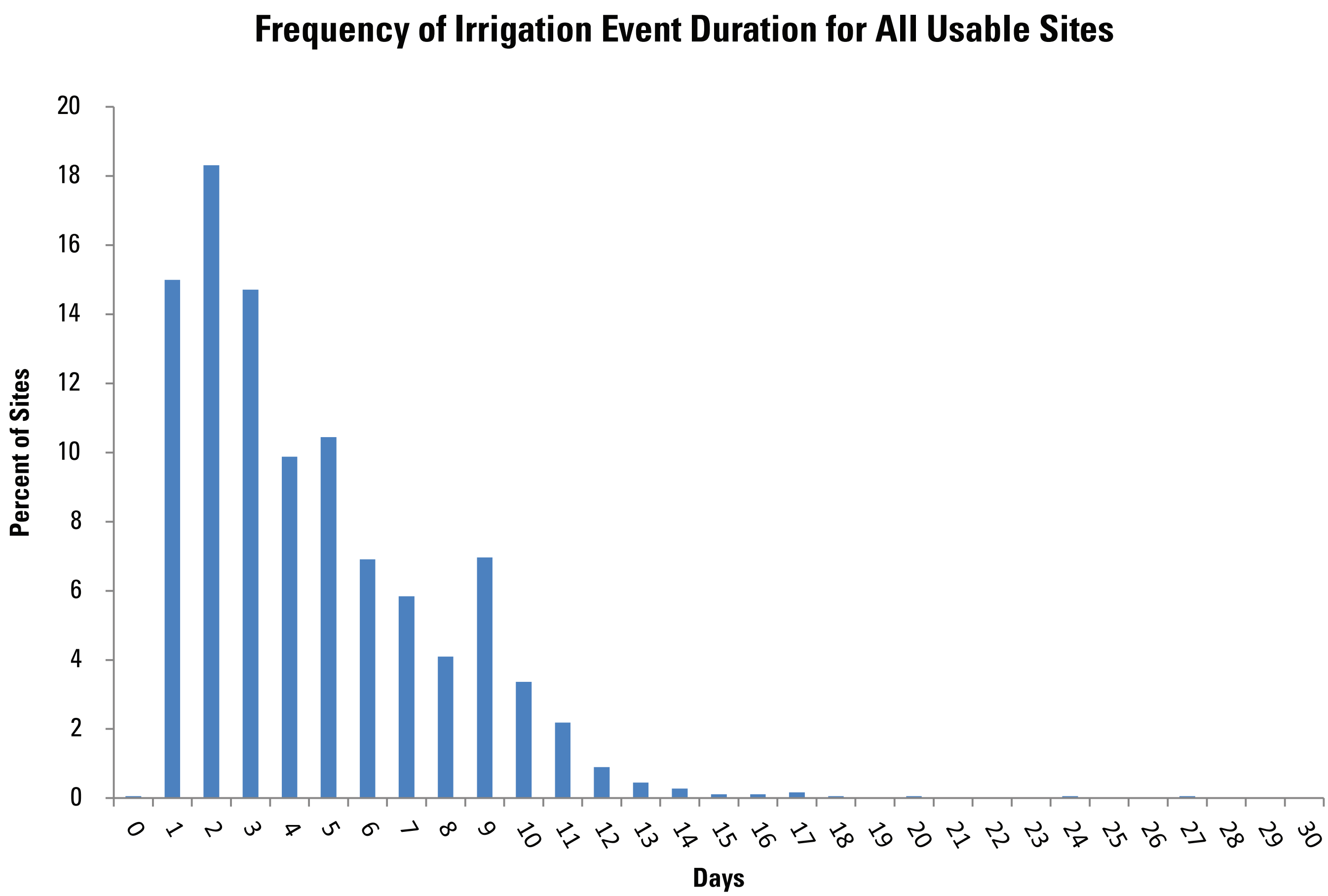


Figure 20. Frequency chart of irrigation event duration in days for all usable sites in Grand Valley, Lower Gunnison, and McElmo Creek Units.

Deep Percolation versus Seasonal Irrigation Efficiency

One of the more important results from the NRCS evaluation is a determination of how DP varies with SIE changes. The NRCS investments in irrigation system improvements lead to increases in seasonal irrigation efficiency, as demonstrated by the irrigation system improvement order. The question then arises as to how much deep percolation is reduced for these investments in irrigation efficiency improvements. A scatter plot of DP versus SIE with a trend line of changes in DP for changes in SIE illustrates the dependency of DP on SIE (figs. 21 and 22).

The trend line method chosen for the USGS study is the LOESS smoothing curve (Helsel and Hirsch, 2002). LOESS stands for LOcal regrESSion. LOESS is a non-parametric statistical method, meaning that the data need not be normally (Gaussian) distributed. The LOESS method uses a nearest neighbor's algorithm to select how much of the surrounding data are used to fit a local regression polynomial for each pair of DP and SIE values. The nearest data points are thus given the most weight in determining the LOESS local regression model for a given point. The result is a smoothing curve of running mean values (Helsel and Hirsch, 2002).

Two subsets of NRCS evaluation data were plotted for this analysis—all usable sites from 1985 to 2003 (268 pairs of data) and the Grand Valley Unit gold standard sites from 1985 to 1996 (168 data pairs). For the Lower Gunnison and McElmo Creek Units, there were not enough data points to calculate a reliable LOESS smoothing curve.

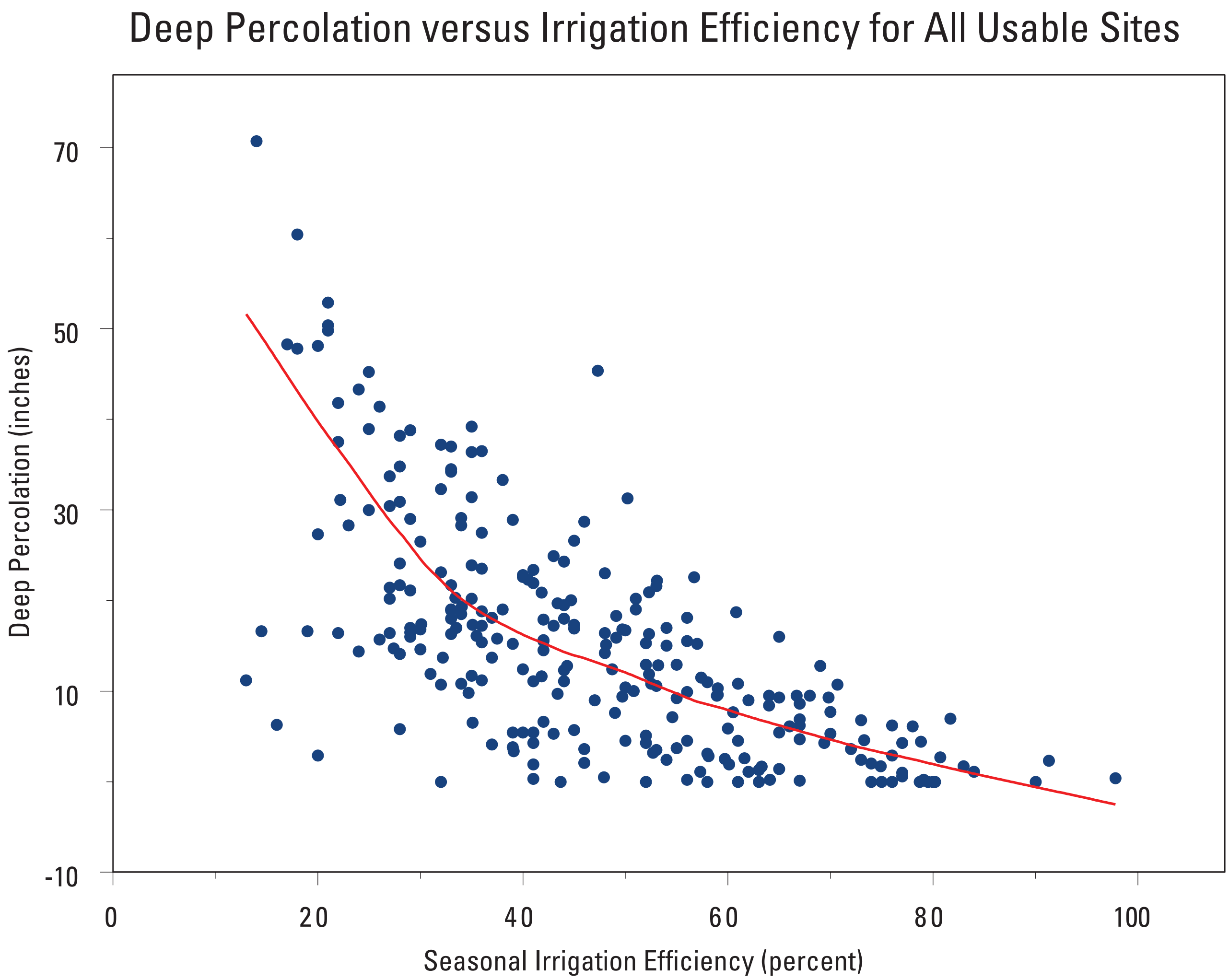


Figure 21. Scatter plot chart with LOESS trend line of deep percolation versus seasonal irrigation efficiency for all usable Grand Valley, Lower Gunnison, and McElmo Creek Unit sites from 1985 to 2003.

Figure 21 plots DP against SIE for all 268 usable site-year records. In figure 21, the LOESS trend line (red trace) shows that as SIE increases from about 10 to 35 percent, a rapid decline occurs in DP. Above 35 percent SIE, DP continues to decline but at a slower rate. Because increases in SIE require more advanced irrigation technology, the implication is that improvements from the most primitive types of systems up to middle level irrigation technology yield the largest improvements in DP, while improvements from middle levels of system types to the most advanced types yield less improvement in DP by comparison. This could have policy implications for which on-farm improvement projects are selected for funding by water managers.

The LOESS trend line method does not provide a single prediction equation (as would a regression model), but it does produce predicted DP and SIE values along a line that approximates the distribution of the data. Table 22 shows a summary of the LOESS values of DP for approximately every 5 percent increase in value of SIE from 20 percent to 95 percent for the LOESS trend line in figure 21.

Table 22. Summary table of LOESS predicted values of deep percolation and seasonal irrigation efficiency from figure 21.

[LOESS, Local regression trend line]

LOESS Seasonal Irrigation Efficiency (Percent)	LOESS Predicted Deep Percolation (Inches)
20.0	39.7
25.1	31.7
30.2	24.3
35.0	19.4
40.1	16.2
45.2	13.9
50.0	12.1
55.1	9.7
60.2	7.8
65.0	6.2
70.1	4.6
75.2	3.2
80.3	1.9
85.0	0.6
90.1	–0.6
95.2	–1.9

Because of the downward trend of the LOESS trend line as it approaches 100 percent SIE, the predicted values are actually negative starting at 90.1 percent SIE, which is a physical impossibility. This reinforces the fact that table 22 only represents an approximation and should not be expected to perfectly reflect the relation between DP and SIE for the scatter data in figure 21. This is particularly true for DP at the lowest and highest values of SIE where the underlying data are sparse.

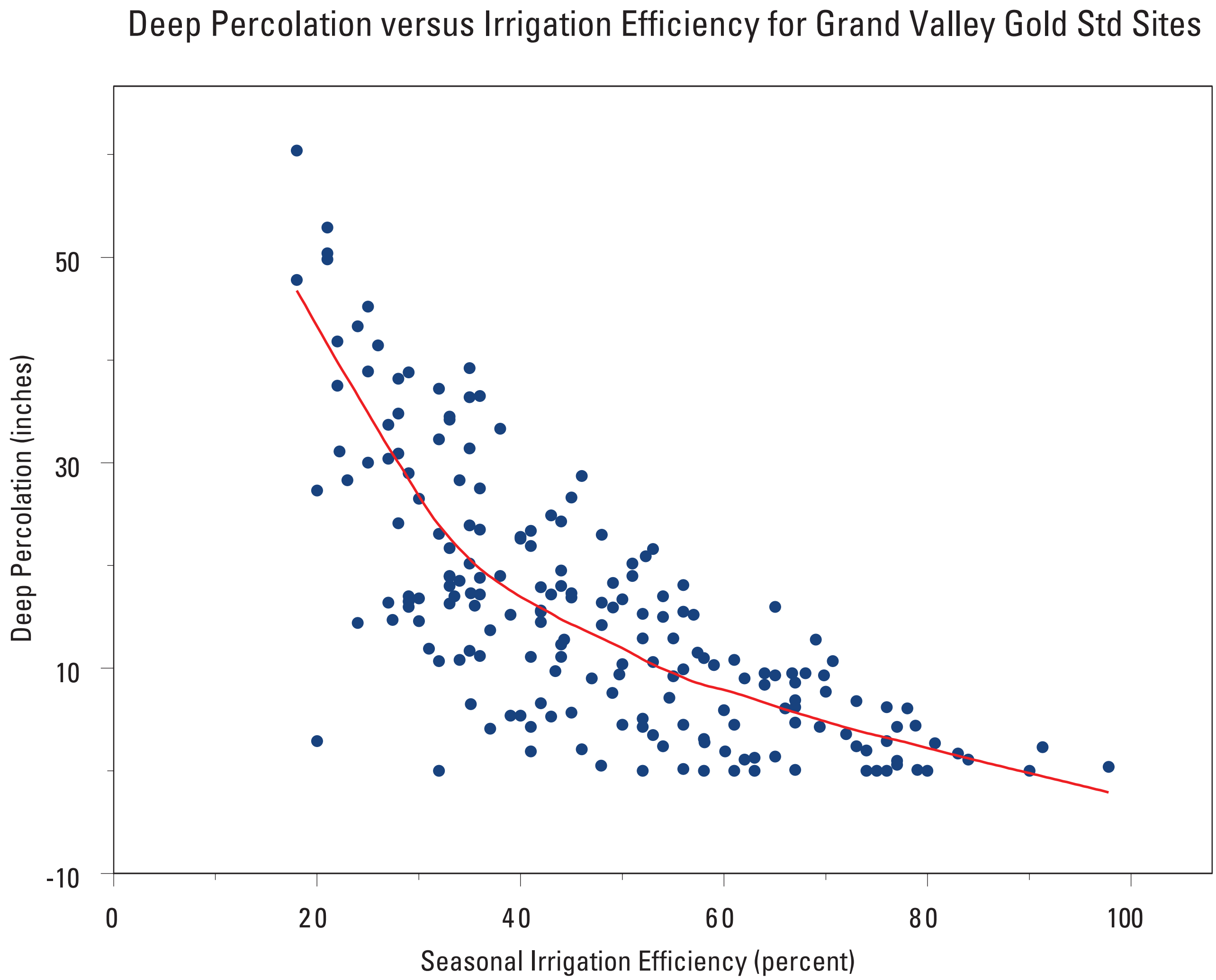


Figure 22. Scatter plot chart with LOESS trend line of deep percolation versus seasonal irrigation efficiency for Grand Valley Unit gold standard sites.

Figure 22 shows the relation between SIE and DP for the 168 Grand Valley Unit gold standard sites. It is apparent by comparing figure 21 with figure 22 that the response of DP to changes in SIE for the Grand Valley Unit gold standard sites is very similar to that of the total population of usable sites in the NRCS evaluation. It should again be noted that the LOESS curve in figure 22 is an approximation and should not be expected to perfectly reflect the relation between DP and SIE for the scatter data in figure 22. The LOESS predicted values of DP for approximately every 5 percent from 20 percent SIE to 95 percent SIE for the Grand Valley Unit gold standard sites are shown in table 23.

Table 23. Summary table of LOESS predicted values of deep percolation and seasonal irrigation efficiency from figure 22.

[LOESS, local regression trend line]

LOESS Seasonal Irrigation Efficiency (Percent)	LOESS Predicted Deep Percolation (Inches)
20.0	43.2
25.4	34.2
30.3	26.3
35.2	20.4
40.1	16.9
45.0	14.3
50.3	11.8
55.2	9.4
60.2	7.8
65.1	6.3
70.0	4.8
75.3	3.4
80.2	2.2
85.1	1.0
90.0	–0.2
95.3	–1.5

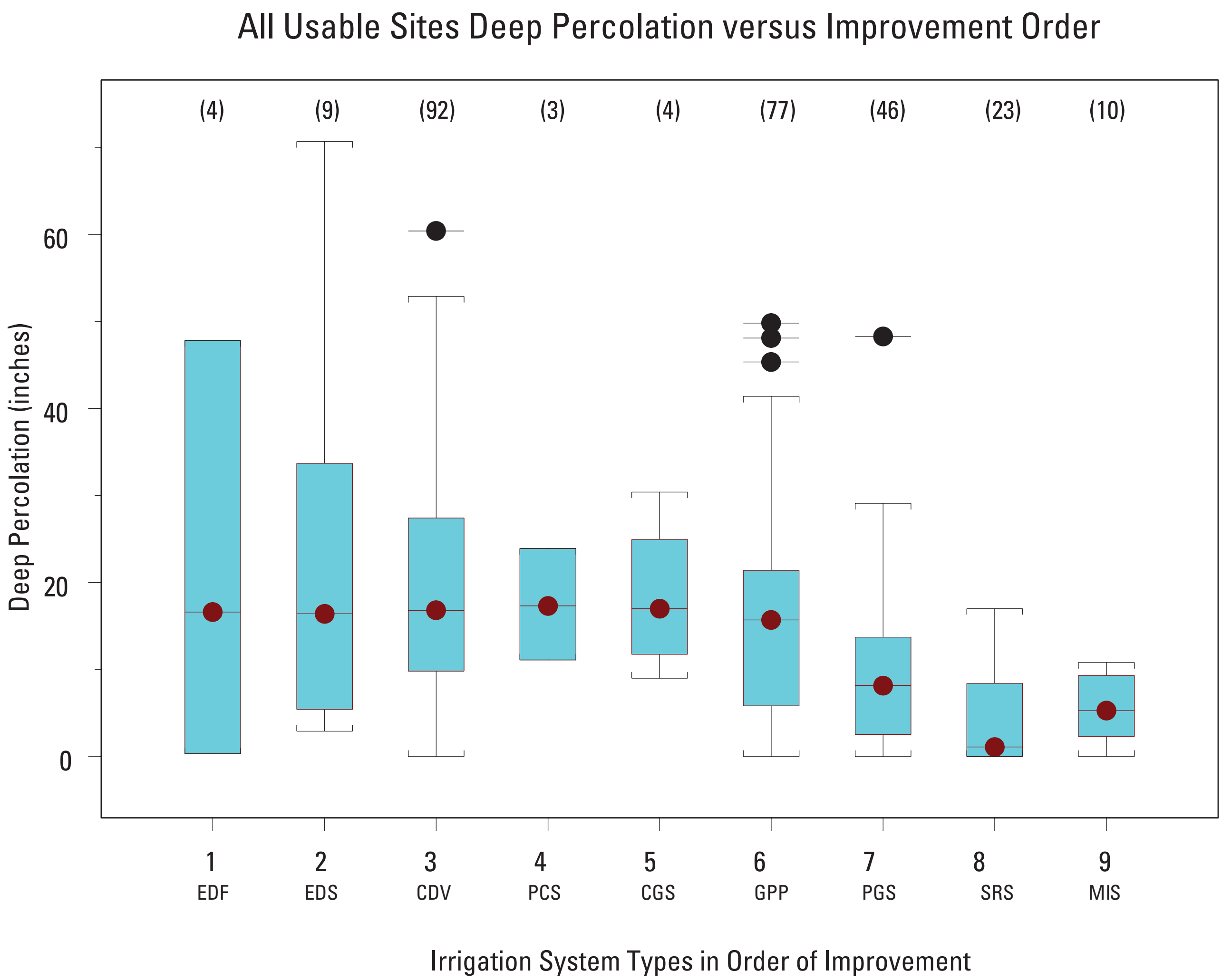
Deep percolation and irrigation system box plots are a convenient way to illustrate the differences between groups of data. The median value (50 percentile) for a category of data is shown as a red dot. The top of the box is the 75 percentile value for the data group, and the bottom of the box is the 25 percentile value. The span (height of box) from 25 to 75 percentile is called the interquartile range. The whiskers above and below the box show the largest and smallest data values within 1.5 times the interquartile range. Values outside this whisker range are shown as individual black dots. The values in parentheses at the top of each box are the number of samples represented by each box column.

Box plots were created for DP by irrigation system type (in system improvement order), and for SIE by irrigation system type in improvement order. Four datasets were used for these two plots: (1) all usable sites, (2) Grand Valley Unit gold standard sites, (3) Lower Gunnison Unit gold standard sites, and (4) McElmo Creek Unit gold standard sites.

Additionally, box plots were created for DP by crop type and SIE by crop type for all gold standard sites in the three evaluation units. Box plots of DP by crop type and SIE by crop type are shown separately for flood irrigation only, sprinkler irrigation only, and microspray irrigation only for all gold standard sites. Appendix 4 shows additional box plots of DP, SIE, crop evapotranspiration, and irrigation water infiltrated depth, grouped variously by soil type, crop rooting depth, irrigation system improvement order, and irrigation system type.

Figure 23 shows that as irrigation systems advance in order of improvement, the variability in DP (overall height of the blue boxes) is reduced. There is also a general decline in median DP for system types 7 through 9. This means that at higher levels of system technology, there is increased confidence that the amount of DP is more predictable, which is of benefit in terms of irrigation management. Because the more advanced irrigation technologies—by their design—contribute less DP as they apply water to the crop, they also make it less likely that the operator will contribute to DP through inattention or inexperience.

It should be noted that a small amount of DP is necessary to manage salt in the root zone of the soil. How much DP is required to flush salt from the root zone is a function of crop salt tolerance, the incoming salt level of the irrigation water, and salt concentrations inherent in the type of soil (Frank Riggle, NRCS, written commun., April 20, 2013). This necessary DP is referred to as the “leaching requirement.” The leaching requirement for the Grand Valley Unit has been estimated to be from 5 to 15 percent of annual ET_c (Grand Valley Annual Report, 1989, *in* U.S. Department of Agriculture, 1986–2003).



Irrigation System Types

EDF	Earth Ditch to Feeder Ditch
EDS	Earth Ditch to Siphon Tubes
CDV	Concrete Ditch to Various Distribution
PCS	Ported Concrete Ditch to Surge
CGS	Concrete Ditch to Gated Pipe Surge
GPP	Gated Pipe
PGS	Pipeline to Gated Pipe Surge
SRS	Side-roll Sprinkler
MIS	Microspray

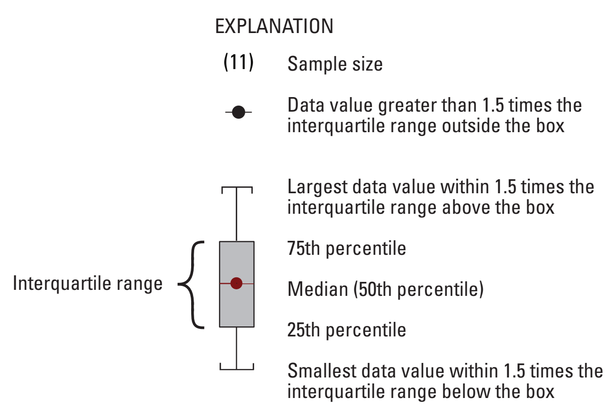
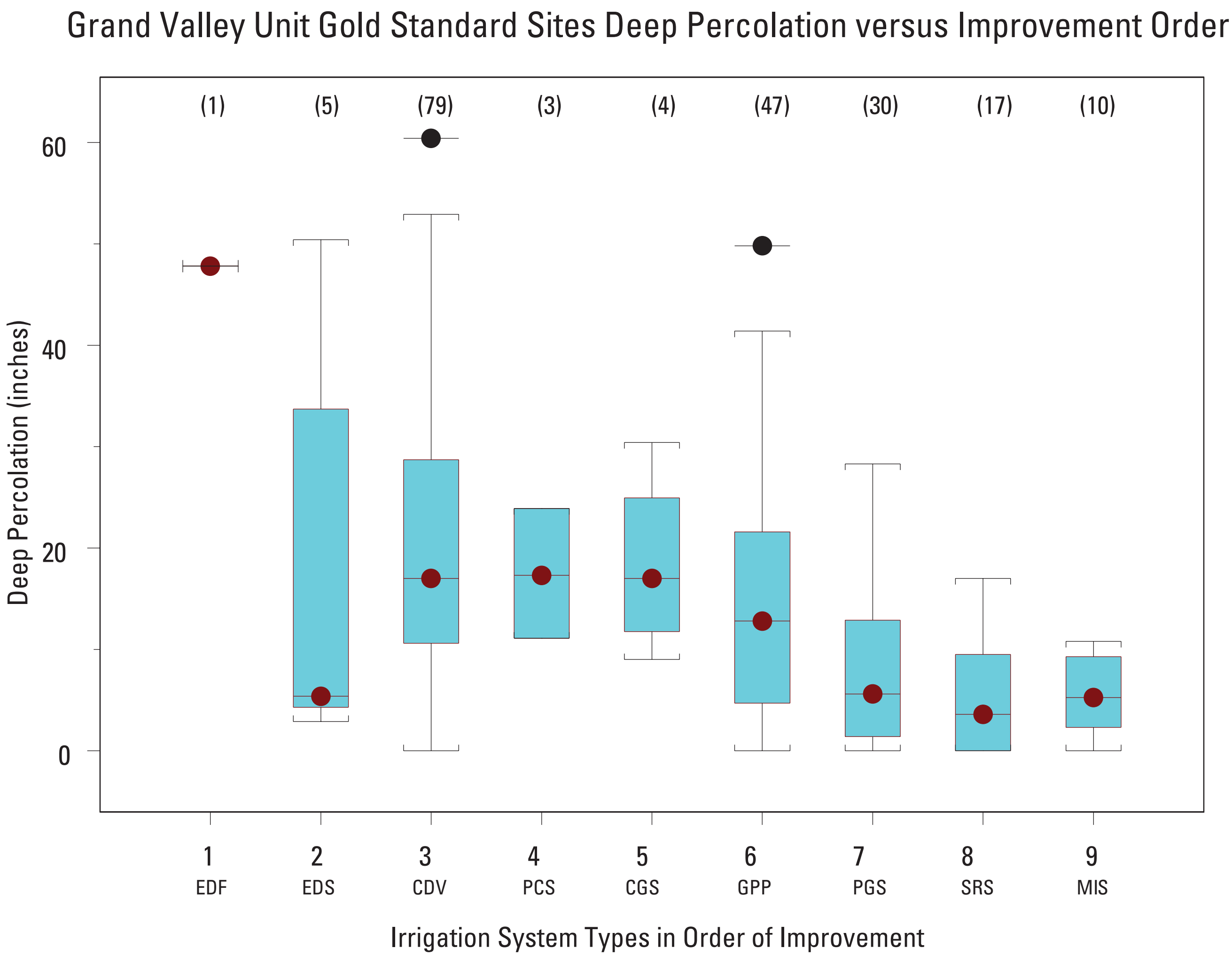


Figure 23. Box plot chart of deep percolation versus irrigation system types in order of improvement (1–9) for all usable Grand Valley, Lower Gunnison, and McElmo Creek Unit sites.

Figure 24 shows the same general trend of declining DP and declining DP variability as the box plot shown in figure 23. This box plot includes only Grand Valley Unit gold standard records.



Irrigation System Types

EDF	Earth Ditch to Feeder Ditch
EDS	Earth Ditch to Siphon Tubes
CDV	Concrete Ditch to Various Distribution
PCS	Ported Concrete Ditch to Surge
CGS	Concrete Ditch to Gated Pipe Surge
GPP	Gated Pipe
PGS	Pipeline to Gated Pipe Surge
SRS	Side-roll Sprinkler
MIS	Microspray

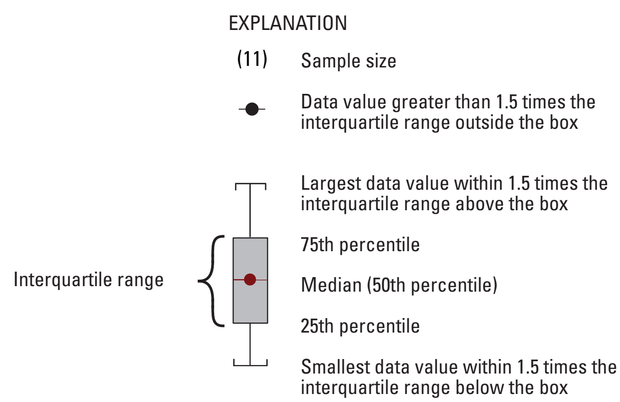
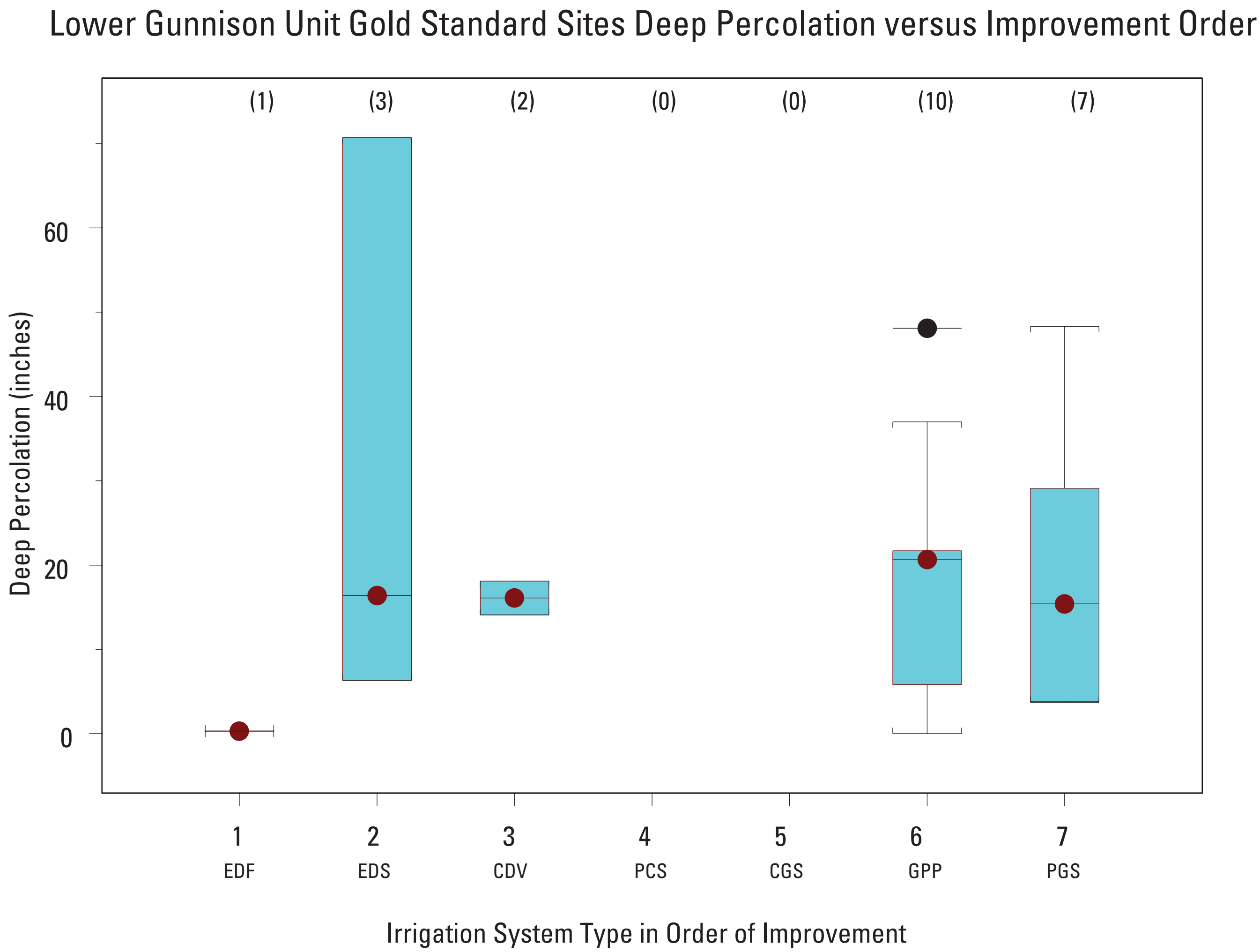


Figure 24. Box plot chart of deep percolation versus irrigation system types in order of improvement (1–9) for Grand Valley Unit gold standard sites.

Figure 25 shows a box plot of DP by irrigation system improvement order for Lower Gunnison Unit gold standard sites. There is no clear trend of declining DP as the improvement order increases for Lower Gunnison Unit sites. This is most likely because of the limited number of samples for the Lower Gunnison Unit.



Irrigation System Types

EDF	Earth Ditch to Feeder Ditch
EDS	Earth Ditch to Siphon Tubes
CDV	Concrete Ditch to Various Distribution
PCS	Ported Concrete Ditch to Surge
CGS	Concrete Ditch to Gated Pipe Surge
GPP	Gated Pipe
PGS	Pipeline to Gated Pipe Surge
SRS	Side-roll Sprinkler
MIS	Microspray

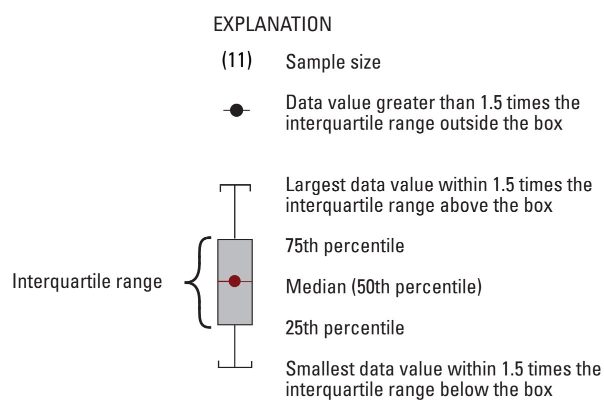
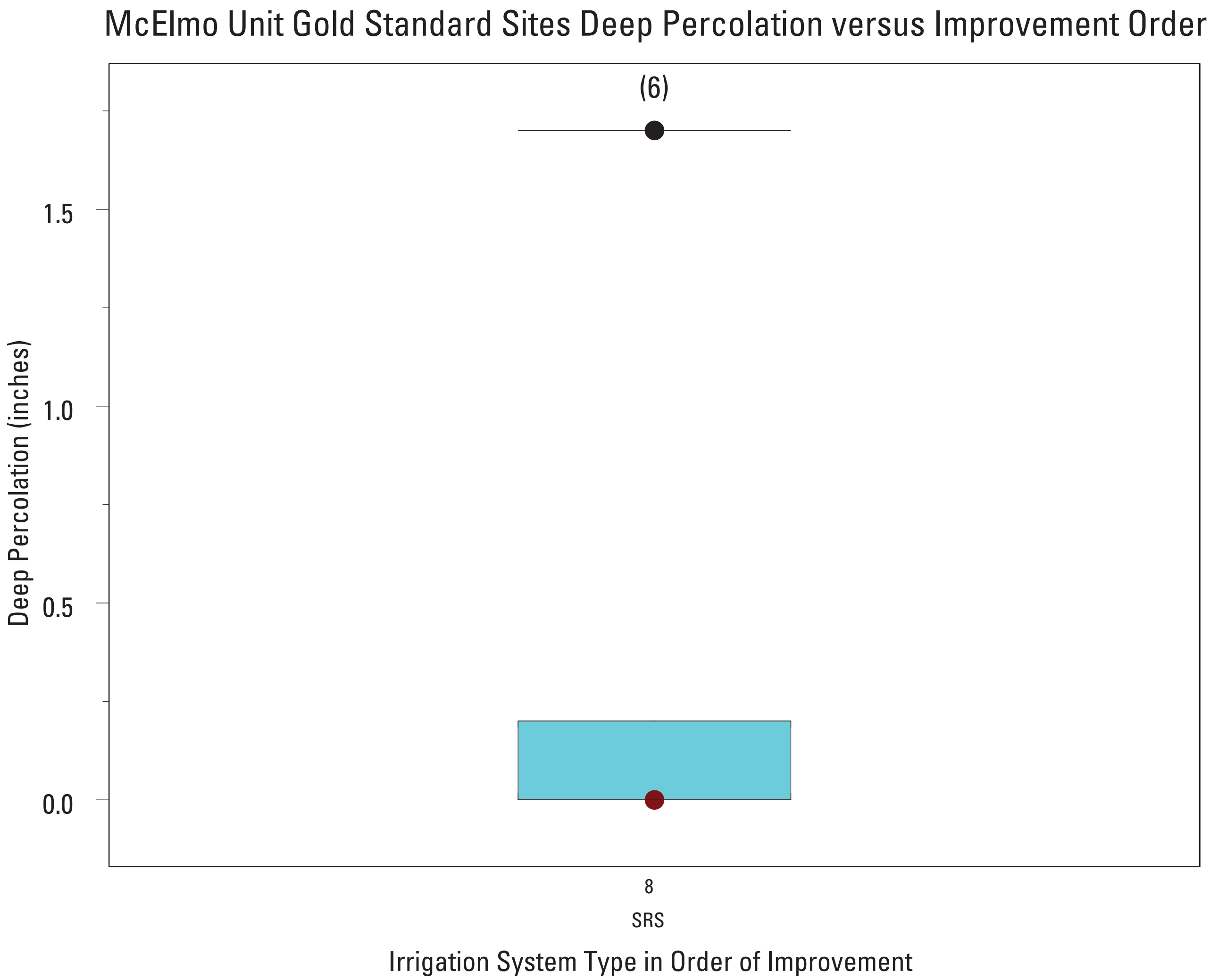


Figure 25. Box plot chart of deep percolation versus irrigation system improvement order for Lower Gunnison Unit gold standard sites.

Figure 26 shows that only side-roll irrigation systems are represented in the NRCS evaluation for the McElmo Creek Unit, and the DP is tightly grouped below 0.5 inch except for the one outlier at about 1.75 inches. This is quite low DP when compared with DP for other types of irrigation systems in the other units.



Irrigation System Types

EDF	Earth Ditch to Feeder Ditch
EDS	Earth Ditch to Siphon Tubes
CDV	Concrete Ditch to Various Distribution
PCS	Ported Concrete Ditch to Surge
CGS	Concrete Ditch to Gated Pipe Surge
GPP	Gated Pipe
PGS	Pipeline to Gated Pipe Surge
SRS	Side-roll Sprinkler
MIS	Microspray

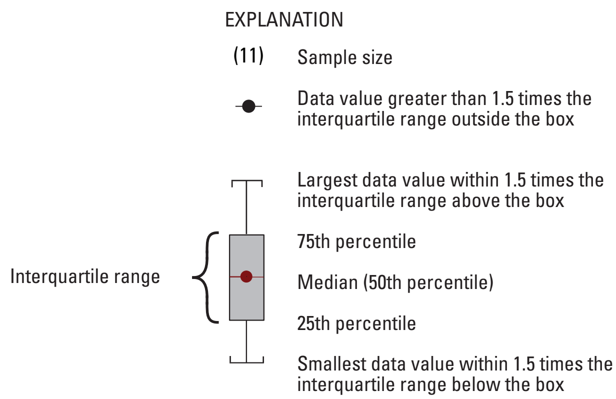
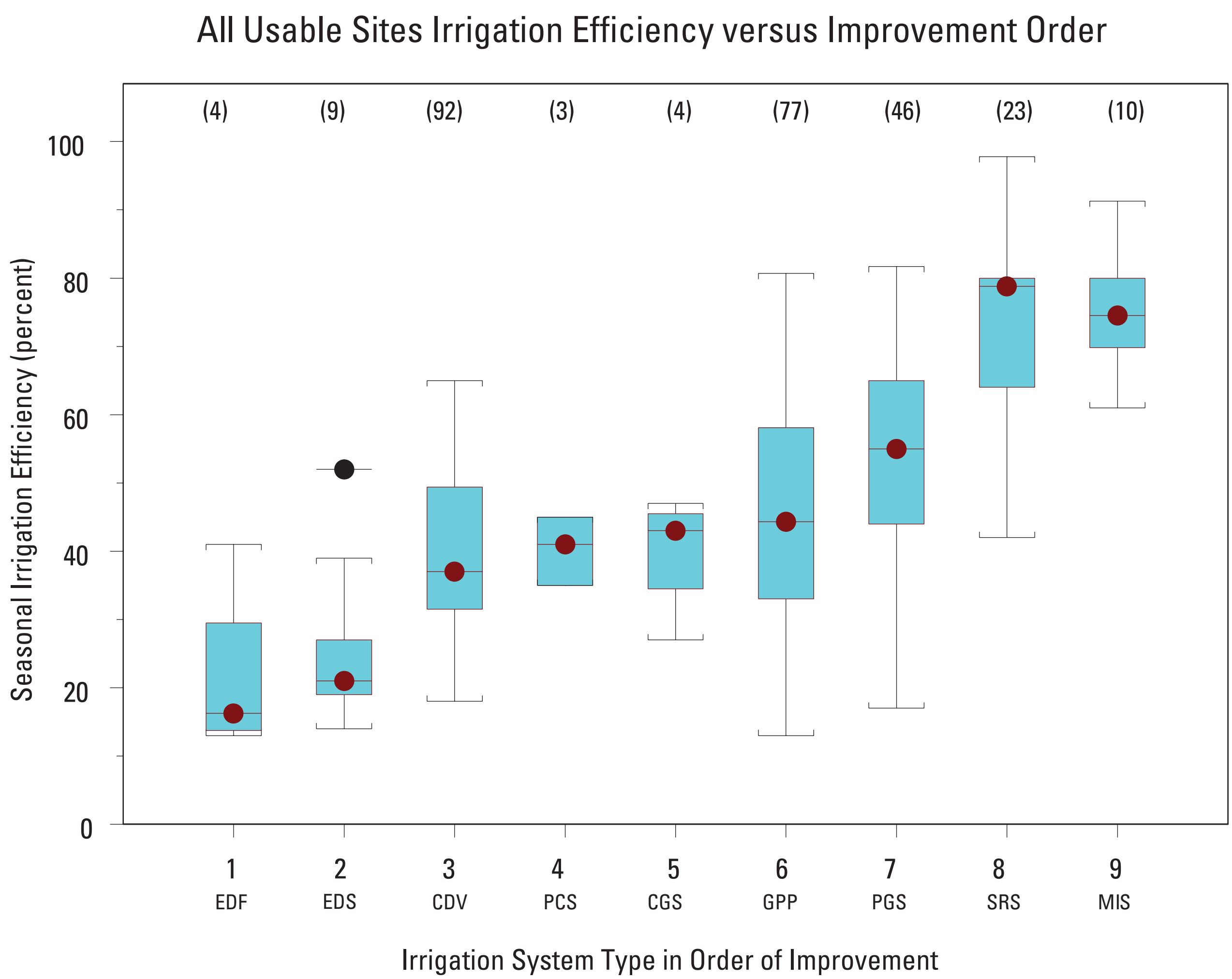


Figure 26. Box plot chart of deep percolation versus irrigation system improvement order for McElmo Creek Unit gold standard sites.

Seasonal Irrigation Efficiency and Irrigation System Type

Figure 27 shows a box plot for SIE by types of irrigation systems for all usable site-year records. Figure 27 demonstrates that as irrigation systems advance in order of improvement, the median values (red dot in the vertical box) of SIE increase, with the exception of MIS (microspray) irrigation in the far right box. It is possible that because the use of microspray systems was in its infancy in the Grand Valley Unit during the NRCS evaluation, the inherent high efficiency of microspray was not being fully optimized by the early adopters of this type of irrigation (Frank Riggle, NRCS, written commun., May 30, 2013). There is little difference in median SIE between SRS and MIS systems. However, this might simply imply that both systems are very similar in efficiency. No reduction in SIE variability is evident as the improvement level of the irrigation system increases. This may have been due to operators being in the learning phase with the more advanced types of irrigation technology during the NRCS evaluation.



Irrigation System Types

EDF	Earth Ditch to Feeder Ditch
EDS	Earth Ditch to Siphon Tubes
CDV	Concrete Ditch to Various Distribution
PCS	Ported Concrete Ditch to Surge
CGS	Concrete Ditch to Gated Pipe Surge
GPP	Gated Pipe
PGS	Pipeline to Gated Pipe Surge
SRS	Side-roll Sprinkler
MIS	Microspray

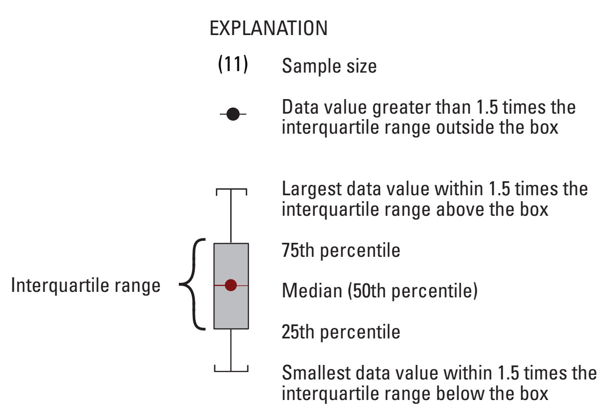
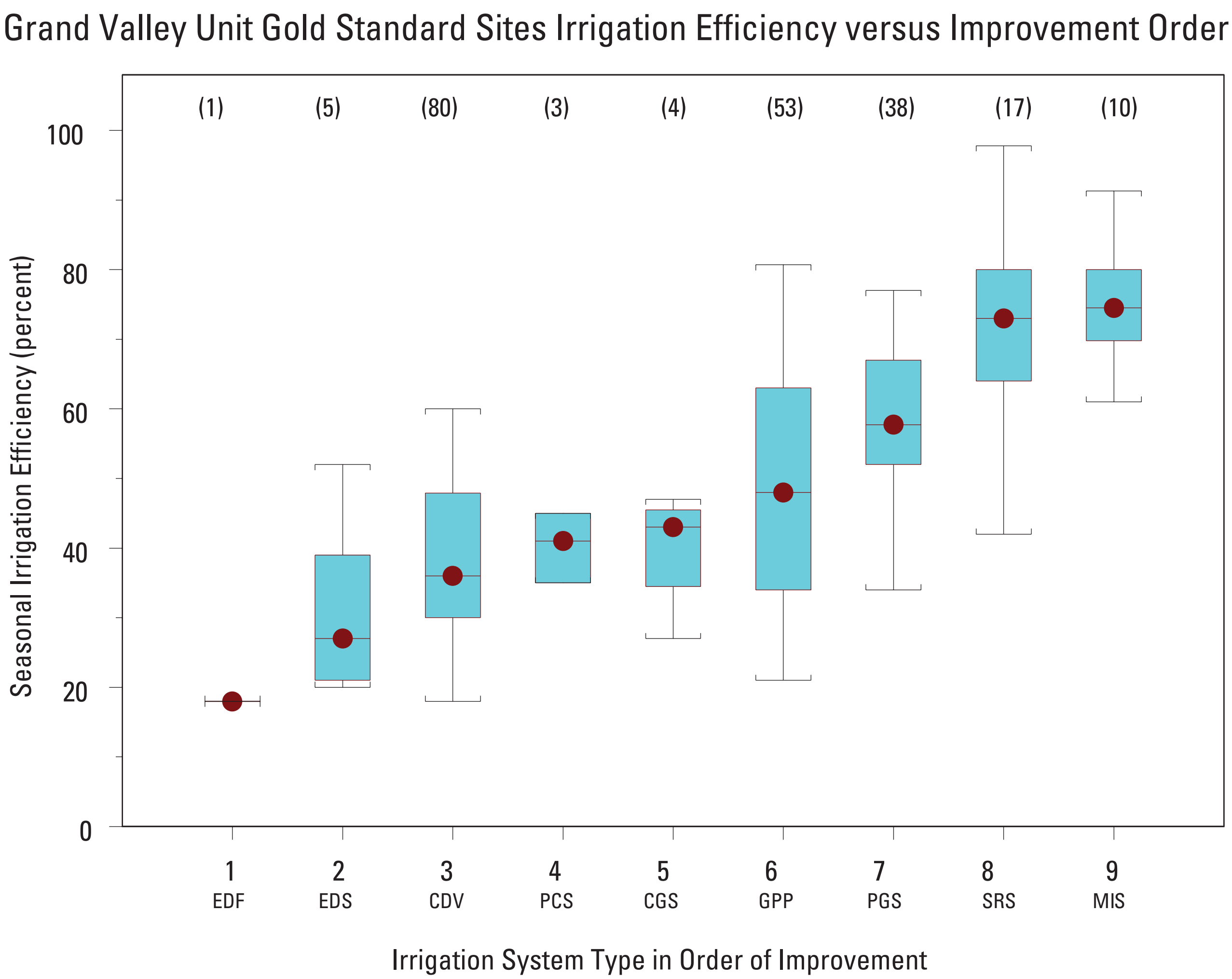


Figure 27. Box plot chart of seasonal irrigation efficiency versus irrigation system improvement order for all usable sites in the Grand Valley, Lower Gunnison, and McElmo Creek Units.

Figure 28 shows the change in SIE with increasing system improvement order for only the Grand Valley Unit gold standard sites. The pattern seen in figure 28 is quite similar to that of figure 27, which is to be expected because most of sites in figure 27 are Grand Valley Unit sites.



Irrigation System Types

EDF	Earth Ditch to Feeder Ditch
EDS	Earth Ditch to Siphon Tubes
CDV	Concrete Ditch to Various Distribution
PCS	Ported Concrete Ditch to Surge
CGS	Concrete Ditch to Gated Pipe Surge
GPP	Gated Pipe
PGS	Pipeline to Gated Pipe Surge
SRS	Side-roll Sprinkler
MIS	Microspray

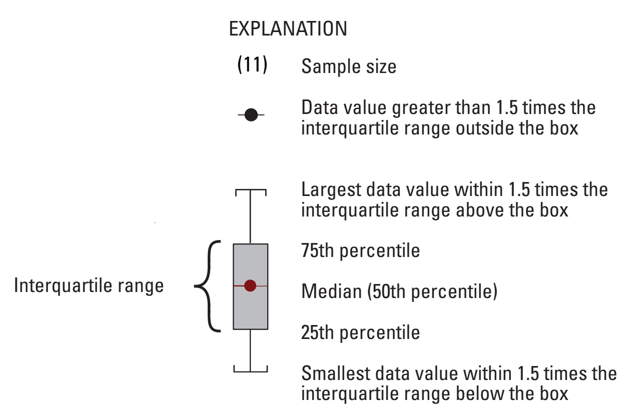
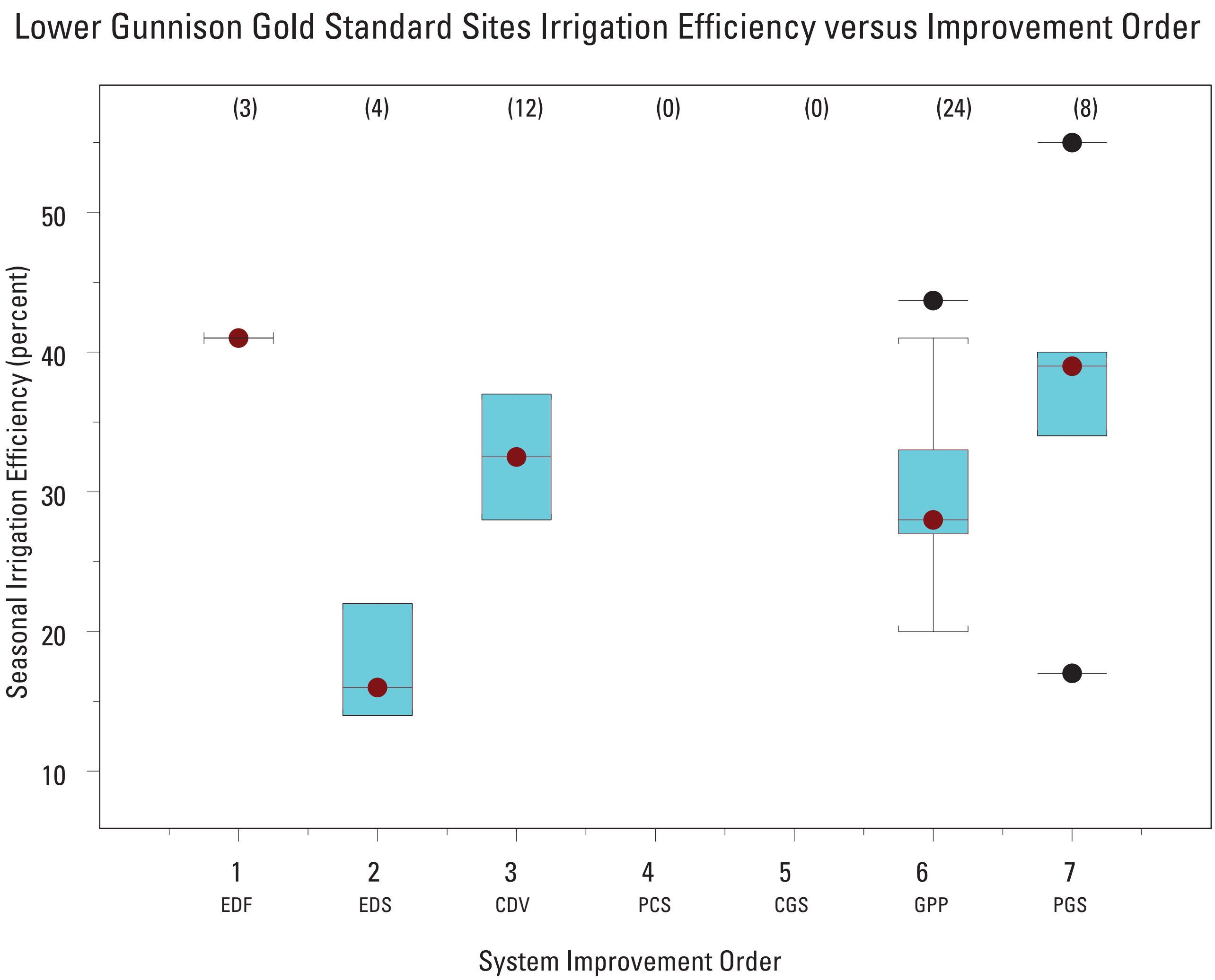


Figure 28. Box plot chart of seasonal irrigation efficiency versus irrigation system improvement order for Grand Valley Unit gold standard sites.

Figure 29 shows the change in SIE with increases in system improvement order for the Lower Gunnison Unit. The results are highly variable and do not indicate a strong pattern of SIE increasing with irrigation system improvements.



Irrigation System Types

EDF	Earth Ditch to Feeder Ditch
EDS	Earth Ditch to Siphon Tubes
CDV	Concrete Ditch to Various Distribution
PCS	Ported Concrete Ditch to Surge
CGS	Concrete Ditch to Gated Pipe Surge
GPP	Gated Pipe
PGS	Pipeline to Gated Pipe Surge
SRS	Side-roll Sprinkler
MIS	Microspray

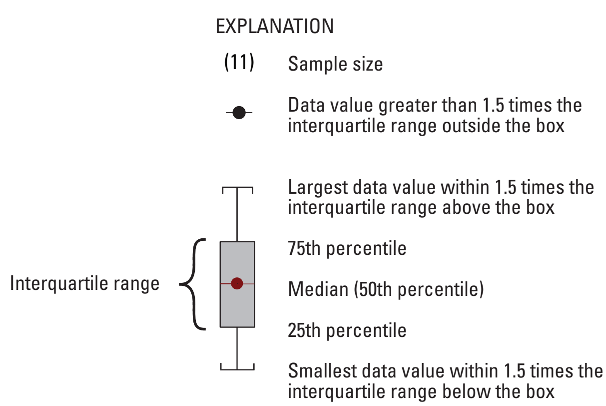
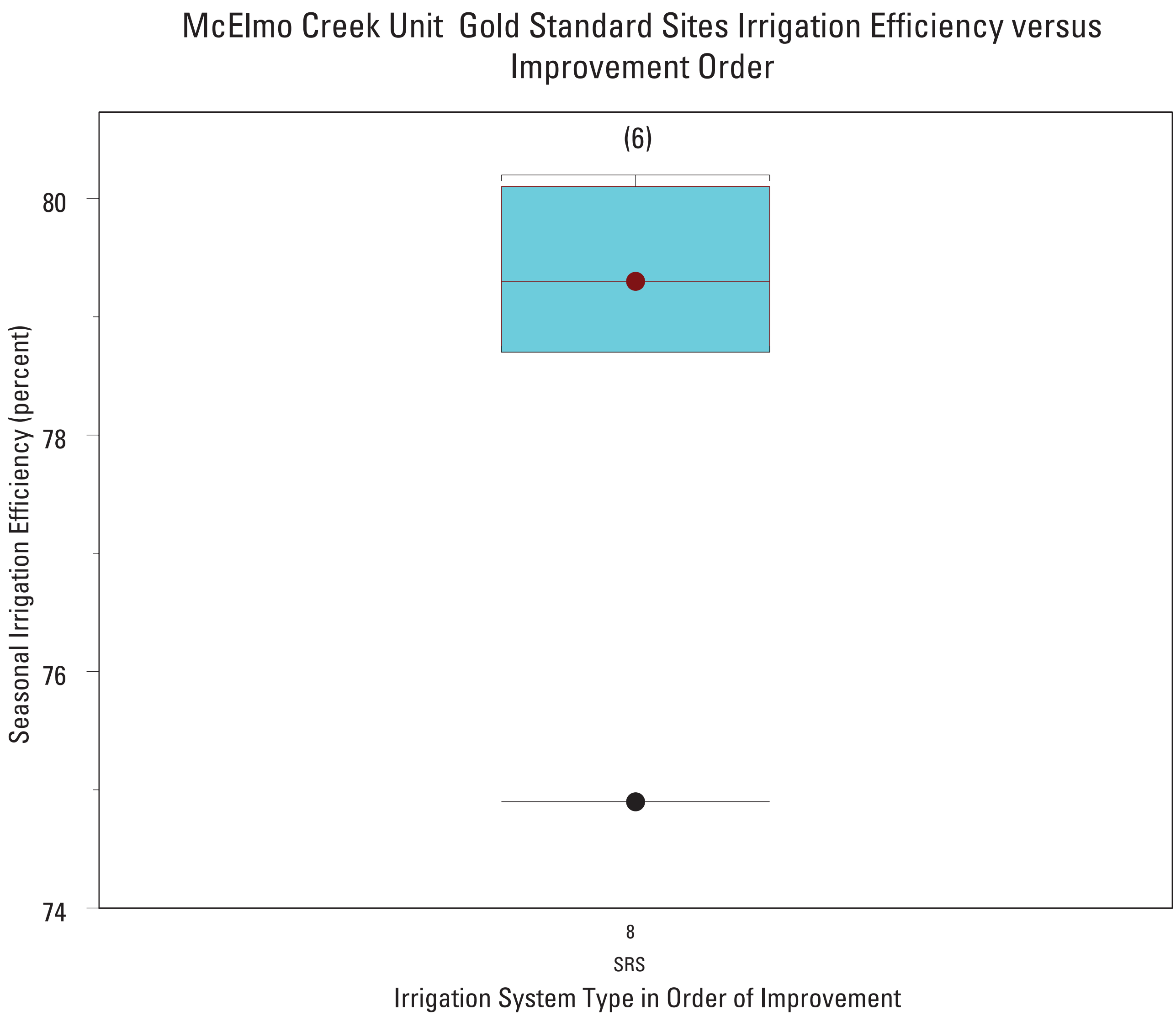


Figure 29. Box plot chart of seasonal irrigation efficiency versus irrigation system improvement order for Lower Gunnison Unit gold standard sites.

Figure 30 indicates that SIE is clustered for the McElmo Creek Unit sites between 75 and 80 percent for five of the six sites, with the outlier still close at about 74.5 percent.



Irrigation System Types

EDF	Earth Ditch to Feeder Ditch
EDS	Earth Ditch to Siphon Tubes
CDV	Concrete Ditch to Various Distribution
PCS	Ported Concrete Ditch to Surge
CGS	Concrete Ditch to Gated Pipe Surge
GPP	Gated Pipe
PGS	Pipeline to Gated Pipe Surge
SRS	Side-roll Sprinkler
MIS	Microspray

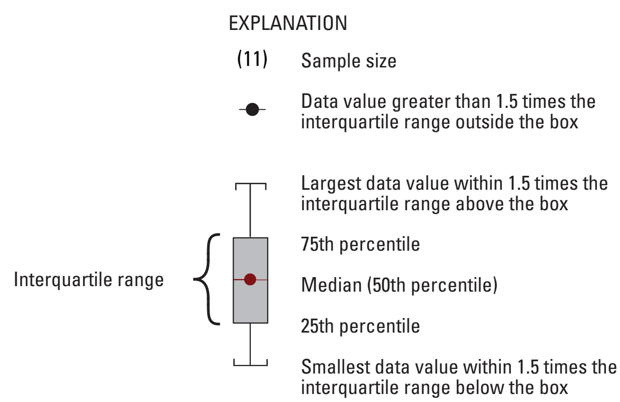


Figure 30. Box plot chart of seasonal irrigation efficiency versus irrigation system improvement order for McElmo Creek Unit gold standard sites.

Deep Percolation and Crop Type

Figure 31 shows the variation of DP by crop type for all gold standard sites. The large DP variability in grain is most likely caused by having only two samples of that crop type. There does not appear to be a strong correlation between DP and crop type, with the exception that onions and grain have higher median DP than the other crop types.

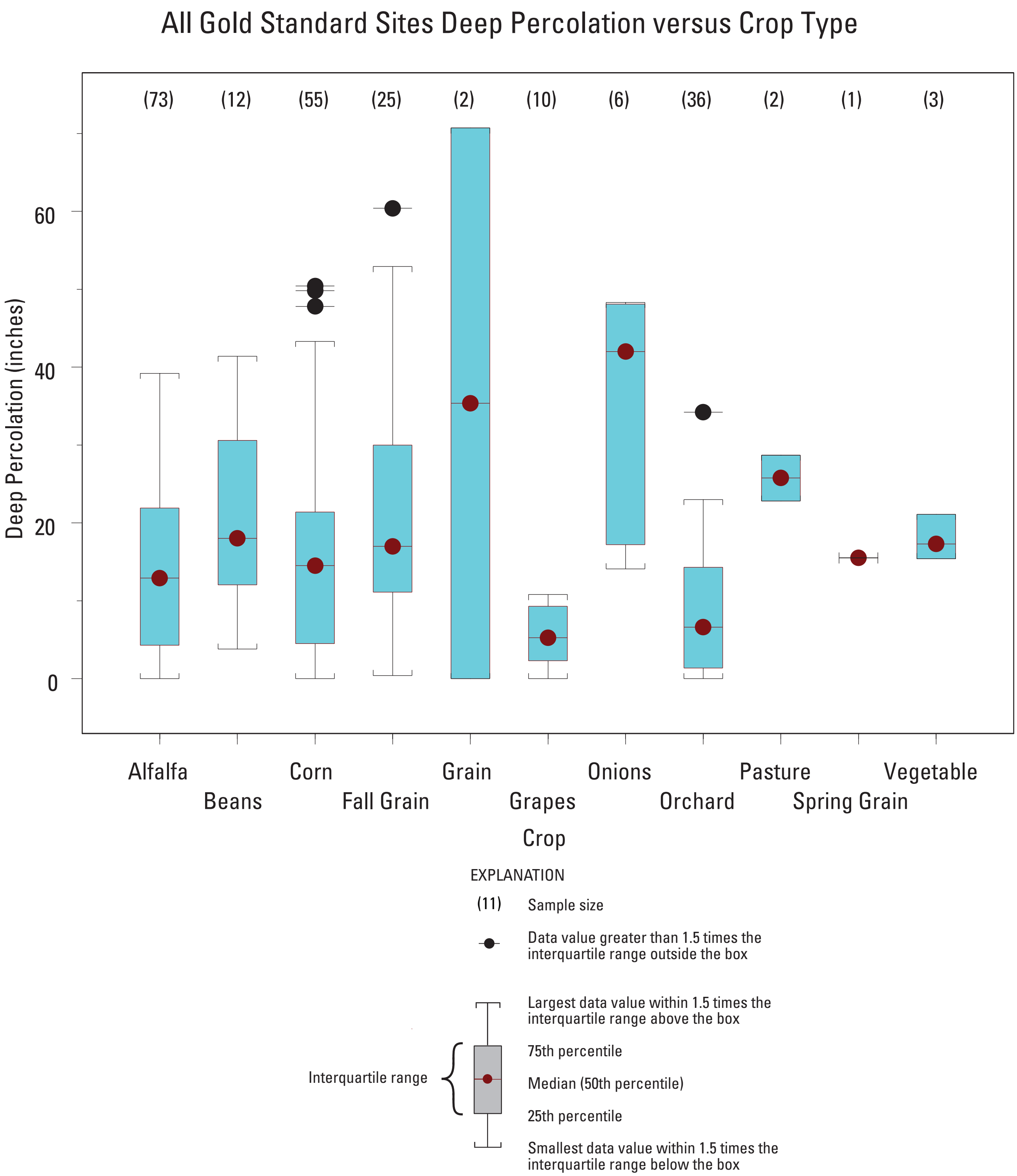


Figure 31. Box plot chart of deep percolation versus crop type for all gold standard sites.

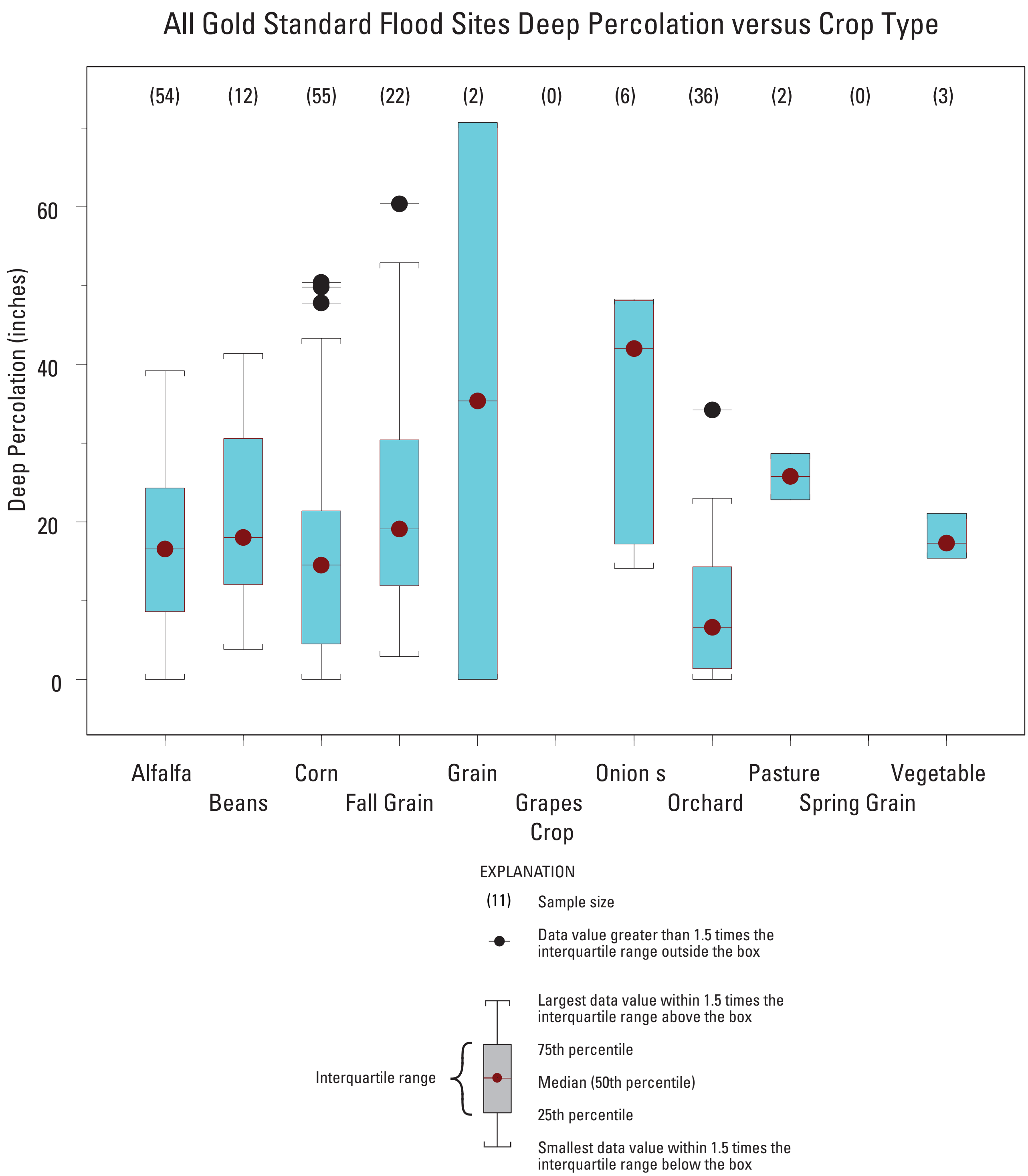


Figure 32. Box plot chart of deep percolation versus crop type for all gold standard flood irrigation sites.

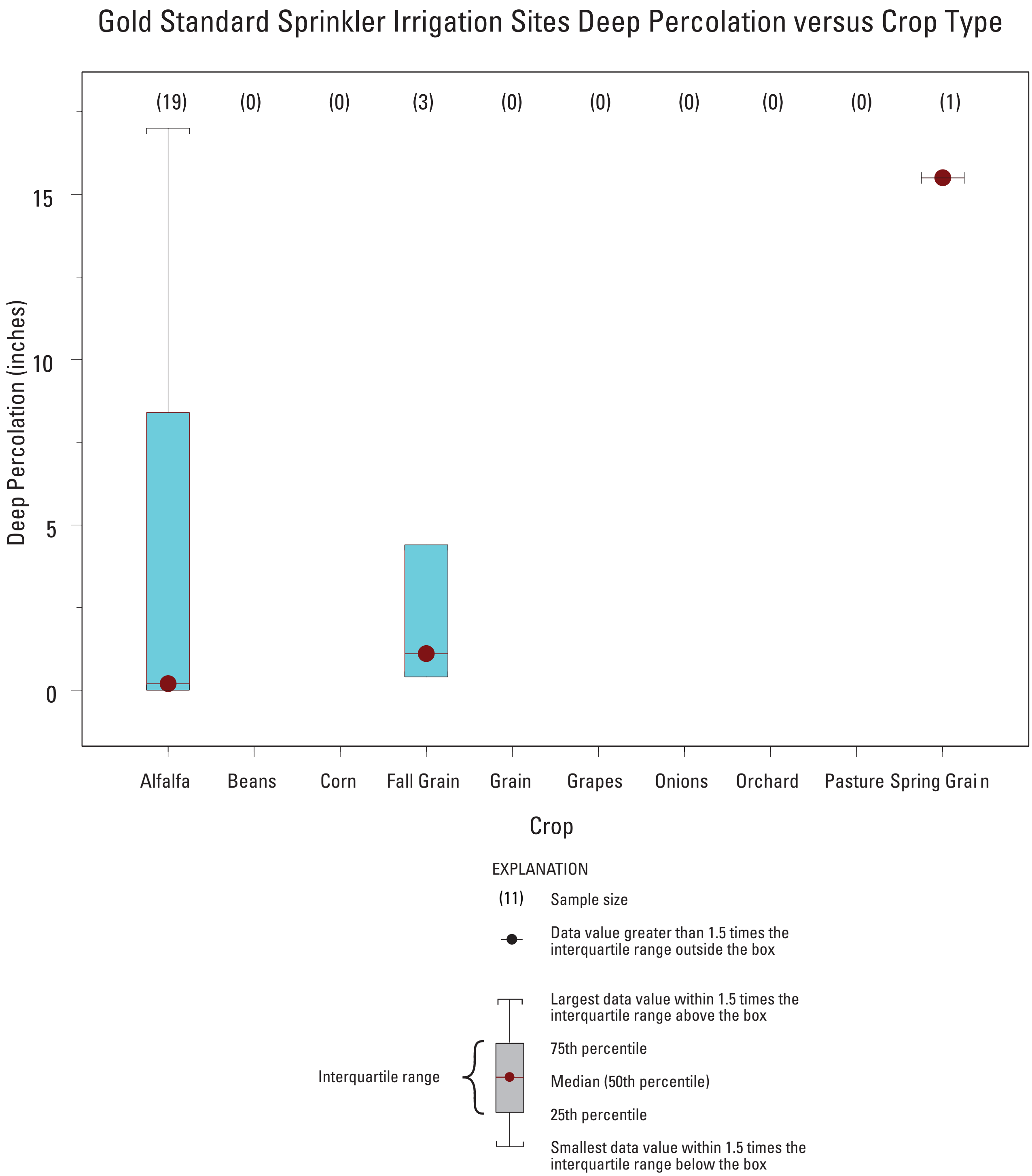


Figure 33. Box plot chart of deep percolation versus crop type for all gold standard sprinkler irrigation sites.

Figures 32-34 show DP by crop type for flood irrigation, sprinkler irrigation, and microspray sites. The pattern seen for flood irrigation sites in figure 32 is quite similar to that of figure 31, which would be expected because 192 of the 225 site-year records in figure 31 represent flood irrigation. Figure 33 shows deep percolation for sprinkler irrigation sites. Almost all of the site-year records in figure 33 represent side-roll sprinkler irrigation of alfalfa, which typically has very low deep percolation. Figure 34 shows deep percolation for microspray sites, all of which are Grand Valley Unit grapes sites. The 10 sites in figure 34 show a mean deep percolation of about 5 inches per season, which indicates the superior DP performance of microspray systems compared with flood irrigation systems.

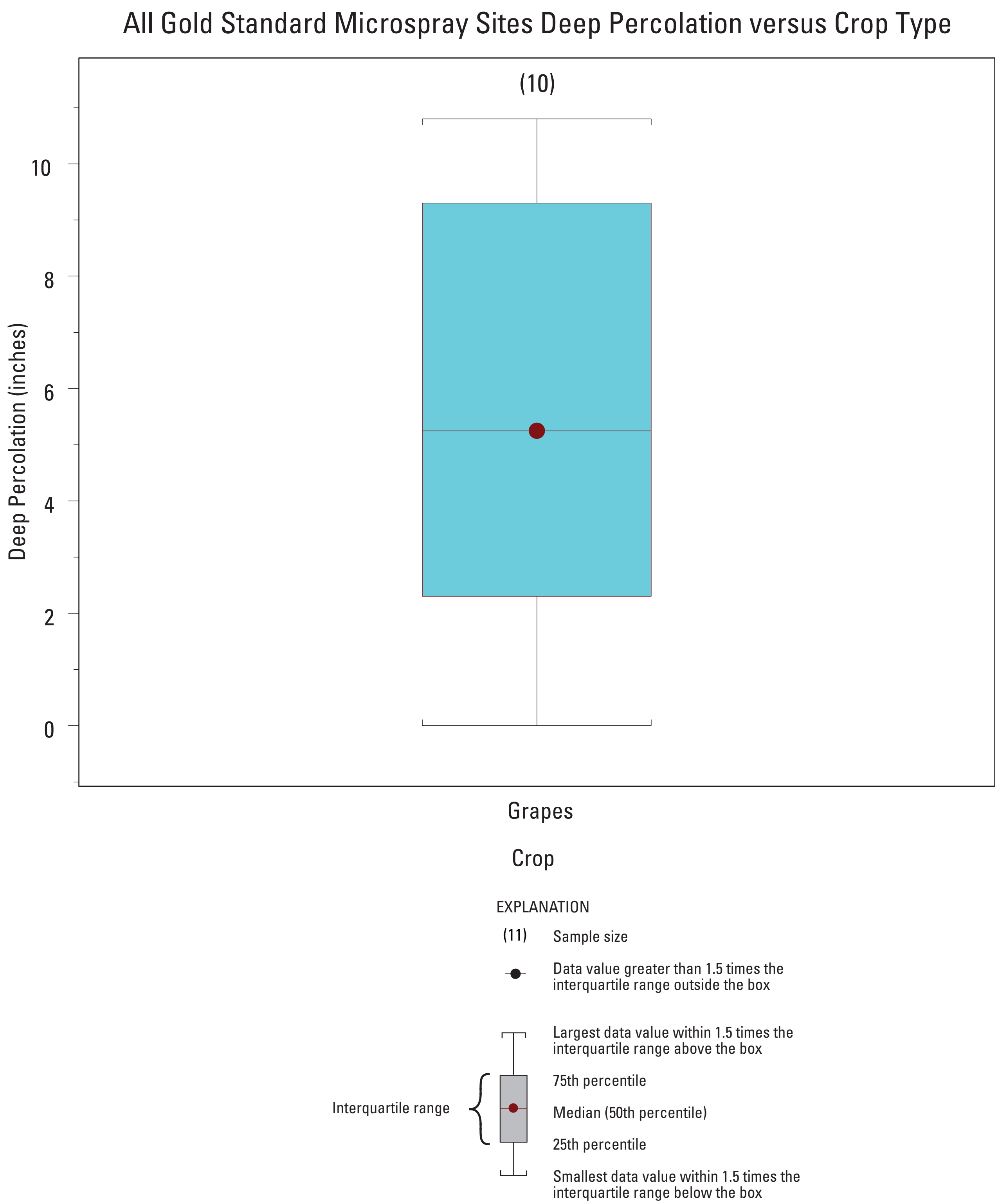


Figure 34. Box plot chart of deep percolation versus crop type for all gold standard microspray sites.

Seasonal Irrigation Efficiency and Crop Type

Figure 35 shows SIE by crop type for all gold standard sites. SIE ranges from about 25 percent for grain up to about 75 percent for grapes using microspray technology, as would be expected when comparing flood irrigation systems with microspray systems.

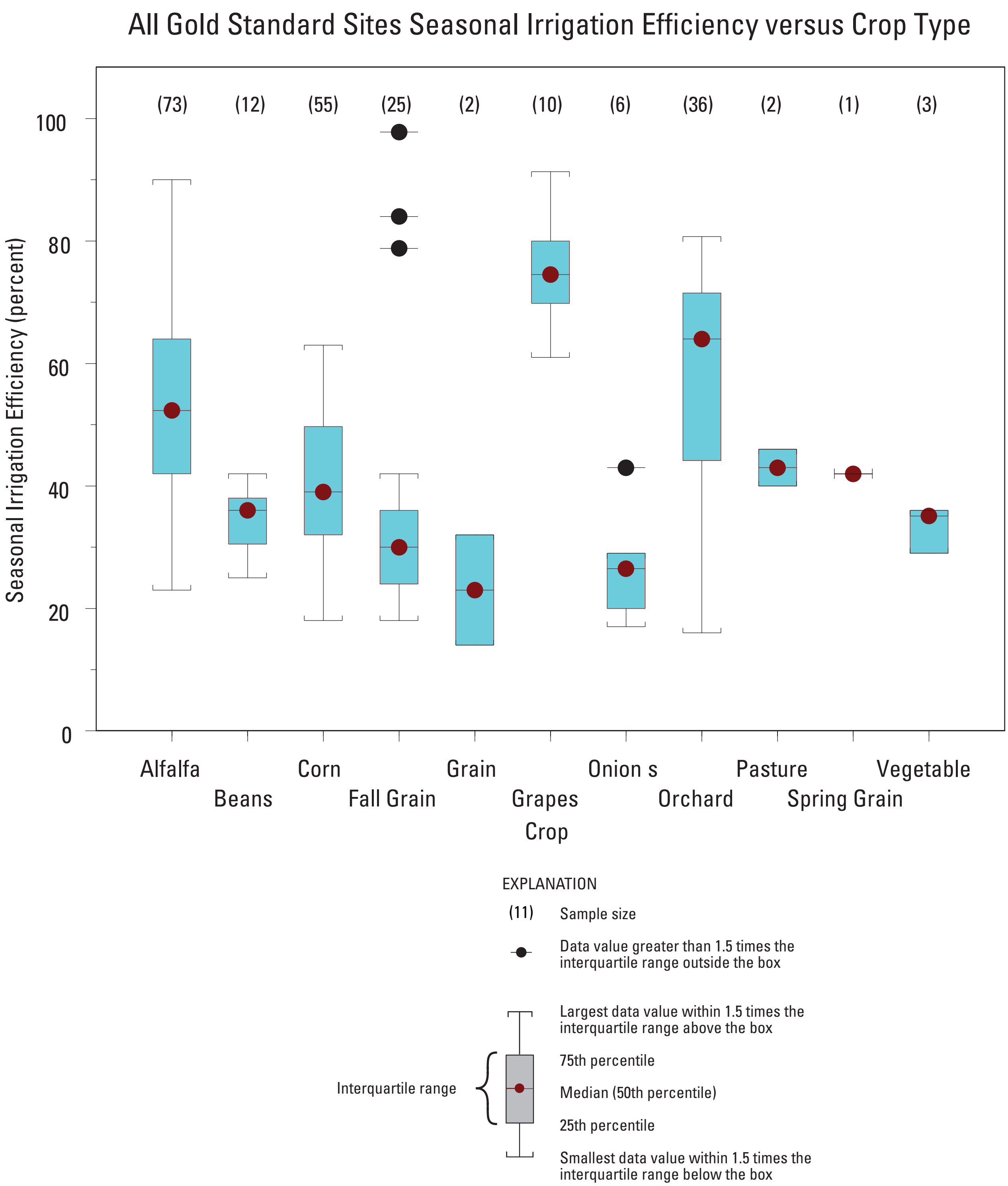


Figure 35. Box plot chart of seasonal irrigation efficiency versus crop type for all gold standard sites.

Figure 36 illustrates the variability of SIE by crop type for all gold standard flood irrigation sites. Alfalfa sites comprise the largest group, with a median irrigation efficiency of about 50 percent, while the next largest group, orchard, has a median irrigation efficiency of about 65 percent. Alfalfa uses both flood and side-roll sprinkler irrigation, while orchards mainly use micro-spray irrigation.

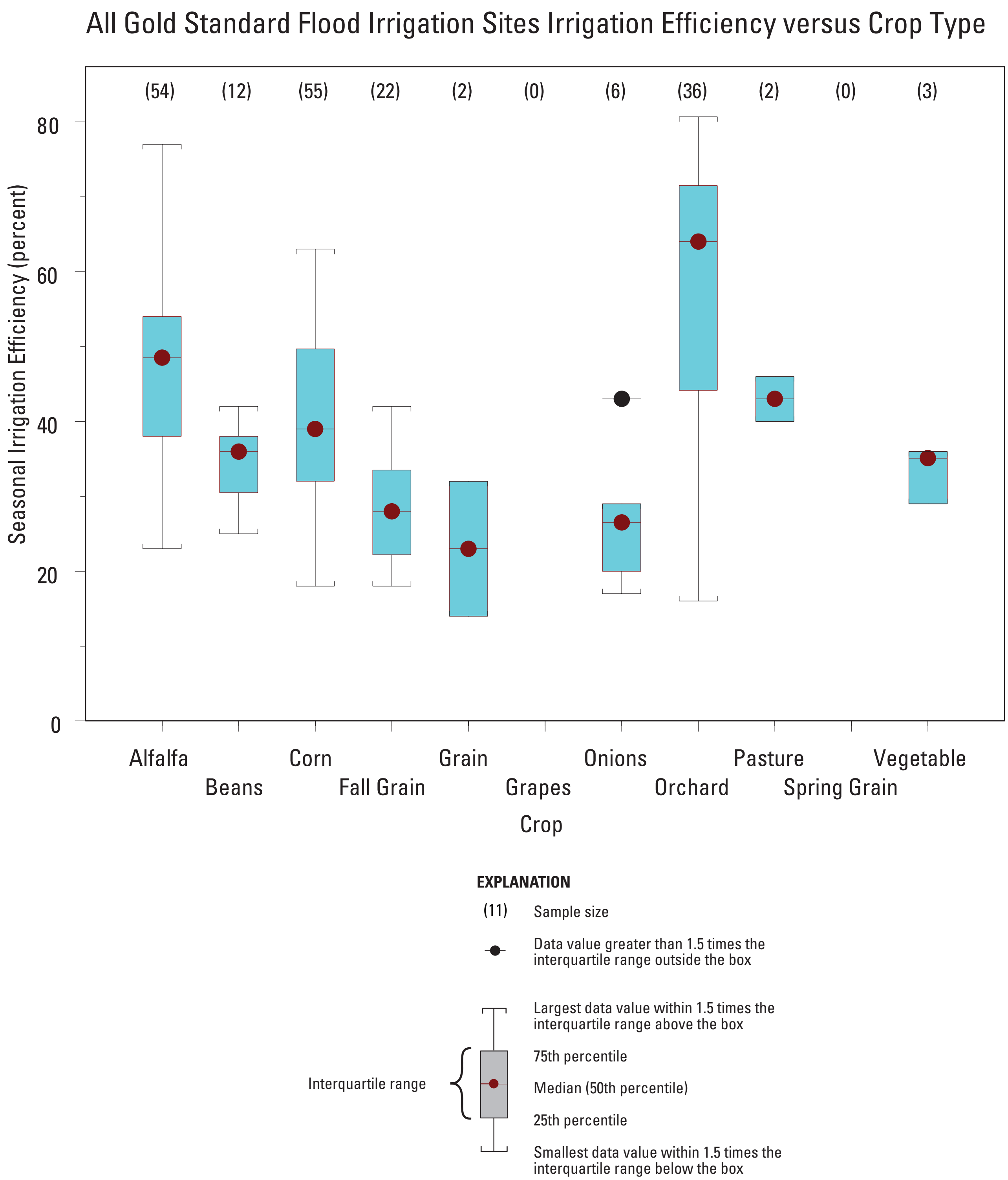


Figure 36. Box plot chart of seasonal irrigation efficiency versus crop type for all gold standard flood irrigation sites.

Figure 37 shows the variability of SIE by crop type for all gold standard sprinkler irrigation sites. All but four of the sites that use sprinkler technology are alfalfa sites, found primarily in the Lower Gunnison Unit. Their median efficiency is almost 80 percent. The low efficiency of the spring grain site corresponds with high DP reported for that site as seen in figure 33.

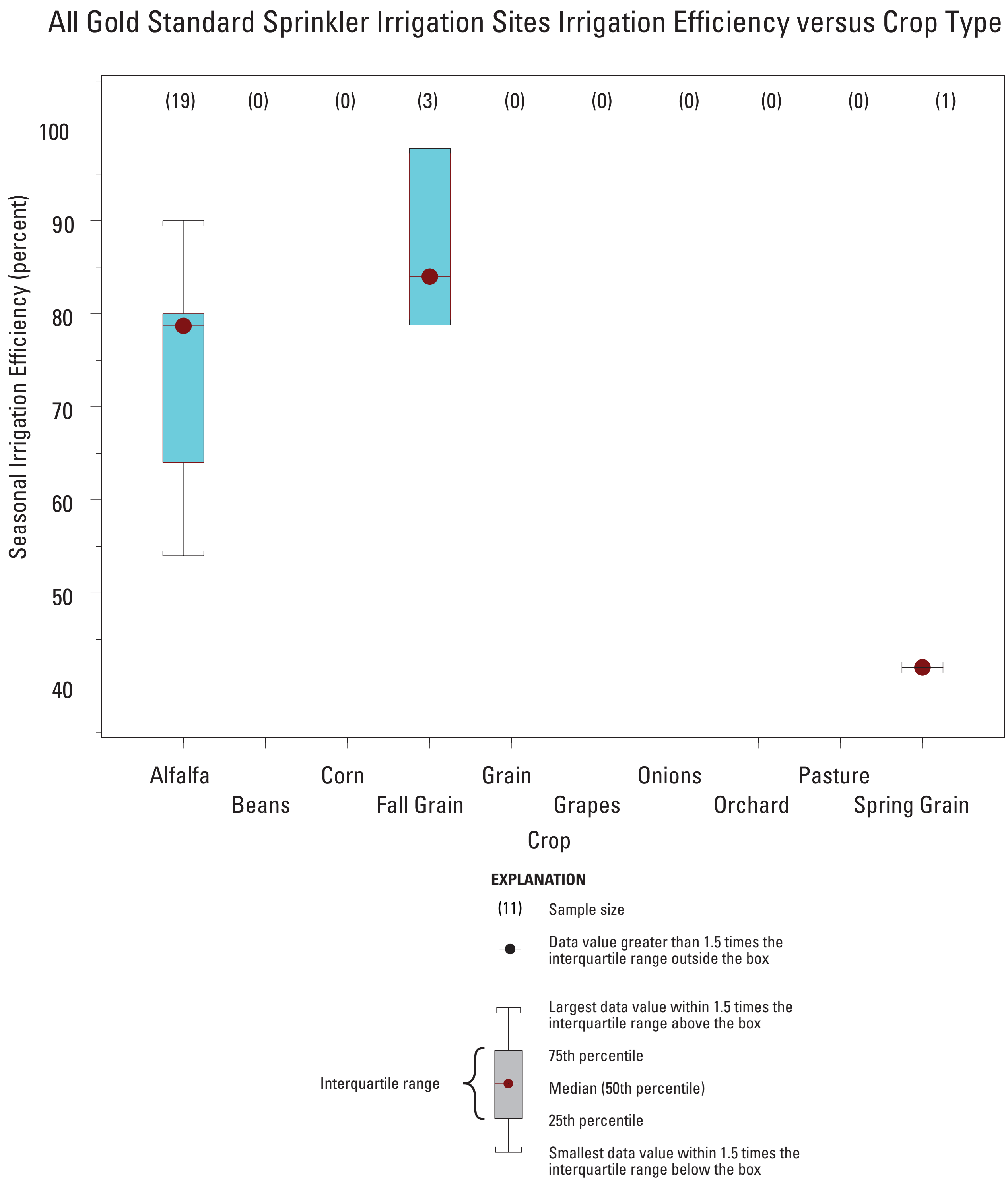


Figure 37. Box plot chart of seasonal irrigation efficiency versus crop type for all gold standard sprinkler irrigation sites.

Figure 38 shows a median SIE of about 75 percent for the 10 sites with grapes and microspray technology. These 10 sites are all located in the Grand Valley Unit.

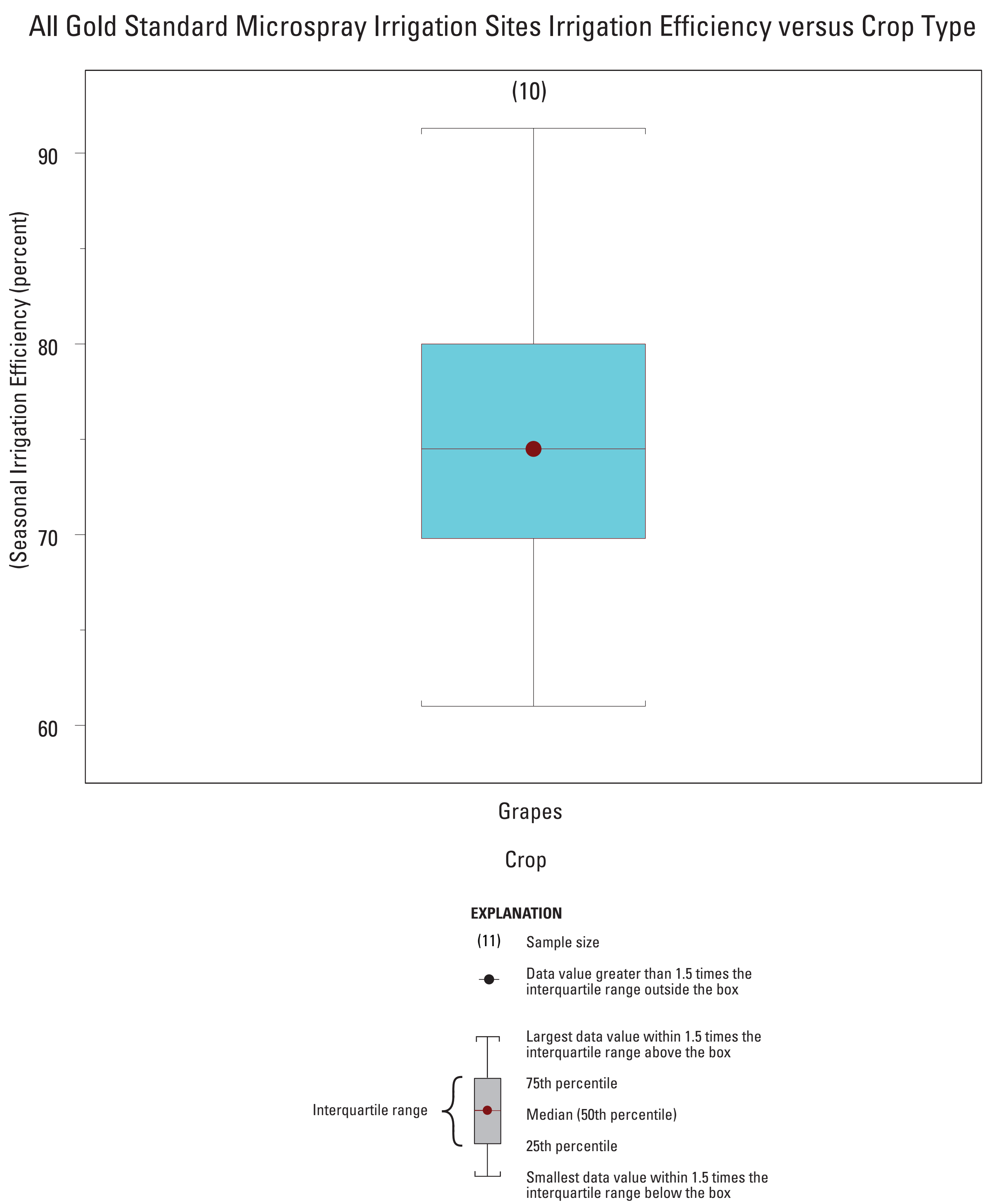


Figure 38. Box plot chart of seasonal irrigation efficiency versus crop type for all gold standard microspray sites.

Multiple Comparison Statistics

Continuous variables are made up of a series of measurements (for example, SIE), whereas discrete variables are categories (for example, crop type). Continuous variables are often grouped by discrete variables (for example, SIE by crop type). Tests were performed to determine whether the median value of a primary NRCS evaluation continuous variable (SIE, DP, ET_c, or infiltrated depth of irrigation water) significantly differs when grouped by a discrete category variable (irrigation system type, crop type, soil type, evaluation unit, evaluation year, crop rooting depth, or number of irrigation events). For example, it is possible to test whether DP has different median values that are statistically significant when grouped by crop type.

A ranked multiple comparison test was performed using the USGS library functions in S-PLUS (Lorenz and others, 2011) to perform these tests (Helsel and Hirsch, 2002). The ranked test was used because the continuous variables were not necessarily normally distributed. The ranked multiple comparison test indicates whether a significant difference in median value exists between two categories, but does not give the actual magnitude of the differences between the categories. If a significant median difference between two categories was detected by the multiple comparison test, then a Hodges-Lehmann estimate of the value of the difference was performed in S-PLUS (Helsel and Hirsch, 2002). The Hodges-Lehmann estimate gives the percent difference in median value for the continuous variable between two categories of the group.

Some of the comparisons yielded statistically significant results at a 95 percent confidence level (table 24). A “yes” in a cell of table 24 indicates that a statistically significant difference was found for the column category of the continuous response row variable, while a “no” indicates that no statistically significant difference was found. For example, DP was not found to have significant differences in median values when grouped by evaluation year. Many of these relations would be expected, such as irrigation efficiency depending significantly on different types of irrigation system technology, or evapotranspiration being dependent on crop type. Other relations, such as infiltrated depth of irrigation water being dependent on evaluation year, are not intuitive. It is beyond the scope of the USGS study to provide a physical explanation of these test results; tables 24-26 characterize the NRCS evaluation results and are provided for use by water managers. See appendix 5 for the remainder of the multiple comparison test results.

Table 24. Multiple comparisons performed on Natural Resources Conservation Service evaluation dataset with yes-no indication of significant correlations for all usable site-year records.

[Yes indicates a statistically significant correlation was found at the 95 percent confidence level between the categories and the median continuous response variable; No indicates that no statistically significant correlation was found.

Continuous Response Variable	Category Variables						
	Irrigation System Type in Improvement Order	Crop Type	Soil Type	Evaluation Unit	Evaluation Year	Crop Rooting Depth	Number of Irrigation Events
Irrigation efficiency	Yes	Yes	Yes	Yes	Yes	Yes	No
Deep percolation	Yes	Yes	Yes	Yes	No	Yes	No
Crop evapotranspiration	No	Yes	No	Yes	Yes	Yes	No
Infiltrated depth	No	No	Yes	Yes	Yes	No	No

Table 25 shows an example of a multiple comparison chart that compares SIE for various irrigation system types, while table 26 shows the comparison of DP for the same irrigation system types. To read the chart, use the following example. In table 25 find the cell containing +36 in the row labeled “EDF” (earth ditch to feeder tube). The column irrigation system type for the +36 cell is PGS, or pipeline to gated surge. The conclusion from the value of +36 in this cell is that system type PGS (column) has a 36 percent greater median irrigation efficiency than system type EDF (row) as indicated by the + (positive) sign, and the 36 percent value has a 95 percent confidence of being correct. If there had been a – (negative) sign on the 36, then the opposite conclusion would be drawn—that the median efficiency of the PGS column system type is 36 percent lower than the median efficiency of the EDF row system type.

In terms of NRCS salinity reduction efforts, the positive values of SIE in table 25 for the more advanced types of irrigation systems are desirable because they demonstrate that SIE increases with the more advanced systems. Similarly, negative values for DP in table 26 for the more advanced types of irrigation systems are also desirable, indicating that DP is reduced for more advanced system types. Positive values for SIE in table 25 indicate higher SIE for the advanced system types, while negative values of DP in table 26 indicate lower DP for the advanced system types. These results agree with the falling median DP and rising median SIE shown in the box plots for DP and SIE by irrigation system type (fig. 23 and fig. 27).

Table 25. Differences in median irrigation efficiency by system improvement order for all usable site-year records.

[Numbers at row and column intersections indicate the statistically significant difference between the median seasonal irrigation efficiency for the column system type as compared to the median seasonal irrigation efficiency for the row system type, significant at the 95 percent confidence level; EDF, earth ditch to feeder tube; EDS, earth ditch to siphon tube; CDV, concrete ditch to various distribution methods; PCS, ported concrete ditch to surge; CGS, concrete ditch to gated pipe surge; GPP, gated pipe; PGS, pipeline to gated surge; SRS, side-roll sprinkler; MIS, microspray]

Irrigation System Type	Difference in Median Seasonal Irrigation Efficiency of Column System Type Over Row System Type (Percent)								
	EDF	**EDS**	**CDV**	**PCS**	**CGS**	**GPP**	**PGS**	**SRS**	**MIS**
EDF							+36	+35	+36
EDS						+20	+31	+52	+52
CDV							+16	+35	+36
PCS									
CGS								+35	
GPP								+28	+30
PGS								+20	
SRS									
MIS									

Table 26. Multiple comparisons of deep percolation by improvement order irrigation system type codes for all usable site-year records.

[Numbers at row and column intersections indicate the statistically significant difference between the median seasonal irrigation efficiency for the column system type as compared to the median seasonal irrigation efficiency for the row system type, significant at the 95 percent confidence level; EDF, earth ditch to feeder tube; EDS, earth ditch to siphon tube; CDV, concrete ditch to various distribution methods; PCS, ported concrete ditch to surge; CGS, concrete ditch to gated pipe surge; GPP, gated pipe; PGS, pipeline to gated surge; SRS, side-roll sprinkler; MIS, microspray.]

Irrigation System Type	Difference in Median Deep Percolation of Column System Type Over Row System Type (Inches)								
	EDF	**EDS**	**CDV**	**PCS**	**CGS**	**GPP**	**PGS**	**SRS**	**MIS**
EDF									
EDS								–8	
CDV							–9	–14	–12
PCS									
CGS									
GPP								–10	
PGS									
SRS									
MIS									

Soil Moisture Balance Models

To test the implicit data collection and data processing assumptions that resulted in the NRCS evaluation dataset, 12 sites in the Grand Valley Unit from 1989 to 1993 were selected for soil moisture balance (SMB) modeling. It was not possible to model sites in the other evaluation units due to a lack of daily ET_c data for those units. The sites selected for modeling included four crops (alfalfa, corn, grapes, and fall grain), and five different irrigation system technologies (table 27). These choices represented a good cross-section of system types and crop types.

Table 27. Summary of sites selected from Natural Resources Conservation Service evaluation dataset for soil moisture balance modeling.

[CDV, concrete ditch to various distribution methods; GPP, gated pipe; SRS, side-roll sprinkler; PGS, pipeline to gated surge; MIS, microspray.]

Crop Type	Irrigation System Type Code	Evaluation Years	Number of Sites Modeled
Alfalfa	CDV	1989	1
Alfalfa	GPP	1989	1
Alfalfa	SRS	1989, 1993	2, 2
Alfalfa	PGS	1993	2
Corn	GPP	1989	2
Grapes	MIS	1989	1
Fall Grain	CDV	1991	1

An SMB model is a mathematical spreadsheet model of the daily sum of water inputs and outputs for an evaluation site for one irrigation season. The USGS study SMB models enable the testing of assumptions contained in the reported NRCS evaluation data for the site being modeled. Per-irrigation-event data are required for the site, as well as daily ET_p values. Site crop and soil characteristics are taken into account. Calculated daily SMBs are compared with reported balances. Customized ET crop coefficient curves are constructed for each site to enable calculation of ET_c.

The SMB models were created in Microsoft Excel 2010 (Microsoft Corporation, 2010). The original versions of these SMB model spreadsheets were built as part of another USGS study (Mayo, 2008).

Soil Moisture Balance Calculations

The basic soil moisture formula is

Daily Ending Soil Moisture = Previous Daily Ending Soil Moisture + Daily Moisture Inputs – Daily Moisture Outputs (3)

where

Daily Moisture Inputs are inches of precipitation and irrigation applied, and

Daily Moisture Outputs are inches of ET_c, runoff, and DP.

Precipitation is the net precipitation, taking into account runoff from the rain event. The net irrigation applied to a flood-irrigated field is the inflow to the field minus outflow, or tail water. For sprinkler irrigation, the net applied irrigation is the inflow to the sprinkler system minus a correction factor for wind effects and overspray.

To calculate DP with the SMB model, the field capacity, or soil moisture holding capacity at saturation, is used as the maximum amount of soil moisture that can be stored in the crop root zone for the day in question. The water balance is calculated for the day, which yields a trial ending soil moisture balance (eq. 3). The trial value is then compared with the field capacity for the soil type at the site. If the trial balance exceeds field capacity (FC), then the amount of water in excess of field capacity is considered to be DP that leaves the bottom of the root zone (eq. 4). In this case, the ending SMB is equal to FC (eq. 5). If the trial balance is less than the FC, then no DP has occurred, and the ending SMB is equal to the trial balance (eqs. 6 and 7).

Trial Daily Ending Balance = Previous Daily Ending Balance + Precipitation + Irrigation – Runoff – ET_c (4)
If Trial Daily Ending Balance > FC, then
Deep Percolation = Trial Daily Ending Balance – FC, (5)
and Daily Ending Balance = FC (6)
Otherwise,
Deep Percolation = 0, (7)
and Daily Ending Balance = Trial Daily Ending Balance (8)

Soil Moisture Balance Inputs

Evapotranspiration for Soil Moisture Balance Models

The ET inputs required for the SMB models are reference evapotranspiration (ET_p), crop evapotranspiration (ET_c), and the crop coefficient (K_c), which when multiplied with ET_p yields ET_c. The presumed NRCS evaluation ET_p data were used in the SMB models, as was a K_c curve equation developed by the USDA Agricultural Research Service (ARS).

Reference Evapotranspiration

The ARS supported the NRCS evaluation by providing the Modified Penman equations for calculating alfalfa referenced ET_p. The NRCS evaluation used data from the two NRCS weather stations shown in figure 15 (Grand Valley Annual Report, 1985, *in* U.S. Department of Agriculture, 1986–2003). The only existing record of ET_p data from the NRCS evaluation is contained in a spreadsheet dating from 1999 that was used by the CSU Extension to provide daily ET_p values to the media in the Grand Valley (Colorado State University Cooperative Extension, 1999). That spreadsheet (ZETA.wks) contains daily ET_p data for Grand Junction and Fruita from 1989 through 1999. It was assumed for the USGS study that this is the same ET_p data that would have come from the NRCS Evaluation weather stations. This assumption is difficult to fully test, as no other record of ET_p data in the Grand Valley can be found from 1985 to 1991. Daily ET_p is available starting in 1992 for Fruita and 1993 for Grand Junction from the CoAgMet network operated by Colorado State University (Colorado State University, 2013). Daily raw weather station data required for the Penman ET_p equation (maximum and minimum temperature, vapor pressure, solar radiation, and wind run) are unavailable before 1992 for Fruita and 1993 for the Grand Valley. (It is possible to retrieve maximum and minimum temperature and precipitation.) This means that it is impossible to recreate the Penman equation ET_p values prior to 1992 for comparison with the ZETA.wks spreadsheet ET_p values.

Comparisons of the ZETA.wks ET_p values with CoAgMet ET_p from 1992 to 1999 were made, and in general the ZETA.wks ET_p is lower than comparable CoAgMet ET_p by about 21 percent from 1992 through 1997 for some unknown reason. In 1998 and 1999, the ZETA.wks ET_p values are identical to the CoAgMet ET_p values. This discrepancy will be discussed further in the section “Reference Evapotranspiration Discrepancies.”

Crop Evapotranspiration Coefficient

A K_c curve is used to adjust the daily ET_p for the particular crop type and its actual evapotranspiration behavior. Each SMB model site requires a different K_c curve because the crop cycles vary by site, by planting date, and the length of time to harvest. Alfalfa crops usually have three or four cuttings or harvests each irrigation season, and the crop cycle for each cutting is different in amplitude and duration. To test the model assumptions, several types of K_c curves were created for each site and made selectable in the SMB models for comparisons. The original SMB models developed for the USGS Urban DP study (Mayo, 2008) required extensive additions for this USGS study because of the need to incorporate K_c curves that varied by crop stage and multiple alfalfa cuttings per season. The Urban DP study only dealt with established grass lawns.

The K_c curve, which is generally accepted as a current standard, is the K_c curve presented in the United Nations Food and Agricultural Organization (FAO) Irrigation and Drainage Paper No. 56 (FAO-56; Allen and others, 1998), a generic representation of which is shown in figure 39. The FAO-56 paper was commissioned by the FAO to provide a global reference document for the calculation of evapotranspiration. The lead author was Dr. Richard Allen of the University of Idaho.

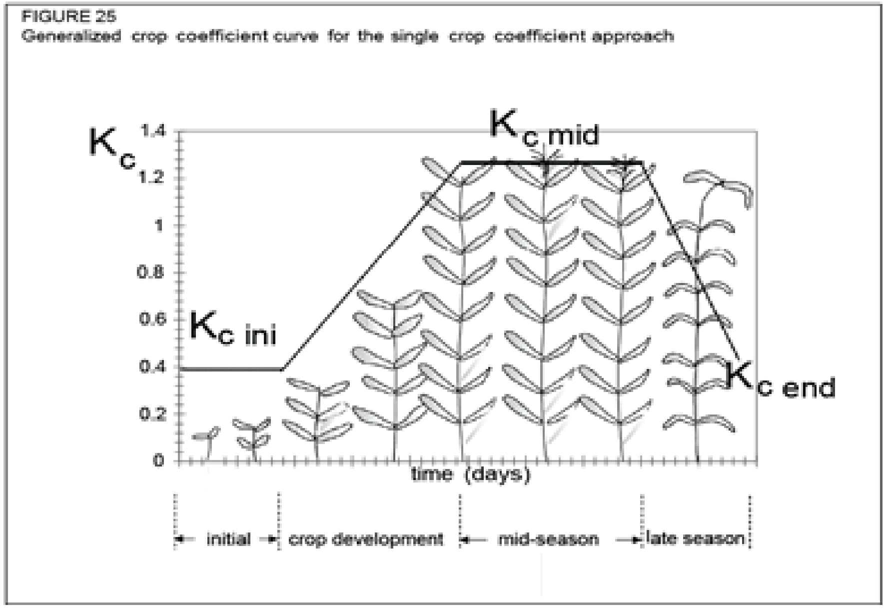


Figure 39. Generalized crop coefficient curve K_c from United Nations Food and Agriculture Organization Irrigation and Drainage Paper No. 56 (from Allen and others, 1998).

The FAO-56 K_c curve shows four stages of crop growth: initial, crop development, mid-season, and late season. K_c has a constant level in the initial stage of crop growth (K_c ini), increases during the crop development stage, holds at a constant level during mid-season (K_c mid), and gradually declines in late season to an end value (K_c end). Each site requires a custom K_c curve which depends on the planting data and harvest date. For alfalfa, which is harvested ("cut") typically three or four times during an irrigation season, a series of K_c curves is required, with each cutting varying in length of days. Because the NRCS evaluation did not report the cutting dates for any of the alfalfa sites, these dates were inferred from the pattern of irrigation events for the site in discussions with a CSU extension agronomist (Calvin Pearson, Colorado State University Extension Service, oral commun., April 19, 2012). The amplitude of the K_c curve at each of the four stages of development was made adjustable in the SMB model spreadsheet for each site, as well as the overall amplitude of the entire season K_c curve(s). This adjustable amplitude is one of the keys to achieving the best fit of the model to the reported results for the site.

To model the FAO-56 K_c curve, it was decided, based on published information (Allen and others, 1998) to standardize the proportion of the four periods of the K_c curve at 10 percent of the total period for the initial phase, 30 percent for crop development, 40 percent for mid-season, and 20 percent for late season. See appendix 6 for a listing of SMB model spreadsheet columns that pertain to K_c calculations.

The other K_c curve used in the SMB models is from the ZETA.wks spreadsheet and ultimately derived from the ARS publication "Scheduling Irrigations: A Guide for Improved Irrigation Water Management Through Proper Timing and Amount of Water Application" (Duke, 1987). The ARS-supplied crop coefficient equation results in the curve shown in figure 40 and is referred to as the NRCS K_c curve.

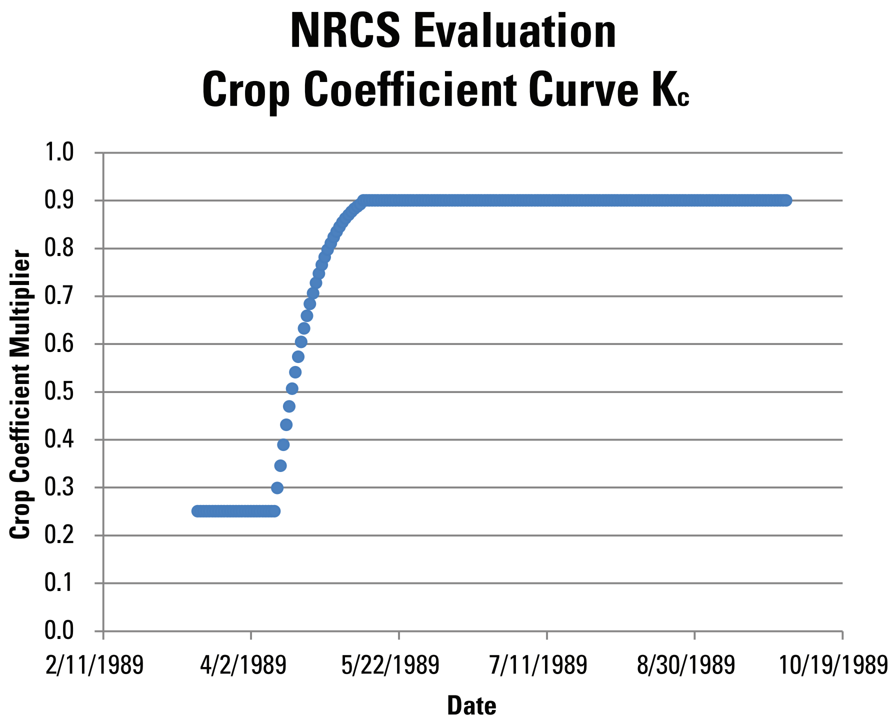


Figure 40. Natural Resources Conservation Service evaluation crop coefficient curve for a typical irrigation season (from Duke, 1987).

The duration of the K_c curve in figure 40 is from March 15 to September 30, 1989. The FAO-56 K_c curve in figure 39 is quite different from the NRCS K_c curve in figure 40. In particular, no late season decline is provided for in the NRCS curve, and the ramp-up in K_c during the crop development stage is quite rapid. Also, no repetitive use of the K_c curve was apparent in the NRCS spreadsheet to accommodate multiple alfalfa crop cuttings, although this could have been applied by manipulating the ZETA.wks spreadsheet crop development dates manually. Once K_c reached the mid-season level, it stayed at that level for the remainder of the season. The duration of the ramp-up during crop development phase of the NRCS curve is set by the length of time from planting to full cover. The full-cover amplitude of the NRCS K_c curve is determined by the coefficient tables for each crop.

No explanation can be given for the differing NRCS K_c equation, other than improvements that have been made in evapotranspiration science since the early 1980s when the NRCS evaluation curve was originally used. The relatively poor fit of the NRCS evaluation K_c equation to actual crop growth might explain some of the discrepancies in ET_c and DP results that will be discussed in a subsequent section "Potential Discrepancies in Results between SMB models and NRCS Evaluation." Both the FAO-56 K_c curve and the NRCS evaluation K_c curve were included as selectable choices for comparison purposes in the USGS study SMB models for comparison purposes, although in the final analysis, all models were set to use the NRCS evaluation K_c curve. This will be discussed in more detail in the later section "Potential Discrepancies in Results between SMB Models and NRCS Evaluation."

Stress Correction of Crop Evapotranspiration

The availability of soil moisture to the crop changes as the amount of moisture in the root zone varies between field capacity and wilting point. It is typically assumed in irrigation management that 50 to 60 percent of the moisture in the root zone is "readily available," with the remainder being "not readily available" (Allen and others, 1998). The crop is said to be "stressed" when the soil moisture is in the not readily available range. Based on this assumption, it is possible to adjust the manner that the crop coefficient affects ET_c. This is done by adding an additional multiplier K_s to the ET_c equation:

$$ET_c = ET_p * K_c * K_s \tag{9}$$

where

ET_c is crop evapotranspiration in inches,
ET_p is reference evapotranspiration in inches,
K_c is the crop coefficient multiplier, and
K_s is the stress coefficient multiplier.

In the Urban DP report (Mayo, 2008), a stress multiplier curve with the stress point set at 60 percent is shown (fig. 41), based on the FAO-56 report (Allen and others, 1998). Figure 41 shows that between the 60 percent total available water value and field capacity, the value of K_s is 1, so ET_c performs as normal. Below the ET_c stress point, K_s declines linearly from 1 to 0 at the permanent wilting point.

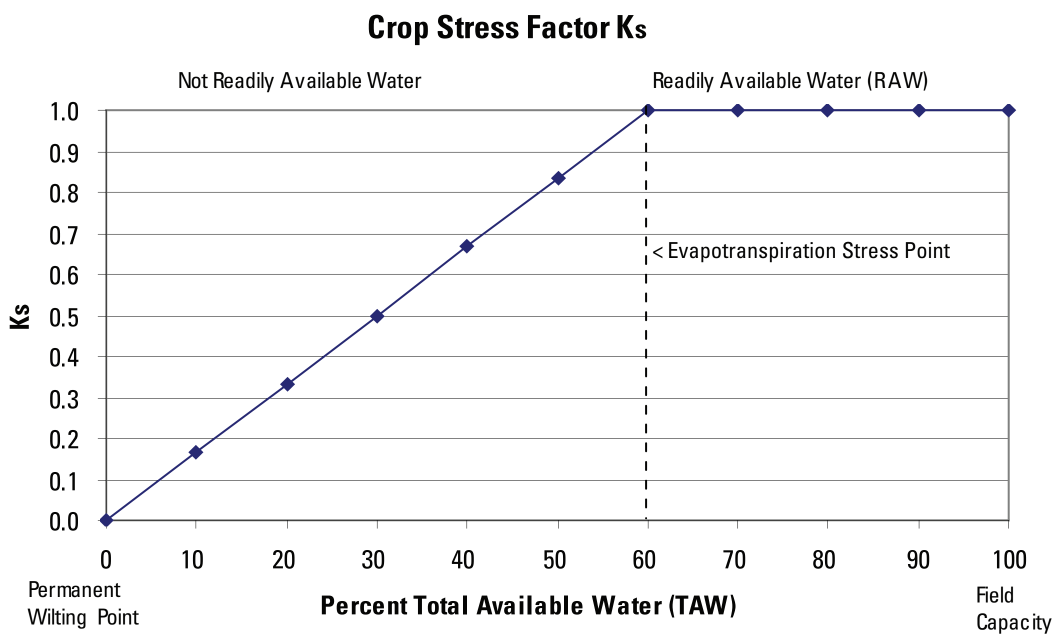


Figure 41. Crop stress coefficient curve (from Mayo, 2008).

The NRCS evaluation reports refer to “stress correction” of an unspecified type being applied to the evaluation results. In the SMB model spreadsheets used in the USGS study, the FAO-56 stress correction curve shown in figure 41 is applied to ET_c through the use of a Visual Basic macro program in Excel. As will be discussed in the later section “Crop Evapotranspiration Stress Correction Discrepancies,” it was necessary to switch off the stress correction in the SMB model spreadsheets to achieve the best match of model results with NRCS evaluation results.

Site Physical Parameters for Soil Moisture Balance Models

A number of physical parameters were required as inputs to calculations for the SMB models. Table 28 lists those parameters.

Table 28. Site physical parameters required as inputs for soil moisture balance models.

[commun., communication; NRCS, Natural Resources Conservation Service; CSU, Colorado State University; GIS, geographic information system; NOAA, National Oceanic and Atmospheric Administration; FAO, Food and Agricultural Organization of the United Nations; ET_p, reference evapotranspiration; K_c, crop coefficient multiplier; Colorado Irrigation Guide, U.S. Department of Agriculture, 1988]

Parameter	Note	Source of Parameter
Crop rooting depth	Determines total field capacity and wilting point	Jason Peel, NRCS, Ft. Collins, Colo., written commun., September 5, 2012
Reported site precipitation for season	For comparison with weather station precipitation	NRCS evaluation annual reports
Weather station to use for daily precipitation	CSU Fruita Experiment Station, Walker Field Airport, CSU Orchard Mesa Experiment Station, NRCS Palisade weather station	Manually selected from GIS measurement of closest weather station to site
Weather station daily precipitation	Historic records	NOAA National Climate Data Center
Precipitation dataset to use	NRCS reported or Weather station	Manually selected for comparisons
ET_p dataset to use	CSU Fruita or CSU Orchard Mesa experiment station values	Manually selected from GIS measurement of closest weather station to site
Crop coefficient curve to use	FAO K_c curves or NRCS K_c curves	Manually selected for comparisons
Planting and harvest dates	Sets start and end of season	NRCS evaluation annual reports
Readily available water percent	Typically set at 50 percent	Manually selected
Site irrigated acres	For conversion of irrigation water inflow quantities	NRCS evaluation annual reports
Site soil type	Determines field capacity and wilting point	NRCS evaluation annual reports, updated to current NRCS soil types
Field capacity for first 12 inches of soil	Determined by soil type	1988 Colorado Irrigation Guide
Field capacity below first 12 inches of soil	Determined by soil type	1988 Colorado Irrigation Guide
Wilting point for first 12 inches of soil	Determined by soil type	1988 Colorado Irrigation Guide
Wilting point below first 12 inches of soil	Determined by soil type	1988 Colorado Irrigation Guide
Assumed start of season soil moisture	Not to exceed field capacity	Manually selected for best-fit of SMB curve
Monthly mean Grand Valley irrigation water consumptive use by crop type	For comparison with SMB model monthly consumptive use	Colorado Irrigation Guide 1988

Precipitation for Soil Moisture Balance Models

Daily precipitation for the 12 Grand Valley Unit sites in the SMB models can be selected from among four different sets of historic weather data: (1) CSU Fruita Experiment Station, (2) NOAA weather station at Grand Junction Regional Airport (Walker Field), (3) CSU Orchard Mesa Experiment Station, and (4) NRCS Palisade weather station. These data were retrieved from the Colorado Climate Center (Colorado State University Colorado Climate Center, 2012). Historic weather data for the NRCS evaluation weather station at Highline Lake apparently were not preserved. The site map for the Grand Valley Unit was used to select the closest weather station to each of the 12 SMB model sites. A threshold value for effective precipitation is used in the models, which has the effect of disregarding the precipitation requirements below a small fraction of an inch of water, assuming that some of the precipitation that falls is lost to evaporation, runoff, and other processes and is not available to the crop. (U.S. Department of Agriculture, 1997). The effective precipitation threshold set for all the models was 0.05 inch of precipitation.

When the mean irrigation season total precipitation for all four Grand Valley weather stations is compared with the mean reported NRCS evaluation precipitation for all gold standard Grand Valley Unit sites, some striking differences appear (fig. 42).

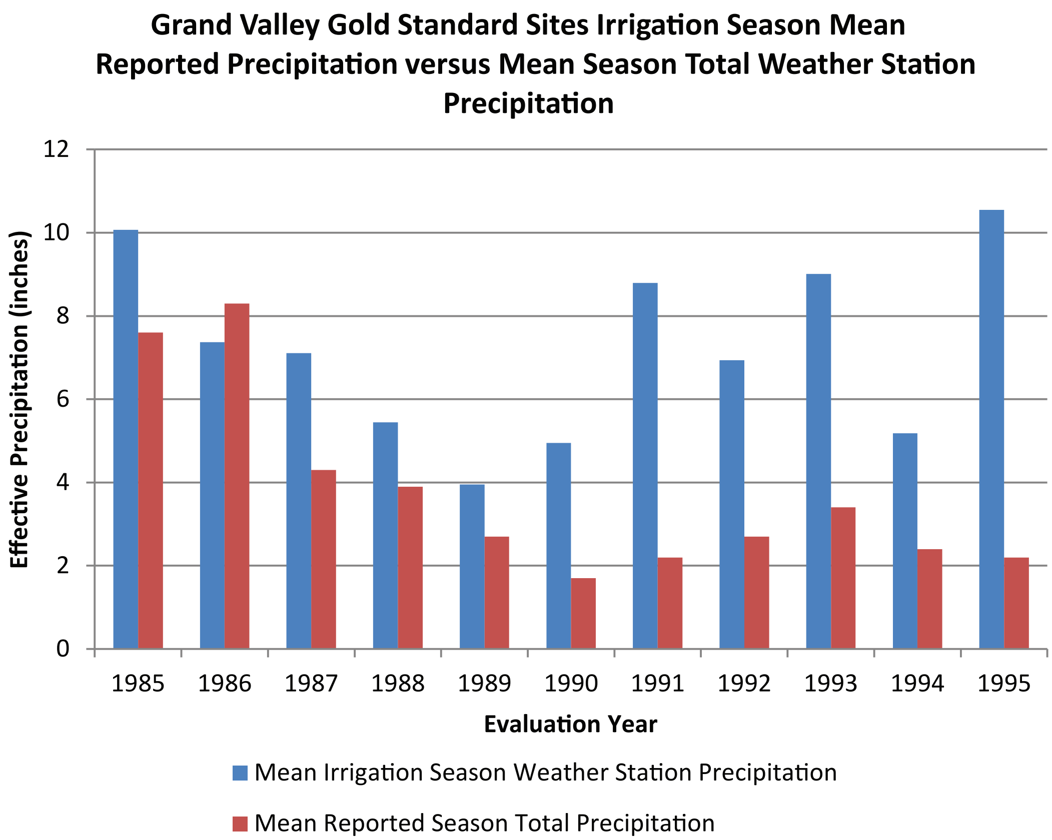


Figure 42. Comparison between mean season total effective precipitation for four Grand Valley weather stations and mean season total Natural Resources Conservation Service evaluation reported precipitation, corrected for effective precipitation, for Grand Valley Unit gold standard sites from 1985 and 1995.

For 1985 and 1986, the weather station precipitation (blue bars) and the NRCS evaluation reported precipitation (red bars) are in relatively good agreement. For the years after 1986, however, the mean precipitation for the four Grand Valley weather stations is substantially greater than the reported NRCS evaluation precipitation for all Grand Valley Unit gold standard sites. Mean annual Grand Valley weather station precipitation from 1985 to 1995 was 7.2 inches, whereas mean annual NRCS reported precipitation for Grand Valley Unit sites for those years was 3.8 inches. This is a relative percent difference (RPD) of 61.8 percent. The RPD is calculated as the difference of the two values divided by the mean of the two values multiplied by 100. RPD is used in this report when neither of the values being compared is considered to be more accurate than the other. For example, when an NRCS reported value of DP is being compared with an SMB model value of DP, neither value is considered to be inherently correct, so the RPD is calculated. In these cases, the term “relative percent difference” or RPD will be used. When standard percent difference (SPD) is being calculated, the term “standard percent difference” or SPD will be used. Standard percent difference is calculated as the difference between an old value and a new value, divided by the old value, then multiplied by 100.

Figure 43 shows further detail for each weather station compared with the reported NRCS precipitation. The total season precipitation for each of the four weather stations generally agrees within a few inches for a particular year. Data from some weather stations are not shown in figure 43 for certain years when a month or more of data were missing for that year and weather station.

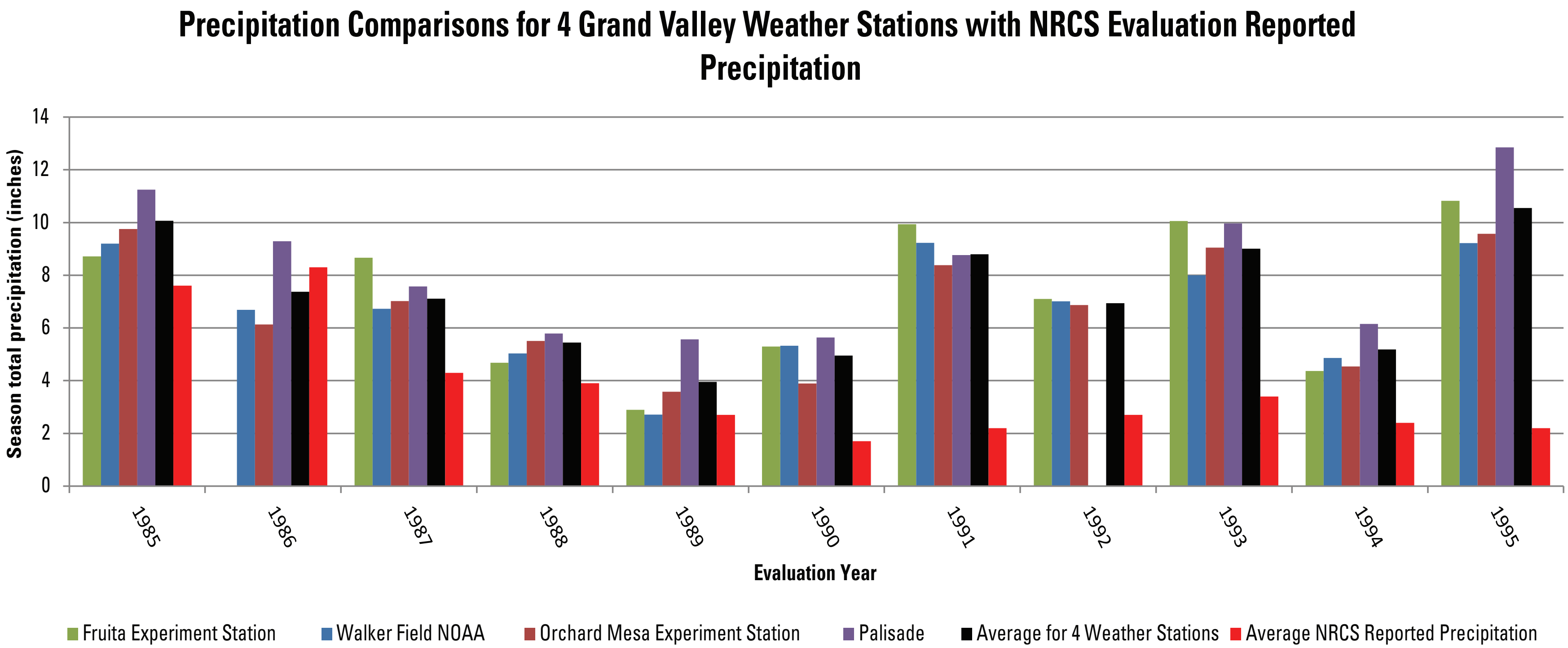


Figure 43. Precipitation comparisons for four Grand Valley weather stations with Natural Resources Conservation Service evaluation reported precipitation. [NOAA, National Oceanic and Atmospheric Administration; NRCS, Natural Resources Conservation Service.]

Irrigation Events for Soil Moisture Balance Models

Table 29 shows the reported duration of irrigation events for the 12 sites with SMB models. The mean duration of irrigation events for the 12 sites is 4.8 days, and the mean number of events is 9.3.

Table 29. Natural Resources Conservation Service evaluation reported irrigation event details for the 12 Grand Valley Unit sites with soil moisture balance models.

[CDS, concrete ditch to siphon tube; GPP, gated pipe; SRS, side-roll sprinkler; EDS, earth ditch to siphon tube; MIS, microspray; CDP, concrete ditch ported; GV, Grand Valley Unit]

Site Number	Evaluation Year	Crop	Irrigation System Type	Number of Irrigation Events	Mean Irrigation Event Duration (Hours)	Mean Irrigation Event Duration (Days)
GV-12	1989	Alfalfa	CDS	7	98.0	4.1
GV-21	1989	Alfalfa	GPP	8	191.5	8.0
GV-33	1989	Alfalfa	SRS	15	196.0	8.2
GV-33	1993	Alfalfa	SRS	11	198.1	8.3
GV-36	1989	Alfalfa	SRS	12	133.4	5.6
GV-36	1993	Alfalfa	SRS	10	129.5	5.4
GV-53	1993	Alfalfa	GPS	8	37.6	1.6
GV-58	1993	Alfalfa	EDS	5	97.0	4.0
GV-17	1989	Wine Grapes	MIS	17	7.8	0.3
GV-26	1989	Field Corn	GPP	8	109.8	4.6
GV-27	1989	Field Corn	GPP	6	95.7	4.0
GV-49	1991	Fall Grain	CDP	4	80.8	3.4
Totals				110		
Mean values				9.3	114.6	4.8

Figure 44 shows the distribution of irrigation event durations in days for all 12 SMB model sites. Over 25 percent of the events (28 out of 110) lasted between 9 and 10 days. These 9- to 10-day events are predominately at side-roll sprinkler alfalfa sites. The length of irrigation events and how they are handled in the SMB models is discussed later in the section "Potential Discrepancies in Results between SMB Models and NRCS Evaluation."

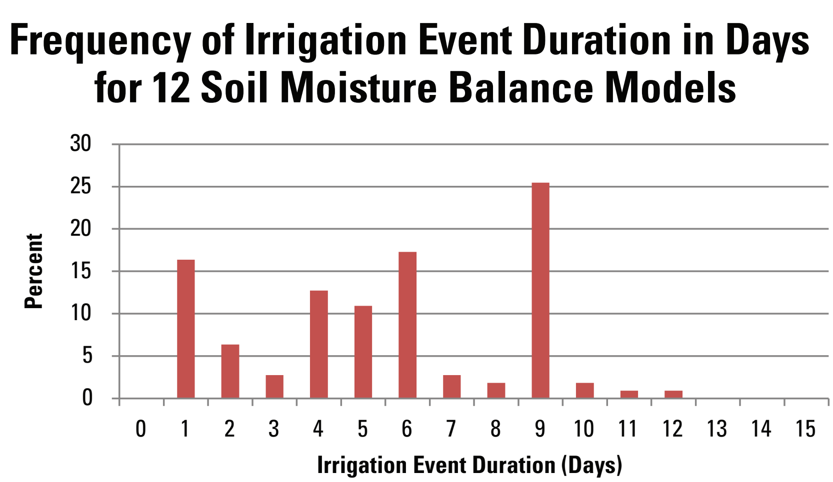


Figure 44. Distribution of irrigation event durations in days for 12 soil moisture balance models.

Individual irrigation event data for the 12 Grand Valley Unit Sites were reported in the NRCS evaluation reports and were used in the SMB models. The irrigation event data reported include the event start date, the duration of the event in hours, and the mean water inflow during the event in cubic feet per second (ft^3/s), the soil water deficit before and after the event (inches), the depth of infiltration (inches), and precipitation (inches). For flood irrigation sites, the number of furrows, mean furrow flow in gallons per minute, and the total outflow (tail-water) in inches is also reported.

Worksheets in the Soil Moisture Balance Model Spreadsheets

The SMB model spreadsheet contains multiple worksheets for each site. There are also general worksheets for data common to all sites: daily precipitation from each weather station, daily ET_p calculated from data for each weather station, soil properties (field capacity and wilting point), and crop rooting depths.

Each site in the spreadsheet has the same set of worksheets which contain the following:

1. Crop coefficient worksheets that provides daily K_c curve values from planting to harvest, and in the case of alfalfa, a worksheet for each cutting. Two sets of crop coefficient worksheets are needed, one for the FAO-56 K_c model, and one for the NRCS evaluation K_c model. For an alfalfa site with four cuttings, eight crop coefficient worksheets would be needed.

2. A K_c summary worksheet that provides selectable columns of daily K_c values for the several K_c curve models. The entire season of K_c values for both types of K_c curves is brought together in this worksheet as a continuous series of K_c values by date.

3. An NRCS evaluation data worksheet that contains per-event irrigation data from the NRCS evaluation annual reports, as well as calculations for per-day application amounts of irrigation water based on the reported number of hours of the event and the total infiltrated depth of water.

4. An NRCS evaluation irrigation schedule worksheet that contains the assumed irrigation event starting and ending dates, and the assumed cutting dates for alfalfa sites. In this worksheet, minor adjustments are made to the starting and ending times of some irrigation events where insufficient time for movement of irrigation equipment was accounted for in the original reported times. This particularly applies to side-roll sprinkler sites.

5. An irrigation season calendar worksheet that graphically shows the months and days of the irrigation season, the planting and harvest dates, duration of irrigation events, major precipitation events, and, in the case of alfalfa sites, the cutting dates.

6. A precipitation chart which shows reported precipitation between each irrigation event, and SMB calculated precipitation between and during irrigation events.

7. A deep percolation worksheet where the water inputs and outputs are used to calculate the daily SMB, and it is determined if any DP occurred on that day. See appendix 6 for a complete listing of columns which appear in the deep percolation worksheet.

8. An SMB chart worksheet where the daily model values are charted. Also, on the chart worksheet is a "control panel" where all of the model variables that are adjustable are combined in one place. This allows for the visual observation of changes in the SMB chart as the model constants and variables are adjusted. The control panel on the SMB chart worksheet contains:

   - Selector for the type of K_c curve desired.
   - Amplitude multipliers for each of the crop cycles of the K_c curves, either for the entire growing season, or for each cutting in the case of alfalfa, and an overall amplitude multiplier for each type of K_c curves.
   - Two sets of K_c curve amplitude multipliers—one for weather station effective precipitation, and one for NRCS reported precipitation.
   - A switch to turn off ET_c stress correction.
   - Field capacity and wilting points for the soil type at the site. Separate values are used for the first 12 inches of rooting depth and for the zone below 12 inches.
   - Crop rooting depth.

- Percent of readily available water.
- Assumed value of soil moisture for the start of the season. (This was not reported in the NRCS evaluation.)
- Weather station and ET_p data source selection.
- Per-event comparison tables of DP, precipitation, and ET_c for NRCS evaluation reported values and the SMB model calculated values. The SMB calculated values are broken out for during and between irrigation events.
- A chart by month of typical crop consumptive use of irrigation water from the 1988 Colorado Irrigation Guide (U.S. Department of Agriculture, 1988) compared with the model calculated monthly consumptive use for the crop in question.
- A table of difference values between the NRCS reported soil moisture values and the SMB model calculated soil moisture values at the start and end of each irrigation event. By minimizing these difference values, the goodness of fit of the model SMB curve can be measured and optimized.

Soil Moisture Balance Charts

Figure 45 shows a typical SMB chart that was created by the USGS study for an alfalfa site.

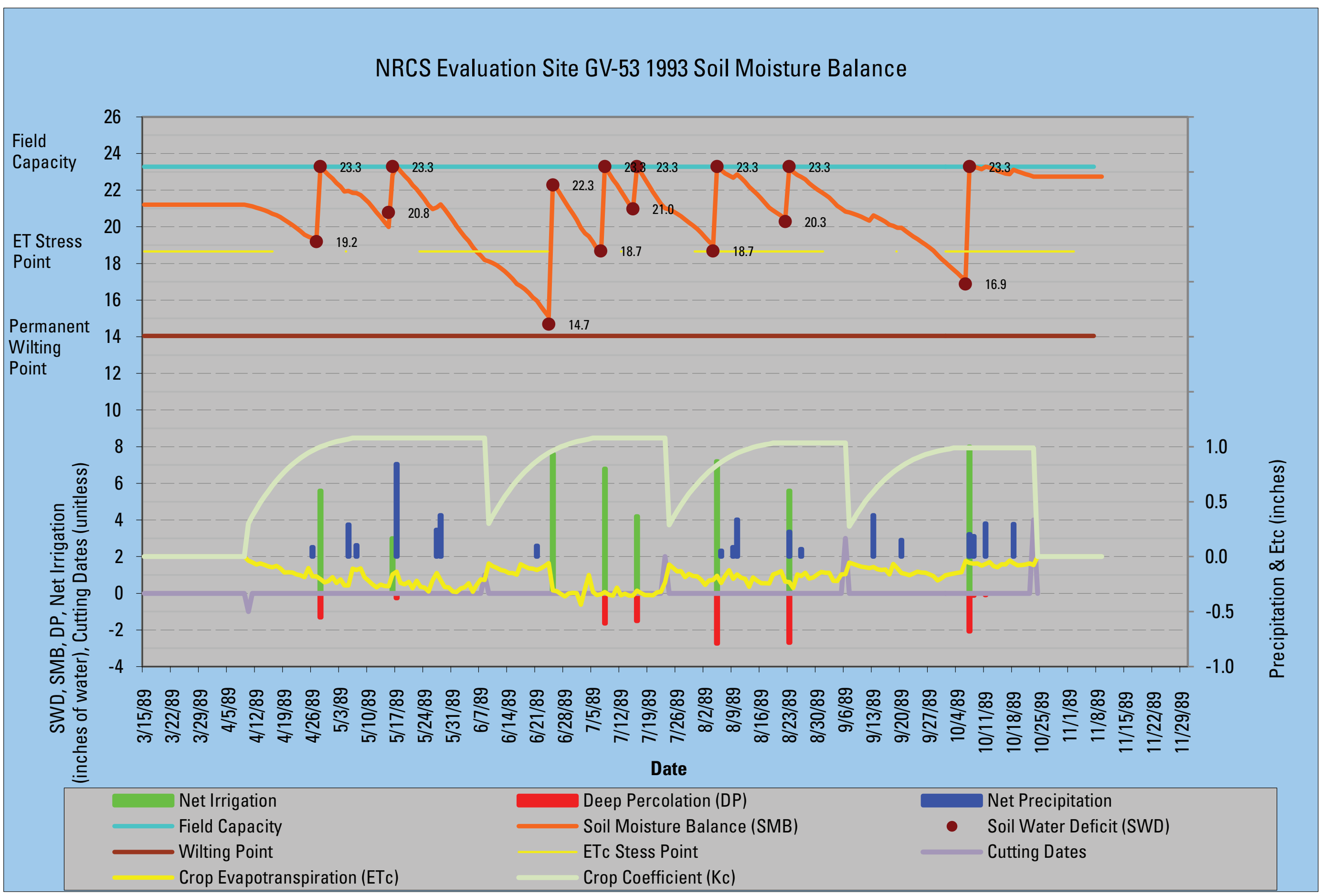


Figure 45. Soil moisture balance chart for Grand Valley Unit 1993 site 53, an alfalfa site with a pipeline to gated surge irrigation system. [NRCS, Natural Resources Conservation Service; GV, Grand Valley; ET, evapotranspiration; SWD, soil water deficit; SMB, soil moisture balance; DP, deep percolation; K_c, crop coefficient; ET_c, crop evapotranspiration; Crop Coefficient (K_c) curve (white trace) is not to scale.]

The various curves and bars on the SMB chart represent different inputs, outputs, and calculated values for the SMB model. All values on the vertical axis are in inches of water. Outputs (water losses) from the model are negative on the vertical axis, and inputs (water gains) to the model are positive. The NRCS evaluation crop coefficient curve (white) is not to scale but is representative of the relative shape and amplitude of the crop coefficient over time, and shows the curve's correspondence with stages of crop growth and harvests. Table 30 describes the chart elements.

Table 30. Explanation of soil moisture balance chart elements.

[NRCS, Natural Resources Conservation Service; ET_p, reference evapotranspiration; ET_c, crop evapotranspiration; K_c, crop coefficient; K_s, crop stress coefficient; %, percent]

Chart Element	Description	Display Units	Data Source
Horizontal axis	Irrigation season dates	Days	Date range for irrigation season
Vertical axis	Inches of irrigation water	Inches of water	Negative to positive scale of inches of water
Yellow solid line	Daily ET_p	Negative inches of water	Calculated from product of ET_p, crop coefficient K_c, and stress correction Ks
Red negative vertical bars	Deep percolation events	Negative inches of water	Calculated from daily soil moisture balance greater than field capacity
Blue positive vertical bars	Precipitation events	Positive inches of water	Daily precipitation data from National Weather Service Grand Junction weather station
Green positive vertical bars	Net irrigation water applied	Positive inches of water	NRCS evaluation per-irrigation reports–measured value of water inflow minus water outflow
White solid line	Relative crop coefficient curve	None–amplitude is adjusted for ease of viewing	Soil moisture balance model selection of crop coefficient curve
Brown solid line	Permanent wilting point	Inches of water	NRCS soil properties data in Colorado Irrigation Handbook for 1988
Yellow dashed line	ET_c stress threshold	Inches of water	Soil moisture balance model constant setting—typically 50% of available soil water
Teal solid line	Field capacity	Inches of water	NRCS soil properties data in Colorado Irrigation Handbook for 1988
Brown dots	Reported NRCS soil water balances at beginning and ending of irrigation events	Inches of water	NRCS evaluation per-irrigation reported soil water deficit values—converted to soil water balance values as field capacity minus reported soil water deficit
Grey solid line	For crops with one harvest per season, negative pulse is the crop planting date; positive pulse is the crop harvest date. For alfalfa sites, there are no negative pulses, and positive pulses are cutting dates	For crops with one harvest season, amplitude is -1 for planting and +1 for harvest. For alfalfa, amplitude is +1 for first cutting, +2 for second cutting, ET_c, and so forth.	NRCS evaluation per-irrigation reported values for crop planting and harvest dates. Alfalfa cutting dates are estimated.
Orange solid line	Model calculated daily soil moisture balance	Inches of water	Soil moisture balance model calculated value from net effect of daily water inputs and outputs

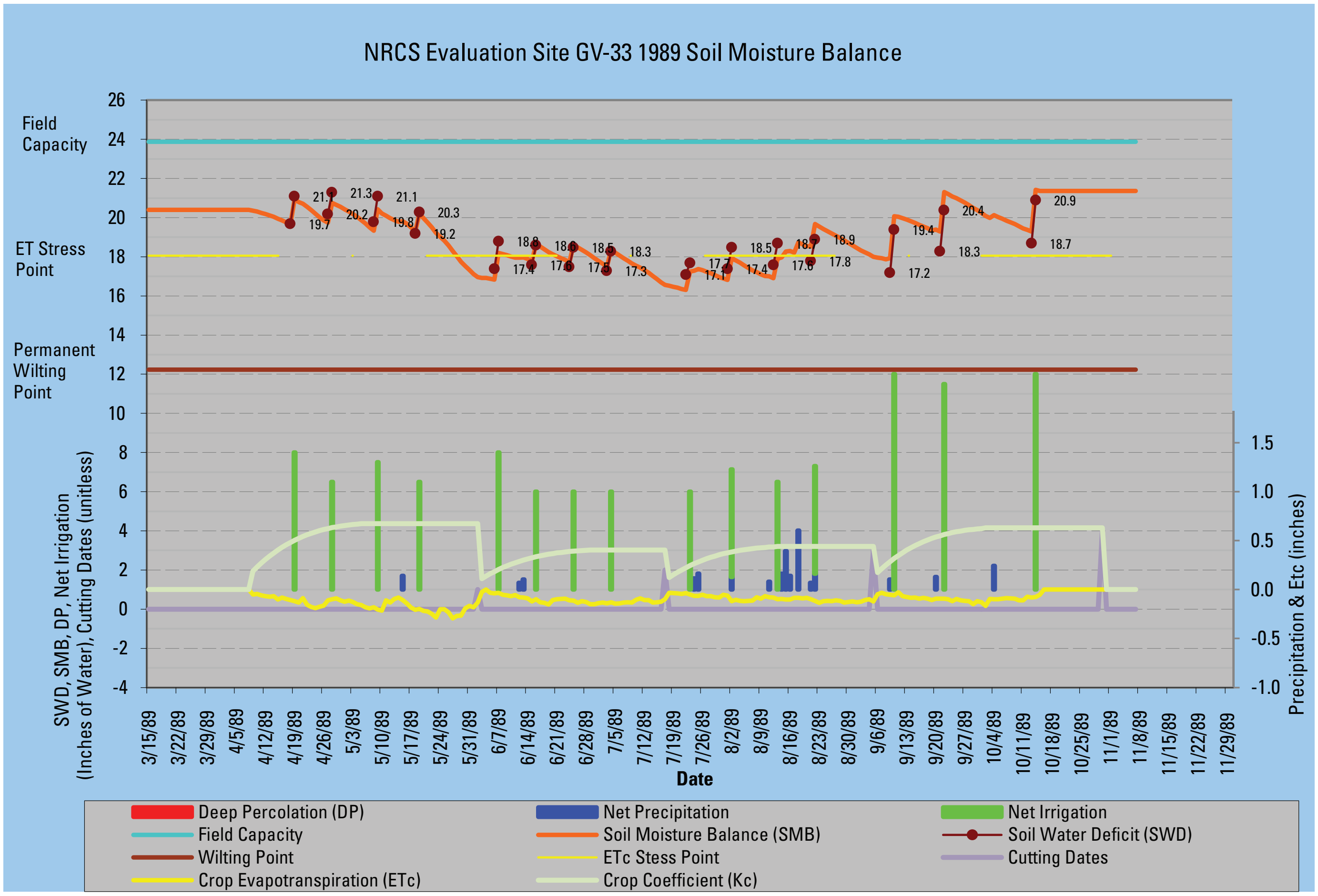


Figure 46. Soil moisture balance chart for Grand Valley Unit 1989 site 33, an alfalfa site with a side-roll sprinkler irrigation system. [NRCS, Natural Resources Conservation Service; GV, Grand Valley; ET, evapotranspiration; SWD, soil water deficit; SMB, soil moisture balance; DP, deep percolation; K_c, crop coefficient; ET_c, crop evapotranspiration; Crop Coefficient (K_c) curve (white trace) is not to scale.]

Figure 46 shows an SMB chart for alfalfa under a side-roll sprinkler irrigation system.

The use of side-roll irrigation technology with impulse sprinkler heads results in frequent irrigation events. Side-roll sites typically irrigate a 40-foot wide section of the field for 12 hours before the sprinkler set is moved. (U.S. Department of Agriculture, 1988). The fact that the soil moisture values in the middle of the season fall below the ET stress level is typical of side-roll sprinkler systems that practice “deficit” irrigation. This means that the soil moisture rarely if ever gets to field capacity, so the soil moisture is said to be in a deficit condition.

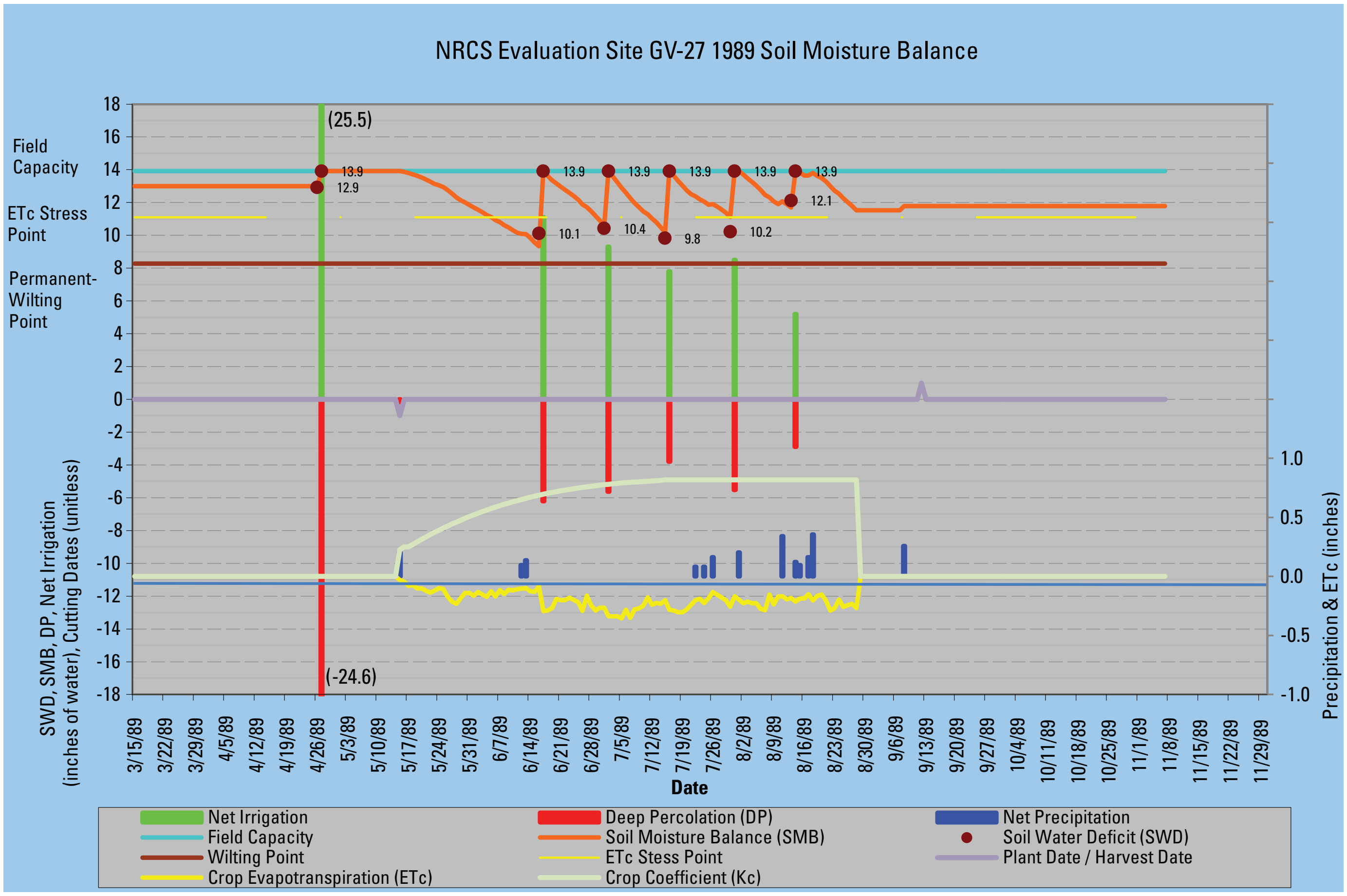


Figure 47. Soil moisture balance chart for Grand Valley Unit 1989 site 27, a field corn site with a pipeline to gated pipe flood irrigation system. [NRCS, Natural Resources Conservation Service; GV, Grand Valley; ET, evapotranspiration; SWD, soil water deficit; SMB, soil moisture balance; DP, deep percolation; K_c, crop coefficient; ET_c, crop evapotranspiration; Crop Coefficient (K_c) curve (white trace) is not to scale.]

Figure 47 shows an SMB chart for field corn using a gated pipe flood irrigation system.

Flood irrigation causes typically large amounts of DP for each event, particularly the initial event in the beginning of the season. Excess pre-irrigation or the first irrigation of the season is the biggest contributor to seasonal DP losses. The large amounts of DP are directly related to high infiltration rates during these irrigations due to freshly tilled soils, the need to germinate seeds, and the physics of flood irrigation that require application of more water at the top of the field than the root zone requires (Grand Valley Annual Report, 1988, *in* U.S. Department of Agriculture, 1986–2003).

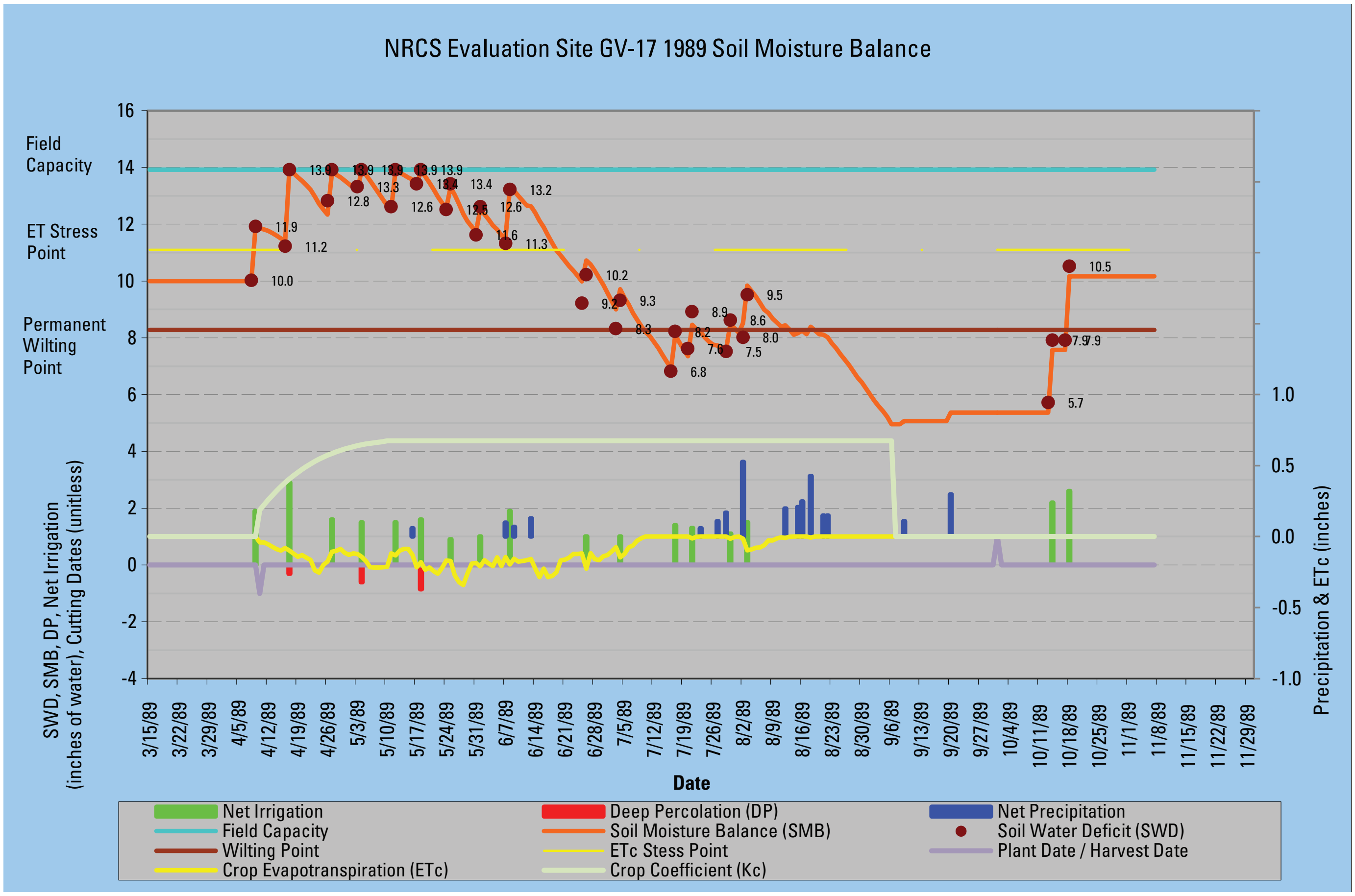


Figure 48. Soil moisture balance chart for Grand Valley Unit 1989 site 17, a wine grapes site with a microspray sprinkler irrigation system. [NRCS, Natural Resources Conservation Service; GV, Grand Valley; ET, evapotranspiration; SWD, soil water deficit; SMB, soil moisture balance; DP, deep percolation; K_c, crop coefficient; ET_c, crop evapotranspiration; Crop Coefficient (K_c) curve (white trace) is not to scale.]

Figure 48 shows an SMB chart for a wine grapes site that used a microspray sprinkler system. The use of microspray necessitated frequent irrigation events, which resulted in measurable DP in the early part of the irrigation season (April and May). The irrigation events stopped in August to stress the grapes in preparation for harvest, with a final burst of irrigation after harvest to prepare the vines for over-wintering (Horst Caspari, Viticulturist, Colorado State University Extension Service, written commun., April 7, 2012).

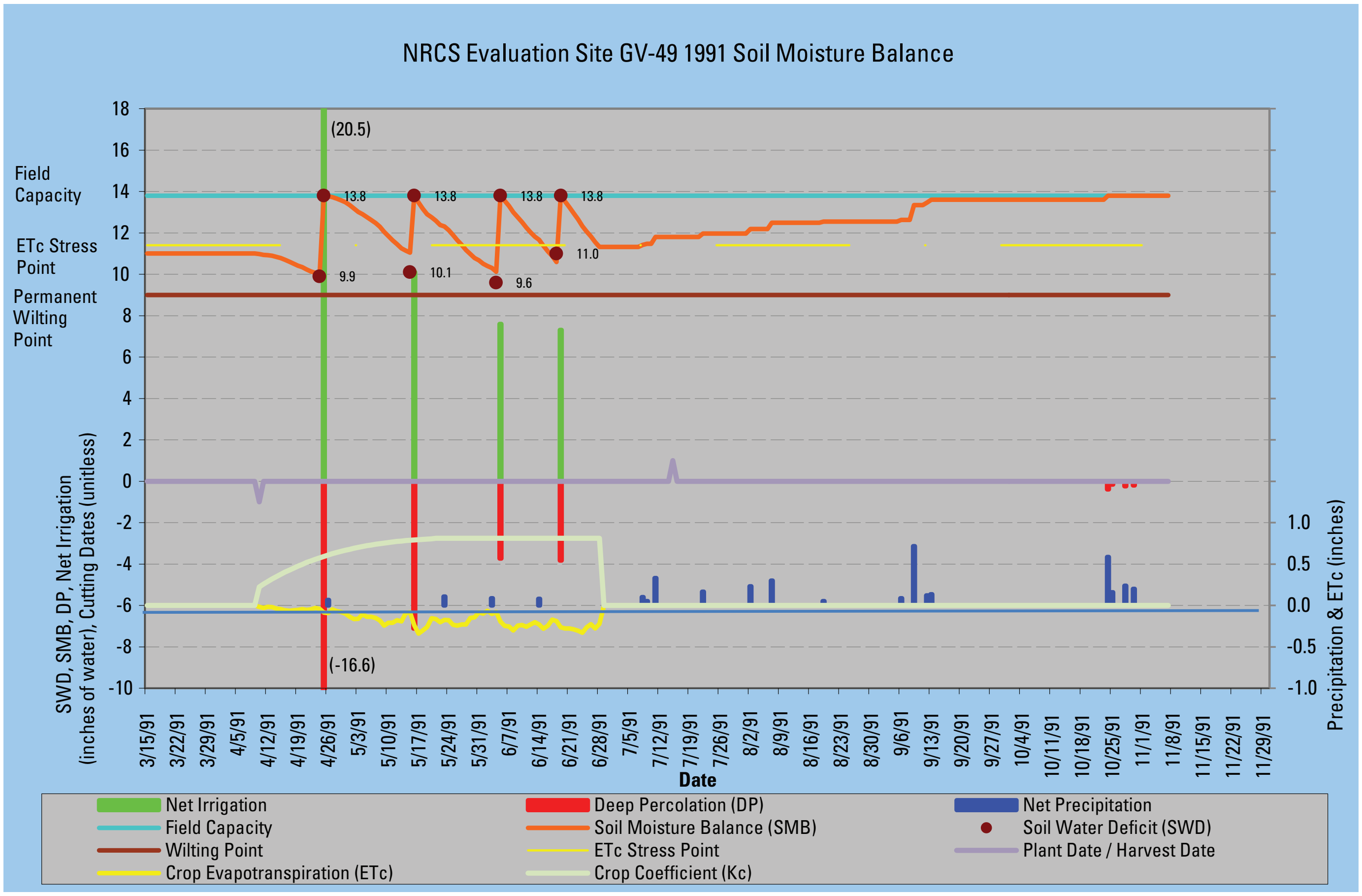


Figure 49. Soil moisture balance chart for Grand Valley Unit 1991 site 49, a fall grain site with a concrete ditch to gated pipe flood sprinkler irrigation system. [NRCS, Natural Resources Conservation Service; GV, Grand Valley; ET, evapotranspiration; SWD, soil water deficit; SMB, soil moisture balance; DP, deep percolation; K_c, crop coefficient; ET_c, crop evapotranspiration; Crop Coefficient (K_c) curve (white trace) is not to scale.]

Figure 49 shows an SMB chart for fall grain site using a concrete ditch to gated pipe flood irrigation system. It can be seen that the early harvest date in July necessitated a short crop cycle with frequent intense irrigations. Each of these flood irrigations resulted in substantial DP. Appendix 7 includes all 12 of the SMB charts for completeness, including the five discussed in this section.

Soil Moisture Balance Curve Best-Fit Procedures

The SMB model spreadsheet parameters can be adjusted to match ("best-fit"), as closely as possible, NRCS soil water deficits that were reported at the beginning and ending dates of each irrigation event. A number of inputs to the SMB model can be varied by type and amplitude to achieve the best-fit of the SMB results. Once the constant values for the site (FC, WP, rooting depth, ET_c stress threshold percent) are set in the SMB model, the parameters that can be adjusted to achieve the best-fit of the SMB trace are:

1. Type of K_c curve (NRCS or FAO-56).
2. Amplitude of the K_c curve, with separate amplitude values for each alfalfa cutting.
3. Duration of K_c curve, with separate durations for each alfalfa cutting.
4. Daily $ET_{p,}$ depending on whether the site is closer to the Fruita or Grand Junction NRCS weather station.
5. Daily precipitation for the closest of four Grand Valley weather stations (Fruita, Walker Field, Orchard Mesa, or Palisade), or NRCS reported season total precipitation for that site.
6. Soil moisture balance at the start of season (assumed, since this was not reported by NRCS).
7. ET_c stress correction setting on or off.

These input parameters are manipulated to achieve the best-fit of the SMB curve, which then results in the best match of SMB model ET_c to NRCS reported ET_c, SMB model precipitation to NRCS reported precipitation, and SMB model DP to NRCS reported DP. In this report, this best-fit match to NRCS reported values is called the "baseline-fit." To achieve the baseline-fit, the difference (error) in soil moisture value between the orange trace and the red dot at each irrigation event is calculated. The goal for adjusting the model is to minimize the sum of all the beginning and (separately) all of the ending event errors. If the two errors are non-zero, then the goal is to balance the beginning and ending error sums. This indicates that the SMB trace is closest to the starting and ending irrigation event SMB values, respectively.

The NRCS K_c curve can be adjusted in overall amplitude, but lacks the ability to change the shape of the curve, as this is set by the crop season length for the NRCS K_c equation. (See appendix 8 for details of the NRCS K_c curve derivation.) For alfalfa sites, the NRCS K_c equation was restarted after each presumed cutting date. Each NRCS K_c equation can have its amplitude adjusted independently for each alfalfa crop cycle.

For the final analysis, it was decided that using the NRCS K_c curves would be most appropriate to model the NRCS evaluation data, if a best-fit could be achieved with the NRCS K_c curve. Because a best-fit of the SMB curve at each site could be achieved using the NRCS K_c curves, the use of the FAO-56 curves was not necessary. All examples of SMB charts in this report will be shown using NRCS K_c curves.

Figure 50 shows what happens when the amplitude for the K_c curve is set too low to achieve a best-fit. This creates a low value of daily ET_c, making the orange SMB curve in the chart track above the reported soil water deficit values, because the ET_c output from the model is insufficient.

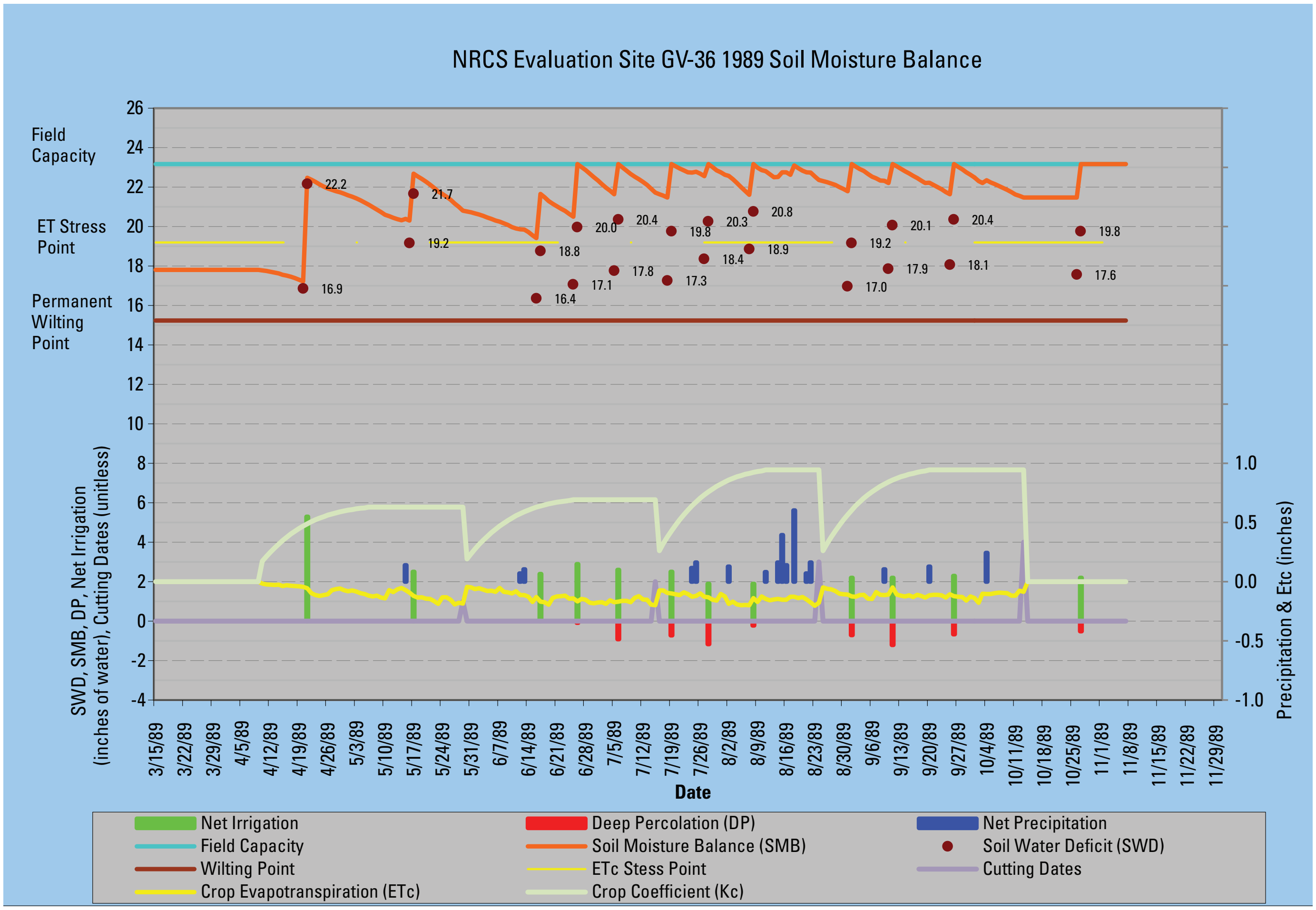


Figure 50. Example of an SMB chart with a low value for the crop coefficient amplitude. [NRCS, Natural Resources Conservation Service; GV, Grand Valley; ET, evapotranspiration; SWD, soil water deficit; SMB, soil moisture balance; DP, deep percolation; K_c, crop coefficient; ET_c, crop evapotranspiration; Crop Coefficient (K_c) curve (white trace) is not to scale.]

Figure 51 shows what happens when the amplitude for the K_c curve is set too high to achieve a best-fit. This creates a high value of daily ET_c, making the orange SMB curve in the chart track below the reported soil water deficit values, because the ET_c output from the model is overstated.

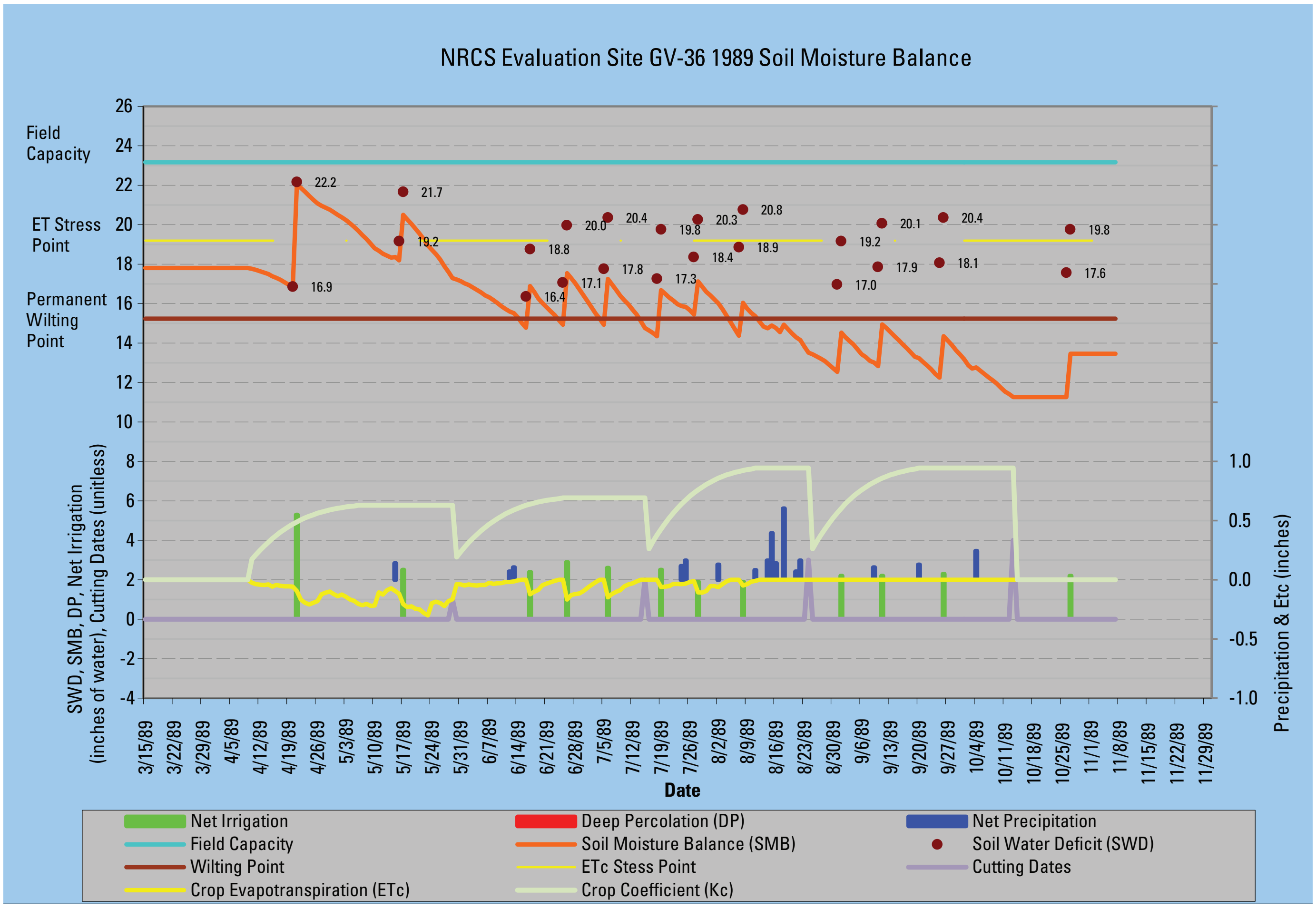


Figure 51. Example of an SMB chart with a high value for the crop coefficient amplitude. [NRCS, Natural Resources Conservation Service; GV, Grand Valley; ET, evapotranspiration; SWD, soil water deficit; SMB, soil moisture balance; DP, deep percolation; K_c, crop coefficient; ET_c, crop evapotranspiration; Crop Coefficient (K_c) curve (white trace) is not to scale.]

Figure 52 shows how the error between reported soil water deficit and calculated SMB is minimized (best-fit) when the orange trace is closest to the red dots across the season, or at least a balanced distance between each pair of beginning event and ending event dots.

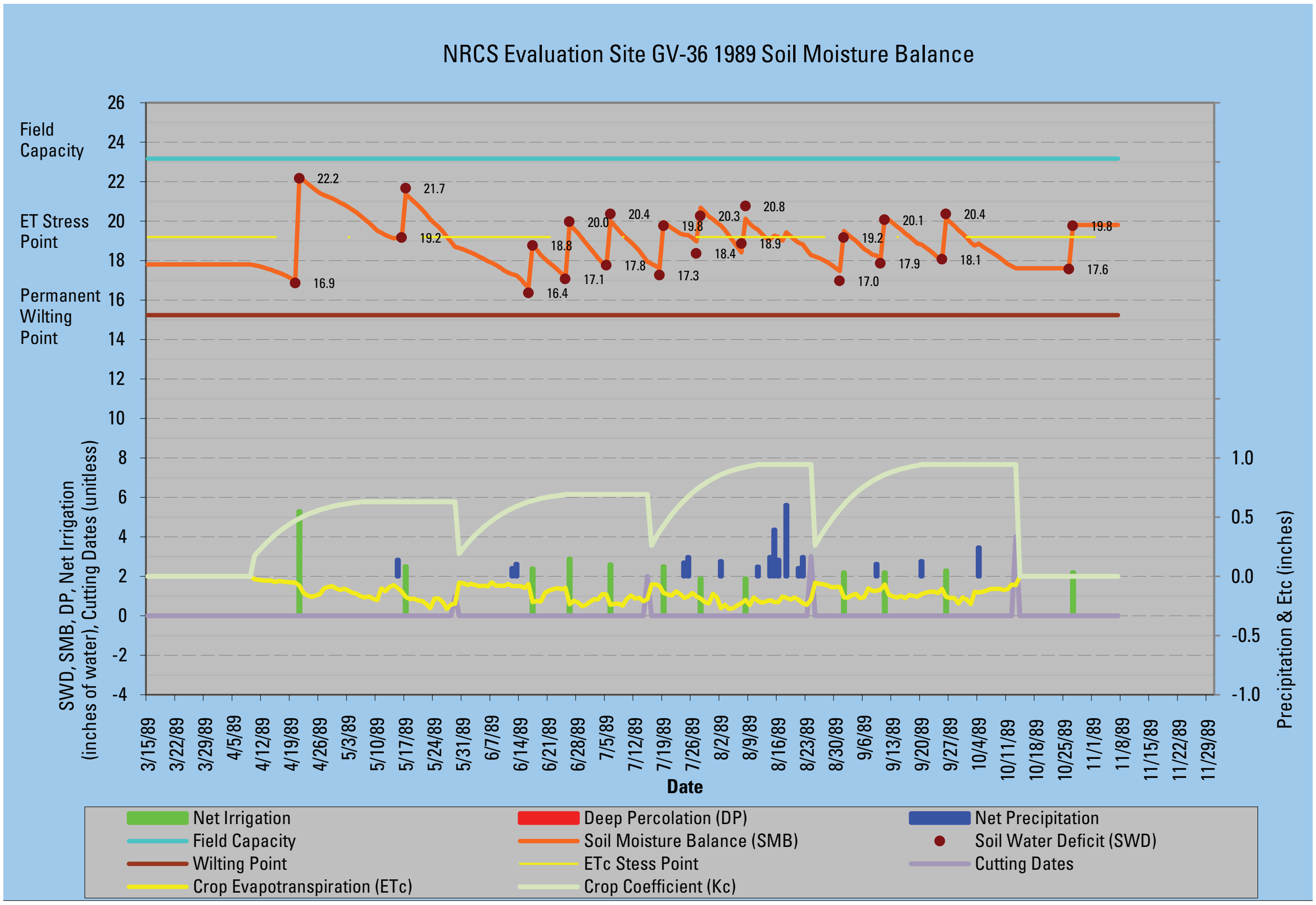


Figure 52. Example of an SMB chart with a value selected for the best-fit of the soil moisture balance trace. [NRCS, Natural Resources Conservation Service; GV, Grand Valley; ET, evapotranspiration; SWD, soil water deficit; SMB, soil moisture balance; DP, deep percolation; K_c, crop coefficient; ET_c, crop evapotranspiration; Crop Coefficient (K_c) curve (white trace) is not to scale.]

Results for Baseline-Fit of Soil Moisture Balance Curves

The SMB models were initially baseline-fit to the NRCS evaluation reported results as closely as possible. Then various adjustments were temporarily made in the model inputs to perform a sensitivity analysis of some of the assumptions of the NRCS evaluation SMB accounting. Table 31 summarizes the precipitation, ET_c, DP, and SIE results for the baseline-fit of the 12 SMB model sites, with the NRCS reported values for each site. The input values used for the baseline-fit SMB model in table 31 are NRCS reported precipitation, no ET_c stress correction applied, and NRCS ET_p.

Table 31. Comparison between Natural Resources Conservation Service evaluation reported deep percolation, precipitation, crop evapotranspiration, and seasonal irrigation efficiency with soil moisture balance model results.

[NRCS, Natural Resources Conservation Service, SMB, soil moisture balance, DP, deep percolation in inches of water; Precip, precipitation in inches of water; Calc, calculated; ET_c, crop evapotranspiration; SIE, seasonal irrigation efficiency]

Site Number	NRCS Reported Precip	SMB Model Season Total Precip	NRCS Reported Crop ET_c	Total SMB Model Season Total ET_c	NRCS Reported DP	Total SMB Model Season Total DP	NRCS Reported SIE	SMB Model SIE
GV-12 1989	2.8	2.8	39.3	39.7	19.0	19.7	51.1	50.0
GV-21 1989	2.8	2.8	31.6	34.4	23.5	22.4	35.7	37.0
GV-33 1989	2.8	2.8	20.7	22.0	0.0	0.0	80.1	80.1
GV-36 1989	2.8	2.8	31.4	31.7	0.0	0.0	80.5	80.5
GV-17 1989	3.0	3.0	23.3	28.0	2.9	1.8	75.7	79.3
GV-26 1989	2.4	2.4	17.7	22.4	10.7	8.2	32.0	38.4
GV-27 1989	2.3	2.3	21.0	22.1	49.8	48.8	21.0	22.2
GV-49 1991	0.8	0.8	13.8	14.3	30.9	31.2	27.8	27.1
GV-33 1993	3.9	3.9	30.6	30.9	2.4	4.3	73.2	68.2
GV-36 1993	3.9	3.9	24.2	26.6	0.0	2.1	79.9	72.7
GV-53 1993	4.0	4.0	34.8	31.6	12.9	12.3	54.9	55.8
GV-58 1993	4.7	4.7	36.7	39.2	4.3	3.6	52.4	53.5
Mean values	3.0	3.0	27.1	28.6	13.0	12.9	55.4	55.4
Median values	2.8	2.8	27.4	29.4	7.5	6.2	53.7	54.7

Baseline-Fit of Crop Evapotranspiration

Figure 53 shows a comparison of NRCS reported ET_c (horizontal axis) with SMB model ET_c (vertical axis) for the 12 model sites. The red dotted trace is a one-to-one line. Each symbol is labeled for the site number, year of evaluation, irrigation method code (table 8), season total number of irrigation days, and the crop type. It can be seen that the various symbol groups are clustered along the one-to-one line. A linear regression trend line has also been created through the 12 model values. R-squared (R^2) is a measure of how close the data are to a fitted regression line (y represents calculated SMB ET_c, and x represents NRCS reported ET_c in the equation). The R^2 for this trend line is 0.9289, indicating that much of the variance in the 12 data points is explained by the regression equation. The four flood alfalfa sites are to the right, indicating reported ET_c in the range of 30 to 40 inches per season, while the four side-roll alfalfa sites are clustered between about 20 to 30 inches of ET_c per season. The two flood corn sites show about 20 inches of reported ET_c per season. No correlation between reported ET_c and the season total days of irrigation is evident in figure 53.

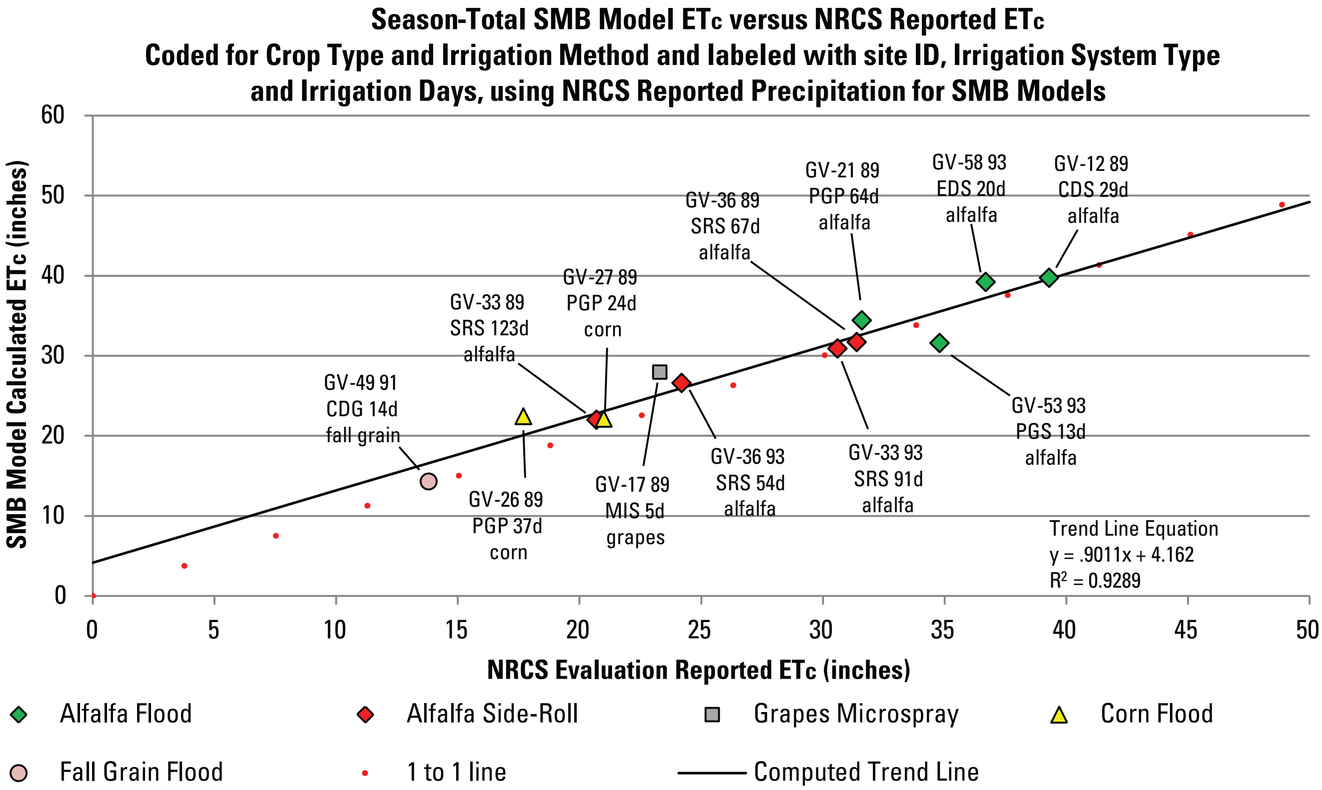


Figure 53. Chart of SMB model calculated season total crop evapotranspiration versus Natural Resources Conservation Service evaluation reported season total crop evapotranspiration showing site number, irrigation method (table 8), total days of irrigation (d), and crop type for 12 Grand Valley SMB model sites. [SMB, soil moisture balance; ET_c, crop evapotranspiration; ID, identification; NRCS, Natural Resources Conservation Service; GV, Grand Valley Salinity Control Unit; EDS, earth ditch to siphon tube; CDG, concrete ditch to gated pipe; CDS, concrete ditch to siphon tube; PGP, pipeline gated pipe; PGS, pipeline to gated surge; SRS, side-roll sprinkler; MIS, microspray; R2, measure of goodness of fit of data to regression line.]

Baseline-Fit of Soil Moisture Balance Deep Percolation

Figure 54 shows site parameters for the 12 SMB model sites on a DP comparison plot similar to figure 53. The symbol codes and labels are the same as in figure 53. It can be seen that the alfalfa groups are clustered along the one-to-one line. A linear regression trend line has also been created through the 12 model values. The R^2 for this trend line is 0.9927, indicating that almost all of the variance in the 12 data points is explained by the regression equation. Three of the four flood alfalfa sites (green diamonds) have reported DP in the range of about 13 to 25 inches per season, while the four side-roll alfalfa sites (red diamonds) are grouped with less than 5 inches of DP per season. The two flood corn sites (yellow triangles) are widely separated. No correlation between reported DP and the season total days of irrigation is evident in figure 54.

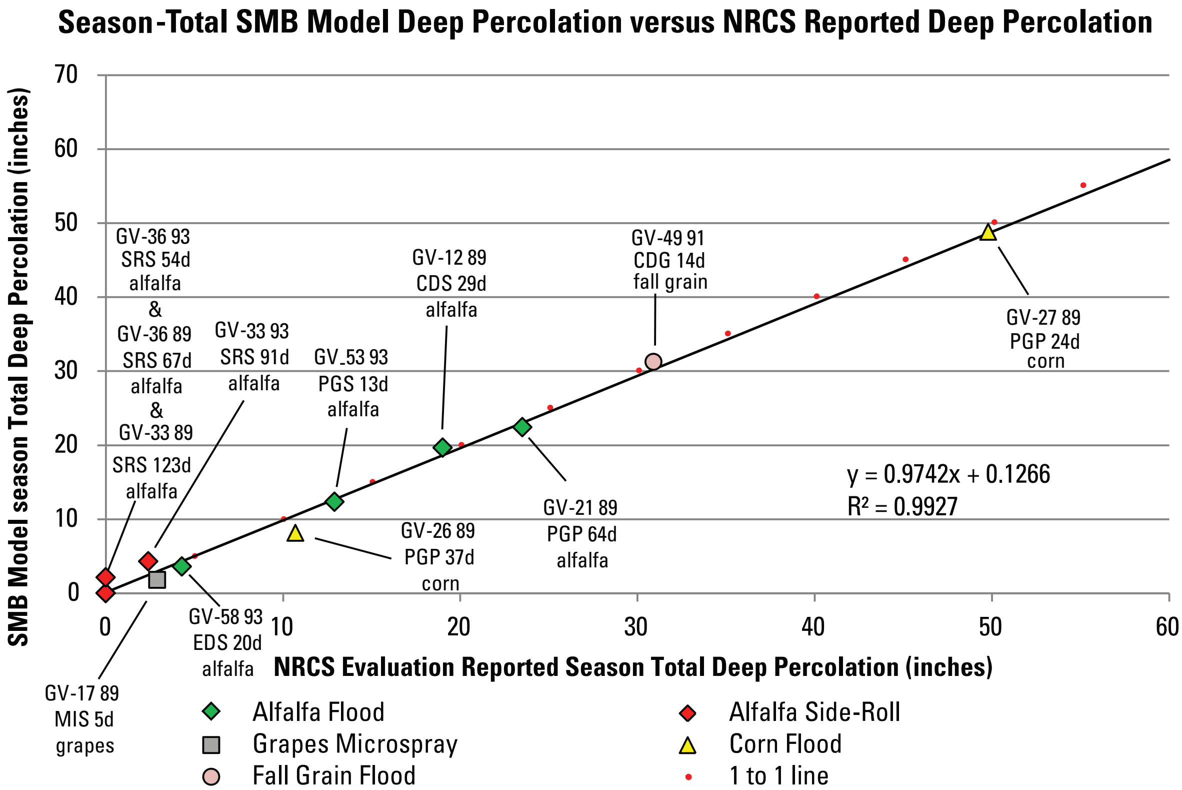


Figure 54. Chart of season-total SMB model deep percolation versus Natural Resources Conservation Service reported deep percolation for 12 Grand Valley SMB model sites. [SMB, soil moisture balance; DP, deep percolation; ID, identification; NRCS, Natural Resources Conservation Service; GV, Grand Valley Salinity Control Unit; EDS, earth ditch to siphon tube; CDG, concrete ditch to gated pipe; CDS, concrete ditch to siphon tube; PGP, pipeline gated pipe; PGS, pipeline to gated surge; SRS, side-roll sprinkler; MIS, microspray; R^2, measure of goodness of fit of data to regression line.]

Baseline-Fit of Seasonal Irrigation Efficiency

Figure 55 shows site parameters for the 12 SMB model sites on an SIE comparison plot similar to figure 53. It can be seen that the alfalfa and corn groups are roughly clustered along the one-to-one line. A linear regression trend line has also been created through the 12 model values. The R^2 for this trend line is 0.9772, indicating that much of the variance in the 12 data points is explained by the regression equation. The four alfalfa flood sites (green diamonds) have reported SIE in the range of about 30 to 50 percent, while the four side-roll alfalfa sites (red diamonds) are clustered with SIE around 70 to 80 percent. The two flood corn sites have SIE values (yellow triangles) around 20 to 40 percent. No correlation between reported SIE and the season total days of irrigation is evident in figure 55.

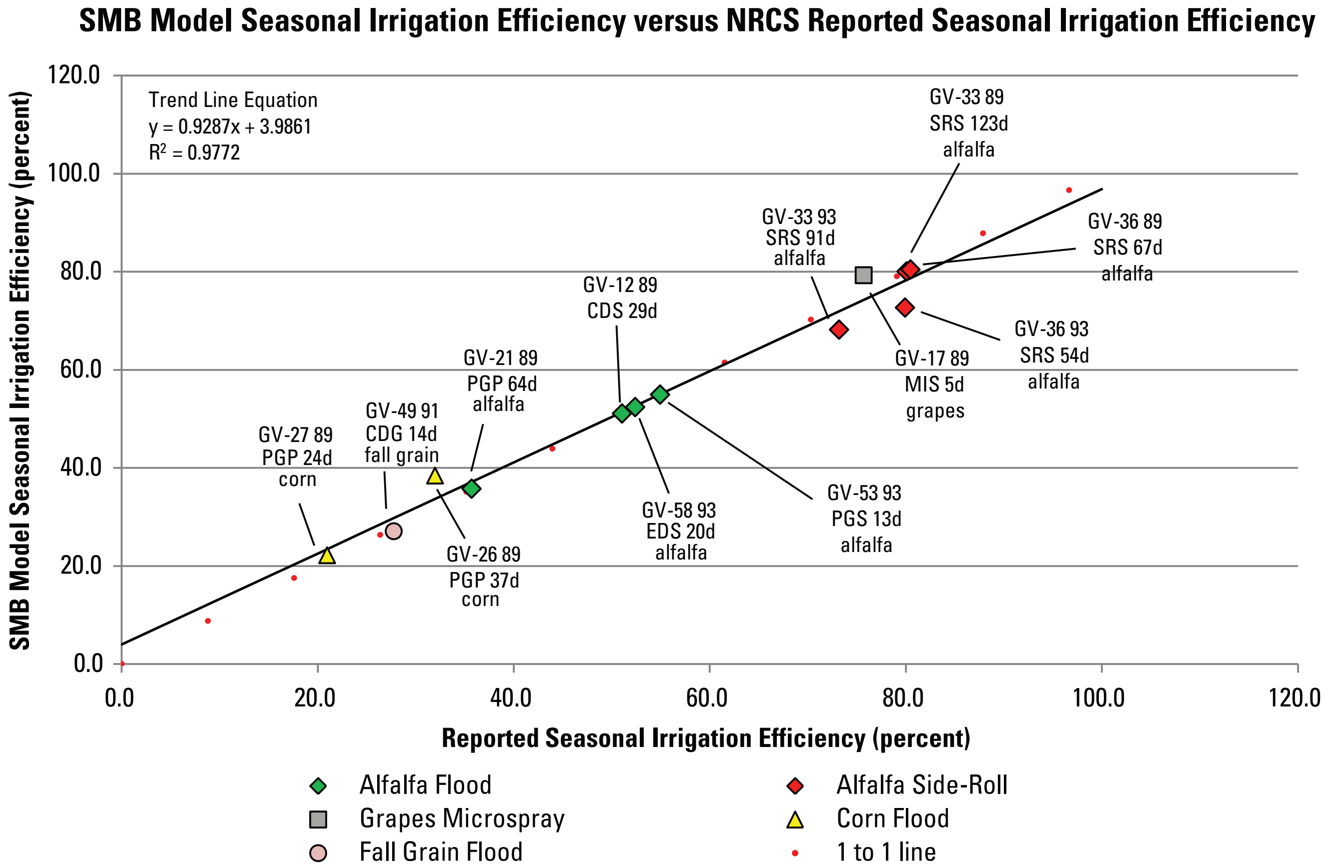


Figure 55. Chart of SMB model seasonal irrigation efficiency versus NRCS reported seasonal irrigation efficiency for 12 Grand Valley SMB model sites. [SMB, soil moisture balance; ID, identification; NRCS, Natural Resources Conservation Service; GV, Grand Valley Salinity Control Unit; EDS, earth ditch to siphon tube; CDG, concrete ditch to gated pipe; CDS, concrete ditch to siphon tube; PGP, pipeline gated pipe; PGS, pipeline to gated surge; SRS, side-roll sprinkler; MIS, microspray; R^2, measure of goodness of fit of data to regression line.]

Potential Discrepancies in Results between SMB Models and NRCS Evaluation

Any model of a physical process entails a number of assumptions as to how to create and manipulate the model. The primary reason for creating a model for this report was first, to understand the assumptions which were implicit (if sometimes unstated) in the NRCS evaluation reported results, and second, to examine whether those assumptions were an appropriate way to evaluate the raw data. By adjusting the SMB model inputs to achieve a baseline-fit, the primary assumptions of the NRCS data accounting were discovered, and the consequences of those setting choices by the NRCS evaluation became apparent. It is not the purpose of this report to suggest that the NRCS evaluation results are “right” or “wrong.” However, the NRCS evaluation results can be tested in the light of current day understanding, and can be compared with published outside standards, to get an indication of whether the evaluation results stand the scrutiny of objective examination.

After discussing several sources and types of uncertainty in the NRCS data which create discrepancies with the SMB models in the sections below, a sensitivity analysis will be shown that tests the effect of three sets of trial inputs on the SMB model results. These three sets of inputs are (1) the closest Grand Valley weather station precipitation or NRCS reported precipitation; (2) the use of crop evapotranspiration stress correction or not; and (3) the use of NRCS reported ET_p, or a 10 percent upward adjustment in ET_p to match published standards of crop consumptive use. The sensitivity analysis will suggest some possible offsets to the NRCS results that result from these tests.

Several sources of uncertainty and discrepancies arise that can affect the NRCS evaluation results. These sources are (1) precipitation, (2) evapotranspiration, (3) soil moisture balance accounting, (4) NRCS methodology changes, (5) NRCS software problems, and (6) human error. Some of these discrepancies can be quantified, and some cannot be quantified.

Quantifiable Discrepancies

Precipitation Discrepancies

The basic differences in precipitation between published Grand Valley weather station data and NRCS reported values were discussed earlier in the section "Precipitation for Soil Moisture Balance Models." The question arises as to whether the differences in per-site precipitation as reported by the NRCS and the precipitation at the four Grand Valley weather stations have an effect on the performance of the SMB models. To test this, the SMB models are set up to use either NRCS reported per-site precipitation or the closest Grand Valley weather station effective precipitation values. It is possible in the SMB model spreadsheet to easily switch any or all of the model sites back and forth between these two precipitation choices.

There is not a ready explanation for the discrepancy in weather station precipitation and NRCS reported precipitation. Precipitation values at each Grand Valley Unit NRCS evaluation site were reported to be collected from two sources: (1) the NRCS-operated weather stations at Highline Lake (western Grand Valley) and Palisade (eastern Grand Valley) (see map fig. 15), and (2) local rain gages that were manually operated by the field owner. It is not documented in the annual reports how discrepancies between these two sources were resolved by the NRCS evaluation. How often the local rain gages were read or maintained was not recorded, which could have resulted in inaccurate readings. The precipitation discrepancies shown in figure 42 and figure 43 appear to be systematic over the years of the evaluation. The NRCS evaluation annual reports make vague remarks about "adjustments" being made to precipitation readings without specifying how the adjustments were made. The NRCS evaluation does not report the dates when precipitation events occurred, so it is not possible to compare the NRCS evaluation reported precipitation to weather station records on a daily basis. The reported precipitation was simply totaled from the start of one irrigation event to the start of the next event.

Under-reported precipitation in the NRCS evaluation would have resulted in under-reporting of DP, because missing precipitation would lead to lower soil moisture balances, and thus a reduced tendency to create DP during irrigation and heavy rain events. Over-reporting of precipitation would have the opposite effect of over-reported DP. Changes in the amount of DP that results from switching between NRCS reported precipitation and Grand Valley weather station precipitation will be shown in the "Sensitivity Analysis" section.

Types of Evapotranspiration Discrepancies

There are several ways that ET affects the SMB models. The first way is through the daily values of ET_p, which are dependent on raw weather station data and on the calibration of the Penman ET equation to the local agricultural area. Higher ET_p results in higher values of ET_c, which can result in a lower amount of DP for the season.

The second way that ET affects the SMB models is the season total ET_c, which can also be called crop consumptive use. The 1988 Colorado Irrigation Guide (U.S. Department of Agriculture, 1988) includes a set of tables for typical monthly and season total crop consumptive use of water by crop, agricultural area, and climate zones within the agricultural areas. This enables a comparison between NRCS reported season-total ET_c and season total consumptive use from the Irrigation Guide.

The third way that ET affects the SMB model is in the shape, duration, and amplitude of the crop coefficient equation for K_c. A possible software error in the ZETA.wks spreadsheet is discussed below in the section "Crop Evapotranspiration Discrepancies."

The final way in which ET affects the SMB model is through the use of a stress correction based on readily available soil moisture levels. The basics of this have been discussed in the section "Stress Correction of Crop Evapotranspiration."

Reference Evapotranspiration Discrepancies

The language in the NRCS evaluation annual reports contains evidence that the calculation methods for ET_p changed over the course of the evaluation. These changes are not well documented. The 1988 Grand Valley annual report states: "Potential evapotranspiration was calculated using a Modified Penman equation developed by the ARS in Fort Collins, Colorado. The measured data parameters included wind run, solar radiation, maximum and minimum temperatures, relative humidity, and precipitation. The calculated ET_p results were calibrated with the ET_p results gathered by the ARS on the Colorado State University Experimental Farm in the Grand Valley" (Grand Valley Annual Report, 1988, *in* U.S. Department of Agriculture, 1986–2003). How this calibration was accomplished is not stated.

A comparison was made for this report between daily ET_p reported by NRCS and daily ET_p from the Grand Junction and Fruita weather stations operated by CoAgMet in the Grand Valley. Daily weather data have been published for Fruita since 1992, and for Grand Junction since 1993. Unfortunately, there are no CoAgMet or other weather data available that would allow for an ET_p comparison prior to 1992.

Figure 56 shows a comparison between daily ET_p for the Fruita CoAgMet station with NRCS reported ET_p for 1992. The blue trace (ZETA.wks Fruita reference ET_p) indicates that NRCS ET_p is systematically lower than CoAgMet ET_p (red trace) by a mean value of 23.1 percent for the 1992 season. Similar differences occur until 1998 and 1999, when the NRCS ET_p is identical to CoAgMet, indicating that the CSU staff who were operating the NRCS evaluation at that time changed their ET_p source. Not counting 1998 and 1999, NRCS ET_p has a mean season total difference from CoAgMet for 1992 to 1997 of 21.2 percent.

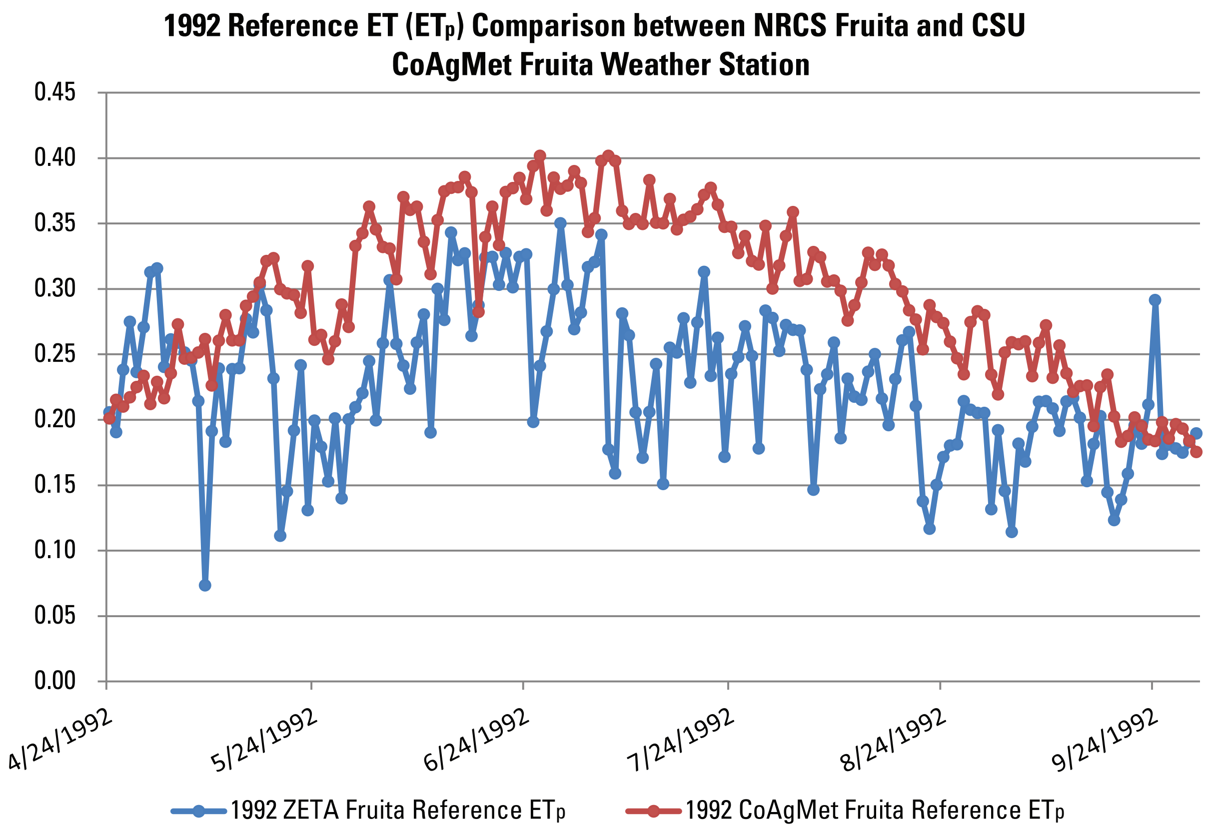


Figure 56. Comparison between CoAgMet ET_p with NRCS evaluation ET_p for Fruita in 1992. [ET_p, reference evapotranspiration; NRCS, Natural Resources Conservation Service; CSU, Colorado State University; CoAgMet, Colorado Agricultural Meteorological Network ZETA.wks; NRCS ET_p software program.]

Figure 57 shows a different story for the Grand Junction ET_p for 1993. The NRCS ET_p is close to the CoAgMet daily values, with a season total difference of only 6.1 percent. The differences vary by subsequent years, with some years having NRCS ET_p higher than CoAgMet, and some years being lower. The same convergence between NRCS ET_p and CoAgMet ET_p occurs starting in 1998. From 1993 to 1997, the NRCS ET_p has a mean lower value of 6.7 percent.

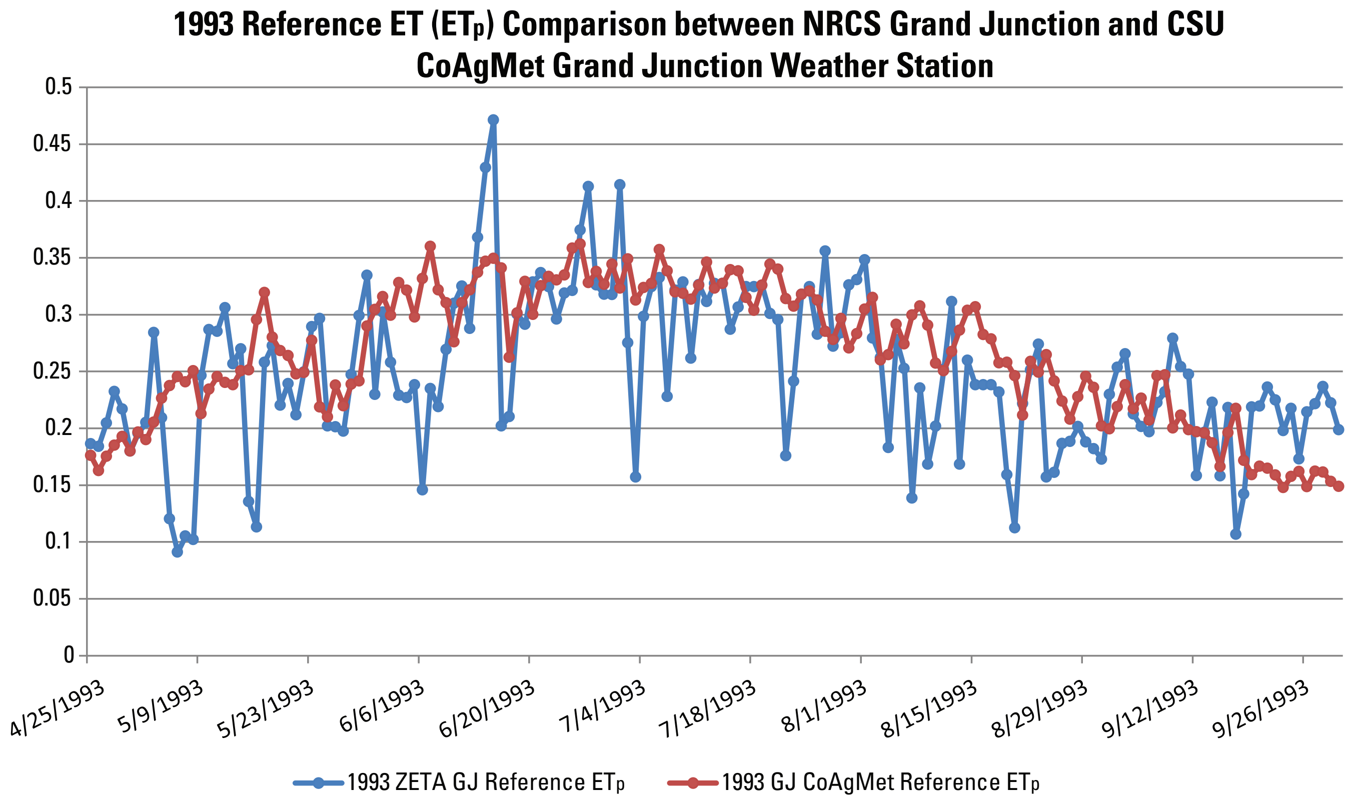


Figure 57. Comparison between Colorado State University (CSU) CoAgMet ET_p with Natural Resources Conservation Service NRCS evaluation ET_p for Grand Junction in 1993. [ET_p, reference evapotranspiration; NRCS, Natural Resources Conservation Service; CSU, Colorado State University; CoAgMet, Colorado Agricultural Meteorological Network; ZETA.wks, NRCS ET_p software program; GJ, Grand Junction.]

Crop Consumptive Use Discrepancies

Crop consumptive use in this analysis means the same thing as crop evapotranspiration. The 1988 Colorado Irrigation Guide (U.S. Department of Agriculture, 1988) published expected consumptive use values for each major agricultural area of the state. Monthly and season total consumptive use values are available for both Fruita and Grand Junction. See appendix 9 for the crop consumptive use tables for Grand Junction (fig. 9-2 in appendix 9) and Fruita (fig. 9-3 in appendix 9), as well as a climate zone map of Colorado that shows peak monthly use for pasture grasses in the climatic zones (fig. 9-1 in appendix 9). The Grand Valley, for example, has two climate zones, one each for alfalfa and for orchards (fig. 9-2). These zones roughly divide the Grand Valley Unit north and south of I-70. Using the crop consumptive use tables, comparisons can be made between NRCS reported season total ET_c. The length of season implied in the consumptive use tables corresponds generally to the reported planting and harvest dates in the NRCS annual reports.

When these consumptive use values are compared with NRCS evaluation reported ET_c, some differences are apparent. The 1988 Colorado Irrigation Guide numbers are representative of typical years, so actual values would vary somewhat with wet or dry years. But the NRCS evaluation data covers both wet and dry years as well, so a comparison can be made on mean. Figure 58 shows the frequency (histogram) chart of different values of standard percent difference (not RPD) between NRCS ET_c and 1988 Colorado Irrigation Guide consumptive use for all 196 Grand Valley Unit gold standard site-years. It can be seen that 73 percent of the NRCS sites (red bars) have lower season-total ET_c than the Irrigation Guide standards, while 27 percent (blue bars) have higher ET_c than the Irrigation Guide standards. The median ET_c difference is -8.7 percent. If NRCS ET_c matched consumptive use guidelines, one would see most of this distribution to be close to zero percent difference, symmetrical about zero, and not be so widely spread.

Figure 59 shows the 1988 Colorado Irrigation Guide consumptive use, season total NRCS reported ET_c, and season total SMB model ET_c plotted for the 12 SMB model sites. The NRCS reported ET_c has a mean value that is 8.7 percent lower than consumptive use. The SMB model ET_c for baseline-fit settings is 11.1 percent lower than consumptive use. Site GV-33 89 is a special case because in 1989, it was newly seeded to alfalfa the previous fall. This slows the growth of the crop in the spring, and would account for lower season-total ET_c.

It was found that increasing ET_p for the 12 SMB models by 10 percent would increase the mean consumptive use for the SMB model sites (season total ET_c) to less than a 2 percent difference from mean 1988 Colorado Irrigation Guide consumptive use. Therefore, a trial increase of SMB model ET_p by 10 percent is included in the sensitivity analysis.

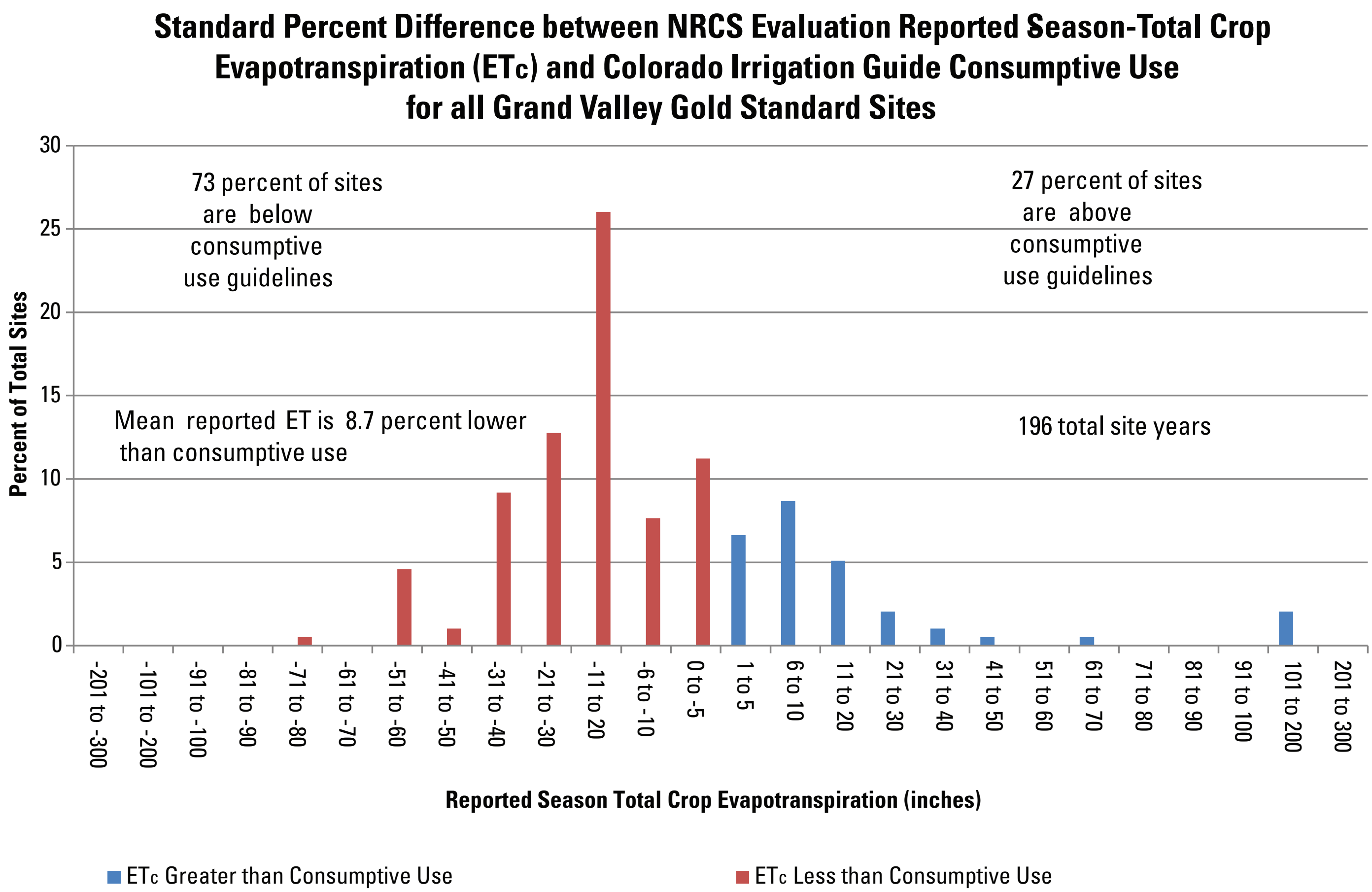


Figure 58. Histogram of percent difference between Natural Resources Conservation Service reported crop evapotranspiration and 1988 Colorado Irrigation Guide consumptive use for all Grand Valley Unit gold standard sites. [ET_c, crop evapotranspiration; NRCS, Natural Resources Conservation Service; 1988 Colorado Irrigation Guide, U.S. Department of Agriculture, 1988.]

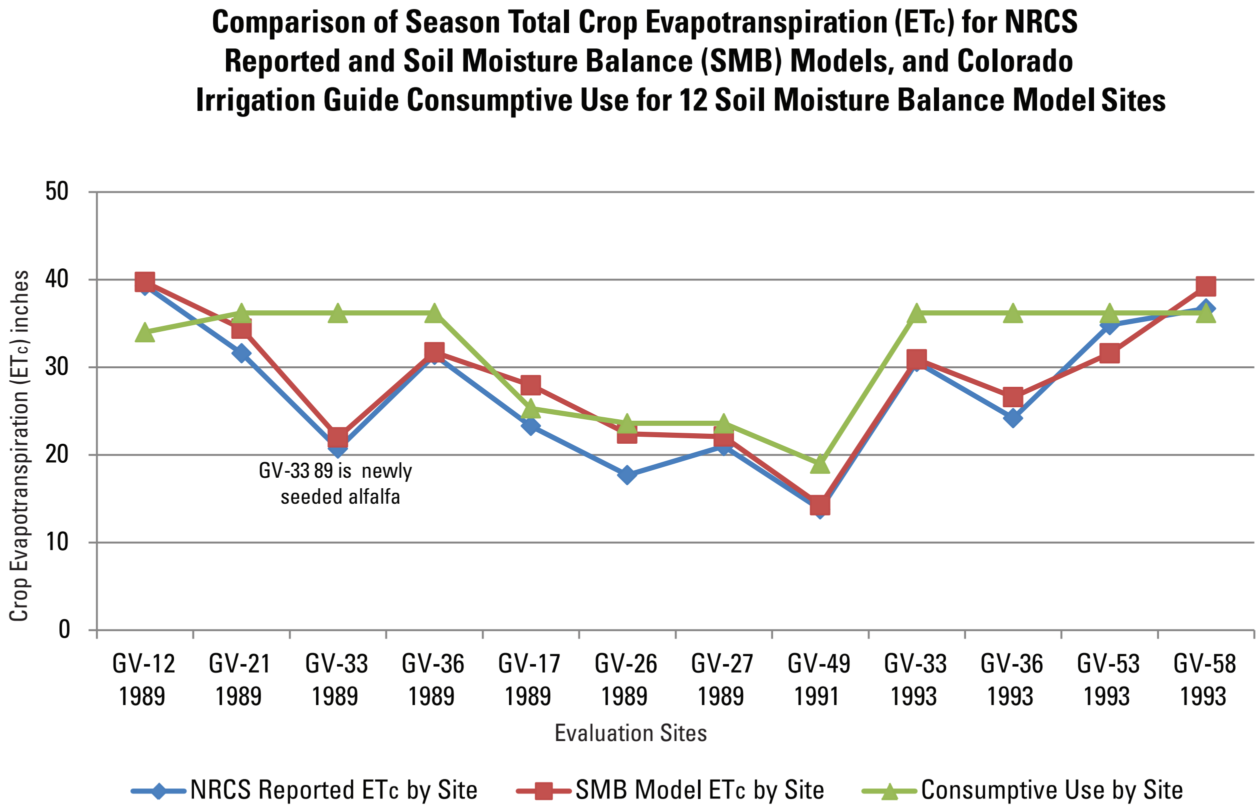


Figure 59. Comparison between 1988 Colorado Irrigation Guide consumptive use and NRCS reported ET_c for the 12 soil moisture balance sites. [ET_c, crop evapotranspiration; NRCS, Natural Resources Conservation Service; SMB, soil moisture balance; GV, Grand Valley; 1988 Colorado Irrigation Guide, U.S. Department of Agriculture, 1988.]

Crop Evapotranspiration Discrepancies

The NRCS evaluation staff recognized that there was a problem with their ET_c software in 1987. This language is from the 1987 Grand Valley annual report: "At the beginning of this portion of the project an ET program using a Modified Penman equation was developed with the assistance of the ARS Staff in Fort Collins, Colorado. This year ARS Staff at Grand Junction provided us (NRCS) with an ET program for disseminating daily ET information to local TV, radio, and newspapers. Though the two programs use the same basic equation, the variables in the equation must be different, because there is a significant variance between the predicted two ET totals for the season of about 1 inch per month. This discrepancy needs to be resolved" (Grand Valley Annual Report, 1987, *in* U.S. Department of Agriculture, 1986–2003).

It has been confirmed (Dick Bartholomay, CSU Cooperative Extension, retired, oral commun., September 10, 2013) that the ET program created for media use by the Grand Junction ARS staff was the ZETA.wks spreadsheet (Colorado State University Cooperative Extension, 1999), which has been discussed previously in the section "Reference Evapotranspiration" under "Soil Moisture Balance Inputs" and is documented in appendix 6.

The 1987 annual report does not report which software program had higher or lower ET. No further mention of a resolution to this problem occurs in subsequent annual reports. The most likely answer was discovered during the USGS study when the design of the ZETA.wks spreadsheet was carefully studied. A coding error was found in the calculation of the K_c crop coefficient which caused the crop coefficient values to be incorrect. Figure 60 shows the results of the coding error. The rising value of K_c in the rapid growth phase of the crop cycle takes a sudden jump upward at $K_c = 0.600$. This results in an overstatement of ET_c when this crop coefficient equation is used. Compare this curve to the K_c curve in figure 40, which represents the correction made to the ZETA.wks software code by the USGS study. This could be the source of the 1 inch per month discrepancy noted in the 1987 annual report.

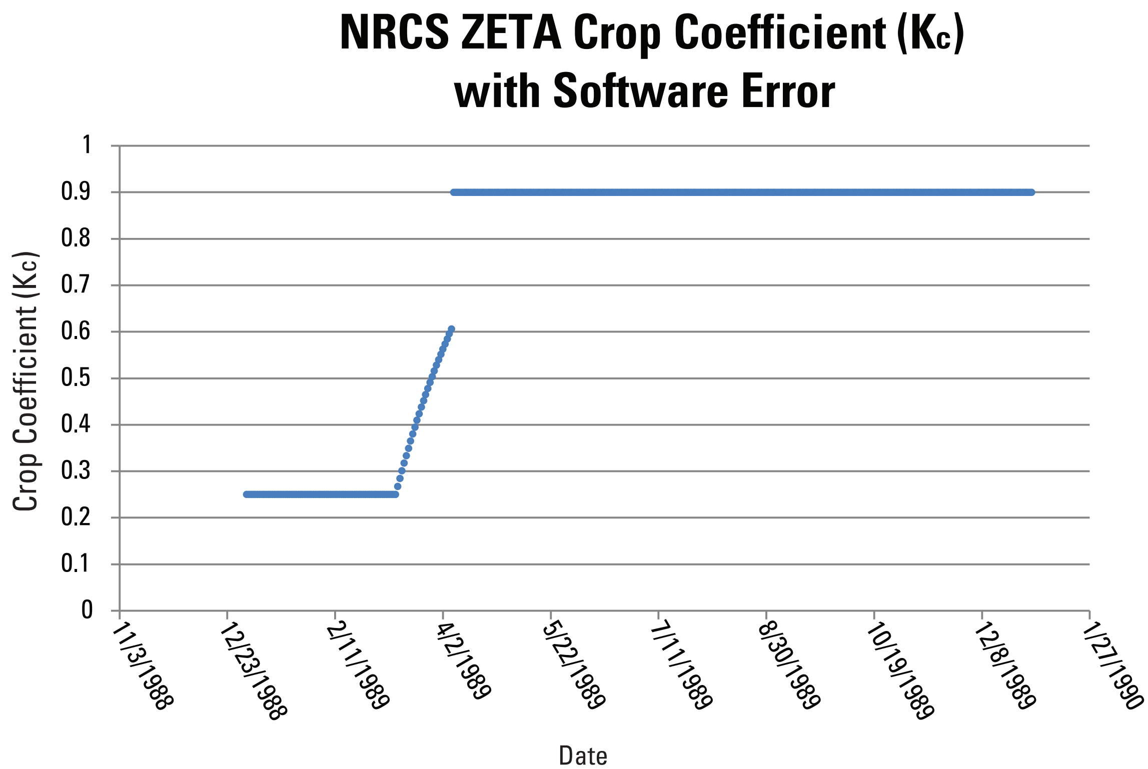


Figure 60. Example of ZETA.wks spreadsheet crop coefficient curve with software coding error in ZETA.wks program. [K_c, crop coefficient; NRCS, Natural Resources Conservation Service; ZETA.wks, NRCS ET_p software program.]

Because the ZETA.wks spreadsheet version that was obtained by USGS was dated December 1999, and the coding error was still present, it is assumed that this ZETA.wks spreadsheet coding error was present from the beginning. It is thus likely that the incorrect ET_c mentioned in the annual report quote above was coming from the ZETA.wks spreadsheet, and that the correct ET_c was being calculated by the ARS-provided software (coded in Basic) being used by the NRCS evaluation staff. If this assumption is correct, then the reported ET_c values in the NRCS evaluation annual reports would not have contained this error.

Crop Evapotranspiration Stress Correction Discrepancies

Stress correction is a contemporary method to increase the accuracy of ET_c calculations for a crop. The SMB model spreadsheets use the FAO-56 stress correction method, as was described in the section "Evapotranspiration for Soil Moisture Balance Models." Some method of ET_c stress correction was also performed in the NRCS evaluation. The NRCS annual reports for 1985 through 1988 mention that "The crop coefficient and stress adjustments used were supplied by ARS in Grand Junction and Fort Collins.", and "The soil water deficits were calculated ... using an adjustment factor based on the days since precipitation or irrigation to simulate plant stress" (Grand Valley Annual Report, 1987, *in* U.S. Department of Agriculture, 1985). The actual method of applying this stress adjustment is not given. It was found while manipulating the SMB models that a baseline-fit could not be achieved unless the SMB model stress correction algorithm was disabled. With SMB model stress correction turned on, 7.1 percent more ET_c was required to achieve the baseline-fit. This would indicate that the NRCS reported results do not reflect the use of a rigorous stress correction procedure. The sensitivity analysis will include a factor for turning the stress correction off and on in the SMB models to measure the effect of stress correction on DP and SIE.

Irrigation Water Application Timing Discrepancies

Initially, the design of the SMB models was such that the total net irrigation water inflow (inflow minus outflow) was assumed to have a constant rate of application over the duration of the event. The net inflow was converted to inches (using the field size), a per-day application value was calculated in inches using the number of event days, and the daily applications were applied equally over the event days. In trying to achieve the baseline-fit for the 12 sites, it became evident that dividing the applied irrigation water over the duration of the event was not allowing a baseline-fit of the SMB models to the NRCS reported values. The solution was in realizing that the NRCS soil moisture accounting assumed that all the irrigation water was applied instantaneously at the beginning of each irrigation event. While this may seem counter-intuitive, there is some logic in its favor.

Fields are typically divided into sections (sets) for irrigation application. Each set usually lasts either 12 or 24 hours, after which the irrigation water is applied to the next set. When a typical irrigation event is analyzed set by set, it is apparent that there are an equal number of days between irrigations for each set, and that the season-total number of irrigation days for each set is the same. Thus, there should be no season-total ET_c differences from one set to the next.

The accounting of soil water deficits in the NRCS evaluation depends on the assumption that the irrigation water is completely applied as soon as the irrigation event starts. This starts the ticking of the ET_c clock, which runs until the start of the next irrigation event. The value of NRCS reported SWD at the beginning of that next event is dependent on the daily ET_c and precipitation that occur from the very beginning of one event (the same day the irrigation event starts) to the start day of the subsequent event. Recall that SWD is the field capacity minus the current soil moisture amount, which is described as the deficit amount of water below field capacity in the soil. For example, a soil profile with a field capacity of 20 inches, which has a current soil water amount of 16 inches, would have a 4-inch soil water deficit. In a sense, the NRCS accounting only looks at the first set of each event, and assumes that the set had a duration of zero hours, achieving the ending SWD value immediately.

To achieve a baseline-fit, the SMB model was changed from taking into account the entire duration of the event to assuming that each event lasts for 24 hours. It is not possible in the SMB model to have two different simultaneous values of soil water balance (event beginning SWD and ending SWD) on the beginning day of an event, so allowing for 24 hours delay is the shortest amount of time in which the model can achieve the ending event SWD. An analysis of this 24-hour difference between SMB model accounting and NRCS accounting shows that the loss of one day of ET_c for every irrigation event in the SMB models requires a mean value of 6.1 percent more ET_c to be input to the models to reach the NRCS reported SWD value at the start of the next event. This is an offset in the SMB model ET_c which can be allowed for when analyzing the difference in ET_c inputs between the SMB models and the NRCS sites.

Non-Quantifiable Discrepancies

Discrepancies due to Lack of NRCS Field Tests for Soil Water Deficit Values

The most likely source of errors in SWD values at the beginning of each irrigation event is the reliance by the NRCS evaluation on calculated SWD values at the start and end of each irrigation event, without using field measurements of SWD values to cross-check the calculated SWD values. An initial SWD for the season was determined by NRCS using a gravimetric analysis in 1985 and 1986, but whether this practice was continued was not reported in subsequent years. There is some indication that a "hand-feel" method of soil moisture determination was used in later years (Frank Riggle, NRCS, written commun., August 8, 2013). For whatever reason, the start of season soil moisture was never reported by NRCS.

The evaluation staff must have realized the computed SWD values at the start and end of each event were subject to cumulative errors, because the 1989 Grand Valley annual report stated: "Actual field soil moisture needs to be compared with computer generated values using crop ET data to determine if adjustments have to be made. Current techniques and equipment available are time consuming and do not provide an accurate estimate of actual soil moisture conditions" (Grand Valley Annual Report, 1987, *in* U.S. Department of Agriculture, 1986–2003). The 1990 Grand Valley annual report noted: "Currently the monitoring water budget program does not have the capacity to adjust for high water table. Additionally, there is no equipment on hand that could give a quick reliable estimate of soil moisture in the field to make needed adjustments to the computer generated values" (Grand Valley Annual Report, 1990, *in* U.S. Department of Agriculture, 1986–2003).

It is not stated in subsequent annual reports whether this problem was ever solved. If a quick field method for measuring SWD had been available, the calculated SWD values from the soil moisture software could have been compared with measured SWD at each site and corrected if necessary.

Discrepancies due to Precipitation Data Collection Changes

The NRCS evaluation precipitation field methods changed after 1987. From 1985 through 1987, site precipitation was measured using a rain gage at every evaluation site. After 1987, only "some" sites had precipitation measured using rain gages, and the number of sites with gages was not reported. The other source of precipitation data for each site was the two NRCS operated weather stations. The 1985 through 1987 Grand Valley annual reports state: "The precipitation was electronically recorded at the two weather stations (NRCS). On-site precipitation was also recorded at each of the monitored locations" (Grand Valley Annual Reports, 1985–1987, *in* U.S. Department of Agriculture, 1986–2003). Then, the 1988 through 1995 Grand Valley annual reports state: "The precipitation was electronically recorded at the two weather stations (NRCS). On-site precipitation was also recorded at some of the monitored locations" (Grand Valley Annual Reports, 1988–1995, *in* U.S. Department of Agriculture, 1986–2003).

Refer to the sections titled "Precipitation for Soil Moisture Balance Models" for more details regarding precipitation discrepancies in the NRCS evaluation reports.

Discrepancies due to Deep percolation Calculation changes

There were changes in the calculation method used for season total DP. The 1990 Grand Valley annual report states, "In 1990, the water budget program was updated to more accurately estimate deep percolation for annual crops. In the past, deep percolation for the first irrigation and or pre-irrigation was considered to be any amount that was in excess of that required to fill up the first foot of soil; the full root profile was not taken into account. With this method, deep percolation estimates were higher than what they should be. All previous data from 1986 to 1989 have been re-processed using the updated program to get a better estimate of deep percolation, soil moisture, and ET_c" (Grand Valley Annual Report, 1990, *in* U.S. Department of Agriculture, 1986–2003). The changed DP values due to this retroactive per-site change are not shown in the 1990 annual report, so presumably the data available to the USGS study from the annual reports from 1985 to 1989 contain the original DP values, not the corrected values. It is thus impossible to determine the effect of this change on reported DP values.

Seasonal Irrigation Efficiency Calculation Changes

There was a change in the formula used to calculate SIE in 1990. The Grand Valley annual report for 1990 states,

> *"In the past, the overall seasonal irrigation application efficiency was computed erroneously: it was calculated as the mean of all individual site irrigation efficiencies. In 1989 and 1990, the overall mean efficiency was calculated using the seasonal irrigation efficiency formula shown at the bottom of table 2 and defined on page 16. This formula is also used for calculating individual irrigation efficiency as was done in the past. The overall irrigation efficiency for the past five years has been recalculated and provided in table 4. These values are slightly lower than previously reported"* (Grand Valley Annual Report, 1990, in U.S. Department of Agriculture, 1986–2003). The formulas referred to in the quote are:

Table 2 formula: Seasonal Irr. Eff. = (vol. of inflow – vol. of outflow)/Vol. of inflow x 100
Table 4 formula: Seasonal Irr. Eff. = (vol. of inflow – vol. of outflow – D.P.)/Vol. of inflow x 100

Note the absence of DP in the table 2 formula. The changed SIE season total values were reported in table 4 of the 1990 Grand Valley annual report as a six-year summary of values by year.

Undocumented NRCS Data Corrections

All of the NRCS annual reports have asterisks for many of the tables of individual site records stating that "corrections have been applied to the data." The exact nature of these corrections is never documented. In addition, there are individual irrigation event data records scattered throughout the annual reports where the basic arithmetic of water balance calculations does not "add up" for the irrigation event. These records were excluded from the USGS study analysis when these tables obviously were in error mathematically. Refer to the section titled "Site-Year Record Quality Determination" for a discussion of how the usability of records was determined.

Discrepancies Due to Software Problems

The 1994 Grand Valley annual report mentions unspecified software problems that were being encountered: "Data downloading, processing, and evaluation is being done using several computer programs. These programs have been in place for several years but problems still exist. Existing programs need to be updated when problems are encountered. It would be beneficial to have one M&E team member with computer programming knowledge" (Grand Valley Annual Report, 1994, *in* U.S. Department of Agriculture, 1986–2003). No mention in subsequent annual reports was found about whether these software problems were ever solved or exactly what kinds of problems they were causing.

Discrepancies Due to Human Error

Finally, one must recognize the inherent problems in collecting field data and keeping accurate records over the period of 19 years, with many changes in staff during those years. Even the most rigorous of projects will have some human error which is impossible to quantify.

Sensitivity Analysis of SMB Models

A review was done by the USGS to ensure that the SMB models were free from calculation and assumption errors. Three crop scientists in the NRCS and the Colorado State University Extension Service provided reviews and input as to the accuracy of the SMB models and configuration variables, particularly the ET_c assumptions (Lorenz Sutherland, Natural Resources Conservation Service, oral commun., September 13, 2012; Calvin Pearson, Colorado State University Extension Service, oral commun., April 7, 2012; and Frank Riggle, Natural Resources Conservation Service, oral commun., August 24, 2013).

The baseline-fit discussed in previous SMB model sections shows that the 12 SMB models can be made to match NRCS evaluation results at those sites. But do the SMB model assumptions which must be made in order to achieve this baseline-fit withstand scrutiny in light of current practices in irrigation system analysis? In the end, can the NRCS evaluation methods and results be accepted as accurate?

A sensitivity analysis shows the effect on SMB model results when various changes are made to the model inputs. The analysis shows which changes in model inputs result in the largest changes in model outputs. In particular, it is of interest to measure variations in model DP and SIE. The estimation of DP and SIE are some of the most important results from the NRCS evaluation, and tests of the accuracy of DP and SIE go to the heart of the NRCS evaluation conclusions. When a sensitivity analysis was done using three sets of variables, discrepancies were seen between the NRCS reported ET_c, DP, and SIE and the SMB model values. This sensitivity analysis shows some possible effects of manipulating the SMB model inputs to move the SMB models away from the baseline-fit.

Sensitivity Test Inputs

There are three sets of model inputs, each having two values, which are manipulated in the sensitivity tests. These pairs of inputs are

1. Closest Grand Valley NOAA or CSU weather station precipitation or NRCS reported precipitation;
2. Crop evapotranspiration stress correction used or not; and
3. NRCS reported daily ET_p, or a 10 percent upward adjustment in ET_p to match published standards of crop consumptive use.

This results in eight combinations of inputs. By setting the SMB model inputs to these eight combinations, it is possible to calculate the value changes in the SMB model outputs.

Sensitivity Test Outputs

SMB model outputs for DP and SIE were measured for changes from the various input combinations. Results are reported separately for flood irrigation systems and sprinkler irrigation systems. The resulting changes in ET_c are also reported. While ET_c is not strictly an SMB model output, it is an intermediate result which affects DP and SIE, and it is changed by modifying the sensitivity test inputs.

Crop Evapotranspiration Sensitivity Test Results

Table 32 shows the changes in SMB model season total ET_c when various sensitivity tests are performed. All percent difference values in table 32 are relative percent difference (RPD). The SMB model ET_c is 5.4 percent higher even at the “baseline-fit” settings in test 1 because of the minimum 1 day irrigation event requirement for the SMB models, as discussed in the previous section “Irrigation Water Application Timing Discrepancies.” Test 3 only changes the precipitation data source from the test 1 conditions, and shows by yielding the same results as test 1 that precipitation data source has no effect on ET_c, as would be expected. Test 2 includes the use of stress correction, and test 4 includes stress correction and also changes the precipitation setting choice. Tests 2 and 4 both result in model ET_c that is 12.8 percent higher than reported ET_c. This shows that the while the precipitation selection does not affect the sensitivity results for ET_c, the use of stress correction increases the mean ET_c relative percent difference by 7.4 percent (12.8–5.4 = 7.4) over reported ET_c.

Tests 5 and 7 both yield a model ET_c that is 14.7 percent higher than reported, indicating again that precipitation setting selection does not affect ET_c. Tests 6 and 8 result in a 22.3 percent higher model ET_c than reported results. The difference between tests 1 and 5 show that an increase of 10 percent in ET_p increases ET_c by 9.3 percent (14.7 – 5.4 = 9.3) over reported ET_c. It would be expected that increasing ET_p by 10 percent should yield a similar increase in ET_c, and this is confirmed by this result. The largest difference between reported and model results occurs with tests 6 and 8, resulting in a 16.9 percent difference over baseline results when weather station precipitation is selected, stress correction is turned on, and 110 percent reference is used.

Table 32. Comparison between Natural Resources Conservation Service reported values and eight sensitivity test results for mean season total ET_c. at 12 SMB model sites.

[NRCS, Natural Resources Conservation Service; ET_p, reference evapotranspiration; ET_c, crop evapotranspiration, SMB, soil moisture balance.]

Sensitivity Test Number	Stress Correction Setting	Precipitation Setting	Reference ET_p Setting (Percent)	NRCS Reported ET_c for 12 SMB Sites (Mean Inches)	Model ET_c for 12 SMB Sites (Mean Inches)	Relative Percent Difference Between Reported and SMB Model ET_c (Percent)
1	Off	Reported	100	27.1	28.6	5.4
2	On	Reported	100	27.1	30.8	12.8
3	Off	Weather station	100	27.1	28.6	5.4
4	On	Weather station	100	27.1	30.8	12.8
5	Off	Reported	110	27.1	31.4	14.7
6	On	Reported	110	27.1	33.9	22.3
7	Off	Weather station	110	27.1	31.4	14.7
8	On	Weather station	110	27.1	33.9	22.3

DP Sensitivity Test Results

Flood Irrigation DP Sensitivity Test Results

The blue bars in figure 61 and figure 62 show the sensitivity test results for differences in flood irrigation DP between the SMB models and NRCS reported results. Figure 61shows differences in inches of water, while figure 62 shows relative percent difference between SMB model results and NRCS reported results. The baseline-fit results in both figures are the first pair of bars on the left (test 1). The baseline-fit test settings are NRCS reported precipitation, crop stress correction setting off, and ET_p at NRCS reported levels.

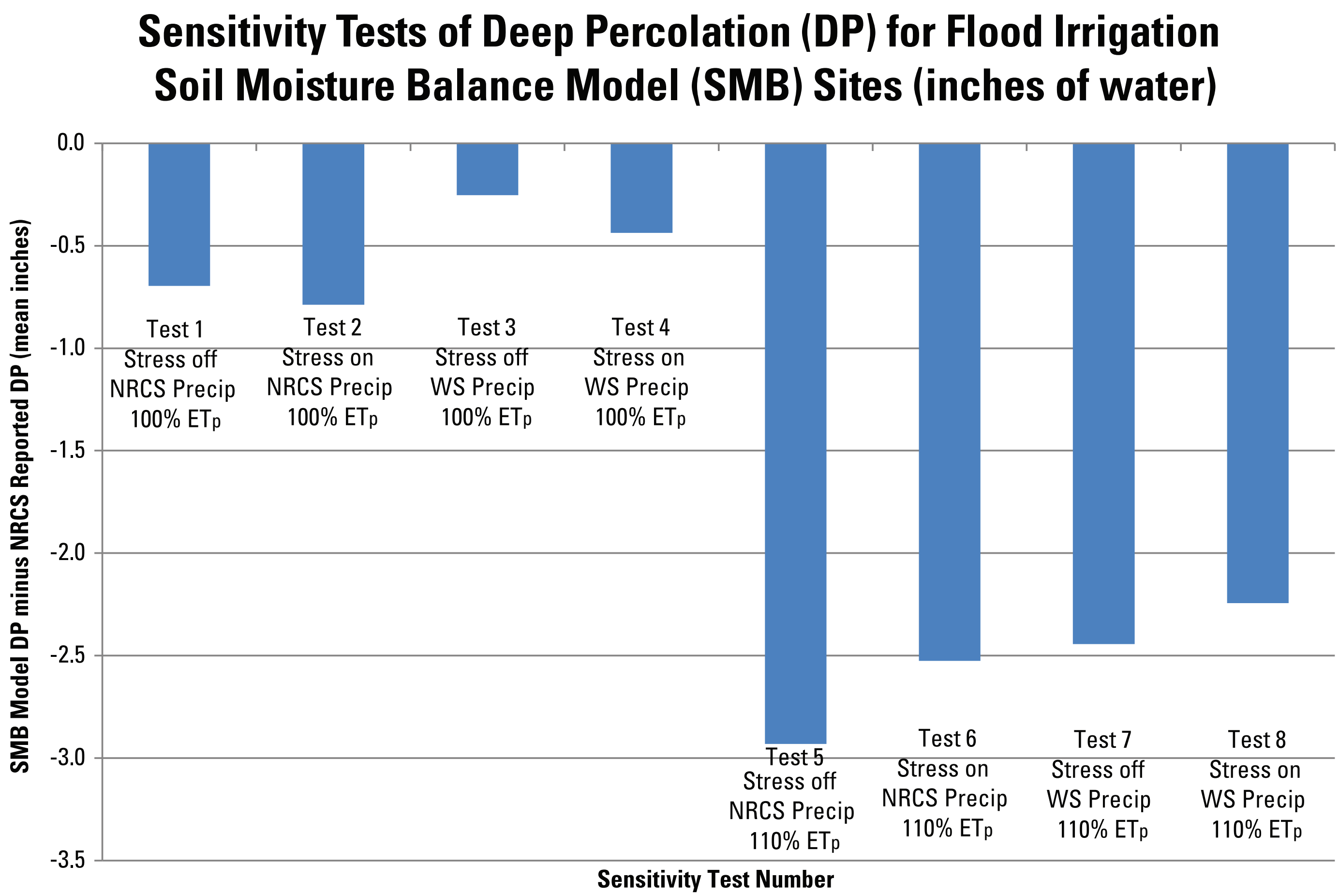


Figure 61. Sensitivity test results in soil moisture balance model deep percolation in inches of water for flood irrigation system types. [%, relative percent; SMB, soil moisture balance; DP, deep percolation; NRCS, Natural Resources Conservation Service; Precip, precipitation; WS, weather station; ET_p, reference evapotranspiration.]

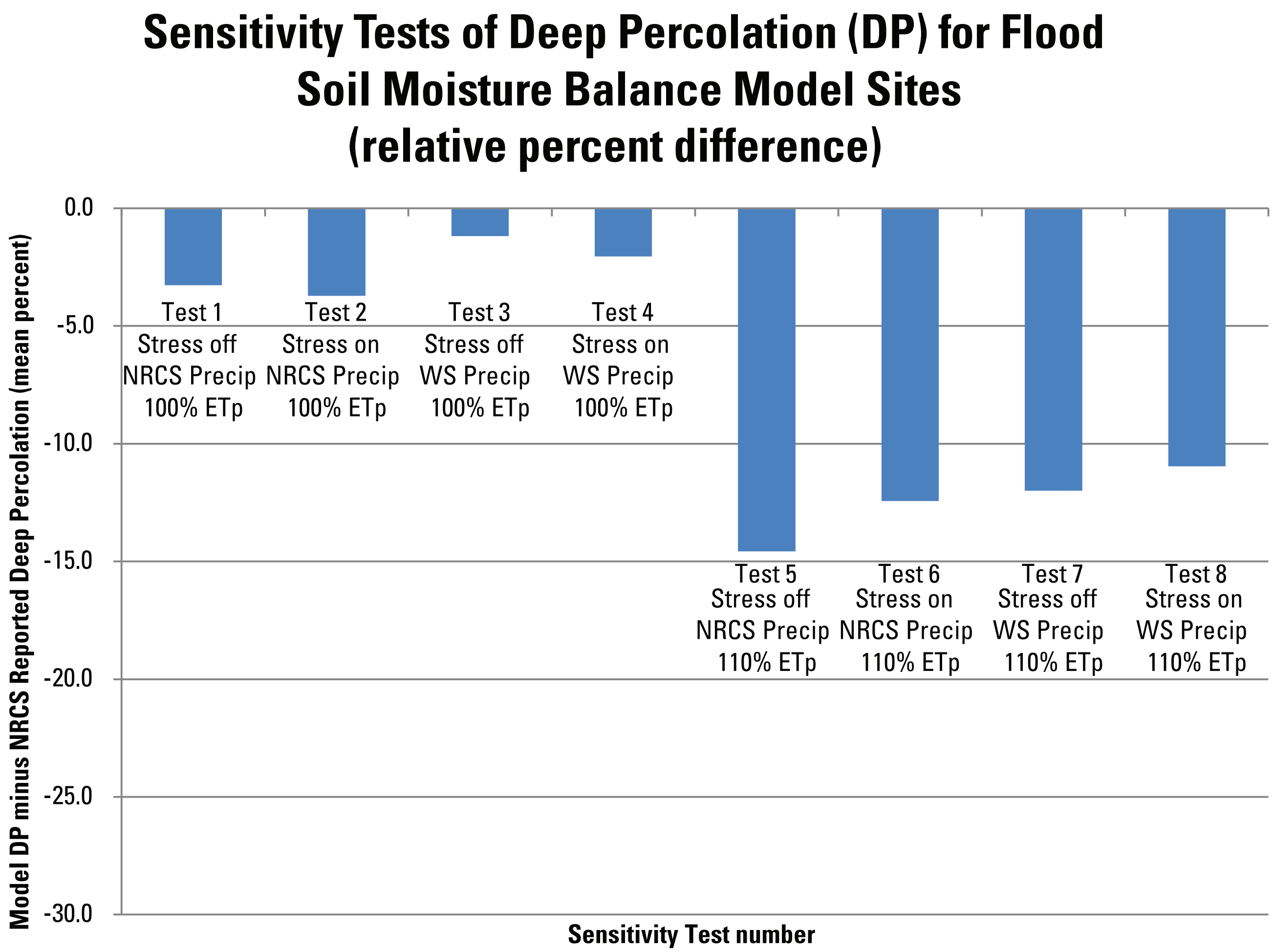


Figure 62. Sensitivity test results in soil moisture balance model deep percolation in relative percent difference for flood irrigation system types. [%, relative percent; SMB, soil moisture balance; DP, deep percolation; NRCS, Natural Resources Conservation Service; Precip, precipitation; WS, weather station; ET_p, reference evapotranspiration.]

For flood irrigation sites, in the first 4 tests shown in figure 61 the model mean DP was lower than mean NRCS reported DP by less than an inch of water. Stress correction setting and precipitation setting made little difference in the results of the four tests. When weather station precipitation replaced NRCS reported precipitation (3d and 4th tests), the difference between SMB model and NRCS reported DP decreased to less than 0.5 inch. These differences are shown as percent differences from NRCS reported values in figure 62. The changes seen in the 5th through 8th tests in figure 61 indicate that when ET_p is increased by 10 percent to raise the season total ET_p to match 1988 Colorado Irrigation Guide consumptive use values, mean DP for the seven flood model sites decreased by a range of 2.9 to 2.2 inches when compared with NRCS reported DP for the seven flood SMB sites. The effect is about the same regardless of the precipitation setting or whether the crop stress is on or off. In figure 62, the 5th through 8th tests result in a mean DP of about 13 percent lower than NRCS reported DP.

Sprinkler Irrigation DP Sensitivity Test Results

The red bars in figure 63 (in inches) and figure 64 (in relative percent difference) show the sensitivity test results for sprinkler and microspray sites. Sensitivity tests 1, 2, 7, and 8 show model DP being higher than NRCS reported DP by about 0.5 inch. Tests 5 and 6 show slightly lower model DP compared with NRCS reported DP of about a negative 0.5 inch. Tests 3 and 4 show greater model DP between 1 and 2 inches, which is the largest difference in sensitivity results for sprinkler and microspray DP. This occurred when weather station precipitation was substituted for NRCS reported precipitation. This result could be anticipated from the discrepancies in weather station versus reported precipitation discussed earlier.

Because sprinkler and microspray sites tend to have very low season total DP (compared to flood sites), small changes in precipitation of a few inches in a season could result in greater changes in SMB model DP. The mean NRCS reported DP for the five model sprinkler and microspray sites is only 1.1 inches. Thus an increase of 1 to 2 inches in SMB model DP is a large percentage change but is not of interest in absolute terms.

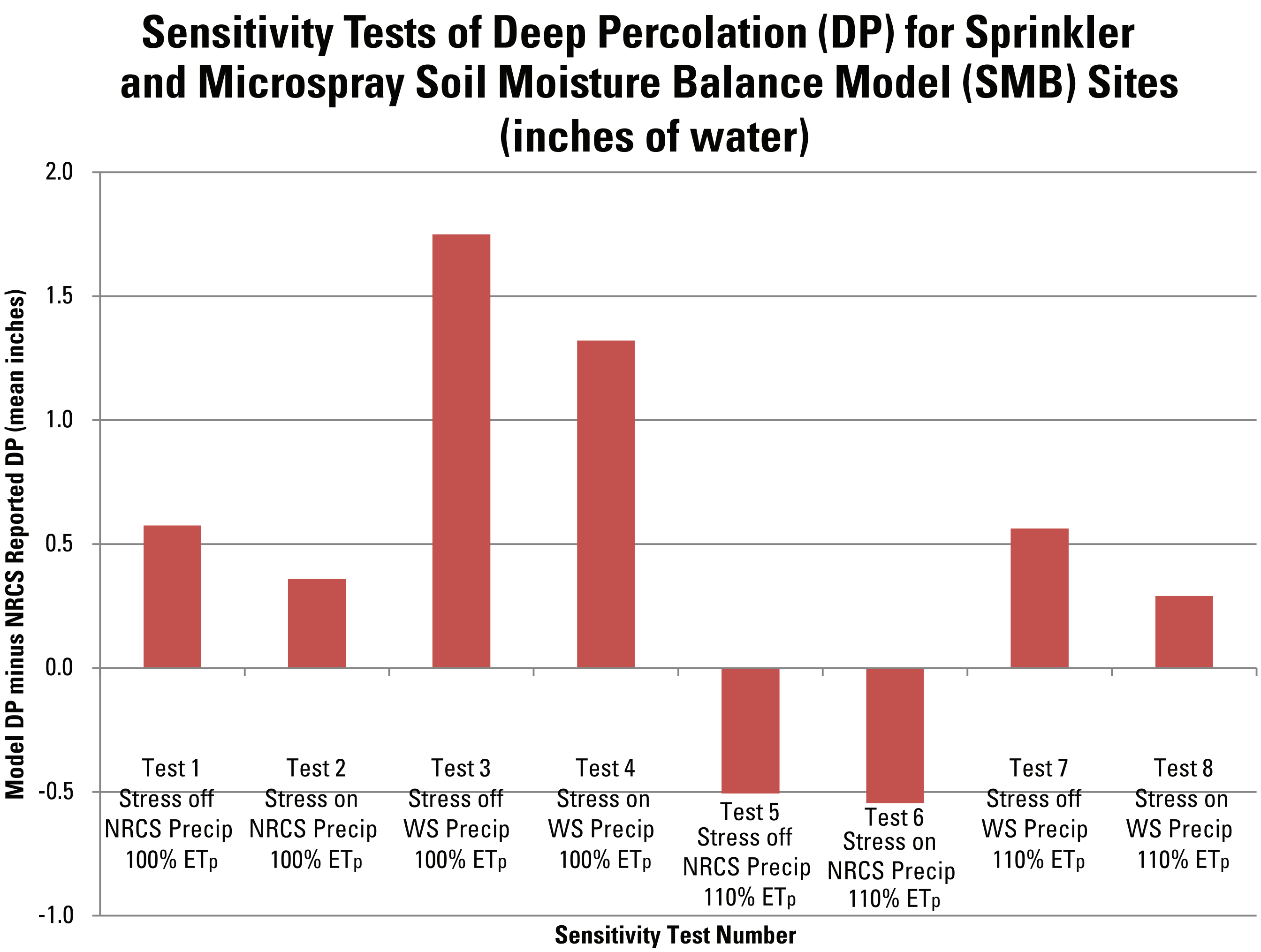


Figure 63. Sensitivity test results for soil moisture balance model deep percolation in inches of water for sprinkler and microspray irrigation system types. [%, relative percent; SMB, soil moisture balance; DP, deep percolation; NRCS, Natural Resources Conservation Service; Precip, precipitation; WS, weather station; ET_p, reference evapotranspiration.]

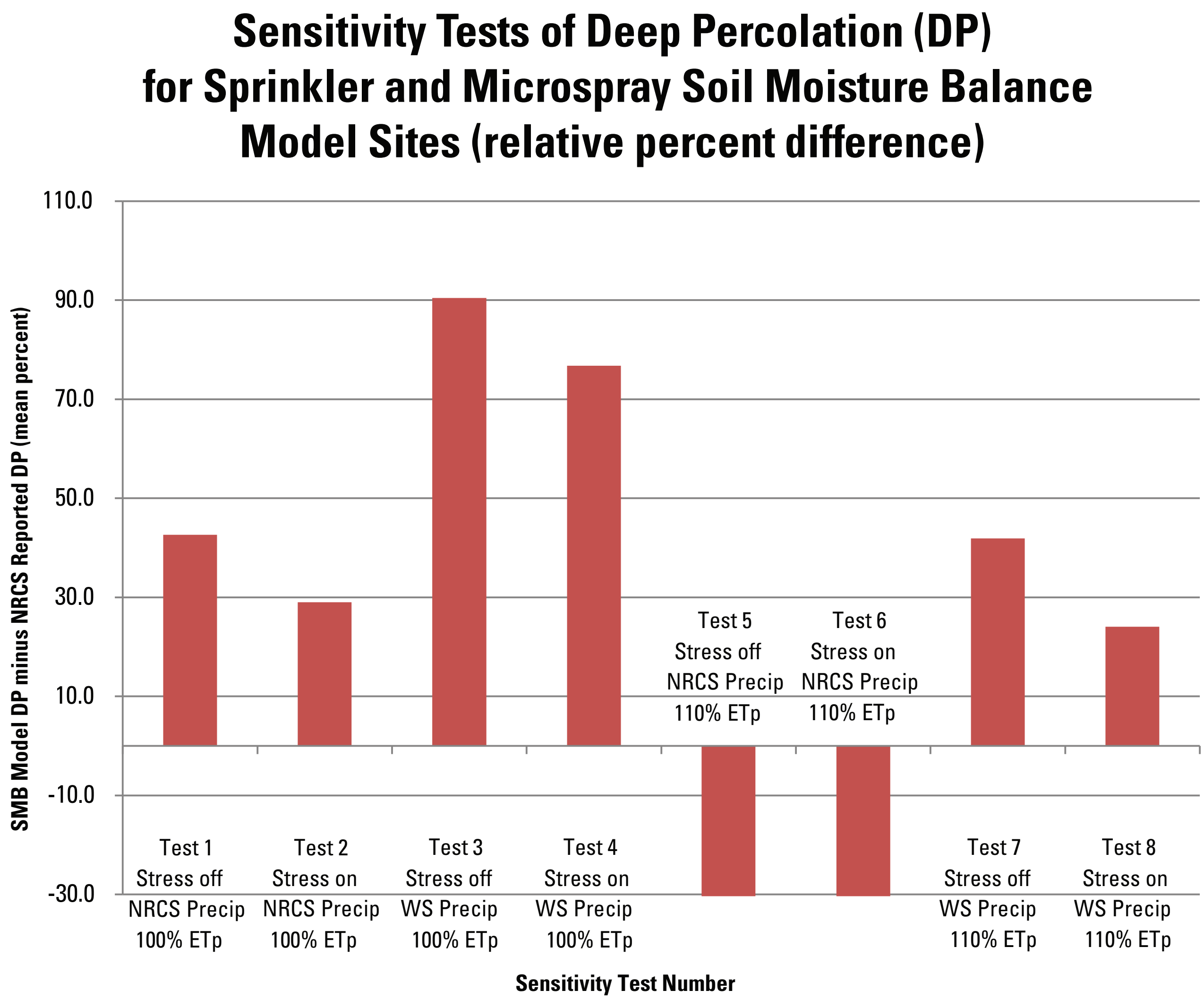


Figure 64. Sensitivity test results for soil moisture balance model deep percolation in relative percent difference for sprinkler and microspray irrigation system types. [%, relative percent; SMB, soil moisture balance; DP, deep percolation; NRCS, Natural Resources Conservation Service; Precip, precipitation; WS, weather station; ET_p, reference evapotranspiration.]

Seasonal Irrigation Efficiency Sensitivity Test Results

SIE is determined in part by the magnitude of DP. SIE is calculated as

$$SIE = (Inflow - Outflow - DP) / Inflow \quad (10)$$

where

SIE is seasonal irrigation efficiency,
Inflow is the amount of water entering a field,
Outflow is the amount of water leaving a field, and
DP is deep percolation of irrigation water downward from the field.

If there are no changes in inflow or outflow, as is the case in the sensitivity tests, a decrease in DP results in an increase to SIE, because DP is subtractive in equation 10.

Flood Irrigation SIE Sensitivity Test Results

Figure 65 shows the flood irrigation sensitivity test results in relative percent difference for SIE. The baseline-fit results (test 1) on the left are for NRCS reported precipitation, crop stress correction setting off, and ET_p at NRCS reported levels. In tests 1 through 4, one can see that there is a difference in SIE between mean NRCS reported flood and mean SMB flood model results of less than 1 percent for model sites. When crop stress correction is turned on (test 2), not much change is evident. When weather station precipitation replaces NRCS reported precipitation (tests 3 and 4), the difference between SMB model and NRCS reported SIE decreases to about 0.5 percent.

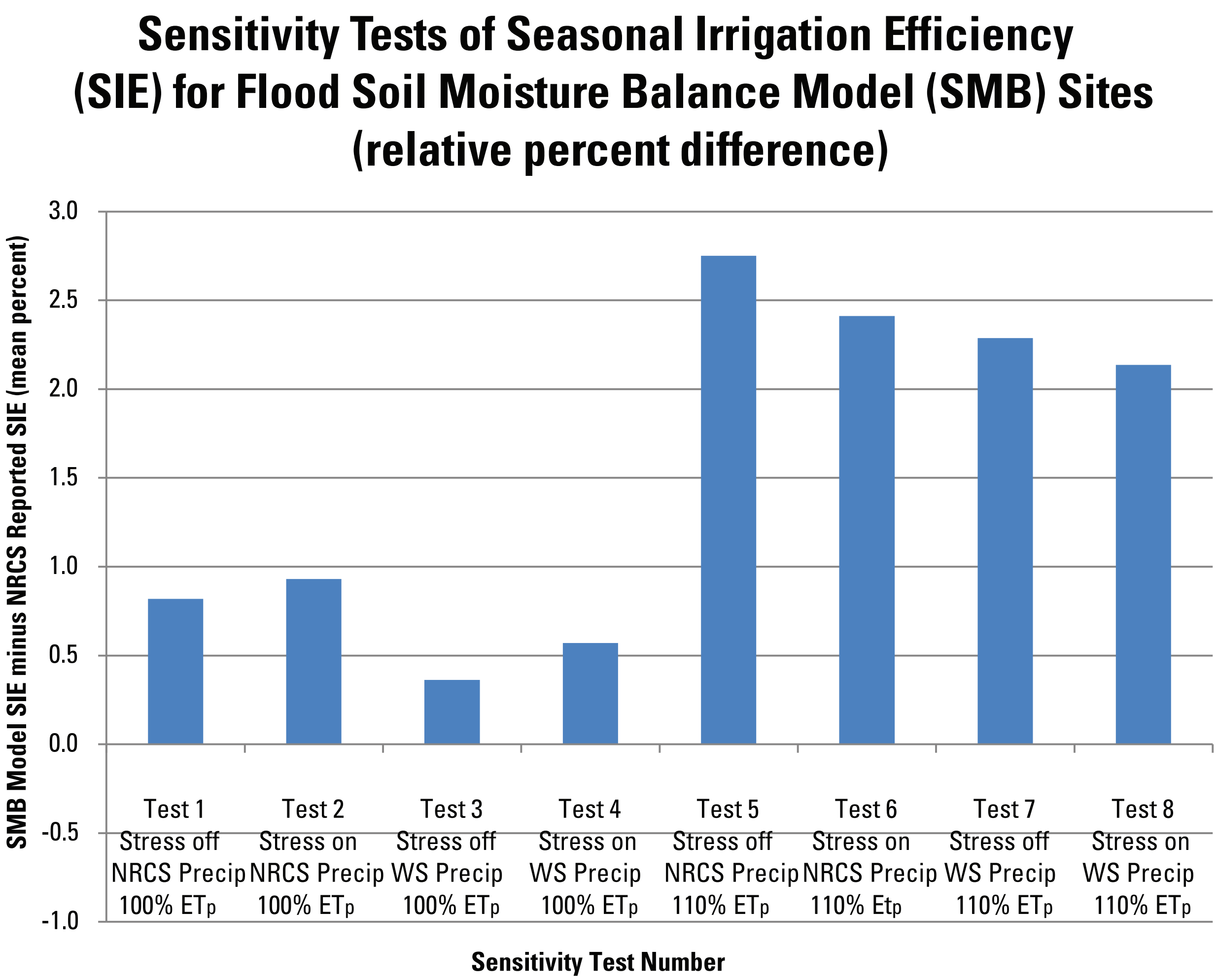


Figure 65. Sensitivity test results for soil moisture balance model seasonal irrigation efficiency in relative percent difference for flood irrigation system types. [%, relative percent; SMB, soil moisture balance; SIE, seasonal irrigation efficiency; NRCS, Natural Resources Conservation Service; Precip, precipitation; WS, weather station; ET_p, reference evapotranspiration.]

The changes seen in tests 5 through 8 (fig. 65) indicate that when ET_p is increased by 10 percent to raise the season total ET_p (ET_p=110 percent) to more closely match 1988 Colorado Irrigation Guide consumptive use values, mean SIE for the seven flood model sites increases in magnitude by about 2 to 2.7 percent. The increases in SIE for flood sites is greatest for NRCS precipitation and crop stress setting off and least for weather station precipitation and crop stress setting on. None of these 8 test results show dramatic differences between SMB model results and NRCS reported results.

Sprinkler and Microspray Irrigation SIE Sensitivity Test Results

Figure 66 shows the sprinkler and microspray sensitivity test results in relative percent difference for SIE. All eight tests show higher SIE for the SMB models when compared with NRCS reported SIE. The differences range from about 1.5 to 3.7 percent. None of the 8 test results show dramatic differences between SMB model results and NRCS reported results.

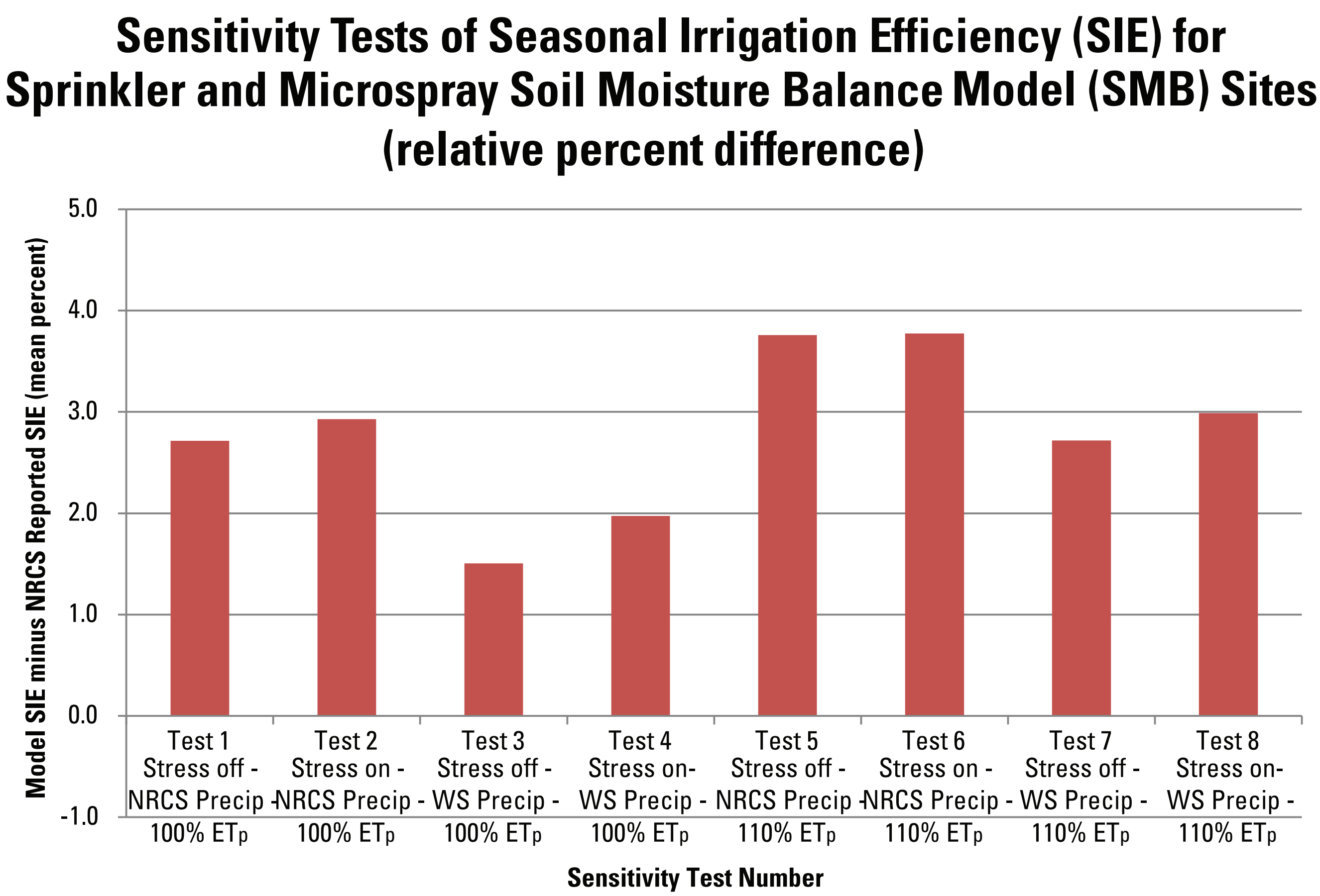


Figure 66. Sensitivity test results for soil moisture balance model seasonal irrigation efficiency in relative percent difference for sprinkler irrigation system types. [%, relative percent; SMB, soil moisture balance; SIE, seasonal irrigation efficiency; NRCS, Natural Resources Conservation Service; Precip, precipitation; WS, weather station; ET_p, reference evapotranspiration.]

Summary Tables of Sensitivity Test Results

Flood Irrigation Sites

Table 33 shows a summary of results for the eight sensitivity tests for mean changes in DP and SIE from NRCS reported values for the seven SMB model flood irrigation sites. The percent difference values in table 33 are relative. In table 33, the results for tests 1 through 4 are combined as mean values, as are the results for tests 5 through 8. Isolating the values for tests 1 through 4 in one group and tests 5 through 8 in a separate group has the effect of ignoring the effects of setting stress correction on or off or selecting different precipitation sources, showing only the effect of setting ET_p to either 100 percent (tests 1 through 4) or 110 percent (tests 5 through 8).

It can be seen in table 33 that there is a small decrease of 2.6 percent (0.5 inches) in DP for flood sites for the sensitivity tests 1 through 4 that keep ET_p at 100 percent of the NRCS reported values. When ET_p is increased to 110 percent to bring the SMB ET_c into closer agreement with 1988 Colorado Irrigation Guide consumptive use values, mean DP decreases by 12.5 percent (2.5 inches). Although a decrease of 2.6 percent (0.5 inches) in DP for tests 1 through 4 is probably not important in an absolute sense, a decrease of 12.5 percent (2.5 inches) in DP for tests 5 through 8 could be meaningful, given the relatively high NRCS reported mean DP of 21.6 inches for the seven SMB model flood sites.

Likewise, test results of SIE for flood sites are combined in table 33 into the same two groups with ET_p at 100 and 110 percent, respectively. Tests 1 through 4 result in a mean increase of SIE of 0.7 percent, whereas tests 5 through 8 result in a mean increase of SIE of 2.4 percent. The 2.4 percent increase in SIE for flood sites with 110 percent ET_p may be of interest to water managers, while the 0.7 percent change resulting from tests 1 through 4 is probably not of interest.

Table 33. Mean sensitivity test results for the seven SMB model flood irrigation sites for deep percolation and seasonal irrigation efficiency.

[%, relative percent; DP, deep percolation; SIE, seasonal irrigation efficiency; SMB, Soil Moisture Balance; precip, precipitation; ET_p, reference evapotranspiration; stress, evapotranspiration stress correction; NRCS, Natural Resources Conservation Service]

Irrigation System Type	Site Variable	NRCS Reported Mean Values for 7 SMB Model Flood Sites	Sensitivity Test Results Grouped by Tests Having Either 100% ET_p Or 110% ET_p With Results in Inches of DP and Percent SIE and (Difference in Test Results from NRCS Reported Mean Values for 7 SMB Model Flood Sites In Inches and Relative Percent Difference)	
			Tests: 1-4 Stress: Any Precip: Any ET_p: 100%	Tests: 5-8 Stress: Any Precip: Any ET_p: 110%
Flood	Deep percolation	21.6 inches	21.0 inches (-0.5 inch, -2.6 %)	19.0 inches (-2.5 inches, -12.5 %)
Flood	Seasonal irrigation efficiency	39.3 %	40.3 % (+0.7 %)	43.2 % (+2.4 %)

Sprinkler and Microspray Irrigation Sites

Table 34 shows a summary of results for the eight sensitivity tests for changes in mean DP and SIE from NRCS reported values for the five SMB model sprinkler and microspray irrigation sites. The percent difference values in table 34 are relative. In table 34, the results for tests 1 through 4 were combined as mean values, as are results for tests 5 through 8. It can be seen in table 34 that the DP results are mixed, with tests 1 through 4 having an increase in DP of 59.7 percent (1.0 inch), while tests 5 through 8 have a decrease in DP of 16.5 percent (0.1 inch). Because the NRCS reported mean DP is only 1.1 inches for these five sites, the DP percentage changes in table 34 for tests 1 through 4 and for tests 5 through 8 appear large; however, neither of the test groups resulted in large changes in the actual amount of DP. In general, sprinkler and microspray systems have very low DP, so changes of an inch or less in DP are not particularly meaningful in the real world.

Test results of SIE for sprinkler and microspray sites are combined in table 34 into the same two groups as for DP. In tests 1 through 4, SIE increases by 2.3 percent, and in tests 5 through 8, SIE increases by 3.3 percent. However, because it has been determined that the decreases in DP shown in table 34 are not meaningful because of the very low mean DP value of 1.1 inches, the 2.3 percent and 3.3 percent changes in SIE should not be considered to be meaningful either.

Table 34. Mean sensitivity test results for the four sprinkler irrigation and one microspray SMB model sites for deep percolation and seasonal irrigation efficiency.

[%, relative percent; DP, deep percolation; SIE, seasonal irrigation efficiency; SMB, soil moisture balance; precip, precipitation; ET_p, reference evapotranspirtion; stress, evapotranspiration stress correction; NRCS, Natural Resources Conservation Service]

Irrigation System Type	Site Variable	NRCS Reported Mean Values for 5 SMB Model Sprinkler & Microspray Sites	Sensitivity Test Results Grouped by Tests Having Either 100% ET_p Or 110% ET_p With Results in Inches of DP and Percent SIE and (Difference in Test Results from NRCS Reported Mean Values for 5 SMB Model Sprinkler and Microspray Sites In Inches and Relative Percent Difference)	
			Tests: 1-4 Stress: Any Precip: Any ET_p: 100%	Tests: 5-8 Stress: Any Precip: Any ET_p: 110%
Sprinkler and microspray	Deep percolation	1.1 inches	2.1 inches (+1.0 inch, 59.7 %)	1.0 inches (-0.1 inch, -16.5 %)
Sprinkler and microspray	Seasonal irrigation efficiency	68.3 %	74.8 % (+2.3 %)	78.0 % (+3.3 %)

Suggested Revisions to NRCS Evaluation Results

Suggested revisions to NRCS evaluation results based on the sensitivity tests for flood and sprinkler irrigation systems are summarized in table 35.

Table 35. Suggested revisions to NRCS evaluation results.

[NRCS, Natural Resources Conservation Service]

Irrigation System Type	Deep Percolation	Seasonal Irrigation Efficiency
Flood	Reduce NRCS reported values by 12.5 relative percent	Increase NRCS reported values by 2.4 relative percent
Sprinkler and Microspray	No change	No change

The suggested revisions in DP and SIE in table 35 for flood irrigation sites may be of interest to water managers who have relied on the NRCS evaluation results over the years for decision making, but only the users of this analysis can determine whether these differences are large enough to warrant a revision of their interpretation of the NRCS evaluation results. There are no suggested changes to sprinkler and microspray results from the NRCS evaluation. Overall, the NRCS evaluation results were found to most likely be as accurate as could have been achieved in such a complex, long-running data collection effort, especially with early versions of computers and automated field equipment. Any discrepancies found in the NRCS evaluation results are important to understand because water managers use results of the NRCS evaluation, along with many other sources, as a baseline to predict the effects of irrigation on salinity in the rivers and to develop salinity control policy. Accurately estimating salt loading from irrigation use is always a challenging task, so increasing the accuracy of baseline data could help in creating better salt loading models. Discussions with NRCS salinity control managers indicate that the cost per ton of salt reduction (which is used for salinity control project planning) would be reduced somewhat if changes in DP and SIE assumptions were implemented (Travis James and Ed Wicker, NRCS, oral commun., August 7, 2013).

The overall implication of less DP and more SIE than reported from the NRCS evaluation would be that the salinity control projects that have been undertaken over the years by NRCS, Reclamation, and the Salinity Control Forum possibly have resulted in a greater amount of salt reduction than had been originally calculated.

Summary

The increasing salinity levels in water delivered to Mexico and the Lower Colorado River Basin States in the early 1970s created concern about economic damages to downstream water users, resulting in the enactment of the Colorado River Basin Salinity Control Act (Salinity Control Act). As part of that effort, the U.S. Department of Agriculture Natural Resources Conservation Service (NRCS) established a program in 1982 to make on-farm irrigation system improvements to reduce deep percolation (DP) and irrigation ditch seepage. In 1982 the NRCS also initiated a monitoring and evaluation study (NRCS evaluation) of irrigation water application practices in the Grand Valley Salinity Control Unit located in western Colorado. One part of the NRCS evaluation was an effort to assess the effectiveness of the NRCS irrigation system improvement program in reducing salt loading in the Colorado River. Salt loading in the river was not directly measured or estimated in the NRCS evaluation. The NRCS evaluation was later extended to the Lower Gunnison Unit in 1992 and the McElmo Creek Unit in 1993.

The NRCS evaluation gathered a total of 287 site-years of irrigation application data at landowner sites in the three Units between 1985 and 2003. The evaluation sites were diverse in terms of crop types, acreage, soil types, and irrigation system types. The results of the evaluation were recorded by NRCS in internal annual reports, and were also shared with the Colorado River Basin Salinity Control Forum (Forum). In 2011, the U.S. Geological Survey (USGS), in cooperation with the Bureau of Reclamation and the Colorado River Basin Salinity Control Forum, began a study to evaluate the NRCS evaluation data to (1) document the methods of the evaluation, and (2) analyze and summarize the data collected during the evaluation. The NRCS gathered the existing physical documents from the evaluation, transferred the raw site data to Microsoft Excel spreadsheets, and assisted the USGS in understanding the dataset. The term “NRCS evaluation” is used throughout this report to refer to the NRCS monitoring and evaluation study, and the term “USGS study” refers to the USGS analysis of the NRCS evaluation.

Irrigation practices in the Grand Valley Unit, the Lower Gunnison Unit, and the McElmo Creek Unit were evaluated by the NRCS in western Colorado. To characterize the methodology of the NRCS evaluation, interviews were conducted by the UGSG study with available current and retired NRCS staff who participated in the NRCS evaluation. To summarize the NRCS evaluation results, the raw data from over 1,800 pages of printed NRCS evaluation annual reports and documentation were entered into two Excel spreadsheets, one for season total results, and one for individual irrigation event results. The entire set of printed NRCS evaluation documents were scanned to an Adobe PDF file. Any information which might lead to personal identification of the evaluation participants was redacted by NRCS from the evaluation documents before scanning. The NRCS field data collection methods were summarized from the results of the interviews and printed documents. The raw irrigation event data were analyzed for quality and rated on the basis of completeness and internal consistency.

The NRCS evaluation sites were selected to represent the variety of crops and irrigation systems common in the evaluation units. Individual irrigation event data were collected, and a water budget was computed for each site. Basic characteristics recorded by the evaluation at the start of the irrigation season for each site included the type of irrigation system, length of field run (feet), field slope (percent), field size (acres), soil type, crop type, planting and harvest dates, specific soil type, and soil water holding capacity. Periodic site data collected during the irrigation season included daily precipitation amount, irrigation event dates and durations, and water inflow to the field and outflow from the field during events. The initial soil water balance was estimated at the beginning of the season, and was also calculated using the water balance method at the start and finish of each irrigation event. Reference evapotranspiration (ET_p) was calculated daily from weather station data. Crop evapotranspiration (ET_c) was estimated using a time-dependent crop coefficient (K_c). DP values were calculated using the infiltrated depth of water from each irrigation event and the initial soil water deficit for each event. Electronic instruments were used to collect inflow and outflow data in the field. Numerous problems were encountered and overcome with the instrumentation.

Potential causes of inaccuracy in field collection results are summarized by the USGS study. Tables are presented that summarize the span of years that each site in the three salinity control units was evaluated.

Geographic information system (GIS) maps of the approximate locations for evaluation sites in the Grand Valley Unit and the Lower Gunnison Unit were generated. No site location data was reported for the McElmo Creek Unit. Bar charts show the distribution of different irrigation system types evaluated over the duration of the evaluation, and scatter plots show examples of the evolution of irrigation technology and crop type changes at two sites.

An improvement order was established to rank the irrigation system types by level of technological sophistication. The soil types originally reported in the evaluation have changed names since the evaluation, and a cross-reference table of original to current soil type names is shown. The quality of data for each site-year record was evaluated based on completeness and internal consistency, which resulted in the creation of several classes of data. Of the 292 total evaluation site-year records, 268 were determined to be usable for analysis, while 225 records from 1985 to 1996 (from all three Salinity Control Units) were determined to be the most complete and consistent of the evaluation records. These records were labeled as gold standard records in this report. Analyses in this report are performed with either all usable records, gold standard records, or both sets.

Summary statistics were generated for each evaluation unit for discrete and continuous site variables. Tables of summary statistics grouped by discrete and continuous variables are shown for each of the three evaluation units. A table of annual mean results for field data for all sites, and for gold standard sites by year and Unit is shown. Frequency charts are shown for irrigation system types, NRCS reported seasonal irrigation efficiency, and NRCS reported deep percolation by evaluation unit. A chart showing frequency of irrigation event duration is shown. Scatter plots with a LOESS curve for deep percolation versus seasonal irrigation efficiency was created for all usable site records and for all gold standard site records. In general, these scatter plots show that DP decreases with increasing seasonal irrigation efficiency (SIE), but the rate of decrease in DP declines above SIE values of about 35 percent. The implication is that as irrigation technology improvements raise SIE, the rate of payoff in decreased DP is smaller for the most advanced irrigation technologies.

Box plots of deep percolation by system improvement order were created for all usable sites and separately for Grand Valley, Lower Gunnison, and McElmo Creek Units. Where enough site-years of data exist (all usable sites and Grand Valley Unit gold standard sites), these box plots show a decline in the variance of deep percolation as system improvement order improves, and reduced median deep percolation for irrigation system types pipeline to gated surge, side-roll sprinkler, and microspray. Similar box plots of seasonal irrigation efficiency by system improvement order show that efficiency increases as system improvement order increases, but the variance in seasonal irrigation efficiency is not reduced. Box plots of deep percolation and seasonal irrigation efficiency by crop type are also presented.

Multiple comparison statistics are shown to explore correlations of irrigation efficiency, deep percolation, crop evapotranspiration, and irrigation water infiltrated depth by discrete categories such as system improvement order, crop type, soil type, evaluation unit, evaluation year, crop rooting depth, and number of irrigation events.

Soil moisture balance (SMB) models were used to test the data collection and data processing assumptions of the reported NRCS evaluation dataset. SMB models were created for 12 gold standard sites selected from the Grand Valley Unit having various evaluation years, crop types, and irrigation system types. An SMB model is a spreadsheet model of the daily sum of water inputs and outputs for an evaluation site for one irrigation season. Per-irrigation-event data are required for the site, as well as daily reference evapotranspiration, ET_p values. Crop and soil characteristics for each site are also considered. Calculated daily soil moisture balances are compared with NRCS reported balances in a soil moisture balance chart.

The various required inputs to SMB models are discussed: reference evapotranspiration (ET_p), crop coefficient (K_c), ET_c stress correction, precipitation, and irrigation event data. The worksheets needed to construct an SMB model are discussed. The elements of the SMB chart are explained, and examples of SMB charts for several different crop types and irrigation system types are discussed. The procedure to produce a “baseline-fit” of the SMB model to the NRCS evaluation results for each site is given, including example charts. A comparison table of baseline-fit results for SMB models and NRCS reported results is shown for precipitation, ET_c, DP, and SIE , and comparison charts for the baseline fit results are shown and discussed.

Potential discrepancies in results between SMB models and NRCS evaluation are listed for quantifiable and non-quantifiable discrepancies. Quantifiable discrepancies which are discussed are precipitation, ET_p, crop consumptive use, ET_c, ET stress correction, and irrigation water application timing. Mean season-total crop consumptive use of irrigation water for all Grand Valley Unit NRCS evaluation sites was found to be about 8.7 percent lower than 1988 Colorado Irrigation Guide published values. Mean annual Grand Valley weather station precipitation from 1985 to 1995 was 7.2 inches, while NRCS reported mean annual precipitation for the same period was only 3.8 inches. Non-quantifiable discrepancies that are discussed include lack of soil water field tests, precipitation data collection changes, DP calculation changes, seasonal irrigation efficiency calculation changes, undocumented data corrections, software problems, and human error.

A sensitivity analysis is described which measures changes in SMB model results with changes in three SMB input variables: (1) source of precipitation data, (2) use of ET_c stress correction or not, and (3) use of NRCS reported ET_p, or increasing reported ET_p by 10 percent to match published consumptive use values. The changes in ET_c, DP, and SIE output variables were measured and reported. Changes in DP and SIE were grouped for flood irrigation systems and sprinkler irrigation systems. All results for sensitivity tests are in relative percent difference. ET_c was found not to increase over baseline-fit levels when precipitation was changed from NRCS reported to Grand Valley weather station sources. ET_c increased by 7.4 percent over baseline when stress correction was switched on, and ET_c increased by 9.3 percent over baseline when ET_p was increased 10 percent to bring ET_c up to published consumptive use values. It would be expected that increasing ET_p by 10 percent should yield a similar increase in ET_c, and this is confirmed by this result.

Separate bar charts (for inches of change and percent change) of DP sensitivity test results for flood irrigation sites and sprinkler and (or) microspray sites show changes in SMB model DP results in comparison to NRCS reported values from the sensitivity tests. Separate bar charts of percent changes in SIE sensitivity results for flood irrigation sites and sprinkler/microspray sites show the changes in SMB model SIE for changes in from the sensitivity tests.

Sensitivity test results for changes in precipitation sources or use of evapotranspiration stress correction were found not to be meaningful in absolute magnitude for both flood and sprinkler sites. Sensitivity test changes resulting from ET_p values of 100 percent of NRCS reported values were also found not to be of meaningful magnitude for both flood and sprinkler sites. Changing ET_p to 110 percent was found to be meaningful for flood irrigation sites, but not for sprinkler and microspray sites.

When ET_p was increased to 110 percent for flood sites to match 1988 Colorado Irrigation Guide crop consumptive use values, the mean DP for flood irrigation SMB model sites decreased by 12.5 relative percent (2.5 inches), and SIE increased 2.4 relative percent when compared with NRCS reported values for the 7 SMB model flood irrigation sites. These suggested changes to NRCS reported values for flood irrigation sites may be of interest to water managers. For sprinkler and microspray sites, the resulting changes in DP and SIE for ET_p values of 110 percent were not judged to be of interest because the reported mean value of DP for sprinkler and microspray sites is quite low to begin with (1.1 inches).

The NRCS evaluation results have been used in past years as part of the basis for estimating reductions in salt loading due to irrigation system improvements, so changes of the magnitude found in this analysis will have to be evaluated by water managers and their organizations to determine whether any change in salt loading baseline calculations are warranted. Lower DP and higher SIE in the calculations for salt loading would suggest that more salt load savings have been achieved than previously estimated using the original reported NRCS evaluation results.

References Cited

Adobe Systems, Inc., 2013, Adobe Reader XI software for Windows: San Jose, Calif., Adobe Systems, Inc.

Allen, R.G., Pereira, L.S., Raes, Dirk, and Smith, Martin, 1998, Crop evapotranspiration—Guidelines for computing crop water requirements—Irrigation and drainage paper 56: Rome, Italy, Food and Agriculture Organization of the United Nations, 290 p.

Colorado River Basin Salinity Control Forum [2013]: Colorado River Basin Salinity Control Forum web site, accessed June 19, 2013, at *http://www.coloradoriversalinity.org/organization.php.*

Colorado State University Colorado Climate Center [2012], Daily data access: Colorado State University web page, accessed June 19, 2012, at *http://ccc.atmos.colostate.edu/dly_form.html.*

Colorado State University Cooperative Extension, 1999, ZETA.wks evapotranspiration spreadsheet.

Colorado State University, 2013, CoAgMet homepage monthly summaries: Colorado State University web page, accessed August 20, 2013, at *http://ccc.atmos.colostate.edu/~coagmet/.*

Colorado Water Conservation Board, 2013, Division of Water Resources, Colorado's Decision Support System (CDSS) All Irrigated Lands: Colorado Water Conservation Board, accessed May 2, 2013, at *http://cdss.state.co.us/Pages/CDSSHome.aspx*.

Delta County Development, Inc., 2013, Delta County Agriculture web page, accessed 5-3-13 at URL *http://www.deltaareadevelopment.org/agriculture.html;* [no longer available].

Duke, Harold, 1987, ed., U.S. Department of Agriculture, 1987, Scheduling irrigations—A guide for improved irrigation water management through proper timing and amount of water application, December 1987, 76 p.

Environmental Systems Research, Inc., 1999–2010, ArcMap, version 10.0: Redlands, Calif., Environmental Systems Research, Inc.

Helsel, D.R., and Hirsch, R.M., 2002, Statistical methods in water resources: U.S. Geological Survey Techniques of Water-Resources Investigations, book 4, chap. A3, 510 p.

Higgins, J.J., 2004, Introduction to modern nonparametric statistics: Pacific Grove, California, Duxbury Press, 384 p.

Kenney, T.A., Gerner, S.J., Buto, S.G., and Spangler, L.E., 2009, Spatially referenced statistical assessment of dissolved-solids load sources and transport in streams of the Upper Colorado River Basin: U.S. Geological Survey Scientific Investigations Report 2009–5007, 50 p. [Available at URL *http://pubs.usgs.gov/sir/2009/5007*.]

Lorenz, D.L., and others, 2011, USGS library for S-PLUS for Windows—Release 4.0: U.S. Geological Survey Open-File Report 2011-1130, [Available at *http://water.usgs.gov/software/S-PLUS/*.]

Magnan, Nick, and Seidl, Andy, 2004, The economic base of Montezuma County, Colorado: Colorado State University, June 2004 EDR 04–02, 35 p., accessed May 3, 2013, at *http://dare.colostate.edu/pubs/EDR/EDR04-02.pdf*.

Mayo, J.W., 2008, Estimating the effects of conversion of agricultural land to urban land on deep percolation of irrigation water in the Grand Valley, western Colorado: U.S. Geological Society Scientific Investigations Report 2008-5086, 58 p.

Microsoft Corporation, 2010, Office 2010 software for Windows: Redmond, Washington, Microsoft Corporation.

TIBCO Software Inc., 1988–2008, Spotfire S-PLUS 8.1 for Windows: Somerville, Mass., TIBCO Software Inc.

U.S. Department of Agriculture, 1982, Monitoring and evaluation plan, Colorado River Basin Salinity Control Program for Grand Valley Unit, Colorado and Uinta Basin Unit, Utah, July 1982: USDA-Soil Conservation Service, 93 p.

U.S. Department of Agriculture, 1986–2003, Grand Valley salinity program monitoring and evaluation annual reports: Grand Junction, Colorado, Soil Conservation Service, Grand Junction Area Office, variously paged.

U.S. Department of Agriculture, 1988, 1988 Colorado Irrigation Guide: U.S. Department of Agriculture, Soil Conservation Service, Denver, Colorado, variously paged.

U.S. Department of Agriculture, 1997, National engineering manual, irrigation guide, Chapter 3 Crop growth characteristics: U.S. Department of Agriculture Natural Resources Conservation Service.

U.S. Department of Agriculture, 2009, Colorado agricultural statistics 2009, National Agricultural Statistics Service, Colorado Field Office, 2008 Preliminary, 2007 Revised: U.S. Department of Agriculture, accessed May 2, 2013, *http://www.nass.usda.gov/Statistics_by_State/Colorado/Publications/Annual_Statistical_Bulletin/bulletin2009.pdf*.

U.S. Department of Agriculture, 2012, Soil Data Mart website: U.S. Department of Agriculture, accessed August 13, 2012, *http://soildatamart.nrcs.usda.gov/*.

U.S. Department of Agriculture, 2013, National Cooperative Soil Survey (NCSS) web soil survey: U.S. Department of Agriculture, accessed June 3, 2013, at *http://websoilsurvey.nrcs.usda.gov/app/*.

U.S. Department of Commerce, 2013, National Oceanic and Atmospheric Administration, National Climate Data Center: U.S. Department of Commerce, accessed May 3, 2013, at *www1.ncdc.noaa.gov*.

Veihmeyer, F.J., and Hendrickson, A.H., 1949, The application of some basic concepts of soil moisture to orchard irrigation: Proceedings of Washington State Horticultural Association, v. 45, p. 25–41.

ISSN 2331-1258 (online)
http://dx.doi.org/10.3133/ofr20141261

NRCS Evaluation Glossary

These definitions are from the 1989 Grand Valley annual report (Grand Valley Annual Report, 1989, *in* U.S. Department of Agriculture, 1986–2003), and were repeated in most of the other annual reports.

Volume of Inflow— The total volume of inflow to the field was measured with electronic flow recorders at most sites or from flow meters located at some sites. The inflows have been converted to an mean depth in inches over the entire field.

Volume of Outflow (runoff)— The total volume of surface outflow from the field was measured with electronic flow recorders and converted to a mean depth in inches over the entire field. For sites with microspray or side-roll sprinkler systems, outflow values were considered to be evaporation losses; 10 and 20 percent respectively of inflow volume.

Infiltrated Depth— The infiltrated depth in inches equals the inflow minus the outflow. This gave the mean amount of water in entering the soil over the entire field.

Precipitation— The precipitation was electronically measured and recorded at the two weather stations. On-site precipitation was also recorded manually at some of the monitored locations.

Potential Evapotranspiration (ET_p)—Potential evapotranspiration was calculated using a modified Penman equation developed by the Agricultural Research Service (ARS) in Fort Collins, Colorado. The measured data parameters included wind run, solar radiation, maximum and minimum temperatures, relative humidity, and precipitation. The calculated ET_p results were calibrated with ET_p results gathered by ARS on the Colorado State University Experimental Farm in the Grand Valley.

Actual Crop Evapotranspiration (ET_a)—Actual evapotranspiration was calculated using the ET_p times a crop coefficient based type of crop and stage of development and stress factor based on days since precipitation or irrigation. The crop coefficient and stress adjustments were supplied by the ARS in Grand Junction and Fort Collins.

Soil Water Deficit (S.W.D.)—The soil water deficit was computed as 1) the measured pre-season S.W.D. plus ET_c minus effective rainfall prior to the first irrigation and 2) post-irrigation S.W.D. plus ET_c minus effective rainfall after the first irrigation.

Deep Percolation (D.P.)—Deep percolation equals the infiltrated water depth minus the soil water deficit in inches at the time of irrigation. The deep percolation was calculated using a computerized water budget program.

Seasonal Irrigation Efficiency—The seasonal/individual irrigation efficiency, expressed as a percentage, equals the volume of inflow minus the volume of outflow minus the deep percolation times one hundred, divided by the volume of inflow.

Appendix 1. Contact Information for Research Access to NRCS Evaluation Data and Instructions for Requests to Access the Data

To protect the privacy of the landowners who participated in the Natural Resources Conservation Service (NRCS) evaluation, all references to personal information have been removed by NRCS from the evaluation data made available to the USGS for this study. The USGS is not able to provide access to the redacted NRCS evaluation data. Independent researchers should apply directly to NRCS for access to these redacted datasets: (1) the NRCS evaluation annual and irrigation event data by site in spreadsheet form, (2) the USGS study analysis and soil moisture balance model spreadsheets, and (3) an Adobe PDF file containing all of the scanned NRCS evaluation annual reports plus supporting documents.

NRCS Instructions for Requests to Access NRCS Evaluation Data

The parties would agree that certain information may be withheld from parties relative to 1619 which stipulates that "Information requested is withheld based on Exemption 3 of the FOIA, 5 U.S.C. 552(b)(3). Exemption 3 permits the government to withhold information in NRCS' records specifically exempted from disclosure by another Federal Statute. In this case, Section 1619 (b) of the Food, Conservation and Energy Act of 2008". NRCS would always be receptive to an individual FOIA request to evaluate what is needed by the given party. FOIA requests should be sent to:

Colorado NRCS FOIA Officer
Denver Federal Center Building 56, Room 2604
P.O. Box 25426
Denver, CO 80225

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Persons with disabilities who require alternative means for communication of program information (e.g., Braille, large print, audiotape, etc. .) should contact USDA's TARGET Center at (202) 720-2600 (voice and TDD).

Appendix 2. Natural Resources Conservation Service (NRCS) Evaluation Software and Data Instructions for NRCS staff

The following document—Colorado River Salinity Control Project Monitoring and Evaluation Programs—was scanned and converted to Microsoft Word for inclusion in this report. The format reflects that of the original document. Conversion errors were corrected to the extent possible; however, some formatting and typographical errors may remain. There is no date given for the document.

COLORADO RIVER SALINITY CONTROL PROJECT MONITORING AND EVALUATION PROGRAMS

INTRODUCTION

The Colorado River Salinity Control {CRSC) Project is an activity of the Soil Conservation Service, U.S. Department of Agriculture, to monitor and evaluate the effects of irrigation on the salinity levels of the Colorado River. The CRSC Project is being carried out in three different areas in Colorado and includes the Grand Valley Unit, the Lower Gunnison Unit and the McElmo Unit.

At all three areas, several sites have been equipped with automated data sensors and loggers that permit the monitoring of both irrigation inflow and outflow. In addition, there are several weather stations that periodically collect and transmit climatological data for crop evapotranspiration (ET) determination.

The Grand Valley Unit has two completely automated weather stations that periodically transmit readings to a recorder located in the Grand Junction Field Office. The Lower Gunnison Unit has a few small weather stations that collect data in chips which have to be manually downloaded in the computer. The McElmo Unit obtains data from the Extension Office. The collected data is then processed by a micro-computer to determine the effectiveness of the applied irrigation. This document describes the Monitoring and Evaluation (M&E) programs that process the information to arrive at the irrigation effectiveness.

There are three discrete functions involved in this process as follows:

1. Collection of data

    a) Collection, transformation and storage of climatological data from weather stations.
    b) Collection and storage of individual site parameters.
    c) Collection of crop and soil texture characteristics.
    d) Collection of irrigation inflow and outflow volumes from individual M&E irrigation sites.

2. Extraction and storage of inflow and outflow volumes from the Omnilogger data storage packs and Datapod storage modules for each monitored site.
3. Development of an irrigation water budget by event for each irrigation site and a seasonal summary for all sites.

Each function and the associated programs are described in the following sections. The program used to perform the function is given in dark capital letters enclosed in parenthesis. Refer to "Program Descriptions" section for the required inputs and resultant outputs for each program.

1. COLLECTION OF DATA

The data required for irrigati0n monitoring and evaluation study comes from three distinct sources: Weather stations, Omnidata Datapod and or Easy Logger recorders or both, and site-related information including crop and soil texture information.

a) Collection, Transformation and Storage of Climatological Data from Weather stations (WSTOEL/RECORDER)

The two weather station sites in the Grand Valley {Orchard Mesa and Highline) each transmit approximately 2 to 4 sets of readings per hour. The readings are transmitted via microwave to the Grand Junction field office AT&T microcomputer used as a recording device which stores the transmitted weather data on 5 1/4 inch diskettes. At periodic intervals (daily from April to September and weekly from October to March) the raw weather data on the diskette, is then transmitted to a AT&T PC6300 computer using the **"TW"** program {See appendix D for downloading and processing of weather data). The raw data is then processed using the **WSTOEL** and **RECORDER** programs to provide the maximum, average, minimum and dew point temperatures; in degrees Fahrenheit; relative humidity; wind run in miles; precipitation in inches; solar radiation in Langley minutes; and the potential Evapo-Transpiration in inches. The **RECORDER** program scans the data and prints a warning message if the interval between readings is over several hours. Additionally, if there are less than 20 readings per day per site, the previous day's readings are projected forward and another warning message is printed.

A utility program, WSRCOUNT, has been developed to count the readings per hour transmitted from the weather stations to the office receiving AT&T computer. It is menu driven.

In the event of a transmission failure, a backup system has been developed utilizing the Easy Logger recorder with a data storage pack (DSP). The readings recorded on the DSP are down-loaded to the CTX computer (monitoring room) using the DUMPEL program (see appendix on how to use this program) and then processed using the RECORDER program to produce the same weather data described above.

In the Lower Gunnison Unit the two weather stations are not automated to send data directly to the office. Omnidata data-pods are used as recording devices to collect and record data on temperature (high/low), and solar radiation. Rainfall data is manually read from precipitation gauge. The microchips are picked up daily and brought to the office to be downloaded on to the CTX computer (monitoring computer) using the DATAPOD program. The downloaded raw weather data is then processed using the RECORDER program as described above.

b) Collection and storage of Site Parameters (SITEDATA)

Each site participating in this project is assigned a unique 2-digit identification number (10 through 99). Associated with that site ID is such information as crops grown; planting, cover, and harvest dates; the closest weather station; soil type and texture; initial soil moisture; number of acres monitored; field slope in percent; soil intake family; length of water run; and weir and gage types. Each site can have up to 2 inflow weirs and gages, up to 3 outflow weirs and gages, 1 inflow reduction weir and gage, 1 outflow reduction weir and gage, and 3 soil moisture probes (currently not being used).

c) Collection of crop (CROPCOEF) and soil Texture (SOILDATA) Data

Information about the crops grown in the Grand Valley is required in order to compute the water usage figures. The items required include the polynomial factors before and after effective cover has been reached, m1n1mum and maximum allowable crop coefficients, rooting depth, days from planting until effective cover is reached, and the management allowed deficit. In addition to the crop data, soils information is also required to calculate the water budget for a site.

Items needed are soil texture, average bulk density, field capacity, wilting point, and the available water holding capacity.

d) Collection of Inflow and outflow Volumes (DATAPOD, LOGGER), by Site

Site inflow/outflow volumes are recorded on either Easy Logger Data Storage Packs(DSP)or Datapod Storage Modules (DSM) depending on the kind of equipment that has been set up. The DSM's contain only one type of data, either inflow or outflow readings. The Easy Logger DSP's can contain several types of information--inflow/outflow and soil moisture probe readings. Currently only the inflow or outflow readings are recorded on the DSP's. Both these values are used in the water budget calculations. However, the Logger program was constructed so that the soil moisture readings can be extracted and saved if needed.

2. EXTRACTION AND STORAGE OF INFLOW/OUTFLOW VOLUME (LOGGER, DATAPOD FOR EACH MONITORED SITE

The DSP's and DSM's used on the Omnidata Easy Logger and Datapod Recording devices are periodically replaced; usually after each irrigation. The data contained in these modules is downloaded and stored on the CTX computer. The information on the Datapod modules is downloaded - directly by the DATAPOD program. The Lower Gunnison and McElmo units go through one more DATAPOD program to download the data. For the Easy Logger packs, the initial extraction is performed by DUMPEL, a communications package. The raw data is then processed by the LOGGER program. The resultant files from both DATAPOD and LOGGER programs are then passed through the EXTRACT program which removes non-significant values and breaks the data into discrete irrigation events.

3. DEVELOPMENT OF WATER BUDGET FOR EACH SITE AND SEASONAL SUMMARIES (CALCIRRG, IRRIGBAL, SITESMRY AND SEASONAL)

After the irrigation events have been isolated into individual files, each event is passed through the **CALCIRRG** program to obtain the volume of inflow/outflow in inches for inflow and outflow sites, the average flow (in cubic feet per second- cfs), and the total irrigation time. The next step is to calculate the water budget by event by site using the **IRRIGBAL** program. The output generated will show the amount of water applied, runoff from the field, crop ET and the resultant soil moisture deficit for the irrigation event. After each irrigation event for a site has been processed, the next action is to request a site summary through the **SITESMRY** program. The final step is to ask for a seasonal summary of all sites after all the data has been processed for the season. This is accomplished by using the **SEASONAL** program.

In addition to the above programs, a utility program called **FILESCAH** has been developed that allows the operator to display and/or modify the water budget information. It is menu driven.

PROGRAM DESCRIPTIONS

More than 16 M&E programs are available to download, process, reduce, and evaluate data (irrigation and weather) collected from the fields. The final data output will show the effectiveness of applied irrigation. Each program used by the three project areas (Grand Valley, Lower Gunnison, and McElmo) is described in a logical flow sequence.

Except where noted, the following conventions are followed:

M&E site ID	A 3-digit'number that uniquely identifies a particular site and data type. The first two digits represent the cooperator's site identifier and can range from 10 through 99. The last digit indicates the type of data under consideration. The data types are: 0-10 Inflow data 2-4 outflow data 5-7 Soil moisture blocks 8 Inflow reduction data 9 Outflow reduction data
Dates	Dates are numeric and must be entered in Month, Day, Year format. Use either a period (.), slash(/), comma(,) or a dash (-) to separate the Month, Day and Year fields.
Clock Time	All times are based on a 24-hour clock and must be entered in Hour:Minute format. Only the colon is acceptable as a separator.

All programs are menu driven and requested input may be in either upper or lower case characters. All programs scan the input data and trap any data that does not meet the developed criteria. In addition, any errors occurring during execution of any program are also trapped and give the operator a choice to either continue execution or to exit to the MS-DOS operating system.

COLLECTION OF DATA

Various data such as weather related, site specific, soil characteristics, crop specific, and irrigation inflow and outflow volumes need to be collected in order to determine irrigation efficiencies and the amount of deep percolation for each monitored site. The programs (right hand column in dark bold letters) being used to collect the different kinds of data are:

Weather related	**DATAPOD, WSTOEL, RECORDER SITE-**
Site Specific	**DATA**
Soil Characteristics	**SOILDATA**
Crop Specific	**CROPCOEF**
Inflow/Outflow Volumes	**DATAPOD, LOGGER**

Each program is described in detail, below.

Weather Related Data:

WSTOEL is the program used in Grand Junction to separate and format the raw weather data to Easy Logger format; usable with the **RECORDER** program. Eight items of raw data are transmitted every 10 to 20 minutes from each weather station via a repeater station. The information is sent to a receiving AT&T micro computer. Periodically (daily or weekly), the data is transferred to another AT&T micro-computer using the **TW** program (see Appendix D for more details). The raw data is processed through the **WSTOEL** program for formatting.

The initial **WSTOEL** menu has 3 options. Respond by entering the appropriate number.

```
1)   Convert Cromemco readings to Easylogger format
2)   Link to another M & E program
3)   Exit to the System

     Your choice?
```

Option 1 solicits the input file name. This is the file name (e.g.

mo.et, fr.et etc.) created when the data was transferred from the receiving AT&T PC6300 computer to the AT&T PC6300 computer used for processing weather data. There are two output files created by this program, WSOM##.WYY for Orchard Mesa station and WSHL##.WYY for Highline Lake station where "##'' is the weather - data transfer number and "YY'' is the last two digits of the year.

Option 2 allows linking to any other M&E program.

Option 3 will exit and return control to the MS-DOS operating system.

The DATAPOD program is used in The Lower Gunnison unit to process raw weather data rather than the WSTOEL program. The raw weather data collected is downloaded using the DATAPOD program which is menu driven. The main menu of the DATAPOD program has five options as follows:

1) Retrieve I/O data from a Datapod
2) Retrieve Weather data from DATAPOD 219
3) Print an existing Datapod file
4) Link to another M&E program
5) Exit to the System

Your choice?

Option 2 needs to be selected for weather data retrieval. When this option is selected, the computer asks for the name of the weather file and the first day on the chip. At this point, the weather data gets transmitted from the DSM (microchip) to the computer through a "reader" and then takes you to the main menu again.

Option 4 needs to be selected to link to the RECORDER program. The downloaded weather data is then processed using the RECORDER program as described below.

The RECORDER program is used to extract, modify and print data collected from the different weather stations. Two at Grand Junction - Orchard Mesa and Highline Lake; and two at Lower Gunnison - Cedaredge and ---------------.

In Grand Junction, the data is then reduced to daily readings for high, low, dew point and average temperatures; relative humidity; wind run in miles; precipitation in inches; solar radiation in Langley minutes; and the Potential Evapo-transpiration in inches (Modified Penman Equation). The calculation for Evapotranspiration were taken from a draft manuscript by H. R. Duke, G. W. Buchleiter and D. F. Heerman, USDA Agricultural Research Service, Fort Collins, Colorado.
In Lower Gunnison, the data collected is reduced to daily

readings for high, low, and average temperatures; solar radiation in Langley minutes; precipitation in inches (read and entered manually); and the potential Evapo-transpiration in inches (Jensen-Hayes Equation). Daily ET is calculated by the software program installed in the Omnidata 219 Datapod used for collection of daily data.

The initial **RECORDER** menu has nine options. The operator responds by entering the appropriate number. The options are:

```
 GJFO ONLY!   1)    Add data to files
              2)    Delete the existing files
 GJFO ONLY!   3)    Discard a portion of the stored data
              4)    List data stored in files
              5)    Modify ETp readings
              6)    Modify Rainfall
              7)    Change Study Year .
              8)    Link to another M&E program
              9)    Exit this program

                    Your choice?
```

Option 1 is used in Grand Junction only. This option solicits the input file name for the weather station selected for data addition. This is the file name created by **WSTOEL** (e.g. “from.et” if Orchard Mesa station has been selected). If an extent is not provided with the file name, the program will append “et”; “et” must be provided as a part of the file name. The computer will then check to see if a partial day’s readings are available in files named “WSHLPART.WYY or WSOMPART.WYY”. If so, this data is appended to the beginning of the file named above and the entire data is processed. If the partial file does not exist, only the named file is processed. If the information for a day is either, missing or there are less than 20 readings, the previous day’s values are projected and a flag is set to show the projections when the data is printed or used by another program. There are two output files either created or modified by this program, ORCHARDM.WYY for the Orchard Mesa site and HIGHLINE.WYY for Highline Lake site; where “YY” is the last two digits of the year.

If Option 2 is used, the computer will ask if you are sure you want to delete the files. If the response is “NO,” the program returns to the main menu. If “YES” is the answer, then the processed weather files e.g. ORCHARDM.WYY and HIGHLINE.WYY (Grand Junction) and CEDAREDG.WYY (Lower Gunnison) are deleted.

The third Option (Grand Junction only) allows selective deleting of daily events. The computer solicits two dates for each weather station. The first is the date to begin deleting or a "S" to begin at the start of the data. The second is the date to stop deleting or an "E" to delete to the end of the file.

Selecting Option 4 (Grand Junction and Lower Gunnison) transfers you to the print portion of the program. The print menu permits the sub-options on the next page to be selected:

1) Potential E.T. by Date
2) Weather Data by Station by Date
3) Maximum Rainfall intensity and Wind Velocity by Date
4) Return to Main Menu

Your choice?

Sub-option 1 lists the potential Evapo-Transpiration by weather station by date.

Sub-option 2 lists the daily information by station by date. Items printed are date, high temperature, average temperature, low temperature, solar radiation, and precipitation for all the weather stations. For the Grand Junction stations, wind run and relative humidity are also listed.

Sub-option 3 will print the maximum hourly precipitation and wind velocity by station by date and the hour these occurred. After the print activity described· above is completed, control is returned to the print menu.

Sub-option 4 will return control to the Main Menu.

Option 5 of the Main Menu permits the selective modification to the potential Evapo-Transpiration values calculated under Option 1. Either those values that were projected from a previous day or for given dates can be updated. If the projected values are selected, then the operator is solicited for a new value for each date that was flagged for the weather stations. If the date option is selected, the name of the weather station is solicited along with the starting date. The program will step through the data date by date, allowing the operator to make the necessary changes. An "E" will return control to the Main Menu.

Option 7 allows changing of study year.

Option 6 allows the rainfall values to be modified. The procedure used is the same as that used under Option 5.

Option 8 allows linking to any of the other M&E programs.

Option 9 will exit the program and return control to the MS-DOS operating system.

In Grand Junction there is an Easy Logger backup system at the two weather stations in case data transmission through the Popcorn telemetry system fails. The Easy Logger collects and stores data in the data storage packs and the data downloaded weekly during the irrigation season. Menus, inputs and outputs are identical with those described under RECORDER. The raw data output from the Easy Logger (using the **DUMPEL** program) is used with **RECORDER**.

Site Specific Data:

SITEDATA program is used to collect and. store site specific information. Note that the program uses only the 2-digit cooperator's farm number when it requests the M&E farm number. Output from SITEDATA program consists of 3 random access files SITEGNRL.IYY SITEWEIR.IYYand SITEIRRG.IYY. The Main Menu display for this program is:

```
1)   Add a new Farm
2)   Update an existing Farm
3)   Delete a Farm
4)   Display Farm(s)
5)   Print Farm(s)
6)   Adj. Farm for next Irrig. Season
7)   Change Study Year
8)   Link to another program
9)   Return to system

     Your choice?
```

Option 1 is used to input information about a new farm. The information requested consists of the following:

1. M&E Farm Number	The cooperator’s unique 2-digit number Enter an “E” to exit to the Main Menu
2. Cooperator’s Name	The land user’s name, maximum 17 characters
3. Weather Station	The weather station nearest to this farm
4. Crop Grown	Crop to be monitored
5. Planting Date	The date that the growing season starts
6. Cover Date	The date when effective cover is reached
7. Harvest Date	Self-explanatory
8. Start SWD (inches)	The starting soil moisture deficit before the first irrigation
9. Field Number	A numeric identifier of field to be monitored
10. Monitored Acres	The number of acres to be monitored
11. Adj. % Cover	Crop cover, single digit number (see appendix ---)
12. Soil Depth	Self-explanatory
13. Total Furrows	Total number of furrows in the monitored field
14. Texture/AWC(in/ft)	Enter either soil texture of the field under study or available water holding capacity in inches per foot
15. Soil Type	Soil type of the monitored field
16. Slope, %	The percent slope of the field in feet per hundred
17. Intake Family	A numeric value related to the soil’s ability to absorb moisture
18. Irrigation system	-- A 3-character abbreviation used to designate the type of irrigation system used (Appendix -- provides codes and descriptions)
19. Length of Run	The average length that irrigation water flows from the inlet to the outlet, in feet
20 to 33. Inflow/Outflow Weir & Gage Types	The numbers assigned to the weir and gage that control and monitor irrigation flows (Appendix -- provides a list of weirs and gages). Additionally, a”?” at the prompt, the 14 weir and 4 gage types are displayed on the screen

Note: Planting/cover/harvest dates are entered automatically when a crop is entered but may be changed manually if desired.

There are two special weir/gage combinations, one for inflow and one for outflow. The "reduction" weirs and gages are used when a portion of the irrigation water exits the system before passing through the entire field.

Option 2 allows data previously entered and saved farm data to be up-dated. The computer asks for the 2-digit farm number. A zero or null entry at this point returns control to the Main Menu. If the entry is a farm number, the information is displayed and the operator is asked to enter the line· number of the item to be updated. This action repeats until a zero or null entry is entered at which time a new M&E farm num-ber is requested and the process is repeated.

Option 3 deletes a non-active farm from the files. The overall procedure is the same as for Option 2 except that after the correct farm number is selected, the operator is asked if it is the requested. If the an-swer is "Yes" then the farm is deleted from the files and a new M&E farm number is requested. Again, a zero or null entry terminates this option and returns control to the Main Menu.

Option 4 displays the farm information on the computer's monitor. The operator is asked if a single farm or all farms are to be displayed and the processing proceeds as directed.

Option 5 is identical to Option 4 except the information is sent to the computer's printer.

Option 6 allows the operator to transfer and adjust site data informa-tion from the previous monitoring season to the next season; saves data input time.

Option 7 lets the operator change the study year.

Option 8 permits the operator to change to another M&E program without going through the system.

Option 9 returns control of the computer to the MS-DOS operating system.

Soil Characteristics Data:

The SOILDATA program allows entry of the necessary data for different soils located within the Grand Valley study area. The only file used in this system is SOILDATA.DAT, a random access file. The spelling of the soil texture must be identical to that given in the SITEDATA program. The Main Menu options are:

```
1)   Add a soils series
2)   List the soil series
3)   Modify an existing series
4)   Delete a series
5)   Link to another M & E program
6)   Exit to the System

     Your choice?
```

Option 1, when selected, will display a screen and request information on item numbers 1 to 5 shown below. Items from 6 through 9 are calculated automatically.

1) Soil Texture	The texture of the soil in the rooting zone
2) Avg. Bulk Density	Mass per unit volume of soil, dried to constant weight
3) Field Cap. % Moist	The maximum amount of moisture thesoil can hold at full capacity, inpercent
4) Wilt. Point % Moist	The capacity at which wilting begins, expressed as a percentage
5) Avail. WHC % Moist	The available water holding capacity of the soil, in percent
6) Wilt. Point/Field cap.	The percent of field capacity at wilting point
7) Field Cap. Inches	Field capacity in inches per foot
8) Wilt. Point inches	Wilting point in inches per foot
9) Avail. WHC inches	Available water holding capacity in inches per foot

When information on items 1 to 5 is obtained, the computer calculates the percent of the field capacity at wilting point (item 6). Next the computer converts the soil moisture percentages into inches per foot and saves the results under items 7, 8, and 9. This process is repeated. To exit back to the Main Menu, enter an “E” for the soil texture.

Option 2 will list the soil texture information on the screen. The operator is asked if the listing is for all soils or for a single one. If “All” is entered, the program displays all the soil textures stored in the computer. Selecting “Single” lists only the requested texture.

Option 3 permits changes to be made to the existing data for a given soil texture. If an “E” is entered when the soil texture is solicited, control returns to the Main Menu. If a valid soil texture is entered then all information relating to that soil is displayed, the operator is then asked for the item number to change. Enter an “E” to end changes and a new soil texture is requested.

Option 4 will delete a soil texture from the file or the whole soildata file. Again, entering an “E’’ for soil texture returns control to the Main Menu.

Option 5 permits a direct link to another program in the M&E series.

Option 6 transfers control to the MS-DOS operating system.

Crop Specific Data:

The CROPCOEF program is used to enter the polynomial constants for basal crop coefficient curves and other crop specific information. The spelling of crop names must be identical with that used in the SITEDATA program. The only file used is a random access file named CROPCOEF.DAT. The Main Menu is as follows:

```
1)   Add a crop record to the file
2)   Display the stored crops
3)   Update an existing crop
4)   Delete an existing crop
5)   Link to another M & E program
6)   Exit to the System

     Your choice?
```

Option 1 is used when it is necessary to add a new crop to the existing file. The information needed is:

1. Crop Name	Crop to be monitored
2. Days to Effective Cover	The number of day from planting to reach effective cover
3. Maximum Kcb	The maximum coefficient that a crop can have
4. Minimum Kcb	The minimum coefficient that a crop can have
5. Rooting Depth	Effective rooting depth
6. Mgt. Allowed Deficit	percentage of available water which can be depleted prior to irrigation - generally 50%
7. 'A' Before Effective Cover	Items 7 to 14 are polynomial constants for use in crop coefficient equation

8. 'B' Before Effective Cover
9. 'C' Before Effective Cover
10.'D' Before Effective Cover
11.'A' After Effective Cover
12.'B' After Effective cover
13.'C' After Effective Cover
14.'D' After Effective Cover

Inflow/Outflow Volume Data:

The **DATAPOD** program being used in all three project areas allows down-loading of raw inflow/outflow data from the microchip to the computer using a “reader”. This program is the same as described earlier under “weather related data”. For inflow/outflow volume data downloading, a different option is chosen from the Main Menu. The main menu options are:

1) Retrieve I/O data from a Datapod
2) Retrieve Weather data from Datapod 219
3) Print an existing Datapod file
4) Link to another M&E program
5) Exit to the System

Your choice?

Option 1 will allow retrieval and transfer of raw inflow/outflow data from a Datapod microchip to the computer. The computer will request the year and the Datapod model being used. The Datapod model (112/312 or 115) needs to be selected from the sub-menu. The computer then solicits information on the three digit site number, and starting date/time of the chip. When the requested information is provided, an 8-digit output file name is created consisting of the 3-digit site ID plus the first month and day pulled from the stored data and the last digit of the year. The extent added to the name is “.iod” (e.g. 13209133.iod- outflow site with starting date of September 13, 1993). After the data has all been retrieved, the control is returned to the main menu.

Option 3 will print the retrieved data. If no data has been retrieved, a file name is requested and the printout is generated. Line numbers are printed for each reading for use in the **EXTRACT** program described in a later paragraph. The data is also plotted.

Option 4 allows the operator to link to another M&E program.

Option 5 will transfer control to the operating system.

The **LOGGER** program is used in Grand Junction only (Lower Gunnison

?). It allows processing of data from an Easy Logger file. The Easy Logger file is created when the **DUMPEL** program is used to retrieve and transfer raw data from an Easy Logger data storage pack to the computer using a “reader”. An 8-digit file name with a “.flo” extent is requested, the first four digit consists of letters and the last four, the month and day the pack was started (e.g. mato0913.flo).

The **LOGGER** program consists of the following menu:

```
1) Process data from Easy Logger file
2) Print stored data
3) Link to another M&E Program
4) Exit to the System

   Your choice?
```

Option 1 will process data from an Easy Logger file. A file name is requested and an Easy Logger file with “.flo” extent needs to be provided (e.g. mato0913.flo). After the file name is entered, the M&E site number and the sensor type are requested. once the site number and sensor type is known,._ an output file name is created consisting of the 3-digit site ID plus the first month and day pulled from the stored- data and the last digit of the year. The extent added to the name is “.IOD” for inflow/outflow sites (1320913.iod- outflow, 1300913.iod - inflow) and “.SMB” for soil moisture blocks. After the data has all been retrieved, control is returned to the Main Menu.

Option 2 will print the stored information. If the previous operation pulled information from the blocks, then a printout is given of that particular file. If no data has been retrieved, a file name is solicited and the printout is generated. Line numbers are printed for each reading for use in the EXTRACT program described in a later paragraph. The data is also plotted if the information is inflow or outflow.

Option 3 Allows the operator to load another M&E program directly.

Option 4 return to the computer’s operating system.

When the inflow and outflow readings have been collected, it is necessary to isolate the values into discrete irrigation events, calculate the inflow or outflow volumes, and produce an irrigation water budget. Three programs are used in this process: EXTRACT, CALCIRRG, and IRRIGBAL.

The EXTRACT program is used to divide the readings into individual irrigation events if there is more than one irrigation event in the input data file (*.iod file) and to extract significant values within an irrigation event. This is accomplished by discarding non-significant readings and saving the usable readings in a new -file. Input files are those having an extent of ".IOD" described earlier in this document. output file names will be identical to the input file names except the extent is changed to ".CL#" where "#" is irrigation event number (e.g. 1320913.cl1).

The Main Menu for the program is:

1) Extract Data for a new site
2) Continue Extraction for this Site
3) Extract Data for a new Event
4) Link to another M&E program
5) Print the Readings
6) Exit to the System

Your choice?

Option 1, when selected, will ask for the M&E Site number and the starting date (MO.DA.YR). The site number is the 3-digit number that reflects inflow or outflow data. The starting date is the date that the DSM module or the DSP pack was installed in the field. This information is used to create the input and output file names. The next data items requested are the line numbers to begin and end extraction. The line numbers are the ones generated during processing through the DATAPOD and/or LOGGER programs. Next, the computer asks if the data needs to be adjusted. If the answer is "No", extraction begins without any further questions. For a "Yes" answer, the operator is asked if it is an adjustment or a replacement. After that query is satisfied, the computer will ask if the adjustment value is to be multiplied or added/subtracted to the readings. The next questions from the computer are for the line numbers to begin and end adjustment and the amount of the adjustment. If the ending adjustment line number is less than the ending extraction line number, the process is repeated. Enter "C" to end this process.

Option 2 is used to add more readings to the output file from the same input file and proceeds as Option 1 with the exception that the input file name is not requested.

Option 3 is used when more than one irrigation event is stored in the same input file. The file name extent, ".CL#", where "#" is the event number, is incremented by 1 and processing continues as described in Option 1.

Option 4 will link to another M&E program.

Option 5 will print the extracted readings (with a digital plot) Option 6 will transfer control to the operating system. After the proper readings have been extracted, the next required step is to compute the volumes and flows for each irrigation event. The program CALCIRRG performs this function. The Main Menu is on the next page:

1. Calculate flow for a Site
2. Calculate flow for another Event
3. Change Study Year
4. Link to another M&E program
5. Exit to the System

Your choice?

Option 1 requests the following information:

1) M&E Site Number	The 3-digit site ID number
2) Seasonal Irrigation Number	The sequential number of this irrigation, starting with 1 for the season's first irrigation and incrementing by one for each additional irrigation.
3) Calculate or Enter amount	Tells the computer if the flow is to be computed from stored data or will be entered through the keyboard.
4) Starting Date (MO.DA.YR)	The date that the module was installed in the field or the date inflow or outflow started if data is to be entered.

Note: The following queries are displayed only if "Enter" in item *#3* was selected

5) starting Time (HR.MN)	The time, Based on a 24- hour clock, that the inflow or outflow began. Note that a period may be used to separate the hours and minutes.

6)	Ending Date (MO.DA.YR)	The day that inflow or outflow ceased.
7)	Ending Time (HR.MN)	The time inflow or outflow stopped.
8)	Acre inches or Cfs	The type of information to be entered.
9)	Enter the amount	Enter the number in acre inches or flow in CFS
10)	Total Flow Hours	Enter the number of hours that flow actually occurred.

After the above information is entered, the computer asks if the data is okay. The operator now has the option of changing any of the line information by responding "No", giving the line number in error when asked and entering the new value. This will repeat until a "Yes" response is given to the question.

After a "Yes" is given, the computer wants to know if a printout is required for irrigation volume estimates. Answer "Yes" or "No". If the response is "Yes," the operator is then asked if all the information should be printed or only the results. Answer according to needs. The computer now calculates the volume and flows. After it has finished calculating, it then asks if the volume is to be modified. If "No", the values are saved and printed as is. If "Yes", the adjustment value is requested and is algebraically added to the volume.

If the values have been manually entered, a summary printout is always given.

The computed volumes and flows are saved in a random access file named "XXWATERB.BYY" where "XX" is the 2-digit site identifier and "YY" is the last two digits of the current year (e.g. 13WATERB.B93). In addition, the program uses two of the 3 site data files, SITEGNRL.IYY" and "SITE-WEIR.IYY".

Option 2 gives the user the option to continue calculations for another seasonal irrigation event if more than one event was extracted from the stored data (see EXTRACT program). Option 2 cannot be used if the information was entered manually.

Option 3 links to another M&E program. Option 4 returns control to the system.

After all the irrigation events have been reduced to total volumes, the

next step is to run the data through the irrigation water balance program IRRIGBAL. The Main Menu for this program
is:

```
1)   Calculate Water Balance for a Farm
2)   Print an additional Water Balance for a Farm
3)   Link to another M & E program
4)   Change the study year
5)   Exit to the System

     Your Choice?
```

Option 1 asks for an M&E site number. Enter the 2-digit site identifier and the water balance will run any irrigation event not previously run. Input files used in this program are the “SOILDATA.DAT”, ”CROPCOEF.DAT”, “SITEGNRL.IYY”, one of the two weather station files, “JIGHLINE.WYY” or “ORCHARDM.WYY”, and “XXWATERB.BYY”. The output file is an updated version of “XXWATERB.BYY”.

Note: If the crop grown is “small grain, winter” and the current date is after August lst, the computer will ask if this run is for the current year or for next year.

Option 2 allows printing water balances for sites already processed when extra copies are needed.

Option 3 links to another M&E program.

Option 4 allows the operator to change the study year

Option 5 exits to the system.

The next step is to use the SITESMRY program. This program will print individual site summary data for each irrigation event that has been processed.

The SITESMRY program is menu driven. program is:

The Main Menu for this

```
1) Print the Summary Report for a Farm
2) Print the Brief Report for a Farm
2) Link to another M&E program
3) Exit to System
```

If Option 1 is selected, the 2-digit M&E site identifier is solicited and a summarized printout is given of all irrigation events processed for that site. Two input files are required by this program. They are "SITEIRRG.IYY", created by the program SITEDATA, and "XXWATERB.BYY" as described previously. A summary output file is created or updated for use with the program SEASONAL and is named "SITESMRY.SYY", where "YY" is the last 2 digits of the current year. At the conclusion of the print, control returns to the Main Menu.

Option 2 gives the option of printing a brief simple report instead of the detailed provided by Option 1. This report is primarily for farmer use and distribution.

Option 3 permits direct linking with another M&E program. Option 4 returns control to the System. The last step in this whole M&E process is to go through the **SEASONAL** program. This needs to be used only at the end of the year after all the data is processed and adjusted. The program SEASONAL is used to print a seasonal summary of selected information extracted by the program SITESMRY and saved in file "SITESMRY.SYY". The Main Menu for this program is:

1) Print the Seasonal Report
2) Change study Year
3) Link to another M&E program
4) Exit to System

Your choice?

Option 1 prints the requested report and returns control to the Main Menu. Several different reports can be produced using the sub-menu under this option. The sub-menu is as follows:

1) Report All Sites
2) Report by Crop and Surface Irrigation
3) Report by Crop and Sprinkler irrigation
4) Report by crop and both Irrigation Types
5) Report by surface Irrigation
6) Report by Sprinkler Irrigation
7) Return to Main Menu

Your choice?

Option 2 of the Main Menu allows the operator to change the study year

Option 3 links to any other M&E program. Option 4 exits to the system.

Note:There is no output file created by the SEASONAL program.

Appendix A

Types of Irrigation Systems
(For Input in Sitedata Files)

	Code	Description
1.	EDF	Earth Ditch to Feeder Ditch
2.	EDS	Earth Ditch to Siphon Tubes
3.	CDF	Concrete Ditch to Feeder Ditch
4.	CDS	Concrete Ditch to Siphon Tubes
5.	COG	Concrete Ditch to Gated Pipe
6.	COP	Ported Concrete Ditch
7.	SGC	Skate Gate concrete Ditch
8.	PFD	Pipeline to Feeder Ditch
9.	PGP	Pipeline to Gated Pipe
10.	GPP	Gated Pipe (includes Flextube)
11.	CBG	Cablegation
12.	TOR	Tubing Drip
13.	EDR	Emitter Drip
14.	MIS	Microspray
15.	SBD	Subsurface Drip
16.	HMS	Hand Move Sprinkler
17.	SRS	Sideroll Sprinkler
18.	CPS	Center Pivot Sprinkler
19.	SSS	Solid Set Sprinkler
20.	CGS	Concrete Ditch to Gated Pipe (Surge)
21.	PCS	Ported Concrete Ditch (Surge)
22.	PGS	Pipeline to Gated Pipe (Surge)
23.	GPS	Gated Pipe (Surge)
22.		(Reserved)
23.		(Reserved)
24.		(Reserved)
25.		(Reserved)

Appendix B

Weir and Gage Types for Input in Sitedata Files

No.	Weir Type
1.	12 inch Broadcrested
2.	18 inch Broadcrested
3.	6 inch Parshall
4.	9 inch- Parshall
5.	8 inch Cutthroat
6.	12 inch Cutthroat
7.	18 inch cutthroat
8.	12 inch Rectangular
9.	12 inch Trapezoidal
10.	8 inch Magnetic Flow Meter
11.	10 inch Magnetic Flow Meter
12.	Flowmeter
13.	36 inch S.C. Rectangular
14.	24 inch Rectangular

No. Gage -Type-

1. Linear Flow Sensor
2. R/H pressure Transducer
3. Potentiometer - Float Sensor
4. Magnetic Flow Meter

M & E PROGRAMS

Condensed Description)

1. CROPCOEF Input or change crop data
2. SOILDATA Input or change soil data
3. SITEDATA Input or change field data
4. RECORDER Process weather data - calculate E.T.
5. DATAPOD Download and plot: DSM data
6. DUMPEL Download Easylogger data from DSP
7. LOGGER Process DSP data - plot if weir site
8. EXTRACT Extract only the useable data
9. CALCIRRG Calculate the flow volume
10. IRRIGBAL Calculate the soil moisture balance and C.U.
11. FILESCAN View or change the processed data
12. SITESMRY Summarize the seasonal data for a field
13. SEASONAL Report-seasonal data for all fields
14. WSTOEL Convert Cromemco data to Easylogger format
15. WSRCOUNT Count readings *I* hour from raw weather data
16. GETWETHR Receive weather data from Popcorn receiver to AT&T computer (receiving)
17. TW Transfer/receive raw data to AT&T PC6300 computer
18. ARSSCS Run ET for all crops after processing weather data

Programs have EXE or BAS extension

M & E FILES

All M&E programs and data files (input and output) need to be backed-up initially and then whenever changes are made. The following files are created when different programs are used:

CROPCOEF.DAT   Output from Cropcoef

SOILDATA.DAT - Output from Soildata

SITEGNRL.IYY
SITEWEIR.IYY - Output from Sitedata
SITEIRRG.IYY

WSS##.DAT - Output from GETWETHR on computer receiving the raw data

WS###.WYY - Output from TW program

EL   ###.WYY - Output from WSTOEL

WS   PART.WYY
HIGHLINE.WYY - Output from RECORDER
ORCHARDM.WYY

##---.IOD - Output from DATAPOD and LOGGER

##---.SMB - soil moisture output from LOGGER

(1st 4 LETTERS)(IRR.NO).FLO- Output from DUMPEL

(for weir or SM)

##---.CL# - Output from EXTRACT

##WATERB.BYY - Output from CALCIRRG

##WATERB.BYY- Output from IRRIGBAL

##WATERB.BYY - View data from Calcirrg and Irrigbal

SITESMRY.SYY - Output from Sitesmry

Note: “YY” - Last two digits of year
SEASONAL and WSRCOUNT programs produce hardcopies only - no files

Appendix C

Sitedata File Data Entry

Crop	Root Depth (ft.)
Alfalfa	6
Beans	3
Corn	4
Pasture	3
Vegetable	3
Potato	3
Fall Grain(F)	2
Spring s Grain	3
Sugarbeets	3
orchard	6
Grapes	4
Corn Silage	4
Fall Grain{S}	3
Onions	2
Soybeans	4

When entering the starting soil water deficit (SWD) for a crop in the SITEDATA program file, it must be the estimated water deficit for the total root depth profile. Use the above root depths for this purpose as they are installed in the program. In instances where soil is the limiting factor then rooting depth would be the same as the soil depth and soil moisture deficit would be based on this depth.

COVER ADJUSTMENT

Menu item #11 Adj. % Cover (one digit number)
Enter 0 = 100% cover (normal) if mature crop expected to have full cover
Enter # = # (#*10 = % full cover) e.g. 7 = 70% of full value

Recommendations:

Use #8 = 80% cover for first year alfalfa
Use #*O* = 100% cover for annual crops and most perennial crops after first year of establishment

For orchards, use # based on percent canopy cover and cover crop. Measure actual canopy cover in field. Follow the recommendations provided on the next page:

Orchard	With Cover	Without Cover
>70% canopy	# = 0	# = 0
70% canopy	# = 0	# = 9
60% canopy	# = 9	# = 8
50% canopy	# = 8	# = 7
40% canopy	# = 7	# = 6
Young trees	# = 7	# = 5

Cover value numbers affect crop ET estimates. An “O” will estimate full ET for the crop; numbers less than a “O” will estimate lower ET.

Appendix 3. Additional NRCS Evaluation Summary Statistics

The report section “Summary Statistics and Charts of Natural Resources Conservation Service (NRCS) Evaluation” includes NRCS evaluation summary statistics for all gold standard NRCS evaluation sites. Summary statistics are shown here for all usable sites and for all nongold standard sites.

Table 3-1. Discrete variable summary statistics for all usable records collected between 1985 and 2003 in Natural Resources Conservation Service evaluation.

[GV, Grand Valley; LG, Lower Gunnison Basin; ME, McElmo Creek Basin; EDF, earth ditch to feeder tube; EDS, earth ditch to siphon tube; CDV, concrete ditch to various distribution methods; PCS, ported concrete ditch to surge; CGS, concrete ditch to gated pipe surge; GPP, gated pipe; PGS, pipeline to gated surge; SRS, side-roll sprinkler; MIS, microspray.]

Number of Usable Site-Year Records by Evaluation Unit	Number of Site-Year Records with Irrigation Event Data	Number of Site-Year Records by Irrigation System Type Codes	Number of Site-Year Records by Crop Type	Number of Site-Year Records by Irrigation System Type	Number of Site-Year Records by Irrigation Flow Type	Number of Site-Year Records by Irrigation Distribution Type
GV: 211	No: 35	EDF: 4	Alfalfa: 88	Flood: 235	Feeder ditch: 4	Concrete ditch: 99
LG: 51	Yes: 223	EDS: 9	Barley: 1	Microspray: 10	Gated pipe: 80	Ditch: 1
ME: 6		CDV: 92	Beans: 20	Sprinkler: 23	Gated pipe surge: 49	Earth ditch: 13
		PCS: 3	Corn: 62		Ported: 7	Pipeline: 155
		CGS: 4	Fall grain: 25		Ported surge: 3	
		GPP: 77	Grain: 3		Side-roll: 23	
		PGS: 46	Grapes: 10		Siphon tube: 91	
		SRS: 23	Kenafe: 1		Spray: 10	
		MIS: 10	Lettuce: 2		Surge: 1	
			Oats: 2			
			Onions: 6			
			Orchard: 36			
			Pasture: 3			
			Spelt: 1			
			Spring grain: 1			
			Sweet corn: 2			
			Vegetable: 3			
			Wheat: 2			
Total: 268						

Table 3-2. Continuous variable summary statistics for all usable records in all evaluation units collected between 1985 and 2003 in Natural Resources Conservation Service evaluation.

[All water quantities are in inches; N, number of records; Std Dev, standard deviation; NA, not applicable]

Statistic	Field Size	Number of Irrigation Events	Volume Irrigation Water Inflow	Volume Irrigation Water Outflow	Infiltrated Irrigation Water Depth	Precipitation	Evapo-transpiration	Deep Percolation	Seasonal Irrigation Efficiency
Minimum	1.4	2.0	11.4	0	3.7	0.4	2.2	0	13.0
1st Quartile	7.0	6.0	39.6	8.6	27.3	2.2	20.3	4.5	33.9
Mean	20.4	7.7	55.9	17.0	38.9	3.5	26.0	14.8	47.6
Median	15.0	7.0	53.6	14.9	37.6	2.8	25.2	12.8	45.0
3rd Quartile	26.0	9.0	70.5	22.7	48.8	4.3	33.3	20.2	60.0
Maximum	327.3	22.0	123.0	80.1	87.9	11.8	41.3	70.7	97.8
Total N	268	268	268	268	268	268	268	268	268
NA	0	0	0	0	0	39	0	0	0
Std Dev	27.7	3.4	22.2	12.04	15.6	2.2	8.06	12.8	17.9

Table 3-3. Discrete variable summary statistics for all nongold standard records, whether usable or not, collected between 1985 and 2003 in Natural Resources Conservation Service evaluation.

[GV, Grand Valley; LG, Lower Gunnison Basin; ME, McElmo Creek Basin; EDF, earth ditch to feeder tube; EDS, earth ditch to siphon tube; CDV, concrete ditch to various distribution methods; PCS, ported concrete ditch to surge; CGS, concrete ditch to gated pipe surge; GPP, gated pipe; PGS, pipeline to gated surge; SRS, side-roll sprinkler; MIS, microspray.]

Number of Usable Site-Year Records by Evaluation Unit	Number of Site-Year Records with Irrigation Event Data	Number of Site-Year Records by Irrigation System Type Codes	Number of Site-Year Records by Crop Type	Number of Site-Year Records by Irrigation System Type	Number of Site-Year Records by Irrigation Flow Type	Number of Site-Year Records by Irrigation Distribution Type
GV: 15	No: 0	EDF: 0	Alfalfa: 15	Flood: 39	Feeder Ditch: 0	Concrete ditch: 11
LG: 24	Yes: 39	EDS: 0	Barley: 1	Microspray: 0	Gated Pipe: 19	Ditch: 0
ME: 0		CDV: 11	Beans: 8	Sprinkler: 0	Gated pipe surge: 8	Earth Ditch: 0
		PCS: 0	Corn: 5		Ported: 0	Pipeline: 28
		CGS: 0	Fall Grain: 0		Ported Surge: 0	
		GPP: 19	Grain: 0		Side-roll: 0	
		PGS: 9	Grapes: 0		Siphon tube: 11	
		SRS: 0	Kenafe: 1		Spray: 0	
		MIS: 0	Lettuce: 2		Surge: 1	
			Oats: 2			
			Onions: 0			
			Orchard: 0			
			Pasture: 0			
			Spelt: 1			
			Spring Grain: 0			
			Sweet Corn: 2			
			Vegetable: 0			
			Wheat: 2			
Total: 39						

Table 3-4. Continuous variable summary statistics for all nongold standard records, whether usable or not, collected between 1985 and 2003 in Natural Resources Conservation Service evaluation.

[All water quantities are in inches; N, number of records; Std Dev, standard deviation; NA, not applicable]

Statistic	Field Size	Number of Irrigation Events	Volume Irrigation Water Inflow	Volume Irrigation Water Outflow	Infiltrated Irrigation Water Depth	Precipitation	Evapo-transpiration	Deep Percolation	Seasonal Irrigation Efficiency
Minimum	2.0	4.0	20.0	4.3	11.3	NA	NA	0.2	30.1
1st Quartile	7.5	6.0	45.5	10.9	33.7	NA	NA	5.4	42.6
Mean	18.2	7.2	59.4	18.2	41.2	NA	NA	12.9	51.3
Median	15	7.0	56.9	14.6	40.6	NA	NA	11.9	52.3
3rd Quartile	30.2	8.0	71.2	21.9	50.4	NA	NA	19.0	59.4
Maximum	37	12	111.4	54.1	83.9	NA	NA	39.0	81.7
Total N	39	39	39	39	39	39	39	39	39
NA	0	9	0	0	0	39	39	0	0
Std Dev	1.1	2.1	22.2	11.6	15.7	NA	NA	9.2	11.8

Appendix 4. Additional Box Plot Charts

The report section “Deep Percolation versus Seasonal Irrigation Efficiency” includes box plots of deep percolation and seasonal irrigation efficiency grouped by irrigation system improvement order and by crop type. This appendix shows additional box plots of deep percolation and seasonal irrigation efficiency grouped by soil type and by crop rooting depth; crop evapotranspiration by soil type, by crop rooting depth, and by irrigation system improvement order; and water infiltrated depth grouped by soil type and by irrigation system improvement order.

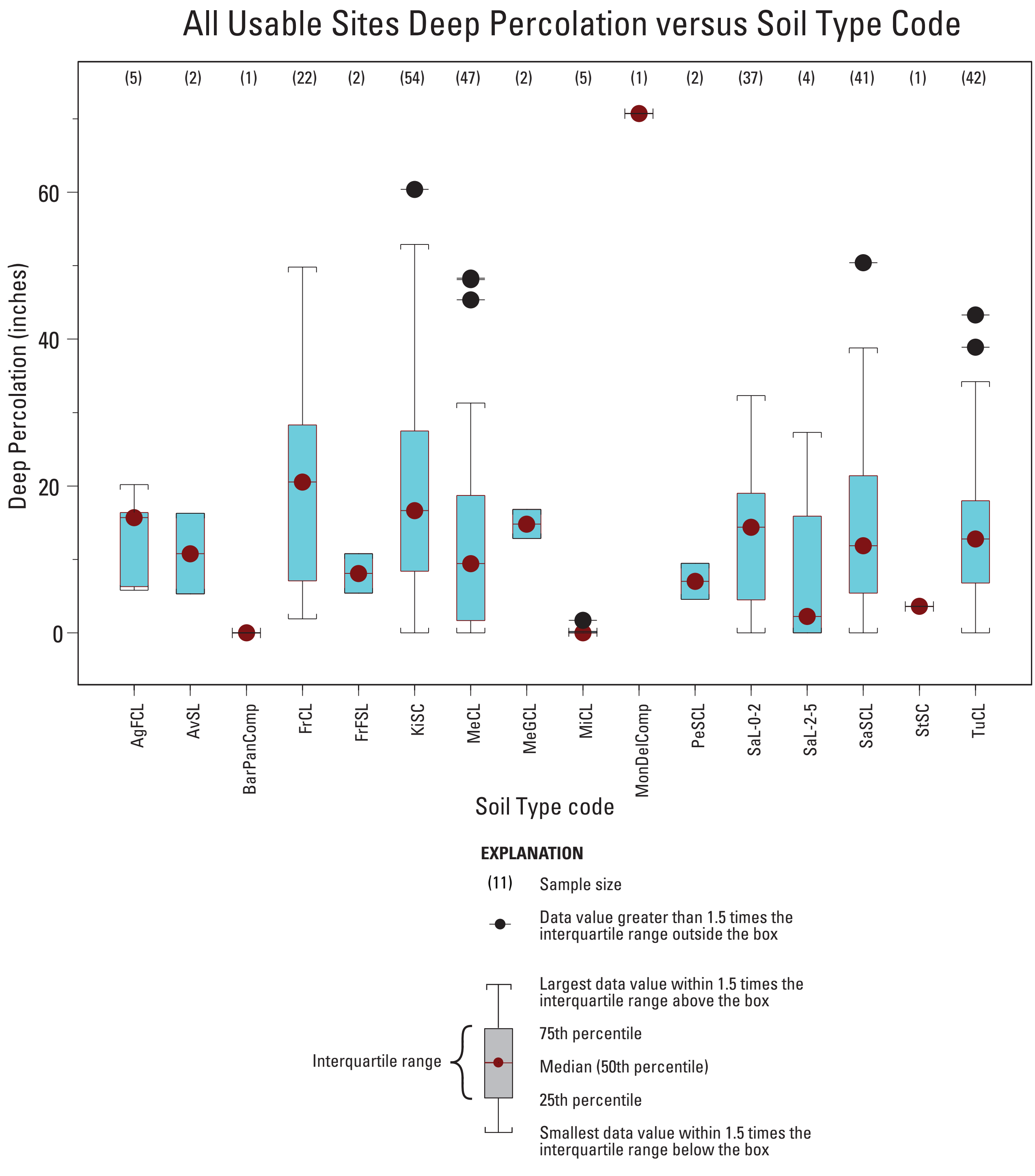


Figure 4-1. Box plot of deep percolation by soil type[1] for all usable evaluation site-years. [[1]AgFCL, Agua Fria clay loam; AvSL, Avalon sandy loam; BarPanComp, Barx-Panitchen complex; FrCL, Fruita clay loam; KiSC, Killpack silty clay; MeCL, Mesa clay loam; MiCL, Mikim clay loam; SaL-0-2, Sagerlite loam, 0-2 percent slope; SaL-2-5, Sagerlite loam, slope 2-5 percent; SaSCL, Sagers silty clay loam; TuCL, Turley clay loam.]

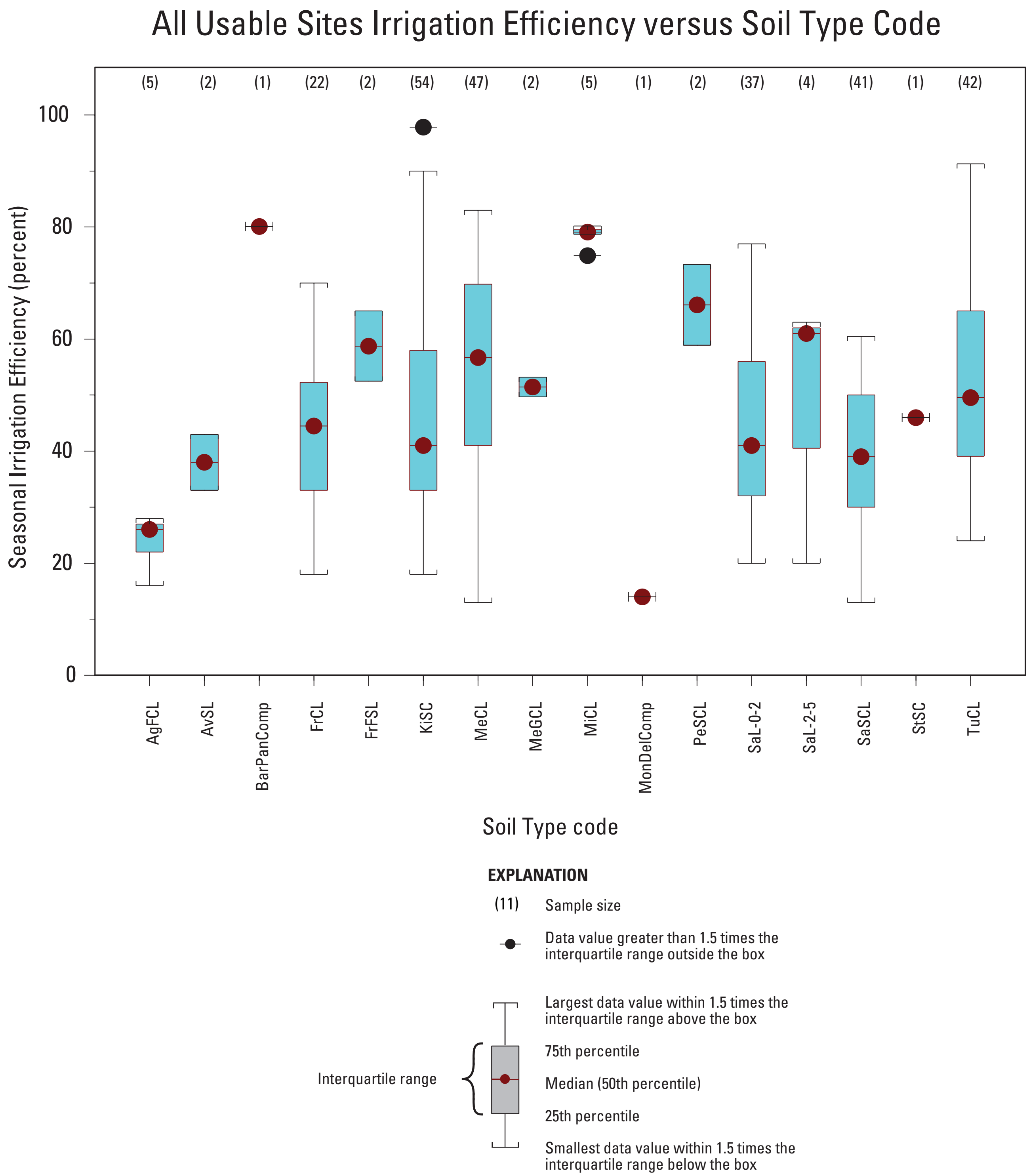


Figure 4-2. Box plot of seasonal irrigation efficiency by soil type[1] for all usable evaluation site-years. [[1]AgFCL, Agua Fria clay loam; AvSL, Avalon sandy loam; BarPanComp, Barx-Panitchen complex; FrCL, Fruita clay loam; KiSC, Killpack silty clay; MeCL, Mesa clay loam; MiCL, Mikim clay loam; SaL-0-2, Sagerlite loam, 0-2 percent slope; SaL-2-5, Sagerlite loam, slope 2-5 percent; SaSCL, Sagers silty clay loam; TuCL, Turley clay loam.]

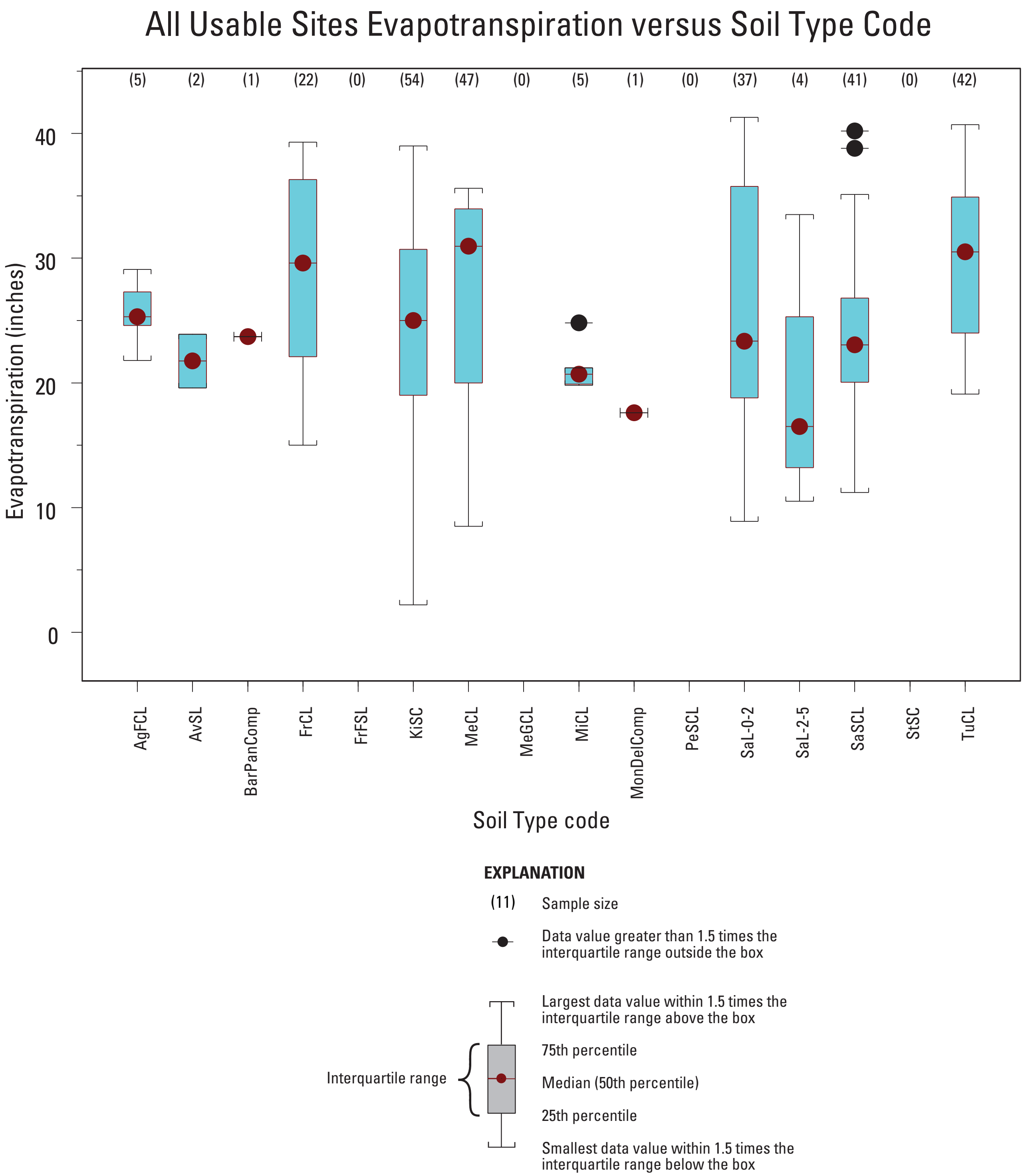


Figure 4-3. Box plot of crop evapotranspiration by soil type[1] for all usable evaluation site-years. [[1]AgFCL, Agua Fria clay loam; AvSL, Avalon sandy loam; BarPanComp, Barx-Panitchen complex; FrCL, Fruita clay loam; KiSC, Killpack silty clay; MeCL, Mesa clay loam; MiCL, Mikim clay loam; SaL-0-2, Sagerlite loam, 0-2 percent slope; SaL-2-5, Sagerlite loam, slope 2-5 percent; SaSCL, Sagers silty clay loam; TuCL, Turley clay loam.]

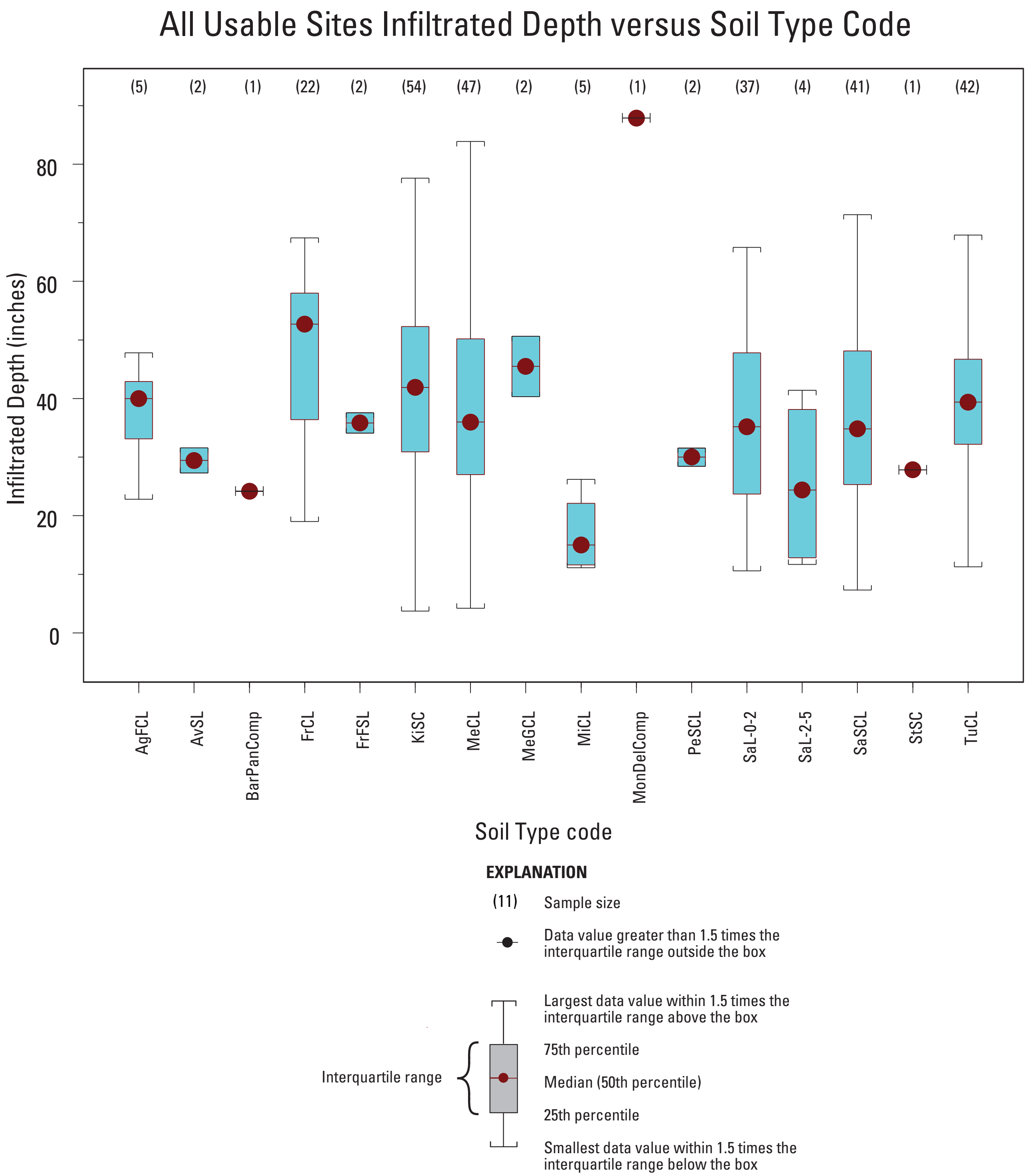


Figure 4-4. Box plot of irrigation water infiltrated depth by soil type[1] for all usable evaluation site-years. [[1]AgFCL, Agua Fria clay loam; AvSL, Avalon sandy loam; BarPanComp, Barx-Panitchen complex; FrCL, Fruita clay loam; KiSC, Killpack silty clay; MeCL, Mesa clay loam; MiCL, Mikim clay loam; SaL-0-2, Sagerlite loam, 0-2 percent slope; SaL-2-5, Sagerlite loam, slope 2-5 percent; SaSCL, Sagers silty clay loam; TuCL, Turley clay loam.]

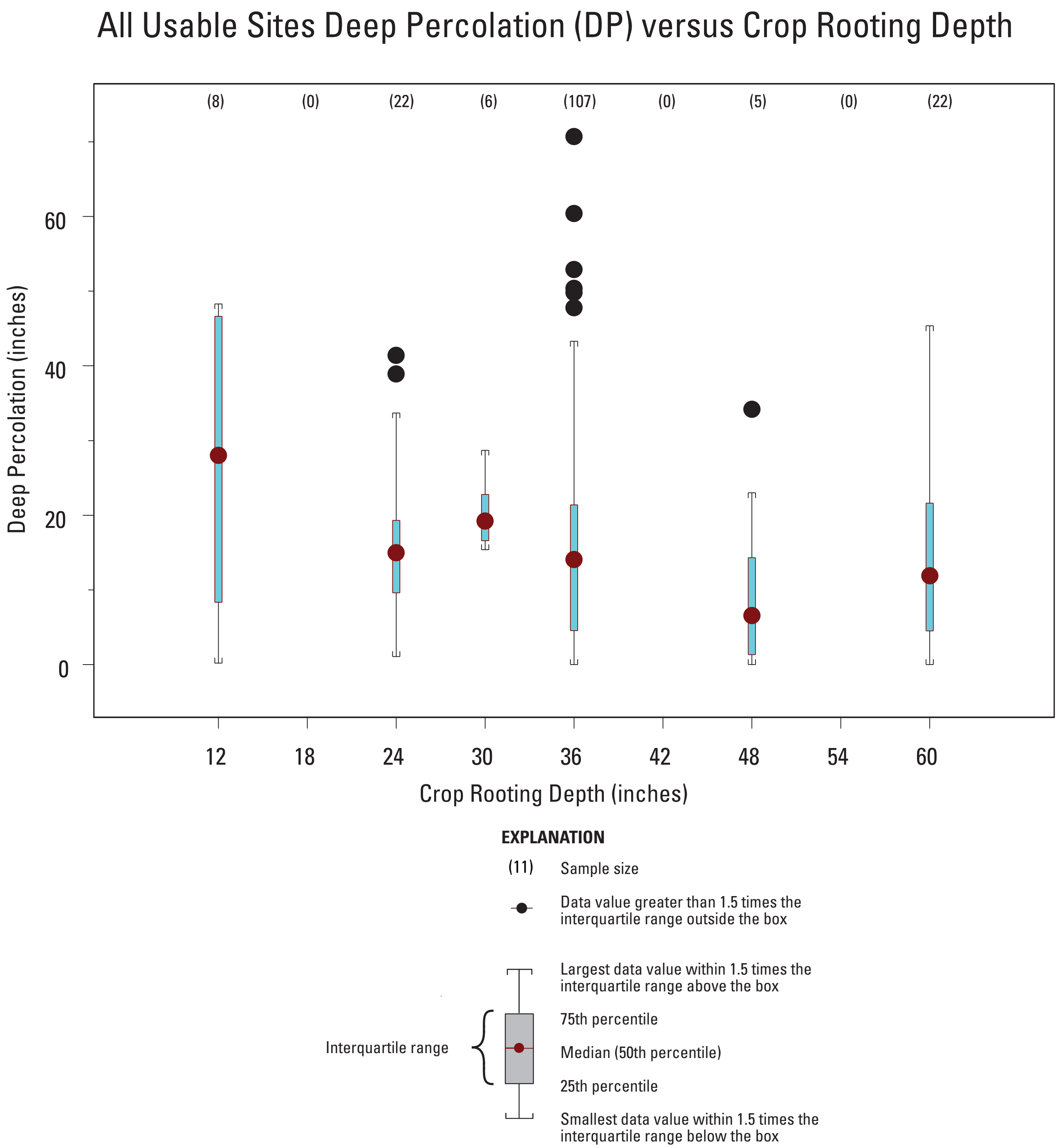


Figure 4-5. Box plot of deep percolation by crop rooting depth for all usable evaluation site-years. [DP, deep percolation.]

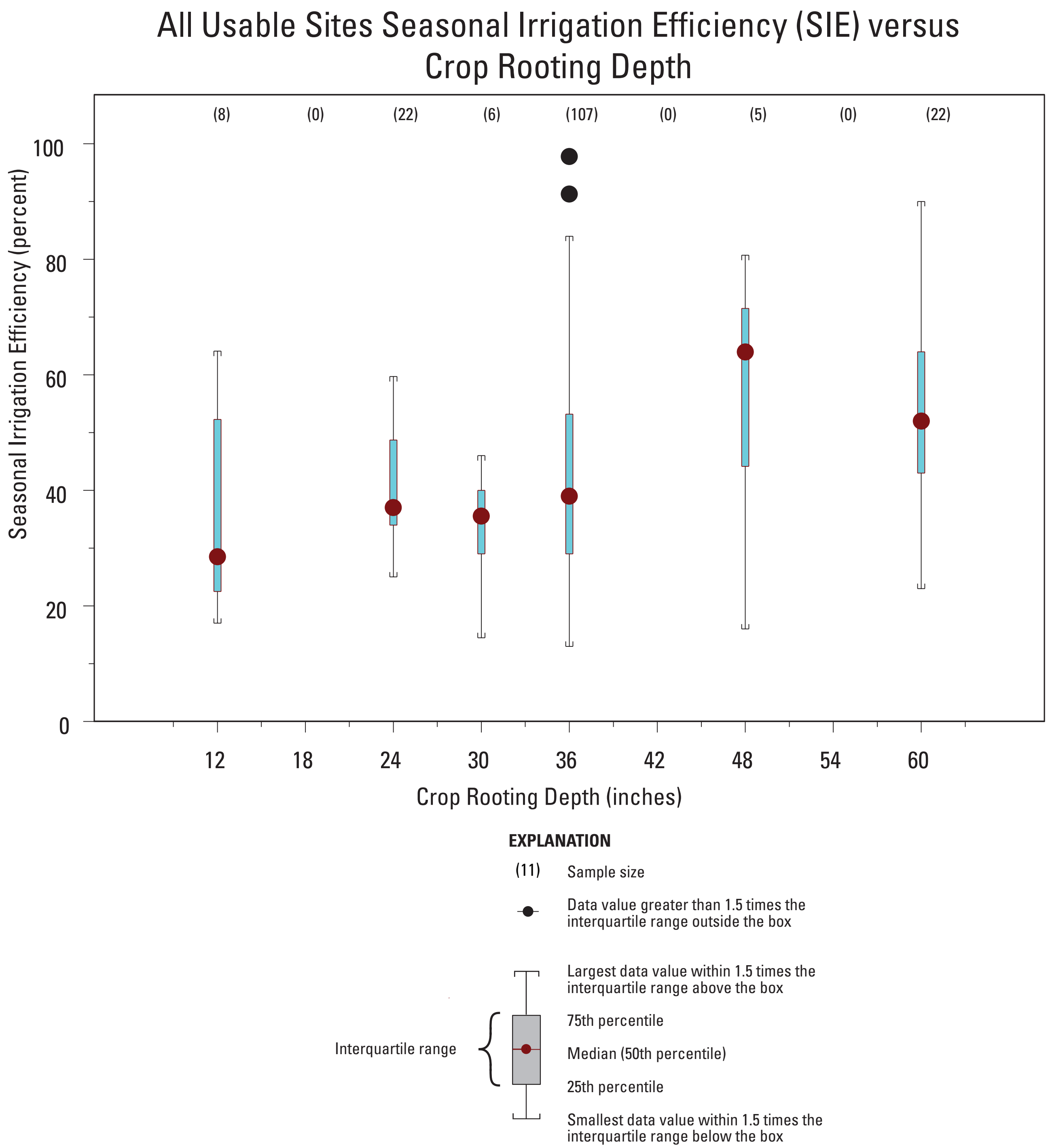


Figure 4-6. Box plot of seasonal irrigation efficiency by crop rooting depth for all usable evaluation site-years. [SIE, seasonal irrigation efficiency.]

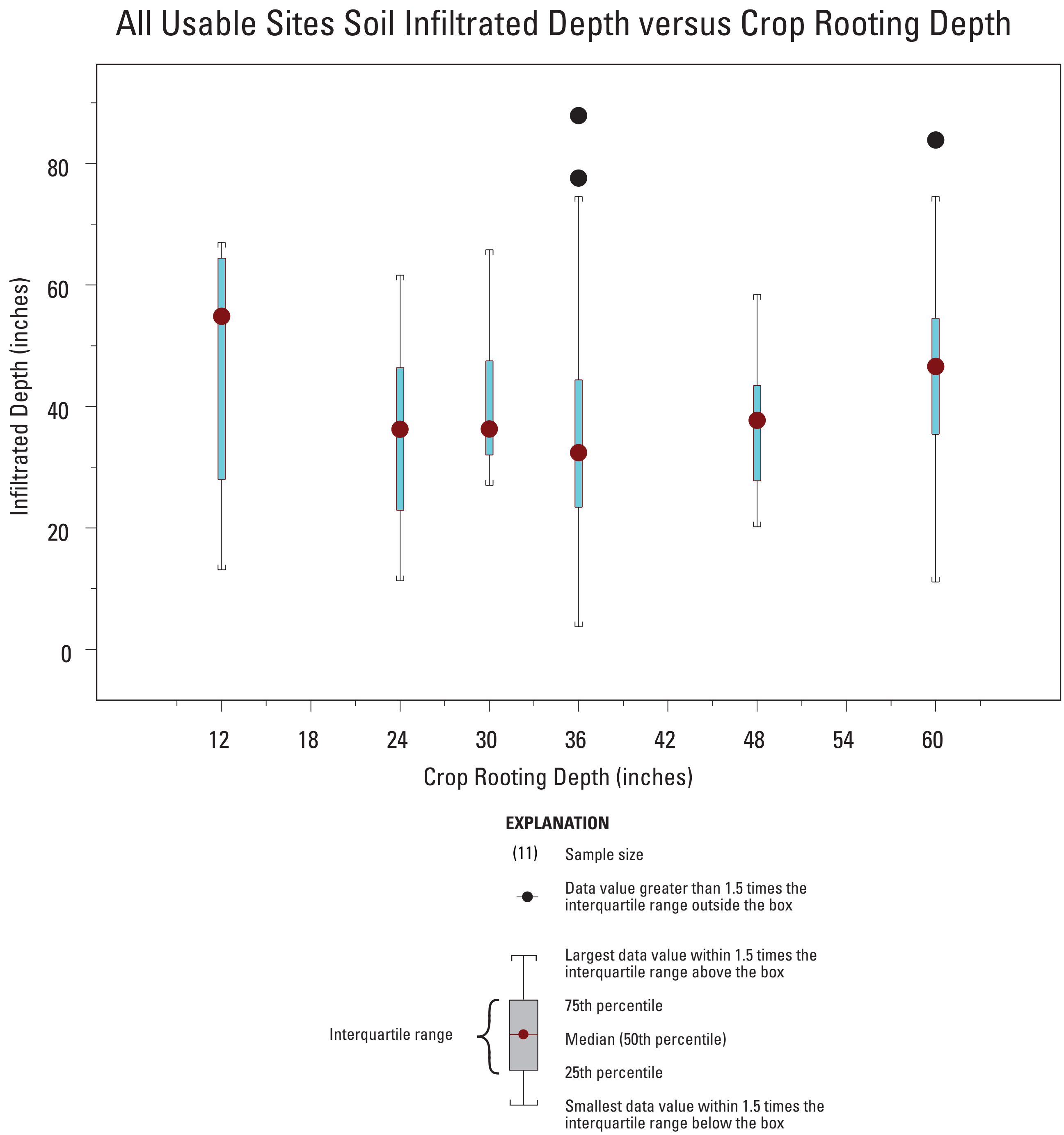


Figure 4-7. Box plot of irrigation water infiltrated depth by soil type for all usable evaluation site-years. [ETc, crop evapotranspiration.]

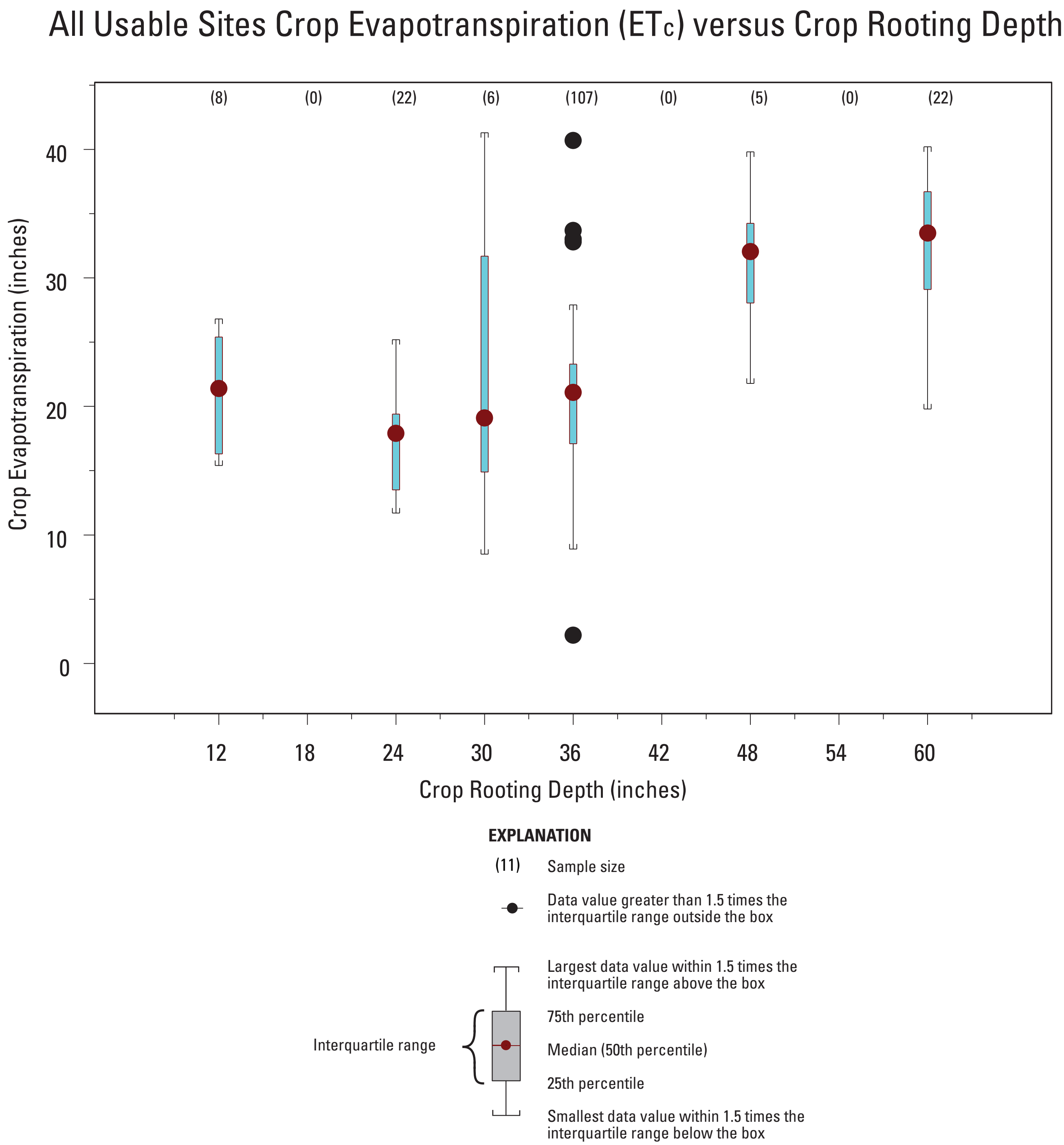
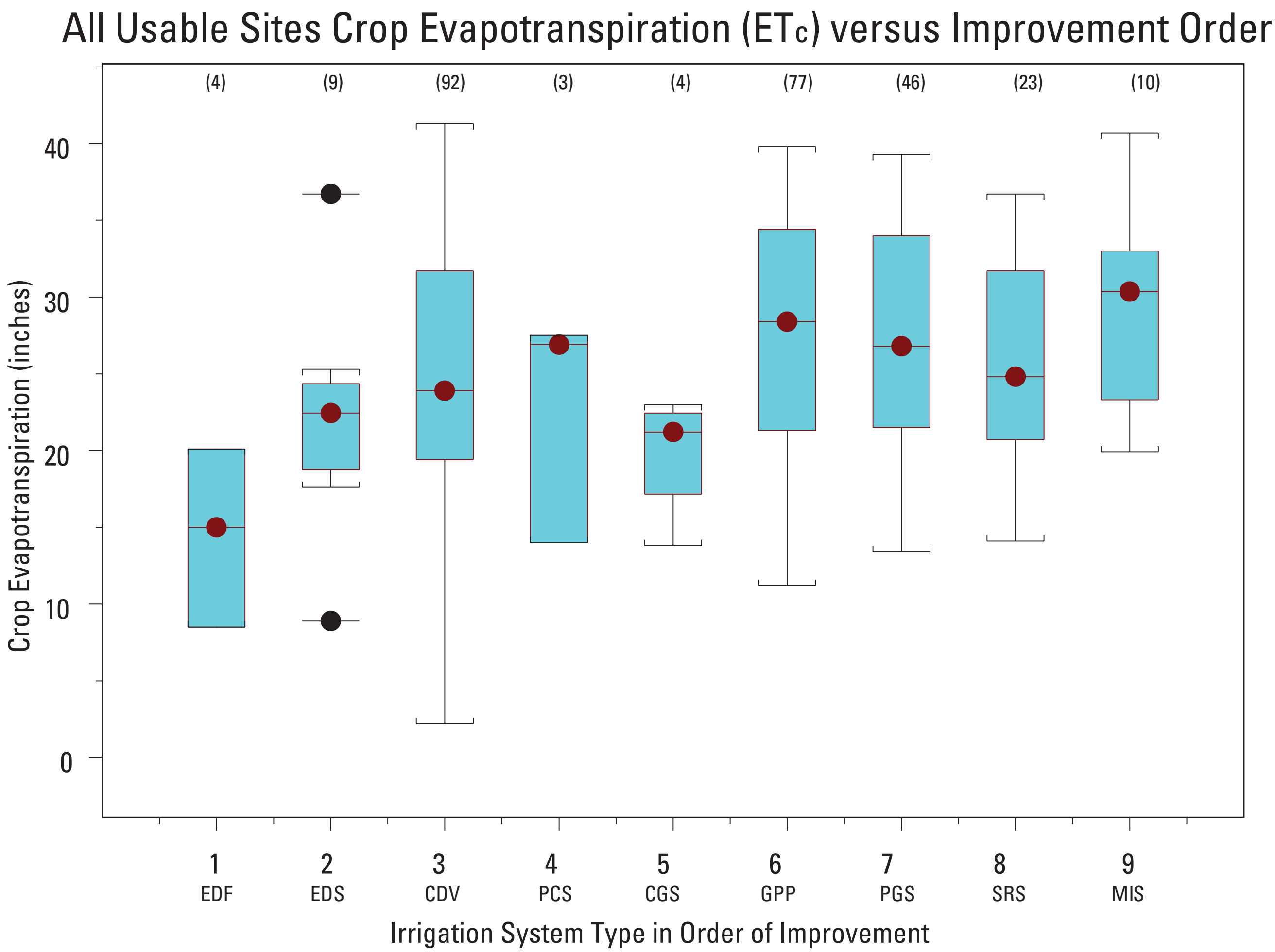


Figure 4-8. Box plot of crop evapotranspiration by crop rooting depth for all usable evaluation site-years. [ETc, crop evapotranspiration.]



Irrigation System Types

EDF	Earth Ditch to Feeder Ditch
EDS	Earth Ditch to Siphon Tubes
CDV	Concrete Ditch to Various Distribution
PCS	Ported Concrete Ditch to Surge
CGS	Concrete Ditch to Gated Pipe Surge
GPP	Gated Pipe
PGS	Pipeline to Gated Pipe Surge
SRS	Sideroll Sprinkler
MIS	Microspray

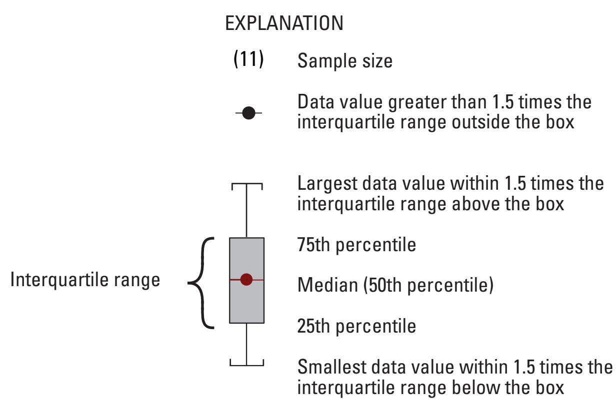
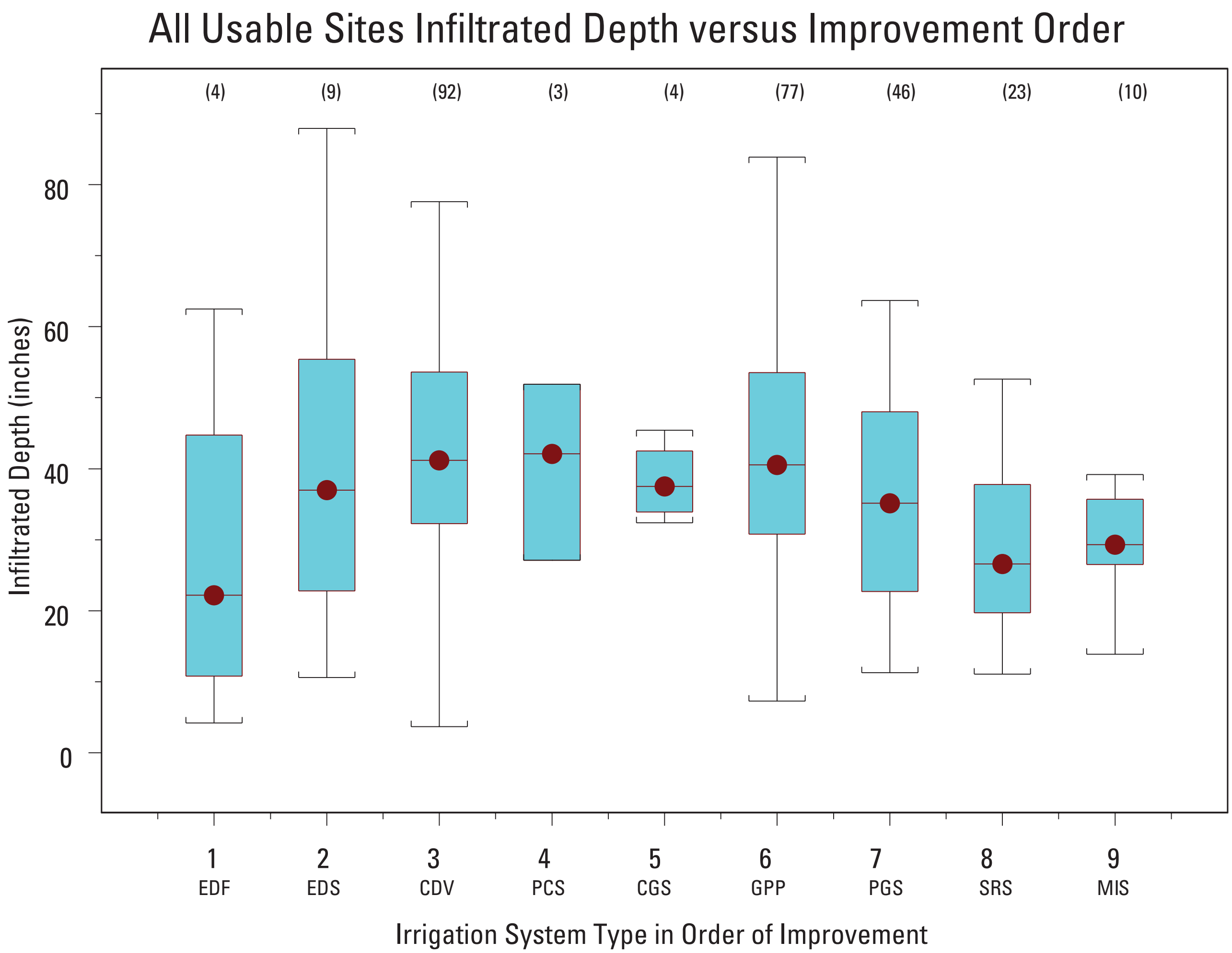


Figure 4-9. Box plot of crop evapotranspiration by irrigation system type in improvement order for all usable evaluation site-years. [ETc, crop evapotranspiration.]



Irrigation System Types

EDF	Earth Ditch to Feeder Ditch
EDS	Earth Ditch to Siphon Tubes
CDV	Concrete Ditch to Various Distribution
PCS	Ported Concrete Ditch to Surge
CGS	Concrete Ditch to Gated Pipe Surge
GPP	Gated Pipe
PGS	Pipeline to Gated Pipe Surge
SRS	Sideroll Sprinkler
MIS	Microspray

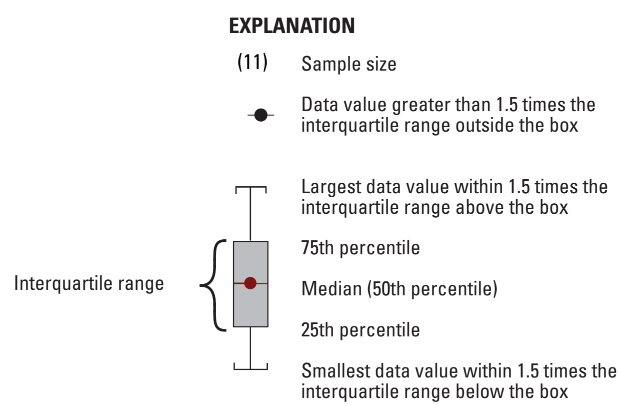


Figure 4-10. Box plot of irrigation water infiltrated depth by irrigation system type in improvement order for all usable evaluation site-years. [EDF, earth ditch to feeder tube; EDS, earth ditch to siphon tube; CDV, concrete ditch to various distribution methods; PCS, ported concrete ditch to surge; CGS, concrete ditch to gated pipe surge; GPP, gated pipe; PGS, pipeline to gated surge; SRS, side-roll sprinkler; MIS, microspray.]

Appendix 5. Additional Multiple Comparison Tables

The report section “Multiple Comparison Statistics” includes two tables of multiple comparison statistics for seasonal irrigation efficiency by irrigation system improvement order and for deep percolation by irrigation system improvement order. Appendix 5 shows additional multiple comparison tables for both seasonal irrigation efficiency irrigation and deep percolation by crop type, by soil type, by evaluation unit, and by crop rooting depth. Also shown are multiple comparison tables for crop evapotranspiration by Natural Resources Conservation Service (NRCS) evaluation unit, by gold standard evaluation year, and by crop rooting depth. Finally, a multiple comparison table for irrigation water infiltrated depth is shown by NRCS evaluation unit. For reference, a reference table of irrigation system improvement order, system type codes, and descriptions is shown.

Table 5-1. Table of irrigation system improvement order, type codes, and descriptions.

[EDF, earth ditch to feeder tube; EDS, earth ditch to siphon tube; CDV, concrete ditch to various distribution methods; PCS, ported concrete ditch to surge; CGS, concrete ditch to gated pipe surge; GPP, gated pipe; PGS, pipeline to gated surge; SRS, side-roll sprinkler; MIS, microspray.]

Improvement Order	Irrigation System Code	Description
1	EDF	Earth Ditch to Feeder Ditch
2	EDS	Earth Ditch to Siphon Tubes
3	CDV	Concrete Ditch to Various Distribution
4	PCS	Concrete Ditch Ported Surge
5	CGS	Concrete Ditch to Gated Pipe Surge
6	GPP	Gated Pipe
7	PGS	Pipeline to Gated Surge
8	SRS	Sideroll Sprinkler
9	MIS	Microspray

Table 5-2. Multiple comparison table of seasonal irrigation efficiency by crop type.

Crop Type	Difference in Median Seasonal Irrigation Efficiency of Column Crop Type Over Row Crop Type (Percent)									
	Alfalfa	Beans	Corn	Fall Grain	Grapes	Onions	Orchard	Pasture	Spring Grain	Vegetable
Alfalfa										
Beans	+17				+40		+27			
Corn	+14						+20			
Fall grain	+21				+44		+29			
Grapes										
Onions					+48		+35			
Orchard										
Pasture										
Spring grain										
Vegetable					+41					

Table 5-3. Multiple comparison table of deep percolation by crop type.

Crop Type	Difference in Median Deep Percolation of Column Crop Type Over Row Crop Type (Percent)									
	Alfalfa	**Beans**	**Corn**	**Fall Grain**	**Grapes**	**Onions**	**Orchard**	**Pasture**	**Spring Grain**	**Vegetable**
Alfalfa										
Beans										
Corn										
Fall grain										
Grapes										
Onions					-36		-31			
Orchard										
Pasture										
Spring grain										
Vegetable					+41					

Table 5-4. Multiple comparison table of crop evapotranspiration by crop type.

Crop Type	Difference in Median Crop Evapotranspiration of Column Crop Type Over Row Crop Type (Percent)									
	Alfalfa	**Beans**	**Corn**	**Fall Grain**	**Grapes**	**Onions**	**Orchard**	**Pasture**	**Spring Grain**	**Vegetable**
Alfalfa										
Beans	+16				+13		+15			
Corn	+12						+11			
Fall grain	+16				+12		+15			
Grapes										
Onions	+16									
Orchard										
Pasture										
Spring grain										
Vegetable	+16						+14			

Table 5-5. Multiple comparison table of seasonal irrigation efficiency by soil type.

[AgFCL, Agua Fria clay loam; AvSL, Avalon sandy loam; BarPanComp, Barx-Panitchen complex; FrCL, Fruita clay loam; KiSC, Killpack silty clay; MeCL, Mesa clay loam; MiCL, Mikim clay loam; SaL-0-2, Sagerlite loam, 0-2 percent slope; SaL-2-5, Sagerlite loam, slope 2-5 percent; SaSCL, Sagers silty clay loam; TuCL, Turley clay loam.]

Soil Type Code	Difference in Median Seasonal Irrigation Efficiency of Column Soil Type Over Row Soil Type (Percent)										
	AgFCL	AvSL	BarPanComp	FrCL	KiSC	MeCL	MiCL	SaL-0-2	SaL-2-5	SaSCL	TuCL
AgFCL						+44	+53				+28
AvSL											
BarPanComp											
FrCL							+35				
KiSC							+38				
MeCL											
MiCL											
SaL-0-2							+38				
SaL-2-5											
SaSCL						+26	+40				
TuCL											

Table 5-6. Multiple comparison table of deep percolation by soil type.

[AgFCL, Agua Fria clay loam; AvSL, Avalon sandy loam; BarPanComp, Barx-Panitchen complex; FrCL, Fruita clay loam; KiSC, Killpack silty clay; MeCL, Mesa clay loam; MiCL, Mikim clay loam; SaL-0-2, Sagerlite loam, 0-2 percent slope; SaL-2-5, Sagerlite loam, slope 2-5 percent; SaSCL, Sagers silty clay loam; TuCL, Turley clay loam.]

Soil Type Code	Difference in Median Deep Percolation of Column Soil Type Over Row Soil Type (Percent)										
	AgFCL	AvSL	BarPanComp	FrCL	KiSC	MeCL	MiCL	SaL-0-2	SaL-2-5	SaSCL	TuCL
AgFCL											
AvSL											
BarPanComp											
FrCL											
KiSC											
MeCL				-45	-48						
MiCL				-58	-62						
SaL-0-2											
SaL-2-5											
SaSCL											
TuCL											

Table 5-7. Multiple comparison table of irrigation water infiltrated depth by soil type.

[AgFCL, Agua Fria clay loam; AvSL, Avalon sandy loam; BarPanComp, Barx-Panitchen complex; FrCL, Fruita clay loam; KiSC, Killpack silty clay; MeCL, Mesa clay loam; MiCL, Mikim clay loam; SaL-0-2, Sagerlite loam, 0-2 percent slope; SaL-2-5, Sagerlite loam, slope 2-5 percent; SaSCL, Sagers silty clay loam; TuCL, Turley clay loam.]

Soil Type Code	Difference in Median Irrigation Water Infiltrated Depth of Column Soil Type Over Row Soil Type (Percent)										
	AgFCL	AvSL	BarPanComp	FrCL	KiSC	MeCL	MiCL	SaL-0-2	SaL-2-5	SaSCL	TuCL
AgFCL											
AvSL											
BarPanComp											
FrCL						+17					
KiSC											
MeCL											
MiCL				+33	+25						+23
SaL-0-2											
SaL-2-5											
SaSCL											
TuCL											

Table 5-8. Multiple comparison table of seasonal irrigation efficiency by evaluation unit.

[GV, Grand Valley Unit; LG, Lower Gunnison Unit; ME, McElmo Creek Unit]

Evaluation Unit Code	Difference in Median Seasonal Irrigation Efficiency of Column Evaluation Area Over Row Evaluation Area (Percent)		
	GV	LG	ME
GV			+32
LG	+16		+47
ME			

Table 5-9. Multiple comparison table of deep percolation by evaluation unit.

[GV, Grand Valley Unit; LG, Lower Gunnison Unit; ME, McElmo Creek Unit]

Evaluation Unit Code	Difference in Median Deep Percolation of Column Evaluation Area Over Row Evaluation Area (Percent)		
	GV	LG	ME
GV			-65
LG			-63
ME			

Table 5-10. Multiple comparison table of crop evapotranspiration by evaluation unit.

[GV, Grand Valley Unit; LG, Lower Gunnison Unit; ME, McElmo Creek Unit]

Evaluation Unit Code	Difference in Median Crop Evapotranspiration of Column Evaluation Area Over Row Evaluation Area (Percent)		
	GV	LG	ME
GV			
LG	+7		
ME			

Table 5-11. Multiple comparison table of irrigation water infiltrated depth by evaluation unit.

[GV, Grand Valley Unit; LG, Lower Gunnison Unit; ME, McElmo Creek Unit]

Evaluation Unit Code	Difference in Median Irrigation Water Infiltrated Depth of Column Evaluation Area Over Row Evaluation Area (Percent)		
	GV	LG	ME
GV			
LG			
ME	+17	+16	

Table 5-12. Multiple comparison table of crop evapotranspiration by Natural Resources Conservation Service evaluation gold standard years.

Evaluation Year	Difference in Median Crop Evapotranspiration of Column Evaluation Year Over Row Evaluation Year (Percent)											
	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
1985												
1986												
1987												
1988												
1989												
1990												
1991												
1992												
1993												
1994												
1995		+14	+13	+11								
1996												

Table 5-13. Multiple comparison table of seasonal irrigation efficiency by crop rooting depth.

	Difference in Median Seasonal Irrigation Efficiency of Column Rooting Depth Over Row Rooting Depth (Percent)				
Crop Rooting Depth (Inches)	**12**	**24**	**36**	**48**	**60**
12				+35	+26
24				+27	+17
36				+19	+13
48					
60					

Table 5-14. Multiple comparison table of deep percolation by crop rooting depth.

	Difference in Median Deep Percolation of Column Rooting Depth Over Row Rooting Depth (Percent)					
Crop Rooting Depth (Inches)	**12**	**24**	**30**	**36**	**48**	**60**
12					-31	-23
24					-11	
30						
36						
48						
60						

Table 5-15. Multiple comparison table of crop evapotranspiration by crop rooting depth.

	Difference in Median Crop Evapotranspiration of Column Rooting Depth Over Row Rooting Depth (Percent)					
Crop Rooting Depth (Inches)	**12**	**24**	**30**	**36**	**48**	**60**
12					+11	+11
24					+15	+16
30					+15	+12
36					+11	+12
48						
60						

Appendix 6. Columns in the soil moisture balance deep percolation worksheet

Appendix 6 shows a table of columns used in the soil moisture balance deep percolation worksheets. The table lists the category, column heading, and a descriptive note for each column. This explanation is to aid in the understanding of the various model parameters included in the soil moisture balance spreadsheets.

Table 6-1. Columns in the soil moisture balance deep percolation worksheet.

[Ref ET, reference evapotranspiration; ET_c, crop evapotranspiration; K_c, crop coefficient; SMB, soil moisture balance; precip, precipitation; SWD, soil water deficit; FAO-56, United Nations Food and Agricultural Organization Irrigation and Drainage Paper No. 56; NRCS, Natural Resources Conservation Service; RAW, readily available water; TAW, total available water; WP, wilting point.]

Category	Column Heading	Note
Date	Date	Microsoft Excel date format mm/dd/yyyy
Note	Note	Planting, harvest, ETc
Ordinal Date	Ordinal Date	The day number of the year
Water Applied	Net application quantity inches	From reported total value apportioned equally over the days of event
Crop ET	Ref ET	Selects from Fruita or Orchard Mesa weather station ET
Crop ET	Crop cycle days	Count of crop growth cycle days
Crop ET	Crop coefficient K_c	Selects from various models of K_c
Crop ET	Crop ET	Ref ET * K_c
Crop ET	Total ET between & during events	Reported on chart page
Crop ET	Total ET per month	Used to calculate monthly consumptive use on chart page
Crop ET	Plant date (-1) Harvest date (+1) flag	Used in chart to flag planting & harvest(s)
Precipitation	Ref precipitation	Selects from 4 weather station sources
Precipitation	Effective precipitation	Ref precip—effective threshold
Precipitation	Total precip between & during events	Reported on chart page
Reported Soil Moisture	Reported soil water deficit (SWD)	NRCS reported values at beginning and ending of each irrigation event
Reported Soil Moisture	Soil moisture	Field capacity minus SWD
Reported Soil Moisture	Crop cycle K_c	Selects from among several models of K_c
Preliminary Soil Moisture Balance	Daily soil moisture = previous soil moisture balance + water applied + local precipitation – ETc	Trial balance before ET stress correction and deep percolation determination
Preliminary Soil Moisture Balance	K_c stress correction factor	Uses FAO-56 stress model in VBA macro program
Preliminary Soil Moisture Balance	Stress corrected ETc	Output from VBA macro
Deep Percolation Calculation	Soil water deficit (SWD)	Repeated from above
Deep Percolation Calculation	Daily accumulated soil moisture balance without ET stress correction	Previous day ending SMB + net irrigation applied + effective precip – stress corrected ETc
Deep Percolation Calculation	Daily deep percolation	= soil moisture balance greater than field capacity
Deep Percolation Calculation	Daily net available soil moisture balance	(max=field capacity, min=0)
	Irrigation event total deep percolation	Reported on chart page
Field Capacity	Total FC for rooting depth	Constant
Wilting Point	Total WP for rooting depth	Constant
	Total available water (TAW)	= Field capacity – wilting point
	ET stress point	= ((1-SWD)*TAW) + WP
	Readily available water (RAW)	TAW * readily available water constant

Appendix 7. All Soil Moisture Balance Charts

In the report section "Soil Moisture Balance Charts" 5 of the 12 soil moisture balance charts created for this report are discussed in detail. Appendix 7 includes all 12 of the soil moisture balance charts for completeness, including the five already discussed. All soil moisture balance charts in appendix 7 were created using Natural Resources Conservation Service (NRCS) reported precipitation, no ET stress correction, and NRCS reported ET_p.

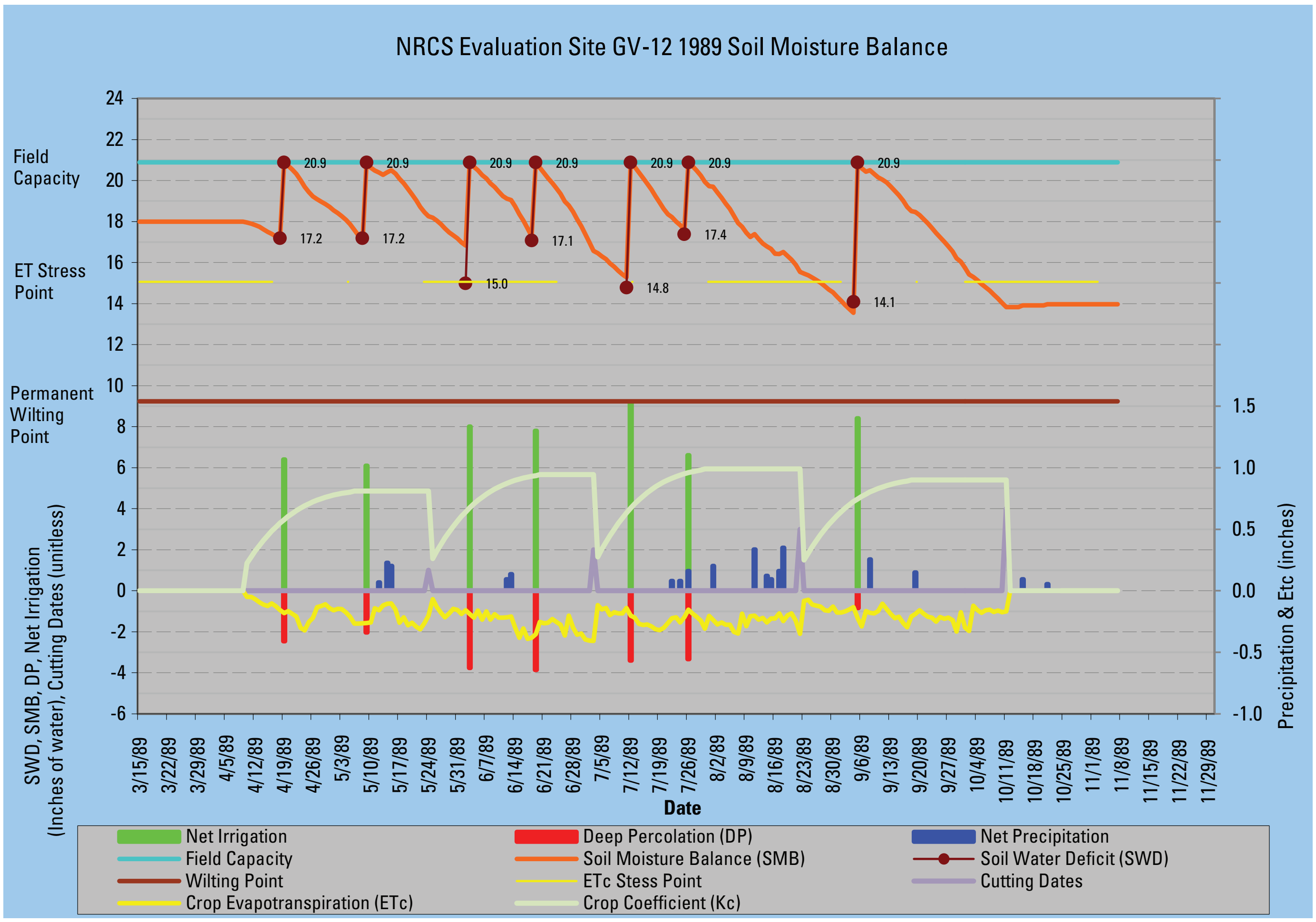


Figure 7-1. Soil moisture balance chart for Grand Valley Unit 1989 site 12, an alfalfa site with a concrete ditch to siphon tube irrigation system. [NRCS, Natural Resources Conservation Service; GV, Grand Valley; SWD, soil water deficit; SMB, soil moisture balance; DP, deep percolation; K_c, crop coefficient; ET_c, crop evapotranspiration.]

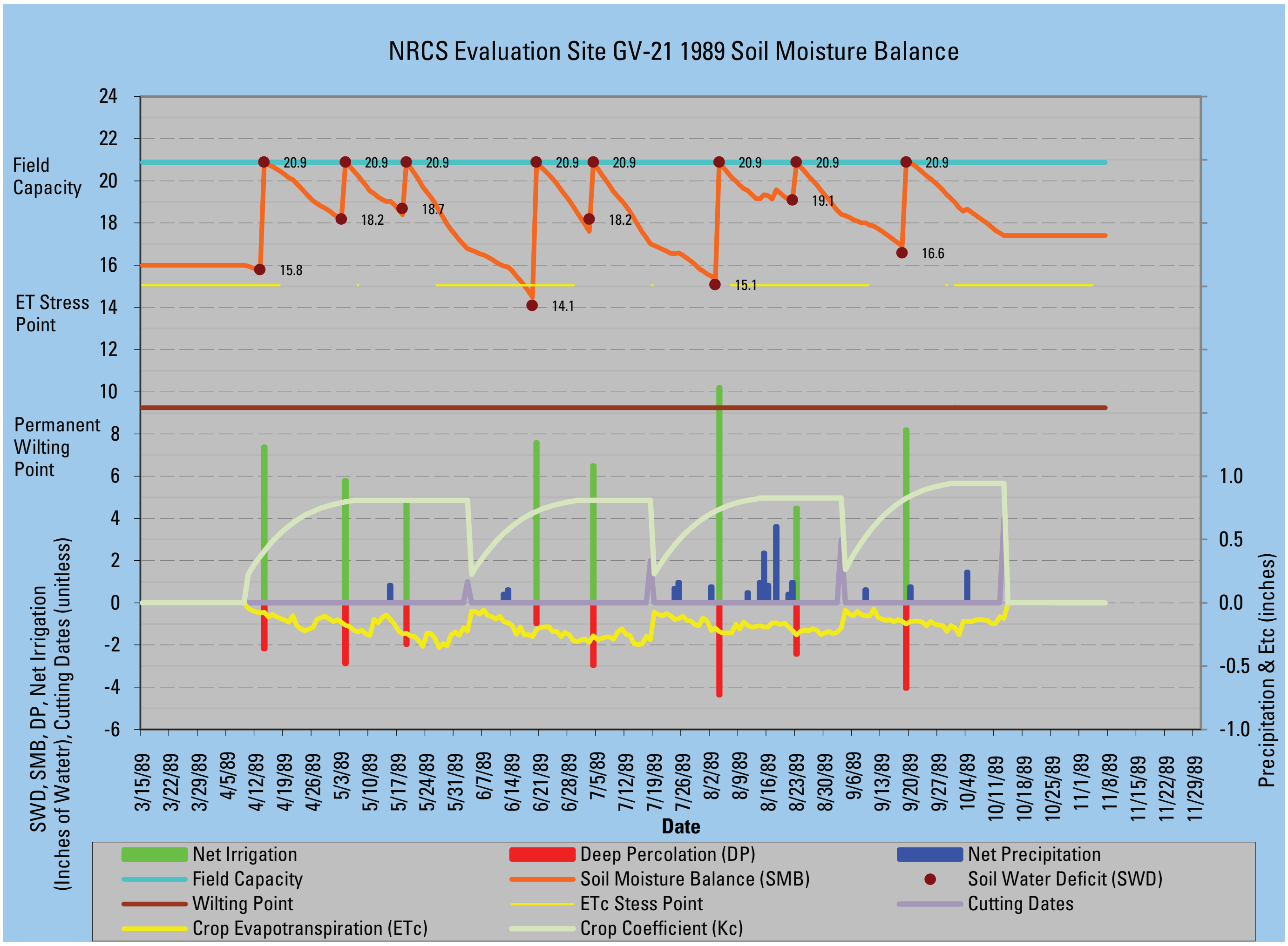


Figure 7-2. Soil moisture balance chart for Grand Valley Unit 1989 site 21, a newly-fall-seeded alfalfa site with a pipeline to gated pipe irrigation system. [NRCS, Natural Resources Conservation Service; GV, Grand Valley; SWD, soil water deficit; SMB, soil moisture balance; DP, deep percolation; K_c, crop coefficient; ET_c, crop evapotranspiration.]

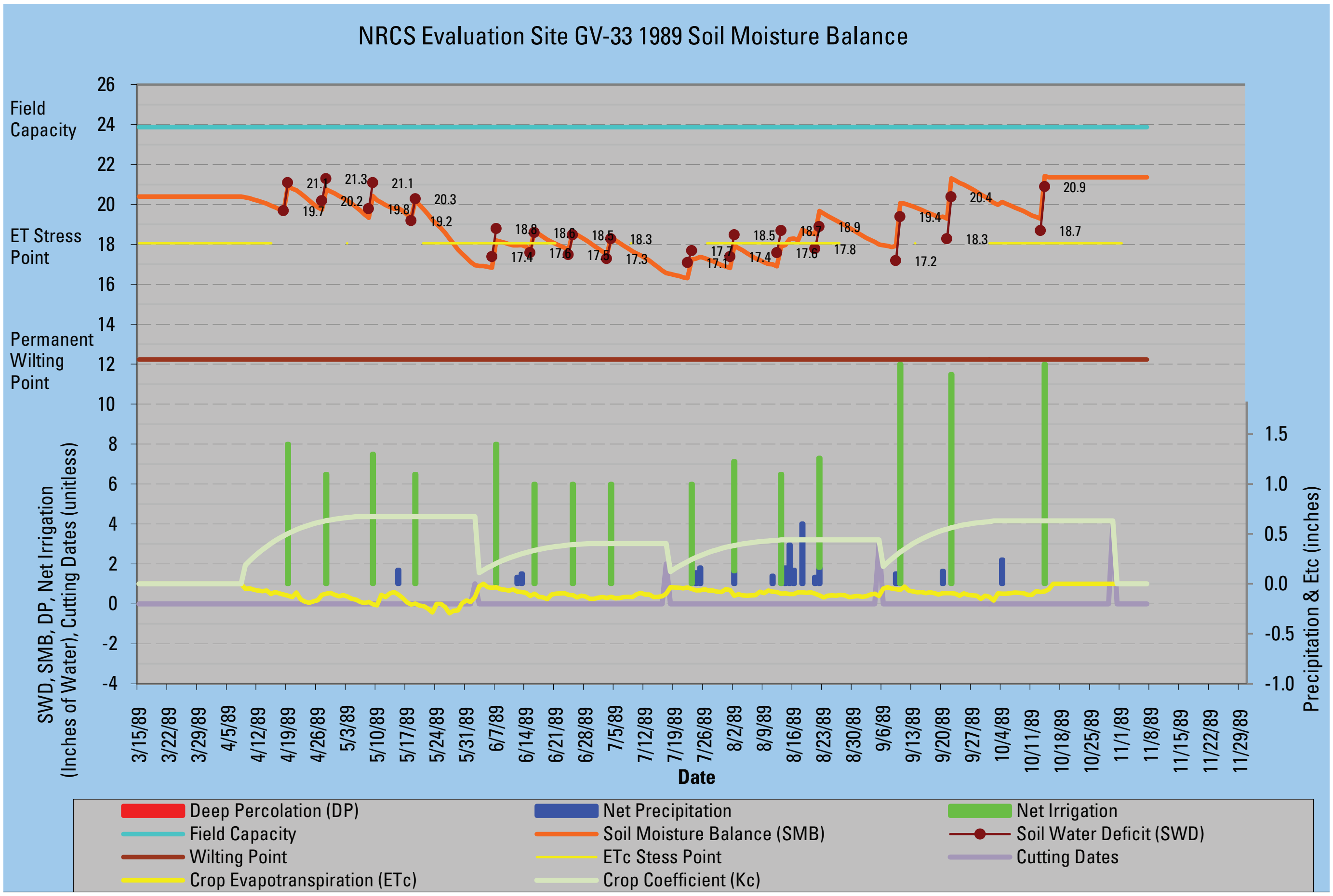


Figure 7-3. Soil moisture balance chart for Grand Valley Unit 1989 site 33, a newly-fall-seeded alfalfa site with a side-roll sprinkler irrigation system. [NRCS, Natural Resources Conservation Service; GV, Grand Valley; SWD, soil water deficit; SMB, soil moisture balance; DP, deep percolation; K_c, crop coefficient; ET_c, crop evapotranspiration.]

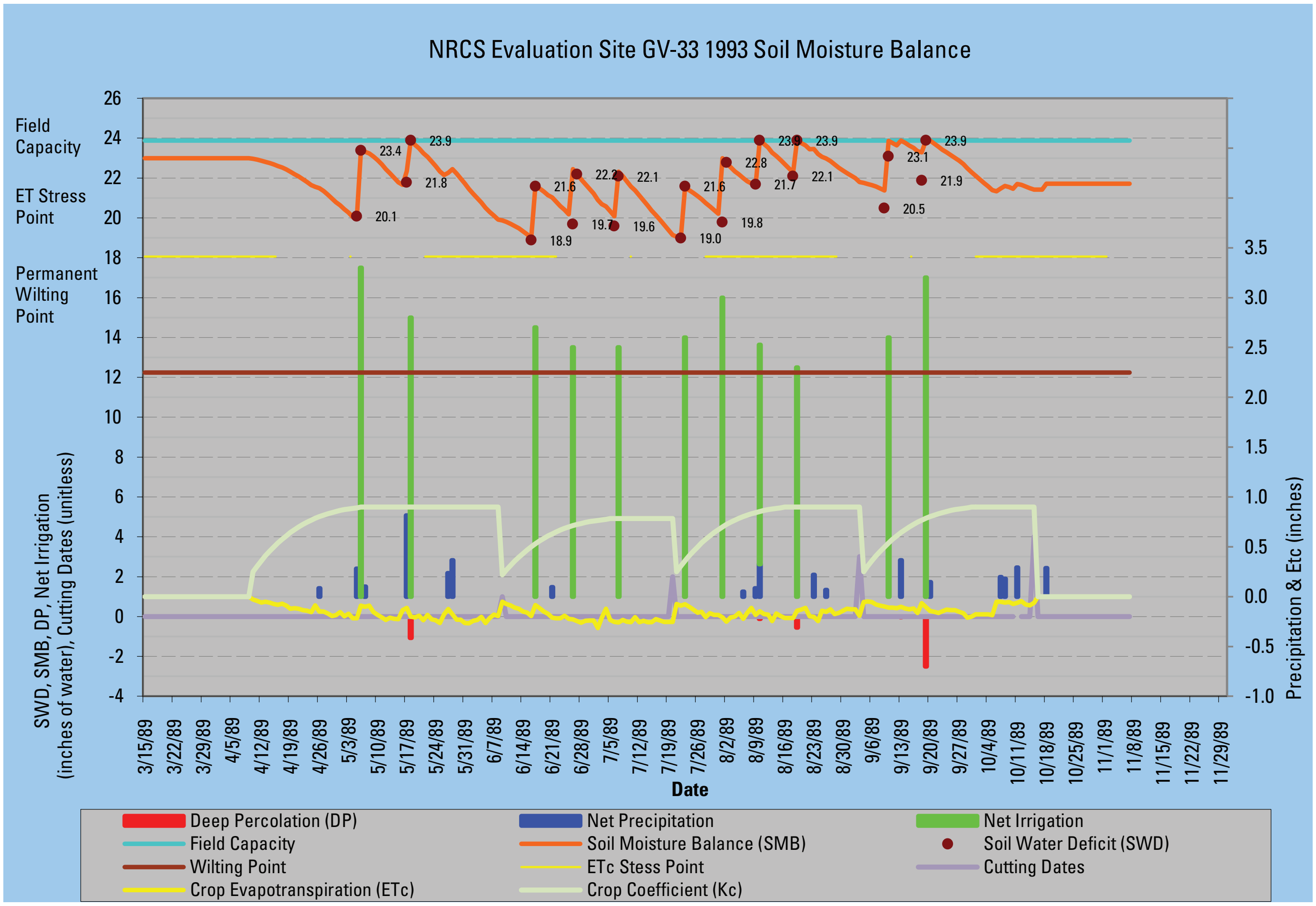


Figure 7-4. Soil moisture balance chart for Grand Valley Unit 1993 site 33, an alfalfa site with a side-roll sprinkler irrigation system. [NRCS, Natural Resources Conservation Service; GV, Grand Valley; SWD, soil water deficit; SMB, soil moisture balance; DP, deep percolation; K_c, crop coefficient; ET_c, crop evapotranspiration.]

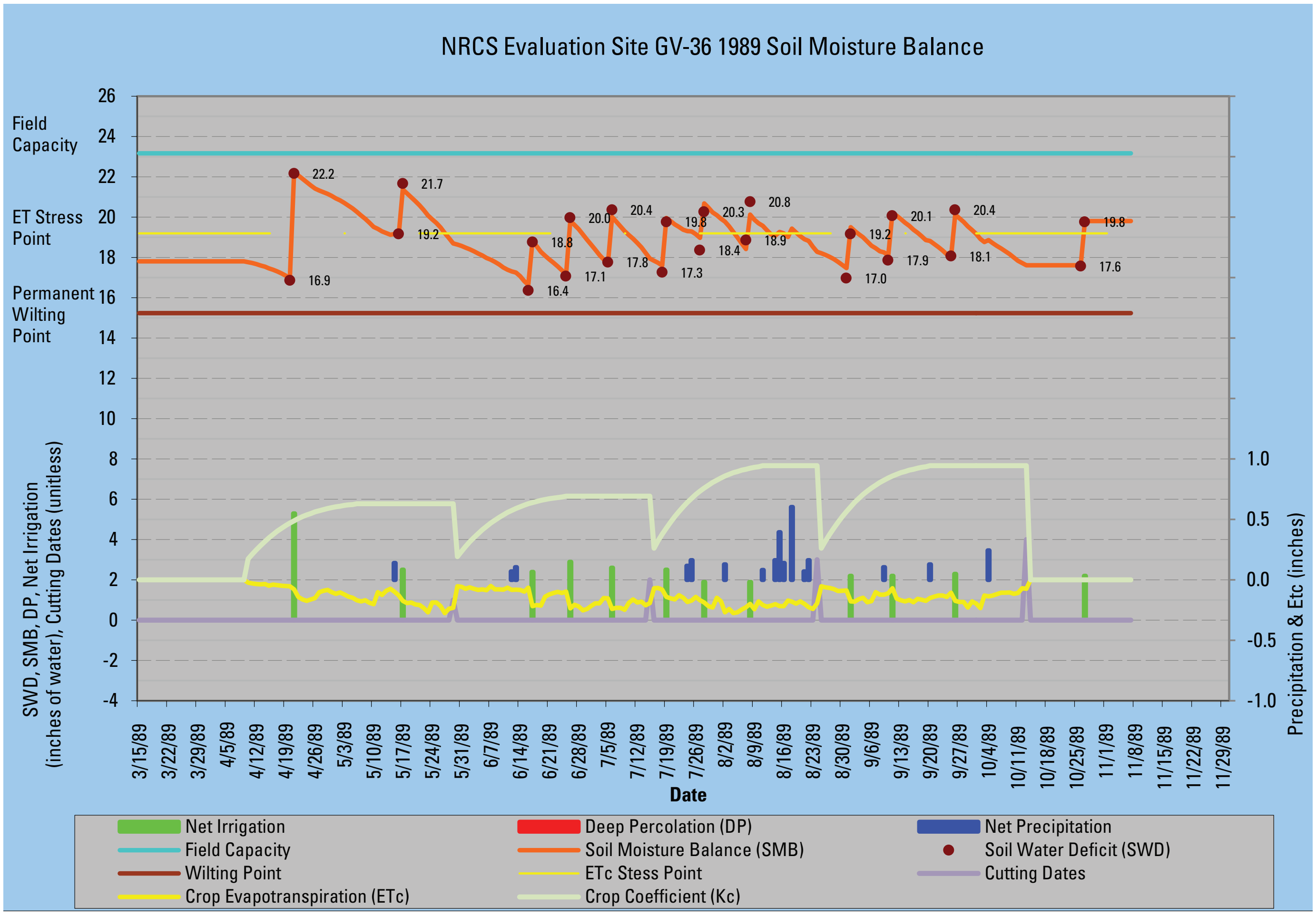


Figure 7-5. Soil moisture balance chart for Grand Valley Unit 1989 site 36, an alfalfa site with a side-roll sprinkler irrigation system. [NRCS, Natural Resources Conservation Service; GV, Grand Valley; SWD, soil water deficit; SMB, soil moisture balance; DP, deep percolation; K_c, crop coefficient; ET_c, crop evapotranspiration.]

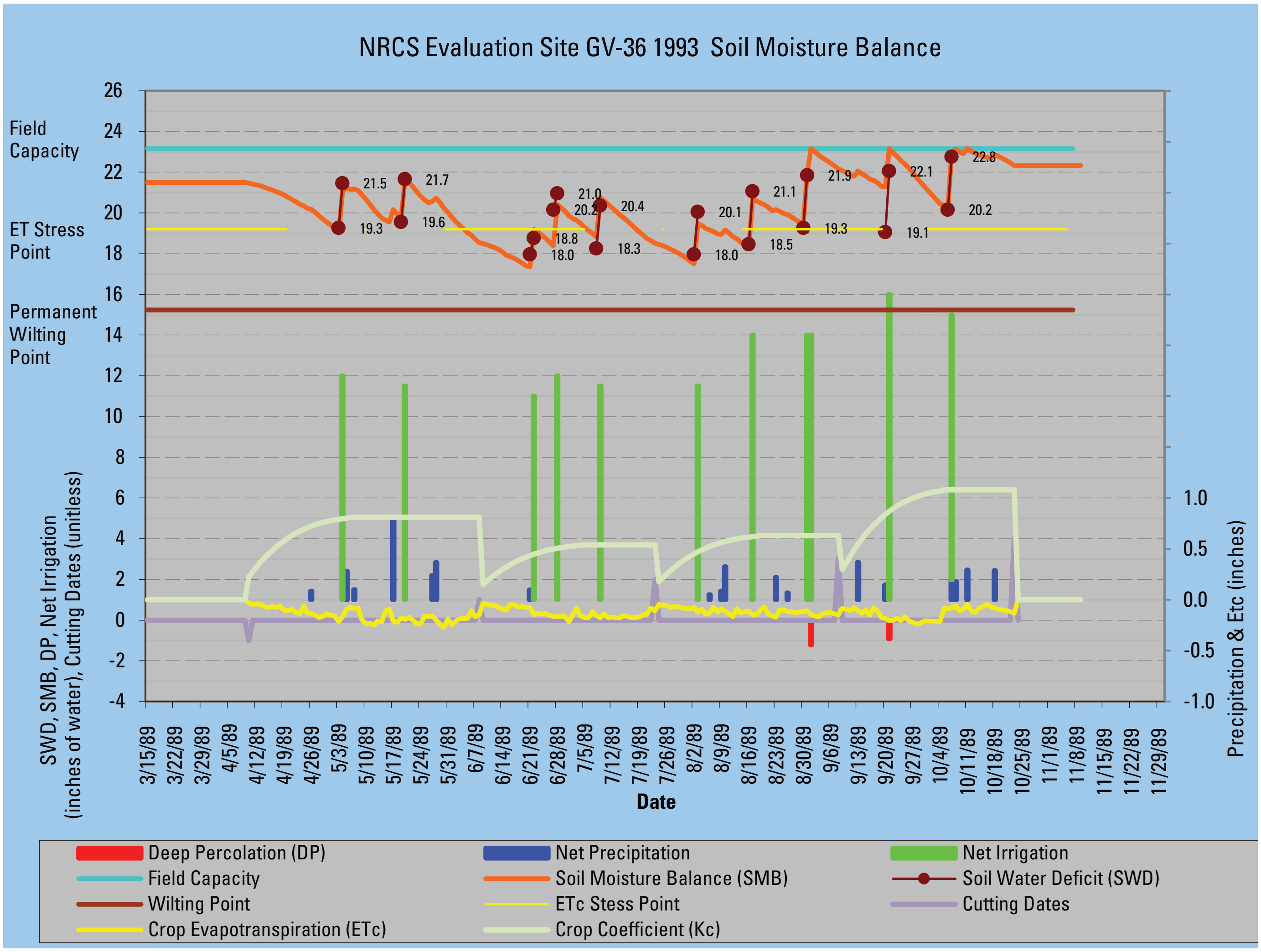


Figure 7-6. Soil moisture balance chart for Grand Valley Unit 1993 site 36, an alfalfa site with a side-roll sprinkler irrigation system. [NRCS, Natural Resources Conservation Service; GV, Grand Valley; SWD, soil water deficit; SMB, soil moisture balance; DP, deep percolation; K_c, crop coefficient; ET_c, crop evapotranspiration.]

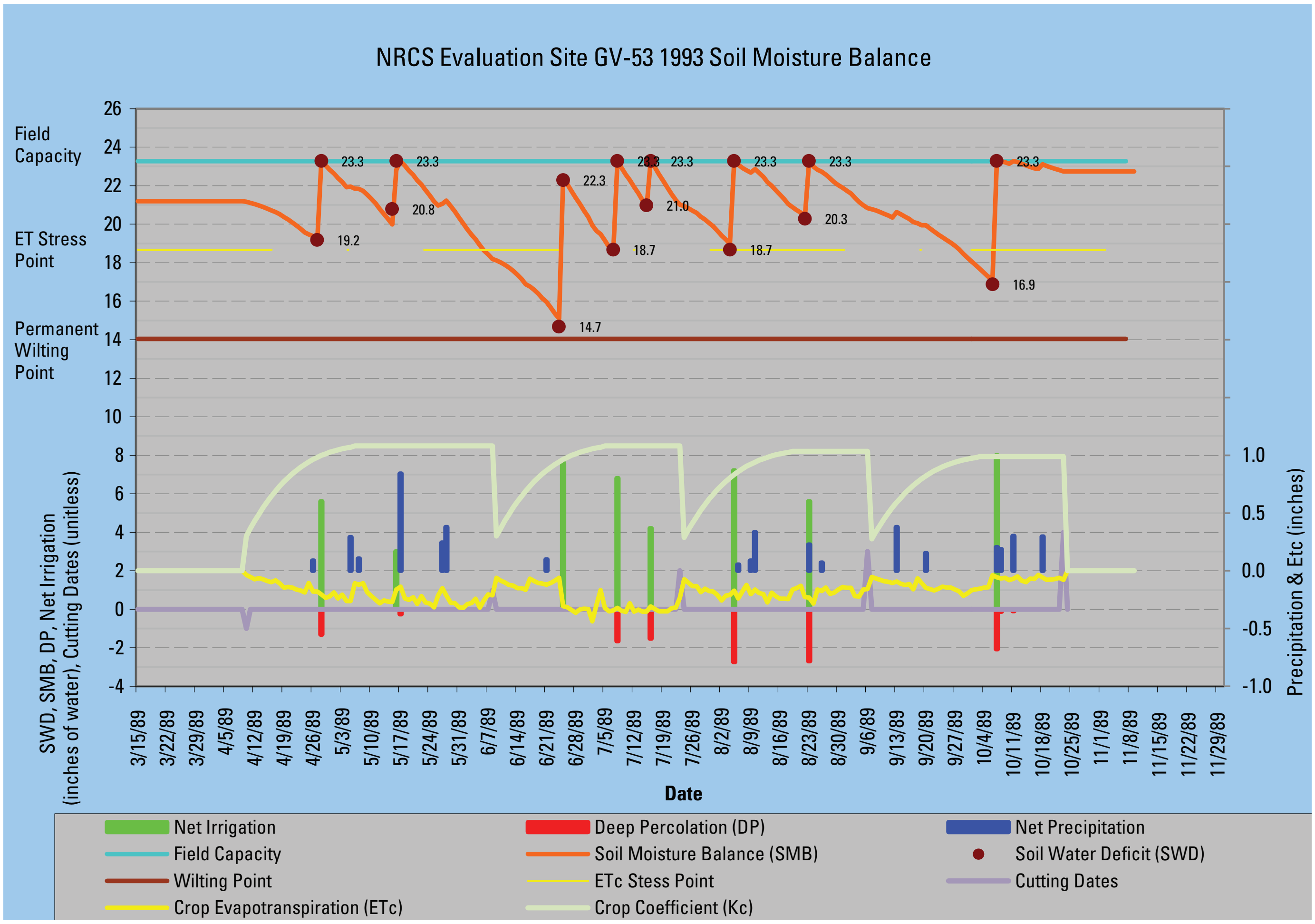


Figure 7-7. Soil moisture balance chart for Grand Valley Unit 1993 site 53, an alfalfa site with a pipeline to gated surge irrigation system. [NRCS, Natural Resources Conservation Service; GV, Grand Valley; SWD, soil water deficit; SMB, soil moisture balance; DP, deep percolation; K_c, crop coefficient; ETc, crop evapotranspiration.]

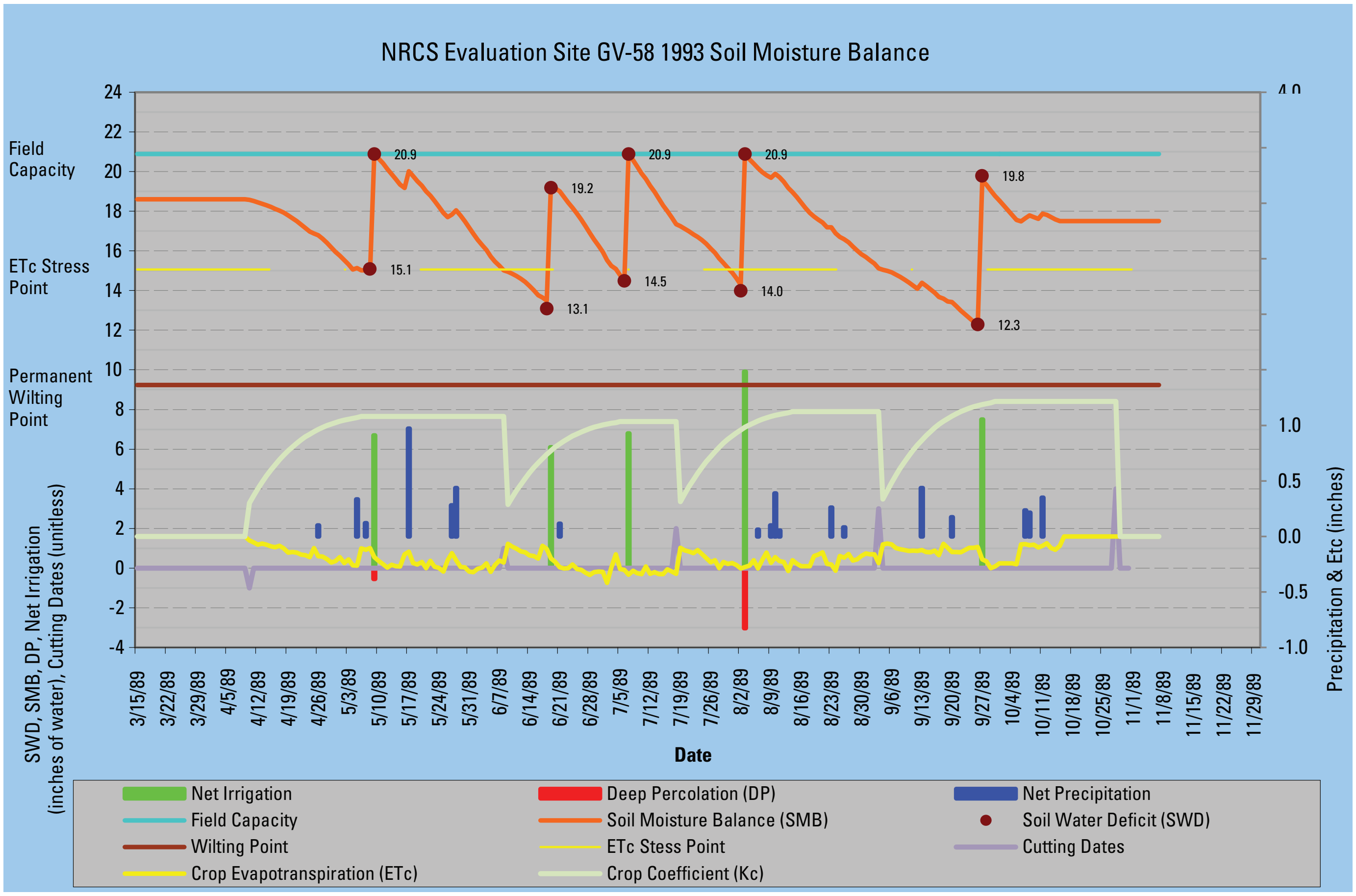


Figure 7-8. Soil moisture balance chart for Grand Valley Unit 1993 site 58, an alfalfa site with an earth ditch to siphon tube irrigation system. [NRCS, Natural Resources Conservation Service; GV, Grand Valley; SWD, soil water deficit; SMB, soil moisture balance; DP, deep percolation; K_c, crop coefficient; ET_c, crop evapotranspiration.]

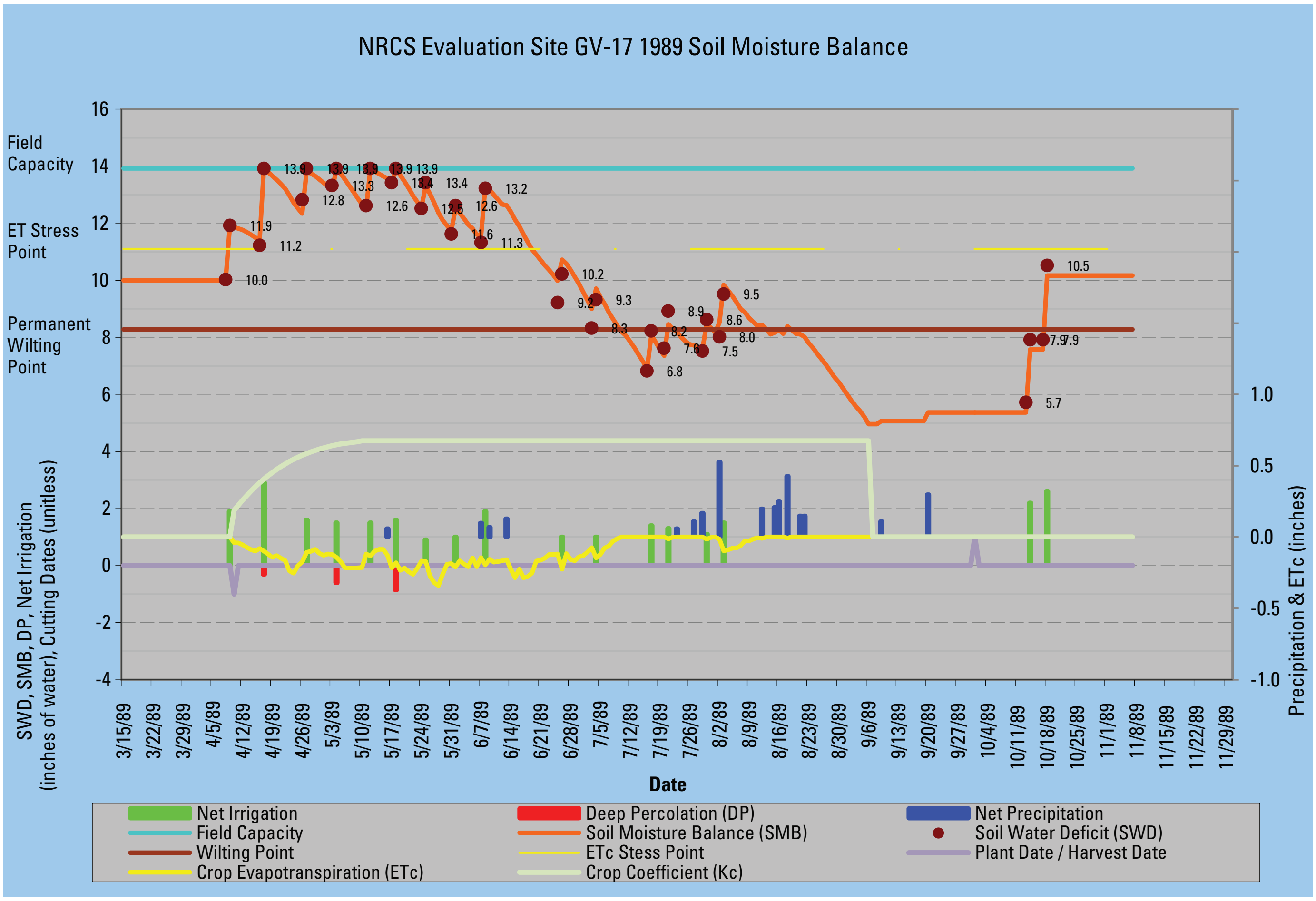


Figure 7-9. Soil moisture balance chart for Grand Valley Unit 1989 site 17, a wine grapes site with a microspray irrigation system. [NRCS, Natural Resources Conservation Service; GV, Grand Valley; SWD, soil water deficit; SMB, soil moisture balance; DP, deep percolation; K_c, crop coefficient; ET_c, crop evapotranspiration.]

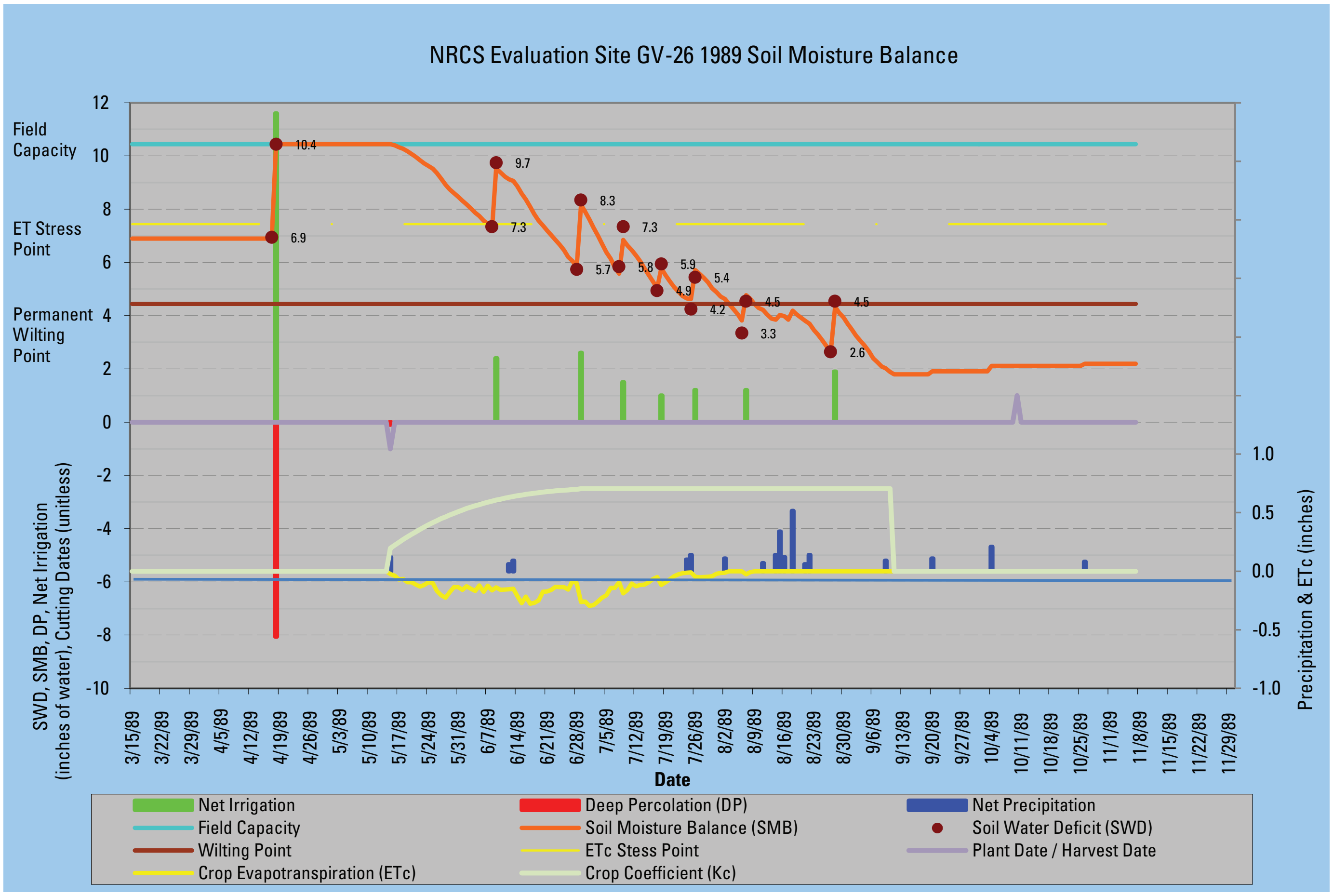


Figure 7-10. Soil moisture balance chart for Grand Valley Unit 1989 site 26, a grain corn site with a pipeline to gated pipe irrigation system. [NRCS, Natural Resources Conservation Service; GV, Grand Valley; SWD, soil water deficit; SMB, soil moisture balance; DP, deep percolation; K_c, crop coefficient; ET_c, crop evapotranspiration.]

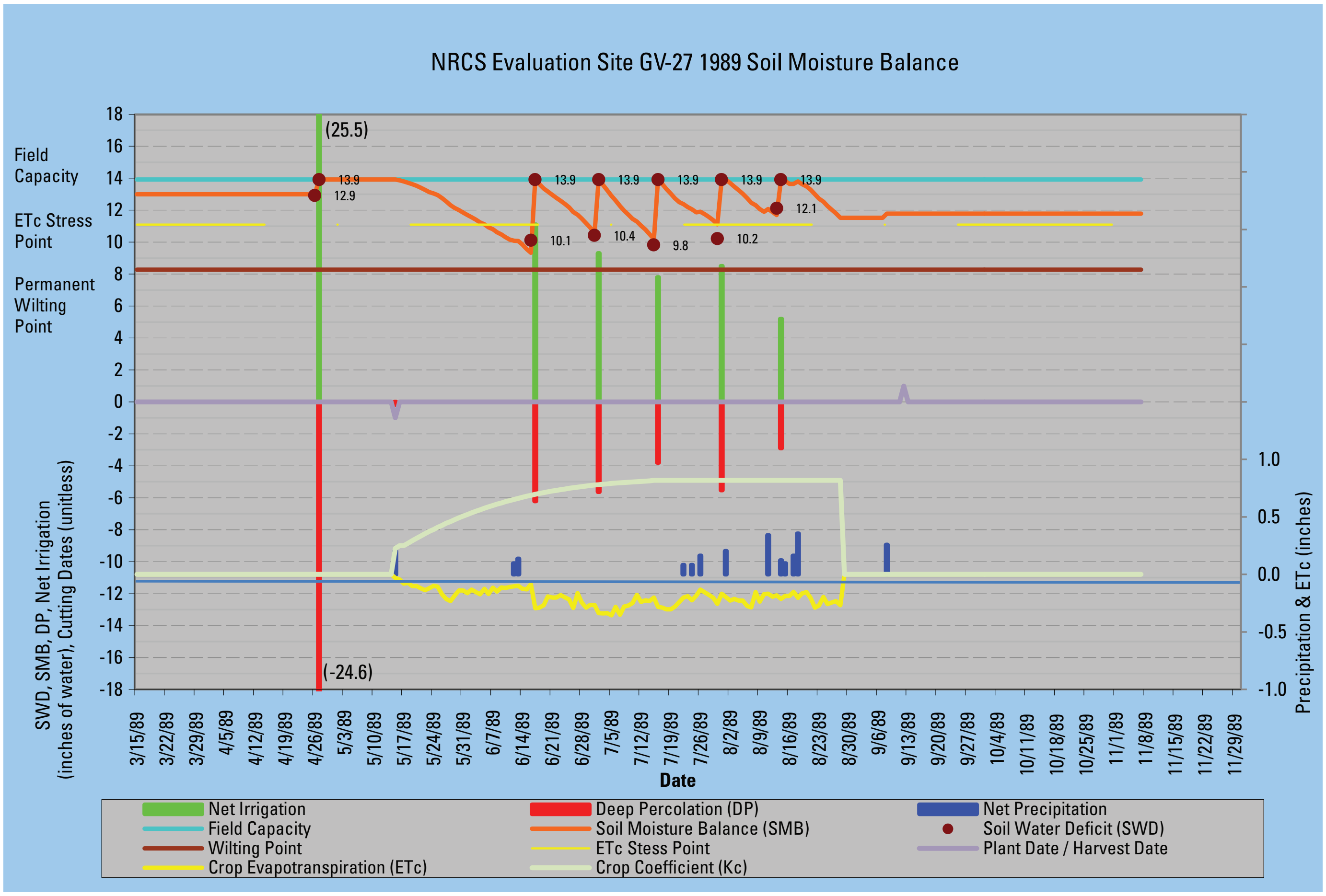


Figure 7-11. Soil moisture balance chart for Grand Valley Unit 1989 site 27, a grain corn site with a pipeline to gated pipe irrigation system. The corn crop was cut for silage. [NRCS, Natural Resources Conservation Service; GV, Grand Valley; SWD, soil water deficit; SMB, soil moisture balance; DP, deep percolation; K_c, crop coefficient; ET_c, crop evapotranspiration.]

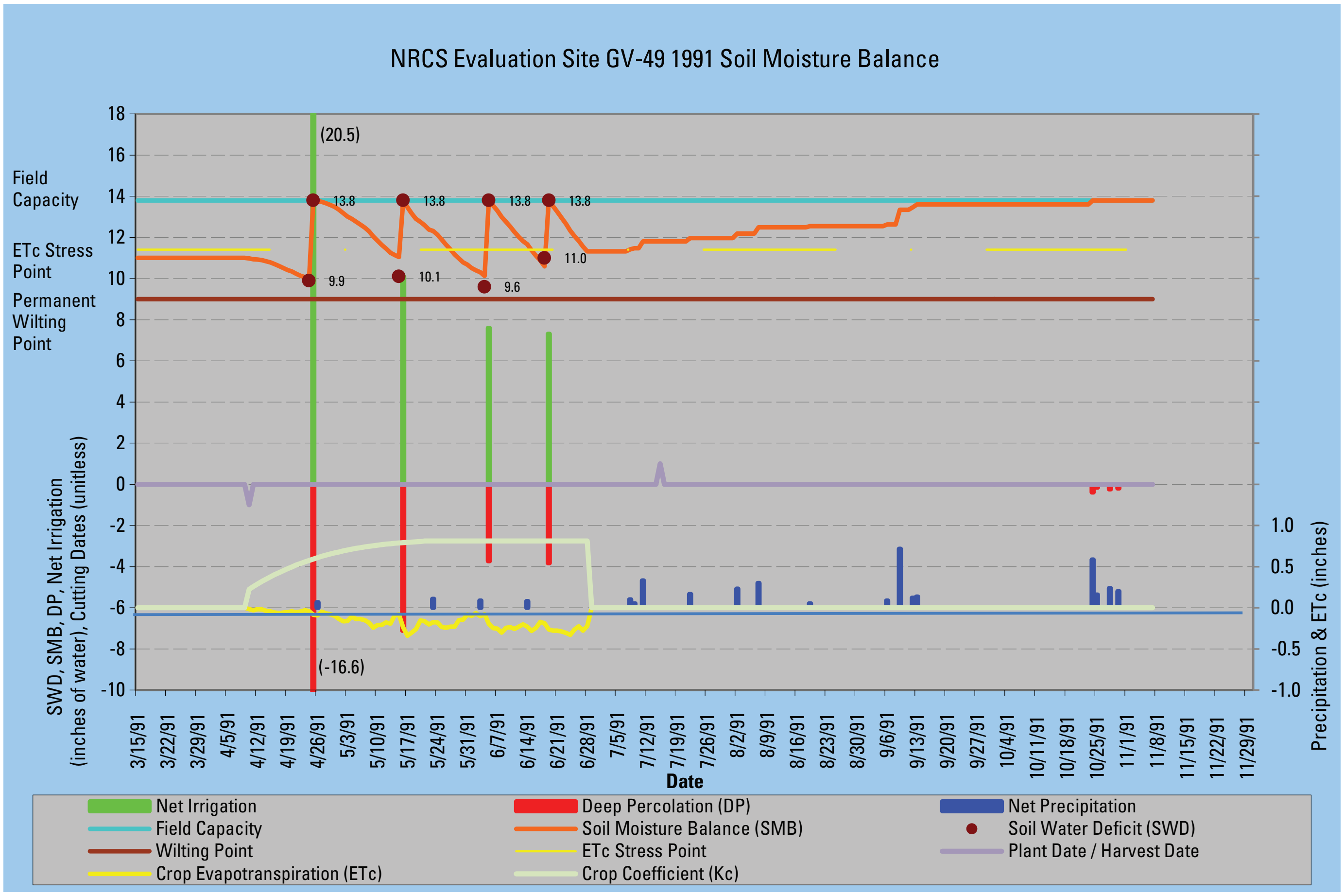


Figure 7-12. Soil moisture balance chart for Grand Valley Unit 1991 site 49, a fall grain site with a concrete ditch to gated pipe irrigation system. [NRCS, Natural Resources Conservation Service; GV, Grand Valley; SWD, soil water deficit; SMB, soil moisture balance; DP, deep percolation; K_c, crop coefficient; ET_c, crop evapotranspiration.]

Appendix 8. Derivation of NRCS Evaluation Crop Coefficient Curves

The ZETA.wks spreadsheet was obtained from the few Natural Resources Conservation Service (NRCS) evaluation records preserved at CSU Extension Orchard Mesa Research Station. This spreadsheet was used by the NRCS evaluation staff to calculate one day's ET_c for a selected crop to be made available to the agricultural community for use in irrigation management decisions. The crop coefficient equation in the ZETA.wks spreadsheet was published in the booklet "Scheduling Irrigation" by the Agricultural Research Service (ARS) in Fort Collins, Colo. (U.S. Department of Agriculture, 1987).

The ZETA.wks spreadsheet is designed to only calculate ET_c for one day and one crop type at a time. The user enters the crop and current date as an ordinal date (the number of the day of the year). The code then calculates K_c and ET_c for that day of the year for that crop. The ZETA.wks spreadsheet is organized into several sections. The leftmost section shows the ET_c data for the selected crop for all Julian days of the year. The center section shows two tables of daily potential ET_p covering 1989 through 1999—one table for Grand Junction and a separate table for Fruita. Presumably these came from data collected at the two NRCS evaluation weather stations. The code to calculate ET_p from raw weather data must have resided in a separate program, probably written in Basic, which no longer exists.

The right-hand section of the spreadsheet contains a data table containing emergence, cover, maturity, and harvest dates for 27 crop types. The dates are stated as ordinal dates. Below that table is the code to calculate the crop coefficient K_c for each crop type, given the current Julian date.

There is an error in the coding of the crop coefficient equation in ZETA.wks. This causes the K_c crop coefficient curve from ZETA.wks to jump suddenly from about midpoint in the rising limb of the equation up to the steady state value. Former ARS employees have identified the ZETA.wks spreadsheet as having been developed by CSU Extension, and it is presumed that they coded the spreadsheet independently from the NRCS evaluation team(Clay Gibson, National Park Service, former ARS Grand Valley staff, oral commun., August 20, 2013). For this reason, it may further be assumed that the implementation error in ZETA.wks for the K_c equation did not necessarily exist in the Basic software used by the NRCS evaluation.

The ZETA.wks spreadsheet calculates an R value based on the current Julian date desired as follows:

BEFORE FULL COVER—R is a fraction of time from planting date to full cover date (0.0 to 1.0)

AFTER FULL COVER—R is days after full cover date

The crop coefficient K_c is then calculated with this equation:

$$K_c = A\,R\text{^}3 + B\,R\text{^}2 + C\,R + D$$

Where A, B, C, and D are constants in the table below which are selected for the crop in question.

Table 56 shows the various dates associated with crops in the ZETA.wks spreadsheet. Table 56 gives the A, B, C, and D coefficients for the K_c equation when the crop stage is before full cover, and table 57 gives the coefficients for after full cover is achieved. Table 56 and table 57 were extended in the ZETA.wks spreadsheet to more crop types than the Scheduling Irrigations - A guide for improved irrigation water management through proper timing and amount of water application booklet published. Sample crop data from NRCS evaluation crop evapotranspiration spreadsheet "ZETA.wks" from 1999.

Table 8-1. Sample crop data from Natural Resources Conservation Service evaluation crop evapotranspiration spreadsheet “ZETA.wks” from 1999.

[EMERG, crop emergence date; Ordinal date, the day number of the year; COVER, crop full cover; MATURE, crop maturity date; QUIT, end of irrigation season; R, multiplier; K_c, crop coefficient]

Crop	Emerge	Cover	Mature	Quit
	Ordinal date	Ordinal date	Ordinal date	Ordinal date
Alfalfa	70.00	96.00	156.00	304.00
Turf grass	70.00	90.00	164.00	304.00
Pasture	80.00	111.00	227.00	304.00
Corn	136.00	181.00	242.00	260.00
Silage corn	136.00	181.00	246.00	260.00
Beans	154.00	194.00	232.00	258.00
Onion	94.00	152.00	254.00	254.00
Small grain spring	91.00	147.00	199.00	199.00
Smalll grain fall	70.00	111.00	189.00	189.00
Sorghum	142.00	216.00	261.00	261.00
Apple w/cover	100.00	167.00	270.00	304.00
Peach/pear w/cover	100.00	167.00	250.00	304.00
Apple	100.00	167.00	270.00	304.00
Cherry/cot	100.00	167.00	175.00	304.00
Peach/pear	100.00	167.00	250.00	304.00
Young tree	90.00	140.00		304.00
Grapes	100.00	130.00	250.00	300.00
Conifer	70.00	150.00	300.00	330.00
Asparagus	70.00	160.00	164.00	194.00
Broccoli	89.00	112.00	183.00	183.00
Cabbage	110.00	137.00	244.00	245.00
Cantaloupe	110.00	137.00	270.00	290.00
Carrots	97.00	137.00	257.00	257.00
Cauliflower	110.00	137.00	183.00	185.00
Cucumber	130.00	137.00	250.00	250.00
Lettuce	100.00	130.00	170.00	170.00
Squash	130.00	137.00	284.00	285.00
Tomatos	130.00	137.00	279.00	280.00

Table 8-2. Sample before full cover constant values from Natural Resources Conservation Service evaluation crop evapotranspiration spreadsheet "ZETA.wks" from 1999.

[COVER, crop full cover; R, multiplier; K_c, crop coefficient]

Constants for use in the crop coefficient equation K_c= A R^3 + B R^2 + C R+ D Before full cover—R is a Fraction of Time from Planting to Full Cover (0.0 to 1.0)				
Crop	**A**	**B**	**C**	**D**
Alfalfa	0.33	-1.19	1.51	0.25
Turf grass	0.00	0.00	1.51	0.25
Pasture	0.00	0.00	1.51	0.25
Corn	-1.58	2.76	-0.43	0.21
Silage corn	-1.58	2.76	-0.43	0.21
Dry beans	-1.35	2.56	-0.35	0.21
Onion	-1.46	2.58	-0.74	0.43
Small grains spring	-2.89	4.84	-1.14	0.23
Small grains winter	-2.89	3.83	-0.15	0.23
Sorghum	-1.58	2.76	-0.43	0.21
Apple w/cover	-2.87	4.64	-1.02	0.45
Peach/pear w/cover	-2.44	3.95	-0.86	0.45
Apple	-0.65	1.28	0.00	0.27
Cherry/cot	-0.80	1.45	-0.02	0.27
Peach/pear	-0.63	1.17	0.00	0.20
Young tree	0.67	-0.73	0.19	0.27
Grapes	-0.82	1.13	0.08	0.32
Conifer	0.00	0.00	0.38	0.67
Asparagus	6.61	-2.24	0.21	0.29
Broccoli	-0.45	0.86	0.12	0.27
Cabbage	-1.06	1.56	-0.07	0.09
Cantaloupe	-1.24	2.24	-0.64	0.21
Carrots	-0.98	1.69	-0.33	0.21
Cauliflower	-4.52	5.42	0.46	0.15
Cucumber	-1.35	2.45	-0.69	0.22
Lettuce	-1.23	3.20	-0.44	0.31
Squash	-1.24	2.24	-0.64	0.21
Tomatoes market	-11.27	11.21	-0.71	0.25
Tomato canned	-14.21	12.82	-0.82	0.20

Table 8-3. Sample after full cover constant values from Natural Resources Conservation Service evaluation crop evapotranspiration spreadsheet "ZETA.wks" from 1999.

[COVER, crop full cover; R, multiplier; K_c, crop coefficient]

	After full cover—R is days after full cover			
Crop	**A**	**B**	**C**	**D**
Alfalfa	0.00	0.00	0.00	0.90
Turf grass	0.00	0.00	0.00	0.87
Pasture	0.00	0.00	0.00	0.87
Corn	0.00	0.00	0.02	0.95
Silage corn	0.00	0.00	0.02	0.95
Dry beans	0.00	0.00	0.00	1.05
Onion	0.00	0.00	0.00	0.80
Small grains spring	0.00	0.00	0.01	1.02
Small grains winter	0.00	0.00	0.01	1.02
Sorghum	0.00	0.00	0.00	0.92
Apple w/cover	0.00	0.00	0.00	1.21
Peach/pear w/cover	0.00	0.00	0.00	1.10
Apple	0.00	0.00	0.02	0.90
Cherry/cot	0.00	0.00	0.00	0.94
Peach/pear	0.00	0.00	0.00	0.75
Young tree	0.00	0.00	0.00	0.41
Grapes	0.00	0.00	0.01	0.72
Conifer	0.00	0.00	0.01	0.81
Asparagus	0.00	0.00	0.03	0.94
Broccoli	0.00	0.00	0.00	0.75
Cabbage	0.00	0.00	0.00	0.51
Cantaloupe	0.00	0.00	0.00	0.64
Carrots	0.00	0.00	0.00	0.59
Cauliflower	0.00	0.00	0.01	1.03
Cucumber	0.00	0.00	0.00	0.63
Lettuce	0.00	0.00	0.02	0.92
Squash	0.00	0.00	0.00	0.57
Tomato market	0.00	0.00	0.02	1.12
Tomato canned	0.00	0.00	0.01	

Appendix 9. 1988 Colorado Irrigation Guide Consumptive Use Tables for Grand Junction and Fruita

In the report section "Crop Consumptive Use Discrepancies," the use of published crop consumptive use for the Grand Valley Unit is discussed. The Grand Valley Unit primarily consists of the towns of Grand Junction and Fruita. The two tables in this appendix (fig. 9-2 for Grand Junction and 9-3 for Fruita) are reproduced from the 1988 Colorado Irrigation Guide (U.S. Department of Agriculture, 1988) to provide a more complete understanding of how crop consumptive use data were derived for this report. The Colorado climate zone map (fig. 9-1), also from the 1988 Colorado Irrigation Guide, shows the various Colorado climate zones, including those which are required in the Grand Junction table in the Perennials row for alfalfa. The soil moisture balance sites which have a crop type of alfalfa were geo-located on the climate zone map to determine the correct climate zone and crop consumptive use from the Grand Junction table. The Fruita table does not require a climate zone for alfalfa.

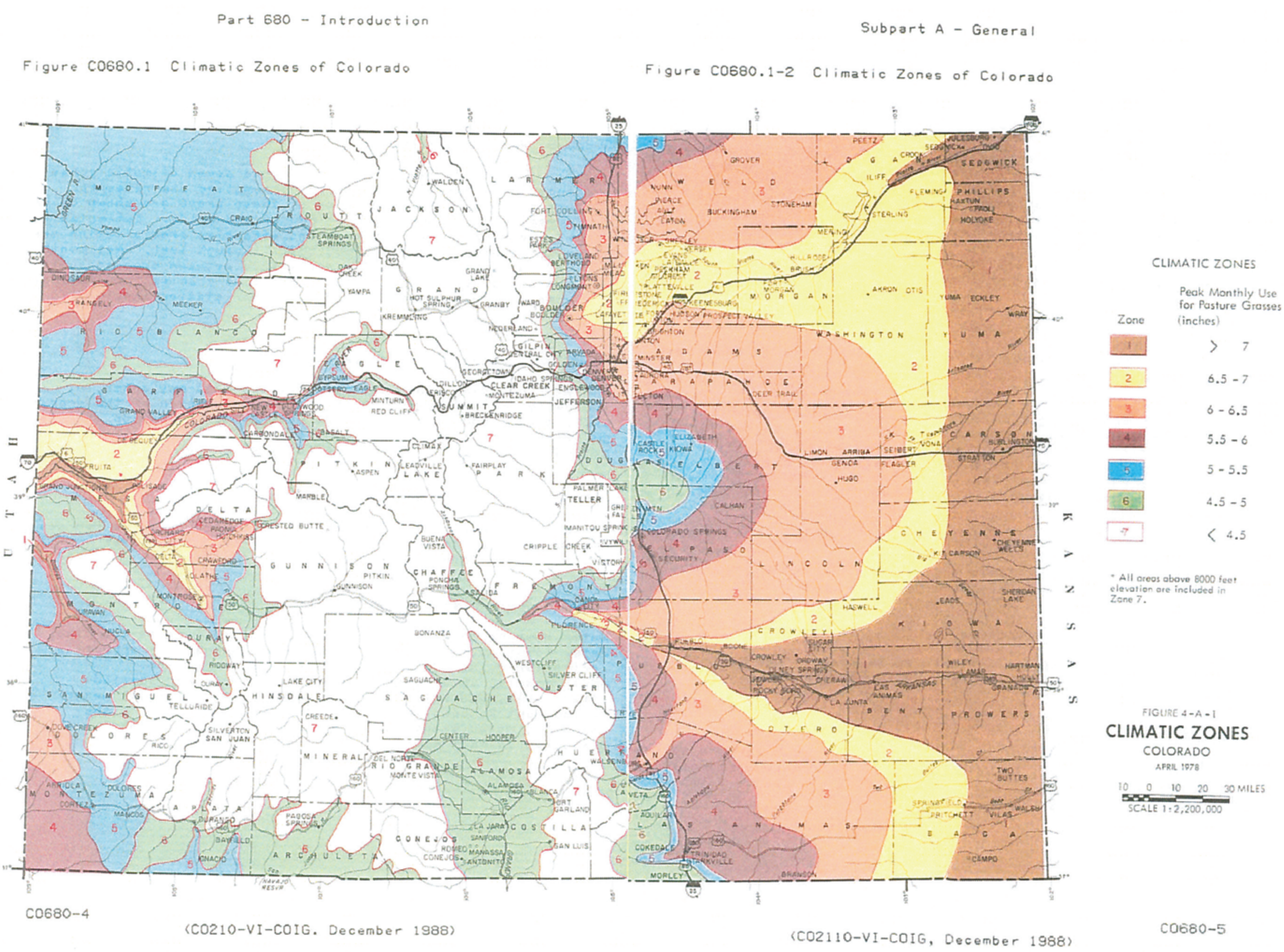


Figure 9-1. Map of Colorado climate zones for crop consumptive use of water (1988 Colorado Irrigation Guide, U.S. Department of Agriculture, 1988).

Subpart F - Tables

CO683.50(k)

ESTIMATED SEASONAL AND MONTHLY CONSUMPTIVE USE OF CROPS

Table CO683.50(k)

Grand Junction, Colorado

TR-21 Blaney Criddle Method

	Growing Season	Average Consumptive Use (inches of water)													
CROPS	Average Dates	Days	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	TOTAL
Perennials															
Alfalfa zone 1	3/12 - 11/4	237	0	0	0.74	2.58	5.15	7.69	9.35	7.59	4.65	2.43	0.10	0	40.28
Alfalfa zone 2	3/2 - 9/25	207	0	0	1.36	2.32	4.34	6.20	8.68	7.28	3.81	0	0	0	33.99
Grass, Pasture	3/2 - 11/3	246	0	0	1.17	2.01	3.59	5.05	7.20	6.23	4.02	2.02	0.06	0	31.35
Annuals															
Beans, Dry	6/1 - 9/15	106	0	0	0	0	0	4.29	8.70	7.07	1.64	0	0	0	21.70
Corn, Grain Corn, Silage	5/1 - 9/15	137	0	0	0	0	1.97	4.32	8.28	6.95	2.07	0	0	0	23.59
Grain, Spring	4/5 - 8/1	118	0	0	0	0.97	4.13	6.62	3.47	0	0	0	0	0	15.19
Orchard zone 1 (w/ cover)	4/1 - 10/10	192	0	0	0	2.50	5.14	7.68	9.36	7.59	4.64	0.78	0	0	37.69
Orchard zone 2 (w/o cover)	5/9 - 9/29	143	0	0	0	0	3.07	6.19	8.69	7.28	4.41	0	0	0	29.64
Small Vegetables	4/15 - 10/15	183	0	0	0	0.43	2.40	4.91	6.81	5.73	3.13	0.59	0	0	24.00
Sugar Beets	4/15 - 10/15	183	0	0	0	0.60	2.72	5.75	9.25	8.85	5.59	1.42	0	0	34.18
Wheat, Winter	4/5 - 8/1	118	0	0	0	2.66	5.33	6.16	2.86	0	0	0	0	0	17.01
Average Precipitation			0.64	0.61	0.75	0.79	0.63	0.55	0.46	1.05	0.84	0.93	0.61	0.55	8.41
Effective Precipitation			0	0	0.29	0.54	0.49	0.49	0.45	0.97	0.65	0.64	0.04	0	4.59

Net irrigaiton requirement is the difference between crop consumptive use and effective precipitation.

CO683-31

(CO210-VI-COIG, December 1988)

Figure 9-2. Table of estimated seasonal crop consumptive use for Grand Junction, Colo. (1988 Colorado Irrigation Guide, U.S. Department of Agriculture, 1988).

Subpart F - Tables

CO683.50(i

ESTIMATED SEASONAL AND MONTHLY CONSUMPTIVE USE OF CROPS

Table CO683.50(i)

Fruita, Colorado

TR-21 Blaney Criddle Method

	Growing Season		Average Consumptive Use (inches of water)												
CROPS	Average Dates	Days	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	TOTAL
Perennials															
Alfalfa	3/13 - 10/16	217	0	0	0.68	2.61	4.88	6.97	8.56	7.04	4.34	1.13	0	0	36.22
Pasture Grasses	3/13 - 10/31	232	0	0	0.58	2.26	4.04	5.68	7.10	6.03	3.82	1.93	0	0	31.44
Annuals															
Beans, Dry	6/1 - 9/15	106	0	0	0	0	0	3.88	7.96	6.56	1.53	0	0	0	19.93
Corn, Grain	5/10 - 10/15	158	0	0	0	0	1.44	3.86	7.29	7.12	4.36	1.05	0	0	25.12
Corn, Silage	5/10 - 9/20	133	0	0	0	0	1.41	3.85	7.39	7.10	2.92	0	0	0	22.67
Grain, Spring	4/20 - 8/20	122	0	0	0	0.30	3.30	7.56	7.43	1.02	0	0	0	0	19.61
Orchard (w/ cover)	4/1 - 9/20	172	0	0	0	1.58	3.84	5.90	7.31	5.45	1.63	0	0	0	25.71
Small Vegetables	4/15 - 9/1	139	0	0	0	0.45	2.63	4.86	6.16	3.91	0.05	0	0	0	18.06
Sugar Beets	4/15 - 10/15	183	0	0	0	0.61	2.58	5.21	8.46	8.22	5.22	1.28	0	0	31.58
Wheat, Winter	3/20 - 7/10 9/1 - 11/1	112 61	0	0	0.66	3.56	5.67	3.88	0.24	0	2.20	2.71	0.03	0	18.95
Average Precipitation			0.68	0.53	0.70	0.77	0.54	0.56	0.58	1.13	0.75	0.84	0.62	0.60	8.30
Effective Precipitation			0	0	0.27	0.51	0.36	0.37	0.62	0.91	0.68	0.26	0	0	3.98

Net irrigaiton requirement is the difference between crop consumptive use and effective precipitation.

CO683-29

(CO210-VI-COIG, December 1988)

Figure 9-3. Table of estimated seasonal crop consumptive use for Fruita, Colo. (1988 Colorado Irrigation Guide, U.S. Department of Agriculture, 1988).

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